A "poor man's approach" to topology optimization of cooling channels based on a Darcy flow model

A topology optimization methodology for optimizing cooling channels using an approximate but low-cost flow and heat transfer model is presented. The fluid flow is modeled using the Darcy model, which is a linear problem that can be solved very efficiently compared to the Navier–Stokes equations. The obtained fluid velocity is subsequently used in a stabilized convection–diffusion heat transfer model to calculate the temperature distribution. The governing equations are cast in a monolithic form such that both the solid and fluid can be modeled using a single equation set. The material properties: permeability, conductivity, density and specific heat capacity are interpolated using the Solid Isotropic Material with Penalization (SIMP) scheme. Manufacturable cooling-channel designs with clear topologies are obtained with the help of a pressure drop constraint and a geometric length-scale constraint. Several numerical examples demonstrate the applicability of this approach. Verification studies with a full turbulence model show that, although the equivalent model has limitations in yielding a perfect realistic velocity field, it generally provides well-performing cooling channel designs.
A short numerical study on the optimization methods influence on topology optimization

Structural topology optimization problems are commonly defined using continuous design variables combined with material interpolation schemes. One of the challenges for density based topology optimization observed in the review article (Sigmund and Maute Struct Multidiscip Optim 48(6):1031-1055 2013) is the slow convergence that is often encountered in practice, when an almost solid-and-void design is found. The purpose of this forum article is to present some preliminary observations on how designs evolves during the optimization process for different choices of optimization methods. Additionally, the authors want to open a discussion on how to properly define and identify the boundary translation that is often observed in practice. The authors hope that these preliminary observations can open for fruitful discussions and stimulate further investigations concerning slowly moving boundaries. Although the discussion is centered on density based methods it may be equally relevant to level-set and phase-field approaches.

General information
State: Published
Organisations: Department of Wind Energy, Wind Turbine Structures and Component Design, Department of Mechanical Engineering, Solid Mechanics
Authors: Rojas Labanda, S. (Intern), Sigmund, O. (Intern), Stolpe, M. (Intern)
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Publication information
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Benchmarking five computational methods for analyzing large photonic crystal membrane cavities

We benchmark five state-of-the-art computational methods by computing quality factors and resonance wavelengths in photonic crystal membrane L5 and L9 line defect cavities. The convergence of the methods with respect to resolution, degrees of freedom and number of modes is investigated. Convergence is not obtained for some of the methods, indicating that some are more suitable than others for analyzing line defect cavities.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonics Theory and Signal Processing, Nanophotonic Devices, Plasmonics and Metamaterials, Department of Mechanical Engineering, Solid Mechanics, Department of Electrical Engineering, Electromagnetic Systems, St. Petersburg National Research University of Information
Combined shape and topology optimization for minimization of maximal von Mises stress

This work shows that a combined shape and topology optimization method can produce optimal 2D designs with minimal stress subject to a volume constraint. The method represents the surface explicitly and discretizes the domain into a simplicial complex which adapts both structural shape and topology. By performing repeated topology and shape optimizations and adaptive mesh updates, we can minimize the maximum von Mises stress using the p-norm stress measure with p-values as high as 30, provided that the stress is calculated with sufficient accuracy.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Acoustic Technology, Lawrence Livermore National Laboratory
Authors: Lian, H. (Intern), Christiansen, A. N. (Intern), Tortorelli, D. A. (Ekstern), Sigmund, O. (Intern), Aage, N. (Intern)
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Pages: 1541-1557
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Scopus rating (2014): CiteScore 2.77
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
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Scopus rating (2012): CiteScore 2.08
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Comparison of Five Computational Methods for Computing Q Factors in Photonic Crystal Membrane Cavities

Five state-of-the-art computational methods are benchmarked by computing quality factors and resonance wavelengths in photonic crystal membrane L5 and L9 line defect cavities. The convergence of the methods with respect to resolution, degrees of freedom and number of modes is investigated. Special attention is paid to the influence of the size of the computational domain. Convergence is not obtained for some of the methods, indicating that some are more suitable than others for analysing line defect cavities.

General information
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Number of pages: 2
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Photonic crystal, Microcavity, Line defect cavity, Quality factor, Numerical simulations
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10.1109/ICTON.2017.8024813
Comparison of Five Numerical Methods for Computing Quality Factors and Resonance Wavelengths in Photonic Crystal Membrane Cavities

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Authors: Gregersen, N. (Intern), de Lasson, J. R. (Intern), Frandsen, L. H. (Intern), Kim, O. S. (Intern), Breinbjerg, O. (Intern), Wang, F. (Intern), Sigmund, O. (Intern), Ivinskaya, A. (Ekstern), Lavrinenko, A. (Intern), Gutsche, P. (Ekstern), Burger, S. (Ekstern), Häyrynen, T. (Intern), Mørk, J. (Intern)
Number of pages: 1
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DOIs: 10.1109/CLEOE-EQEC.2017.8087750
Source: PublicationPreSubmission
Source-ID: 133789916
Publication: Research - peer-review › Article in proceedings – Annual report year: 2017

Cross-flow heat exchanger design using thermofluid topology optimization

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Electrofunctional materials, Department of Mechanical Engineering, Solid Mechanics
Authors: Haertel, J. H. K. (Intern), Engelbrecht, K. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
Number of pages: 2
Publication date: 2017

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Article number: 160006
Main Research Area: Technical/natural sciences
Conference: 10th International Conference on Computational Heat, Mass and Momentum Transfer (ICCHM²T 2017), Seoul, Korea, Democratic People's Republic of, 28/05/2017 - 28/05/2017
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2017

Design of Passive Acoustic Wave Shaping Devices and Their Experimental Validation
We discuss a topology optimization based approach for designing passive acoustic wave shaping devices and demonstrate its application to; directional sound emission [1], sound focusing and wave splitting. Optimized devices, numerical and experimental results are presented and benchmarked against other designs proposed in the literature. We focus on design problems where the size of the device is on the order of the wavelength, a problematic region for traditional design methods, such as ray tracing. The acoustic optimization problem is formulated in the frequency domain and modeled by the Helmholtz equation. An exterior 2D model domain is used and an array of point sources is considered as sound emitters. The optimization goal is to identify a distribution of solid material in a design sub-domain which produces a desired spatial sound field pattern across a frequency band of interest in a target sub-domain. The objective is the integral of the deviation in pressure magnitude, between a pre-scribed sound field and the solution to the model problem for a given design realization over the target sub-domain. Filtering is used for regularization and to allow for meaningful optimization for geometric robustness [2]. The Globally Convergent Method of Moving Asymptotes is used to perform the optimization [3].

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Department of Electrical Engineering, Acoustic Technology
Authors: Christiansen, R. E. (Intern), Sigmund, O. (Intern), Fernandez Grande, E. (Intern)
Number of pages: 1
Frequency response as a surrogate eigenvalue problem in topology optimization

This article discusses the use of frequency response surrogates for eigenvalue optimization problems in topology optimization that may be used to avoid solving the eigenvalue problem. The motivation is to avoid complications that arise from multiple eigenvalues and the computational complexity associated with computation of eigenvalues in very large problems.

General information
State: Accepted/In press
Organisations: Department of Mechanical Engineering, Solid Mechanics, Università degli Studi di Modena e Reggio Emilia, Michigan State University
Authors: Andreassen, E. (Intern), Ferrari, F. (Ekstern), Sigmund, O. (Intern), Diaz, A. R. (Ekstern)
Number of pages: 20
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Scopus rating (2013): SJR 2.415 SNIP 1.894 CiteScore 2.8
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
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Scopus rating (2012): SJR 2.47 SNIP 2.103 CiteScore 2.7
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.193 SNIP 1.935 CiteScore 2.47
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BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.177 SNIP 1.717
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.983 SNIP 1.601
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.122 SNIP 1.74
Web of Science (2008): Indexed yes
In the design of industrial products ranging from hearing aids to automobiles and aeroplanes, material is distributed so as to maximize the performance and minimize the cost. Historically, human intuition and insight have driven the evolution of mechanical design, recently assisted by computer-aided design approaches. The computer-aided approach known as topology optimization enables unrestricted design freedom and shows great promise with regard to weight savings, but its applicability has so far been limited to the design of single components or simple structures, owing to the resolution limits of current optimization methods. Here we report a computational morphogenesis tool, implemented on a supercomputer, that produces designs with giga-voxel resolution—more than two orders of magnitude higher than previously reported. Such resolution provides insights into the optimal distribution of material within a structure that were hitherto unachievable owing to the challenges of scaling up existing modelling and optimization frameworks. As an example, we apply the tool to the design of the internal structure of a full-scale aeroplane wing. The optimized full-wing design has unprecedented structural detail at length scales ranging from tens of metres to millimetres and, intriguingly, shows remarkable similarity to naturally occurring bone structures in, for example, bird beaks. We estimate that our optimized design corresponds to a reduction in mass of 2–5 per cent compared to currently used aeroplane wing designs, which translates into a reduction in fuel consumption of about 40–200 tonnes per year per aeroplane. Our morphogenesis process is generally applicable, not only to mechanical design, but also to flow systems, antennas, nano-optics and micro-systems.

General information
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Organisations: Department of Mechanical Engineering, Solid Mechanics, Acoustic Technology
Authors: Aage, N. (Intern), Andreassen, E. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
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Scopus rating (2016): CiteScore 13.33
Higher-order multi-resolution topology optimization using the finite cell method

This article presents a detailed study on the potential and limitations of performing higher-order multi-resolution topology optimization with the finite cell method. To circumvent stiffness overestimation in high-contrast topologies, a length-scale is applied on the solution using filter methods. The relations between stiffness overestimation, the analysis system, and the applied length-scale are examined, while a high-resolution topology is maintained. The computational cost associated with nested topology optimization is reduced significantly compared with the use of first-order finite elements. This reduction is caused by exploiting the decoupling of density and analysis mesh, and by condensing the higher-order modes out of the stiffness matrix.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Delft University of Technology, University of Glasgow
Authors: Groen, J. P. (Intern), Langelaar, M. (Ekstern), Sigmund, O. (Intern), Ruess, M. (Ekstern)
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Scopus rating (2015): SJR 1.912 SNIP 1.689 CiteScore 2.67
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ISI indexed (2013): ISI indexed yes
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Scopus rating (2012): SJR 2.47 SNIP 2.103 CiteScore 2.7
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BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.193 SNIP 1.935 CiteScore 2.47
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.177 SNIP 1.717
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.983 SNIP 1.601
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.122 SNIP 1.74
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.023 SNIP 1.775
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.678 SNIP 1.823
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.085 SNIP 1.545
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.002 SNIP 1.846
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 3.369 SNIP 1.956
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 2.739 SNIP 1.698
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 2.197 SNIP 1.777
Web of Science (2001): Indexed yes
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Topology optimization, Finite cell method, Method; higher-order FEM
Homogenization-based topology optimization for high-resolution manufacturable micro-structures

This paper presents a projection method to obtain high-resolution, manufacturable structures from efficient and coarse-scale, homogenization-based topology optimization results. The presented approach bridges coarse and fine scale, such that the complex periodic micro-structures can be represented by a smooth and continuous lattice on the fine mesh. A heuristic methodology allows control of the projected topology, such that a minimum length-scale on both solid and void features is ensured in the final result. Numerical examples show excellent behavior of the method, where performances of the projected designs are almost equal to the homogenization-based solutions. A significant reduction in computational cost is observed compared to conventional topology optimization approaches.
Infill Optimization for Additive Manufacturing - Approaching Bone-like Porous Structures

Porous structures such as trabecular bone are widely seen in nature. These structures exhibit superior mechanical properties whilst being lightweight. In this paper, we present a method to generate bone-like porous structures as lightweight infill for additive manufacturing. Our method builds upon and extends voxel-wise topology optimization. In particular, for the purpose of generating sparse yet stable structures distributed in the interior of a given shape, we propose upper bounds on the localized material volume in the proximity of each voxel in the design domain. We then aggregate the local per-voxel constraints by their p-norm into an equivalent global constraint, in order to facilitate an efficient optimization process. Implemented on a high-resolution topology optimization framework, our results demonstrate mechanically optimized, detailed porous structures which mimic those found in nature. We further show variants of the optimized structures subject to different design specifications, and analyze the optimality and robustness of the obtained structures.
Minimum Compliance Topology Optimization of Shell-Infill Composites for Additive Manufacturing

Additively manufactured parts are often composed of two sub-structures, a solid shell forming their exterior and a porous infill occupying the interior. To account for this feature this paper presents a novel method for generating simultaneously optimized shell and infill in the context of minimum compliance topology optimization. Our method builds upon two recently developed approaches that extend density-based topology optimization: A coating approach to obtain an optimized shell that is filled uniformly with a prescribed porous base material, and an infill approach which generates optimized, non-uniform infill within a prescribed shell. To evolve the shell and infill concurrently, our formulation assigns two sets of design variables: One set defines the base and the coating, while the other set defines the infill structures. The resulting intermediate density distributions are unified by a material interpolation model into a physical density field, upon which the compliance is minimized. Enhanced by an adapted robust formulation for controlling the minimum length scale of the base, our method generates optimized shell-infill composites suitable for additive manufacturing. We demonstrate the effectiveness of the proposed method on numerical examples, and analyze the influence of different design specifications.

General information
State: Accepted/In press
Organisations: Department of Mechanical Engineering, Solid Mechanics, Delft University of Technology
Authors: Wu, J. (Ekstern), Clausen, A. (Intern), Sigmund, O. (Intern)
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Main Research Area: Technical/natural sciences

Publication information

On fully stressed design and p-norm measures in structural optimization
This brief note revisits the fully stressed design schemes and p-norm measures used in stress-based structural optimization. Two simple shape optimization cases are used to remind the reader that fully stressed designs only are
optimal when unimpeded by geometrical restrictions and that high values of the stress norm are needed in order to achieve satisfactory designs.

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Authors: Zhou, M. (Ekstern), Sigmund, O. (Intern)
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Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
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Web of Science (2005): Indexed yes
Web of Science (2004): Indexed yes
Web of Science (2003): Indexed yes
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Structural shape optimization, Stress minimization, Fully stressed design, P-norm constraints
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Optimal design of a microgripper-type actuator based on AlN/Si heterogeneous bimorph

This work presents a systematic procedure to design piezoelectrically actuated microgrippers. Topology optimization combined with optimal design of electrodes is used to maximize the displacement at the output port of the gripper. The fabrication at the microscale leads us to overcome an important issue: the difficulty of placing a piezoelectric film on both top and bottom of the host layer. Due to the non-symmetric lamination of the structure, an out-of-plane bending spoils the behaviour of the gripper. Suppression of this out-of-plane deformation is the main novelty introduced. In addition, a robust formulation approach is used in order to control the length scale in the whole domain and to reduce sensitivity of the designs to small manufacturing errors.

General information
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Organisations: Department of Mechanical Engineering, Solid Mechanics, Universidad de Castilla-La Mancha
Authors: Ruiz, D. P. (Ekstern), Díaz-Molina, A. (Ekstern), Sigmund, O. (Intern), Donoso, A. (Ekstern), Bellido, J. (Ekstern), Sánchez-Rojas, J. L. (Ekstern)
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Optimal design of robust piezoelectric microgrippers undergoing large displacements

Topology optimization combined with optimal design of electrodes is used to design piezoelectric microgrippers. Fabrication at micro-scale presents an important challenge: due to non-symmetrical lamination of the structures, out-of-plane bending spoils the behaviour of the grippers. Suppression of this out-of plane deformation is the main novelty introduced in this work. In addition, a robust approach is used to control length scale in the whole domain and to reduce sensitivity of the design to small fabrication errors. Geometrically non-linear modelling is used for the in-plane deformations whereas out-of-plane motions are modelled by a linear, un-coupled plate model to save computational time. Model and resulting designs are validated by subsequent 3D geometrically non-linear modelling.

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Organisations: Department of Mechanical Engineering, Solid Mechanics, Universidad de Castilla-La Mancha
Authors: Ruiz, D. (Ekstern), Sigmund, O. (Intern)
Number of pages: 12
Publication date: 2017
Main Research Area: Technical/natural sciences
Optimal design of robust piezoelectric unimorph microgrippers

Topology optimization can be used to design piezoelectric actuators by simultaneous design of host structure and polarization profile. Subsequent micro-scale fabrication leads us to overcome important manufacturing limitations: difficulties in placing a piezoelectric layer on both top and bottom of the host layer. Unsymmetrical layer placement makes the actuator bend, spoiling the predicted performance of the device. The aim of this work is to maximize the in-plane displacement of a microgripper-type actuator while out-of-plane displacement at some points of interest is suppressed. This last issue is the main novelty introduced in this work, and the emphasis is placed on the modelling and its applicability rather than numerical methods. In addition, a robust formulation of the problem has been used in order to ensure minimum length scale in the optimal designs, which it is crucial from the manufacturability point of view.
Optimization of photonic crystal cavities
We present optimization of photonic crystal cavities. The optimization problem is formulated to maximize the Purcell factor of a photonic crystal cavity. Both topology optimization and air-hole-based shape optimization are utilized for the design process. Numerical results demonstrate that the Purcell factor of the photonic crystal cavity can be significantly improved through optimization.

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Authors: Wang, F. (Intern), Sigmund, O. (Intern)
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Main Research Area: Technical/natural sciences
Conference: 17th International Conference on Numerical Simulation of Optoelectronic Devices (NUSOD17), Kgs. Lyngby, Denmark, 24/07/2017 - 24/07/2017
Photonic crystal, Cavity, Topology optimization, Shape optimization
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Authors: Vester-Petersen, J. (Ekstern), Christiansen, R. E. (Intern), Julsgaard, B. (Ekstern), Balling, P. (Ekstern), Sigmund, O. (Intern), Madsen, S. P. (Ekstern)
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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.085 SNIP 0.983 CiteScore 2.47
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.799 SNIP 1.462 CiteScore 3.25
Web of Science (2014): Indexed yes
Reproducing the hierarchy of disorder for Morpho-inspired, broad-angle color reflection

The scales of Morpho butterflies are covered with intricate, hierarchical ridge structures that produce a bright, blue reflection that remains stable across wide viewing angles. This effect has been researched extensively, and much understanding has been achieved using modeling that has focused on the positional disorder among the identical, multilayered ridges as the critical factor for producing angular independent color. Realizing such positional disorder of identical nanostructures is difficult, which in turn has limited experimental verification of different physical mechanisms that have been proposed. In this paper, we suggest an alternative model of inter-structural disorder that can achieve the same broad-angle color reflection, and is applicable to wafer-scale fabrication using conventional thin film technologies. Fabrication of a thin film that produces pure, stable blue across a viewing angle of more than 120 ° is demonstrated, together with a robust, conformal color coating.
Thermofluid topology optimization of heat sinks

General information
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Organisations: Department of Energy Conversion and Storage, Electrofunctional materials, Department of Mechanical Engineering, Solid Mechanics
Authors: Haertel, J. H. K. (Intern), Lei, T. (Intern), Alexandersen, J. (Intern), Engelbrecht, K. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
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Topology optimization for optical microlithography with partially coherent illumination

This article revisits a topology optimization design approach for micro-manufacturing and extends it to optical microlithography with partially coherent illumination. The solution is based on a combination of two technologies, the topology optimization and the proximity error correction in microlithography/nanolithography. The key steps include (i) modeling the physical inputs of the fabrication process, including the ultraviolet light illumination source and the mask, as the design variables in optimization and (ii) applying physical filtering and heaviside projection for topology optimization, which corresponds to the aerial image formulation and the pattern development processes, respectively. The proposed approach results in an effective source and a binary design mask, which can be sent directly to fabrication without additional post-processing steps for proximity error correction. Meanwhile, the performance of the device is optimized and robust with respect to process variations, such as dose/photo-resist variations and lens defocus. A compliant micro-gripper design example is considered to demonstrate the applicability of this approach.

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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Zhou, M. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
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BFI (2013): BFI-level 2
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ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
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ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.177 SNIP 1.717
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.983 SNIP 1.601
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.122 SNIP 1.74
This paper presents a topology optimization approach for reducing thermo-elastic dissipation (TED) in MEMS resonators. This algorithm is applied to a clamped-clamped resonant beam to maximize the quality factor (Q). Optimal designs have a Q ten times higher than a solid beam and are 75% higher than previously optimized devices. Furthermore, new designs have intuitive topologies. Beams are fabricated in <111> silicon wafers and experimental measurements of Q agree well with simulation.
Topology optimization of 3D shell structures with porous infill

This paper presents a 3D topology optimization approach for designing shell structures with a porous or void interior. It is shown that the resulting structures are significantly more robust towards load perturbations than completely solid structures optimized under the same conditions. The study indicates that the potential benefit of using porous structures is higher for lower total volume fractions. Compared to earlier work dealing with 2D topology optimization, we found several new effects in 3D problems. Most notably, the opportunity for designing closed shells significantly improves the performance of porous structures due to the sandwich effect. Furthermore, the paper introduces improved filter boundary conditions to ensure a completely uniform coating thickness at the design domain boundary.

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Authors: Clausen, A. (Intern), Andreassen, E. (Intern), Sigmund, O. (Intern)
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Scopus rating (2011): SJR 0.279 SNIP 0.683 CiteScore 1
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
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Topography of heat exchangers and heat sinks

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Authors: Haertel, J. H. K. (Intern), Lei, T. (Intern), Alexandersen, J. (Intern), Engelbrecht, K. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
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We consider the design of individual and periodic arrangements of metal or semiconductor nanoparticles for localized electromagnetic field enhancement utilizing a topology optimization based numerical framework as the design tool. We aim at maximizing a function of the electromagnetic field amplitude in a region of space through the introduction of nanoparticles in and/or near the region.

Topography of nanoparticles for localized electromagnetic field enhancement

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Aarhus University
Authors: Christiansen, R. E. (Intern), Vester-Petersen, J. (Forskerdatabase), Madsen, S. P. (Forskerdatabase), Sigmund, O. (Intern)
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Topography optimized gold nanostrips for enhanced near-infrared photon upconversion

This letter presents a topology optimization study of metal nanostructures optimized for electric-field enhancement in the infrared spectrum. Coupling of such nanostructures with suitable ions allows for an increased photon-upconversion yield, with one application being an increased solar-cell efficiency by exploiting the long-wavelength part of the solar spectrum. In this work, topology optimization is used to design a periodic array of two-dimensional gold nanostrips for electric-field enhancements in a thin film doped with upconverting erbium ions. The infrared absorption band of erbium is utilized by simultaneously optimizing for two polarizations, up to three wavelengths, and three incident angles. Geometric robustness towards manufacturing variations is implemented considering three different design realizations simultaneously in the optimization. The polarization-averaged field enhancement for each design is evaluated over an 80 nm wavelength range and a ±15-degree incident angle span. The highest polarization-averaged field enhancement is 42.2 varying by maximally 2% under ±5 nm near-uniform design perturbations at three different wavelengths (1480 nm, 1520 nm, and 1560 nm). The proposed method is generally applicable to many optical systems and is therefore not limited to enhancing photon upconversion.

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Authors: Vester-Petersen, J. (Ekstern), Christiansen, R. E. (Intern), Julsgaard, B. (Forskerdatabase), Balling, P. (Ekstern), Sigmund, O. (Intern), Madsen, S. P. (Ekstern)
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Scopus rating (2014): SJR 1.799 SNIP 1.462 CiteScore 3.25
Web of Science (2014): Indexed yes
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Scopus rating (2013): SJR 2.149 SNIP 1.652 CiteScore 3.77
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.554 SNIP 1.754 CiteScore 3.76
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
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Scopus rating (2011): SJR 2.805 SNIP 1.94 CiteScore 4.04
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.926 SNIP 1.789
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.857 SNIP 1.848
Web of Science (2009): Indexed yes
A design approach for integrating thermoelectric devices using topology optimization

Efficient operation of thermoelectric devices strongly relies on the thermal integration into the energy conversion system in which they operate. Effective thermal integration reduces the temperature differences between the thermoelectric module and its thermal reservoirs, allowing the system to operate more efficiently. This work proposes and experimentally demonstrates a topology optimization approach as a design tool for efficient integration of thermoelectric modules into systems with specific design constraints. The approach allows thermal layout optimization of thermoelectric systems for different operating conditions and objective functions, such as temperature span, efficiency, and power recovery rate. As a specific application, the integration of a thermoelectric cooler into the electronics section of a downhole oil well intervention tool is investigated, with the objective of minimizing the temperature of the cooled electronics. Several challenges are addressed: ensuring effective heat transfer from the load, minimizing the thermal resistances within the integrated system, maximizing the thermal protection of the cooled zone, and enhancing the conduction of the rejected heat to the oil well.

The design method incorporates temperature dependent properties of the thermoelectric device and other materials. The 3D topology optimization model developed in this work was used to design a thermoelectric system, complete with insulation and heat sink, that was produced and tested. Good agreement between experimental results and model forecasts was obtained and the system was able to maintain the load at more than 33 K below the oil well temperature. Results of this study support topology optimization as a powerful design tool for thermal design of thermoelectric systems.

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Publication information
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Comparison of four computational methods for computing Q factors and resonance wavelengths in photonic crystal membrane cavities

We benchmark four state-of-the-art computational methods by computing quality factors and resonance wavelengths in photonic crystal membrane L5 and L9 line defect cavities. The convergence of the methods with respect to resolution,
degrees of freedom and number of modes is investigated. Special attention is paid to the influence of the size of the computational domain. Convergence is not obtained for some of the methods, indicating that some are more suitable than others for analyzing line defect cavities.

General information
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Organisations: Department of Photonics Engineering, Nanophotonics Theory and Signal Processing, Nanophotonic Devices, Centre of Excellence for Silicon Photonics for Optical Communications, Department of Electrical Engineering, Electromagnetic Systems, Department of Mechanical Engineering, Solid Mechanics, Zuse Institute Berlin
Authors: de Lasson, J. R. (Intern), Frandsen, L. H. (Intern), Burger, S. (Ekstern), Gutsche, P. (Ekstern), Kim, O. S. (Intern), Breinbjerg, O. (Intern), Sigmund, O. (Intern), Mark, J. (Intern), Gregersen, N. (Intern)
Number of pages: 2
Publication date: 2016

Creating Materials with Negative Refraction Index using Topology Optimization
We apply topology optimization along with full modeling of the electromagnetic (acoustic) field to create metamaterials with negative refraction index. We believe that our approach can be used in the design of metamaterials with specific effective permittivity and permeability e.g. by adapting the approach presented in [1]. We model the problem in 2D in the frequency domain using the Helmholtz equation and discretize the model using the hybrid WBM-FEM method [2]. We consider a modulated plane wave incident at an angle on a slab consisting of a periodic array of identical design cells whose size is on the order of the wavelength. We seek a distribution of solid and air in the design cell yielding a prescribed negative refraction index for the slab. Our objective is to minimize the difference in amplitude between the solution to the model problem and a prescribed modulated plane wave behind the slab. The direction of propagation for the prescribed wave is chosen to match the angle of incidence of the incoming plane wave and its position is used to select the refraction index for the slab. We introducing a continuous design field and apply The Method of Moving Asymptotes to perform the optimization. A filter is used for regularization and a projection step applied to obtain clean 0/1 designs. A continuation scheme is used to avoid stagnation in the optimization.

Metamaterials with negative refraction index designed using this method are presented. The angular dependence of the refraction index and of the reflection and transmission coefficients are investigated.

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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Christiansen, R. E. (Intern), Sigmund, O. (Intern)
Number of pages: 1
Publication date: 2016

Designing Meta Material Slabs Exhibiting Negative Refraction Using Topology Optimization
This paper proposes a topology optimization based approach for designing meta materials exhibiting a desired negative refraction with high transmission at a given angle of incidence and frequency. The approach considers a finite slab of meta material consisting of axis-symmetric designable unit cells subjected to an exterior field. The unit cell is designed to achieve the desired properties based on tailoring the response of the meta material slab under the exterior field. The approach is directly applicable to physical problems modeled by the Helmholtz equation, such as acoustic, elastic and electromagnetic wave problems. Acoustic meta materials with unit cell size on the order of half the wave length are considered as examples. Optimized designs are presented and their performance under varying frequency and angle of incidence is investigated.
Efficient topology optimisation of multiscale and multiphysics problems

The aim of this Thesis is to present efficient methods for optimising high-resolution problems of a multiscale and multiphysics nature. The Thesis consists of two parts: one treating topology optimisation of microstructural details and the other treating topology optimisation of conjugate heat transfer problems.

Part I begins with an introduction to the concept of microstructural details in the context of topology optimisation. Relevant literature is briefly reviewed and problems with existing methodologies are identified. The proposed methodology and its strengths are summarised.

Details on the proposed methodology, for the design of structures with periodic and layered microstructural details, are given and the computational performance is investigated. It is shown that the used spectral coarse basis preconditioner, and its associated basis reutilisation scheme, significantly reduce the computational cost of treating structures with fully-resolved microstructural details.

The methodology is further applied to examples, where it is shown that it ensures connectivity of the microstructural details and that forced periodicity of the microstructural details can yield an implicit robustness to load position. An example of expansion control of a structure under compression is treated in detail, where it is shown that taking boundary effects into account is paramount.

Part II starts with an introduction to conjugate heat transfer and briefly reviews relevant literature. The governing equations used to describe heat transfer and fluid flow are outlined, describing both a commonly-used simplified convection model and the full natural convection model.

Topology optimisation using the simplified model is investigated as a means to reduce the computational time of optimising heat sinks. The model is shown to be useful in an industrial context to provide a first approximation in the design of heat sinks. However, serious flaws and drawbacks of combining the model with topology optimisation are identified.

In order to take full advantage of topology optimisation for providing insight into optimal design of heat sinks, a full conjugate heat transfer model is introduced. Optimised heat sinks are presented for both two- and three-dimensional natural convection problems, where similarities and differences are discussed. Generally, the observations are in line with classical heat sink design, but topology optimisation spawns designs exhibiting optimal characteristics without any prerequisite knowledge. Furthermore, it is shown that when using the full model, the local convection coefficients and surface fluxes are in direct disagreement with the assumptions of the simplified model.

The computational performance and scalability of the developed framework is presented and it is shown that it allows for efficient optimisation of problems with more than 300 million degrees of freedom and almost 30 million design variables. Finally, the framework is used to generate novel passive coolers for light-emitting diode (LED) lamps, where a 20 – 25% lower temperature of the LED package is achieved as compared to reference designs, using around 16% less material.

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Experimental validation of systematically designed acoustic hyperbolic meta material slab exhibiting negative refraction
This Letter reports on the experimental validation of a two-dimensional acoustic hyperbolic metamaterial slab optimized to exhibit negative refractive behavior. The slab was designed using a topology optimization based systematic design
method allowing for tailoring the refractive behavior. The experimental results confirm the predicted refractive capability as well as the predicted transmission at an interface. The study simultaneously provides an estimate of the attenuation inside the slab stemming from the boundary layer effects—insight which can be utilized in the further design of the metamaterial slabs. The capability of tailoring the refractive behavior opens possibilities for different applications. For instance, a slab exhibiting zero refraction across a wide angular range is capable of funneling acoustic energy through it, while a material exhibiting the negative refractive behavior across a wide angular range provides lensing and collimating capabilities.
Exploiting Additive Manufacturing Infill in Topology Optimization for Improved Buckling Load

Additive manufacturing (AM) permits the fabrication of functionally optimized components with high geometrical complexity. The opportunity of using porous infill as an integrated part of the manufacturing process is an example of a unique AM feature. Automated design methods are still incapable of fully exploiting this design freedom. In this work, we show how the so-called coating approach to topology optimization provides a means for designing infill-based components that possess a strongly improved buckling load and, as a result, improved structural stability. The suggested approach thereby addresses an important inadequacy of the standard minimum compliance topology optimization approach, in which buckling is rarely accounted for; rather, a satisfactory buckling load is usually assured through a post-processing step that may lead to sub-optimal components. The present work compares the standard and coating approaches to topology optimization for the MBB beam benchmark case. The optimized structures are additively manufactured using a filamentary technique. This experimental study validates the numerical model used in the coating approach. Depending on the properties of the infill material, the buckling load may be more than four times higher than that of solid structures optimized under the same conditions.

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Improving topology optimization intuition through games

This paper describes the educational game, TopOpt Game, which invites the player to solve various optimization challenges. The main purpose of gamifying topology optimization is to create a supplemental educational tool which can be used to introduce concepts of topology optimization to newcomers as well as to train human intuition of topology optimization. The players are challenged to solve the standard minimum compliance problem in 2D by distributing material in a design domain given a number of loads and supports with a material constraint. A statistical analysis of the gameplay data shows that players achieve higher scores the more they play the game. The game is freely available for the iOS platform at Apple's App Store and at http://www.topopt.dtu.dk/?q=node/909 for Windows and OSX.

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Pages: 775–781
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ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Web of Science (2009): Indexed yes
Industrial Application of Topology Optimization for Combined Conductive and Convective Heat Transfer Problems

This paper presents an industrial application of topology optimization for combined conductive and convective heat transfer problems. The solution is based on a synergy of computer aided design and engineering software tools from Dassault Systemes. The considered physical problem of steady-state heat transfer under convection is simulated using SIMULIA-Abaqus. A corresponding topology optimization feature is provided by SIMULIA-Tosca. By following a standard workflow of design optimization, the proposed solution is able to accommodate practical design scenarios and results in efficient conceptual design proposals. Several design examples with verification results are presented to demonstrate the applicability.

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Scopus rating (2012): CiteScore 2.08
Inverse design engineering of all-silicon polarization beam splitters

Utilizing the inverse design engineering method of topology optimization, we have realized high-performing all-silicon ultra-compact polarization beam splitters. We show that the device footprint of the polarization beam splitter can be as compact as similar to 2 µm² while performing experimentally with a polarization splitting loss lower than similar to 0.82 dB and an extinction ratio larger than similar to 15 dB in the C-band. We investigate the device performance as a function of the device length and find a lower length above which the performance only increases incrementally. Imposing a minimum feature size constraint in the optimization is shown to affect the performance negatively and reveals the necessity for light to scatter on a sub-wavelength scale to obtain functionalities in compact photonic devices.
Large scale three-dimensional topology optimisation of heat sinks cooled by natural convection
This work presents the application of density-based topology optimisation to the design of three-dimensional heat sinks cooled by natural convection. The governing equations are the steady-state incompressible Navier-Stokes equations coupled to the thermal convection-diffusion equation through the Bousinessq approximation. The fully coupled non-linear multiphysics system is solved using stabilised trilinear equal-order finite elements in a parallel framework allowing for the optimisation of large scale problems with order of 20-330 million state degrees of freedom. The flow is assumed to be laminar and several optimised designs are presented for Grashof numbers between $10^3$ and $10^6$. Interestingly, it is observed that the number of branches in the optimised design increases with increasing Grashof numbers, which is opposite to two-dimensional topology optimised designs. Furthermore, the obtained topologies verify prior conclusions regarding fin length/thickness ratios and Biot numbers, but also indicate that carefully tailored and complex geometries may improve cooling behaviour considerably compared to simple heat fin geometries. (C) 2016 Elsevier Ltd. All rights reserved.
Since its original introduction in structural design, density-based topology optimization has been applied to a number of other fields such as microelectromechanical systems, photonics, acoustics and fluid mechanics. The methodology has been well accepted in industrial design processes where it can provide competitive designs in terms of cost, materials and functionality under a wide set of constraints. However, the optimized topologies are often considered as conceptual due to loosely defined topologies and the need of postprocessing. Subsequent amendments can affect the optimized design performance and in many cases can completely destroy the optimality of the solution. Therefore, the goal of this paper is to review recent advancements in obtaining manufacturable topology-optimized designs. The focus is on methods for imposing minimum and maximum length scales, and ensuring manufacturable, well-defined designs with robust performances. The overview discusses the limitations, the advantages and the associated computational costs. The review is completed with optimized designs for minimum compliance, mechanism design and heat transfer.
On nanostructured silicon success

Recent Letters by Piggott et al. 1 and Shen et al. 2 claim the smallest ever dielectric wave length and polarization splitters. The associated News & Views article by Aydin3 states that these works "are the first experimental demonstration of on-chip, silicon photonic components based on complex all-dielectric nanophotonic structures." Here, we question the rationale behind the competition for a small device footprint as set out by the authors of the two papers 1,2 and also point out a lack of appropriate historical context in the three contributions 1–3.

General information

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Organisations: Department of Mechanical Engineering, Solid Mechanics, Department of Electrical Engineering, Acoustic Technology, Department of Photonics Engineering, Nanophotonic Devices
Authors: Sigmund, O. (Intern), Jensen, J. S. (Intern), Frandsen, L. H. (Intern)
Pages: 142-143
On the implementation and effectiveness of morphological close-open and open-close filters for topology optimization

This note reconsiders the morphological close-open and open-close filters for topology optimization introduced in an earlier paper (Sigmund Struct Multidiscip Optim 33(4-5):401–424 (2007)). Close-open and open-close filters are defined as the sequential application of four dilation or erosion filters. In the original paper, these filters were proposed in order to provide length scale control in both the solid and the void phase. However, it was concluded that the filters were not useful in practice due to the computational cost of the sensitivity analysis. In this note, it is shown that the computational cost is much lower if the sensitivity analysis for each erosion or dilation step is performed sequentially. Unfortunately, it is also found that the close-open and open-close filters do not have the expected effect in terms of length scale control; each close or open operation ruins the effect of the preceding filters, resulting in a design with a minimum length scale in either the solid phase or the void phase, but not both.
On the (non-)optimality of Michell structures

Optimal analytical Michell frame structures have been extensively used as benchmark examples in topology optimization, including truss, frame, homogenization, density and level-set based approaches. However, as we will point out, partly the interpretation of Michell's structural continua as discrete frame structures is not accurate and partly, it turns out that limiting structural topology to frame-like structures is a rather severe design restriction and results in structures that are quite far from being stiffness optimal. The paper discusses the interpretation of Michell’s theory in the context of numerical topology optimization and compares various topology optimization results obtained with the frame restriction to cases with no design restrictions. For all examples considered, the true stiffness optimal structures are composed of sheets (2D) or closed-walled shell structures (3D) with variable thickness. For optimization problems with one load case, numerical results in two and three dimensions indicate that stiffness can be increased by up to 80 % when dropping the frame restriction. For simple loading situations, studies based on optimal microstructures reveal theoretical gains of +200 %. It is also demonstrated how too coarse design discretizations in 3D can result in unintended restrictions on the design freedom and achievable compliance.

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Web of Science (2011): Indexed yes
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Topology Optimization for Additive Manufacturing

This PhD thesis deals with the combination of topology optimization and additive manufacturing (AM, also known as 3D-printing). In addition to my own works, the thesis contains a broader review and assessment of the literature within the field.

The thesis first presents a classification of the various AM technologies, a review of relevant manufacturing materials, the properties of these materials in the additively manufactured part, as well as manufacturing constraints with a potential for design optimization.

Subsequently, specific topology optimization formulations relevant for the most important AM-related manufacturing constraints are presented. These constraints are divided into directional and non-directional constraints. Non-directional constraints include minimum/uniform length scale and a cavity constraint. It is shown that modified filter boundary conditions are required in order for the so-called robust formulation to ensure satisfaction of the minimum feature size in the vicinity of the design domain boundary.

The most important directional constraint is a so-called overhang constraint. In relation to this, mainly two formulations from the literature are discussed.

My own work has mainly been focused on better exploiting the new opportunities provided by AM. These are treated under the categories of multi-material applications, multi-scale approaches, and interface problems which incorporates elements from both of the preceding categories. It is shown how the material microstructure for a material with programmable, nearly constant Poisson's ratio for large deformations may be designed and fabricated using direct ink writing. Structures are generated for the full interval \([-0.8, 0.8]\), all with uniform feature size and a continuous print path, ensuring the potential for scalable manufacturing.

In relation to interface problems it is shown how a flexible void area may be included into a standard minimum compliance problem by employing an additional design variable field and a sensitivity filter. Furthermore, it is shown how the design of coated structures may be modeled as a differentiable topology optimization problem. This is done partly by using spatial gradients of the density variable in the interpolation function between the design variable field and physical variables, partly by employing a two-step filtering scheme in order to control the gradient field. The approach is implemented for both 2D and 3D problems. A special case of this type of design problem is porous shell structures which are often used within AM. Based on numerical as well as experimental studies it is shown that such structures have a lower stiffness than fully solid structures, however, they possess significantly improved buckling properties and are less sensitive towards load perturbations. These properties are inherently ensured, that is, without the explicit definition of additional constraints.
Topology optimization for simplified structural fire safety

Topology optimization is applied in an idealized structural fire safety model, where the minimum compliance problem is constrained by temperature-controlled structural degradation. The constraint ensures a certain structural stiffness after a prescribed time. As this time period is extended, resulting optimized topologies tend to become thicker or introduce redundant members that can take over when structural parts near the origin of the fire lose their load carrying capability. Hence, the structural degradation model acts as an erosion operator on the topology and indirectly enforces a minimum length scale on the final designs.
Topology optimization for transient heat transfer problems

The focus of this work is on passive control of transient heat transfer problems using the topology optimization (TopOpt) method [1]. The goal is to find distributions of a limited amount of phase change material (PCM), within a given design domain, which optimizes the heat energy storage [2]. Our aim is to obtain manufacturable designs [3] as well as demonstrating TopOpt for mixed multiphysics problems [4]. TopOpt provides material distributions in a given design domain, optimized with respect to a given objective and satisfying a set of constraints. Originating in static mechanical problems, TopOpt has later been extended to transient problems in mechanics and photonics (e.g. [5], [6] and [7]). In the presented approach, the optimization is gradient-based, where in each iteration the non-steady heat conduction equation is solved, using the finite element method and an appropriate time-stepping scheme. A PCM can efficiently absorb heat while keeping its temperature nearly unchanged [8]. The use of PCM in e.g. electronics [9] and mechanics [10], yields improved performance and lower costs depending on a.o., the spatial distribution of PCM. The considered problem consists in optimizing the distribution of PCM in a design domain, subject to a periodic heat influx. The objective is to stabilize the heat outflow. Application examples include keeping constant room temperature for oscillatory heat input or keeping constant working temperature of a CPU subjected to time varying computational load.
model problems under consideration. A short discussion of the benefits and drawbacks of applying the hybrid method compared to the finite element method, used in conjunction with topology optimization, is included. Preliminary results for novel preconditioners used in conjunction with the generalized minimal residual method for the iterative solution of wave problems, potentially suited for use with topology optimization, are discussed.

The development of an extension to an existing method, for assuring geometric robustness of designs created using density-based topology optimization, is presented. The method is applied to acoustic cavity design, and a significant improvement in the geometric robustness of several cavities demonstrated. Experimental validation of an acoustic cavity designed using the proposed method is provided.

A novel approach for designing meta material slabs with selectively tuned negative refractive behavior is outlined. Numerical examples demonstrating the behavior of a slab under different conditions is provided. Results from an experimental study demonstrating agreement with numerical predictions are presented.

Finally an approach for designing acoustic wave shaping devices is treated. Three examples of applications are presented, a directional sound emission device, a wave splitting device and a flat focusing lens. Experimental results for the first two devices demonstrating good agreement between measurements and the numerical predictions, are provided.

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Topology optimization of piezo modal transducers with null-polarity phases
Piezo modal transducers in 2d can be designed theoretically by tailoring polarity of the surface electrodes. However, it is also necessary to include null-polarity phases of known width separating areas of opposite polarity in the manufacturing process in order to avoid short-circuiting. Otherwise the performance of such devices could be spoiled. In this work, we propose an appropriate topology optimization interpolation function for the electrode profile such that the effect of this new phase (hereafter gap-phase) is included in the formulation of the design problem. The approach is density-based, where the interface is controlled by including the gradient norm in the electrode profile interpolation. Through a detailed case study in 1d, conclusions on how to control the width of this gap-phase are extracted, and subsequently extended to the 2d case.

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Topology optimization of two-dimensional elastic wave barriers

Topology optimization is a method that optimally distributes material in a given design domain. In this paper, topology optimization is used to design two-dimensional wave barriers embedded in an elastic halfspace. First, harmonic vibration sources are considered, and stiffened material is inserted into a design domain situated between the source and the receiver to minimize wave transmission. At low frequencies, the stiffened material reflects and guides waves away from the surface. At high frequencies, destructive interference is obtained that leads to high values of the insertion loss. To handle harmonic sources at a frequency in a given range, a uniform reduction of the response over a frequency range is
pursued. The minimal insertion loss over the frequency range of interest is maximized. The resulting design contains features at depth leading to a reduction of the insertion loss at the lowest frequencies and features close to the surface leading to a reduction at the highest frequencies. For broadband sources, the average insertion loss in a frequency range is optimized. This leads to designs that especially reduce the response at high frequencies. The designs optimized for the frequency averaged insertion loss are found to be sensitive to geometric imperfections. In order to obtain a robust design, a worst case approach is followed. (C) 2016 Elsevier Ltd. All rights reserved.
This article demonstrates and discusses topology optimization for unsteady incompressible fluid flows. The fluid flows are simulated using the lattice Boltzmann method, and a partial bounceback model is implemented to model the transition between fluid and solid phases in the optimization problems. The optimization problem is solved with a gradient based method, and the design sensitivities are computed by solving the discrete adjoint problem. For moderate Reynolds number flows, it is demonstrated that topology optimization can successfully account for unsteady effects such as vortex shedding and time-varying boundary conditions. Such effects are relevant in several engineering applications, i.e. fluid pumps and control valves.
The investigation of methods to support the ever increasing demand for data transfer has continued for years; one such method suggested within the field of optical communication, is space division multiplexing (SDM) [1]. Simultaneously the field of photonic integrated circuits (PICs) is being investigated due to attractive features such as high device density and low operating power [2]. For PICs it is necessary with a toolbox of devices and one such of importance to the processing of on chip SDM is the mode converter. Several schemes have been used to realize such devices [3] [4]. In this paper we present the possibility of employing topology optimization (TO) to design a device that allows for reversible conversion between the transverse electric fundamental even (TE0) mode and the second higher order odd mode (TE2). Topology optimization is an iterative inverse design process, where repeated finite-difference time-domain (FDTD) calculations are made in accordance with a sensitivity analysis. This is done using a software package which has been developed in-house, and which has shown to deliver low loss designs with a controllable bandwidth in addition to small device footprints [5]. The design is made for fabrication in silicon-on-insulator (SOI) and previous work has shown excellent concordance between simulations and experimental results when employing 3D TO [6].
Topology-optimized mode converter in a silicon-on-insulator photonic wire waveguide

A 1.4 μm × 3.4 μm fundamental to first order mode converter for the transverse electric polarization was designed using topology optimization. Insertion loss <2 dB (100 nm bandwidth) and extinction ratio >9.5 dB.

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Topology optimized mode multiplexing in silicon-on-insulator photonic wire waveguides

We design and experimentally verify a topology optimized low-loss and broadband two-mode (de-)multiplexer, which is (de-)multiplexing the fundamental and the first-order transverse-electric modes in a silicon photonic wire. The device has a footprint of 2.6 μm x 4.22 μm and exhibits a loss 14 dB in the C-band. Furthermore, we demonstrate that the design method can be expanded to include more modes, in this case including also the second order transverse-electric mode, while maintaining functionality.

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3D interactive topology optimization on hand-held devices
This educational paper describes the implementation aspects, user interface design considerations and workflow potential of the recently published TopOpt 3D App. The app solves the standard minimum compliance problem in 3D and allows the user to change design settings interactively at any point in time during the optimization. Apart from its educational nature, the app may point towards future ways of performing industrial design. Instead of the usual geometrize, then model and optimize approach, the geometry now automatically adapts to the varying boundary and loading conditions. The app is freely available for iOS at Apple’s App Store and at http://www.topopt.dtu.dk/TopOpt3Dfor Windows and OSX.

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Combined Shape and Topology Optimization

Shape and topology optimization seeks to compute the optimal shape and topology of a structure such that one or more properties, for example stiffness, balance or volume, are improved. The goal of the thesis is to develop a method for shape and topology optimization which uses the Deformable Simplicial Complex (DSC) method. Consequently, we present a novel method which combines current shape and topology optimization methods. This method represents the surface of the structure explicitly and discretizes the structure into non-overlapping elements, i.e. a simplicial complex. An explicit surface representation usually limits the optimization to minor shape changes. However, the DSC method uses a single explicit representation and still allows for large shape and topology changes. It does so by constantly applying a set of mesh operations during deformations of the structure. Using an explicit instead of an implicit representation gives rise to several advantages including straightforward modeling of the surface, improved scalability and ability to optimize multiple materials.

This dissertation describes the essential parts of the novel method for combined shape and topology optimization. This includes the structural analysis in Chapter 2, the optimization in Chapter 3 and the Deformable Simplicial Complex method in Chapter 4. Finally, four applications of the developed method are presented in the included papers and summarized in Chapter 5.

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Combined shape and topology optimization of 3D structures

We present a method for automatic generation of 3D models based on shape and topology optimization. The optimization procedure, or model generation process, is initialized by a set of boundary conditions, an objective function, constraints and an initial structure. Using this input, the method will automatically deform and change the topology of the initial structure such that the objective function is optimized subject to the specified constraints and boundary conditions. For
example, this tool can be used to improve the stiffness of a structure before printing, reduce the amount of material needed to construct a bridge, or to design functional chairs, tables, etc. which at the same time are visually pleasing.

The structure is represented explicitly by a simplicial complex and deformed by moving surface vertices and relabeling tetrahedra. To ensure a well-formed tetrahedral mesh during these deformations, the Deformable Simplicial Complex method is used. The deformations are based on optimizing the objective, which in this paper will be maximizing stiffness. Furthermore, the optimization procedure will be subject to constraints such as a limit on the amount of material and the difference from the original shape.
Creating geometrically robust designs for highly sensitive problems using topology optimization: Acoustic cavity design

Resonance and wave-propagation problems are known to be highly sensitive towards parameter variations. This paper discusses topology optimization formulations for creating designs that perform robustly under spatial variations for acoustic cavity problems. For several structural problems, robust topology optimization methods have already proven their worth. However, it is shown that direct application of such methods is not suitable for the acoustic problem under consideration. A new double filter approach is suggested which makes robust optimization for spatial variations possible. Its effect and limitations are discussed. In addition, a known explicit penalization approach is considered for comparison. For near-uniform spatial variations it is shown that highly robust designs can be obtained using the double filter approach. It is finally demonstrated that taking non-uniform variations into account further improves the robustness of the designs.

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Designing visual appearance using a structured surface

We present an approach for designing nanostructured surfaces with prescribed visual appearances, starting at design analysis and ending with a fabricated sample. The method is applied to a silicon wafer structured using deep ultraviolet lithography and dry etching and includes preliminary design followed by numerical and experimental verification. The approach comprises verifying all design and fabrication steps required to produce a desired appearance. We expect that the procedure in the future will yield structurally colored surfaces with appealing prescribed visual appearances.

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Experimental validation of a topology optimized acoustic cavity
This paper presents the experimental validation of an acoustic cavity designed using topology optimization with the goal of minimizing the sound pressure locally for monochromatic excitation. The presented results show good agreement between simulations and measurements. The effect of damping, errors in the production of the cavity, and variations in operating frequency is discussed and the importance of taking these factors into account in the modeling process is highlighted.

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Scopus rating (2011): SJR 0.695 SNIP 1.642 CiteScore 1.68
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BFI (2010): BFI-level 2
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Outperforming conventional design concepts, a flat-top drop filter has been designed by applying 3D topology optimization to a single waveguide-coupled L3 photonic crystal cavity. Measurements on the design fabricated in silicon-on-insulator material reveal that the pass-band of the drop channel is flat within 0.44 dB over a wavelength range of 9.7 nm with an insertion loss lower than 0.85 dB.
Mathematical programming methods for large-scale topology optimization problems
This thesis investigates new optimization methods for structural topology optimization problems. The aim of topology optimization is finding the optimal design of a structure. The physical problem is modelled as a nonlinear optimization problem. This powerful tool was initially developed for mechanical problems, but has rapidly extended to many other disciplines, such as fluid dynamics and biomechanical problems. However, the novelty and improvements of optimization methods has been very limited. It is, indeed, necessary to develop of new optimization methods to improve the final designs, and at the same time, reduce the number of function evaluations. Nonlinear optimization methods, such as sequential quadratic programming and interior point solvers, have almost not been embraced by the topology optimization community. Thus, this work is focused on the introduction of this kind of second-order solvers to drive the field forward.

The first part of the thesis introduces, for the first time, an extensive benchmarking study of different optimization methods in structural topology optimization. This comparison uses a large test set of instance problems and three different structural topology optimization problems. The thesis additionally investigates, based on the continuation approach, an alternative formulation of the problem to reduce the chances of ending in local minima, and at the same time, decrease the number of iterations. The last part is focused on special purpose methods for the classical minimum compliance problem. Two of the state-of-the-art optimization algorithms are investigated and implemented for this structural topology optimization problem. A Sequential Quadratic Programming (TopSQP) and an interior point method (TopIP) are developed exploiting the specific mathematical structure of the problem. In both solvers, information of the exact Hessian is considered. A robust iterative method is implemented to efficiently solve large-scale linear systems. Both TopSQP and TopIP have successful results in terms of convergence, number of iterations, and objective function values. Thanks to the use of the iterative method implemented, TopIP is able to solve large-scale problems with more than three millions degrees of freedom.

General information
State: Published
Organisations: Department of Wind Energy, Wind Turbines, Department of Mechanical Engineering, Solid Mechanics
Authors: Rojas Labanda, S. (Intern), Stolpe, M. (Intern), Sigmund, O. (Intern)
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Main Research Area: Technical/natural sciences
Electronic versions:
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Mathematical programming methods for large-scale topology optimization problems
Publication: Research › Ph.D. thesis – Annual report year: 2015

Minimum length scale in topology optimization by geometric constraints
A density-based topology optimization approach is proposed to design structures with strict minimum length scale. The idea is based on using a filtering-threshold topology optimization scheme and computationally cheap geometric constraints. The constraints are defined over the underlying structural geometry represented by the filtered and physical fields. Satisfying the constraints leads to a design that possesses user-specified minimum length scale. Conventional topology optimization problems can be augmented with the proposed constraints to achieve minimum length scale on the final design. No additional finite element analysis is required for the constrained optimization. Several benchmark examples are presented to show the effectiveness of this approach.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Zhou, M. (Intern), Lazarov, B. S. (Intern), Wang, F. (Intern), Sigmund, O. (Intern)
Pages: 266-282
Publication date: 2015
Main Research Area: Technical/natural sciences

Publication information
Journal: Computer Methods in Applied Mechanics and Engineering
Volume: 293
ISSN (Print): 0045-7825
Ratings:
Optimal Design of Porous Materials
The focus of this thesis is topology optimization of material microstructures. That is, creating new materials, with attractive properties, by combining classic materials in periodic patterns. First, large-scale topology optimization is used to design complicated three-dimensional materials with exotic properties, such as isotropic negative Poisson's ratio and negative thermal expansion. Furthermore, it is shown how topology optimization can be used to design materials with a good compromise between stiffness and damping. Both a simple quasi-static method suited for low frequency wave propagation, and a more general dynamic method (using Floquet-Bloch theory) applicable to arbitrary frequency ranges are presented. The quasi-static method is applied to the design of both two- and three-dimensional material microstructures. And it is shown, using two-dimensional examples, how the general method can be used to design materials with frequency dependent loss, which can be higher than depicted by the quasi-static bounds. The work is inspired by the increased availability of additive manufacturing facilities, and, thus, the possibility of manufacturing complicated structures. Therefore, throughout the thesis extra attention is given to obtain structures that can be manufactured. That is also the case in the final part, where a simple multiscale method for the optimization of structural damping is presented. The method can be used to obtain an optimized component with structural details on the same scale as the manufacturing precision, without being computationally exhaustive. Furthermore, the connectivity of the stiff phase is assured, making it possible to design components that can be manufactured, using additive manufacturing to print the stiff material phase, and, thereafter, infuse the component with the soft and lossy material phase.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Department of Electrical Engineering, Acoustic Technology
Authors: Andreassen, E. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern), Thomsen, J. J. (Intern)
Number of pages: 176
Publication date: 2015

Stress-constrained topology optimization for compliant mechanism design
This article presents an application of stress-constrained topology optimization to compliant mechanism design. An output displacement maximization formulation is used, together with the SIMP approach and a projection method to ensure convergence to nearly discrete designs. The maximum stress is approximated using a normalized version of the commonly-used p-norm of the effective von Mises stresses. The usual problems associated with topology optimization for compliant mechanism design: one-node and/or intermediate density hinges are alleviated by the stress constraint. However, it is also shown that the stress constraint alone does not ensure mesh-independency.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Federal University of Rio Grande do Sul
Authors: de Leon, D. M. (Ekstern), Alexandersen, J. (Intern), Jun, J. S. (Ekstern), Sigmund, O. (Intern)
Pages: 929-943
Publication date: 2015
Main Research Area: Technical/natural sciences
Electronic versions: S172_Erik_Andreassen.pdf
Publication: Research › Ph.D. thesis – Annual report year: 2015
This paper presents new results within the design of three-dimensional (3D) coated structures using topology optimization. The work is an extension of a recently published two-dimensional (2D) method for including coated structures into the minimum compliance topology optimization problem. The high level of control over key parameters demonstrated for the 2D model can likewise be achieved in 3D. The effectiveness of the approach is demonstrated with numerical examples, which for the 3D problems have been solved using a parallel topology optimization implementation based on the PETSc toolkit.

**General information**

State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Clausen, A. (Intern), Andreassen, E. (Intern), Sigmund, O. (Intern)
Number of pages: 6
Topology Optimization of an Actively Cooled Electronics Section for Downhole Tools

Active cooling systems represent a possible solution to the electronics overheating that occurs in wireline downhole tools operating in high temperature oil and gas wells. A Peltier cooler was chosen to maintain the downhole electronics to a tolerable temperature, but its integration into the downhole electronics unit proved to be challenging, because of the space constraints and the proximity of the cooling zone (electronics) to the heat sink (well fluid). The topology optimization approach was therefore chosen to optimize the thermal design of the actively cooled electronics section and the SIMP (Solid Isotropic Material with Penalization) method was implemented in COMSOL Multiphysics. Several optimized designs were obtained for different operating conditions and their sensitivity to the change in the boundary conditions was evaluated. A final design for the electronics unit was selected, according to the topology optimization results and assembly constraints, and compared to the optimized cases.

Topology optimization of coated structures and material interface problems

This paper presents a novel method for including coated structures and prescribed material interface properties into the minimum compliance topology optimization problem. Several elements of the method are applicable to a broader range of interface problems. The approach extends the standard SIMP method by including the normalized norm of the spatial gradient of the design field into the material interpolation function, enforcing coating material at interfaces by attributing particular properties. The length scales of the base structure and the coating are separated by introducing a two-step filtering/projection approach. The modeled coating thickness is derived analytically, and the coating is shown to be accurately controlled and applied in a highly uniform manner over the structure. An alternative interpretation of the model is to perform single-material design for additive manufacturing. Infill is assumed to be constituted of an isotropic porous microstructure satisfying the Hashin-Shtrikman bounds and is modeled using the homogenized material properties. A range of numerical results illustrate the effectiveness of the approach.
Topology Optimization of Coupled Photonic Crystal Cavities for Flat-top Drop Filter Functionality

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, Centre of Excellence for Silicon Photonics for Optical Communications, Department of Mechanical Engineering, Solid Mechanics, Haldor Topsoe AS
Authors: Frandsen, L. H. (Intern), Elesin, Y. (Ekstern), Sigmund, O. (Intern), Yvind, K. (Intern)
Publication date: 2015
Event: Abstract from CLEO/Europe - EQEC 2015, Munich, Germany.
Main Research Area: Technical/natural sciences
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Source: PublicationPreSubmission
Source-ID: 118268249
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2015

Topology Optimization of Thermal Heat Sinks
In this paper, topology optimization is applied to optimize the cooling performance of thermal heat sinks. The coupled two-dimensional thermofluid model of a heat sink cooled with forced convection and a density-based topology optimization including density filtering and projection are implemented in COMSOL Multiphysics. The optimization objective is to minimize the heat sink's temperature for a prescribed pressure drop and fixed heat generation. To conduct the optimization, COMSOL's Optimization Module with GCMMA as the optimization method is used. The implementation of this topology optimization approach in COMSOL Multiphysics is described in this paper and results for optimized two-dimensional heat sinks are presented. Furthermore, parameter studies regarding the effect of the prescribed pressure drop of the system on Reynolds number and realized heat sink temperature are presented and discussed.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Electrofunctional materials, Department of Mechanical Engineering, Solid Mechanics
Authors: Klaas Haertel, J. H. (Intern), Engelbrecht, K. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
Number of pages: 6
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Relations
Projects:
Topology Optimization of Thermal Heat Sinks
Source: PublicationPreSubmission
Source-ID: 118522177
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

Topology Optimized Architectures with Programmable Poisson's Ratio over Large Deformations
Topology optimized architectures are designed and printed with programmable Poisson's ratios ranging from -0.8 to 0.8 over large deformations of 20% or more.

General information
State: Published
Topology optimized design for silicon-on-insulator mode converter

The field of photonic integrated circuits (PICs) has attracted interest in recent years as they allow high device density while requiring only low operating power. The possibility of exploiting mode division multiplexing (MDM) in future optical communication networks is being investigated as a potential method for supporting the constantly increasing internet traffic demand [1]. Mode converters are important components necessary to support on-chip processing of MDM signals and multiple approaches has been followed in realizing such devices [2], [3]. Topology optimization (TO) [4] is a powerful inverse design tool which has experimentally proven to deliver robust designs with controllable bandwidth and low loss [5], [6]. Here it is shown how TO has been used to obtain a small footprint, low-loss, broad-band design for mode conversion between the transverse electric fundamental even (TE0) mode and the first higher order odd mode (TE1) in a photonic wire. The design is to be fabricated in silicon-on-insulator (SOI) material, and previous work has shown excellent correspondence between simulations and experimental results for 3D TO [7].

General information

State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, Centre of Excellence for Silicon Photonics for Optical Communications, High-Speed Optical Communication, Department of Mechanical Engineering, Solid Mechanics, Haldor Topsoe AS
Authors: Frellsen, L. F. (Intern), Frandsen, L. H. (Intern), Ding, Y. (Intern), Elesin, Y. (Ekstern), Sigmund, O. (Intern), Yvind, K. (Intern)
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Conference: 2015 IEEE Photonics Conference, Reston, Virginia, United States, 04/10/2015 - 04/10/2015
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Topologically optimized silicon photonic wire mode (de)multiplexer

We have designed and for the first time experimentally verified a topology optimized mode (de)multiplexer, which demultiplexes the fundamental and the first order mode of a double mode photonic wire to two separate single mode waveguides (and multiplexes vice versa). The device has a footprint of ~4.4 μm x ~2.8 μm and was fabricated for different design resolutions and design threshold values to verify the robustness of the structure to fabrication tolerances. The multiplexing functionality was confirmed by recording mode profiles using an infrared camera and vertical grating couplers. All structures were experimentally found to maintain functionality throughout a 100 nm wavelength range limited by available laser sources and insertion losses were generally lower than 1.3 dB. The cross talk was around -12 dB and the extinction ratio was measured to be better than 8 dB.

General information

State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, High-Speed Optical Communication, Department of Mechanical Engineering, Solid Mechanics, Technical University of Denmark
Authors: Frellsen, L. F. (Intern), Frandsen, L. H. (Intern), Ding, Y. (Intern), Elesin, Y. (Intern), Sigmund, O. (Intern), Yvind, K. (Intern)
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Article number: 93670X-1
ISBN (Print): 9781628414578
Benefits and Challenges when Performing Robust Topology Optimization for Interior Acoustic Problems

The objective of this work is to present benefits and challenges of using robust topology optimization techniques for minimizing the sound pressure in interior acoustic problems. The focus is on creating designs which maintain high performance under uniform spatial variations. This work takes off from previous work considering topology optimization for interior acoustic problems, [1]. However, in previous work the robustness of the designs was not considered.

Combined shape and topology optimization for minimization of von Mises Stress

We present a method to design manufacturable extremal elastic materials. Extremal materials can possess interesting properties such as a negative Poisson's ratio. The effective properties of the obtained microstructures are shown to be close to the theoretical limit given by mathematical bounds, and the deviations are due to the imposed manufacturing constraints. The designs are generated using topology optimization. Due to high resolution and the imposed robustness requirement they are manufacturable without any need for post-processing. This has been validated by the manufacturing of an isotropic material with a Poisson's ratio of $\nu=-0.5$ and a bulk modulus of 0.2% times the solid base material's bulk modulus. © 2013 Elsevier Ltd. All rights reserved.
**General information**
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Andreassen, E. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.76 SJR 1.256 SNIP 1.546
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.224 SNIP 1.785 CiteScore 2.66
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.357 SNIP 1.838 CiteScore 2.56
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.204 SNIP 1.758 CiteScore 2.58
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.325 SNIP 1.909 CiteScore 2.2
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.488 SNIP 1.915 CiteScore 2.22
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.413 SNIP 1.846
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.905 SNIP 2.067
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.882 SNIP 2.112
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.87 SNIP 2.135
Scopus rating (2006): SJR 1.797 SNIP 2.136
Scopus rating (2005): SJR 1.638 SNIP 1.881
Scopus rating (2004): SJR 1.47 SNIP 1.711
Scopus rating (2003): SJR 1.691 SNIP 1.661
Scopus rating (2002): SJR 1.611 SNIP 1.312
Scopus rating (2001): SJR 1.173 SNIP 1.042
Scopus rating (2000): SJR 1.54 SNIP 1.27
Scopus rating (1999): SJR 0.832 SNIP 0.887
Original language: English
Design, Elastic moduli, Manufacture, Poisson ratio, Shape optimization, Microstructure
Electronic versions:
Design of materials with prescribed nonlinear properties

We systematically design materials using topology optimization to achieve prescribed nonlinear properties under finite deformation. Instead of a formal homogenization procedure, a numerical experiment is proposed to evaluate the material performance in longitudinal and transverse tensile tests under finite deformation, i.e. stress-strain relations and Poisson's ratio. By minimizing errors between actual and prescribed properties, materials are tailored to achieve the target. Both two dimensional (2D) truss-based and continuum materials are designed with various prescribed nonlinear properties. The numerical examples illustrate optimized materials with rubber-like behavior and also optimized materials with extreme strain-independent Poisson's ratio for axial strain intervals of $\varepsilon_i \in [0.00,0.30]$. © 2014 Elsevier Ltd. All rights reserved.

General information

State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Department of Electrical Engineering, Acoustic Technology
Authors: Wang, F. (Intern), Sigmund, O. (Intern), Jensen, J. S. (Intern)
Pages: 156-174
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Main Research Area: Technical/natural sciences

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ISSN (Print): 0022-5096
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BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.33 SJR 2.155 SNIP 2.048
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.439 SNIP 2.157 CiteScore 4.29
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.677 SNIP 2.304 CiteScore 4.7
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.597 SNIP 2.304 CiteScore 4.43
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.284 SNIP 2.08 CiteScore 3.5
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.865 SNIP 2.267 CiteScore 3.6
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 3.34 SNIP 2.474
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.981 SNIP 2.173
Design of structurally colored surfaces based on scalar diffraction theory

In this paper we investigate the possibility of controlling the color and appearance of surfaces simply by modifying the height profile of the surface on a nanoscale level. The applications for such methods are numerous: new design possibilities for high-end products, color engraving on any highly reflective surface, paint-free text and coloration, UV-resistant coloring, etc. In this initial study, the main focus is on finding a systematic way to obtain these results. For now the simulation and optimization is based on a simple scalar diffraction theory model. From the results, several design issues are identified: some colors are harder to optimize for than others, and some can be produced by only a few height levels, whereas others require more complex structures. It is shown that a wide range of results can be obtained. © 2014 Optical Society of America

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Johansen, V. E. (Intern), Andkjær, J. A. (Intern), Sigmund, O. (Intern)
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Journal: Optical Society of America. Journal B: Optical Physics
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Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.81 SJR 0.894 SNIP 1.015
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.023 SNIP 1.002 CiteScore 1.78
Interpolation scheme for fictitious domain techniques and topology optimization of finite strain elastic problems

The focus of this paper is on interpolation schemes for fictitious domain and topology optimization approaches with structures undergoing large displacements. Numerical instability in the finite element simulations can often be observed, due to excessive distortion in low stiffness regions. A new energy interpolation scheme is proposed in order to stabilize the numerical simulations. The elastic energy density in the solid and void regions is interpolated using the elastic energy densities for large and small deformation theory, respectively. The performance of the proposed method is demonstrated for a challenging test geometry as well as for topology optimization of minimum compliance and compliant mechanisms. The effect of combining the proposed interpolation scheme with different hyperelastic material models is investigated as well. Numerical results show that the proposed approach alleviates the problems in the low stiffness regions and for the simulated cases, results in stable topology optimization of structures undergoing large displacements. © 2014 Elsevier B.V.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Department of Electrical Engineering, Acoustic Technology
Authors: Wang, F. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern), Jensen, J. S. (Intern)
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Main Research Area: Technical/natural sciences

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Journal: Computer Methods in Applied Mechanics and Engineering
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Ratings:
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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.31 SJR 2.743 SNIP 1.962
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.823 SNIP 2.126 CiteScore 3.91
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.418 SNIP 2.087 CiteScore 3.41
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 3.095 SNIP 2.252 CiteScore 3.5
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.543 SNIP 2.247 CiteScore 3.04
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.679 SNIP 1.959 CiteScore 3.03
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.463 SNIP 1.937
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.274 SNIP 1.73
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.184 SNIP 1.985
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.22 SNIP 1.863
Inverse design of nanostructured surfaces for color effects

We propose an inverse design methodology for systematic design of nanostructured surfaces for color effects. The methodology is based on a 2D topology optimization formulation based on frequency-domain finite element simulations for E and/or H polarized waves. The goal of the optimization is to maximize color intensity in prescribed direction(s) for a prescribed color (RGB) vector. Results indicate that nanostructured surfaces with any desirable color vector can be generated; that complex structures can generate more intense colors than simple layerings; that angle independent colorings can be obtained at the cost of reduced intensity; and that performance and optimized surface topologies are relatively independent on light polarization. © 2013 Optical Society of America

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Organisations: Solid Mechanics, Department of Mechanical Engineering, Department of Management Engineering
Authors: Andkjær, J. A. (Intern), Johansen, V. E. (Intern), Friis, K. S. (Intern), Sigmund, O. (Intern)
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BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.81 SJR 0.894 SNIP 1.015
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.023 SNIP 1.002 CiteScore 1.78
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.188 SNIP 1.156 CiteScore 2.09
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.354 SNIP 1.281 CiteScore 2.33
ISI indexed (2013): ISI indexed yes
On the realization of the bulk modulus bounds for two-phase viscoelastic composites

Materials with good vibration damping properties and high stiffness are of great industrial interest. In this paper the bounds for viscoelastic composites are investigated and material microstructures that realize the upper bound are obtained by topology optimization. These viscoelastic composites can be realized by additive manufacturing technologies followed by an infiltration process. Viscoelastic composites consisting of a relatively stiff elastic phase, e.g. steel, and a relatively lossy viscoelastic phase, e.g. silicone rubber, have non-connected stiff regions when optimized for maximum damping. In order to ensure manufacturability of such composites the connectivity of the matrix is ensured by imposing a conductivity constraint and the influence on the bounds is discussed. © 2013 Elsevier Ltd. All rights reserved.

Bibliographical note

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On the realization of the bulk modulus bounds for two-phase viscoelastic composites

Materials with good vibration damping properties and high stiffness are of great industrial interest. In this paper the bounds for viscoelastic composites are investigated and material microstructures that realize the upper bound are obtained by topology optimization. These viscoelastic composites can be realized by additive manufacturing technologies followed by an infiltration process. Viscoelastic composites consisting of a relatively stiff elastic phase, e.g. steel, and a relatively lossy viscoelastic phase, e.g. silicone rubber, have non-connected stiff regions when optimized for maximum damping. In order to ensure manufacturability of such composites the connectivity of the matrix is ensured by imposing a conductivity constraint and the influence on the bounds is discussed. © 2013 Elsevier Ltd. All rights reserved.
Structural colours and applications to anodised aluminium surfaces

This thesis investigates possible ways of creating aluminium with a milky white, metallic appearance for decorative purposes. Since white cannot be obtained through traditional absorption based dyeing of aluminium, optical mechanisms based on scattering by nanostructures are studied in order to solve the problem. The problem is investigated by first reviewing existing work within colouration and visual appearance. This includes a study on how colours are perceived by humans and an investigation of the characteristics with which a surface appearance is properly described. Subsequently, nanostructures and surface profiles are investigated using optimisation and topology optimisation in order to understand the limitations and design freedom of colour engineering. This is then followed by a study of the effect of disorder on a nanoscale level in order to tailor surface reflections for a smooth, pleasing appearance. Afterwards, optical models for scattering of non-deterministic geometries suitable for anodised aluminium are considered. The outcome of the investigations are several different proposals for obtaining a white appearance for aluminium. These are described in the thesis alongside a brief note on the experimental work performed to try out the proposals. Results from the most successful experiment in which a satisfactory white appearance is obtained is then presented.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Acoustic Technology, Department of Electrical Engineering, Electromagnetic Systems
Authors: Johansen, V. E. (Intern), Sigmund, O. (Intern), Aage, N. (Intern), Breinbjerg, O. (Intern)
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Time domain topology optimization of 3D nanophotonic devices

We present an efficient parallel topology optimization framework for design of large scale 3D nanophotonic devices. The code shows excellent scalability and is demonstrated for optimization of broadband frequency splitter, waveguide intersection, photonic crystal-based waveguide and nanowire-based waveguide. The obtained results are compared to simplified 2D studies and we demonstrate that 3D topology optimization may lead to significant performance improvements. © 2013 Elsevier B.V. All rights reserved.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Elesin, Y. (Intern), Lazarov, B. S. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
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Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.621 SNIP 0.882 CiteScore 1.8
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.749 SNIP 0.715 CiteScore 1.56
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.746 SNIP 0.801 CiteScore 1.54
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.842 SNIP 0.785 CiteScore 1.67
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.972 SNIP 1.159 CiteScore 1.73
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.333 SNIP 1.172 CiteScore 2.29
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.456 SNIP 1.167
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.58 SNIP 0.991
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.247 SNIP 1.187
Scopus rating (2007): SJR 1.4 SNIP 1.053
Scopus rating (2006): SJR 1.41 SNIP 0.913
Scopus rating (2005): SJR 1.516 SNIP 1.274
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.391 SNIP 1.302
Web of Science (2003): Indexed yes
Original language: English
Time domain topology optimization, Nanophotonic structures, 3D designs, Large scale simulations
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Source: dtu
Source-ID: n:oai:DTIC-ART:elsevier/434048132::37821
Publication: Research - peer-review › Journal article – Annual report year: 2014

Topology optimisation of natural convection problems
This paper demonstrates the application of the density-based topology optimisation approach for the design of heat sinks and micropumps based on natural convection effects. The problems are modelled under the assumptions of steady-state laminar flow using the incompressible Navier-Stokes equations coupled to the convection-diffusion equation through the Boussinesq approximation. In order to facilitate topology optimisation, the Brinkman approach is taken to penalise velocities inside the solid domain and the effective thermal conductivity is interpolated in order to accommodate differences in thermal conductivity of the solid and fluid phases. The governing equations are discretised using stabilised finite elements and topology optimisation is performed for two different problems using discrete adjoint sensitivity analysis. The study shows that topology optimisation is a viable approach for designing heat sink geometries cooled by natural convection and micropumps powered by natural convection. Copyright © 2013 John Wiley & Sons, Ltd.
Topology optimisation, Natural convection, Buoyancy, Convective cooling, Heat sink, Micropump

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Topology Optimisation of Thermomechanical Functionally Graded Materials and Material Interfaces

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Alexandersen, J. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
Number of pages: 1
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JAlexandersen_et_al.pdf

Relations
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Publication: Research › Conference abstract for conference – Annual report year: 2014

Topology optimised design of robust material microstructures without length scale separation

General information
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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Alexandersen, J. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
Number of pages: 1
Publication date: 2014
Main Research Area: Technical/natural sciences
Electronic versions:
Topology_optimised_design.pdf

Relations
Activities:
International Conference on Engineering and Applied Sciences Optimization (OPT-i)
Source: PublicationPreSubmission
Source-ID: 100112677
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2014

Topology optimization for optical projection lithography with manufacturing uncertainties
This article presents a topology optimization approach for micro- and nano-devices fabricated by optical projection lithography. Incorporating the photolithography process and the manufacturing uncertainties into the topology optimization process results in a binary mask that can be sent directly to manufacturing without additional optical proximity correction (OPC). The performance of the optimized device is robust toward the considered process variations. With the proposed unified approach, the design for photolithography is achieved by considering the optimal device performance and manufacturability at the same time. Only one optimization problem is solved instead of two as in the conventional separate procedures by (1) blueprint design and (2) OPC. A micro-gripper design example is presented to demonstrate the potential of this approach. (C) 2014 Optical Society of America

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Zhou, M. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
Pages: 2720-2729
Topology optimization of fail-safe structures using a simplified local damage model

Topology optimization of mechanical structures often leads to efficient designs which resemble statically determinate structures. These economical structures are especially vulnerable to local loss of stiffness due to material failure. This paper therefore addresses local failure of continuum structures in topology optimization in order to design fail-safe structures which remain operable in a damaged state. A simplified model for local failure in continuum structures is adopted in the robust approach. The complex phenomenon of local failure is modeled by removal of material stiffness in patches with a fixed shape. The damage scenarios are taken into account by means of a minimax formulation of the optimization problem which minimizes the worst case performance. The detrimental influence of local failure on the nominal design is demonstrated in two representative examples: a cantilever beam optimized for minimum compliance and a compliant mechanism. The robust approach is applied successfully in the design of fail-safe alternatives for the structures in these examples.
Topology optimization using an explicit interface representation

We introduce the Deformable Simplicial Complex method to topology optimization as a way to represent the interface explicitly yet being able to handle topology changes. Topology changes are handled by a series of mesh operations, which also ensures a well-formed mesh. The same mesh is therefore used for both finite element calculations and shape representation. In addition, the approach unifies shape and topology optimization in a complementary optimization strategy. The shape is optimized on the basis of the gradient-based optimization algorithm MMA whereas holes are introduced using topological derivatives. The presented method is tested on two standard minimum compliance problems which demonstrates that it is both simple to apply, robust and efficient.
Topology optimization with flexible void area

This paper presents a methodology for including fixed-area flexible void domains into the minimum compliance topology optimization problem. As opposed to the standard passive elements approach of rigidly specifying void areas within the design domain, the suggested approach allows these areas to be flexibly reshaped and repositioned subject to penalization on their moments of inertia, the positions of their centers of mass, and their shapes. The flexible void areas are introduced through a second, discrete design variable field, using the same discretization as the standard field of continuous density variables. The formulation is based on a combined approach: The primary sub-problem is to minimize compliance, subject to a volume constraint, with a secondary sub-problem of minimizing the disturbance from the flexible void areas. The design update is performed iteratively between the two subproblems based on an optimality criterion and a discrete update scheme, respectively. The method is characterized by a high flexibility, while keeping the formulation very simple. The robustness and applicability of the method are demonstrated through a range of numerical examples. The flexibility of the method is demonstrated through several extensions, including a shape measure requiring the flexible void area to fit a given reference geometry.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Clausen, A. (Intern), Aage, N. (Intern), Sigmund, O. (Intern)
Pages: 927-943
Publication date: 2014
Main Research Area: Technical/natural sciences

Publication information
Journal: Structural and Multidisciplinary Optimization
Volume: 50
Issue number: 6
We propose a design methodology for systematic design of surface relief transmission gratings with optimized diffraction efficiency. The methodology is based on a gradient-based topology optimization formulation along with 2D frequency domain finite element simulations for TE and TM polarized plane waves. The goal of the optimization is to find a grating design that maximizes diffraction efficiency for the -1st transmission order when illuminated by unpolarized plane waves. Results indicate that a surface relief transmission grating can be designed with a diffraction efficiency of more than 40% in a broadband range going from the ultraviolet region, through the visible region and into the near-infrared region.
Topology optimized mode conversion in a photonic crystal waveguide fabricated in silicon-on-insulator material

We have designed and for the first time experimentally verified a topology optimized mode converter with a footprint of ∼6.3 μm × ∼3.6 μm which converts the fundamental even mode to the higher order odd mode of a dispersion engineered photonic crystal waveguide. 2D and 3D topology optimization is utilized and both schemes result in designs theoretically showing an extinction ratio larger than 21 dB. The 3D optimized design has an experimentally estimated insertion loss lower than ∼2 dB in an ∼43 nm bandwidth. The mode conversion is experimentally confirmed in this wavelength range by recording mode profiles using vertical grating couplers and an infrared camera. The experimentally determined extinction ratio is > 12 dB and is believed to be limited by the spatial resolution of our setup. © 2014 Optical Society of America.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, Department of Mechanical Engineering, Solid Mechanics, High-Speed Optical Communication
Authors: Frandsen, L. H. (Intern), Elesin, Y. (Intern), Frellsen, L. F. (Intern), Mitrovic, M. (Intern), Ding, Y. (Intern), Sigmund, O. (Intern), Yvind, K. (Intern)
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Main Research Area: Technical/natural sciences

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BFI (2016): BFI-level 2
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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.976 SNIP 1.755 CiteScore 3.78
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
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Web of Science (2014): Indexed yes
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Scopus rating (2013): SJR 2.358 SNIP 2.226 CiteScore 4.38
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.587 SNIP 2.145 CiteScore 3.85
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
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Scopus rating (2011): SJR 2.579 SNIP 2.606 CiteScore 4.04
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.943 SNIP 2.466
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 3.092 SNIP 2.669
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 3.195 SNIP 2.393
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 3.27 SNIP 2.032
A Review of the Scattering-Parameter Extraction Method with Clarification of Ambiguity Issues in Relation to Metamaterial Homogenization

The scattering-parameter extraction method of metamaterial homogenization is reviewed to show that the only ambiguity is that related to the choice of the branch of the complex logarithmic function (or the complex inverse cosine function). It is shown that the method has no ambiguity for the sign of the wavenumber and intrinsic impedance. While the method indeed yields two signs for the intrinsic impedance and thus the wavenumber, the signs are dependent. Moreover, both sign combinations lead to the same permittivity and permeability, and are thus permissible. This observation is in distinct contrast to a number of statements in the literature where the correct sign of the intrinsic impedance and wavenumber resulting from the scattering-parameter method is chosen by imposing additional physical requirements, such as passivity. The scattering-parameter method is reviewed through an investigation of a uniform plane wave normally incident on a planar slab in free space. The severity of the branch ambiguity is illustrated through simulations of a known metamaterial realization. Several approaches for proper branch selection are reviewed, and the suitability to metamaterial samples is discussed.

General information
State: Published
Organisations: Department of Electrical Engineering, Electromagnetic Systems, Department of Photonics Engineering, Structured Electromagnetic Materials, Department of Mechanical Engineering, Solid Mechanics, University of Arizona
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Web of Science (2017): Indexed Yes
Experimental Validation of Topology Optimization for RF MEMS Capacitive Switch Design

In this paper, we present 30 distinct RF MEMS capacitive switch designs that are the product of topology optimizations that control key mechanical properties such as stiffness, response to intrinsic stress gradients, and temperature sensitivity. The designs were evaluated with high-accuracy simulations prior to micro-fabrication. We built and tested more than 170 switches, including at least five per distinct design. Experimental results confirm that the finite element models are accurate and that the switches behave as intended by the different optimizations. Extensive testing results include actuation and release voltages as a function of temperature, switching times, capacitance ratios, fitted S-parameters, and profile measurements during actuation and over temperature.$\hfill{[2013\hbox{-}0203]}$

General information

State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Stanford University, University of California, San Diego
Authors: Philippine, M. A. (Ekstern), Zareie, H. (Ekstern), Sigmund, O. (Intern), Rebeiz, G. M. (Ekstern), Kenny, T. W. (Ekstern)
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BFI (2016): BFI-level 2
Scopus rating (2016): SJR 0.712 SNIP 1.223 CiteScore 2.09
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 0.791 SNIP 1.594 CiteScore 2.47
Web of Science (2015): Indexed yes
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Scopus rating (2014): SJR 0.868 SNIP 1.574 CiteScore 2.22
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.952 SNIP 1.793 CiteScore 2.81
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.159 SNIP 2.024 CiteScore 2.7
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.208 SNIP 1.861 CiteScore 2.83
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.237 SNIP 1.95
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.493 SNIP 1.851
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.492 SNIP 1.979
Scopus rating (2007): SJR 1.65 SNIP 2.171
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.772 SNIP 2.825
Scopus rating (2005): SJR 1.971 SNIP 3.217
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.987 SNIP 3.211
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 3.159 SNIP 3.107
Scopus rating (2002): SJR 2.672 SNIP 2.949
Scopus rating (2001): SJR 1.813 SNIP 2.972
Scopus rating (2000): SJR 1.65 SNIP 2.293
Scopus rating (1999): SJR 2.514 SNIP 2.493
Original language: English
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Source: dtu
Improving Topology Optimization using Games

Topology optimization has had, and still has, a great impact on the design of structures and mechanical elements. Even though computers and topology optimization algorithms are able to find good solutions to most problems, it is also important for users of such programs to have a good intuition for whether a structure is optimal. We hypothesize that human intuition regarding topology optimization is often led astray. Our goal is to collect data in order to test this hypothesis and at the same time to actively train users (in particular students of mechanical engineering) in designing optimal structures. Consequently, we have created a game, the TopOptGame, which improves the player's topology optimization intuition in a fun and engaging way while collecting data about the users performance.

Technically, the TopOptGame builds on the TopOptApp [1] - an interactive topology optimization application designed for hand-held devices. The TopOptApp solves the 2D minimum compliance problem with interactive control of loads, supports and volume fraction, and thus the TopOptApp allows the user to change the problem on the fly and watch the design evolve to a new optimum in real time. TopOptApp is available free of charge on iOS and Android devices1.

The TopOptGame is inspired by puzzle-games (a genre of computer games), which constantly challenges the players and gives rewards when progress is made. This engagement loop will take the player on a journey starting with simple problems with few supports and a single load and gradually increase the difficulty by adding more loads, restrictions on the design domain, distributed loads and multiple load cases. The goal is to distribute material in a discretized design domain, under some volume and time constrains, while searching for a good solution (minimum compliance). A visualization of the strain energy density will help the player finding a feasible solution.

Besides training the player in topology optimization, the game also tracks the progress of each player and sends this progress in anonymized form to a database. When enough data has been collected, this will allow us to analyze the data to measure human performance of topology optimization and more importantly, in which cases people's intuition succeed or fail.

The game is currently a working prototype and is scheduled for final release on both iOS and Android before WCSMO-10.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Department of Mechanical Engineering, Solid Mechanics
Authors: Nobel-Jørgensen, M. (Intern), Christiansen, A. N. (Intern), Bærentzen, J. A. (Intern), Aage, N. (Intern), Sigmund, O. (Intern)
Number of pages: 2
Publication date: 2013
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Electronic versions:
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Source: du
Source-ID: u::8565
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Interactive topology optimization on hand-held devices
This paper presents an interactive topology optimization application designed for hand-held devices running iOS or Android. The TopOpt app solves the 2D minimum compliance problem with interactive control of load and support positions as well as volume fraction. Thus, it is possible to change the problem settings on the fly and watch the design evolve to a new optimum in real time. The use of an interactive app makes it extremely simple to learn and understand the influence of load-directions, support conditions and volume fraction. The topology optimization kernel is written in C# and the graphical user interface is developed using the game engine Unity3D. The underlying code is inspired by the publicly available 88 and 99 line Matlab codes for topology optimization but does not utilize any low-level linear algebra routines such as BLAS or LAPACK. The TopOpt App can be downloaded on iOS devices from the Apple App Store, at Google Play for the Android platform, and a web-version can be run from www.topopt.dtu.dk.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics
Authors: Aage, N. (Intern), Nobel-Jørgensen, M. (Intern), Andreasen, C. S. (Intern), Sigmund, O. (Intern)
Pages: 1-6
Publication date: 2013
On the similarities between micro/nano lithography and topology optimization projection methods

The aim of this paper is to incorporate a model for micro/nano lithography production processes in topology optimization. The production process turns out to provide a physical analogy for projection filters in topology optimization. Blueprints supplied by the designers cannot be directly used as inputs to lithographic processes due to the proximity effect which
causes rounding of sharp corners and geometric interaction of closely spaced design elements. Therefore, topology optimization is applied as a tool for proximity effect correction. Furthermore, it is demonstrated that the robust projection filter can be used to account for uncertainties due to lithographic production processes which results in manufacturable blueprint designs and eliminates the need for subsequent corrections.
Optimization of extraordinary optical absorption in plasmonic and dielectric structures

Extraordinary optical absorption (EOA) can be obtained by plasmonic surface structuring. However, studies that compare the performance of these plasmonic devices with similar structured dielectric devices are rarely found in the literature. In this work we show different methods to enhance the EOA by optimizing the geometry of the surface structuring for both plasmonic and dielectric devices, and the optimized performances are compared. Two different problem types with periodic structures are considered. The first case shows that strips of silicon on a surface can increase the absorption in an underlying silicon layer for certain optical wavelengths compared to metal strips. It is then demonstrated that by topology optimization it is possible to generate nonintuitive surface designs that perform even better than the simple strip designs for both silicon and metals. These results indicate that in general it is important to compare the absorption performance of plasmonic devices with similarly structured dielectric devices in order to find the best possible solution.
This article presents a new procedure for the layout design of reinforcement in concrete structures. Concrete is represented by a gradient-enhanced continuum damage model with strain-softening and reinforcement is modeled as elastic bars that are embedded into the concrete domain. Adjoint sensitivity analysis is derived in complete consistency with respect to path-dependency and the nonlocal model. Classical truss topology optimization based on the ground structure approach is applied to determine the optimal topology and cross-sections of the reinforcement bars. This approach facilitates a fully digital work flow that can be highly effective, especially for the design of complex structures. Several test cases involving two- and three-dimensional concrete structures illustrate the capabilities of the proposed procedure.
Robust topology optimization accounting for geometric imperfections

Topology optimization is a powerful method to optimize the performance of macro, micro, or nano structures. However, the geometry of the actual structure may differ from the optimized design due to manufacturing errors. Such geometric imperfections can have a significant impact on the structural performance. As a consequence, the actual structure may be far from optimal. In this paper, a robust approach to topology optimization is presented, taking into account two types of geometric imperfections: variations of (1) the crosssections and (2) the locations of structural elements. The first type is modeled by means of a scalar non-Gaussian random field, which is represented as a translation process. The underlying Gaussian field is simulated by means of the EOLE method. The second type of imperfections is modeled as a Gaussian vector-valued random field, which is simulated directly by means of the EOLE method. In each iteration of the optimization process, the relevant statistics of the structural response are evaluated by means of a Monte Carlo simulation. The proposed methodology is successfully applied to a test problem involving the design of a compliant mechanism (for the first type of imperfections) and a vertical load carrying system (for the second type). © 2013 Taylor & Francis Group,
Robust topology optimization accounting for misplacement of material

The use of topology optimization for structural design often leads to slender structures. Slender structures are sensitive to geometric imperfections such as the misplacement or misalignment of material. The present paper therefore proposes a robust approach to topology optimization taking into account this type of geometric imperfections. A density filter based approach is followed, and translations of material are obtained by adding a small perturbation to the center of the filter kernel. The spatial variation of the geometric imperfections is modeled by means of a vector valued random field. The random field is conditioned in order to incorporate supports in the design where no misplacement of material occurs. In the robust optimization problem, the objective function is defined as a weighted sum of the mean value and the standard deviation of the performance of the structure under uncertainty. A sampling method is used to estimate these statistics during the optimization process. The proposed method is successfully applied to three example problems: the minimum compliance design of a slender column-like structure and a cantilever beam and a compliant mechanism design. An extensive Monte Carlo simulation is used to show that the obtained topologies are more robust with respect to geometric imperfections.
Shape optimization of the Stokes flow problem based on isogeometric analysis

Design-dependent loads related to boundary shape, such as pressure and convection loads, have been a challenging issue in optimization. Isogeometric analysis, where the analysis model has smooth boundaries described by spline functions can handle design-dependent loads with ease. In the present study, shape optimization based on isogeometric analysis is applied to the Stokes flow problems such as minimizing energy dissipation and drag force. The drag force objective is based on accurate integration of boundary pressures. Local control point insertion schemes are employed for accurate representation of geometry in an adaptive manner.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Korea Advanced Institute of Science & Technology, Samsung Display
Authors: Park, B. (Ekstern), Seo, Y. (Ekstern), Sigmund, O. (Intern), Youn, S. (Ekstern)
Pages: 965-977
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Main Research Area: Technical/natural sciences

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Structural Color Optimization using Scalar Diffraction Theory

General information
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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Johansen, V. E. (Intern), Sigmund, Ø. (Intern)
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Event: Abstract from 10th World Congress on Structural and Multidisciplinary Optimization, Orlando, FL, United States.
Main Research Area: Technical/natural sciences
Electronic versions: Structural_Color_Optimization.pdf
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Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013
Topological design of electromechanical actuators with robustness toward over- and under-etching

In this paper, we combine the recent findings in robust topology optimization formulations and Helmholtz partial differential equation based density filtering to improve the topological design of electromechanical actuators. For the electromechanical analysis, we adopt a monolithic formulation to model the coupled electrostatic and mechanical equations. For filtering, we extend the Helmholtz-based projection filter with Dirichlet boundary conditions to ensure appropriate design boundary conditions. For the optimization, we use the method of moving asymptotes, where the sensitivity is obtained from the adjoint approach.

Our study shows that the robust filter approach produces topology optimized actuators with minimal length control and crisp structural boundaries. In particular, the minimal length control of both structural features and gap widths avoids common modeling artifacts in topology optimization, i.e. one-element wide structural parts or gaps. It thus leads to physically realizable designs that are robust against manufacturing imprecision such as over- and under-etching. © 2012 Elsevier B.V. All rights reserved.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Illinois Institute of Technology
Authors: Qian, X. (Ekstern), Sigmund, O. (Intern)
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  Scopus rating (2016): CiteScore 4.31 SJR 2.743 SNIP 1.962
  BFI (2015): BFI-level 2
  Scopus rating (2015): SJR 2.823 SNIP 2.126 CiteScore 3.91
  Web of Science (2015): Indexed yes
  BFI (2014): BFI-level 2
  Scopus rating (2014): SJR 2.418 SNIP 2.087 CiteScore 3.41
  Web of Science (2014): Indexed yes
  BFI (2013): BFI-level 2
  Scopus rating (2013): SJR 3.095 SNIP 2.252 CiteScore 3.5
  ISI indexed (2013): ISI indexed yes
  Web of Science (2013): Indexed yes
  BFI (2012): BFI-level 2
  Scopus rating (2012): SJR 2.543 SNIP 2.247 CiteScore 3.04
  ISI indexed (2012): ISI indexed yes
  Web of Science (2012): Indexed yes
  BFI (2011): BFI-level 2
  Scopus rating (2011): SJR 2.679 SNIP 1.959 CiteScore 3.03
  ISI indexed (2011): ISI indexed yes
  Web of Science (2011): Indexed yes
  BFI (2010): BFI-level 2
  Scopus rating (2010): SJR 2.463 SNIP 1.937
  BFI (2009): BFI-level 1
  Scopus rating (2009): SJR 2.274 SNIP 1.73
  Web of Science (2009): Indexed yes
  BFI (2008): BFI-level 1
  Scopus rating (2008): SJR 2.184 SNIP 1.985
  Web of Science (2008): Indexed yes
  Scopus rating (2007): SJR 2.22 SNIP 1.863
Topology Optimisation for Coupled Convection Problems

This thesis deals with topology optimisation for coupled convection problems. The aim is to extend and apply topology optimisation to steady-state conjugate heat transfer problems, where the heat conduction equation governs the heat transfer in a solid and is coupled to thermal transport in a surrounding uid, governed by a convection-diffusion equation, where the convective velocity field is found from solving the isothermal incompressible steady-state Navier-Stokes equations. Topology optimisation is also applied to steady-state natural convection problems.

The modelling is done using stabilised finite elements, the formulation and implementation of which was done partly during a special course as preparatory work for this thesis. The formulation is extended with a Brinkman friction term in order to facilitate the topology optimisation of fluid flow and convective cooling problems. The derived finite element formulation is implemented in an object-oriented parallel finite element framework programmed in the C++ programming language, developed by the Top-Opt research group of the Department of Mechanical Engineering at The Technical University of Denmark.

The presented work is seen as contributing new research to the field of topology optimisation for multiphysics problems. The topology optimisation of conjugate heat transfer problems is not very well documented in the literature, with only a few notable papers on the subject and to the authors knowledge, topology optimisation has not yet been applied to natural convection problems. Although the presented results are very simple and remain academic, it is envisioned that by further development, the methodology presented in this thesis, can be used to optimise realistic industrial problems such as the cooling of combustion engines or electronics. This thesis confines itself to steady-state laminar flow at low to moderate Reynolds, Pécel and Rayleigh numbers.
Topology Optimisation for Coupled Convection Problems
The work focuses on applying topology optimisation to forced and natural convection problems in fluid dynamics and conjugate (fluid-structure) heat transfer. To the authors' knowledge, topology optimisation has not yet been applied to natural convection flow problems in the published literature and the current work is thus seen as contributing new results to the field. In the literature, most works on the topology optimisation of weakly coupled convection-diffusion problems focus on the temperature distribution of the fluid, but a selection of notable exceptions also focusing on the temperature in the solid are [3-6]. The developed methodology is applied to several two-dimensional solid-fluid thermal interaction problems, such as cooling of electronic components and heat exchangers, as well as to the design of micropumping devices based on natural convection effects. The implementation utilises the widely used Brinkman-penalisation approach to fluid topology optimisation [2] combined with suitable interpolation functions for thermal conductivity. The Method of Moving Asymptotes (MMA) is used and density filtering is applied in order to ensure a minimum lengthscale. The results are generated using stabilised finite elements implemented in a parallel multiphysics analysis and optimisation framework DFEM [1], developed and maintained in house. Focus is put on control of the temperature field within the solid structure and the problems can therefore be seen as conjugate heat transfer problems, where heat conduction governs in the solid parts of the design domain and couples to convection-dominated heat transfer to a surrounding fluid. Both loosely coupled and tightly coupled problems are considered. The loosely coupled problems are convection-diffusion problems, based on an advective velocity field from solving the isothermal incompressible Navier-Stokes equations. The tightly coupled problems are natural convection problems, where the Boussinesq approximation has been applied to couple the temperature and velocity fields both ways. All of the considered flows are assumed to be laminar and steady.

General Information
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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Alexandersen, J. (Intern), Andreasen, C. S. (Intern), Aage, N. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
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Topology Optimisation for Coupled Convection Problems

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Publication date: 2013
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Topology optimization approaches: A comparative review
Topology optimization has undergone a tremendous development since its introduction in the seminal paper by Bendsøe and Kikuchi in 1988. By now, the concept is developing in many different directions, including "density", "level set", "topological derivative", "phase field", "evolutionary" and several others. The paper gives an overview, comparison and critical review of the different approaches, their strengths, weaknesses, similarities and dissimilarities and suggests guidelines for future research.
Topology optimization of fluid-structure-interaction problems in poroelasticity
This paper presents a method for applying topology optimization to fluid-structure interaction problems in saturated poroelastic media. The method relies on a multiple-scale method applied to periodic media. The resulting model couples the Stokes flow in the pores of the structure with the deformation of the elastic skeleton through a macroscopic Darcy-type flow law. The method allows to impose pressure loads for static problems through a one way coupling, while transient problems are fully coupled modeling the interaction between fluid and solid. The material distribution is determined by topology optimization in order to optimize the performance of a shock absorber and test the pressure loading capabilities and optimization of an internally pressurized lid. © 2013 Published by Elsevier B.V.
Optimization, Shape optimization, Loading, Topology optimization, Finite elements, Poroelasticity, Coupled problem

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Topology Optimization of Stressed Capacitive RF MEMS Switches
Geometry design can improve a capacitive radio-frequency microelectromechanical system switch's reliability by reducing the impacts of intrinsic biaxial stresses and stress gradients on the switch's membrane. Intrinsic biaxial stresses cause stress stiffening, whereas stress gradients cause out-of-plane curling. We use topology optimization to systematically generate designs, by minimizing stress stiffening, minimizing curling, or minimizing stress stiffening while constraining the curling behavior. We present the corresponding problem formulations and sensitivity derivations and discuss the role of key elements in the problem formulation.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Stanford University, University of California, San Diego
Authors: Philippine, M. A. (Ekstern), Sigmund, O. (Intern), Rebeiz, G. M. (Ekstern), Kenny, T. W. (Ekstern)
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Journal: IEEE Journal of Microelectromechanical Systems
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BFI (2016): BFI-level 2
Scopus rating (2016): SJR 0.712 SNIP 1.223 CiteScore 2.09
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Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 0.868 SNIP 1.574 CiteScore 2.22
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.952 SNIP 1.793 CiteScore 2.81
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Topology Optimization using an Explicit Interface Representation

Current methods for topology optimization primarily represent the interface between solid and void implicitly on fixed grids. In contrast, shape optimization methods represent the interface explicitly, but do not allow for any topological changes to the structure. Using an explicit interface representation has a number of advantages as described below. Consequently, we propose to use the Deformable Simplicial Complex (DSC) method [1] which represents the interface explicitly as one or more closed piecewise linear curves in 2D.

As opposed to pure shape optimization methods, the DSC method is able to handle topology changes. It does so by discretizing the entire design domain into an irregular adaptive triangle mesh and thereby explicitly representing both the structure and the embedding space. In other words, the entire design domain is divided into triangles, where the interface is represented as piecewise linear curves between void and non-void triangles.

Another advantage of the DSC method is that we can exploit the triangle mesh for the FEM computations used in the optimization procedure. The non-void elements define the structure and their deformation is described by second order shape functions. To increase performance, degrees of freedom associated with void triangles are eliminated from the FE equation. Using the triangle mesh for computations is possible since the DSC method ensures a mesh with no degenerate elements. If the mesh contained degenerate or close to degenerate elements the FEM computations would break down and the results would no longer be valid. The DSC method solves this issue by a series of mesh operations which keeps the mesh ever well-formed. The consequence of using a well-formed adaptive mesh is that the representation for the FEM calculations and the shape of the structure can be one and the same.

In addition to unifying calculations and representation of the structure, the approach also unifies shape and topology optimization into a single framework. Furthermore, it combines the two in a simultaneous optimization strategy. Here, the shape is optimized on the basis of the gradient based optimization algorithm Method of Moving Asymptotes whereas holes are introduced using topological derivatives. Since we combine these methods, and since FEM calculations are performed only on non-void triangles and gradients are calculated only for the interface nodes, the presented approach is efficient.

An explicit representation is not just useful when considering simplicity and performance. In many cases, the explicitly represented interface is necessary to be able to model a problem. For example for ow or electromagnetic problems with localized boundary effects. Furthermore, control of boundary smoothness is simple to implement and can e.g. be used to
control fillet radius at corners. The method also opens up for the opportunity to apply other local constraints, such as min/max length scale of the structure. Finally, the explicit interface is in all cases necessary when interpreting the final design. The status of the work is that the method has been developed and is showing promising results. For instance, the cantilever beam problem has been solved to a high precision using a fine discretization by evaluating the objective function approximately 500 times. This took around 100 seconds on an ordinary laptop utilizing a single thread. In addition, a coarse solution to the same problem has been obtained in approximately 10 seconds.

**General information**

State: Published
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Number of pages: 1
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Main Research Area: Technical/natural sciences
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**Topological optimization of cloaks for airborne sound**

Directional acoustic cloaks that conceal an aluminum cylinder for airborne sound waves are presented in this paper. Subwavelength cylindrical aluminum inclusions in air constitute the cloak design to aid practical realizations. The positions and radii of the subwavelength cylinders are determined by minimizing scattering from the cloak-structure and cylinder using the gradient-based topology optimization method. In the final optimization step, the radii of the subwavelength cylinders are constrained to three discrete values. A near-perfect narrow-banded and angular cloaking effect is obtained by optimizing for one target frequency. To get a larger bandwidth, the acoustic cloak is optimized for three frequencies at the cost of reduced peak cloaking performance at the center frequency. Copyright © 2013 by ASME.

**General information**

State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Andkjær, J. A. (Intern), Sigmund, O. (Intern)
Publication date: 2013
Main Research Area: Technical/natural sciences

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Scopus rating (2016): SJR 0.794 SNIP 1.203 CiteScore 1.58
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Scopus rating (2015): SJR 0.69 SNIP 1.007 CiteScore 1.17
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.849 SNIP 1.29 CiteScore 1.42
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.863 SNIP 1.45 CiteScore 1.47
ISI indexed (2013): ISI indexed yes
Topology Optimized Mode Conversion In a Photonic Crystal Waveguide

We experimentally demonstrate an ultra-compact TE0-TE1 mode converter obtained in a photonic crystal waveguide by utilizing topology optimization and show a ~39 nm bandwidth around 1550 nm with an insertion loss lower than ~3 dB.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, Solid Mechanics, Department of Mechanical Engineering, High-Speed Optical Communication
Authors: Frandsen, L. H. (Intern), Elesin, Y. (Intern), Ding, Y. (Intern), Sigmund, O. (Intern), Yvind, K. (Intern)
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Topology Optimized Mode Conversion In a Photonic Crystal Waveguide.pdf
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Source-ID: u::9110
Publication: Research - peer-review › Article in proceedings – Annual report year: 2013
Topology optimized RF MEMS switches

Topology optimization is a rigorous and powerful method that should become a standard MEMS design tool - it can produce unique and non-intuitive designs that meet complex objectives and can dramatically improve the performance and reliability of MEMS devices. We present successful uses of topology optimization for an RF MEM capacitive switch. Extensive experimental data confirms that the switches perform as designed by the optimizations, and that our simulation models are accurate. A subset of measurements are presented here. Broader results have been submitted in full journal format.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Stanford University, University of California, San Diego
Authors: Philippine, M. A. (Ekstern), Zareie, H. (Ekstern), Sigmund, O. (Intern), Rebeiz, G. M. (Ekstern), Kenny, T. W. (Ekstern)
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microswitches, network topology, optimisation, reliability, Computing and Processing, Engineering Profession, General Topics for Engineers, Geoscience, Nuclear Engineering
DOIs: 10.1109/Transducers.2013.6627308
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Wavelength Selective 3D Topology Optimized Photonic Crystal Devices

A compact photonic crystal drop filter has been designed using 3D topology optimization and fabricated in silicon-on-insulator material. Measurements and modeling are in excellent agreement showing a low-loss ~11nm 3dB bandwidth of the filter.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, Solid Mechanics, Department of Mechanical Engineering
Authors: Frandsen, L. H. (Intern), Elesin, Y. (Intern), Sigmund, O. (Intern), Jensen, J. S. (Intern), Yvind, K. (Intern)
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Conference: Conference on Lasers and Electro-Optics (CLEO 2013), San Jose, California, United States, 09/06/2013 - 09/06/2013
Mathematical methods in physics, Photonic crystal waveguides, Wavelength filtering devices
DOIs: 10.1364/CLEO_SI.2013.CTh4L.6
Source: Bibtex
Source-ID: urn:a00f41f75e8c28a15dedfd04cf9dad3b
Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

Design of robust and efficient photonic switches using topology optimization

The aim of this article is to introduce a systematic approach for design of non-linear optical devices. The designs are obtained using gradient-based topology optimization coupled with a time-domain Maxwell's equations solver. Direct application of the optimization procedure results in devices with a performance which is very sensitive to geometric manufacturing errors (under- or over-etching). Such behavior is undesirable and robustness is achieved by optimizing for several design realizations. The possible geometric uncertainties are modeled by random variables. It is shown that the
designs are insensitive with respect to variations of signal parameters, such as signal amplitudes and phase shifts. The obtained robust designs of a 1D photonic switch can substantially outperform simple bandgap designs, known from the literature, where switching takes place due to the bandgap shift produced by a strong control pulse.
Efficient reanalysis techniques for robust topology optimization

The article focuses on the reduction of the computational effort involved in robust topology optimization procedures. The performance of structures designed by means of topology optimization may be seriously degraded due to fabrication errors. Robust formulations of the optimization problem were shown to yield optimized designs that are tolerant with respect to such manufacturing uncertainties. The main drawback of such procedures is the added computational cost associated with the need to evaluate a set of designs by performing multiple finite element analyses. In this article, we propose efficient robust topology optimization procedures based on reanalysis techniques. The approach is demonstrated on two compliant mechanism design problems where robust design is achieved by employing either a worst case formulation or a stochastic formulation. It is shown that the time spent on finite element analysis within robust topology optimization can be reduced significantly, without affecting the outcome of the optimization process.

General information
State: Published
Organisations: Applied functional analysis, Department of Mechanical Engineering, Solid Mechanics, KU Leuven
Authors: Amir, O. (Intern), Sigmund, O. (Intern), Lazarov, B. S. (Intern), Schevenels, M. (Ekstern)
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Scopus rating (2016): CiteScore 4.31 SJR 2.743 SNIP 1.962
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.823 SNIP 2.126 CiteScore 3.91
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.418 SNIP 2.087 CiteScore 3.41
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 3.095 SNIP 2.252 CiteScore 3.5
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.543 SNIP 2.247 CiteScore 3.04
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.679 SNIP 1.959 CiteScore 3.03
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.463 SNIP 1.937
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.274 SNIP 1.73
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.184 SNIP 1.985
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.22 SNIP 1.863
Enhancing the Damping Properties of Viscoelastic Composites by Topology Optimization

Vibrations, if undamped, might be annoying or even dangerous. Most often some kind of damping mechanism is applied in order to limit the vibration level. Vibration insulators, for instance of rubber material, have favorable damping characteristics but lack the structural stiffness often needed in engineering structures. Thus, materials or composites with high stiffness and high damping are of great interest to the industry.

The inherent compromise between high stiffness and high damping in viscoelastic materials has been treated theoretically [2, 3] and experimentally [1]. It has been shown that high stiffness and high damping can be realized by Hashin-type composites or Rank-N laminates. However, in order to manufacture such composites it is favorable to obtain single length scale microstructures, i.e. without multiscale structures such that the materials can be manufactured by modern manufacturing techniques. As an example, by the use of e.g. SLM/SLS - Selective Laser Melting/Sintering, an open metallic microstructure can be printed and in a subsequent process the porospace can be filled with a high loss compliant material.

Yi and co-workers [6] applied topology optimization to design the 2D microstructural layout of a stiff elastic and a soft viscoelastic material constituent in order to obtain high damping, however, without specific focus on neither the theoretical bounds [2] nor the manufacturability. In this work we extend this work and consider manufacturability by use of various filtering techniques [4, 5]. The inverse homogenization problem is formulated such that the imaginary part of the bulk modulus for the composite is maximized while the real part is constrained from below. This formulation makes it possible to exploit the microstructures related to the upper bound of the imaginary part of the bulk modulus. Figure 1 shows the bounds on the bulk modulus for a viscoelastic composite using the formulation of [2] along with preliminary structures obtained using topology optimization. It is seen that for low bulk stiffness, the obtained designs approach the bounds for viscoelastic composites. The theoretical bounds exist for a limited combination of base materials e.g. with equal Poisson’s ratio and isotropic composites. In our work we will, numerically, further exploit the parameter space in order to search for composites that offer favorable compromises between loss and stiffness for different loading scenarios. Further, we will extend the study to three dimensions and in future work we plan to investigate the possibility for using the nonlinear response of viscoelastic materials such as rubber to further enhance the damping capabilities.

General information
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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Andreasen, C. S. (Intern), Andreassen, E. (Intern), Sigmund, O. (Intern), Jensen, J. S. (Intern)
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Fundamental Limitations to Gain Enhancement in Periodic Media and Waveguides

A common strategy to compensate for losses in optical nanostructures is to add gain material in the system. By exploiting slow-light effects it is expected that the gain may be enhanced beyond its bulk value. Here we show that this route cannot be followed uncritically: inclusion of gain inevitably modifies the underlying dispersion law, and thereby may degrade the slow-light properties underlying the device operation and the anticipated gain enhancement itself. This degradation is generic; we demonstrate it for three different systems of current interest (coupled-resonator optical waveguides, Bragg stacks, and photonic crystal waveguides). Nevertheless, a small amount of added gain may be beneficial.
Fundamental limitations to gain enhancement in slow-light photonic structures

We present a non-perturbative analysis of light-matter interaction in active photonic crystal waveguides in the slow-light regime. Inclusion of gain is shown to modify the underlying dispersion law, thereby degrading the slow-light enhancement.
High-performance slow light photonic crystal waveguides with topology optimized or circular-hole based material layouts

Photonic crystal waveguides are optimized for modal confinement and loss related to slow light with high group index. A detailed comparison between optimized circular-hole based waveguides and optimized waveguides with free topology is performed. Design robustness with respect to manufacturing imperfections is enforced by considering different design realizations generated from under-, standard- and over-etching processes in the optimization procedure. A constraint ensures a certain modal confinement, and loss related to slow light with high group index is indirectly treated by penalizing field energy located in air regions. It is demonstrated that slow light with a group index up to $n_g=278$ can be achieved by topology optimized waveguides with promising modal confinement and restricted group-velocity-dispersion. All the topology optimized waveguides achieve a normalized group-index bandwidth of 0.48 or above. The comparisons between circular-hole based designs and topology optimized designs illustrate that the former can be efficient for dispersion engineering but that larger improvements are possible if irregular geometries are allowed.

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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Wang, F. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
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BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.749 SNIP 0.715 CiteScore 1.56
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.746 SNIP 0.801 CiteScore 1.54
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.842 SNIP 0.785 CiteScore 1.67
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.972 SNIP 1.159 CiteScore 1.73
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.333 SNIP 1.172 CiteScore 2.29
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.456 SNIP 1.167
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.58 SNIP 0.991
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.247 SNIP 1.187
Scopus rating (2007): SJR 1.4 SNIP 1.053
Scopus rating (2006): SJR 1.41 SNIP 0.913
Scopus rating (2005): SJR 1.516 SNIP 1.274
Web of Science (2005): Indexed yes
Interactive topology optimization

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Department of Informatics and Mathematical Modeling, Image Analysis and Computer Graphics, Department of Mathematics
Authors: Aage, N. (Intern), Nobel-Jørgensen, M. (Intern), Andreasen, C. S. (Intern), Sigmund, O. (Intern)
Publication date: 2012
Event: Abstract from 6th European Congress on Computational Methods in Applied Sciences and Engineering, Vienna, Austria
Main Research Area: Technical/natural sciences
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Electronic versions:
ECCOMAS2012_NielsAage_TopOptApp.pdf
Source: dtu
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Publication: Research › Conference abstract for conference – Annual report year: 2012

Inverse design of dielectric materials by topology optimization
The capabilities and operation of electromagnetic devices can be dramatically enhanced if artificial materials that provide certain prescribed properties can be designed and fabricated. This paper presents a systematic methodology for the design of dielectric materials with prescribed electric permittivity. A gradient-based topology optimization method is used to find the distribution of dielectric material for the unit cell of a periodic microstructure composed of one or two dielectric materials. The optimization problem is formulated as a problem to minimize the square of the difference between the effective permittivity and a prescribed value. The optimization algorithm uses the adjoint variable method (AVM) for the sensitivity analysis and the finite element method (FEM) for solving the equilibrium and adjoint equations, respectively. A Heaviside projection filter is used to obtain clear optimized configurations. Several design problems show that clear optimized unit cell configurations that provide the prescribed electric permittivity can be obtained for all the presented cases. These include the design of isotropic material, anisotropic material, anisotropic material with a non-zero off-diagonal terms, and anisotropic material with loss. The results show that the optimized values are in agreement with theoretical bounds, confirming that our method yields appropriate and useful solutions.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Kyoto University
Authors: Otomori, M. (Ekstern), Andkjær, J. A. (Intern), Sigmund, O. (Intern), Izui, K. (Ekstern), Nishiwaki, S. (Ekstern)
Pages: 93-120
Publication date: 2012
Main Research Area: Technical/natural sciences

Light Scattering of TiO₂ Nanoparticles Embedded in Polyurethane
A new approach of enhancing light scattering in polyurethane polymer through the effect of TiO2 nanoparticles (NP) is explored. The TiO2 NP with sizes of 360 nm, 410 nm and 500 nm were dispersed in polyurethane polymer in concentrations ranging from 0.25 wt% up to 2 wt%. Reflectivity and UV-visible absorption measurements were employed for studying the scattering and absorption properties of TiO2 NP.
Multiscale modeling and topology optimization of poroelastic actuators

This paper presents a method for design of optimized poroelastic materials which under internal pressurization turn into actuators for application in, for example, linear motors. The actuators are modeled in a two-scale fluid–structure interaction approach. The fluid saturated material microstructure is optimized using topology optimization in order to achieve a better macroscopic performance quantified by vertical or torsional deflections. Constraints are introduced to ensure a certain deflection/extension ratio of the actuator.
Optimized manufacturable porous materials

Topology optimization has been used to design two-dimensional material structures with specific elastic properties, but optimized designs of three-dimensional material structures are more scarcely seen. Partly because it requires more computational power, and partly because it is a major challenge to include manufacturing constraints in the optimization. This work focuses on incorporating the manufacturability into the optimization procedure, allowing the resulting material structure to be manufactured directly using rapid manufacturing techniques, such as selective laser melting/sintering (SLM/S). The available manufacturing methods are best suited for porous materials (one constituent and void), but the optimization procedure can easily include more constituents.

The elasticity tensor is found from one unit cell using the homogenization method together with a standard finite element (FE) discretization. The distribution of the material in the unit cell is optimized according to a given objective (e.g. maximum bulk modulus or minimum Poisson’s ratio) and some given constraints (e.g. isotropy) using topology optimization. The manufacturability is achieved using various filtering techniques together with a stochastic approach, where the mean performance of several slightly different designs is optimized. In most cases this assures a minimum length scale for the intermediate design, and thereby manufacturability is achieved.

Furthermore, the study will look at how “negative” aspects of the manufacturing method can be exploited to achieve exotic material properties. An example of this is how the SLM/S causes softer regions in the structure due to insufficient heating of the metal powder. If the goal is to design a material, which to some degree is compliant, such as negative Poisson’s ratio material, softer regions are desirable. Another example is closedcell materials, e.g. maximum bulk modulus material, where the cells will be filled by metal powder if manufactured using SLM/S. This is considered as a drawback, because it makes the structure heavier. However, it also drastically increases the damping ratio of the structure, which is beneficial in many applications.
Plasmonic versus dielectric enhancement in thin-film solar cells
Several studies have indicated that broadband absorption of thin-film solar cells can be enhanced by use of surface-plasmon induced resonances of metallic parts like strips or particles. The metallic parts may create localized modes or scatter incoming light to increase absorption in thin-film semiconducting material. For a particular case, we show that coupling to the same type of localized slab-waveguide modes can be obtained by a surface modulation consisting of purely dielectric strips. The purely dielectric device turns out to have a significantly higher broadband enhancement factor compared to its metallic counterpart. We show that the enhanced normalized short-circuit current for a cell with silicon strips can be increased 4 times compared to the best performance for strips of silver, gold, or aluminium. For this particular case, the simple dielectric grating may outperform its plasmonic counterpart due to the larger Ohmic losses associated with the latter.

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Organisations: Department of Mechanical Engineering, Department of Photonics Engineering, Structured Electromagnetic Materials, Solid Mechanics
Authors: Dühring, M. B. (Intern), Mortensen, N. A. (Intern), Sigmund, O. (Intern)
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ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
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Reduction of initial stress stiffening by topology optimization

Topology optimization is a rigorous method of obtaining non-intuitive designs. We use it to obtain a capacitive RF switch that stiffens little in response to an increase of the in-plane biaxial stresses that typically develop during MEMS fabrication. The actuation voltage is closely related to the membrane's stiffness, and is more stable for a stress insensitive switch. We employ the Solid Isotropic Material with Penalization (SIMP) method with the Method of Moving Asymptotes (MMA) and a robust formulation to minimize the ratio between the compliance at a low stress level and that at a high stress level. We include a volume constraint and a compliance constraint. Topology optimized designs are compared to an intuitively-designed RF switch. The switches contain similar features. The compliance constraint is varied such that the topology optimized switch performance approaches the intuitively-designed one. Finally, the importance of the compliance constraint and of the robust formulation are discussed.
Robust topology design of periodic grating surfaces

Modern nanoscale manufacturing techniques allow for a high degree of flexibility in designing surface microstructures and nanostructures. Injection molding of nanosized features allows for mass production of plastic components with a tailored nanostructure producing specific optical effects depending on the purpose. This work details the use of topology optimization for designing periodic polymer grating surfaces with complex optical properties. A method based on robust topology optimization is formulated for designing the nanostructure of plastic surfaces with extreme reflection or transmission properties. Topology optimization allows for free distribution of material but a mechanical constraint based on the fundamental free mechanical vibration frequency ensures connected structures. Several examples are given to illustrate the efficiency of the method.
Sensitivity filtering from a continuum mechanics perspective

In topology optimization filtering is a popular approach for preventing numerical instabilities. This short note shows that the well-known sensitivity filtering technique, that prevents checkerboards and ensures mesh-independent designs in density-based topology optimization, is equivalent to minimizing compliance for nonlocal elasticity problems known from continuum mechanics. Hence, the note resolves the long-standing quest for finding an explanation and physical motivation for the sensitivity filter.

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Authors: Sigmund, O. (Intern), Maute, K. (Ekstern)
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This paper employs topology optimization to systematically design free-topology loss-engineered slow-light waveguides with enlarged group index bandwidth product (GBP). The propagation losses of guided modes are evaluated by the imaginary part of eigenvalues in complex band structure calculations, where the scattering losses due to manufacturing imperfections are represented by an edge-related effective dissipation. The loss engineering of slow-light waveguides is realized by minimizing the propagation losses of design modes. Numerical examples illustrate that the propagation losses of free-topology dispersion-engineered waveguides can be significantly suppressed by loss engineering. Comparisons between fixed- and free-topology loss-engineered waveguides demonstrate that the GBP can be enhanced significantly by the free-topology loss-engineered waveguides with a small increase of the propagation losses.
Systematic Design of Slow Light Waveguides

Light can propagate much slower in photonic crystal waveguides and plasmonic waveguides than in vacuum. Slow light propagation in waveguides shows broad prospects in the terabit communication systems. However, it causes severe signal distortions and displays large propagation loss. Moreover it is vulnerable to manufacturing disorders. This thesis aims to design novel waveguides to alleviate signal distortions and propagation loss using optimization methodologies, and to explore the design robustness with respect to manufacturing imperfections.

To alleviate the signal distortions in waveguides, an optimization formulation is presented to tailor the slope of the dispersion curve. The design robustness is enforced by considering different manufacturing realizations in the optimization procedure. Both free- and fixed-topology (circular-hole based) slow light photonic crystal waveguides are obtained using two different parameterizations. Detailed comparisons show that the bandwidth of slow light propagation can be significantly enhanced by allowing irregular geometries in the waveguides.

To mitigate the propagation loss due to scattering in the photonic crystal waveg-
uides, an optimization problem is formulated to minimize the average propagation loss of the designed modes. The presented approach is employed to design a free-topology slow light waveguide. Numerical result illustrates that slow light propagation in the optimized waveguide displays significantly suppressed propagation loss while keeping the same bandwidth.

The first optimization formulation is further employed to design slow light metal-dielectric-metal plasmonic waveguides. It is shown that dispersionless slow light propagation is achieved in the optimized plasmonic waveguide. Further study reveals that the loss in metal can be compensated by integrating gain media in the optimized waveguide, while keeping negligible signal distortions.

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**Topography optimization considering material and geometric uncertainties using stochastic collocation methods**

The aim of this paper is to introduce the stochastic collocation methods in topology optimization for mechanical systems with material and geometric uncertainties. The random variations are modeled by a memory-less transformation of spatially varying Gaussian random fields which ensures their physical admissibility. The stochastic collocation method combined with the proposed material and geometry uncertainty models provides robust designs by utilizing already developed deterministic solvers. The computational cost is discussed in details and solutions to decrease it, like sparse grids and discretization refinement are proposed and demonstrated as well. The method is utilized in the design of compliant mechanisms.

**General information**

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Topology optimization of antennas and resonators

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- **Niels_Aage.pdf**
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Topology optimization of nano-photonic systems

We describe recent developments within nano-photonic systems design based on topology optimization. Applications include linear and non-linear optical waveguides, slow-light waveguides, as well as all-dielectric cloaks that minimize scattering or back-scattering from hard obstacles.
Topology optimization of optical surfaces

The aim of this paper was to present a topology optimization methodology for obtaining robust designs insensitive to small uncertainties in the geometry. The variations are modeled using a stochastic field. The model can represent spatially varying geometry imperfections in devices produced by etching techniques. Because of under-etching or over-etching parts of the structure may become thinner or thicker than a reference design supplied to the manufacturer. The uncertainties are assumed to be small and their influence on the system response is evaluated using perturbation techniques. Under the above assumptions, the proposed algorithm provides a computationally cheap alternative to previously introduced stochastic optimization methods based on Monte Carlo sampling. The method is demonstrated on the design of a minimum compliance cantilever beam and a compliant mechanism. Copyright © 2012 John Wiley & Sons, Ltd.
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Web of Science (2009): Indexed yes
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Towards all-dielectric, polarization-independent optical cloaks

Fully enclosing, all-dielectric cloaks working for both E-z and H-z polarizations simultaneously are presented in this letter. The cloaks are effective for two antiparallel angles of incidence, and the layout of standard dielectric material in the cloak is determined by topology optimization. Scattering from cylinder and cloak is reduced for an H-z-polarized wave compared to an E-z-polarized wave by taking advantage of the surface mode at the perfectly electric conducting boundary. Perhaps contrary to simple intuition, fully enclosed, all-dielectric, low-contrast cloaks cannot be designed effectively when distributing a material with lower permittivity than the background material.

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BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.857 SNIP 1.848
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Scopus rating (2008): SJR 2.934 SNIP 1.83
Wave Manipulation by Topology Optimization

Sound and light propagate as waves and are scattered, reflected and change direction when encountering other media and obstacles. By optimizing the spatial placement and distribution of the media, which the waves encounter, one can obtain useful and interesting effects. This thesis describes how topology optimization can be used to design structures for manipulation of the electromagnetic and acoustic waves. The wave problems considered here fall within three classes. The first class concerns the design of cloaks, which when wrapped around an object will render the object undetectable for an outside observer. In the study the material layout of cloaks are restricted to isotropic materials readily available in nature. For fully enclosed, all-dielectric cloaks the cloaking is shown to be nearly perfect for a few discrete angles of incidences in a limited frequency range. The working principle for the cloak is to delay the waves in regions of higher permittivity than the background and subsequently phase match them to the waves outside. Directional acoustic cloaks can also be designed using the topology optimization method. Aluminum cylinders constitutes the design and their placement and size is optimized such that their combined scattering pattern cancel the scattering from a big cylinder. If only the backscattering in a limited angular range needs to be eliminated the electromagnetic cloak design simplifies to surprisingly simple annular Bragg-like grating structures with layer dimensions that depend on the obstacle radius.

The second class concerns the optimization of grating couplers for efficient inand out-coupling of electromagnetic surface waves at a metal-dielectric interface. Results indicate that efficiencies beyond 68% are possible for slanted groove-based gratings. The third class concerns the design of planar Fresnel zone plate lenses for focusing electromagnetic waves. The topology optimized zone plates improve the focusing performance compared to results known from the literature.

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Authors: Andkjær, J. A. (Intern), Sigmund, O. (Intern), Breinbjerg, O. (Intern)
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Wireless communication for hearing aid system

This thesis focuses on the wireless coupling between hearing aids close to a human head. Hearing aids constitute devices with advanced technology and the wireless communication enables the introduction of a range of completely new functionalities. Such devices are small and the available power is limited, it is therefore important to characterize the wireless link-budget and to understand the mechanisms that control propagation of waves inside and outside the head. For this purpose, different approaches have been used.

There are two objectives for this thesis. The first objective is to characterize the ear-to-ear wireless communication channel by understanding the mechanisms that control the propagations of the signals and the losses. The second objective is to investigate the properties of magneto-dielectric materials and their potential in antenna miniaturization.

There are three approaches to study the ear-to-ear wireless communication link; a theoretical approach models the human head as a sphere that has the electrical properties of the head, a numerical approach implements a more realistic geometry of the head, and an experimental approach measures directly the coupling between the antennas near a real person or a phantom head imitating the human head’s electrical properties. Each approach has advantages and disadvantages; the analytical approach gives accurate results and is very fast, though it does not treat complex structures. The numerical approach can treat complex structures but is limited by the electrical size of the structures and requires large memory and long processing time. The experimental approach yields accurate coupling between the antennas but does not provide detailed information about the field distribution. Therefore, we combine all these three approaches to gain some understanding of the ear-to-ear wireless communication channel.

A circular patch antenna was used to study the properties of the magneto-dielectric materials. In the thesis, we focused on three properties; efficiency, quality factor and bandwidth of the antenna. An analytical method is used to calculate the properties of a low-loss circular patch antenna, while a numerical method was used to analyze a high-loss circular patch antenna. The low-loss magneto-dielectric materials can potentially be used to miniaturize the size of the antennas, offering higher efficiency and wider bandwidth than the dielectric materials.

Antenna Miniaturization in Complex Electromagnetic Environments: Designs and Measurements of Electrically Small Antennas for Hearing-Aid Applications

Hearing aids today constitute devices with an advanced technology, and wireless communication integrated into hearing aids will introduce a range of completely new functionalities. The antenna is an important component in any wireless system, and the demand for compact wireless systems with stringent specifications makes the antenna size reduction a significant challenge. Antenna miniaturization is thus one of the key technologies in designing a successful wireless unit for the hearing-aid application. This dissertation is focused on three areas that are related to the integration of a wire-less communication system into the hearing-aids, and these are the antenna miniaturization, the measurement techniques for electrically small antennas and the influence of complex environments on the characteristics of electrically small antennas,
Antenna Miniaturization

In this dissertation, we present several novel designs of electrically small loop antennas for the hearing-aid application. First antenna design is a two-dimensional (2-D) planar differential-fed electrically small loop. The working mechanism of this antenna is based on the capacitive loading and the inductive coupling between two small loops. An analytical model, simulations, fabrications and measurements are presented for this antenna. Second antenna design is a planar two-turn electrically small loop antenna. The working mechanism of this antenna is based on the capacitive loading, and both the capacitive and inductive coupling between two small loops that are of a comparable size are taken into account. An analytical model is provided to give a guidance in the impedance tuning. Third, several three-dimensional (3-D) folded electrically small loop antennas are proposed, the properties of which are significantly improved compared to the 2-D planar electrically small loop antennas.

Measurement Techniques for ESAs

In this dissertation we proposed two novel measurement techniques for electrically small antennas. A modified Wheeler cap method for the radiation efficiency measurement of balanced electrically small antennas is proposed. This method provides the following advantages. First, no balun is required during the measurement and thus the problems of narrow impedance bandwidth and extra scattering effect caused by the balun are avoided. As a result, the proposed method is valid in a broad frequency band. Second, the application of proposed method and the proper use of the circle fitting for the measured scattering parameters ensure that the cavity resonances do not have any significant effect on the measurement results. By using the Wheeler cap method in the proposed way, most of its limitations and disadvantages are avoided. The method is, therefore, suitable for input impedance and radiation efficiency measurement for most types of antennas in a broad frequency band. The antennas under test are not limited to be electrically small and these can be balanced or unbalanced, symmetric or asymmetric type. Moreover, the modified Wheeler cap method for measurements of small antennas in complex environments is further developed. A cable-free impedance and gain measurement technique for electrically small antennas is also proposed. The electromagnetic model of this technique is derived by using the spherical wave expansion, and it is valid for arbitrary electrically small AUT at arbitrary distances between the probe and AUT. The whole measurement setup is modeled by the cascade of three coupled multiple port networks. The electromagnetic model, the simulation results, and the obtained measurement results are presented.

Influence of the Complex Environments on ESA Characteristics

The influence of complex environments on the characteristics of electrically small antennas is also investigated such as the human head phantom and the hearing-aids. First, the sensitivity analysis of the head phantom parameters on the antenna characteristics is presented, including the influence of the head permittivity and conductivity. Second, the sensitivity analysis of the positions of electrically small antennas is presented, including the orientations and locations of antennas and the distance between the small antenna and head. Third, the influence of the hearing-aid shell material on the antenna characteristics is investigated.
Comparison between different dispersion engineering methods in slow light photonic crystal waveguides

This paper compares the performance of different dispersion engineering methods in slow light photonic crystal waveguides, i.e., geometrical parameter optimization and topology optimization. In both methods, the design robustness is enforced by considering the dilated, intermediate and eroded designs corresponding to the under-, standard- and over-etching processes in the manufacturing process. For \( v_g^* = c/50 \), the parameter optimized design achieves a normalized group index bandwidth product of 0.33 and the topology optimized design achieves 0.53. The numerical results illustrate that waveguides with optimized hole sizes and positions can be efficient for dispersion engineering but that large improvements are possible if irregular geometries are allowed using topology optimization.

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Authors: Wang, F. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
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ISI indexed (2011): ISI indexed no
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Scopus rating (2008): SJR 0.162 SNIP 0.112
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.157 SNIP 0.125
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Web of Science (2004): Indexed yes
Efficient Reanalysis Procedures in Structural Topology Optimization

This thesis examines efficient solution procedures for the structural analysis problem within topology optimization. The research is motivated by the observation that when the nested approach to structural optimization is applied, most of the computational effort is invested in repeated solutions of the analysis equations. For demonstrative purposes, the discussion is limited to topology optimization problems within the field of structural mechanics. Nevertheless, the results can be relevant for a wide range of problems in structural and topology optimization. The main focus of the thesis is on the utilization of various approximations to the solution of the analysis problem, where the underlying model corresponds to linear elasticity. For computational environments that enable the direct solution of large linear equation systems using matrix factorization, we propose efficient procedures based on approximate reanalysis. For cases where memory limitations require the utilization of iterative equation solvers, we suggest efficient procedures based on alternative termination criteria for such solvers. These approaches are tested on two- and three-dimensional topology optimization problems including minimum compliance design and compliant mechanism design. The topologies generated by the approximate procedures are practically identical to those obtained by the standard approach. At the same time, it is shown that the computational cost can be reduced by up to one order of magnitude. The main observation in the context of optimal design of linear structures is that relatively rough approximations are acceptable, in particular in early stages of the optimization process. The thesis also addresses topology optimization of structures exhibiting nonlinear response. In such cases, the computational effort invested in the solution of the nested problem is even more dominant since nonlinear equation systems are to be solved repeatedly. Efficient procedures for nonlinear structural analysis are proposed, based on transferring solutions and factorized tangent stiffnesses from one design cycle to the following one. This approach is demonstrated on several design problems involving either geometric or material nonlinearities. The suggested procedures are shown to be effective mainly for problems that do not involve path-dependent solutions.

General information

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Main Research Area: Technical/natural sciences

Efficient topology optimization in MATLAB using 88 lines of code

The paper presents an efficient 88 line MATLAB code for topology optimization. It has been developed using the 99 line code presented by Sigmund (Struct Multidisc Optim 21(2):120–127, 2001) as a starting point. The original code has been extended by a density filter, and a considerable improvement in efficiency has been achieved, mainly by preallocating arrays and vectorizing loops. A speed improvement with a factor of 100 is obtained for a benchmark example with 7,500 elements. Moreover, the length of the code has been reduced to a mere 88 lines. These improvements have been accomplished without sacrificing the readability of the code. The 88 line code can therefore be considered as a valuable successor to the 99 line code, providing a practical instrument that may help to ease the learning curve for those entering the field of topology optimization. The paper also discusses simple extensions of the basic code to include recent PDE-based and black-and-white projection filtering methods. The complete 88 line code is included as an appendix and can be downloaded from the web site www.topopt.dtu.dk.

General information
**Factorized parallel preconditioner for the saddle point problem**

The aim of this paper is to apply the factorized sparse approximate inverse (FSAI) preconditioner to the iterative solution of linear systems with indefinite symmetric matrices. Until now the FSAI technique has been applied mainly to positive definite systems and with a limited success for the indefinite case. Here, it is demonstrated that the sparsity pattern for the preconditioner can be chosen in such a way that it guarantees the existence of the factorization. The proposed scheme shows excellent parallel scalability, performance and robustness. It is applicable with short recurrence iterative methods such as MinRes and SymmLQ. The properties are demonstrated on linear systems arising from mixed finite element discretizations in linear elasticity. © 2009 John Wiley & Sons, Ltd.

**Filters in topology optimization based on Helmholtz-type differential equations**

The aim of this paper is to apply a Helmholtz-type partial differential equation as an alternative to standard density filtering in topology optimization problems. Previously, this approach has been successfully applied as a sensitivity filter. The usual filtering techniques in topology optimization require information about the neighbor cells, which is difficult to obtain for fine
meshes or complex domains and geometries. The complexity of the problem increases further in parallel computing, when
the design domain is decomposed into multiple non-overlapping partitions. Obtaining information from the neighbor
subdomains is an expensive operation. The proposed filter technique requires only mesh information necessary for the
finite element discretization of the problem. The main idea is to define the filtered variable implicitly as a solution of a
Helmholtz-type differential equation with homogeneous Neumann boundary conditions. The properties of the filter are
demonstrated for various 2D and 3D topology optimization problems in linear elasticity, solved on serial and parallel
computers. Copyright © 2010 John Wiley & Sons, Ltd.
Isogeometric shape optimization of photonic crystals via Coons patches

In this paper, we present an approach that extends isogeometric shape optimization from optimization of rectangular-like NURBS patches to the optimization of topologically complex geometries. We have successfully applied this approach in designing photonic crystals where complex geometries have been optimized to maximize the band gaps. Salient features of this approach include the following: (1) multi-patch Coons representation of design geometry. The design geometry is represented as a collection of Coons patches where the four boundaries of each patch are represented as NURBS curves. The use of multiple patches is motivated by the need for representing topologically complex geometries. The Coons patches are used as a design representation so that designers do not need to specify interior control points and they provide a mechanism to compute analytical sensitivities for internal nodes in shape optimization, (2) exact boundary conversion to the analysis geometry with guaranteed mesh injectivity. The analysis geometry is a collection of NURBS patches that are converted from the multi-patch Coons representation with geometric exactness in patch boundaries. The internal NURBS control points are embedded in the parametric domain of the Coons patches with a built-in mesh rectifier to ensure the injectivity of the resulting B-spline geometry, i.e. every point in the physical domain is mapped to one point in the parametric domain, (3) analytical sensitivities. Sensitivities of objective functions and constraints with respect to design variables are derived through nodal sensitivities. The nodal sensitivities for the boundary control points are directly determined by the design parameters and those for internal nodes are obtained via the corresponding Coons patches.
Maximizing opto-mechanical interaction using topology optimization
This paper studies topology optimization of a coupled opto-mechanical problem with the goal of finding the material layout which maximizes the optical modulation, i.e. the difference between the optical response for the mechanically deformed and undeformed configuration. The optimization is performed on a periodic cell and the periodic modeling of the optical and mechanical fields have been carried out using transverse electric Bloch waves and homogenization theory in a plane stress setting, respectively. Two coupling effects are included being the photoelastic effect and the geometric effect caused by the mechanical deformation. For the studied objective and material choice it is concluded that the photoelastic effect and the geometric effect counteract each other, which yields designs which are fundamentally different if the optimization takes only one effect into account. When both effects are active a compromise is found; however, a strong regularization is needed in order to achieve reasonable 0–1 designs with a clear physical interpretation. Copyright © 2011 John Wiley & Sons, Ltd.

General information
State: Published
Minimal compliance design for metal–ceramic composites with lamellar microstructures

Metal–ceramic composites produced by melt infiltration of ceramic preforms are studied in an optimal design context. The ceramic preforms are manufactured through a process of freeze-casting of Al2O3 particle suspension. The microstructure of these composites can be presented as distributions of lamellar domains. With local ceramic volume fraction and lamella orientation chosen as the design variables, a minimum compliance optimization problem is solved based on topology optimization and finite element methods for metal–ceramic samples with different geometries and boundary conditions. Micromechanical models are applied for the calculation of the effective elastic properties of the composites. Optimized local lamella orientations and ceramic contents are calculated, and the difference between the initial (specimen with constant ceramic content and orientation) and the optimized designs is analyzed. Significant reductions in absolute values of the maximum, minimum and mean values of strain fields in the optimized structures are observed.

General information
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Organisations: Solid Mechanics, Department of Mechanical Engineering, Karlsruhe Institute of Technology KIT
Authors: Piat, R. (Ekstern), Sinchuk, Y. (Ekstern), Vasoya, M. (Ekstern), Sigmund, O. (Intern)
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Web of Science (2012): Indexed yes
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Scopus rating (2011): SJR 3.247 SNIP 2.81 CiteScore 4.27
ISI indexed (2011): ISI indexed yes
Modelling of Active Semiconductor Photonic Crystal Waveguides and Robust Designs based on Topology Optimization

In this paper, we present a theoretical analysis of slow-light enhanced light amplification in an active semiconductor photonic crystal line defect waveguide. The impact of enhanced light-matter interactions on propagation effects and local carrier dynamics are investigated in the framework of the Lorentz reciprocity theorem. We highlight topology optimization as a systematic and robust design methodology considering manufacturing imperfections in optimizing active photonic crystal device performances, and compare the performance of standard photonic crystal waveguides with optimized structures.

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Organisations: Department of Photonics Engineering, Nanophotonics Theory and Signal Processing, Department of Mechanical Engineering, Solid Mechanics
Authors: Chen, Y. (Intern), Wang, F. (Intern), Ek, S. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern), Mørk, J. (Intern)
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Multiscale optimization of saturated poroelastic actuators

A multiscale method for optimizing the material microstructure in a macroscopically heterogeneous saturated poroelastic media with respect to macro properties is presented. The method is based on topology optimization using the homogenization technique, here applied to the optimization of a bi-morph saturated poroelastic actuator.

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Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Andreasen, C. S. (Intern), Sigmund, O. (Intern)
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Electronic versions: CSAndreasen.pdf
Links: http://www.euromech522.de/
Source: orbit
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Multiscale topology optimization of solid and fluid structures

This thesis considers the application of the topology optimization method to multiscale problems, specifically the fluid-structure interaction problem. By multiple-scale methods the governing equations, the Navier-Cauchy and the incompressible Navier-Stokes equations are expanded and separated leaving a set of micro- and macroscale equations for the interaction modeling. The topology optimization method is applied to the material design in order to optimize the pressure coupling properties of porous materials. Furthermore, by combining both the material design and the macroscopic modeling, it is shown that the material microstructure can be optimized with respect to application scale properties. A poroelastic actuator consisting of two saturated porous materials is optimized using this approach. Based on the homogenization of a fixed microstructure topology, material design interpolation functions are obtained for use in material distribution problems of a saturated poroelastic structure. Topology optimization is applied for the optimization of an impact absorbing structure and the fluid-structure-interaction of a pressurized lid. A third application considers the pure fluid flow in a microfluidic mixer. The mixing of a transported matter is optimized by means of topology optimization and it is shown that the optimized designs contain geometric elements such as slanted grooves and staggered herringbones also used in the literature. To ensure the manufacturability of the topology optimized designs a new explicit parametrization is proposed. It allows for casting/milling type manufacturing and ensures a binary design. The method is successfully applied to micromixer design.

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On projection methods, convergence and robust formulations in topology optimization

Mesh convergence and manufacturability of topology optimized designs have previously mainly been assured using density or sensitivity based filtering techniques. The drawback of these techniques has been gray transition regions between solid and void parts, but this problem has recently been alleviated using various projection methods. In this paper we show that simple projection methods do not ensure local mesh-convergence and propose a modified robust topology optimization formulation based on erosion, intermediate and dilation projections that ensures both global and local mesh-convergence.

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Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Wang, F. (Intern), Lazarov, B. S. (Intern), Sigmund, O. (Intern)
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Scopus rating (2011): CiteScore 1.85
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Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
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On reducing computational effort in topology optimization: how far can we go?
An approximate approach to solving the nested analysis equations in topology optimization is proposed. The procedure consists of only one matrix factorization for the whole design process and a small number of iterative corrections for each design cycle. The approach is tested on 3D topology optimization problems. It is shown that the computational cost can be reduced by one order of magnitude without affecting the outcome of the optimization process.

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Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Amir, O. (Intern), Sigmund, O. (Intern)
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Web of Science (2012): Indexed yes
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Scopus rating (2011): CiteScore 1.85
On the usefulness of non-gradient approaches in topology optimization

Topology optimization is a highly developed tool for structural design and is by now being extensively used in mechanical, automotive and aerospace industries throughout the world. Gradient-based topology optimization algorithms may efficiently solve fine-resolution problems with thousands and up to millions of design variables using a few hundred (finite element) function evaluations (and even less than 50 in some commercial codes). Nevertheless, non-gradient topology optimization approaches that require orders of magnitude more function evaluations for extremely low resolution examples keep appearing in the literature. This forum article discusses the practical and scientific relevance of publishing papers that use immense computational resources for solving simple problems for which there already exist efficient solution techniques.

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BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 2.42
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 2.77
Robust design of large-displacement compliant mechanisms

The aim of this article is to introduce a new topology optimisation formulation for optimal robust design of Micro Electro Mechanical Systems. Mesh independence in topology optimisation is most often ensured by using filtering techniques, which result in transition grey regions difficult to interpret in practical realisations. This problem has been alleviated recently by projection techniques, but these destroy the mesh independence introduced by the filters and result in single node connected hinges. Such features in the design are undesirable as they are not robust with respect to geometric manufacturing errors (such as under/over etching). They can be avoided by optimising for several design realisations which take into account the possible geometry errors. The design variations are modelled with the help of random variables. The proposed stochastic formulation for the design variations results in nearly black and white mechanism designs, robust with respect to uncertainties in the production process, i.e. without any hinges or small details which can create manufacturing difficulties.

General information

State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering, KU Leuven
Authors: Lazarov, B. S. (Intern), Schevenels, M. (Ekstern), Sigmund, O. (Intern)
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Main Research Area: Technical/natural sciences

Publication information

Journal: Mechanical Sciences
Volume: 2
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Robust topology optimization accounting for spatially varying manufacturing errors

This paper presents a robust approach for the design of macro-, micro-, or nano-structures by means of topology optimization, accounting for spatially varying manufacturing errors. The focus is on structures produced by milling or etching; in this case over- or under-etching may cause parts of the structure to become thinner or thicker than intended. This type of error is modeled by means of a projection technique: a density filter is applied, followed by a Heaviside projection, using a low projection threshold to simulate under-etching and a high projection threshold to simulate over-etching. In order to simulate the spatial variation of the manufacturing error, the projection threshold is represented by a (non-Gaussian) random field. The random field is obtained as a memoryless transformation of an underlying Gaussian field, which is discretized by means of an EOLE expansion. The robust optimization problem is formulated in a probabilistic way: the objective function is defined as a weighted sum of the mean value and the standard deviation of the structural performance. The optimization problem is solved by means of a Monte Carlo method: in each iteration of the optimization scheme, a Monte Carlo simulation is performed, considering 100 random realizations of the manufacturing error. A more thorough Monte Carlo simulation with 10000 realizations is performed to verify the results obtained for the final design. The proposed methodology is successfully applied to two test problems: the design of a compliant mechanism and a heat conduction problem.
Robust topology optimization of photonic crystal waveguides with tailored dispersion properties

A robust topology optimization method is formulated to tailor dispersion properties of photonic crystal waveguides, with consideration of manufacturing uncertainties. Slightly dilated and eroded realizations are considered as well as the real structure, and by worst-case optimization, we also ensure a satisfactory performance in the case of an under- or overetching scenario in the manufacturing process. Two photonic crystal waveguides facilitating slow light with group indexes of $n_g = 25$ and $n_g = 100$ and bandwidths of $\Delta \omega / \omega = 2.3\%$ and $0.3\%$, respectively, are obtained through the proposed robust design procedure. In addition, a novel waveguide design with two different constant group index waveguide regions is demonstrated. The numerical examples illustrate the efficiency of the robust optimization formulation and indicate that the topology optimization procedure can provide a useful tool for designing waveguides that are robust to manufacturing uncertainties such as under or overetching. © 2011 Optical Society of America.

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Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Wang, F. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
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Main Research Area: Technical/natural sciences
Saturated poroelastic actuators generated by topology optimization

In this paper the fluid-structure interaction problem of a saturated porous media is considered. The pressure coupling properties of porous saturated materials change with the microstructure and this is utilized in the design of an actuator using a topology optimized porous material. By maximizing the coupling of internal fluid pressure and elastic shear stresses a slab of the optimized porous material deflects/deforms when a pressure is imposed and an actuator is created. Several phenomenologically based constraints are imposed in order to get a stable force transmitting actuator.
A pulse-delaying optimization scheme based on topology optimization for transient response of photonic crystal structures (PhCs) is formulated to obtain slow-light devices. The optimization process is started from a qualified W1 PhC waveguide design with group index ng≈40 obtained from a simple Edisonian parameter search. Based on this, the proposed pulse delaying and subsequent pulse restoring strategies yield a design that increases the group index by 75% to ng≈70±10% for an operational full-width at half-maximum (FWHM) bandwidth BFWHM=6 nm, and simultaneously minimizes interface penalty losses between the access ridge and the W1 PhC waveguide. To retain periodicity and symmetry, the active design set is limited to the in-/outlet region and a distributed supercell, and manufacturability is further enhanced by density filtering techniques combined with material phase projections.
Topology optimization for nano-photonics

Topology optimization is a computational tool that can be used for the systematic design of photonic crystals, waveguides, resonators, filters and plasmonics. The method was originally developed for mechanical design problems but has within
the last six years been applied to a range of photonics applications. Topology optimization may be based on finite element and finite difference type modeling methods in both frequency and time domain. The basic idea is that the material density of each element or grid point is a design variable, hence the geometry is parameterized in a pixel-like fashion. The optimization problem is efficiently solved using mathematical programming-based optimization methods and analytical gradient calculations. The paper reviews the basic procedures behind topology optimization, a large number of applications ranging from photonic crystal design to surface plasmonic devices, and lists some of the future challenges in non-linear applications. © 2011 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

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Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 5.155 SNIP 4.864 CiteScore 9.26
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 5.159 SNIP 3.679 CiteScore 7.59
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 5.79 SNIP 4.788 CiteScore 7.98
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 5.909 SNIP 4.118
Web of Science (2010): Indexed yes
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Scopus rating (2009): SJR 5.065 SNIP 4.67
Web of Science (2009): Indexed yes
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Topology Optimization for Transient Wave Propagation Problems
The study of elastic and optical waves together with intensive material research has revolutionized everyday as well as cutting edge technology in very tangible ways within the last century. Therefore it is important to continue the investigative work towards improving existing as well as innovate new technology, by designing new materials and their layout. The thesis presents a general framework for applying topology optimization in the design of material layouts for transient wave propagation problems. In contrast to the high level of modeling in the frequency domain, time domain topology optimization is still in its infancy. A generic optimization problem is formulated with an objective function that can be field, velocity, and acceleration dependent, as well as it can accommodate the dependency of filtered signals essential in signal shape optimization [P3]. The analytical design gradients are derived by use of the adjoint variable method. Many wave propagation problems are open-region problems, i.e. the outer boundaries of the modeling domain must be reflection-less. The thesis contains new and independent developments within perfectly matched layer techniques for scalar as well as for vectorial elastic wave propagation problems using finite element analysis [P2], [P4]. The concept is implemented in a parallel computing code that includes efficient techniques for performing gradient based topology optimization. Using the developed computational framework the thesis considers four optimization problems from nano-photonics: First, an optical taper [P1] and a notch filter [P2] - both optimized by energy maximization. The last two cases demonstrate pulse shaping and delay in one [P3] and two [P5] dimensions. Whereas the test problem in [P3] is rather academic, the example considered in [P5] optimizes structures that accommodate non-dispersive slow light, with important applications for optical buffering devices.

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Topology Optimization of Nanophotonic Devices
This thesis explores the various aspects of utilizing topology optimization in designing nanophotonic devices. Either frequency-domain or time-domain methods is used in combination with the optimization algorithms, depending on various aims of the designing problems. The frequency-domain methods are appropriate for problems where the power is to be maximized or minimized at a few frequencies, without regards on the detailed profile of the optical pulse or the need of large amount of frequency samplings. The design of slow light couplers connecting ridge waveguides and the photonic crystal waveguides is showcased here. It is demonstrated both numerically and experimentally that the optimized couplers could improve the coupling efficiency prominently. With more focus on the time-domain optimization method, the thesis discusses extensively the design of pulse-shaping filters, which greatly exploits the benefits of time-domain methods. Finite-difference time-domain method is used here as the modeling basis for the inverse problem. Filters based on both one-dimensional gratings and two-dimensional planar structures are designed and different issues regarding local minima, black and white design, minimum lengthscale and flexible pulse delay are addressed to demonstrate time-domain based topology optimization's potential in designing complicated photonic structures with specifications on the time characteristics of pulses.

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Organisations: Plasmonics and Metamaterials, Department of Photonics Engineering, Nanophotonics Theory and Signal Processing, Solid Mechanics, Department of Mechanical Engineering
Authors: Yang, L. (Intern), Hvam, J. M. (Intern), Sigmund, O. (Intern), Lavrinenko, A. (Intern)
Number of pages: 105
Publication date: 2011
Topology optimization of radio frequency and microwave structures
This thesis focuses on topology optimization of conductor-based microwave and radio frequency electromagnetic devices. The research is motivated by the ever increasing usage of small hand-held, or autonomous, electric devices, which have lead to a series of new challenges for the design of efficient antennas and power supplies. A topology optimization methodology is proposed based on a design parameterization which incorporates the skin effect. The numerical optimization procedure is implemented in Matlab, for 2D problems, and in a parallel C++ optimization framework, for 3D design problems. The optimization procedure is first applied to the design of energy focusing devices. The examples cover 2D and 3D resonators, which can be thought of as simplified energy harvesting systems. This is followed by a more practical example, in which the design and optimization of Fresnel plate zone lenses are investigated. It is shown that the performance can be increased with more than 30 % compared to a conventional design. The second optimization problem investigated concerns the design of sub-wavelength antennas. In order to alleviate dependence on the initial design and to obtain a generally applicable design formalism, a two step optimization procedure is presented. This scheme is applied to the design and optimization of a hemispherical sub-wavelength antenna. The optimized antenna configuration displayed a ratio of radiated power to input power in excess of 99 %. The third, and last, design problem considered in this thesis, concerns the optimization of devices for wireless energy transfer via strongly coupled magnetic resonators. A single design problem is considered to demonstrate proof of concept. The resulting design illustrates the possibilities of the optimization method, but also reveals its numerical limitations with respect to the resolution of the different length-scales involved.

Topology Optimization of Sub-Wavelength Antennas
We propose a topology optimization strategy for the systematic design of a three-dimensional (3D), conductor-based sub-wavelength antenna. The post-processed finite-element (FE) models of the optimized structure are shown to be self-resonant, efficient and exhibit distorted omnidirectional, elliptically polarized far-field radiation patterns. The computed approximate Q value for this antenna is $Q_0(\omega_0) = 7.74$ for $\omega_0 = 2\pi \times 350.8$ MHz and it is 1.64 times larger than the theoretical lower bound value.
The aim of this paper is to demonstrate 1D switch designs obtained by topology optimization which show better performance than the designs considered in the literature. Such devices are non-linear and their performance depends on the efficiency of light-matter interaction. Simple optical switches can be designed using physical considerations and intuition. Alternatively, the proposed topology optimization scheme provides a systematic methodology for obtaining and optimizing the layout of the devices. It is shown that the algorithm can efficiently handle more than two materials and that the obtained switches possess excellent performance.
Topology optimized low-contrast all-dielectric optical cloak
A systematic methodology for designing low-contrast all-dielectric cloaks operating in the optical range is presented. Topology optimization is used to find the layout of standard dielectric material that minimizes the norm of the scattered field in the surroundings of the cloak. Rotational symmetries are exploited to optimize for multiple angles based on the solution for a single angle of incidence. For a few discrete angles of incidences (1-4) the cloaking is shown to be nearly perfect in a limited frequency range, and even for a rotational symmetric design, cloak and object appear smaller than the noncloaked object. (C) 2011 American Institute of Physics. [doi:10.1063/1.3540687]
Efficient use of iterative solvers in nested topology optimization

In the nested approach to structural optimization, most of the computational effort is invested in the solution of the analysis equations. In this study, it is suggested to reduce this computational cost by using an approximation to the solution of the analysis problem, generated by a Krylov subspace iterative solver. By choosing convergence criteria for the iterative solver that are strongly related to the optimization objective and to the design sensitivities, it is possible to terminate the iterative solution of the nested equations earlier compared to traditional convergence measures. The approximation is computationally shown to be sufficiently accurate for the purpose of optimization though the nested equation system is not necessarily solved accurately. The approach is tested on several large-scale topology optimization problems, including minimum compliance problems and compliant mechanism design problems. The optimized designs are practically
identical while the time spent on the analysis is reduced significantly.
Topology optimization problems with design-dependent sets of constraints

Topology optimization is a design tool which is used in numerous fields. It can be used whenever the design is driven by weight and strength considerations. The basic concept of topology optimization is the interpretation of partial differential equation coefficients as effective material properties and designing through changing these coefficients. For example, consider a continuous structure. Then the basic concept is to represent this structure by small pieces of material that are coinciding with the elements of a finite element model of the structure. This thesis treats stress constrained structural topology optimization problems. For such problems a stress constraint for an element should only be present in the optimization problem when the structural design variable corresponding to this element has a value greater than zero. We model the stress constrained topology optimization problem using both discrete and continuous design variables. Using discrete design variables is the natural modeling frame. However, we cannot solve real-size problems with the technological limits of today. Using continuous design variables makes it possible to also study topology optimization problems of large scale. We find the global optimal solution to the stress constrained topology optimization problem using discrete design variables. The problem is solved using a parallel cut-and-branch method. The cuts include information about the mathematical structure of our problems and also their physics. The method shows particularly good speedup because of the added cuts. The study of stress constrained topology optimization problem using continuous design variables constitute the main part of this thesis. Primarily we study the problem reformulated into standard form via the Mathematical Program with Equilibrium Constraints (MPEC) formulations. We look at the two variations: Mathematical Program with Complementarity Constraints and Mathematical Program with Vanishing Constraints. These problem formulations are compared to a restricted problem formulation. The restricted problem include stress constraints for all elements independently of the values of the design variables. The investigations include validating constraint qualifications, attacking the problem formulations directly, and bounding the objective function value. We consider different constraint qualifications and whether they hold for the MPEC formulations of some truss topology optimization problems. We provide examples in which none of the considered constraint qualifications hold at the optimal solutions. This occurs when the upper limits of the design variables become active and there are nodal displacements that are non-unique. Note that this situation is generally the case at an optimal solution. However, the numerical experiments show that the MPEC formulations are not less robust than the restricted problem formulation. This indicates that the inherent lack of constraint qualifications is not the main numerical obstacle. We further observe that a general nonlinear interior-point algorithm applied to the MPEC formulations outperforms a general nonlinear active-set sequential quadratic programming method. Inspired by this, we implement an interior-point algorithm such that we have full control of all aspects of the code. Solving the stress constrained structural topology optimization problem is computationally challenging. We therefore present a technique that decides whether it may pay-off to actually treat the stress constrained problem. The technique finds lower and upper bounds on the objective function value of the stress constrained topology optimization problem. It further produces a feasible design. If the upper and lower bounds are far apart, then one should invest in attacking the stress constrained structural topology optimization problem. Otherwise one can use the obtained feasible design.

Microtools for Automated Nanomanipulation

General information

State: Published
Organisations: Department of Micro- and Nanotechnology, Solid Mechanics, Department of Mechanical Engineering, Nanointegration Group, NanoSystemsEngineering Section
Authors: Sardan Sukas, Ö. (Intern), Melhave, K. (Intern), Sigmund, O. (Intern), Bøggild, P. (Intern)
Publication date: Mar 2010
Process optimization of friction stir welding based on thermal models
This thesis investigates how to apply optimization methods to numerical models of a friction stir welding process. The work is intended as a proof-of-concept using different methods that are applicable to models of high complexity, possibly with high computational cost, and without the possibility for efficient gradient calculation. Thus, the focus is on surrogate optimization methods with the aim of reducing the number of expensive function evaluations, by using a low-fidelity model together with the high-fidelity model to be optimized. The methods used here do not require the user to supply gradient information of the high-fidelity model. The optimization schemes are applied to stationary thermal models of differing complexity of the friction stir welding process. The optimization problems considered are based on optimizing the temperature field in the workpiece by finding optimal translational speed and rotational speed of the tool. Besides the deterministic problem a robust optimization problem is considered in which the effects of uncertain material and optimization parameters are taken into account. The objective is to obtain a desired mean response while reducing the standard deviation of the response. Also an optimization problem based on a microstructure model is solved, allowing the hardness distribution in the plate to be optimized. The use of purely thermal models represents a simplification of the real process; nonetheless, it shows the applicability of the optimization methods considered and forms the basis for optimization of more detailed models. Surrogate models of varying complexity, and similarity with the true model, are applied and the effect on the optimization results is discussed. Furthermore, the thesis contributes to the modelling of the heat transfer between the workpiece and the backingplate by solving an inverse modelling problem in which experimental data and a numerical model are used for determining the contact heat transfer coefficient. Different parametrizations of the spatial distribution of the heat transfer coefficient are studied and discussed, and the optimization problem is formulated as a minimization of the difference between measured and calculated temperatures. The magnitude and distribution of the heat transfer coefficient is determined for the available data.

A topology optimization method for design of negative permeability metamaterials
A methodology based on topology optimization for the design of metamaterials with negative permeability is presented. The formulation is based on the design of a thin layer of copper printed on a dielectric, rectangular plate of fixed dimensions. An effective media theory is used to estimate the effective permeability, obtained after solving Maxwell's equations on a representative cell of a periodic arrangement using a full 3D finite element model. The effective permeability depends on the layout of copper, and the subject of the topology optimization problem is to find layouts that result in negative (real) permeability at a prescribed frequency. A SIMP-like model is invoked to represent the conductivity of regions of intermediate density. A number of different filtering strategies are invoked to facilitate convergence to binary solutions. Examples of designs for S-band applications are presented for illustration. New metamaterial concepts are uncovered, beyond the classical split-ring inspired layouts.
Design of photonic bandgap fibers by topology optimization

A method based on topology optimization is presented to design the cross section of hollow-core photonic bandgap fibers for minimizing energy loss by material absorption. The optical problem is modeled by the timeharmonic wave equation and
solved with the finite element program Comsol Multiphysics. The optimization is based on continuous material interpolation functions between the refractive indices and is carried out by the method of moving asymptotes. An example illustrates the performance of the method where air and silica are redistributed around the core so that the overlap between the magnetic field distribution and the lossy silica material is reduced and the energy flow is increased 375% in the core. Simplified designs inspired from optimized geometry are presented, which will be easier to fabricate. The energy flow is increased up to almost 300% for these cases.

**General information**
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering, University of Bern
Authors: Dühring, M. B. (Intern), Sigmund, O. (Intern), Feurer, T. (Ekstern)
Pages: 51-58
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Scopus rating (2016): CiteScore 1.81 SJR 0.894 SNIP 1.015
Web of Science (2016): Indexed yes
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Scopus rating (2015): SJR 1.023 SNIP 1.002 CiteScore 1.78
BFI (2014): BFI-level 1
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Scopus rating (2012): SJR 1.517 SNIP 1.273 CiteScore 2.2
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.527 SNIP 1.495 CiteScore 2.33
ISI indexed (2011): ISI indexed yes
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BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.47 SNIP 1.356
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Scopus rating (2008): SJR 1.645 SNIP 1.33
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.737 SNIP 1.29
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.644 SNIP 1.411
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.071 SNIP 1.686
Efficient computational procedures for topology optimization of nonlinear structures

Extreme non-linear elasticity and transformation optics

Transformation optics is a powerful concept for designing novel optical components such as high transmission waveguides and cloaking devices. The selection of specific transformations is a non-unique problem. Here we reveal that transformations which allow for all dielectric and broadband optical realizations correspond to minimizers of elastic energy potentials for extreme values of the mechanical Poisson's ratio $\nu$. For TE (Hz) polarized light an incompressible transformation $\nu = 1/2$ is ideal and for TM (E z) polarized light one should use a compressible transformation with negative Poisson's's ratio $\nu = -1$. For the TM polarization the mechanical analogy corresponds to a modified Liao functional known from the transformation optics literature. Finally, the analogy between ideal transformations and solid mechanical material models automates and broadens the concept of transformation optics. © 2010 Optical Society of America.
On the unambiguous determination of effective optical properties of periodic metamaterials: a one-dimensional case study

We show how branch ambiguities in the extraction of effective parameters is arising as a direct consequence of the underlying Bloch state physics. The mutual importance of the different branches in general depends on the experimental context, and we show how the Fourier spectrum of the field inside the metamaterial can be used to access this. Different numerical examples illustrate how a predominant branch may be identified for a while at higher frequency the power may be distributed over more branches. This is in particular true near bandedges and strong resonances. Extensions to two- and three-dimensional metamaterial designs are discussed.

General information
State: Published
Organisations: Structured Electromagnetic Materials, Department of Photonics Engineering, Solid Mechanics, Department of Mechanical Engineering, Electromagnetic Systems, Department of Electrical Engineering
Authors: Mortensen, A. (Intern), Yan, M. (Intern), Sigmund, O. (Intern), Breinbjerg, O. (Intern)
Pages: 10010
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BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.565 SNIP 0.655 CiteScore 1.26
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.733 SNIP 0.935 CiteScore 1.42
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.468 SNIP 0.748 CiteScore 0.95
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BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.476 SNIP 0.569 CiteScore 0.71
ISI indexed (2012): ISI indexed yes
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Scopus rating (2011): SJR 0.564 SNIP 0.914 CiteScore 0.83
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BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.744 SNIP 0.751
Web of Science (2010): Indexed yes
Scopus rating (2009): SJR 0.455 SNIP 0.454
Web of Science (2009): Indexed yes
Scopus rating (2008): SJR 0.491 SNIP 0.632
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.317 SNIP 0.293
Web of Science (2007): Indexed yes
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Optimization of the pressure coupling coefficient in periodic poroelastic materials

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Andreasen, C. S. (Intern), Sigmund, O. (Intern)
Pages: 757
Publication date: 2010

Systematic and robust design of photonic crystal waveguides by topology optimization
A robust topology optimization method is presented to consider manufacturing uncertainties in tailoring dispersion properties of photonic crystal waveguides. The under, normal and over-etching scenarios in manufacturing process are represented by dilated, intermediate and eroded designs based on a threshold projection. The objective is formulated to minimize the maximum error between actual group indices and a prescribed group index among these three designs. Novel photonic crystal waveguide facilitating slow light with a group index of n(g) = 40 is achieved by the robust optimization approach. The numerical result illustrates that the robust topology optimization provides a systematic and robust design methodology for photonic crystal waveguide design.

General information
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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Wang, F. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
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Workshop: 3rd International Workshop on Theoretical and Computational Nano-Photonics, Bad Honnef, Germany, 03/11/2010 - 03/11/2010
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BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.165 SNIP 0.191 CiteScore 0.17
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.16 SNIP 0.173 CiteScore 0.16
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BFI (2012): BFI-level 1
Time-Domain Topology Optimization of Pulse-Shaping Filters

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Organisations: Plasmonics and Metamaterials, Department of Photonics Engineering, Solid Mechanics, Department of Mechanical Engineering, Nanophotonics Theory and Signal Processing
Authors: Yang, L. (Intern), Sigmund, O. (Intern), Lavrinenko, A. (Intern), Hvam, J. M. (Intern)
Number of pages: 49
Publication date: 2010

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Main Research Area: Technical/natural sciences
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Source: orbit
Source-ID: 260155
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2010

Topology optimization for transient response of photonic crystal structures
An optimization scheme based on topology optimization for transient response of photonic crystal structures is developed. The system response is obtained by a finite-element time-domain analysis employing perfectly matched layers as an absorbing boundary condition. As an example a waveguide-side- coupled microcavity is designed. The gradient-based optimization technique is applied to redistribute the material inside the microcavity such that the Q factors of a monopole and a dipole mode are improved by 375% and 285%, respectively, while maintaining strong coupling. This is obtained by maximizing the stored energy inside the microcavity in the decaying regime of the transient response. Manufacturable designs are achieved by filtering techniques capable of controlling minimum length scales of the design features. © 2010 Optical Society of America.
Topology optimization of grating couplers for the efficient excitation of surface plasmons

We propose a methodology for a systematic design of grating couplers for efficient excitation of surface plasmons at metal-dielectric interfaces. The methodology is based on a two-dimensional topology optimization formulation based on the H-polarized scalar Helmholtz equation and finite-element method simulations. The efficiency of the method is demonstrated by optimized designs for input and output grating couplers for an Ag-SiO2 interface. The results indicate that slanted groove gratings may raise the coupling efficiency above 68% where the highest previously reported value was 50%.
Topology optimization of metallic devices for microwave applications

In electromagnetic optimization problems of metallic radio-frequency devices, such as antennas and resonators for wireless energy transfer, the volumetric distribution of good conductors, e.g. copper, has been known to cause numerical bottlenecks. In finite element analysis the limiting factor is the skin depth, which calls for highly refined meshing in order to capture the physics. The skin depth problem has therefore prohibited the application of topology optimization to this class of problem. We present a design parameterization that remedies these numerical issues, by the interpolation of Maxwell’s equations and a fictitious element impedance condition. The validity of the proposed design parameterization is confirmed by several numerical examples.
Topology-optimized slow-light couplers for ring-shaped photonic crystal waveguide

We demonstrate a topology-optimized coupler for a ring-shaped photonic crystal waveguide to improve the coupling of light located in the slow-light regime. An enhancement of the coupling efficiency of up to 2.5 dB is experimentally demonstrated.

Optimization of acoustic, optical and optoelectronic devices

Optical fiber communication conference

We demonstrate a topology-optimized coupler for a ring-shaped photonic crystal waveguide to improve the coupling of light located in the slow-light regime. An enhancement of the coupling efficiency of up to 2.5 dB is experimentally demonstrated.
Approximate Reanalysis in Topology Optimization

In the nested approach to structural optimization, most of the computational effort is invested in the solution of the finite element analysis equations. In this study, the integration of an approximate reanalysis procedure into the framework of topology optimization of continuum structures is investigated. The nested optimization problem is re-formulated to accommodate the use of an approximate displacement vector and the design sensitivities are derived accordingly. It is shown that relatively rough approximations are acceptable since the errors are taken into account in the sensitivity analysis. The implementation is tested on several small and medium scale problems, including two and three dimensional minimum compliance problems and two dimensional compliant force inverter problems. Accurate results are obtained and the savings in computation time are promising.
Design of one-dimensional optical pulse-shaping filters by time-domain topology optimization

Time-domain topology optimization is used here to design optical pulse-shaping filters in Si/SiO2 thin-film systems. A novel envelope objective function as well as explicit penalization are used to adapt the optimization method to this unique class of design problems.

General information
State: Published
Organisations: Plasmonics and Metamaterials, Department of Photonics Engineering, Nanophotonics Theory and Signal Processing, Solid Mechanics, Department of Mechanical Engineering
Authors: Yang, L. (Intern), Lavrinenko, A. (Intern), Hvam, J. M. (Intern), Sigmund, O. (Intern)
Pages: 261101
Publication date: 2009
Main Research Area: Technical/natural sciences

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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.085 SNIP 0.983 CiteScore 2.47
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.799 SNIP 1.462 CiteScore 3.25
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BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.149 SNIP 1.652 CiteScore 3.77
ISI indexed (2013): ISI indexed yes
Efficient use of iterative solvers in nested topology optimization

In the nested approach to structural optimization, most of the computational effort is invested in the solution of the finite element analysis equations. In this study, it is suggested to reduce this computational cost by using an approximation to the solution of the nested problem, generated by a Krylov subspace iterative solver. By choosing convergence criteria for the iterative solver that are strongly related to the optimization objective and to the design sensitivities, it is possible to
terminate the iterative solution of the nested equations earlier compared to traditional convergence measures. The approximation is shown to be sufficiently accurate for the practical purpose of optimization even though the nested equation system is not solved accurately. The approach is tested on several medium-scale topology optimization problems, including three dimensional minimum compliance problems and two dimensional compliant force inverter problems. Accurate optimal designs are obtained while the time spent on the nested problem is reduced significantly.

**General information**

State: Published
Organisations: Applied functional analysis, Department of Mathematics, Solid Mechanics, Department of Mechanical Engineering
Authors: Amir, O. (Intern), Stolpe, M. (Intern), Sigmund, O. (Intern)
Publication date: 2009

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Main Research Area: Technical/natural sciences
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**Improving the acousto-optical interaction in a Mach-Zehnder interferometer**

A method for modeling the interaction of the mechanical field from a surface acoustic wave and the optical field in the waveguides of a Mach–Zehnder interferometer is presented. The surface acoustic wave is generated by an interdigital transducer using a linear elastic plane model of a piezoelectric, inhomogeneous material, and reflections from the boundaries are avoided by applying perfectly matched layers. The optical modes in the waveguides are modeled by time-harmonic wave equations for the magnetic field. The two models are coupled using stress-optical relations and the change in effective refractive index introduced in the Mach–Zehnder interferometer arms by the stresses from the surface acoustic wave is calculated. It is then shown that the effective refractive index of the fundamental optical mode increases at a surface acoustic wave crest and decreases at a trough. The height and the width of the waveguides are varied for a silicon on insulator sample, and it is shown that the difference in effective refractive index between the waveguides can be increased 12 times for the right choice of waveguide size such that the optical modulation is improved. The difference is four times bigger if the waveguides are kept single moded. It is furthermore shown that the difference increases more than ten times when the waveguides are buried below the surface, where the mechanical stresses have their maximum, and in the case where two interdigital transducers are used the difference is increased 1.5 times. ©2009 American Institute of Physics

**General information**

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Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Dühring, M. B. (Intern), Sigmund, O. (Intern)
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Main Research Area: Technical/natural sciences

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Web of Science (2017): Indexed yes
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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.618 SNIP 0.84 CiteScore 1.57
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
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Web of Science (2014): Indexed yes
piezoelectric materials, acousto-optical effects, surface acoustic wave waveguides, interdigital transducers, Mach-Zehnder interferometers

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Manufacturing tolerant topology optimization

In this paper we present an extension of the topology optimization method to include uncertainties during the fabrication of macro, micro and nano structures. More specifically, we consider devices that are manufactured using processes which may result in (uniformly) too thin (eroded) or too thick (dilated) structures compared to the intended topology. Examples are MEMS devices manufactured using etching processes, nano-devices manufactured using e-beam lithography or laser micro-machining and macro structures manufactured using milling processes. In the suggested robust topology optimization approach, under- and over-etching is modelled by image processing-based “erode” and “dilate” operators and the optimization problem is formulated as a worst case design problem. Applications of the method to the design of macro structures for minimum compliance and micro compliant mechanisms show that the method provides manufacturing tolerant designs with little decrease in performance. As a positive side effect the robust design formulation also eliminates the longstanding problem of one-node connected hinges in compliant mechanism design using topology optimization.

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Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
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BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.36 SJR 0.386 SNIP 0.764
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.382 SNIP 0.878 CiteScore 1.04
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.312 SNIP 0.775 CiteScore 1.09
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.315 SNIP 0.841 CiteScore 0.95
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.366 SNIP 0.843 CiteScore 0.94
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.279 SNIP 0.683 CiteScore 1
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.309 SNIP 0.791
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.347 SNIP 0.733
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.353 SNIP 1.117
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.211 SNIP 0.838
Scopus rating (2006): SJR 0.286 SNIP 0.595
Scopus rating (2005): SJR 0.322 SNIP 0.544
Scopus rating (2004): SJR 0.455 SNIP 0.879
Scopus rating (2003): SJR 0.267 SNIP 0.597
Optimization of piezoelectric bimorph actuators with active damping for static and dynamic loads

The paper considers optimal design problems in the context of active damping. More specifically, we are interested in controlling the tip-deflection of a cantilever beam subjected to static and time-harmonic loading on its free extreme. First, the thickness profile of a piezoelectric bimorph actuator is optimized and second, the width profile. In the thickness study, formulation and results depend on whether the electric field or the applied voltage is kept constant. For the latter case we propose a differentiable model that connects electric field and piezo-actuator thickness to include electric field breakdown. Results are presented for both design variable cases, for static as well as for dynamic excitation for single frequency and frequency intervals.
Piezoelectricity, Variable thickness, Variable width, Shape optimization, Bimorph actuators

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Source-ID: 206598
Publication: Research - peer-review › Journal article – Annual report year: 2009

PDE-interpolations in topology optimization

General information
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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Sigmund, O. (Intern)
Publication date: 2009

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Editor: Damkilde et al., L.
Main Research Area: Technical/natural sciences
Source: orbit
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2009
Prospects for poor-man's cloaking with low-contrast all-dielectric optical elements

We discuss the prospects for low-contrast all-dielectric cloaking and offer a simple picture illustrating the basic obstacle for perfect cloaking without materials with an effective double-negative response. However, the same simple picture also gives directions for less perfect designs allowing for planar transmitted fields, but at the price of phase-slips which can only be eliminated at well-defined frequencies where the phase-slip amounts to a multiple of 2π. As a particular example, we consider assemblies of all-dielectric Lüneburg lenses forming a porous structure allowing for hiding objects inside the pores, independently on the polarization of the incident field. Cloaking must in general be realized with metamaterials realized through sub-wavelength structures, i.e. L l with L being the period and l the free-space wavelength. Interestingly, cloaking-like operations with Lüneburg-lens arrays perform in the opposite limit with L ≫ l.
Sensitivity Filters In Topology Optimisation As A Solution To Helmholtz Type Differential Equation

The focus of the study in this article is on the use of a Helmholtz type differential equation as a filter for topology optimisation problems. Until now various filtering schemes have been utilised in order to impose mesh independence in this type of problems. The usual techniques require topology information about the neighbour cells, which is difficult to obtain when the mesh program is separated from the computational code, especially for irregular meshes. The problem becomes even tougher in parallel environments, where the domain is decomposed into multiple non-overlapping partitions. Obtaining information about the neighbour sub-domains is an expensive operation. The proposed filtering technique requires only mesh information necessary for the finite element discretisation of the problem. The main idea is to define the filtered variable implicitly as a solution of a Helmholtz type differential equation with homogeneous Neumann boundary conditions. The properties of the filter are demonstrated for various 2D and 3D topology optimisation problems in linear elasticity, solved on sequential and parallel computers.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Lazarov, B. S. (Intern), Sigmund, O. (Intern)
Publication date: 2009

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Title of host publication: WCSMO-8 8th World Congress on Structural and Multidisciplinary Optimization - 8, 2009, LNEC, Lisbon, Portugal
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Systematic design of metamaterials by topology optimization

General information
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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 151-160
Publication date: 2009

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Source-ID: 255335
Publication: Research - peer-review › Article in proceedings – Annual report year: 2009

Topological material layout in plates for vibration suppression and wave propagation control

We propose a topological material layout method to design elastic plates with optimized properties for vibration suppression and guided transport of vibration energy. The gradient-based optimization algorithm is based on a finite element model of the plate vibrations obtained using the Mindlin plate theory coupled with analytical sensitivity analysis using the adjoint method and an iterative design update procedure based on a mathematical programming tool. We demonstrate the capability of the method by designing bi-material plates that, when subjected to harmonic excitation, either effectively suppress the overall vibration level or alternatively transport energy in predefined paths in the plates, including the realization of a ring wave device.
General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Larsen, A. A. (Intern), Laksafoss, B. (Ekstern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Pages: 585-594
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Structural and Multidisciplinary Optimization
Volume: 37
Issue number: 6
ISSN (Print): 1615-147X
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.14
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 2.42
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 2.77
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.08
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 1.85
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Web of Science (2008): Indexed yes
Web of Science (2007): Indexed yes
Web of Science (2006): Indexed yes
Web of Science (2005): Indexed yes
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Web of Science (2003): Indexed yes
Web of Science (2002): Indexed yes
Web of Science (2001): Indexed yes
Web of Science (2000): Indexed yes
Original language: English
Topologies design, Energy transport, Vibration response, Mindlin plate
DOIs:
10.1007/s00158-008-0257-0
Source: orbit
Source-ID: 243275
Topology optimization of devices for wireless energy transfer: The design parametrization

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering, Structured Electromagnetic Materials, Department of Photonics Engineering
Authors: Aage, N. (Intern), Mortensen, A. (Intern), Sigmund, O. (Intern)
Publication date: 2009

Host publication information
Title of host publication: 8th World Congress on Structural and Multidisciplinary Optimization
Main Research Area: Technical/natural sciences
Conference: 8th World Congress on Structural and Multidisciplinary Optimization, Lisbon, Portugal, 01/06/2009 - 01/06/2009
Electronic versions: wcsmo8_paper_TopOpt_EM.pdf
Links:
http://www.mek.dtu.dk/Medarbejdere/MEK_FAM.aspx?lg=showcommon&type=person&id=18078
Source: orbit
Source-ID: 254925
Publication: Research - peer-review › Article in proceedings – Annual report year: 2009

Topology Optimization of Metallic Microwave Devices

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Aage, N. (Intern), Sigmund, O. (Intern)
Publication date: 2009

Host publication information
Title of host publication: Advances in Topology and Material Optimization : Methods and Industrial Applications
Main Research Area: Technical/natural sciences
Conference: Advances in Topology and Material Optimization : Methods and Industrial Applications, 01/01/2009
Electronic versions:
PLATO-N_Niels_Aage_Final_Version.pdf
Links:
Source: orbit
Source-ID: 254928
Publication: Research - peer-review › Article in proceedings – Annual report year: 2009

Topology optimization of microfluidic mixers
This paper demonstrates the application of the topology optimization method as a general and systematic approach for microfluidic mixer design. The mixing process is modeled as convection dominated transport in low Reynolds number incompressible flow. The mixer performance is maximized by altering the layout of flow/non-flow regions subject to a constraint on the pressure drop between inlet and outlet. For a square cross-sectioned pipe the mixing is increased by 70% compared with a straight pipe at the cost of a 2.5 fold increase in pressure drop. Another example where only the bottom profile of the channel is a design domain results in intricate herring bone patterns that confirm findings from the literature.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Andreasen, C. S. (Intern), Gersborg, A. R. (Intern), Sigmund, O. (Intern)
Pages: 498-513
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
1D Grating structures designed by the time domain topology optimization

We report on the time domain application of topology optimization to 1D photonic devices. The method is confirmed to converge to the global minimum when optimizing a Bragg grating structure.
Acoustic design by topology optimization

To bring down noise levels in human surroundings is an important issue and a method to reduce noise by means of topology optimization is presented here. The acoustic field is modeled by Helmholtz equation and the topology optimization method is based on continuous material interpolation functions in the density and bulk modulus. The objective function is the squared sound pressure amplitude. First, room acoustic problems are considered and it is shown that the sound level can be reduced in a certain part of the room by an optimized distribution of reflecting material in a design domain along the ceiling or by distribution of absorbing and reflecting material along the walls. We obtain well defined optimized designs for a single frequency or a frequency interval for both 2D and 3D problems when considering low frequencies. Second, it is shown that the method can be applied to the design of outdoor sound barriers and reduce the sound level in the shadow zone behind the barrier up to 10 dB for a single barrier and almost 30 dB when using 2 barriers compared to utilizing conventional sound barriers.
A monolithic approach for topology optimization of electrostatically actuated devices

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Yoon, G. H. (Intern), Sigmund, O. (Intern)
Pages: 4062-4075
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Computer Methods in Applied Mechanics and Engineering
Volume: 197
ISSN (Print): 0045-7825
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
Approximate Reanalysis in Topology Optimization

General information
State: Published
Organisations: Applied functional analysis, Department of Mathematics, Solid Mechanics, Department of Mechanical Engineering
Focused Ion Beam (FIB) Modification of Topology Optimized Polysilicon Microgrippers

**General information**

State: Published
Organisations: Department of Micro- and Nanotechnology, Center for Electron Nanoscopy, Nanointegration Group, NanoSystemsEngineering Section, Solid Mechanics, Department of Mechanical Engineering, Materials and Surface Engineering
Authors: Sardan, Ö. (Intern), Nordström Andersen, K. (Intern), MacDonald, A. N. (Intern), Bøggild, P. (Intern), Sigmund, O. (Intern), Horsewell, A. (Intern)
Publication date: 2008
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 232086
Publication: Research - peer-review › Poster – Annual report year: 2008

Host publication information

Title of host publication: Proceedings of the ASME 2008 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference
Publisher: American Society of Mechanical Engineers
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 232083
Publication: Research - peer-review › Article in proceedings – Annual report year: 2008

**Geometric properties of optimal photonic crystals**

Photonic crystals can be designed to control and confine light. Since the introduction of the concept by Yablonovitch and John two decades ago, there has been a quest for the optimal structure, i.e., the periodic arrangement of dielectric and air that maximizes the photonic band gap. Based on numerical optimization studies, we have discovered some surprisingly simple geometric properties of optimal planar band gap structures. We conjecture that optimal structures for gaps between bands $n$ and $n+1$ correspond to $n$ elliptic rods with centers defined by the generators of an optimal centroidal Voronoi tessellation (transverse magnetic polarization) and to the walls of this tessellation (transverse electric polarization).

**General information**

State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern), Hougaard, K. G. (Intern)
Pages: 153904
Publication date: 2008
Main Research Area: Technical/natural sciences

**Publication information**
Inverse design of dispersion compensating optical fiber using topology optimization

We present a new numerical method for designing dispersion compensating optical fibers. The method is based on the solving of the Helmholtz wave equation with a finite-difference modesolver and uses topology optimization combined with a regularization filter for the design of the refractive index profile. We illustrate the applicability of the proposed method through numerical examples and, furthermore, address the problem of keeping the optimized design single moded by including a singlemode constraint in the optimization problem.
MAXIMIZING OPTO-ELASTIC INTERACTION

This contribution is concerned with topology optimization of a coupled optical and mechanical problem in photonic crystals. It is motivated by the potential gain in functionality of optical devices where the mechanical loading influences the optical response by distorting the geometry and through the opto-elastic effect. This is a new conquest for the development of topology optimization methods since little work have been carried out on topology optimization of coupled problems. The practical applications of this research cover novel optical modulators, switches and frequency shifters. Furthermore the research can be seen as method development of multi-physics optimization technology which may find future use in advanced optical devices such as an optical computer.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Gersborg, A. R. (Intern), Sigmund, O. (Intern)
Publication date: 2008

Host publication information
Title of host publication: 21 Nordic Seminar on Computational Mechanics : NSCM-21
Publisher: Nordic Association for Computational Mechanics
ISBN (Print): 978-84-96736-56-6
Main Research Area: Technical/natural sciences
Seminar: 21st Nordic Seminar on Computational Mechanics, Trondheim, Norway, 16/10/2008 - 16/10/2008
Source: orbit
Source-ID: 232259
Publication: Research - peer-review › Article in proceedings – Annual report year: 2008
Maximizing opto-elastic interaction using topology optimization

When a photonic device is subjected to a mechanical load, there are two effects which change the optical response relative to the reference configuration. First, there is the geometrical effect caused by geometrical changes, i.e. the deformation of the reference geometry to the deformed geometry. Secondly, there is the photo-elastic effect which changes the refractive index through Pockel's coefficients as the material is strained. For the case of transverse electric modes, we study how the two effects change the material distribution which maximizes the change in the optical transmission properties when the device is subjected to a static mechanical pre-strain. Material distributions consisting of air inclusions in silicon are considered. The optimized material distributions are computed using topology optimization.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Gersborg, A. R. (Intern), Sigmund, O. (Intern)
Publication date: 2008
Event: Poster session presented at Nanoday December 2 : Nano DTU, .
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 232294
Publication: Research - peer-review › Poster – Annual report year: 2008

MAXIMIZING OPTO-ELASTIC INTERACTION USING TOPOLOGY OPTIMIZATION

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Gersborg, A. R. (Intern), Sigmund, O. (Intern)
Publication date: 2008
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 232306
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2008

Rapid prototyping of nanotube-based devices using topology-optimized microgrippers

Nanorobotic handling of carbon nanotubes (CNTs) using microgrippers is one of the most promising approaches for the rapid characterization of the CNTs and also for the assembly of prototypic nanotube-based devices. In this paper, we present pick-and-place nanomanipulation of multi-walled CNTs in a rapid and a reproducible manner. We placed CNTs on copper TEM grids for structural analysis and on AFM probes for the assembly of AFM super-tips. We used electrothermally actuated polysilicon microgrippers designed using topology optimization in the experiments. The microgrippers are able to open as well as close. Topology optimization leads to a 10-100 times improvement of the gripping force compared to conventional designs of similar size. Furthermore, we improved our nanorobotic system to offer more degrees of freedom. TEM investigation of the CNTs shows that the multi-walled tubes are coated with an amorphous carbon layer, which is locally removed at the contact points with the microgripper. The assembled AFM super-tips are used for AFM measurements of microstructures with high aspect ratios.

General information
State: Published
Organisations: Department of Micro- and Nanotechnology, Solid Mechanics, Department of Mechanical Engineering
Authors: Sardan, Ö. (Intern), Eichhorn, V. (Intern), Petersen, D. (Ekstern), Fatikow, S. (Ekstern), Sigmund, O. (Intern), Boggild, P. (Ekstern)
Pages: 495503
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Nanotechnology
Volume: 19
Issue number: 49
ISSN (Print): 0957-4484
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
Simulation of Toology Optimized Microgrippers

General information
State: Published
Organisations: Department of Micro- and Nanotechnology, Nanointegration Group, NanoSystemsEngineering Section, Solid Mechanics, Department of Mechanical Engineering
Authors: Sardan, Ö. (Intern), Petersen, D. H. (Intern), Sigmund, O. (Intern), Bøggild, P. (Intern)
Publication date: 2008

Host publication information
Title of host publication: Proceeding of Comsol Conference
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 232088
Publication: Research - peer-review › Article in proceedings – Annual report year: 2008

Three-dimensional topology optimized electrically-small conformal antenna
A three-dimensional (3D) conductor-based conformal electrically small antenna is obtained using a topology optimization method. The optimization method distributes a certain amount of conductive material to a designated design domain such that the material layout defines an electrically small radiator fed by a coaxial cable over a ground plane. Preliminary investigations show that topology optimization method produced a conformal ESA design that has a radiation efficiency of approximately 80% at 300 MHz.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Erentok, A. (Intern), Sigmund, O. (Intern)
Pages: 1-4
Publication date: 2008

Host publication information
Publisher: IEEE
ISBN (Print): 978-1-4244-2041-4
Main Research Area: Technical/natural sciences
Electronic versions:
Erentok.pdf
DOI:
10.1109/APS.2008.4619200

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Source: orbit
Source-ID: 252148
Publication: Research › Article in proceedings – Annual report year: 2008

Topology optimization for transient wave propagation problems in one dimension: Design of filters and pulse modulators
Structures exhibiting band gap properties, i.e., having frequency ranges for which the structure attenuates propagating waves, have applications in damping of acoustic and elastic wave propagation and in optical communication. A topology optimization method for synthesis of such structures, employing a time domain formulation, is developed. The method is extended to synthesis of pulse converting structures with possible applications in optical communication.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Center for Nanoteknologi
Authors: Dahl, J. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Pages: 585-595
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
This note considers topology optimization of large scale 2D and 3D Stokes flow problems using parallel computations. We solve problems with up to 1,125,000 elements in 2D and 128,000 elements in 3D on a shared memory computer consisting of Sun UltraSparc IV CPUs.

General information
Topology optimization of optical band gap effects in slab structures modulated by periodic Rayleigh waves

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Gersborg, A. R. (Intern), Sigmund, O. (Intern)
Publication date: 2008
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 232296
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2008

TOPOLOGY OPTIMIZATION OF OPTICAL BAND GAP EFFECTS IN SLAB STRUCTURES MODULATED BY PERIODIC RAYLEIGH WAVES
This paper is concerned with topology optimization of a coupled optical and mechanical wave propagation problem in photonic crystals. It is motivated by the potential gain in functionality of optical devices where mechanical Rayleigh waves (travelling in the surface of the material) play a leading role. The practical applications cover novel optical modulators, switches and frequency shifters. The work uses COMSOL Multiphysics which is a modern and finite element based modelling language.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Gersborg, A. R. (Intern), Sigmund, O. (Intern), Aage, N. (Intern)
Publication date: 2008

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
ictam2008_naaargos_optomechanical_optimization.pdf
Source: orbit
Source-ID: 234756
Publication: Research › Sound/Visual production (digital) – Annual report year: 2008

Topology optimized electrothermal polysilicon microgrippers
This paper presents the topology optimized design procedure and fabrication of electrothermal polysilicon microgrippers for nanomanipulation purposes. Performance of the optimized microactuators is compared with a conventional three-beam microactuator design through finite element analysis. The accuracy of the finite element model is verified by comparison of simulated and measured displacement vs. bias voltage curves. A considerable improvement in the mechanical stiffness is indicated by AFM force measurements, being 9 times higher compared to the conventional three-beam actuator. (C) 2008 Elsevier B.V. All rights reserved.

General information
State: Published
Organisations: Department of Micro- and Nanotechnology, Nanointegration Group, NanoSystemsEngineering Section, Solid Mechanics, Department of Mechanical Engineering
Authors: Sardan Sukas, Ö. (Intern), Petersen, D. H. (Intern), Mølhave, K. (Intern), Sigmund, O. (Intern), Bøggild, P. (Intern)
Pages: 1096-1099
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Microelectronic Engineering
Volume: 85
Issue number: 5-6
ISSN (Print): 0167-9317
Ratings:
Topology optimized Microgrippers for Nanomanipulation of Carbon Nanotubes

General information
State: Published
Organisations: Department of Micro- and Nanotechnology, Nanointegration Group, NanoSystemsEngineering Section, Solid Mechanics, Department of Mechanical Engineering
Authors: Sardan, Ö. (Intern), Eichhorn, V. (Intern), Petersen, D. H. (Intern), Fatikow, S. (Ekstern), Sigmund, O. (Intern), Bøggild, P. (Intern)
Publication date: 2008

Host publication information
Title of host publication: Proceeding of IDETC/CIE
Publisher: American Society of Mechanical Engineers
Main Research Area: Technical/natural sciences
Conference: International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Brooklyn, New York, USA, 01/01/2008
Source: orbit
Source-ID: 232064
Publication: Research - peer-review › Article in proceedings – Annual report year: 2008

TopOpt of optical waves and fluids

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Gersborg, A. R. (Intern), Andreasen, C. S. (Intern), Sigmund, O. (Intern)
Publication date: 2008

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 232311
Publication: Research › Sound/Visual production (digital) – Annual report year: 2008

Transient Topology Optimization of Two-Dimensional Elastic Wave Propagation
A tapering device coupling two monomodal waveguides is designed with the topology optimization method based on transient wave propagation. The gradient-based optimization technique is applied to predict the material distribution in the tapering area such that the squared output displacement (a measure for transmission) in the taper is maximized. High transmission in a large frequency range is gained by use of incident wave packets. To avoid nondiscrete properties in the design domain a density filtering technique is employed.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering, Center for Nanoteknologi
Authors: Matzen, R. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Pages: paper 75
Publication date: 2008

Host publication information
Title of host publication: Proceedings of the 9. International Conference on Computational Structures Technology
Place of publication: Stirlingshire, United Kingdom
Publisher: Civil-Comp Press
Editors: Topping, B., Papadrakakis, M.
ISBN (Print): 978-1-905088-23-2
Main Research Area: Technical/natural sciences
Conference: 9th International Conference on Computational Structures Technology, Athens, Greece, 02/09/2008 - 02/09/2008
Source: orbit
Source-ID: 232951
Publication: Research - peer-review › Article in proceedings – Annual report year: 2008
**Topology optimization of flow problems**
This thesis investigates how to apply topology optimization using the material distribution technique to steady-state viscous incompressible flow problems. The target design applications are fluid devices that are optimized with respect to minimizing the energy loss, characteristic properties of the velocity field or mixing properties. To reduce the computational complexity of the topology optimization problems the primary focus is put on the Stokes equation in 2D and in 3D. However, the thesis also contains examples with the 2D Navier-Stokes equation as well as an example with convection dominated transport in 2D Stokes flow. Using Stokes flow limits the range of applications; nonetheless, the thesis gives a proof-of-concept for the application of the method within fluid dynamic problems and it remains of interest for the design of microfluidic devices. Furthermore, the thesis contributes to the development of the topology optimization method by studying different problem formulations related to topology optimization of fluid problems. In addition, the COMSOL software has been used as a post processing tool. Prior to design manufacturing this allows the engineer to quantify the performance of the computed topology design using standard, credible analysis tools with a body-fitted mesh. Also, the thesis encompasses work on how to utilize the finite volume method (FVM) in the topology optimization context. This is motivated by the momentous position the FVM has in the fluid dynamics community. Although the study of the FVM is carried out using a simple heat conduction problem, the work illuminates and discusses the technicalities of employing the FVM in connection with topology optimization. Finally, parallelized solution methods are investigated using the high performance computing facility at the Technical University of Denmark. Large topology optimization problems with 2D and 3D Stokes flow modeling are solved with direct and iterative strategies employing the parallelized Sun Performance Library and the OpenMP parallelization technique, respectively.

**Imprinted silicon-based nanophotonics**
We demonstrate and optically characterize silicon-on-insulator based nanophotonic devices fabricated by nanoimprint lithography. In our demonstration, we have realized ordinary and topology-optimized photonic crystal waveguide structures. The topology-optimized structures require lateral pattern definition on a sub 30-nm scale in combination with a deep vertical silicon etch of the order of ~300 nm. The nanoimprint method offers a cost-efficient parallel fabrication process with state-of-the-art replication fidelity, comparable to direct electron beam writing.

**General information**

State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering, Department of Mathematics
Authors: Gersborg, A. R. (Intern), Sigmund, O. (Intern), Bendsøe, M. P. (Intern)
Number of pages: 202
Publication date: May 2007

Publication information
ISBN (Print): 87-90-41623-6
Original language: English
Series: DCAMM Special Report
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Main Research Area: Technical/natural sciences
Finite volume, Parallel solution, Multiphysics, Topology optimization, Direct solution, Fluid dynamics, Iterative solution, Finite element
Electronic versions:
C:\Agh\PhD\Texts\Thesis\070122b_final\070410_final\Forside\AGH_thesis.pdf
Links:
http://www.topopt.dtu.dk

Bibliographical note
This thesis work received support from the Research School within the Danish Center for Applied Mathematics and Mechanics (DCAMM)
Source: orbit
Source-ID: 192424
Publication: Research › Ph.D. thesis – Annual report year: 2007
Maximizing the Optical Band Gap in 2D Photonic Crystals

Topology optimization is used to find the 2D photonic crystal designs with the largest relative photonic band gaps. Starting points for the topology optimization are found with an exhaustive binary search on a low resolution grid.

Morphology-based black and white filters for topology optimization

State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
Pages: 401-424
Publication date: 2007
Main Research Area: Technical/natural sciences
Simulation of acousto-optical interaction in a Mach-Zehnder interferometer

The acousto-optical modulation of light in a Mach-Zehnder interferometer affected by a surface acoustic wave, is simulated by the finite element method. It is discussed how the modulation can be improved based on a parameter study of the geometry. Summary A new way to control and modulate light in waveguide structures is to let the light interact with surface acoustic waves (SAW) [1]. SAWs are elastic waves that propagate along a material surface, they consist of a longitudinal and a shear component and they have most of their energy density concentrated within one wavelength of the surface [2]. In [3] it is explained how a SAW can be employed to modulate the output light of a GaAs Mach-Zehnder interferometer (MZI) and experimental results with a relative modulation depth of 40% are presented. To modulate the light using a MZI a SAW is transmitted perpendicularly to the two waveguide arms and the elastic stress field from the SAW results in a periodic change of the refractive index and therefore a periodical phase change in the waveguide arms. At a wave crest the refractive index will increase and at a trough it will decrease. Thus, if the distance between the arms is chosen as an unequal multiple of half the SAW wavelength the light at the output waveguide will interfere constructively and destructively in a periodic way and the MZI can hence be used as an optical switch. To understand and improve the interaction of the elastic field from the SAW with the optical field in the waveguides a numerical model of the MZI is constructed. The generation of the SAW by interdigital transducers is studied using a 2D finite element model of a piezoelectric, anisotropic material implemented in the high-level programming language Comsol Multiphysics. By calculating the stresses in the waveguide arms introduced by the SAW the changes in refractive indices are obtained from Pockels constants. This model is then coupled to an optical model where the time independent wave equation is solved as an eigenvalue problem giving the effective refractive index of the lowest modes in the waveguide arms. Numerical results of the modulation for MZIs of both GaAs and Si are presented. Based on results from a parameter study of the geometry it is discussed how the acousto-optical modulation can be improved. References [1] M. M. de Lima Jr. and P. V. Santos, (2005), "Modulation of photonic structures by surface acoustic waves", Rep. Prog. Phys., 68 1639-1701. [2] K.-Y. Hashimoto, "Surface acoustic wave devices in telecommunications modeling and simulation", Springer, Berlin, 2000, ISBN 3-540-67232-X. [3] M. M. de Lima Jr., M. Beck, R. Hey and P. V. Santos, "Compact Mach-Zehnder acousto-optic modulator", Applied Physics Letters, 89, 121104 (2006).
Surface acoustic wave driven light modulation

General information
State: Published
Organisations: Nanophotonics, Department of Photonics Engineering, Solid Mechanics, Department of Mechanical Engineering, Systems
Number of pages: 1
Publication date: 2007

Host publication information
Title of host publication: Proceedings ECIO
Place of publication: Kgs. Lyngby, Denmark
Publisher: COM.DTU
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 199210
Publication: Research - peer-review › Article in proceedings – Annual report year: 2007

Tailoring Dispersion properties of photonic crystal waveguides by topology optimization
The paper describes a systematic method for the tailoring of dispersion properties of slab-based photonic crystal waveguides. The method is based on the topology optimization method which consists in repeated finite element frequency domain analyzes, analytical sensitivity analyzes and gradient based design updates. The goal of the optimization process is to come up with slow light, zero group velocity dispersion photonic waveguides or photonic waveguides with tailored dispersion properties for dispersion compensation purposes. Two examples concerning reproduction of a specific dispersion curve and design of a wide bandwidth, constant low group velocity waveguide demonstrate the efficiency of the method.

General information
State: Published
Organisations: Applied functional analysis, Department of Mathematics, Solid Mechanics, Department of Mechanical Engineering, Center for Nanoteknologi
Authors: Stainko, R. (Intern), Sigmund, O. (Intern)
Pages: 477-489
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: Waves in Random and Complex Media
Volume: 17
Issue number: 4
ISSN (Print): 1745-5030
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.385 SNIP 0.813 CiteScore 1.26
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.529 SNIP 0.932 CiteScore 1.06
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.448 SNIP 0.753 CiteScore 0.97
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.517 SNIP 0.892 CiteScore 1.07
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Tailoring group velocity by topology optimization

The paper describes a systematic method for the tailoring of dispersion properties of slab-based photonic crystal waveguides. The method is based on the topology optimization method which consists in repeated finite element frequency domain analyses. The goal of the optimization process is to come up with slow light, zero group velocity dispersion photonic waveguides or photonic waveguides with tailored dispersion properties for dispersion compensation purposes. An example concerning the design of a wide bandwidth, constant low group velocity waveguide demonstrate the efficiency of the method.
Tailoring group velocity by topology optimization

General information
State: Published
Organisations: Department of Mathematics, Solid Mechanics, Department of Mechanical Engineering
Authors: Stainko, R. (Intern), Sigmund, O. (Intern)
Publication date: 2007
Event: Paper presented at 7th World Congress on Structural and Multidisciplinary Optimization, Seoul, Korea, Republic of.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 205472
Publication: Research › Paper – Annual report year: 2007

Topology optimization
Taking as a starting point a design case for a compliant mechanism (a force inverter), the fundamental elements of topology optimization are described. The basis for the developments is a FEM format for this design problem and emphasis is given to the parameterization of design as a raster image and the techniques associated with solving this class of problems by computational means.

General information
State: Published
Organisations: Applied functional analysis, Department of Mathematics, Solid Mechanics, Department of Mechanical Engineering
Authors: Bendsoe, M. P. (Intern), Sigmund, O. (Intern)
Pages: 161-194
Publication date: 2007

Host publication information
Title of host publication: Optimization of Structural and Mechanical Systems
Place of publication: Singapore
Publisher: World Scientific Publishing Co Pte Ltd
Editor: Arora, J. S.
ISBN (Print): 978-981-256-962-2
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 205639
Publication: Research - peer-review › Book chapter – Annual report year: 2007

Topology Optimization for Acoustic Structure Interaction Problems

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Yoon, G. H. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Pages: 1049-1075
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Volume: 70
ISSN (Print): 0029-5981
Ratings:
BFI (2017): BFI-level 2
Topology optimization of acoustic-structure interaction problems using a mixed finite element formulation

The paper presents a gradient-based topology optimization formulation that allows to solve acoustic-structure (vibro-acoustic) interaction problems without explicit boundary interface representation. In acoustic-structure interaction problems, the pressure and displacement fields are governed by Helmholtz equation and the elasticity equation,
respectively. Normally, the two separate fields are coupled by surface-coupling integrals, however, such a formulation does not allow for free material re-distribution in connection with topology optimization schemes since the boundaries are not explicitly given during the optimization process. In this paper we circumvent the explicit boundary representation by using a mixed finite element formulation with displacements and pressure as primary variables (a u/p-formulation). The Helmholtz equation is obtained as a special case of the mixed formulation for the elastic shear modulus equating to zero. Hence, by spatial variation of the mass density, shear and bulk moduli we are able to solve the coupled problem by the mixed formulation. Using this modelling approach, the topology optimization procedure is simply implemented as a standard density approach. Several two-dimensional acoustic-structure problems are optimized in order to verify the proposed method.

General information
State: Published
Organisations: Department of Mechanical Engineering, Section for Planning and Management of Building Processes, Department of Civil Engineering, Solid Mechanics
Authors: Yoon, G. H. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Pages: 1049-1075
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Volume: 70
Issue number: 9
ISSN (Print): 0029-5981
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BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.64 SJR 1.743 SNIP 1.566
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.912 SNIP 1.689 CiteScore 2.67
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.935 SNIP 1.927 CiteScore 2.73
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.415 SNIP 1.894 CiteScore 2.8
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.47 SNIP 2.103 CiteScore 2.7
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.193 SNIP 1.935 CiteScore 2.47
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.177 SNIP 1.717
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.983 SNIP 1.601
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.122 SNIP 1.74
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.023 SNIP 1.775
Web of Science (2007): Indexed yes
Topology Optimization of Metamaterial-Based Electrically Small Antennas

A topology optimized metamaterial-based electrically small antenna configuration that is independent of a specific spherical and/or cylindrical metamaterial shell design is demonstrated. Topology optimization is shown to provide the optimal value and placement of a given ideal metamaterial in space to maximize far-field radiated power.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Erentok, A. (Intern), Sigmund, O. (Intern)
Number of pages: 425
Pages: 219-223
Publication date: 2007

Host publication information
Title of host publication: TOPOLOGY OPTIMIZATION OF METAMATERIAL-BASED ELECTRICALLY SMALL ANTENNAS
Volume: Electronics
Place of publication: Bursa, Turkey
Publisher: EMO
Edition: 1
ISBN (Print): 978-9944-89-421-0
Main Research Area: Technical/natural sciences
Conference: TOPOLOGY OPTIMIZATION OF METAMATERIAL-BASED ELECTRICALLY SMALL ANTENNAS, BURSA, TURKEY, 01/01/2007
metamaterial
Electronic versions:
ELECO_Erentok_Ole_09_2007c.doc
Source: orbit
Source-ID: 209720
Publication: Research - peer-review › Article in proceedings – Annual report year: 2007

Topology optimization using a mixed formulation: An alternative way to solve pressure load problems

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern), Clausen, P. M. (Ekstern)
Within the last few years, photonic crystal waveguides (PhCWs) with low propagation losses and exotic dispersion properties have been realized and, presently, there is a strong movement towards the deployment of such structures in integrated circuits. Effective passive components such as bends, splitters, and multiplexers are a necessity in optical circuits. However, the designing of such components in the PhC platform has been a great challenge, as they often constitute severe discontinuities in the PhCW and introduce high losses. Presently, the designing of PhCW components mostly rely on an Edisonian design approach combining physical arguments and experimental/numerical verifications. Further optimizations are typically done in an iterative trial-and-error procedure in order to improve a chosen performance measure of the PhCW component. Such an approach is very time-consuming and does not guarantee optimal solutions. The systematic design method based on topology optimization [1] allows creation of improved PhCW components with previously unseen low transmission losses, high operational bandwidths, and/or with wavelength selective functionalities. The method was originally developed for structural optimization problems, but has recently been extended to a range of other design problems. The method is based on repeated finite element analyses where the distribution of material in a given design area is iteratively modified in order to improve a chosen performance measure. The resulting designs are inherently free from geometrical restrictions such as the number of holes, hole shapes etc., thereby allowing the large potentials of PhC components [2] to be exploited to heretofore unseen levels. The intricate confinement of light in a PhCW and its resulting dispersion properties offer sophisticated possibilities for realizing complex nanophotonic circuits. Potentially, PhCWs may facilitate delay lines for package synchronization, dispersion compensation, and enhanced light-matter interactions in nanophotonic circuits by exploiting slow-light phenomena. The practical utilization of ultra-slow light reaching group velocities below \(\sim c_0/200\) in PhCWs may be limited due to an inherent small bandwidth, impedance mismatch, intensified loss mechanisms at scattering centres, and extreme dispersive pulse broadening. However, the dispersion properties of PhCWs can be altered via knowledge of the field distribution for the target mode and through a simple structural tuning of the waveguide geometry [3]. In this way, it is possible to realize a silicon-on-insulator PhCW with semi-slow light having a group velocity in the range \(\sim (c_0/15 - c_0/100)\); vanishing, positive, or negative group velocity dispersion (GVD); and low-loss propagation in a practical \(\sim 5\)–\(15\) nm bandwidth. Such simple PhCW component may find widespread use in passive integrated circuits. The talk will present examples of topology-optimized PhCW components for broadband use and for narrowband use in the slow-light regime of PhCWs and exemplify how the dispersion properties of PhCWs can be tailored for use in passive components.

Controlling the speed of light

Interesting phenomena of photonic crystals (PhCs), like bandgaps and waveguiding, have lead to a tremendous increase of research interest in this area. High-end functionalities in electro-optical circuits urge to optimize these structures. So far mostly trial and error methods have been applied to improve the behaviour of the PhCs components, like, e.g., to maximize the bandgap of PhCs or to reduce the losses of waveguides in PhCs. Recently also topology optimization was applied to synthesize, e.g., high transmission waveguide bends and junctions. In this work we extend the topology optimization method to not only to create a bandgap around an a-priorily chosen guided mode, but also to control it's group-velocity under the light-line.
Maximizing band gaps in plate structures

Band gaps, i.e., frequency ranges in which waves cannot propagate, can be found in elastic structures for which there is a certain periodic modulation of the material properties or structure. In this paper, we maximize the band gap size for bending waves in a Mindlin plate. We analyze an infinite periodic plate using Bloch theory, which conveniently reduces the maximization problem to that of a single base cell. Secondly, we construct a finite periodic plate using a number of the optimized base cells in a postprocessed version. The dynamic properties of the finite plate are investigated theoretically and experimentally and the issue of finite size effects is addressed.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Halkjær, S. (Intern), Sigmund, O. (Intern), Jensen, J. S. (Intern)
Pages: 263-275
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication information
Journal: Structural and Multidisciplinary Optimization
Volume: 32
Issue number: 4
ISSN (Print): 1615-147X
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.14
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 2.42
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 2.77
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
On Topology Optimization with Manufacturing Constraints

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
Publication date: 2006

Host publication information
Title of host publication: III European Conference on Computational Mechanics : Solids, Structures and Coupled Problems in Engineering
Editor: Mota Soares, C.
Main Research Area: Technical/natural sciences
Conference: 3rd European Conference on Computational Mechanics, Lissabon, Portugal, 05/06/2006 - 05/06/2006
Source: orbit
Source-ID: 193620
Publication: Research - peer-review › Article in proceedings – Annual report year: 2006

Optical characterisation of photonic wire and photonic crystal waveguides fabricated using nanoimprint lithography
We have characterised photonic-crystal and photonic-wire waveguides fabricated by thermal nanoimprint lithography. The structures, with feature sizes down below 20 nm, are benchmarked against similar structures defined by direct electron beam lithography.

General information
State: Published
Organisations: Nanophotonics, Department of Photonics Engineering, Lab-on-a-Chip, Department of Micro- and Nanotechnology, Solid Mechanics, Department of Mechanical Engineering, Center for Nanoteknologi
Authors: Borel, P. I. (Intern), Frandsen, L. H. (Intern), Lavrinenko, A. (Intern), Olsen, B. B. (Intern), Nielsen, T. (Intern), Kristensen, A. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Pages: We1.2.4
Publication date: 2006
Photonic crystal and quantum dot technologies for all-optical switch and logic device

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering, Nanophotonics, Department of Photonics Engineering, Center for Nanoteknologi
Pages: 1-26
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication information
Journal: New Journal of Physics
Volume: 8
Issue number: 208
ISSN (Print): 1367-2630
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.97 SJR 1.788 SNIP 1.031
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.938 SNIP 1.047 CiteScore 2.8
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.806 SNIP 1.307 CiteScore 2.89
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.871 SNIP 1.372 CiteScore 2.77
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 3.352 SNIP 1.533 CiteScore 3.4
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Photonic Crystals and Quantum Dots: Towards Integrated Optics for Advanced Ultra-Fast All-Optical Signal Processing

General information
State: Published
Organisations: Department of Photonics Engineering, Department of Mechanical Engineering, Solid Mechanics, Nanophotonics
Authors: Asakawa, K. (Ekstern), Sugimoto, Y. (Ekstern), Watanabe, Y. (Ekstern), Ozaki, N. (Ekstern), Mizutani, A. (Ekstern), Takata, Y. (Ekstern), Kitagawa, Y. (Ekstern), Ikeda, N. (Ekstern), Ohkouchi, S. (Ekstern), Nakamura, S. (Ekstern), Watanabe, A. (Ekstern), Wang, X. (Ekstern), Kristensen, M. (Intern), Sigmund, O. (Intern), Borel, P. I. (Intern), Baets, R. (Ekstern)
Pages: We1.2.1
Publication date: 2006

Host publication information
Title of host publication: ECOC 2006 Proceedings
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 194133
Publication: Research - peer-review › Article in proceedings – Annual report year: 2006

The pressure load problem revisited

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics, Technical University of Denmark
Topological Design for Acoustic-Structure Interaction Problems with a Mixed Finite Element Method

We propose a gradient based topology optimization algorithm for acoustic-structure (Vibro-acoustic) interaction problems without an explicit interfacing boundary representation. In acoustic-structure interaction problems, the pressure field and the displacement field are governed by the Helmholtz equation and the linear elasticity equation, respectively, and it is necessary that the governing equations should be properly evolved with respect to the design variables in the design domain. Moreover, all the boundary conditions obtained by computing surface coupling integrals should be properly imposed to subdomain interfaces evolving during the optimization process. In this paper, we propose to use a mixed finite element formulation with displacements and pressure as primary variables (u/p formulation) which eliminates the need for explicit boundary representation. In order to describe the Helmholtz equation and the linear elasticity equation, the mass density as well as the shear and bulk moduli are interpolated with the design variables. In this formulation, the coupled interface boundary conditions are automatically satisfied without having to compute surface coupling integrals. Two dimensional acoustic-structure interaction problems are optimized to show the validity of the proposed method.
Topology optimised photonic crystal waveguide intersections with high-transmittance and low crosstalk
Numerical and experimental studies on the photonic crystal waveguide intersection based on the topology optimisation design method are reported and the effectiveness of this technique is shown by achieving high transmittance spectra with low crosstalk for the straightforward beam-propagation line in the intersection.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering, Department of Photonics Engineering, Center for Nanoteknologi, University of Tsukuba, Aarhus University
Authors: Ikeda, N. (Ekstern), Sugimoto, Y. (Ekstern), Watanabe, Y. (Ekstern), Ozaki, N. (Ekstern), Mizutani, A. (Ekstern), Takata, Y. (Ekstern), Jensen, J. S. (Intern), Sigmund, O. (Intern), Borel, P. I. (Intern), Kristensen, M. (Ekstern), Asakawa, K. (Ekstern)
Pages: 1031-1033
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication Information
Journal: ELECTRONICS LETTERS
Volume: 42
Issue number: 18
ISSN (Print): 0013-5194
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.442 SNIP 0.882 CiteScore 1.35
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.497 SNIP 1.011 CiteScore 1.31
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.522 SNIP 1.061 CiteScore 1.31
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.59 SNIP 1.155 CiteScore 1.45
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.631 SNIP 1.161 CiteScore 1.45
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.634 SNIP 1.098 CiteScore 1.44
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.637 SNIP 1.011
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.728 SNIP 1.072
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.843 SNIP 0.957
Web of Science (2008): Indexed yes
Topology optimization applied to room acoustic problems and surface acoustic wave devices

The work of this PhD-project is concerned with the method of topology optimization, which has been developed and used since the late eighties to optimize the material distribution of structures in order to minimize static compliance. Since then it has successfully been applied to a range of engineering fields such as mechanism design, fluid problems and photonic and phononic band-gap materials and structures [1,2]. In this project topology optimization is first applied to control acoustic properties in a room [3]. It is shown how the squared sound pressure amplitude in a certain part of a room can be minimized either by distribution of reflecting material in a design domain along the ceiling or by distribution of absorbing and reflecting material along all the walls for both 2D and 3D problems. It is also shown how the method can be used to design sound barriers. The main part of the project is concerned with simulation and optimization of surface acoustic wave (SAW) devices [4]. SAWs are for instance used in filters and resonators in mobile phones and to modulate light waves [5], and it is here essential to obtain waves with a high intensity, to direct the waves or to optimize the shape of the frequency response. To begin with, a 2D model of a Mach-Zehnder interferometer impacted by a SAW is considered and a parameter study of the geometry to get the biggest modulation of the light waves in the interferometer arms is performed. Then a 2D filter is modeled and optimized such that it reflects SAWs at certain frequencies or frequency ranges. To save computational time a 1.5D model will be developed, where an exponential decreasing waveform is introduced into the dept of the material, and the filter is then optimized based on this model. Later, the model will be extended to a 2.5D model in order to optimize more complicated SAW structures such as acoustic horns which focus the SAWs to a small area. [1] M. P. Bendsøe, O. Sigmund, “Topology optimization, theory, methods and applications”, Springer Verlag Berlin Heidelberg New York, 2nd edition, (2003). ISBN 3-540-42992-1. [2] J. S. Jensen and O. Sigmund, “Systematic design of photonic crystal structures using topology optimization: low-loss waveguide bends”, Applied Physics Letters, 84(12), 2022-2024 (2004) [3] M. B. Dühring, “Topology optimization for acoustic problems”, IUTAM Symposium on Topological Design Optimization of Structures, Machines and Materials, Status and Perspectives, Series: Solid Mechanics and Its Applications , Vol. 137, M.P. Bendsoe, N. OIhoff and O. Sigmund (Eds.), Springer (2006). ISBN: 1-4020-4729-0. [4] K.-Y. Hashimoto, **Surface acoustic wave devices in telecommunications modeling and simulation**, Springer, Berlin, (2000). ISBN 3-540-67232-X. [5] M. M. de Lima Jr and P. V. Santos, "Modulation of photonic structures by surface acoustic waves", Rep. Prog. Phys., 68 1639-1701 (2005)
Topology optimization for acoustic-structure interaction problems

We propose a gradient based topology optimization algorithm for acoustic-structure (vibro-acoustic) interaction problems without an explicit interfacing boundary representation. In acoustic-structure interaction problems, the pressure field and the displacement field are governed by the Helmholtz equation and the linear elasticity equation, respectively, and it is necessary that the governing equations should be properly evolved with respect to the design variables in the design domain. Moreover, all the boundary conditions obtained by computing surface coupling integrals should be properly imposed on subdomain interfaces evolving during the optimization process. In this paper, we propose to use a mixed finite element formulation with displacements and pressure as primary variables (u/p formulation) which eliminates the need for explicit boundary representation. In order to describe the Helmholtz equation and the linear elasticity equation, the mass density as well as the shear and bulk moduli are interpolated with the design variables. In this formulation, the coupled interface boundary conditions are automatically satisfied without having to compute surface coupling integrals. Two-dimensional acoustic-structure interaction problems are optimized to show the validity of the proposed method.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Yoon, G. H. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Pages: 355-364
Publication date: 2006

Host publication information
Title of host publication: IUTAM Symposium on Topological Design Optimization of Structures, Machines and Materials
Volume: Part 10
Place of publication: Netherlands
Publisher: Springer
ISBN (Print): 1-4020-4729-0

Series: Solid Mechanics and Its Applications
Volume: 137
ISSN: 0925-0042
Main Research Area: Technical/natural sciences
Conference: Topology optimization for acoustic-structure interaction problems, Lisbon, Portugal, 01/01/2006
Structure interaction, Harmonic loading, Dynamics, Acoustic, Mixed formulation, Coupled problems
DOIs:
10.1007/1-4020-4752-5_35
Source: orbit
Source-ID: 193811
Publication: Research - peer-review › Article in proceedings – Annual report year: 2006

Topology Optimization for Photonic Crystal Waveguide Intersection with Wide and Flat Bandwidths in Ultra-Fast All-Optical Switch (PC-SMZ)

Numerical and experimental studies on the photonic crystal waveguide intersection based on the topology optimization design method are reported and the effectiveness is shown by achieving high transmission spectra with low crosstalk for the straightforward beam-propagation line.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering, Department of Photonics Engineering, Center for Nanoteknologi, University of Tsukuba, Aarhus University, National Institute of Advanced Industrial Science and Technology
Publication date: 2006

Host publication information
Title of host publication: Proceedings European Conference on Optical Communication
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 193356
Publication: Research - peer-review › Article in proceedings – Annual report year: 2006

Topology optimization of 3D Stokes flow problems
The design of MEMS devices have benefitted from the topology optimization tool and complicated layout problems have been solved, see [1] for an overview. This research is aimed at micro fluidic devices known as micro-Total-Analysis-
Systems (muTAS) where the main physical phenomena originate from fluid mechanics. In future practice a muTAS could be used by doctors, engineers etc. as a hand held device with short reaction time that provides on-site analysis of a flowing substance such as blood, polluted water or similar. Borrvall and Petersson [2] paved the road for using the topology optimization tool for micro fluidic design problems by considering design of energy efficient devices subjected to Stokes flow. Several researchers have elaborated on [2], however, this research has focused on 2D fluid modelling which limits the practical impact of the computed designs. This limitation is caused by the finite size domain used in topology optimization problems which ensures that the velocity components couples, even for Stokes flow [3]. Physically Stokes flow is an exotic inertia free flow, which in practice complicates mixing by passive devices. Passive mixing devices are relevant particular at micro scales since they are easily manufacturable and maintenance free. Here we consider topology optimization of 3D Stokes flow problems which is a reasonable fluid model to use at small scales. The presentation elaborates on effects caused by 3D fluid modelling on the design. Numerical examples relevant for optimal micro fluidic mixer design are shown where the design is planar - compliant with micro fabrication techniques - and where the designs are 3D. In addition issues related to the parallel solution of the linear algebra problems are discussed. The implementation uses the commercial COMSOL multiphysics programme which is sufficiently flexible to provide semi--automated analytical sensitivities. 1. M. P. Bendsoe and O. Sigmund, "Topology Optimization - Theory, Methods and Applications", Springer Verlag, Berlin Heidelberg, 2003. 2. T. Borrvall and J. Petersson, "Topology optimization of fluids in Stokes flow", Int. J. Num. Meth. Fluids v. 41, p. 77-107, 2003. DOI:10.1002/fld.426 3 E. Lauga, A. D. Stroock, and H. A. Stone, "Three-dimensional flows in slowly varying planar geometries", Physics of fluids v. 16(8), p. 3051-3062, 2004. DOI: 10.1063/1.1760105

**General information**
State: Published
Organisations: Department of Mathematics, Solid Mechanics, Department of Mechanical Engineering
Authors: Gersborg-Hansen, A. (Intern), Sigmund, O. (Intern), Bendsøe, M. P. (Intern)
Publication date: 2006
Event: Abstract from World Congress on Computational Mechanics, Los Angeles, USA,
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 193817
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2006

**Topology optimization of heat conduction problems using the finite volume method**
This note addresses the use of the finite volume method (FVM) for topology optimization of a heat conduction problem. Issues pertaining to the proper choice of cost functions, sensitivity analysis and example test problems are used to illustrate the effect of applying the FVM as an analysis tool for design optimization. This involves an application of the FVM to problems with non-homogeneous material distributions and the arithmetic and harmonic averages have here been used to provide a unique value for the conductivity at element boundaries. It is observed that when using the harmonic average checkerboards do not form during the topology optimization process.

**General information**
State: Published
Organisations: Applied functional analysis, Department of Mathematics, Solid Mechanics, Department of Mechanical Engineering
Authors: Gersborg-Hansen, A. (Intern), Bendsøe, M. P. (Intern), Sigmund, O. (Intern)
Pages: 251-259
Publication date: 2006
Main Research Area: Technical/natural sciences

**Publication information**
Journal: Structural and Multidisciplinary Optimization
Volume: 31
Issue number: 4
ISSN (Print): 1615-147X
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.14
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 2.42
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Topology optimization of wave-propagation problems

Topology optimization is demonstrated as a useful tool for systematic design of wave-propagation problems. We illustrate the applicability of the method for optical, acoustic and elastic devices and structures.

General information

State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Jensen, J. S. (Intern), Sigmund, O. (Intern)
Number of pages: 608
Pages: 387-390
Publication date: 2006

Host publication information

Title of host publication: IUTAM Symposium on Topological Design Optimization of Structures, Machines and Materials: Status and Perspectives
Place of publication: Dordrecht, The Netherlands
Publisher: Springer
Editors: Bendsøe, M. P., Olhoff, N., Sigmund, O.
ISBN (Print): 1-4020-4729-0

Series: Solid Mechanics and Its Applications
Volume: 137
ISSN: 0925-0042
**Topology Optimized Photonic Wire Splitters**

Photonic wire splitters have been designed using topology optimization. The splitters have been fabricated in silicon-on-insulator material and display broadband low-loss 3dB splitting in a bandwidth larger than 100 nm.

**Towards Integrated Optics for Advanced Ultra-Fast All-Optical Signal Processing**

Several planar photonic crystal components topology-optimized for TE-polarized light, including 60º bends, Y-splitters, and 90º bends, have been characterized for the TM polarization. The experimental results are confirmed by finite-difference time-domain calculations. The surprising efficiency for TM-polarized light is found and paves the way for photonic crystal components suitable for both polarizations.
Implementing topology optimization using the finite volume method

General information
State: Published
Organisations: Department of Mathematics, Department of Mechanical Engineering
Authors: Bendsoe, M. P. (Intern), Gersborg-Hansen, A. (Intern), Sigmund, O. (Intern)
Publication date: 2005
Event: Abstract from International Workshop on "Direct and Inverse Field Computations in Mechanics", Linz, Austria.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 182938
Publication: Research - peer-review › Journal article – Annual report year: 2005

Inverse design of photonic crystals by topology optimization

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Halkjaer, S. (Intern), Sigmund, O. (Intern), Jensen, J. S. (Intern)
Pages: 895-905
Publication date: 2005
Main Research Area: Technical/natural sciences

Publication information
Journal: Zeitschrift fur Kristallographie
Volume: 220
Issue number: 9-10
ISSN (Print): 0044-2968
Ratings:
BFI (2017): BFI-level 1
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.097 SNIP 2.592 CiteScore 3.3
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.805 SNIP 1.232 CiteScore 2.11
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.591 SNIP 0.766 CiteScore 1.21
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.643 SNIP 0.804 CiteScore 1.25
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.611 SNIP 0.842 CiteScore 1.15
ISI indexed (2012): ISI indexed yes
Low-Loss Photonic Crystal Y-Splitter for TM Polarization

General information
State: Published
Organisations: Nanophotonics, Department of Photonics Engineering, Department of Mechanical Engineering, Aarhus University
Authors: Têtu, A. (Ekstern), Kristensen, M. (Ekstern), Frandsen, L. H. (Intern), Harpøth, A. (Intern), Borel, P. I. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Publication date: 2005
Event: Poster session presented at Photonic Crystals: Fundamentals to Devices, Sydney, Australia.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 184628
Publication: Research - peer-review › Journal article – Annual report year: 2005

Optimized planar photonic crystal waveguide 60° bend with more than 200 nm wide 1-dB transmission bandwidth

Topology optimization was used to design a planar photonic crystal waveguide 60° bend leading to a record-breaking transmission bandwidth of more than 200nm. The experimental results agree well with 3D finite-difference-time-domain simulations.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonics, Solid Mechanics, Department of Mechanical Engineering
Authors: Kristensen, M. (Intern), Borel, P. I. (Intern), Frandsen, L. H. (Intern), Harpøth, A. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Publication date: 2005
Systematic design of acoustic devices by topology optimization

We present a method to design acoustic devices with topology optimization. The general algorithm is exemplified by the design of a reflection chamber that minimizes the transmission of acoustic waves in a specified frequency range.

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Jensen, J. S. (Intern), Sigmund, O. (Intern)
Number of pages: 8
Publication date: 2005

The pressure load problem re-visited

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Clausen, P. M. (Ekstern), Sigmund, O. (Intern)
Pages: 153-158
Publication date: 2005

Topology design and fabrication of an efficient double 90° photonic crystal waveguide bend

We have designed and fabricated a novel 90° bend in a photonic crystal waveguide. The design was obtained using topology optimization and the fabricated waveguide displays a bend loss for transverse-electric-polarized light of less than 1 dB per bend in a 200-nm wavelength range.
Topology Optimised Broadband Photonic Crystal Y-Splitter

A planar photonic crystal waveguide Y-splitter that exhibits large-bandwidth low-loss 3 dB splitting for TE-polarised light has been fabricated in silicon-on-insulator material. The high performance is achieved by utilising topology optimisation to design the Y-junction and by using topology optimised low-loss 60° bends. The average excess loss of the entire component is found to be 0.44±0.29 dB for a 100 nm bandwidth, and the excess loss due to the Y-junction is found to be 0.34±0.30 dB in a 175 nm bandwidth.

General information

State: Published
Organisations: Department of Photonics Engineering, Solid Mechanics, Department of Mechanical Engineering
Authors: Borel, P. I. (Intern), Frandsen, L. H. (Intern), Harpøth, A. (Intern), Kristensen, M. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Pages: 69-71
Publication date: 2005
Main Research Area: Technical/natural sciences

Publication information

Journal: Electronics Letters
Volume: 41
Issue number: 2
ISSN (Print): 0013-5194
Ratings:
BFI (2017): BFI-level 1
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.442 SNIP 0.882 CiteScore 1.35
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.497 SNIP 1.011 CiteScore 1.31
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.522 SNIP 1.061 CiteScore 1.31
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.59 SNIP 1.155 CiteScore 1.45
ISI indexed (2013): ISI indexed yes
Topology Optimised Photonic Crystal 1x4 Waveguide Splitter

**General information**

**State:** Published  
**Organisations:** Nanophotonics, Department of Photonics Engineering, Solid Mechanics, Department of Mechanical Engineering  
**Authors:** Frandsen, L. H. (Intern), Harpøth, A. (Intern), Hede, K. K. (Ekstern), Kristensen, M. (Intern), Borel, P. I. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)  
**Publication date:** 2005  
**Event:** Poster session presented at 6th International Symposium on Photonic and Electromagnetic Crystal Structures, Aghia Pelagia, Greece.  
**Main Research Area:** Technical/natural sciences  
**Source-ID:** 156055  
**Publication:** Research - peer-review › Journal article – Annual report year: 2005
**Topology optimised planar photonic crystal building blocks**

A photonic crystal waveguide (PhCW) 1x4 splitter has been constructed from PhCW 60° bends and Y-splitters that have been designed individually by utilising topology optimisation. The splitter has been fabricated in a silicon-on-insulator material (Fig. 1) and exhibits a broadband splitting for the TE-polarisation with an average excess loss of 1.55±0.54 dB for a 110 nm bandwidth. The 1x4 splitter demonstrates that individual topology-optimised parts can be used as building blocks to realise high-performance nanophotonic circuits.


**General information**

State: Published
Organisations: Nanophotonics, Department of Photonics Engineering, Department of Mechanical Engineering
Authors: Frandsen, L. H. (Intern), Hede, K. K. (Ekstern), Borel, P. I. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Publication date: 2005
Main Research Area: Technical/natural sciences
Links:
Source: orbit
Source-ID: 184402
Publication: Research › Poster – Annual report year: 2005

**Topology optimised wavelength dependent splitters**

A photonic crystal wavelength dependent splitter has been constructed by utilising topology optimisation. The splitter has been fabricated in a silicon-on-insulator material (Fig. 1). The topology optimised wavelength dependent splitter demonstrates promising 3D FDTD simulation results. This complex photonic crystal structure is very sensitive against small fabrication variations from the expected topology optimised design. A wavelength dependent splitter is an important basic building block for high-performance nanophotonic circuits.


**General information**

State: Published
Organisations: Nanophotonics, Department of Photonics Engineering, Department of Mechanical Engineering
Authors: Hede, K. K. (Ekstern), Burgos Leon, J. (Ekstern), Frandsen, L. H. (Intern), Borel, P. I. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Publication date: 2005
Main Research Area: Technical/natural sciences
Links:
Source: orbit
Source-ID: 184408
Publication: Research › Poster – Annual report year: 2005

**Topology Optimization - broadening the areas of application**

This paper deals with recent developments of topology optimization techniques for application in some new types of design problems. The emphasis is on recent work of the Danish research groups at Aalborg University and at the Technical University of Denmark and focus is on the central role that the choice of objective functions and design parameterization plays for a successful extension of the material distribution approach to new design settings and to new types of physics models. The applications that will be outlined encompass design of laminated composite structures, design for pressure loads, design in fluids, design in acoustics, and design in photonics. A short outline of other design optimization activities is also given.

**General information**

State: Published
Organisations: Department of Mathematics, Department of Mechanical Engineering, Solid Mechanics
Authors: Bendsøe, M. P. (Intern), Lund, E. (Ekstern), Olhoff, N. (Ekstern), Sigmund, O. (Intern)
Pages: 7-35
Publication date: 2005
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Control and Cybernetics
Topology Optimization of Building Blocks for Photonic Integrated Circuits

Photonic integrated circuits are likely candidates as high speed replacements for the standard electrical integrated circuits of today. However, in order to obtain a satisfactorily performance many design problems that up until now have resulted in too high losses must be resolved. In this work we demonstrate how the method of topology optimization can be used to design a variety of high performance building blocks for the future circuits.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Jensen, J. S. (Intern), Sigmund, O. (Intern)
Number of pages: 10
Publication date: 2005
Topology optimization of Channel flow problems

This paper describes a topology design method for simple two-dimensional flow problems. We consider steady, incompressible laminar viscous flows at low to moderate Reynolds numbers. This makes the flow problem non-linear and hence a non-trivial extension of the work of [Borrvall & Petersson 2002]. Further, the inclusion of inertia effects significantly alters the physics, enabling solutions of new classes of optimization problems, such as velocity–driven switches, that are not addressed by the earlier method. Specifically, we determine optimal layouts of channel flows that extremize a cost function which measures either some local aspect of the velocity field or a global quantity, such as the rate of energy dissipation. We use the finite element method to model the flow, and we solve the optimization problem with a gradient-based math-programming algorithm that is driven by analytical sensitivities. Our target application is optimal layout design of channels in fluid network systems. Using concepts borrowed from topology optimization of compliant mechanisms in solid mechanics, we introduce a method for the synthesis of fluidic components, such as switches, diodes, etc.
Topology optimization of photonic crystal structures: a high-bandwidth low-loss T-junction waveguide

A T junction in a photonic crystal waveguide is designed with the topology-optimization method. The gradient-based optimization tool is used to modify the material distribution in the junction area so that the power transmission in the output ports is maximized. To obtain high transmission in a large frequency range, we use an active-set strategy by using a number of target frequencies that are updated repeatedly in the optimization procedure. We apply a continuation method based on artificial damping to avoid undesired local maxima and also introduce artificial damping in a penalization scheme to avoid nondiscrete properties in the design domain.
TOPOLOGY OPTIMIZATION OF TWO-DIMENSIONAL PHONONIC CRYSTALS WITH THREE MATERIAL PHASES

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern), Halkjær, S. (Intern), Jensen, J. S. (Intern)
Publication date: 2005

Host publication information
Title of host publication: Conference Proceedings
Volume: CD-ROM
Main Research Area: Technical/natural sciences
Conference: 8th U.S. National Congress on Computational Mechanics, Austin, Texas, 01/01/2005
Source: orbit

Original language: English
Source-ID: 184834
Publication: Research - peer-review » Journal article – Annual report year: 2005
Computational procedures for topology optimization of continuum problems using a material distribution method are typically based on the application of the finite element method (FEM) (see, e.g. [1]). In the present work we study a computational framework based on the finite volume method (FVM, see, e.g. [2]) in order to develop methods for topology design for applications where conservation laws are critical such that element--wise conservation in the discretized models has a high priority. This encompasses problems involving for example mass and heat transport. The work described in this presentation is focused on a prototype model for topology optimization of steady heat diffusion. This allows for a study of the basic ingredients in working with FVM methods when dealing with topology optimization problems. The FVM and FEM based formulations differ both in how one computes the design derivative of the system matrix $K$ and how one computes the discretized version of certain objective functions. Thus for a cost function for minimum dissipated energy (like minimum compliance for an elastic structure) one obtains an expression $c = u^\top \tilde{K} u$, where $\tilde{K}$ is different from $K$; in a FEM scheme these matrices are equal following the principle of virtual work. Using a staggered mesh and averaging procedures consistent with the FVM the checkerboard problem is eliminated. Two averages are compared to FE solutions, being the arithmetic and harmonic average with the latter being the well known Reuss lower bound. [1] Bendsøe, M.P.; Sigmund, O. 2004: Topology Optimization - Theory, Methods, and Applications. Berlin Heidelberg: Springer Verlag [2] Versteeg, H. K.; W. Malalasekera 1995: An introduction to Computational Fluid Dynamics: the Finite Volume Method. London: Longman Scientific & Technical
the basic ingredients in working with FVM methods when dealing with topology optimization problems. The FVM and FEM based formulations differ both in how one computes the design derivative of the system matrix $\mathbf{K}$ and in how one computes the discretized version of certain objective functions. Thus for a cost function for minimum dissipated energy (like minimum compliance for an elastic structure) one obtains an expression $c = \mathbf{u}^\top \tilde{\mathbf{K}} \mathbf{u}$, where $\tilde{\mathbf{K}}$ is different from $\mathbf{K}$; in a FEM scheme these matrices are equal following the principle of virtual work. Using a staggered mesh and averaging procedures consistent with the FVM the checkerboard problem is eliminated. Two averages are compared to FE solutions, being the arithmetic and harmonic average with the latter being the well known Reuss lower bound. [1] Bendsøe, MP and Sigmund, O 2004: Topology Optimization - Theory, Methods, and Applications. Berlin Heidelberg: Springer Verlag [2] Versteeg, HK and Malalasekera, W 1995: An introduction to Computational Fluid Dynamics: the Finite Volume Method. London: Longman Scientific Technical
Broadband photonic crystal waveguide 60° bend obtained utilizing topology optimization

Topology optimization has been used to design a 60° bend in a single-mode planar photonic crystal waveguide. The design has been realized in a silicon-on-insulator material and we demonstrate a record-breaking 200-nm transmission bandwidth with an average bend loss of 0.43±0.27 dB for the TE polarization. The experimental results agree well with 3D finite-difference-time-domain simulations.

General information
State: Published
Organisations: Nanophotonics, Department of Photonics Engineering, Solid Mechanics, Department of Mechanical Engineering
Authors: Frandsen, L. H. (Intern), Harpøth, A. (Intern), Borel, P. I. (Intern), Kristensen, M. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Design and fabrication of planar photonic crystals

General information
State: Published
Organisations: Department of Photonics Engineering, Department of Mechanical Engineering
Authors: Borel, P. I. (Intern), Frandsen, L. H. (Intern), Harpøth, A. (Intern), Kristensen, M. (Ekstern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Publication date: 2004
Event: Paper presented at PIPE Symposium, Århus, Denmark.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 129937
Publication: Research - peer-review › Journal article – Annual report year: 2004

We present examples of ultra-compact photonic crystal components realized in silicon-on-insulator material. We have fabricated several different types of photonic crystal waveguide components displaying high transmission features. This includes 60° and 120° bends, different types of couplers, and splitters. Recently, we have designed and fabricated components with more than 200 nm bandwidths. Design strategies to enhance the performance include systematic variation of design parameters using finite-difference time-domain simulations and inverse design methods such as topology optimization.

Design and Fabrication of SOI-based photonic crystal components

We present examples of ultra-compact photonic crystal components realized in silicon-on-insulator material. We have fabricated several different types of photonic crystal waveguide components displaying high transmission features. This includes 60° and 120° bends, different types of couplers, and splitters. Recently, we have designed and fabricated components with more than 200 nm bandwidths. Design strategies to enhance the performance include systematic variation of design parameters using finite-difference time-domain simulations and inverse design methods such as topology optimization.

Fabrication of topology optimized photonic crystal waveguide Z-bend displaying large bandwidth with very low bend loss

We have designed, simulated and fabricated a photonic crystal waveguide Z-bend, which displays a total bend loss of ~1dB per bend in a wavelength range of more than 200nm. The fabricated component performs in excellent agreement
with 3D finite-difference time-domain calculations.

Hinge-free topology optimization with embedded translation-invariant differentiable wavelet shrinkage
In topology optimization applications for the design of compliant mechanisms, the formation of hinges is typically encountered. Often such hinges are unphysical artifacts that appear due to the choice of discretization spaces for design and analysis. The objective of this work is to present a new method to find hinge-free designs using multiscale wavelet-based topology optimization formulation. The specific method developed in this work does not require refinement of the analysis model and it consists of a translation-invariant wavelet shrinkage method where a hinge-free condition is imposed in the multiscale design space. To embed the shrinkage method implicitly in the optimization formulation and thus facilitate sensitivity analysis, the shrinkage method is made differentiable by means of differentiable versions of logical operators. The validity of the present method is confirmed by solving typical two-dimensional compliant mechanism design problems.
Optimal design in nanophotonics

General information
State: Published
Organisations: Department of Photonics Engineering, DTU Danchip, Department of Mechanical Engineering
Authors: Kristensen, M. (Ekstern), Borel, P. I. (Intern), Frandsen, L. H. (Intern), Harpøth, A. (Intern), Lavrinenko, A. (Ekstern), Niemi, T. (Ekstern), Xing, P. (Ekstern), Shi, P. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Publication date: 2004
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 155839
Publication: Research - peer-review › Journal article – Annual report year: 2004

Optimal Shape Design and Modeling

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Lewinski, T. (Ekstern), Sigmund, O. (Intern), Sokolowski, J. (Ekstern), Zochowski, A. (Ekstern)
Publication date: 2004

Host publication information
Title of host publication: Optimal Shape Design and Modeling
Place of publication: Systems Research Institute of the Polish Academy of Sciences, Warszawa
Publisher: Akademicka Oficyna Wydawnicza EXIT
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 155615
Publication: Research - peer-review › Book chapter – Annual report year: 2004
Optimization of Beam Properties with Respect to Maximum Band-Gap
We study numerically the frequency band-gap phenomenon for bending waves in an infinite periodic beam. The outcome of the analysis is then subjected to an optimization problem in order to maximize these band-gaps. The band-gap maximization may be performed with respect to material parameters and cross-sectional geometry.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Halkjær, S. (Intern), Sigmund, O. (Intern)
Publication date: 2004

Host publication information
Title of host publication: Proceedings of 21st International Congress of Theoretical and Applied Mechanics
Editors: Gutkowski, W., Kowalewski, T.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 155794
Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

Planar articulated mechanism design by graph theoretical enumeration
This paper deals with design of articulated mechanisms using a truss-based ground-structure representation. By applying a graph theoretical enumeration approach we can perform an exhaustive analysis of all possible topologies for a test example for which we seek a symmetric mechanism. This guarantees that one can identify the global optimum solution. The result underlines the importance of mechanism topology and gives insight into the issues specific to articulated mechanism designs compared to compliant mechanism designs.

General information
State: Published
Organisations: Department of Mathematics, Solid Mechanics, Department of Mechanical Engineering
Authors: Kawamoto, A. (Ekstern), Bendsøe, M. P. (Intern), Sigmund, O. (Intern)
Pages: 295-299
Publication date: 2004
Main Research Area: Technical/natural sciences

Publication information
Journal: Structural and Multidisciplinary Optimization
Volume: 27
Issue number: 4
ISSN (Print): 1615-147X
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.14
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 2.42
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 2.77
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.08
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Systematic design of photonic crystal structures using topology optimization: Low-loss waveguide bends

Topology optimization is a promising method for systematic design of optical devices. As an example, we demonstrate how the method can be used to design a 90 degrees bend in a two-dimensional photonic crystal waveguide with a transmission loss of less than 0.3% in almost the entire frequency range of the guided mode. The method can directly be applied to the design of other optical devices, e.g., multiplexers and wave splitters, with optimized performance. (C) 2004 American Institute of Physics.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Jensen, J. S. (Intern), Sigmund, O. (Intern)
Pages: 2022-2024
Publication date: 2004
Main Research Area: Technical/natural sciences

Publication information
Volume: 84
Issue number: 12
ISSN (Print): 0003-6951
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.67 SJR 1.132 SNIP 0.996
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.085 SNIP 0.983 CiteScore 2.47
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.799 SNIP 1.462 CiteScore 3.25
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Topology optimization and fabrication of photonic crystal structures

Topology optimization is used to design a planar photonic crystal waveguide component resulting in significantly enhanced functionality. Exceptional transmission through a photonic crystal waveguide Z-bend is obtained using this inverse design strategy. The design has been realized in a silicon-on-insulator based photonic crystal waveguide. A large low loss...
bandwidth of more than 200 nm for the TE polarization is experimentally confirmed.

**General information**
- State: Published
- Organisations: Department of Photonics Engineering, Nanophotonic Devices, Department of Micro- and Nanotechnology, Solid Mechanics, Department of Mechanical Engineering
- Authors: Borel, P. I. (Intern), Harpøth, A. (Intern), Frandsen, L. H. (Intern), Kristensen, M. (Intern), Shi, P. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
- Pages: 1996-2001
- Publication date: 2004
- Main Research Area: Technical/natural sciences

**Publication information**
- Journal: Optics Express
- Volume: 12
- Issue number: 9
- ISSN (Print): 1094-4087
- Ratings:
  - BFI (2017): BFI-level 2
  - Web of Science (2017): Indexed yes
  - BFI (2016): BFI-level 2
  - Scopus rating (2016): CiteScore 3.48 SJR 1.487 SNIP 1.589
  - Web of Science (2016): Indexed yes
  - BFI (2015): BFI-level 2
  - Scopus rating (2015): SJR 1.976 SNIP 1.755 CiteScore 3.78
  - Web of Science (2015): Indexed yes
  - BFI (2014): BFI-level 2
  - Scopus rating (2014): SJR 2.349 SNIP 2.166 CiteScore 4.18
  - Web of Science (2014): Indexed yes
  - BFI (2013): BFI-level 2
  - Scopus rating (2013): SJR 2.358 SNIP 2.226 CiteScore 4.38
  - ISI indexed (2013): ISI indexed yes
  - Web of Science (2013): Indexed yes
  - BFI (2012): BFI-level 2
  - Scopus rating (2012): SJR 2.587 SNIP 2.145 CiteScore 3.85
  - ISI indexed (2012): ISI indexed yes
  - Web of Science (2012): Indexed yes
  - BFI (2011): BFI-level 2
  - Scopus rating (2011): SJR 2.579 SNIP 2.606 CiteScore 4.04
  - ISI indexed (2011): ISI indexed yes
  - Web of Science (2011): Indexed yes
  - BFI (2010): BFI-level 2
  - Scopus rating (2010): SJR 2.943 SNIP 2.466
  - Web of Science (2010): Indexed yes
  - BFI (2009): BFI-level 2
  - Scopus rating (2009): SJR 3.092 SNIP 2.669
  - Web of Science (2009): Indexed yes
  - BFI (2008): BFI-level 2
  - Scopus rating (2008): SJR 3.195 SNIP 2.393
  - Web of Science (2008): Indexed yes
  - Scopus rating (2007): SJR 3.27 SNIP 2.032
  - Web of Science (2007): Indexed yes
  - Web of Science (2006): Indexed yes
  - Scopus rating (2005): SJR 3.334 SNIP 2.379
  - Web of Science (2005): Indexed yes
  - Scopus rating (2004): SJR 2.833 SNIP 2.499
Topology optimization: a systematic method to improve the performance of photonic crystal structures

The method of topology optimization has previously been used to design exotic materials, MEMS and thermo-elastic mechanisms, as well as several other devices in mechanics and multi-physics applications [1]. Recently, the method was applied to design photonic and phononic crystals with maximum size band gaps [2,3]. In [3] the optimization of phononic crystal structures was considered also, with examples demonstrating the possibility for designing wave-reflecting and wave-guiding structures with optimized performance.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Jensen, J. S. (Intern), Sigmund, O. (Intern)
Number of pages: 112
Publication date: 2004

Host publication information
Title of host publication: International Symposium on Photonic and Electromagnetic Crystal Structures PECS-V
Place of publication: Kyoto
Publisher: Kyoto University
Editor: Noda, S.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 155843
Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

Topology optimization: from airplanes to nanooptics

General information
State: Published
Organisations: Department of Mechanical Engineering, Department of Mathematics
Authors: Sigmund, O. (Intern), Bendsøe, M. P. (Intern)
Pages: 40-51
Publication date: 2004

Host publication information
Title of host publication: BRIDGING from technology to society : DTU 1829-2004 - 175 år
Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark (DTU)
Editors: Stubkjær, K., Kortenbach, T.
ISBN (Print): 87-990378-0-7
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 116797
Publication: Communication › Book chapter – Annual report year: 2004
Topology Optimization in wave-propagation and flow problems
We discuss recent extensions of the topology optimization method to wave-propagation and flow problems. More specifically, we optimize material distribution in scalar wave propagation problems modelled by Helmholtz equation. Moreover, we investigate the influence of the inertia term on the optimal flow topology for fluid flow problems with moderate Reynolds numbers.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern), Jensen, J. S. (Intern), Gersborg-Hansen, A. (Ekstern), Haber, R. (Ekstern)
Pages: 45-54
Publication date: 2004

Host publication information
Title of host publication: Warsaw International Seminar on Design and Optimal Modelling WISDOM 2004
Place of publication: Warsaw
Editors: Lewiński, T., Sigmund, O., Sokołowski, J., Żochowski, A.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 155844
Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

Topology optimization of multiple physics problems modelled by Poisson's equation

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Donoso, A. (Ekstern), Sigmund, O. (Intern)
Pages: 169-189
Publication date: 2004
Main Research Area: Technical/natural sciences

Publication information
Journal: Latin American Journal of Solids and Structures
Volume: 1
Issue number: 2
ISSN (Print): 1679-7817
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.459 SNIP 0.788 CiteScore 1.11
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.389 SNIP 0.753 CiteScore 0.98
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.568 SNIP 1.128 CiteScore 1.45
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.411 SNIP 1.042 CiteScore 1.12
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.569 SNIP 1.034 CiteScore 1.2
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.267 SNIP 0.747 CiteScore 0.49
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.207 SNIP 0.439
BFI (2009): BFI-level 1
Topology optimized photonic crystal Z-bent waveguide

General information
State: Published
Organisations: Department of Photonics Engineering, DTU Danchip, Department of Mechanical Engineering
Authors: Borel, P. I. (Intern), Harpøth, A. (Intern), Frandsen, L. H. (Intern), Kristensen, M. (Ekstern), Shi, P. (Intern), Jensen, J. S. (Intern), Sigmund, O. (Intern)
Publication date: 2004
Event: Poster session presented at DTU International Nanosymposium, Kgs. Lyngby, Denmark,
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 155942
Publication: Research - peer-review › Journal article – Annual report year: 2004

Toward the topology design of mechanisms that exhibit snap-through behavior

Topology optimization has proven to be a powerful method for the conceptual design of structures and mechanisms. In previously published work, we concentrated on the development of numerical methods that accommodate the finite deformation and incorporated these analyses into the topology optimization. We demonstrated by relatively straightforward transversely loaded clamped-clamped beam examples that topology optimization can be used to design structures that experience snap-through behavior. Here, we focus our attention on the design problem formulation where the goal is to develop a general approach for the design of mechanisms that experience more complex snap-through behavior. A multiphase design strategy is outlined, numerous significant challenges to this complex design process are discussed, and several examples are presented that demonstrate progress toward this goal. (C) 2004 Elsevier B.V. All rights reserved.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Burns, T. E. (Ekstern), Sigmund, O. (Intern)
Pages: 3973-4000
Publication date: 2004
Main Research Area: Technical/natural sciences

Publication information
Journal: Computer Methods in Applied Mechanics and Engineering
Volume: 193
Issue number: 36-38
ISSN (Print): 0045-7825
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.31 SJR 2.743 SNIP 1.962
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.823 SNIP 2.126 CiteScore 3.91
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.418 SNIP 2.087 CiteScore 3.41
Articulated Mechanism Design – Introduction of DOF Constraints

**General information**

State: Published

Organisations: Department of Mathematics, Department of Mechanical Engineering

Authors: Kawamoto, A. (Intern), Bendsøe, M. P. (Intern), Sigmund, O. (Intern)

Pages: 131-132

Publication date: 2003

**Host publication information**

Title of host publication: Proc. 5th World Congress of Structural and Multidisciplinary Optimization

Place of publication: Milano

Publisher: Italian Polytechnic Press

Editors: Cinquini, C., Rovati, M., Venini, P., Nascimbene, R.

Main Research Area: Technical/natural sciences
**Aspects of the design of microstructures by computational means**

**General information**
State: Published
Organisations: Department of Mathematics, Solid Mechanics, Department of Mechanical Engineering
Authors: Bendsøe, M. P. (Intern), Guedes, J. (Ekstern), Neves, M. M. (Ekstern), Rodrigues, H. (Ekstern), Sigmund, O. (Intern), Carbone, L. (ed.) (Ekstern), De Arcangelis, R. (ed.) (Ekstern)
Pages: 99-112
Publication date: 2003

**Host publication information**
Title of host publication: The First HMS2000 International School and Conference on Homogenization
Place of publication: Gakkotosho, Tokyo
Publisher: GAKUTO Int. Series in Math. Sci, Appl.
Editors: Carbone, L., De Arcangelis, R.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 25588
Publication: Research - peer-review › Article in proceedings – Annual report year: 2003

**Design of acoustic devices by topology optimization**
The goal of this study is to design and optimize structures and devices that are subjected to acoustic waves. Examples are acoustic lenses, sound walls, waveguides and loud speakers. We formulate the design problem as a topology optimization problem, i.e. distribute material in a design domain such that the acoustic response is optimized.

**General information**
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern), Jensen, J. S. (Intern)
Pages: 267-268
Publication date: 2003

**Host publication information**
Title of host publication: Short papers of the fifth world congress of structural and multidisciplinary optimization (WCSMO5)
Place of publication: Milano
Publisher: Italian Polytechnic Press
Main Research Area: Technical/natural sciences
Conference: 5th World Congress of Structural and Multidisciplinary Optimization, Lido de Jesolo, Italy, 19/05/2003 - 19/05/2003
Source: orbit
Source-ID: 25637
Publication: Research - peer-review › Article in proceedings – Annual report year: 2003

**Phononic band gap structures as optimal designs**
In this paper we use topology optimization to design phononic band gap structures. We consider 2D structures subjected to periodic loading and obtain the distribution of two materials with high contrast in material properties that gives the minimal vibrational response of the structure. Both in-plane and out-of-plane vibrations are considered.

**General information**
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Jensen, J. S. (Intern), Sigmund, O. (Intern), Movchan, A. B. (ed.) (Ekstern)
Pages: 71-81
Publication date: 2003

**Host publication information**
Systematic design of periodic micro mechanisms: Extremal material design by topology optimization

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
Publication date: 2003

Publication information
Publisher: Kluwer
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 25581
Publication: Research › Book – Annual report year: 2003

Systematic design of microstructures by topology optimization

The topology optimization method can be used to determine the material distribution in a design domain such that an objective function is maximized and constraints are fulfilled. The method which is based on Finite Element Analysis may be applied to all kinds of material distribution problems like extremal material design, sensor and actuator design and MEMS synthesis. The state-of-the-art in topology optimization will be reviewed and older as well as new applications in phononic and photonic crystals design will be presented.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
Publication date: 2003

Host publication information
Title of host publication: Symposium on Design, Test, Integration and Packaging of MEMS/MOEMS 2003.
Volume: 2
Publisher: IEEE
ISBN (Print): 0-7803-7066-X
Main Research Area: Technical/natural sciences
Conference: Symposium on Design, Test, Integration and Packaging of MEMS/MOEMS, 01/01/2003
Electronic versions:
Sigmund.pdf
DOIs: 10.1109/DTIP.2003.1286997

Bibliographical note
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Source: orbit
Source-ID: 258680
Publication: Research - peer-review › Article in proceedings – Annual report year: 2003

Systematic design of phononic band-gap materials and structures by topology optimization

Phononic band-gap materials prevent elastic waves in certain frequency ranges from propagating, and they may therefore be used to generate frequency filters, as beam splitters, as sound or vibration protection devices, or as waveguides. In this work we show how topology optimization can be used to design and optimize periodic materials and structures exhibiting phononic band gaps. Firstly, we optimize infinitely periodic band-gap materials by maximizing the relative size of the band gaps. Then, finite structures subjected to periodic loading are optimized in order to either minimize the structural response.
along boundaries (wave damping) or maximize the response at certain boundary locations (waveguiding).

**General information**

State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern), Jensen, J. S. (Intern)
Pages: 1001-1019
Publication date: 2003
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Philosophical Transactions of the Royal Society London, Series A (Mathematical, Physical and Engineering Sciences)
Volume: 361
ISSN (Print): 1364-503X
Ratings:

BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.26 SJR 0.874 SNIP 1.024
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 0.78 SNIP 0.985 CiteScore 2.08
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 0.847 SNIP 1.256 CiteScore 2.39
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.12 SNIP 1.534 CiteScore 3.12
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.068 SNIP 1.387 CiteScore 2.89
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.964 SNIP 1.297 CiteScore 2.65
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.095 SNIP 1.365
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.068 SNIP 1.309
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.867 SNIP 1.016
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.683 SNIP 0.685
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.856 SNIP 0.888
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.843 SNIP 0.824
Scopus rating (2004): SJR 0.651 SNIP 0.834
Scopus rating (2003): SJR 0.527 SNIP 0.765
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.368 SNIP 0.631
Scopus rating (2001): SJR 0.296 SNIP 0.4
Scopus rating (2000): SJR 0.315 SNIP 0.393
Scopus rating (1999): SJR 0.436 SNIP 0.297
Original language: English
Source: orbit
Source-ID: 25553
Topology optimization for multiphysics problems: A future FEMLAB application?

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern), Gersborg-Hansen, A. (Intern), Haber, R. (Ekstern)
Pages: 237-242
Publication date: 2003

Host publication information
Title of host publication: Nordic Matlab Conference (NMC2003)
Place of publication: Søborg, Denmark
Publisher: COMSOL A/S
Main Research Area: Technical/natural sciences
Conference: Nordic MATLAB Conference, Copenhagen, Denmark, 21/10/2003 - 21/10/2003
Source: orbit
Source-ID: 25691
Publication: Research - peer-review › Article in proceedings – Annual report year: 2003

Topology optimization of structures or periodic solids with linearized elastic buckling criterion

General information
State: Published
Organisations: Department of Mathematics, Department of Mechanical Engineering
Authors: Neves, M. (Ekstern), Rodrigues, H. (Ekstern), Guedes, J. (Ekstern), Bendsøe, M. P. (Intern), Sigmund, O. (Intern)
Publication date: 2003
Event: Abstract from Seventh US National Congress on Computational Mechanics, Albuquerque, New Mexico
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 28347
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2003

Topology optimization of two-dimensional waveguides
In this work we use the method of topology optimization to design two-dimensional waveguides with low transmission loss.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Jensen, J. S. (Intern), Sigmund, O. (Intern)
Pages: 125-126
Publication date: 2003

Host publication information
Title of host publication: Short papers of the fifth world congress of structural and multidisciplinary optimization (WCSMO5)
Place of publication: Milano
Publisher: Italian Polytechnic Press
Main Research Area: Technical/natural sciences
Conference: 5th World Congress of Structural and Multidisciplinary Optimization, Lido de Jesolo, Italy, 19/05/2003 - 19/05/2003
Source: orbit
Source-ID: 25692
Publication: Research - peer-review › Article in proceedings – Annual report year: 2003

Topology Optimization - Theory, Methods, and Applications

General information
State: Published
Organisations: Department of Mathematics, Department of Mechanical Engineering
Authors: Bendsøe, M. P. (Intern), Sigmund, O. (Intern)
Publication date: 2003
Articulated Mechanism Design by an Enumeration Approach

General information
State: Published
Organisations: Department of Mathematics, Department of Mechanical Engineering
Authors: Kawamoto, A. (Ekstern), Bendsøe, M. P. (Intern), Sigmund, O. (Intern)
Pages: 59-62
Publication date: 2002

Host publication information
Title of host publication: Proc. 15th Nordic Seminar on Computational Mechanics
Place of publication: Aalborg, Denmark
Publisher: Aalborg University
Editors: Lund, E., Olhoff, N., Stegmann, J.
Main Research Area: Technical/natural sciences
Conference: 15th Nordic Seminar on Computational Mechanics, Aalborg, Denmark, 18/10/2002 - 18/10/2002
Source: orbit
Source-ID: 46376
Publication: Research - peer-review › Article in proceedings – Annual report year: 2002

Design of multi-phase structures with optimized vibrational and wave-transmitting properties

General information
State: Published
Organisations: Department of Mechanical Engineering, Department of Mathematics
Authors: Jensen, J. S. (Intern), Sigmund, O. (Intern), Thomsen, J. J. (Intern), Bendsøe, M. P. (Intern)
Publication date: 2002

Host publication information
Title of host publication: Proc. 15th Nordic Seminar on Computational Mechanics
Place of publication: Aalborg, Denmark
Publisher: Aalborg University
Editors: Lund, E., Olhoff, N., Stegmann, J.
Main Research Area: Technical/natural sciences
Conference: 15th Nordic Seminar on Computational Mechanics, Aalborg, Denmark, 18/10/2002 - 18/10/2002
Source: orbit
Source-ID: 46377
Publication: Research - peer-review › Article in proceedings – Annual report year: 2002

Material design by topology optimization

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
Publication date: 2002

Host publication information
Title of host publication: Proceedings of Plasticity ’02: Plasticity, Damage and Fracture at Macro, Micro and Nano Scales
Place of publication: Maryland, USA
Publisher: NEAT Press
Main Research Area: Technical/natural sciences
Conference: Plasticity, Damage and Fracture at Macro, Micro and Nano Scales, Fulton, MD, 03/01/2002 - 03/01/2002
Source: orbit
Topology optimization of elastic band gap structures and waveguides

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern), Jensen, J. S. (Intern)
Publication date: 2002

Host publication information
Title of host publication: Proceedings of the Fifth World Congress on Computational Mechanics
Place of publication: Austria
Publisher: Vienna University of Technology
Main Research Area: Technical/natural sciences
Conference: 5th World Congress on Computational Mechanics, Vienna, Austria, 07/06/2002 - 07/06/2002
Source: orbit
Source-ID: 62624
Publication: Research › Article in proceedings – Annual report year: 2002

Topology optimization of periodic microstructures with a buckling criteria

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Neves, M. M. (Ekstern), Sigmund, O. (Intern), Bendsoe, M. P. (Ekstern)
Publication date: 2002

Host publication information
Title of host publication: Proceedings of the Fifth World Congress on Computational Mechanics
Place of publication: Austria
Publisher: Vienna University of Technology
Main Research Area: Technical/natural sciences
Conference: 5th World Congress on Computational Mechanics, Vienna, Austria, 07/06/2002 - 07/06/2002
Source: orbit
Source-ID: 62625
Publication: Research › Article in proceedings – Annual report year: 2002

Topology Optimization of Periodic Microstructures with a Penalization of Highly Localized Buckling Modes
The problem of determining highly localized buckling modes in perfectly periodic cellular microstructures of infinite extent is addressed. A double scale asymptotic technique is applied to the linearized stability problem for a periodic structure built from linearly elastic microstructures. The obtained stability condition for the microscale level is then used to establish a comparative analysis between different material distributions in the base cell subjected to the same strain field at the macroscale level. The idea is illustrated by some two-dimensional finite element examples and used to design materials with optimal elastic properties that are less prone to localized instability in the form of local buckling modes at the scale of the micro structure. Copyright (C) 2002 John Wiley Sons, Ltd.

General information
State: Published
Organisations: Department of Mechanical Engineering, Department of Mathematics, Instituto Superior Técnico
Authors: Neves, M. M. (Ekstern), Sigmund, O. (Intern), Bendsoe, M. P. (Intern)
Pages: 809-834
Publication date: 2002
Main Research Area: Technical/natural sciences

Publication information
Volume: 54
Issue number: 6
ISSN (Print): 0029-5981
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.64 SJR 1.743 SNIP 1.566
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.912 SNIP 1.689 CiteScore 2.67
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.935 SNIP 1.927 CiteScore 2.73
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.415 SNIP 1.894 CiteScore 2.8
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.47 SNIP 2.103 CiteScore 2.7
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.193 SNIP 1.935 CiteScore 2.47
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.177 SNIP 1.717
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.983 SNIP 1.601
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.122 SNIP 1.74
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.023 SNIP 1.775
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.678 SNIP 1.823
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.085 SNIP 1.545
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.002 SNIP 1.846
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 3.369 SNIP 1.956
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 2.739 SNIP 1.698
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 2.197 SNIP 1.777
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 2.142 SNIP 1.764
Scopus rating (1999): SJR 2.778 SNIP 1.96
Original language: English
Topologies optimization, Periodic microstructures, Linearized elastic buckling, Homogenization
DOIs:
10.1002/nme.449
Source: orbit
A web-based topology optimization program

**General information**

State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Tcherniak, D. M. (Ekstern), Sigmund, O. (Intern)
Pages: 179-187
Publication date: 2001
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Structural and Multidisciplinary Optimization
Volume: 22
Issue number: 3
ISSN (Print): 1615-147X
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.14
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 2.42
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 2.77
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
COMPACT A THERMAL OPTICAL WAVEGUIDE USING THERMAL EXPANSION AMPLIFICATION

A method of temperature stabilising optical waveguides having positive thermal optical path length expansion, in particular fiber Bragg gratings or optical fiber DFB lasers or optical fiber DBR lasers, comprising affixing the optical waveguide to at least two points of a negative expanding fixture; said negative expanding fixture comprising one or two V-shaped displacement amplifiers made from a material with a higher positive CTE mounted in a frame made of a material with lower positive CTE; the V-shaped displacement amplifier is mounted on a support in such a manner that its motion in directions substantially perpendicular to the axis of the mounted fiber device is restrained by the support and transferred to (amplified) displacement along the fiber axis.

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering, Department of Micro- and Nanotechnology
Authors: Sigmund, O. (Intern), Beukema, M. A. (Intern), Pedersen, J. E. (Intern)
Publication date: 2001

Design of multiphysics actuators using topology optimization - Part I: One-material structures

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
Design of multiphysics actuators using topology optimization - Part II: Two-material structures

This is the second part of a two-paper description of the topology optimization method applied to the design of multiphysics actuators and electrothermomechanical systems in particular. The first paper is focussed on one-material structures, the second on two-material structures. The extensions of the topology optimization method in this part include design descriptions for two-material structures, constitutive modelling of elements with mixtures of two materials, formulation of optimization problems with multiple constraints and multiple materials and a mesh-independency scheme for two-material structures. The application in mind is the design of thermally and electro thermally driven micro actuators for use in MicroElectroMechanical Systems (MEMS). MEMS are microscopic mechanical systems coupled with electrical circuits. MEMS are fabricated using techniques known from the semi-conductor industry. Several of the examples from Part I are repeated, allowing for the introduction of a second material in the design domain. The second material can differ in mechanical properties such as Young's modulus or electrical and thermal conductivity. In some cases there are significant gains in introducing a second material. However, the gains depend on boundary conditions and relations between the material properties and are in many cases insignificant. (C) 2001 Elsevier Science B.V. All rights reserved.
Microstructural design of elastic band gap structures

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
Publication date: 2001

Host publication information
Title of host publication: Proceedings of the Fourth World Congress of Structural and Multidisciplinary Optimization
Publisher: Liaoning Electronic Press
Main Research Area: Technical/natural sciences
Conference: 4th World Congress of Structural and Multidisciplinary Optimization, Dalian, China, 04/06/2001 - 04/06/2001
Source: orbit
Source-ID: 64209
Publication: Research - peer-review › Article in proceedings – Annual report year: 2001

Optimal Topology Design of Microstructures with a Constraint on Local Buckling Behaviour

General information
State: Published
Organisations: Department of Mathematics, Department of Mechanical Engineering, Instituto Superior Técnico
Authors: Bendsøe, M. P. (Intern), Neves, M. M. (Ekstern), Sigmund, O. (Intern)
Pages: 53-56
Publication date: 2001

Host publication information
Place of publication: Lund, Sweden
Publisher: Structural Mechanics, LTH
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 46367
Publication: Research - peer-review › Article in proceedings – Annual report year: 2001
Optimization of integrated magnetic field sensors

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Lieneman, J. (Ekstern), Greiner, A. (Ekstern), Korvink, J. G. (Ekstern), Sigmund, O. (Intern)
Publication date: 2001

Host publication information
Title of host publication: Proceedings of MSM2001
Place of publication: Cambridge, MA, USA
Publisher: ACRS Publishing
Main Research Area: Technical/natural sciences
Conference: 4th International Conference on Modeling and Simulation of Microsystems, Hilton Head Island, SC, United States, 19/03/2001 - 19/03/2001
Source: orbit
Source-ID: 64168
Publication: Research - peer-review › Article in proceedings – Annual report year: 2001

Optimum design of MicroElectroMechanical systems

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
Publication date: 2001

Host publication information
Title of host publication: Proceedings of the 20th International Congress of Theoretical and Applied Mechanics
Place of publication: Mechanics for a New Millennium
Publisher: Kluwer Academic Publishers
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 64173
Publication: Research - peer-review › Article in proceedings – Annual report year: 2001

Recent developments in extremal material design

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
Publication date: 2001

Host publication information
Title of host publication: Proceedings of Trends in Computational Mechanics
Publisher: CIMNE
Main Research Area: Technical/natural sciences
Conference: EUROMECH 522 Colloquium, Erlangen, Germany, 10/10/2011 - 10/10/2011
Source: orbit
Source-ID: 64162
Publication: Research - peer-review › Article in proceedings – Annual report year: 2001

Topology design of bistable mechanisms

General information
State: Published
Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Bruns, T. E. (Intern), Sigmund, O. (Intern)
Publication date: 2001
Topology optimization methods with applications in mechanism, MEMS and material design

General information
State: Published
Organisations: Solid Mechanics, Department of Mechanical Engineering
Authors: Sigmund, O. (Intern)
Publication date: 2001

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 64054
Publication: Research › Doctoral thesis – Annual report year: 2001

Topology Optimization of Periodic Materials with Buckling Constraint

General information
State: Published
Organisations: Department of Mechanical Engineering, Department of Mathematics, Instituto Superior Técnico
Authors: Neves, M. M. (Ekstern), Sigmund, O. (Intern), Bendsøe, M. P. (Intern)
Pages: 40-43
Publication date: 2001

Host publication information
Title of host publication: Proceedings of the 2nd Max Planck Workshop on Engineering Design Optimization : Hotel Nyborg Strand, Nyborg, Denmark, October 12-14, 2001
Place of publication: DK-2800 Lyngby
Publisher: Department of Mathematics, Technical University of Denmark
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 46366
Publication: Research › Article in proceedings – Annual report year: 2001

Topology Optimization of Periodic Microstructures with a Penalization of Highly Localized Buckling Modes

General information
State: Published
Organisations: Department of Mathematics, Department of Mechanical Engineering, Instituto Superior Técnico
Authors: Bendsøe, M. P. (Intern), Neves, M. M. (Ekstern), Sigmund, O. (Intern)
Publication date: 2001
Event: Abstract from Conference on mathematical and engineering aspects of optimal design of materials and structures, Poznan University of Technology, Poland,.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 46370
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2001

Topology synthesis of large-displacement compliant mechanisms
This paper describes the use of topology optimization as a synthesis tool for the design of large-displacement compliant mechanisms. An objective function for the synthesis of large-displacement mechanisms is proposed together with a formulation for synthesis of path-generating compliant mechanisms. The responses of the compliant mechanisms are modelled using a total Lagrangian finite element formulation, the sensitivity analysis is performed using the adjoint method and the optimization problem is solved using the method of moving asymptotes. Procedures to circumvent some numerical problems are discussed. Copyright (C) 2001 John Wiley & Sons, Ltd.
A new Class of Extremal Composites

The paper presents a new class of two-phase isotropic composites with extremal bulk modulus. The new class consists of micro geometrics for which exact solutions can be proven and their bulk moduli are shown to coincide with the Hashin-Shtrikman bounds. The results hold for two and three dimensions and for both well- and non-well-ordered isotropic constituent phases. The new class of composites constitutes an alternative to the three previously known extremal composite classes: finite rank laminates, composite sphere assemblages and Vigdergauz microstructures. An isotropic honeycomb-like hexagonal microstructure belonging to the new class of composites has maximum bulk modulus and lower shear modulus than any previously known composite.

Inspiration for the new composite class comes from a numerical topology design procedure which solves the inverse homogenization problem of distributing two isotropic material phases in a periodic isotropic material structure such that the effective properties are extremized. (C) 2000 Elsevier Science Ltd. All rights reserved.
A Buckling Performance Index for Topology Design of Periodic Microstructures

**General information**

State: Published
Organisations: Department of Mathematics
Authors: Neves, M. M. (Ekstern), Sigmund, O. (Intern), Bendsøe, M. P. (Intern)
Publication date: 2000

**Host publication information**

Title of host publication: Proc. ECCOMAS 2000
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 177238
Publication: Research - peer-review › Article in proceedings – Annual report year: 2000

**Multiphase composites with extremal bulk modulus**

This paper is devoted to the analytical and numerical study of isotropic elastic composites made of three or more isotropic phases. The ranges of their effective bulk and shear moduli are restricted by the Hashin-Shtrikman-Walpole (HSW) bounds. For two-phase composites, these bounds are attainable, that is, there exist composites with extreme bulk and shear moduli. For multiphase composites, they may or may not be attainable depending on phase moduli and volume fractions. Sufficient conditions of attainability of the bounds and various previously known and new types of optimal composites are described. Most of our new results are related to the two-dimensional problem. A numerical topology optimization procedure that solves the inverse homogenization problem is adopted and used to look for two-dimensional
three-phase composites with a maximal effective bulk modulus. For the combination of parameters where the HSW bound is known to be attainable, new microstructures are found numerically that possess bulk moduli close to the bound. Moreover, new types of microstructures with bulk moduli close to the bound are found numerically for the situations where the aforementioned attainability conditions are not met. Based on the numerical results, several new types of structures that possess extremal bulk modulus are suggested and studied analytically. The bulk moduli of the new structures are either equal to the HSW bound or higher than the bulk modulus of any other known composite with the same phase moduli and volume fractions. It is proved that the HSW bound is attainable in a much wider range than it was previously believed. Results are readily applied to two-dimensional three-phase isotropic conducting composites with extremal conductivity. They can also be used to study transversely isotropic three-dimensional three-phase composites with cylindrical inclusions of arbitrary cross-sections (plane strain problem) or transversely isotropic thin plates (plane stress or bending of plates problems). (C) 2000 Elsevier Science Ltd. All rights reserved.
On the influence of geometrical non-linearities in topology optimization

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern), Buhl, T. (Intern), Pedersen, C. B. W. (Intern)
Pages: 61-73
Publication date: 2000

Host publication information
Title of host publication: Proceedings of NATO ARW: Topology Optimization of Structures and Composite Continua
Place of publication: Budapest, Hungary
Publisher: Kluwer
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 177261
Publication: Research - peer-review › Article in proceedings – Annual report year: 2000

Recent Results on Topology Optimization of Periodic Composites

General information
State: Published
Organisations: Department of Mathematics
Authors: Bendsøe, M. P. (Intern), Neves, M. M. (Ekstern), Sigmund, O. (Intern)
Pages: 3-17
Publication date: 2000

Host publication information
Title of host publication: Topology Optimization of Structures and Composite Continua (G.I.N. Rozvany, N. Olhoff, eds.)
Place of publication: Dordrecht
Publisher: Kluwer Academic Publishers
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 176999
Publication: Research - peer-review › Article in proceedings – Annual report year: 2000

Stiffness design of geometrically nonlinear structures using topology optimization

The paper deals with topology optimization of structures undergoing large deformations. The geometrically nonlinear behavior of the structures are modelled using a total Lagrangian finite element formulation and the equilibrium is found using a Newton-Raphson iterative scheme. The sensitivities of the objective functions are found with the adjoint method and the optimization problem is solved using the Method of Moving Asymptotes. A filtering scheme is used to obtain
checkerboard-free and mesh-independent designs and a continuation approach improves convergence to efficient designs.

Different objective functions are tested. Minimizing compliance for a fixed load results in degenerated topologies which are very inefficient for smaller or larger loads. The problem of obtaining degenerated "optimal" topologies which only can support the design load is even more pronounced than for structures with linear response. The problem is circumvented by optimizing the structures for multiple loading conditions or by minimizing the complementary elastic work. Examples show that differences in stiffnesses of structures optimized using linear and nonlinear modelling are generally small but they can be large in certain cases involving buckling or snap-through effects.
Systematic design and optimization of multi-material, multi-degree-of-freedom micro actuators

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 36-99
Publication date: 2000

Host publication information
Title of host publication: Proceedings of Modelling and Simulation of Microsystems, Semiconductors, Sensors and Actuators, MSM2000
Place of publication: San Diego, CA
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 177259
Publication: Research - peer-review › Article in proceedings – Annual report year: 2000

Systematic design of mechanical systems using topology optimization

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 5-13
Publication date: 2000

Host publication information
Title of host publication: Proceedings of the 2nd ASMO/ISSMO Conference on Engineering Design Optimization
Place of publication: Swansea, UK
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 177257
Publication: Research - peer-review › Article in proceedings – Annual report year: 2000

Systematic design of micro and macro system

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 373-382
Publication date: 2000

Host publication information
Title of host publication: Symposium on Deployable Structures: Theory and Applications (Eds.: Pellegrino, S.), IUTAM
Place of publication: Cambridge, UK
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 177258
Publication: Research - peer-review › Article in proceedings – Annual report year: 2000

Topology optimization: A tool for the tailoring of structures and materials

General information
Compliant thermal microactuators
Two dimensional compliant metallic thermal microactuators are designed using topology optimisation, and microfabricated using rapid prototyping techniques. Structures are characterised using advanced image analysis, yielding a very high precision. Characterised structures behave in accordance with the intended behaviour. (C) 1999 Elsevier Science S.A. All rights reserved.

General information
State: Published
Organisations: Department of Micro- and Nanotechnology, Department of Solid Mechanics
Authors: Jonsmann, J. (Intern), Sigmund, O. (Intern), Bouwstra, S. (Intern)
Pages: 463-469
Publication date: 30 Aug 1999
Main Research Area: Technical/natural sciences
Publication information
Journal: Sensors and Actuators A: Physical
Volume: 76
Issue number: 1-3
ISSN (Print): 0924-4247
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.79 SJR 0.803 SNIP 1.655
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 0.848 SNIP 1.599 CiteScore 2.73
BFI (2014): BFI-level 2
Compliant electro-thermal microactuators.
This paper describes design, microfabrication and characterisation of topology optimised compliant electro-thermal microactuators. The actuators are fabricated by a fast prototyping process using laser micromachining and electroplating. Actuators are characterised with respect to displacement, force and work, by use of image analysis. Four different actuators are presented. These actuators are capable of displacements of 30 μm and forces of 15 mN. The most recent actuator designs function in reasonable accordance with design predictions.

General information
State: Published
Compliant electrothermal microactuators

Two dimensional compliant metallic thermal microactuators are designed using topology optimisation, and microfabricated using rapid prototyping techniques. Structures are characterised using advanced image analysis, yielding a very high precision. Characterised structures behave in a way which can be explained from the design predictions.

Compliant thermal microactuators

Two dimensional compliant metallic thermal microactuators are designed using topology optimisation, and microfabricated using rapid prototyping techniques. Structures are characterised using advanced image analysis, yielding a very high precision. Characterised structures behave in a way which can be explained from the design predictions.
Designing geometrically non-linear structures using topology optimization

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Buhl, T. (Intern), Pedersen, C. B. W. P. (Intern), Sigmund, O. (Intern)
Pages: 7-9
Publication date: 1999

Host publication information
Title of host publication: Proceedings of 3rd WCSMO
Place of publication: Niagara Falls
Main Research Area: Technical/natural sciences
Conference: 3rd World Congress of Structural and Multidisciplinary Optimization, Buffalo, NY, United States, 17/05/1999 - 17/05/1999
Source: orbit
Source-ID: 173604
Publication: Research - peer-review › Article in proceedings – Annual report year: 1999

Design of smart composite materials using topology optimization

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern), Torquato, S. (Ekstern)
Pages: 365-379
Publication date: 1999
Main Research Area: Technical/natural sciences

Publication information
Journal: Smart Materials and Structures
Volume: 8
ISSN (Print): 0964-1726
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.976 SNIP 1.547 CiteScore 3.1
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.156 SNIP 1.698 CiteScore 3.03
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.254 SNIP 1.869 CiteScore 2.9
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.023 SNIP 1.915 CiteScore 2.61
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.016 SNIP 1.764 CiteScore 2.19
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.196 SNIP 1.972 CiteScore 2.53
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Material Interpolation Schemes in Topology Optimization

General information
State: Published
Organisations: Department of Mathematics
Authors: Bendsøe, M. P. (Intern), Sigmund, O. (Intern)
Pages: 635-654
Publication date: 1999
Main Research Area: Technical/natural sciences

Publication information
Journal: Archive of Applied Mechanics
Volume: 69
ISSN (Print): 0939-1533
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.44 SJR 0.738 SNIP 0.994
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.794 SNIP 1.01 CiteScore 1.17
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.942 SNIP 1.247 CiteScore 1.43
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.825 SNIP 1.261 CiteScore 1.55
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.637 SNIP 1.126 CiteScore 1.12
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.669 SNIP 1.319 CiteScore 1.15
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Material Interpolations in Topology Optimization

General information
State: Published
Organisations: Department of Mathematics
Authors: Bendsøe, M. (Ekstern), Sigmund, O. (Intern)
Pages: 635-654
Publication date: 1999
Main Research Area: Technical/natural sciences

Publication information
Journal: Archive of Applied Mechanics
Volume: 69
ISSN (Print): 0939-1533
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.44 SJR 0.738 SNIP 0.994
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.794 SNIP 1.01 CiteScore 1.17
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.942 SNIP 1.247 CiteScore 1.43
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.825 SNIP 1.261 CiteScore 1.55
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.637 SNIP 1.126 CiteScore 1.12
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.669 SNIP 1.319 CiteScore 1.15
Multi Degrees of Freedom Electro-Thermal Microactuators

General information
State: Published
Organisations: Department of Micro- and Nanotechnology, Department of Solid Mechanics
Authors: Jonsmann, J. (Intern), Sigmund, O. (Intern), Bouwstra, S. (Intern)
Pages: 1372-1375
Publication date: 1999

Host publication information
Title of host publication: Proceedings of the 10th International Conference on Solid-State Sensors and Actuators
Publisher: The Institute of Electrical Engineers of Japan
Main Research Area: Technical/natural sciences
Conference: 10th International Conference on Solid-State Sensors and Actuators (Transducers '99), Sendai, Japan, 01/01/1999
Source: orbit
Source-ID: 173406
Publication: Research - peer-review › Article in proceedings – Annual report year: 1999

On the Optimality of Bone Microstructure

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 221-234
Publication date: 1999

Host publication information
Title of host publication: Synthesis in Bio Solid Mechanics
Publisher: Kluwer
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 173409
Stiffness design of geometrically non-linear structures using topology optimization

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Buhl, T. (Intern), Pedersen, C. B. W. P. (Intern), Sigmund, O. (Intern)
Publication date: 1999

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 173400
Publication: Research - peer-review › Report – Annual report year: 1999

Topology Synthesis of Large-Displacement Compliant Mechanisms

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Pedersen, C. B. W. P. (Intern), Buhl, T. (Intern), Sigmund, O. (Intern)
Publication date: 1999

Host publication information
Title of host publication: Proceedings of 1999 ASME-DETC
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 173407
Publication: Research - peer-review › Article in proceedings – Annual report year: 1999

Topology Synthesis of Two-Material Compliant Actuators

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Publication date: 1999

Host publication information
Title of host publication: Proceedings of 1999 ASME-DETC
Place of publication: Las Vegas
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 173408
Publication: Research - peer-review › Article in proceedings – Annual report year: 1999

A new Class of Extremal Composites

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Publication date: 1998

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 170058
Design of Extreme Materials and Microrobots: Applications of Topology Optimization

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 32-40
Publication date: 1998
Main Research Area: Technical/natural sciences

Publication information
Journal: Naturens Verden
Original language: Danish
Source: orbit
Source-ID: 170056
Publication: Research › Journal article – Annual report year: 1998

Design of materials with extreme elastic or thermoelastic properties using topology optimization

General information
State: Published
Organisations: Department of Solid Mechanics, Princeton University
Authors: Sigmund, O. (Intern), Torquato, S. (Ekstern)
Pages: 233-246
Publication date: 1998

Host publication information
Title of host publication: Proc. of the IUTAM Symposium on Transformation Problems in Composite and Active Materials
Publisher: Kluwer
Main Research Area: Technical/natural sciences
Conference: Proc. of the IUTAM Symposium on Transformation Problems in Composite and Active Materials, Cairo, 01/01/1997
Source: orbit
Source-ID: 170061
Publication: Research - peer-review › Article in proceedings – Annual report year: 1998

Multiphase Composites with Extremal Bulk Modulus

General information
State: Published
Organisations: Department of Solid Mechanics, Princeton University
Authors: Gibiansky, L. (Ekstern), Sigmund, O. (Intern)
Publication date: 1998

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 170059
Publication: Research - peer-review › Report – Annual report year: 1998

New Developments in Handling Optimal Stress Constraints in Optimal Material Distributions

General information
State: Published
Organisations: Department of Solid Mechanics, University of Liege
Authors: Duysinx, P. (Ekstern), Sigmund, O. (Intern)
Pages: 1501-1509
Publication date: 1998

Host publication information
Numerical instabilities in topology optimization: A survey on procedures dealing with checkerboards, mesh-dependencies and local minima

General information
State: Published
Organisations: Department of Solid Mechanics, Linköping University
Authors: Sigmund, O. (Intern), Petersson, J. (Ekstern)
Pages: 68-75
Publication date: 1998
Main Research Area: Technical/natural sciences

Publication Information
Journal: Structural Optimization
Volume: 16
Original language: English
Source: orbit
Source-ID: 170055
Publication: Research - peer-review › Journal article – Annual report year: 1998

On the design of 1-3 piezo-composites using topology optimization
We use a topology optimization method to design 1-3 piezocomposites with optimal performance characteristics for hydrophone applications. The performance characteristics we focus on are the hydrostatic charge coefficient $d_h(\eta)$, the hydrophone figure of merit $d(h)((\eta))g(h)((\eta))$, and the electromechanical coupling factor $k_h((\eta))$. The piezocomposite consists of piezoelectric rods embedded in an optimal polymer matrix. We use the topology optimization method to design the optimal (porous) matrix microstructure. When we design for maximum $d_h((\eta))$ and $d_h((\eta))g(h)((\eta))$ the optimal transversally isotopic matrix material has negative Poisson's ratio in certain directions. When we design for maximum $k_h((\eta))$, the optimal matrix microstructure is layered and simple to build.

General information
State: Published
Organisations: Department of Solid Mechanics, Princeton University
Authors: Sigmund, O. (Intern), Torquato, S. (Ekstern), Aksay, I. (Ekstern)
Pages: 1038-1048
Publication date: 1998
Main Research Area: Technical/natural sciences

Publication Information
Journal: Journal of Materials Research
Volume: 13
Issue number: 4
ISSN (Print): 0884-2914
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.648 SNIP 0.661 CiteScore 1.51
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.649 SNIP 0.73 CiteScore 1.48
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.825 SNIP 0.979 CiteScore 1.8
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.835 SNIP 0.843 CiteScore 1.77
ISI indexed (2013): ISI indexed yes
On the design of hydrophones made as 1-3 piezoelectrics

General information
State: Published
Organisations: Department of Solid Mechanics, Princeton University
Authors: Sigmund, O. (Intern), Torquato, S. (Ekstern), Gibiansky, L. (Ekstern), Aksay, I. (Ekstern)
Pages: 147-160
Publication date: 1998

Host publication information
Title of host publication: Proc. of the IUTAM Symposium on Transformation Problems in composite and Active Materials
Publisher: Kluwer
Main Research Area: Technical/natural sciences
Conference: IUTAM Symposium on Transformation Problems in Composite and Active Materials, Cairo, 01/01/1997
Source: orbit
Source-ID: 170060
Publication: Research - peer-review › Article in proceedings – Annual report year: 1998

Optimering af konstruktioneres topologi, form og materiale

General information
State: Published
Organisations: Department of Mathematics
Authors: Bendsoe, M. (Ekstern), Sigmund, O. (Intern)
Optimization of structural topology, shape, and materials

Slope constrained Topology Optimization

The problem of minimum compliance topology optimization of an elastic continuum is considered. A general continuous density-energy relation is assumed, including variable thickness sheet models and artificial power laws. To ensure existence of solutions, the design set is restricted by enforcing pointwise bounds on the density slopes. A finite element discretization procedure is described, and a proof of convergence of finite element solutions to exact solutions is given, as well as numerical examples obtained by a continuation/SLP (sequential linear programming) method. The convergence proof implies that checkerboard patterns and other numerical anomalies will not be present, or at least, that they can be made arbitrarily weak. (C) 1998 John Wiley & Sons, Ltd.
Systematic design of electrothermomechanical microactuators using topology optimization

**General information**
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 350-355
Publication date: 1998

**Host publication information**
Title of host publication: Proceedings of Modelling and Simulation of Microsystems, Semiconductors, Sensors and Actuators, MSM98
Main Research Area: Technical/natural sciences
Conference: Modelling and Simulation of Microsystems, Semiconductors, Sensors and Actuators, MSM98, Santa Clara, 01/01/1998
Source: orbit
Source-ID: 170062
Publication: Research - peer-review › Article in proceedings – Annual report year: 1998

Systematic design of micro actuators using topology optimization

**General information**
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 23-31
Publication date: 1998

**Host publication information**
Title of host publication: Proceedings of SPIE, Smart Materials Technology, Vol. 3328
Place of publication: San Diego
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 170057
Publication: Research - peer-review › Article in proceedings – Annual report year: 1998

Topology Optimization in Multiphysics Problems

**General information**
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 1492-1500
Publication date: 1998

**Host publication information**
Title of host publication: 7th Symposium in Multidisciplinary Analysis and Optimization, AIAA/USAF/NASA/ISSMO
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 170065
Publication: Research - peer-review › Article in proceedings – Annual report year: 1998

Design of materials with extreme thermal expansion using a three-phase topology optimization method
Composites with extremal or unusual thermal expansion coefficients are designed using a three-phase topology optimization method. The composites are made of two different material phases and a void phase. The topology optimization method consists in finding the distribution of material phases that optimizes an objective function (e.g. thermoelastic properties) subject to certain constraints, such as elastic symmetry or volume fractions of the constituent
phases, within a periodic base cell. The effective properties of the material structures are found using the numerical homogenization method based on a finite-element discretization of the base cell. The optimization problem is solved using sequential linear programming.

To benchmark the design method we first consider two-phase designs. Our optimal two-phase microstructures are in fine agreement with rigorous bounds and the so-called Vigdergauz microstructures that realize the bounds. For three phases, the optimal microstructures are also compared with new rigorous bounds and again it is shown that the method yields designed materials with thermoelastic properties that are close to the bounds.

The three-phase design method is illustrated by designing materials having maximum directional thermal expansion (thermal actuators), zero isotropic thermal expansion, and negative isotropic thermal expansion. It is shown that materials with effective negative thermal expansion coefficients can be obtained by mixing two phases with positive thermal expansion coefficients and void. (C) 1997 Elsevier Science Ltd.
Design and fabrication of compliant mechanisms and material structures with negative Poisson's ratio

General information
State: Published
Organisations: Department of Solid Mechanics, Technical University of Denmark
Authors: Larsen, U. (Ekstern), Sigmund, O. (Intern), Bouwstra, S. (Ekstern)
Pages: 99-106
Publication date: 1997
Main Research Area: Technical/natural sciences

Publication Information
Journal: J. of MicroElectroMechanical Systems
Volume: 6
Issue number: 2
Original language: English
Source: orbit
Source-ID: 167278
Publication: Research - peer-review › Journal article – Annual report year: 1997

Design and fabrication of compliant micromechanisms and structures with negative Poisson's ratio

This paper describes a new way to design and fabricate compliant micromechanisms and material structures with negative Poisson's ratio (NPR). The design of compliant mechanisms and material structures is accomplished in an automated way using a numerical topology optimization method. The procedure allows the user to specify the elastic properties of materials or the mechanical advantages (MA's) or geometrical advantages (GA's) of compliant mechanisms and returns the optimal structures. The topologies obtained by the numerical procedure require practically no interaction by the engineer before they can be transferred to the fabrication unit. Fabrication is carried out by patterning a sputtered silicon on a plasma-enhanced chemical vapor deposition (PECVD) glass with a laser micromachining setup. Subsequently, the structures are etched into the underlying PECVD glass, and the glass is underetched, all in one two-step reactive ion etching (RIE) process. The components are tested using a probe placed on an x-y stage. This fast prototyping allows newly developed topologies to be fabricated and tested within the same day.

General information
State: Published
Organisations: Department of Micro- and Nanotechnology, Department of Solid Mechanics
Authors: Larsen, U. D. (Intern), Sigmund, O. (Intern), Bouwstra, S. (Intern)
Pages: 99-106
Publication date: 1997
Main Research Area: Technical/natural sciences
**Design of materials with extreme thermal expansion using a three-phase topology optimization method**

We show how composites with extremal or unusual thermal expansion coefficients can be designed using a numerical topology optimization method. The composites are composed of two different material phases and void. The optimization method is illustrated by designing materials having maximum thermal expansion, zero thermal expansion, and negative thermal expansion. Assuming linear elasticity, it is shown that materials with effective negative thermal expansion coefficients can be obtained by mixing two phases with positive thermal expansion coefficients and void. We also show that there is no mechanistic relationship between negative thermal expansion and negative Poisson's ratio.

**General information**

**State:** Published  
**Organisations:** Department of Solid Mechanics, Princeton University  
**Authors:** Sigmund, O. (Intern), Torquato, S. (Ekstern)  
**Pages:** 52-60  
**Publication date:** 1997

**Host publication information**

**Title of host publication:** Smart Materials Technology: Smart Structures and Materials 1997  
**Publisher:** SPIE - International Society for Optical Engineering  
**ISBN (Print):** 0-8194-2453-6  
**Series:** Proceedings of SPIE, the International Society for Optical Engineering  
**Volume:** 3040  
**ISSN:** 1605-7422  
**Main Research Area:** Technical/natural sciences  
**Conference:** Conference on Smart Materials Technology, San Diego, CA, United States, 03/03/1997 - 03/03/1997  
**DOIs:** 10.1117/12.267131  
**Source:** orbit  
**Source-ID:** 167323  
**Publication:** Research - peer-review › Article in proceedings – Annual report year: 1997

**Design of thermoelectric actuators using topology optimization**

**General information**

**State:** Published  
**Organisations:** Department of Solid Mechanics  
**Authors:** Sigmund, O. (Intern)  
**Pages:** 393-398  
**Publication date:** 1997

**Host publication information**

**Title of host publication:** Proc. of the Second World Congress of Structural and Multidisciplinary Optimization  
**Main Research Area:** Technical/natural sciences  
**Conference:** Second World congress of Structural and Multidisciplinary Optimization, Zakopane, 01/01/1997  
**Source:** orbit  
**Source-ID:** 167321  
**Publication:** Research - peer-review › Article in proceedings – Annual report year: 1997

**On the design of 1-3 piezo-composites using topology optimization**

**General information**

**State:** Published  
**Organisations:** Department of Solid Mechanics, Princeton University  
**Authors:** Sigmund, O. (Intern), Torquato, S. (Ekstern)  
**Publication date:** 1997

**Publication information**

**Original language:** English  
**Main Research Area:** Technical/natural sciences  
**Source:** orbit  
**Source-ID:** 167317
On the design of compliant mechanisms using topology optimization

This paper presents a method for optimal design of compliant mechanism topologies. The method is based on continuum-type topology optimization techniques and finds the optimal compliant mechanism topology within a given design domain and a given position and direction of input and output forces. By constraining the allowed displacement at the input port, it is possible to control the maximum stress level in the compliant mechanism. The ability of the design method to find a mechanism with complex output behavior is demonstrated by several examples. Some of the optimal mechanism topologies have been manufactured, both in macroscale (hand-size) made in Nylon, and in microscale (<.5mm) made of micromachined glass.

Composites with extremal thermal expansion coefficients

We design three-phase composites having maximum thermal expansion, zero thermal expansion, or negative thermal expansion using a numerical topology optimization method. It is shown that composites with effective negative thermal expansion can be obtained by mixing two phases of positive thermal expansions with a void phase. We also show that there is no mechanistic relationship between negative thermal expansion and negative Poisson's ratio. © 1996 American Institute of Physics.
Design and fabrication of compliant mechanisms and material structures with negative Poisson's ratio

General information
State: Published
Organisations: Department of Solid Mechanics, Technical University of Denmark
Authors: Larsen, U. (Ekstern), Sigmund, O. (Intern), Bouwstra, S. (Ekstern)
Publication date: 1996

Host publication information
Title of host publication: IEEE, Int. Workshop on Microelectromechanical Systems
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 166298
Publication: Research - peer-review › Article in proceedings – Annual report year: 1996

Design and fabrication of compliant micro-mechanisms and structures with negative Poisson's ratio

General information
State: Published
Organisations: Department of Micro- and Nanotechnology, Department of Solid Mechanics
Authors: Larsen, U. D. (Intern), Sigmund, O. (Intern), Bouwstra, S. (Intern)
Pages: 365-371
Publication date: 1996

Host publication information
Title of host publication: Proceedings. IEEE, The Ninth Annual International Workshop on Micro Electro Mechanical Systems
Place of publication: San Diego, Calif.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 166471
Publication: Research - peer-review › Book chapter – Annual report year: 1996

Design and fabrication of compliant micromechanisms and structures with negative Poisson's ratio

This paper describes a new way to design and fabricate compliant micromechanisms and material structures with negative Poisson's ratio (NPR). The design of compliant mechanisms and material structures is accomplished in an automated way using a numerical topology optimization method. The procedure allows the user to specify the elastic properties of materials or the mechanical or geometrical advantages of compliant mechanisms and returns the optimal structures. The topologies obtained by the numerical procedure require practically no interaction by the engineer before they can be transferred to the fabrication unit. Fabrication is carried out by patterning a sputtered silicon on a PECVD-glass with a laser micromachining set-up. Subsequently the structures are etched into the underlying PECVD-glass and the glass are underetched, all in one two-step RIE process. The components are tested using a probe placed on an xy-stage. This fast prototyping allows newly developed topologies to be fabricated and tested within the same day

General information
State: Published
Organisations: Department of Micro- and Nanotechnology, Solid Mechanics, Department of Mechanical Engineering
Authors: Larsen, U. D. (Intern), Sigmund, O. (Intern), Bouwstra, S. (Intern)
Pages: 365-371
Publication date: 1996

Host publication information
Design and manufacturing of material microstructures and micromechanisms

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 856-866
Publication date: 1996

Host publication information
Title of host publication: Proceedings of the 3rd Int. Conf. on Intelligent Materials, ICIM 96
Publisher: SPIE
Main Research Area: Technical/natural sciences
Conference: 3rd Int. Conf. on Intelligent Materials, ICIM 96, Lyon, 01/01/1996
Source: orbit
Source-ID: 166297
Publication: Research - peer-review › Article in proceedings – Annual report year: 1996

Design of Materials with extreme thermal expansion using a three-phase topology optimization method

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Publication date: 1996

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 167149
Publication: Research - peer-review › Report – Annual report year: 1996

On the design of Compliant mechanisms using topology optimization

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Publication date: 1996

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Some inverse problems in topology design of materials and mechanisms

General information
State: Published
Organisations: Department of Solid Mechanics
Authors: Sigmund, O. (Intern)
Pages: 277-284
Publication date: 1996

Host publication information
Title of host publication: Proc. of the IUTAM Symposium on Optimization of Mechanical Systems
Publisher: Kluwer
Main Research Area: Technical/natural sciences
Conference: IUTAM Symposium on Optimization of Mechanical systems, Stuttgart, Germany, 26/03/1995 - 26/03/1995
Source: orbit
Source-ID: 166290
Publication: Research - peer-review › Article in proceedings – Annual report year: 1996

Projects:

Shape and Topology Optimization of Aeroelastic Systems
Department of Mechanical Engineering
Period: 15/11/2017 → 14/11/2020
Number of participants: 4
Phd Student:
Conlan-Smith, Cian James (Intern)
Supervisor:
Ramos García, Néstor (Intern)
Sigmund, Ole (Intern)
Main Supervisor:
Andreasen, Casper Schousboe (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Development of ultra-high quality mechanical oscillators
Department of Physics
Period: 01/11/2017 → 31/10/2020
Number of participants: 3
Phd Student:
Høj, Dennis (Intern)
Supervisor:
Sigmund, Ole (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Grundforskningsfonden
Project: PhD

Topology optimization for transient problems
Department of Mechanical Engineering
Period: 15/09/2017 → 14/09/2020
Number of participants: 4
Phd Student:
Kristiansen, Hansotto (Intern)
Supervisor:
Poulios, Konstantinos (Intern)
Sigmund, Ole (Intern)
Main Supervisor:
Aage, Niels (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Innovativt design af ståltragere til kabelbårne broer
Department of Civil Engineering
Period: 01/01/2017 → 31/12/2019
Number of participants: 4
Phd Student:
Baandrup, Mads Jacob (Intern)
Supervisor:
Olesen, John Forbes (Intern)
Sigmund, Ole (Intern)
Main Supervisor:
Poulsen, Peter Noe (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Industrial PhD
Project: PhD

Multiscale design methods for Topology Optimization
Department of Mechanical Engineering
Period: 01/01/2016 → 31/12/2018
Number of participants: 4
Phd Student:
Groen, Jeroen Peter (Intern)
Supervisor:
Aage, Niels (Intern)
Lazarov, Boyan Stefanov (Intern)
Main Supervisor:
Sigmund, Ole (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Topology Optimization of Transient Heat Transfer Problems
Department of Mechanical Engineering
Period: 01/11/2015 → 30/04/2017
Number of participants: 4
Phd Student:
Zeidan, Said (Intern)
Supervisor:
Engelbrecht, Kurt (Intern)
Lazarov, Boyan Stefanov (Intern)
Main Supervisor:
Sigmund, Ole (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Topology Optimization of Thermoelectric Generators
Department of Mechanical Engineering
Period: 01/04/2015 → 31/05/2018
Number of participants: 4
Phd Student:
Lundgaard, Christian (Intern)
Supervisor:
Engelbrecht, Kurt (Intern)
Lazarov, Boyan Stefanov (Intern)
Main Supervisor:
Sigmund, Ole (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Topology optimization of thermal heat sinks
PhD Project
Department of Energy Conversion and Storage
Electrofunctional materials
Department of Mechanical Engineering
Solid Mechanics
Period: 01/11/2014 → 31/10/2017
Number of participants: 4
Acronym: TOPTEN
Project participant:
Engelbrecht, Kurt (Intern)
Sigmund, Ole (Intern)
Lazarov, Boyan Stefanov (Intern)
Phd Student:
Haertel, Jan Hendrik Klaas (Intern)

Relations
Publications:
Topology Optimization of Thermal Heat Sinks
Project

Topology optimization of thermal heat sinks
Department of Energy Conversion and Storage
Period: 01/11/2014 → 27/12/2017
Number of participants: 7
Phd Student:
Haertel, Jan Hendrik Klaas (Intern)
Supervisor:
Lazarov, Boyan Stefanov (Intern)
Sigmund, Ole (Intern)
Main Supervisor:
Engelbrecht, Kurt (Intern)
Examiner: Frandsen, Henrik Lund (Intern)
Dede, Ercan M. (Ekstern)
Langelaar, Matthijs (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

**Topology Optimization and Lattice Boltzmann Methods**
Department of Mechanical Engineering
Period: 01/09/2014 → 31/10/2017
Number of participants: 7
Phd Student:
Nørgaard, Sebastian Arlund (Intern)
Supervisor: Engelbrecht, Kurt (Intern)
Lazarov, Boyan Stefanov (Intern)
Main Supervisor: Sigmund, Ole (Intern)
Examiner: Fuhrman, David R. (Intern)
Evgrafov, Anton (Intern)
Stingl, Michael Walter (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

**Topology optimization for medium- to high-frequency applications**
Department of Mechanical Engineering
Period: 15/06/2013 → 30/09/2016
Number of participants: 7
Phd Student:
Christiansen, Rasmus Ellebæk (Intern)
Supervisor: Jensen, Jakob Søndergaard (Intern)
Lazarov, Boyan Stefanov (Intern)
Main Supervisor: Sigmund, Ole (Intern)
Examiner: Agerkvist, Finn T. (Intern)
Berggren, Martin (Ekstern)
Schevenels, Mattias (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Institut, samfinansiering

**Relations**
Publications:
Topology Optimization for Wave Propagation Problems with Experimental Validation
Project: PhD
Topology Optimisation for Multiscale Problems
Department of Mechanical Engineering
Period: 15/03/2013 → 09/12/2016
Number of participants: 7
Phd Student:
Alexandersen, Joe (Intern)
Supervisor:
Aage, Niels (Intern)
Lazarov, Boyan Stefanov (Intern)
Main Supervisor:
Sigmund, Ole (Intern)
Examiner:
Jensen, Jakob Søndergaard (Intern)
Guedes, José Arnaldo Pereira Leite Miranda (Ekstern)
Maute, Kurt (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut, samfinansiering

Relations
Publications:
Efficient topology optimisation of multiscale and multiphysics problems
Project: PhD

Topology optimization for additive manufacturing
Department of Mechanical Engineering
Period: 01/03/2013 → 09/12/2016
Number of participants: 7
Phd Student:
Clausen, Anders (Intern)
Supervisor:
Aage, Niels (Intern)
Hansen, Hans Nørgaard (Intern)
Main Supervisor:
Sigmund, Ole (Intern)
Examiner:
Hattel, Jesper Henri (Intern)
Guedes, José Arnaldo Pereira Leite Miranda (Ekstern)
Maute, Kurt (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut, samfinansiering

Relations
Publications:
Topology Optimization for Additive Manufacturing
Project: PhD

Topology Optimisation for Coupled Convection Problems
Master Thesis by Joe Alexandersen, titled "Topology Optimisation for Coupled Convection Problems".
Department of Mechanical Engineering
Solid Mechanics
Period: 03/09/2012 → 22/02/2013
Number of participants: 4
Topology optimisation, Convective cooling, Natural convection, Heat sink
Project participant:
Mathematical programming methods for large-scale structural topology optimization

Department of Wind Energy
Period: 01/09/2012 → 28/01/2016
Number of participants: 6
Phd Student:

Rojas Labanda, Susana (Intern)
Supervisor:
Sigmund, Ole (Intern)
Main Supervisor:

Stolpe, Mathias (Intern)
Examiner:
Jensen, Jakob Søndergaard (Intern)
Evgrafov, Anton (Intern)
Stingl, Michael Walter (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Eksternt finansieret virksomhed

Interactive Topology Optimization

Department of Applied Mathematics and Computer Science
Period: 01/04/2012 → 21/09/2015
Number of participants: 7
Phd Student:

Nobel-Jørgensen, Morten (Intern)
Supervisor:
Aage, Niels (Intern)
Sigmund, Ole (Intern)
Main Supervisor:

Bærentzen, Jakob Andreas (Intern)
Examiner:
Rose, Michael (Intern)
Singh, Karan Sher (Ekstern)
van Keulen, Alfred (Ekstern)
Modelling and design of Anodised Aluminium Surfaces

Department of Mechanical Engineering
Period: 01/12/2011 → 19/03/2015
Number of participants: 7
Phd Student:
Johansen, Villads Egede (Intern)
Supervisor:
Aage, Niels (Intern)
Breinbjerg, Olav (Intern)
Main Supervisor:
Sigmund, Ole (Intern)
Examiner:
Mortensen, N. Asger (Intern)
Berggren, Martin (Ekstern)
Shin, Jung H. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Geometrical Design Representations for Topology Optimization

Department of Applied Mathematics and Computer Science
Period: 01/11/2011 → 23/01/2015
Number of participants: 7
Phd Student:
Christiansen, Asger Nyman (Intern)
Supervisor:
Krzysztof Misztal, Marek (Ekstern)
Sigmund, Ole (Intern)
Main Supervisor:
Bærentzen, Jakob Andreas (Intern)
Examiner:
Dahl, Anders Bjorholm (Ekstern)
Maute, Kurt (Ekstern)
Wojtan, Chris (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

Optimal design of porous materials

Department of Mechanical Engineering
Period: 01/09/2011 → 19/03/2015
Number of participants: 7
Phd Student:
Andreassen, Erik (Intern)
Supervisor:
Sigmund, Ole (Intern)
Thomsen, Jon Juel (Intern)
Main Supervisor:
Jensen, Jakob Søndergaard (Intern)
Examiner:
Høgsberg, Jan Becker (Intern)
Guedes, José Arnaldo Pereira Leite Miranda (Ekstern)
Lund, Erik (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Topology Optimisation for Convection Problems
Bachelor of Engineering thesis and subsequent work in collaboration with FE-Design.

Department of Mechanical Engineering

Solid Mechanics
Period: 30/08/2010 → 30/09/2011
Number of participants: 2
Project participant:
Alexandersen, Joe (Intern)
Main Supervisor:
Sigmund, Ole (Intern)

Relations
Publications:
Topology Optimization for Convection Problems
Documents:
Alexandersen2011
Alexandersen2011a
Project

Energy Harvesting for Photocatalysis

Department of Photonics Engineering
Period: 01/10/2009 → 31/03/2010
Number of participants: 4
Phd Student:
Hansen, Lars Christian (Intern)
Supervisor:
Mørk, Jesper (Intern)
Sigmund, Ole (Intern)
Main Supervisor:
Mortensen, N. Asger (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Systematic design of nano-photonic systems

Department of Mechanical Engineering
Period: 01/09/2009 → 20/12/2012
Number of participants: 7
Phd Student:
Wang, Fengwen (Intern)
Supervisor:
Mørk, Jesper (Intern)
Sigmund, Ole (Intern)
Main Supervisor:
Optimization of Metamaterials
Department of Mechanical Engineering
Period: 01/02/2009 → 02/05/2012
Number of participants: 7
Phd Student:
Andkjær, Jacob Anders (Intern)
Supervisor:
Breinbjerg, Olav (Intern)
Mortensen, N. Asger (Intern)
Main Supervisor:
Sigmund, Ole (Intern)
Examiner:
Lavrinenko, Andrei (Intern)
Bozhevolnyi, Sergey I. (Intern)
Leugering, Günter (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Programbevilling
Project: PhD

Wireless Communication for Hearing Aid Systems
Department of Electrical Engineering
Period: 01/12/2008 → 20/09/2012
Number of participants: 7
Phd Student:
Nour, Baqer (Intern)
Supervisor:
Mortensen, N. Asger (Intern)
Sigmund, Ole (Intern)
Main Supervisor:
Breinbjerg, Olav (Intern)
Examiner:
Meincke, Peter (Intern)
Kabacik, Pawel (Ekstern)
Nosich, Alexander I. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Nanophotonics for terabit communications: VKR centre of excellence - NATEC
We propose to establish a Willum Kann Rasmussen Centre of Excellence that explores the fundamental physics and technology of nanophotonic materials and devices in order to reach data rates in the terabit per second regime. Following a brief introduction, the goals of the Centre, its organization, the main research activities, research plans and proposed budget are described.
Department of Photonics Engineering
Department of Mechanical Engineering
Department of Micro- and Nanotechnology

DTU Danchip
Center for Electron Nanoscopy
Period: 01/09/2008 → 31/08/2014
Number of participants: 13
Acronym: NATEC
Project participant:
Hvam, Jørn Marcher (Intern)
Yvind, Kresten (Intern)
Mortensen, N. Asger (Intern)
Jeppesen, Palle (Intern)
Oxenløwe, Leif Katsuo (Intern)
Peucheret, Christophe (Intern)
Chung, Il-Sug (Intern)
Sigmund, Ole (Intern)
Jensen, Jakob Søndergaard (Intern)
Jauho, Antti-Pekka (Intern)
Burrows, Andrew (Intern)
Hübner, Jörg (Intern)
Project Manager, organisational:
Mørk, Jesper (Intern)

Financing sources
Source: Unknown
Name of research programme: Ukendt Project

Topology Optimization of Transient Optoelastic Wave-interaction Problems
Department of Mechanical Engineering
Period: 01/04/2008 → 31/08/2011
Number of participants: 6
Phd Student:
Matzen, René (Intern)
Supervisor:
Jensen, Jakob Søndergaard (Intern)
Main Supervisor:
Sigmund, Ole (Intern)
Examiner:
Mørk, Jesper (Intern)
Diaz, Alejandro Rafael (Intern)
Kawamoto, Atsushi (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Multiscale Optimization of Materials Subjected to Impact Loading
Department of Mechanical Engineering
Period: 01/03/2008 → 28/09/2011
Number of participants: 5
Phd Student:
Andreasen, Casper Schousboe (Intern)
Antenna Miniaturization in Complex Environments

Department of Electrical Engineering
Period: 01/01/2008 → 28/09/2011
Number of participants: 7
Phd Student:
Zhang, Jiaying (Intern)
Supervisor:
Mortensen, N. Asger (Intern)
Sigmund, Ole (Intern)
Main Supervisor:
Breinbjerg, Olav (Intern)
Examiner:
Meincke, Peter (Intern)
Vázquez, Marta Martínez (Ekstern)
Ziolkowski, Richard W. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Systematic Design of Miniaturized Devices for Energy Transfer

Department of Mechanical Engineering
Period: 01/01/2008 → 31/08/2011
Number of participants: 7
Phd Student:
Aage, Niels (Intern)
Supervisor:
Breinbjerg, Olav (Intern)
Mortensen, N. Asger (Intern)
Main Supervisor:
Sigmund, Ole (Intern)
Examiner:
Stolpe, Mathias (Intern)
Diaz, Alejandro Rafael (Intern)
Kawamoto, Atsushi (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Topology Optimization for Crashworthiness Design Using Approximate Procedures

Department of Mathematics
Automated Design of Advanced Mechatronic Systems

Department of Management Engineering
Period: 15/05/2007 → 11/05/2011
Number of participants: 7
Phd Student: Dupuis, Jean-Francois (Intern)
Supervisor: Goodman, Erik (Ekstern)
Sigmund, Ole (Intern)
Main Supervisor: Fan, Zhun (Intern)
Examiner: Blanke, Mogens (Intern)
Jin, Yaochu (Ekstern)
Zhang, Qingfu (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Design of metamaterials
Metamaterials have interesting properties for wavepropagation and this project will investigate the use of topology optimization techniques for designing such materials and devices made from such materials.

Department of Mathematics
Department of Mechanical Engineering
Michigan State University
Period: 01/05/2007 → 31/12/2007
Number of participants: 3
Acronym: EDS
Project participant: Bendsøe, Martin P. (Intern)
Sigmund, Ole (Intern)
Diaz, Alejandro R. (Ekstern)

Financing sources
Source: Gaver, Private danske Fonde
Name of research programme: Gaver, Private danske Fonde
Amount: 80,000.00 Danish Kroner
Project
**Silicon-based Nanophotonic Structures for Controlling Light**

Department of Photonics Engineering  
Period: 01/11/2006 → 20/04/2011  
Number of participants: 6  
Phd Student:  
Yang, Lirong (Intern)  
Supervisor:  
Lavrinenko, Andrei (Intern)  
Sigmund, Ole (Intern)  
Main Supervisor:  
Hvam, Jørn Marcher (Intern)  
Examiner:  
Melloni, Andrea (Ekstern)  
Willatzen, Morten (Intern)  

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: DTU-lønnet stipendie  
Project: PhD

**Microtools for Automated Nanomanipulation**

Department of Micro- and Nanotechnology  
Period: 15/10/2006 → 03/03/2010  
Number of participants: 7  
Phd Student:  
Sardan Sukas, Özlem (Intern)  
Supervisor:  
Mølhave, Kristian (Intern)  
Sigmund, Ole (Intern)  
Main Supervisor:  
Bøggild, Peter (Intern)  
Examiner:  
Jensen, Jakob Søndergaard (Intern)  
Nelson, Bradley J. (Ekstern)  
Staufer, Urs (Ekstern)  

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Anden EU-finansiering  
Project: PhD

**Tool Optimization for Welding Processes**

Department of Mathematics  
Period: 15/06/2006 → 10/02/2010  
Number of participants: 7  
Phd Student:  
Larsen, Anders Astrup (Intern)  
Supervisor:  
Hattel, Jesper Henri (Intern)  
Sigmund, Ole (Intern)  
Main Supervisor:  
Stolpe, Mathias (Intern)  
Examiner:  
Lindgren, Lars-Erik (Ekstern)  
Duysinx, Pierre (Intern)  
Lund, Erik (Ekstern)
Financing sources
Source: Internal funding (public)
Name of research programme: DTU, Samfinansiering
Project: PhD

Topology Optimization of Surface Acoustic Wave Devices
Department of Mechanical Engineering
Period: 01/02/2006 → 21/10/2009
Number of participants: 6
Phd Student:
Dühring, Maria Bayard (Intern)
Supervisor:
Jensen, Jakob Søndergaard (Intern)
Main Supervisor:
Sigmund, Ole (Intern)
Examiner:
Hansen, Ole (Intern)
Maute, Kurt (Ekstern)
Willatzen, Morten (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Topology Optimization Problems with Design-Dependent Sets of Constraints
Department of Mathematics
Period: 01/01/2006 → 30/06/2010
Number of participants: 7
Phd Student:
Schou, Marie-Louise Højlund (Intern)
Supervisor:
Evgrafov, Anton (Intern)
Sigmund, Ole (Intern)
Main Supervisor:
Stolpe, Mathias (Intern)
Examiner:
Jørgensen, John Bagterp (Intern)
Kocvara, Michal (Intern)
Svanberg, Krister (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Generation of Articulated Mechanisms by Optimization Techniques - Matrix Inequalities and Global Search
Department of Applied Mathematics and Computer Science
Period: 18/03/2005 → 18/03/2005
Number of participants: 6
Phd Student:
Kawamoto, Atsushi (Intern)
Supervisor:
Sigmund, Ole (Intern)
Main Supervisor:
Bendsøe, Martin P. (Intern)
Examiner:
Klit, Peder (Intern)
Topographic optimization of photonic crystals and application to ultra-small and ultra-fast optical signal processing devices

A domestic team in the present proposal has so far proposed an ultra-small and ultra-fast symmetrical Mach-Zehnder (SMZ)-type all-optical switch (PC-SMZ) based on two-dimensional photonic crystals (2DPCs) and optical non-linear quantum dots (QDs) for the future WDM/OTDM system, and demonstrated basic technologies inevitable for the PC-SMZ, such as ultra-low propagation loss, excellent directional-coupler and interferometric optical-switch functions. An overseas team has, on the other hand, proposed an innovative 2DPC simulation method, i.e., topology optimization (TO) method and remarkably improved bandwidth and transmittance properties of 2DPC waveguides. The current proposal involves complementary international collaborations based on these excellent results for establishment of an excellent 2DPC design technology for innovative ultra-small and ultra-fast optical switch with a latch function. The result is definitely thought to pave the road to a optical logic element inevitable for the future photon network system.

Nanophotonics

Department of Photonics Engineering
Department of Mechanical Engineering
University of Tsukuba

Aarhus University
Ghent University

Period: 01/10/2004 → 30/09/2006
Number of participants: 11
Project ID: 70281
Project participant:
Sugimoto, Yoshimasa (Ekstern)
Watanabe, Yoshinori (Ekstern)
Nakamura, Shigeru (Ekstern)
Ishikawa, Hiroshi (Ekstern)
Awazu, Kouichi (Ekstern)
Watanabe, Akira (Ekstern)
Kristensen, Martin (Ekstern)
Borel, Peter Ingo (Intern)
Sigmund, Ole (Intern)
Baets, Roel (Ekstern)

Project Manager, organisational:
Asakawa, Kiyoshi (Ekstern)

Financing sources
Source: Samarb. aftaler - Udenlandske offentlige og private
Name of research programme: Samarb. aftaler - Udenlandske offentlige og private
Amount: 430,000.00 Danish Kroner

Topologioptimering af strømninger under multifysisk belastning

Department of Mathematics

Period: 01/02/2004 → 31/05/2007
Number of participants: 6
Phd Student:
Gersborg, Allan Roulund (Intern)

Supervisor:
Sigmund, Ole (Intern)

Main Supervisor:
It is now more than 15 years ago that the so-called homogenization method was proposed as a basis for computational means to optimize the topology and shape of continuum structures. From initially being capable mainly of treating minimum compliance design we now see the basic material distribution idea of the methodology applied to a wide range of structural and mechanical problems as well as to problems that couple structural response to other physical responses. Also, the method has provided insight for micro-mechanical studies, meaning that the method has given feedback to the area which provided impetus to the field of topological design optimization in its creation. Finally, topological design is now an integral part of most FEM software systems and it has become a standard industrial tool in some fields. The IUTAM Symposium provided a forum for the exchange of ideas for future developments in the area of topological design optimization. This encompassed the application to fluid-solid interaction problems, acoustics problems, and to problems in biomechanics, as well as to other multiphysics problems. New basic modelling paradigms, covering new geometry modelling such as level-set methods and topological derivatives, as well as developments in computational approaches were also focus areas. Without the sponsorship from the International Union of Theoretical and Applied Mechanics (IUTAM) and the International Society for Structural and Multidisciplinary Optimization (ISSMO), and the financial support from the Danish Center for Applied Mathematics and Mechanics (DCAMM), the Villum Kann Rasmussen Foundation, and the Poul Due Jensen Foundation, the symposium and this book would not have been possible. The financial support from the Department of Mechanical Engineering, Aalborg University, and from the Department of Mathematics and the Department of Mechanical Engineering, Technical University of Denmark, is also gratefully acknowledged.
Sigmund, Ole (Intern)
Bouwstra, Siebe (Ekstern)
Lægsgaard, Erik (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

**Fonon**

Department of Mechanical Engineering
Period: 01/01/2003 → 31/12/2005
Number of participants: 2
Project ID: 75339
Project participant:
Tvergaard, Viggo (Intern)
Project Manager, organisational:
Sigmund, Ole (Intern)

**Financing sources**
Source: Forskningsrådene - STVF
Name of research programme: Forskningsrådene - STVF
Amount: 2,900,000.00 Danish Kroner

**Smart indpakning af fiber lasere**

Department of Mechanical Engineering
Period: 01/12/2001 → 18/05/2005
Number of participants: 8
Phd Student:
Voxen, Lars Holfort (Intern)
Supervisor:
Pedersen, Jens Engholm (Intern)
Poulsen, Christian (Intern)
Thomsen, Jon Juel (Intern)
Main Supervisor:
Sigmund, Ole (Intern)
Examiner:
Santos, Ilmar (Intern)
Hald, Jan (Ekstern)
Tinnsten, Mats (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD

**Nanoresonators for high resolution mass detection**

Department of Micro- and Nanotechnology
Period: 01/02/2000 → 30/06/2003
Number of participants: 6
Phd Student:
Davis, Zachary James (Intern)
Supervisor:
Hansen, Ole (Intern)
Main Supervisor:
Boisen, Anja (Intern)
Material Interpolation Schemes in Topology Design

In topology optimization of structures, materials and mechanisms, parametrization of geometry is often performed by a grey-scale density-like interpolation function. In this project we analyze and compare the various approaches to this concept, in the light of variational bounds on effective properties of composite materials. This allows for a derivation of simple necessary conditions for the possible realization of grey-scale via composites, leading to a physical interpretation of all feasible designs as well as the optimal design. Thus it has been shown that the so-called artificial interpolation model in many circumstances actually fall within the framework of microstructurally based models. Single material and multi-material structural design in elasticity as well as in multi-physics problems is studied.
Fabrication, characterization and implementation of cantilevers for biochemical sensing

Department of Micro- and Nanotechnology
Period: 01/01/1999 → 16/11/2001
Number of participants: 7
Phd Student:
Thaysen, Jacob (Intern)
Supervisor:
Bouwstra, Siebe (Ekstern)
Grey, Francois (Intern)
Main Supervisor:
Boisen, Anja (Intern)
Examiner:
Frans de Rooij, Nicolaas (Ekstern)
Brugger, Jürgen (Ekstern)
Sigmund, Ole (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Improving the buckling performance of topology designed periodic microstructures
A formulation of linearized buckling for cellular microstructured solids is developed. The goal is to include instability modes in the design of a microstructure. An asymptotic method provides us with the equations for stability analysis at macroscopic and microscopic level and its range of applicability is analyzed. This is then used to address the problem of the buckling performance of cellular microstructures, leading to a buckling performance index concept that provides the basis for a comparative analysis between different distributions of material in the microstructure, as well as the influence of length scale of the buckling mode (single cell or multiple cell modes). This concept is then used to improve the buckling performance of microstructures designed for, e.g., maximal bulk modulus.
Development of interconnect substrates in silicon with flexible regions for multichip microsystems

Department of Micro- and Nanotechnology
Period: 01/10/1998 → …
Number of participants: 6
Phd Student: Lisby, Torben (Intern)
Supervisor: Branebjerg, Jens (Intern)
Main Supervisor: Hansen, Ole (Intern)
Examiner: Sigmund, Ole (Intern)
Dyrbye, Karsten (Ekstern)
Schweitz, Jan-Åke (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Erhvervsforskerordningen
Project: PhD

Multi-scale Representations in Design Optimization

Department of Mechanical Engineering
Number of participants: 7
Phd Student: Poulsen, Thomas Agersten (Intern)
Supervisor: Bendsøe, Martin P. (Intern)
Pedersen, Pauli (Intern)
Main Supervisor: Sigmund, Ole (Intern)
Examiner: Lund, Erik (Ekstern)
Petersson, Joakim (Ekstern)
Soto, Ciro A. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Optimal topology design of dissipative structures

This project is concerned with the crashworthiness design of structures. The aim of the project is to develop basic optimization concepts for the lay-out design (topology design) of dissipative systems. Presently computational cost prevents the large scale optimization to be coupled with a full crash analysis. Moreover, it is unclear how the basic design modelling of continuum topology design can be applied to such problems. The key idea is thus to simplify the modelling of geometry, analysis and design - using groundstructure type ideas - to an extent where central concepts can be developed emphasizing the design optimization perspective, while capturing the fundamental physics of the problem.

Department of Mathematics
Department of Solid Mechanics
University of Michigan
Period: 01/08/1998 → …
Number of participants: 4
Project participant: Sigmund, Ole (Intern)
Pedersen, Claus B. Wittendorf (Intern)
Taylor, J.E. (Ekstern)
CMOS kompatible multilag metalliske mikrostrukturer for intelligente transducere

Department of Micro- and Nanotechnology
Period: 01/03/1997 → 21/06/2001
Number of participants: 5
Phd Student:
Ravnkilde, Jan Tue (Intern)
Main Supervisor:
Hansen, Ole (Intern)
Examiner:
Sigmund, Ole (Intern)
Gravesen, Peter (Ekstern)
Wagner, Bernd (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-Su Stipendium, Eksperiment
Project: PhD

Teknologiudvikling for mikroakruatorer

Department of Micro- and Nanotechnology
Period: 01/07/1996 → 17/07/2000
Number of participants: 4
Phd Student:
Jonsmann, Jacques (Intern)
Supervisor:
Sigmund, Ole (Intern)
Main Supervisor:
Bouwstra, Siebe (Ekstern)
Examiner:
Sparsø, Jens (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Mic-Finansieret-SU
Project: PhD

Topology Optimization - Methods, Convergence and Adaptive Finite Elements
Mathematical studies are carried out on the convergence of finite element solutions within optimization of structural topology.

Department of Mathematics
Department of Solid Mechanics
Period: 01/03/1996 → 28/02/1997
Number of participants: 3
Project participant:
Bendsøe, Martin P. (Intern)
Sigmund, Ole (Intern)
Project Manager, organisational:
Petersson, Joakim (Intern)

Financing sources
Source: Unknown
Name of research programme: U kendt
Amount: 350,000.00 Danish Kroner
Project
Optimal Design and manufacturing of composite materials
A numerically based topology optimization method is used to design material structures with extremal thermoelastic properties. Examples are two-phase materials with negative Poissons ratio, three-phase materials with negative thermal expansion and piezoelectric-composites with maximum sensitivity to underwater sound (hydrophones). The properties of the numerically designed composites are compared with theoretical bounds. Some of the piezo-electric materials are being manufactured and tested. (Financed by STVF).

Department of Solid Mechanics
Period: 01/09/1995 → …
Number of participants: 2
Other:
Torquato, Salvatore (Extern)
Project Manager, organisational:
Sigmund, Ole (Intern)

Design and Manufacturing of MicroElectroMechanical Systems (MEMS)
A systematic tool for the design of MicroElectroMechanical Systems is being developed. The tool is based on numerical topology optimization methods. In contrast to standard scale mechanisms, the micro systems are built in one piece, implying that movement of the mechanism happens by elastic deformation in parts of the device. Different actuation principles are being investigated and potential applications are scanning devices such as atomic force microscopes or in hearing aids. In cooperation with Mikroelektronik Centret (MIC, DTU) the devices are being manufactured and tested. (Financed by STVF).

Department of Solid Mechanics
Period: 01/06/1994 → …
Number of participants: 3
Project participant:
Pedersen, Niels Leergaard (Intern)
Tcherniak, Dmitri (Intern)
Project Manager, organisational:
Sigmund, Ole (Intern)

Numerical problems in topology optimization
This project investigates different problems appearing in numerical applications of topology optimization methods. Examples are appearance of checkerboard patterns in "optimal" designs, mesh-dependencies and convergence to local minima. Another problem is to implement stress constraints in topology optimization in a numerically efficient way. (Financed by STVF).

Department of Solid Mechanics
Department of Mathematics
Period: 01/01/1993 → …
Number of participants: 3
Project participant:
Petersson, Joakim (Intern)
Bourdin, Blaise (Intern)
Project Manager, organisational:
Sigmund, Ole (Intern)

Optimal design af adaptive konstruktioner
Department of Mechanical Engineering
Period: 09/12/1992 → 20/03/1995
Number of participants: 3
Phd Student:
Sigmund, Ole (Intern)
Supervisor:
Bendsøe, Martin P. (Intern)
Main Supervisor:
Pedersen, Pauli (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Gammel ordning u/skema-SU
Project: PhD

Activities:

International Workshop on Optical Waveguide Theory and Numerical Modelling (OWTNM); 19
Period: 9 Apr 2010 → 10 Apr 2010
Ole Sigmund (Speaker)
Department of Mechanical Engineering
Solid Mechanics

Description
Place: Cambridge, UK

Related external organisation
Unknown external organisation
Activity: Talks and presentations › Conference presentations

Comsol Conference 2008
Period: 4 Nov 2008 → 6 Nov 2008
Ole Sigmund (Participant)
Department of Mechanical Engineering
Solid Mechanics

Description
Talk about "Simulation of Toology Optimized Microgrippers"

Place: Hannover, Germany

Related event
Comsol Conference 2008
04/11/2008 → 06/11/2008
Hannover, Germany
Activity: Attending an event › Participating in or organising a conference

ASME 2008 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference
Ole Sigmund (Participant)
Department of Mechanical Engineering
Solid Mechanics

Description
Talk about "Topology Optimized Microgrippers for Nanomanipulation of Carbon Nanotubes" Presented at IDETC/CIE

Place: Brooklyn, New York, USA

Related event
ASME 2008 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference
03/08/2008 → 06/08/2008
Brooklyn, NY, United States
Activity: Attending an event › Participating in or organising a conference

2008 MRS Spring Meeting & Exhibit
Ole Sigmund (Participant)
Department of Mechanical Engineering
Solid Mechanics

Description
Talk about "3D Pick-and-Place of carbon Nanotubes Using Shape-optimized Grippers" Presented at MRS Spring Meeting

Place: San Fransisco, USA
Degree of recognition: International

Related event

2008 MRS Spring Meeting & Exhibit
24/03/2008 → 28/03/2008
San Francisco, United States
Activity: Attending an event › Participating in or organising a conference