All-Si photodetector for telecommunication wavelength based on subwavelength grating structure and critical coupling

We propose an efficient planar all-Si internal photoemission photodetector operating at the telecommunication wavelength of 1550 nm and numerically investigate its optical and electrical properties. The proposed polarization-sensitive detector is composed of an appropriately engineered subwavelength grating structure topped with a silicide layer of nanometers thickness as an absorbing material. It is shown that a nearly-perfect light absorption is possible for the thin silicide layer by its integration to the grating resonator. The absorption is shown to be maximized when the critical coupling condition is satisfied. Simulations show that the external quantum efficiency of the proposed photodetector with a 2-nm-thick PtSi absorbing layer at the center wavelength of 1550 nm can reach up to ~60%.

Compact dielectric cavities based on frozen bound states in the continuum

Dielectric microcavities are used widely today for confining the light to its wavelength scale, which is important for fundamental physics studies of light-matter interactions such as cavity quantum electrodynamics (QED) and cavity
polaritons, as well as various applications including ultrafast lasers and single-photon light sources [1]. They have been implemented in various platforms such as microrings, microdisks, micropillars, photonic crystals (PhCs), etc. Usually, it is desirable to reduce the mode volume while keeping the quality-factor (Q-factor) as high as possible for an optical cavity to enhance the light-matter interaction. Recently, a particular type of optical mode with an infinite Q-factor has been reported in a PhC slab, which is referred to as bound state in the continuum (BIC) [2]. A BIC is a special solution of a wave equation, which is discrete and bounded while it lies inside a continuum of unbounded states [2].

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Dynamical dispersion engineering in coupled vertical cavities employing a high-contrast grating
Photon's effective mass is an important parameter of an optical cavity mode, which determines the strength of light-matter interaction. Here, we propose a novel method for controlling the photon's effective mass by using coupled photonic cavities and designing the angular dependence of the coupling strength. This can be implemented by employing a high-contrast grating (HCG) as the coupling reflector in a system of two coupled vertical cavities, and engineering both the HCG reflection phase and amplitude response. Several examples of HCG-based coupled cavities with novel features are discussed, including a case capable of dynamically controlling the photon's effective mass to a large extent while keeping the resonance frequency same. We believe that full-control and dynamical-tuning of the photon's effective mass may enable new possibilities for cavity quantum electrodynamics studies or conventional/polariton laser applications. For instance, one can dynamically control the condensate formation in polariton lasers by modifying the polariton mass.

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Efficient quality-factor estimation of a vertical cavity employing a high-contrast grating

Hybrid vertical cavity lasers employing high-contrast grating reflectors are attractive for Si-integrated light source applications. Here, a method for reducing a three-dimensional (3D) optical simulation of this laser structure to lower-dimensional simulations is suggested, which allows for very fast and approximate analysis of the quality-factor of the 3D cavity. This approach enables us to efficiently optimize the laser cavity design without performing cumbersome 3D simulations.
Reciprocal-Space Engineering of Quasi-Bound States in the Continuum in Photonic Crystal Slabs for High-Q Microcavities

The bound states in the continuum (BICs) in photonic crystal (PhC) slabs presume infinite periodicity in the inplane direction. Thus, a large number of unit cells are typically required to implement the BICs with a high quality (Q) factor. Here, we report on a method to engineer the reciprocal-space properties of BICs, which enables to keep the effect of the BIC phenomenon strong even for a microcavity of a few unit cells. For example, based on this method, a 3D microcavity of 4 unit cells can attain a Q factor of 18k. This allows for various BIC studies in a very compact platform, as well as novel functionalities for many important applications.

Vertical cavity laser

The present invention provides a vertical cavity laser comprising a grating layer comprising an in-plane grating, the grating layer having a first side and having a second side opposite the first side and comprising a contiguous core grating region having a grating structure, wherein an index of refraction of high-index sections of the grating structure is at least 2.5, and wherein an index of refraction of low-index sections of the grating structure is less than 2, the core grating region defining a projection in a direction normal to the grating layer; a cap layer having a first side and having a second side opposite the first side, the first side of the cap layer abutting the second side of the grating layer, and an index of refraction of the cap layer within the projection of the core grating region onto the cap layer is at least 2.5, and within the projection of the core grating region, the second side of the cap layer is abutted by a first low-index layer and/or by air, an index of refraction of the first low-index layer or air being less than 2, and wherein a thickness of the cap layer and a thickness of the grating layer, and a pitch and a duty cycle of the grating structure are selected to obtain a resonance having a free-space resonance wavelength in the interval 300 nm to 3 microns, the cap layer comprising an active region configured to generate or absorb photons at the free-space resonance wavelength by stimulated emission or absorption when a sufficient forward or reverse bias voltage is applied.
Hybrid grating reflectors: Origin of ultrabroad stopband

Hybrid grating (HG) reflectors with a high-refractive-index cap layer added onto a high contrast grating (HCG) provide a high reflectance close to 100% over a broader wavelength range than HCGs. The combination of a cap layer and a grating layer brings a strong Fabry-Perot (FP) resonance as well as a weak guided mode (GM) resonance. Most of the reflected power results from the FP resonance, while the GM resonance plays a key role in achieving a reflectance close to 100% as well as broadening the stopband. An HG sample with 7 InGaAlAs quantum wells included in the cap layer has been fabricated by directly wafer-bonding a III-V cap layer onto a Si grating layer. Its reflection property has been characterized. This heterogeneously integrated HG reflector may allow for a hybrid III-V on Si laser to be thermally efficient, which has promising prospects for silicon photonics light sources and high-speed operation.
Hybrid III-V on Si grating as a broadband reflector and a high-Q resonator

Hybrid grating (HG) with a high-refractive-index cap layer added onto a high contrast grating (HCG), can provide a high reflectance close 100 % over a broader wavelength range than HCGs, or work as a ultrahigh quality (Q) factor resonator. The reflection and resonance properties of HGs have been investigated and the mechanisms leading to these properties are discussed. A HG reflector sample integrating a III-V cap layer with InGaAlAs quantum wells onto a Si grating has been fabricated and its reflection property has been characterized. The HG-based lasers have a promising prospect for silicon photonics light sourc or high-speed laser applications

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Hybrid III-V/SOI resonant cavity enhanced photodetector

A hybrid III–V/SOI resonant-cavity-enhanced photodetector (RCE-PD) structure comprising a high-contrast grating (HCG) reflector, a hybrid grating (HG) reflector, and an air cavity between them, has been proposed and investigated. In the proposed structure, a light absorbing material is integrated as part of the HG reflector, enabling a very compact vertical cavity. Numerical investigations show that a quantum efficiency close to 100 % and a detection linewidth of about 1 nm can be achieved, which are desirable for wavelength division multiplexing applications. Based on these results, a hybrid RCE-PD sample has been fabricated by heterogeneously integrating an InP-based material onto a silicon-on-insulator wafer and has been characterized, which shows a clear enhancement in photo-current at the designed wavelength. This indicates that the HG reflector provides a field enhancement sufficient for RCE-PD operation. In addition, a capability of feasibly selecting the detection wavelength during fabrication as well as a possibility of realizing silicon-integrated bidirectional transceivers are discussed.

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Hybrid III-V/SOI Resonant Cavity Photodetector
A hybrid III-V/SOI resonant cavity photo detector has been demonstrated, which comprises an InP grating reflector and a Si grating reflector. It can selectively detect an incident light with 1.54-µm wavelength and TM polarization.

Hybrid vertical cavity laser for silicon photonics light source integration (invited paper)
We explore the use of a modal expansion technique, Fourier modal method (FMM), for investigating the optical properties of vertical cavities employing high-contrast gratings (HCGs). Three techniques for determining the resonance frequency and quality factor (Q-factor) of a cavity mode are compared, and the computational uncertainties in the resonance frequency and Q-factor calculations are analyzed. Moreover, a method for reducing a three-dimensional (3D) simulation to lower-dimensional simulations is suggested, which allows for very fast and approximate analysis of a 3D structure. By using the implemented FMM, the scattering losses of several HCG-based vertical cavities with inplane heterostructures which have promising prospects for fundamental physics studies and on-chip laser applications, are investigated. This type of parametric study of 3D structures would be numerically very demanding using spatial discretization techniques.

Numerical Investigation of Vertical Cavity Lasers With High-Contrast Gratings Using the Fourier Modal Method
We explore the use of a modal expansion technique, Fourier modal method (FMM), for investigating the optical properties of vertical cavities employing high-contrast gratings (HCGs). Three techniques for determining the resonance frequency and quality factor (Q-factor) of a cavity mode are compared, and the computational uncertainties in the resonance frequency and Q-factor calculations are analyzed. Moreover, a method for reducing a three-dimensional (3D) simulation to lower-dimensional simulations is suggested, which allows for very fast and approximate analysis of a 3D structure. By using the implemented FMM, the scattering losses of several HCG-based vertical cavities with inplane heterostructures which have promising prospects for fundamental physics studies and on-chip laser applications, are investigated. This type of parametric study of 3D structures would be numerically very demanding using spatial discretization techniques.
Ultrabroadband Hybrid III-V/SOI Grating Reflector for On-chip Lasers

We report on a new type of III-V/SOI grating reflector with a broad stopband of 350 nm. This reflector has promising prospects for applications in high-speed III-V/SOI vertical cavity lasers with an improved heat dissipation capability.

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Ultrahigh-speed Si-integrated on-chip laser with tailored dynamic characteristics

For on-chip interconnects, an ideal light source should have an ultralow energy consumption per bandwidth (operating energy) as well as sufficient output power for error-free detection. Nanocavity lasers have been considered the most ideal for smaller operating energy. However, they have a challenge in obtaining a sufficient output power. Here, as an alternative, we propose an ultrahigh-speed microcavity laser structure, based on a vertical cavity with a high-contrast grating (HCG) mirror for transverse magnetic (TM) polarisation. By using the TM HCG, a very small mode volume and an un-pumped compact optical feedback structure can be realised, which together tailor the frequency response function for achieving a very high speed at low injection currents. Furthermore, light can be emitted laterally into a Si waveguide. From an 1.54-μm optically-pumped laser, a 3-dB frequency of 27 GHz was obtained at a pumping level corresponding to sub-mA. Using measured 3-dB frequen-cies and calculated equivalent currents, the modulation current efficiency factor (MCEF) is estimated to be 42.1 GHz/mA(1/2), which is superior among microcavity lasers. This shows a high potential for a very high speed at low injection currents or very small heat generation at high bitrates, which are highly desirable for both on-chip and off-chip applications.

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Contributors: Park, G. C., Xue, W., Piels, M., Zibar, D., Mørk, J., Semenova, E., Chung, I.
Vcsel structure
The invention relates to a VCSEL structure based on a novel grating reflector. The grating reflector comprises a grating layer with a contiguous core grating region having a grating structure, wherein an index of refraction of high-index sections of the grating structure is at least 2.5, and wherein an index of refraction of low-index sections of the grating structure is less than 2. The core grating region defines a projection in a direction normal to the grating layer. The grating reflector further comprises a cap layer abutting the grating layer, and an index of refraction of the cap layer within the projection of the core grating region onto the cap layer is at least 2.5, and within the projection of the core grating region, the cap layer is abutted by a first solid dielectric low-index layer, an index of refraction of the first low-index layer or air being less than 2; and within the projection of the core grating region, the grating layer is also abutted by a second low-index layer and/or by air, an index of refraction of the second low-index layer or air being less than 2. The VCSEL structure furthermore comprises a first reflector and an active region for providing a cavity and amplification.

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A New Compact Broadband Reflector: The Hybrid Grating

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Effect of In-plane Mirror Dispersion on Vertical Cavities Based on High-Contrast Grating Mirrors

We report how the in-plane dispersion of a high-index-contrast grating reflector influences the transverse mode properties such as shorter wavelengths for lower-order transverse modes and different transverse-mode wavelength spacings for modes with the same size.

Hybrid III-V-on-Si Laser with Ultra-low Energy Consumption

We report a III-V-on-SOI vertical-cavity laser emitting into an in-plane Si waveguide fabricated by using CMOS-compatible processes. The fabricated laser operates at 1.54 µm with a SMSR of 33 dB and a low threshold.

Hybrid III-V/SOI single-mode vertical-cavity laser with in-plane emission into a silicon waveguide

We report a III-V-on-SOI vertical-cavity laser emitting into an in-plane Si waveguide fabricated by using CMOS-compatible processes. The fabricated laser operates at 1.54 µm with a SMSR of 33 dB and a low threshold.
Hybrid vertical-cavity laser with lateral emission into a silicon waveguide

We experimentally demonstrate an optically-pumped III-V/Si vertical-cavity laser with lateral emission into a silicon waveguide. This on-chip hybrid laser comprises a distributed Bragg reflector, an III-V active layer, and a high-contrast grating reflector, which simultaneously funnels light into the waveguide integrated with the laser. This laser has the advantages of long-wavelength vertical-cavity surface-emitting lasers, such as low threshold and high side-mode suppression ratio, while allowing integration with silicon photonic circuits, and is fabricated using CMOS compatible processes. It has the potential for ultrahigh-speed operation beyond 100 Gbit/s and features a novel mechanism for transverse mode control.
III-V/SOI vertical cavity laser with in-plane output into a Si waveguide
We experimentally demonstrate an optically-pumped III-V-on-SOI hybrid vertical-cavity laser that outputs light into an in-plane Si waveguide, using CMOS-compatible processes. The laser operates at 1.49 $\mu$m with a side-mode suppression ratio of 27 dB and has a similar threshold as long-wavelength VCSELs.

Polarization-Independent Wideband High-Index-Contrast Grating Mirror
Island-type two-dimensional high-index-contrast grating mirror based on a standard silicon-on-insulator wafer have been experimentally demonstrated. The measured spectra shows a bandwidth of $\sim$192 nm with a reflectivity over 99% as well as polarization independence. Numerical simulations show that the designed mirror has large tolerance to fabrication errors.
Study on differences between high contrast grating reflectors for TM and TE polarizations and their impact on VCSEL designs

A theoretical study of differences in broadband high-index-contrast grating (HCG) reflectors for TM and TE polarizations is presented, covering various grating parameters and properties of HCGs. It is shown that the HCG reflectors for TM polarization (TM HCG reflectors) have much thicker grating thicknesses and smaller grating periods than the TE HCG reflectors. This difference is found to originate from the different boundary conditions met for the electric field of each polarization. Due to this difference, the TM HCG reflectors have much shorter evanescent extension of HCG modes into low-refractive-index media surrounding the HCG. This enables to achieve a very short effective cavity length for VCSELs, which is essential for ultrahigh speed VCSELs and MEMS-tunable VCSELs. The obtained understandings on polarization dependences will be able to serve as important design guidelines for various HCG-based devices.
Ultracompact resonator with high quality-factor based on a hybrid grating structure

We numerically investigate the properties of a hybrid grating structure acting as a resonator with ultrahigh quality factor. This reveals that the physical mechanism responsible for the resonance is quite different from the conventional guided mode resonance (GMR). The hybrid grating consists of a subwavelength grating layer and an un-patterned high-refractive-index cap layer, being surrounded by low index materials. Since the cap layer may include a gain region, an ultracompact laser can be realized based on the hybrid grating resonator, featuring many advantages over high-contrast-grating resonator lasers. The effect of fabrication errors and finite size of the structure is investigated to understand the feasibility of fabricating the proposed resonator.

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Vertical-Cavity In-plane Heterostructures: Physics and Applications

We show that the in-plane heterostructures realized in vertical cavities with high contrast grating(HCG) reflector enables exotic configurations of heterostructure and photonic wells. In photonic crystal heterostructures forming a photonic well, the property of a confined mode is determined by the well width and barrier height. We show that in vertical-cavity in-plane heterostructures, anisotropic dispersion curvatures plays a key role as well, leading to exotic effects such as a photonic well with conduction band like well and a valence band like barrier. We investigate three examples to discuss the rich potential of this heterostructure as a platform for various physics studies and propose a system of two laterally coupled cavities which shows the breaking of parity-time symmetry as an example.

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130-nm tunable grating-mirror VCSEL

We have reported that a combination of the high-index-contrast grating (HCG) mirror as movable mirror and the extended cavity configuration with an antireflection layer can provide a tuning wavelength range of 100 nm for tunable VCSELs. Here, we report that using the air-coupled cavity configuration instead of the extended cavity configuration can bring 130-nm tuning range around 1330-nm wavelength. The air-coupled cavity is known to reduce the quantum confinement factor in VCSELs, increasing threshold. In our air-coupled cavity HCG VCSEL case, the very short power penetration length in the HCG minimizes this reduction of the quantum confinement factor, not as significant as in the air-coupled cavity DBR VCSEL.

Comparison of Different Numerical Methods for Quality Factor Calculation of Nano and Micro Photonic Cavities

Four different numerical methods for calculating the quality factor and resonance wavelength of a nano or micro photonic cavity are compared. Good agreement was found for a wide range of quality factors. Advantages and limitations of the different methods are discussed.
Electrical Injection Schemes for Nanolasers

Three electrical injection schemes based on recently demonstrated electrically pumped photonic crystal nanolasers have been numerically investigated: 1) a vertical p-i-n junction through a post structure; 2) a lateral p-i-n junction with a homostructure; and 3) a lateral p-i-n junction with a buried heterostructure. Self-consistent laser-diode simulations reveal that the lateral injection scheme with a buried heterostructure achieves the best lasing characteristics at a low current, whereas the vertical injection scheme performs better at a higher current for the chosen geometries. For this analysis, the properties of different schemes, i.e., electrical resistance, threshold voltage, threshold current, and internal efficiency as energy requirements for optical interconnects are compared and the physics behind the differences is discussed.
Mode selection laser
The invention relates to a semiconductor mode selection laser, particularly to a VCSEL laser (200) having mode selection properties. The mode selection capability of the laser is achieved by configuring one of the reflectors (15,51) in the resonance cavity so that a reflectivity of the reflector (15) varies spatially in one dimension or two dimensions. Accordingly, the reflector (15) with spatially varying reflectivity is part both of the resonance cavity and the mode selection functionality of the laser. A plurality of the lasers configured with different mode selectors, i.e. different spatial reflector variations, may be combined to generate a laser beam containing a plurality of orthogonal modes. The laser beam may be injected into a few-mode optical fiber, e.g. for the purpose of optical communication. The VCSEL may have intra-cavity contacts (31,37) and a Tunnel junction (33) for current confinement into the active layer (34). An air-gap layer (102) may be provided between the upper reflector (15) and the SOI wafer (50) acting as a substrate. The lower reflector may be designed as a high-contrast grating (51) by etching.

Wavelength sweepable laser source
Wavelength sweepable laser source is disclosed, wherein the laser source is a semiconductor laser source adapted for generating laser light at a lasing wavelength. The laser source comprises a substrate, a first reflector, and a second reflector. The first and second reflector together defines an optical cavity, and are arranged to support light oscillation in the optical cavity along an optical path in a direction normal to the substrate. The optical cavity comprises a void in the optical path. The second reflector is resiliently suspended by a suspension in a distance from the first reflector and having a rest position, the second reflector and suspension together defining a microelectromechanical MEMS oscillator. The MEMS oscillator has a resonance frequency and is adapted for oscillating the second reflector on either side of the rest position.; The laser source further comprises electrical connections adapted for applying an electric field to the MEMS oscillator. Furthermore, a laser source system and a method of use of the laser source are disclosed.

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Publication information
1060-nm Tunable Monolithic High Index Contrast Subwavelength Grating VCSEL

We present the first tunable vertical-cavity surface-emitting laser (VCSEL) where the top distributed Bragg reflector has been completely substituted by an air-cladded high-index-contrast subwavelength grating (HCG) mirror. In this way, an extended cavity design can be realized by reducing the reflection at the semiconductor–air interface using an anti-reflective coating (ARC). We demonstrate how the ARC can be integrated in a monolithic structure by oxidizing AlGaAs with high Al-content. The HCG VCSEL has the potential to achieve polarization stable single-mode output with high tuning efficiency. The HCG VCSEL shows a total tuning range of 16 nm around an emission wavelength of 1060 nm with 1-mW output power.

Effect of External Optical Feedback for Nano-laser Structures

We theoretically investigated the effect of optical feedback on a photonic crystal nanolaser, comparing with conventional in-plane and vertical-cavity lasers.
Electrical injection schemes for nanolasers

The performance of injection schemes among recently demonstrated electrically pumped photonic crystal nanolasers has been investigated numerically. The computation has been carried out at room temperature using a commercial semiconductor simulation software. For the simulations two electrical injection schemes have been compared: vertical p-i-n junction through a current post structure as in 1 and lateral p-i-n junction with either uniform material as in 2 or with a buried heterostructure (BH) as in 3. To allow a direct comparison of the three schemes the same active material composition consisting of 3 InGaAsP QWs on an InP substrate has been chosen for the modeling. In the simulations the main focus is on the electrical and optical properties of the nanolasers i.e. electrical resistance, threshold voltage, threshold current and wallplug efficiency. In the current flow evaluation the lowest threshold current has been achieved with the lateral electrical injection through the BH; while the lowest resistance has been obtained from the current post structure even though this model shows a higher current threshold because of the lack of carrier confinement. Final scope of the simulations is the analyses of advantages and disadvantages of different electrical injection schemes for the development of the optimal device design for the future generation of electrically pumped nanolasers for terabit communication.

Hybrid III-V-on-Si Vertical Cavity laser for Optical Interconnects

Combining a III-V active material onto the Si platform is an attractive approach for silicon photonics light source. We have developed fabrication methods for novel III-V on Si vertical cavity lasers.

Hybrid III-V-on-Si Vertical Cavity laser for Optical Interconnects

Combining a III-V active material onto the Si platform is an attractive approach for silicon photonics light source. We have developed fabrication methods for novel III-V on Si vertical cavity lasers.
Laser device
The present invention provides a light source for light circuits on a silicon platform. A vertical laser cavity is formed by a gain region arranged between a first mirror structure and a second mirror structure, both acting as mirrors, by forming a grating region including an active material in a silicon layer in a semiconductor structure or wafer structure. A waveguide for receiving light from the region of the mirrors is formed within or to be connected to the region of the mirrors, and functions as an output coupler for the VCL. Thereby, vertical lasing modes are coupled to lateral in-plane modes of the in-plane waveguide formed in the silicon layer, and light can be provided to e.g. photonic circuits on a SOI or CMOS substrate in the silicon.

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Polarization-independent high-index contrast grating and its fabrication tolerances
A polarization-independent, high-index contrast grating (HCG) with a single layer of cross stripes allowing simple fabrication is proposed. Since the cross stripes structure can be suspended in air by selectively wet-etching the layer below, all the layers can be grown at once when implemented for vertical-cavity surface-emitting lasers. We optimized the structure to have a broad and high reflectivity band centered at around 1 μm using a finite difference time domain method, and obtained an 80 nm high reflectivity band centered at 0.97 μm in which the reflectivity exceeded 99.5%. We also investigated the fabrication tolerances of the structure and found that, assuming careful optimizations of electron beam lithography for the precise grating width and dry-etching for the vertical sidewall, the suggested polarization-independent HCG can be fabricated using standard technologies.

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**Resonant MEMS tunable VCSEL**

We demonstrate how resonant excitation of a microelectro-mechanical system can be used to increase the tuning range of a vertical-cavity surface-emitting laser two-fold by enabling both blue- and red-shifting of the wavelength. In this way a short-cavity design enabling wide tuning range can be realized. A high-index-contrast subwavelength grating vertical-cavity surface-emitting laser with a monolithically integrated anti-reflection coating is presented. By incorporating an antireflection coating into the air cavity, higher tuning efficiency can be achieved at low threshold current. The first result shows 24-nm continuous resonant tuning range around an emission wavelength of 1060 nm with 0.9 mW output power.

**General information**

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Contributors: Ansbæk, T., Chung, I., Semenova, E., Hansen, O., Yvind, K.
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ISI indexed (2013): ISI indexed yes

**Speed enhancement in VCSELs employing grating mirrors**

In recent years, various approaches to improve the speed of directly modulated vertical-cavity surface-emitting lasers (VCSELs) have been reported and demonstrated good improvement. In this paper, we propose and numerically investigate a new possibility of using high-index-contrast grating (HCG) as mirror for VCSELs. By changing the grating design, one can control the reflection delay of the grating mirror, enabling the control of cavity photon lifetime. On the other hand, short energy penetration depth of the HCG results in smaller modal volume, compared to DBR VCSELs. An example structure shows that the HCG VCSEL has a 30-% higher 3-dB bandwidth than the DBR VCSEL.

**General information**

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**Publication information**
Tunable Resonant-Cavity-Enhanced Photodetector with Double High-Index-Contrast Grating Mirrors

In this paper, we propose a broadband-tunable resonant-cavity-enhanced photodetector (RCE-PD) structure with double high-index-contrast grating (HCG) mirrors and numerically investigate its characteristics. The detector is designed to operate at 1550-nm wavelength. The detector structure consists of a top InP HCG mirror, a p-i-n photodiode embedding multiple quantum wells, and a Si HCG mirror formed in the Si layer of a silicon-on-insulator wafer. The detection wavelength can be changed by moving the top InP HCG mirror suspended in the air. High reflectivity and small penetration length of HCGs lead to a narrow absorption linewidth of 0.38 nm and a broad tuning range of 111 nm. The peak absorption efficiency is 76-84% within the tuning range. This broadband-tunable and narrow-absorption-linewidth RCE-PD is desirable for applications where selective wavelength demultiplexing is required. Furthermore, the fact that it can be fabricated on a silicon platform offers us a possibility of integration with electronics.
Ultrahigh-speed hybrid laser for silicon photonic integrated chips

Increasing power consumption for electrical interconnects between and inside chips is posing a real challenge to continue the performance scaling of processors/computers as predicted by D. Moore. In recent processors, energy consumption for electrical interconnects is half of power supplied and will be 80% in near future. This challenge strongly has motivated replacing electrical interconnects with optical ones even in chip level communications [1]. This chip-level optical interconnects need quite different performance of optoelectronic devices than required for conventional optical communications. For a light source, the energy consumption per sending a bit is required to be <10 fJ/bit for on-chip interconnects and <100 fJ/bit for off-chip interconnects; this is two or three orders of magnitude smaller than the conventional devices. To meet the energy/bit requirement, many innovative laser diode and light-emitting diode (LED) structures have been proposed so far. Our hybrid laser is one of these efforts [2].

The hybrid laser consists of a dielectric reflector, a III-V semiconductor active material, and a high-index-contrast grating (HCG) reflector formed in the silicon layer of a silicon-on-insulator (SOI) wafer. 'Hybrid' indicates that a III-V active material is wafer-bonded to a silicon SOI wafer. In the hybrid laser, light is vertically amplified between the dielectric and the HCG reflectors, while the light output is laterally emitted to a normal Si ridge waveguide that is connected to the HCG reflector. The HCG works as a vertical mirror as well as a vertical-to-lateral coupler. Very small field penetration into the HCG allows for 3-4 times smaller modal volume than typical vertical-cavity surface-emitting lasers (VCSELs). This leads to high direct modulation speed. Details on device operating mechanism will be explained in the lecture.

Recently, a nano light-emitting diode (LED) with energy/bit < 1fJ/bit [3] and a nano laser diode with a buried heterostructure (BH) active material [4] have been recently reported in the literature. Additionally, device physics, engineering issue, and error-free light detection issue in quantum limit will be discussed in relation to these two structures.

VCSELs with a high-index-contrast grating for mode-division multiplexing

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Contributors: Ran, Q., Chung, I.
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Source-ID: u::6960
Research output: Non-textual form » Sound/Visual production (digital) – Annual report year: 2013 › Research
Fabrication activity for nanophotonics
We present the fabrication and characterization of new structures and materials to be used in nanophotonics. The first structure presented is a fractal metallic metasurface designed to be used as a high-sensitivity sensor for 810nm wavelength. A second structure is a high-index contrast grating designed for phase and amplitude control of the transmitted beam. By controlling the Au percentage in a Si matrix, one may be able to obtain high refractive index with very limited loss.

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Organisations: Department of Photonics Engineering, Metamaterials, Quantum and Laser Photonics, Technical University of Denmark, Politehnica University of Timisoara
Contributors: Malureanu, R., Chung, I., Carletti, L., Novitsky, A., Sandru, A., Lavrinenko, A.
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Research output: Contribution to conference → Paper – Annual report year: 2012 → Research → peer-review

Low-energy-consumption hybrid lasers for silicon photonics
Physics and characteristics of a hybrid vertical-cavity laser that can be an on-chip Si light source with high speed and low energy consumption are discussed.

General information
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Contributors: Chung, I., Ran, Q., Mørk, J.
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Source: dtu
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Research output: Chapter in Book/Report/Conference proceeding → Article in proceedings – Annual report year: 2012 → Research → peer-review

Reflectivity-modulated grating-mirror
The invention relates to vertical cavity lasers (VCL) incorporating a reflectivity-modulated grating mirror (1) for modulating the laser output. A cavity is formed by a bottom mirror (4), an active region (3), and an outcoupling top grating mirror (1) formed by a periodic refractive index grating region in a layer structure comprising a p- and an n-doped semiconductor layer with an electrooptic material layer (12) arranged there between. The grating region comprises a grating structure formed by periodic perforations to change the refractive index periodically in directions normal to the oscillation axis. A modulated voltage (91) is applied in reverse bias between the n- and p-doped layers to modulate the refractive index of the electrooptic material layer (12) and thereby the reflectivity spectrum of the grating mirror (1). The reflectivity of the grating mirror (1) can be modulated between a reflectivity with little or no out coupling and a reflectivity with normal out coupling, wherein lasing in the VCL is supported at both the first and the second reflectivity. As the out coupling mirror modulates the output, the lasing does not need to be modulated, and the invention provides the advantage of lower power consumption at high modulation speeds.

General information
VCSELs and silicon light sources exploiting SOI grating mirrors

In this talk, novel vertical-cavity laser structure consisting of a dielectric Bragg reflector, a III-V active region, and a high-index-contrast grating made in the Si layer of a silicon-on-insulator (SOI) wafer will be presented. In the Si light source version of this laser structure, the SOI grating works as a highly-reflective mirror as well as routes light into a Si in-plane output waveguide connected to the grating. In the vertical-cavity surface-emitting laser (VCSEL) version, there is no in-plane output waveguide connected to the grating. Thus, light is vertically emitted through the Bragg reflector. Numerical simulations show that both the silicon light source and the VCSEL exploiting SOI grating mirrors have superior performances, compared to existing silicon light sources and long wavelength VCSELs. These devices are highly adequate for chip-level optical interconnects as well as conventional short-distance optical connections. In the talk, device physics will be discussed in detail.

Vertical-cavity surface-emitting laser vapor sensor using swelling polymer reflection modulation

Vapor detection using a low-refractive index polymer for reflection modulation of the top mirror in a vertical-cavity surface-emitting laser (VCSEL) is demonstrated. The VCSEL sensor concept presents a simple method to detect the response of a sensor polymer in the presence of volatile organic compounds. We model the physics as a change in the top mirror loss caused by swelling of the polymer upon absorbing the target volatile organic compound. Further we show how acetone vapors at 82 000 ppm concentration can change the polymer coated VCSEL output power by 20 μW.
Wave-front-engineered grating mirrors for VCSELs

High-index-contrast grating mirrors featuring beam steering abilities for the transmitted beam as well as high reflectivity over a broad bandwidth are suggested. Gratings designed to provide control over the wave front of the transmitted beam are numerically investigated. The proposed structures are then fabricated for experimental characterization. The measurements performed show the beam steering ability of the suggested HCG designs and are also in good agreement with the theoretical predictions. General design rules to engineer these HCG structures for different applications are derived. These grating mirrors would have a significant impact on low cost laser sources fabrication, since a more efficient integration of optoelectronic modules can be achieved by avoiding expensive external lens systems.
High-index-contrast grating reflector with beam steering ability for the transmitted beam

High-index contrast grating mirrors providing wave front control of the transmitted light as well as high reflectivity over a broad bandwidth are suggested and both numerically and experimentally investigated. General design rules to engineer these structures for different applications are derived. Such grating mirrors would have a significant impact on low cost laser fabrication, since a more efficient integration of optoelectronic modules can be achieved by avoiding expensive external lens systems.

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Hybrid Si/III-V vertical-cavity laser for silicon photonics

Hybrid Si/III-V vertical-cavity laser for silicon photonics
Hybrid vertical-cavity laser

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Contributors: Chung, I.
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Modelling of photonic-crystal VCSELs with semi-vectorial and vectorial models
In the talk the results of the COST MP0702 exercise on modeling photonic-crystal (PC) VCSELs are presented. Four different numerical methods are compared through an analysis of a benchmark VCSEL structure, where the PC structure penetrates all VCSEL layers, the entire top-mirror DBR, a fraction of the top-mirror DBR or just the VCSEL cavity. The different models are evaluated by comparing the predicted resonance wavelengths and threshold gains for different hole diameters and pitches of the PC. The agreement between the models is relatively good, with an exception of one case, which corresponds to the effective index method. The simulation results elucidate the strength and weaknesses of the analyzed methods and outline the limits of applicability of different models.

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Source: orbit
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Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2011 › Research › peer-review

80-nm-tunable high-index-contrast subwavelength grating long-wavelength VCSEL: Proposal and numerical simulations
A widely-tunable single-mode long wavelength vertical-cavity surface-emitting laser structure employing a MEMStunable high-index-contrast subwavelength grating (HCG) is suggested and numerically investigated. A very large 80-nm linear tuning range was obtained as the HCG was actuated by -220 to 250 nm. The large tuning range results from making the air gap part of the optical cavity, which was achieved by inserting an antireflection layer below the air gap and by the absence of partial top DBR for current spreading. The single mode operation was maintained throughout the tuning range, thanks to the selective pumping of the fundamental mode and the moderate mode selection by the HCG itself. Analytic expressions for tuning range and tuning sensitivity were derived, using the penetration depth of the HCG for the first time.

General information
Broadband MEMS-tunable high-index-contrast subwavelength grating long-wavelength VCSEL

A widely-tunable single-mode 1.3 μm vertical-cavity surface-emitting laser structure incorporating a microelectromechanical system-tunable high-index-contrast subwavelength grating (HCG) mirror is suggested and numerically investigated. A linear tuning range of 100 nm and a wavelength tuning efficiency of 0.203 are predicted. The large tuning range and efficiency are attributed to the incorporation of the tuning air gap as part of the optical cavity and to the use of a short cavity structure. The short cavity length can be achieved by employing a HCG design of which the reflection mechanism does not rely on resonant coupling. The absence of resonance coupling leads to a 0.59 λ-thick penetration depth of the HCG and enables to use a 0.25 λ-thick tuning air gap underneath the HCG. This considerably reduces the effective cavity length, leading to larger tuning range and efficiency. The basic properties of this new structure are analyzed, and shown to be explained by analytical expressions that are derived in the paper. In this context, the penetration depth of the HCG is introduced and shown to be an important characteristic length scale. Throughout the tuning wavelength range, strong single mode operation was maintained and uniform output power is expected.

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Web of Science (2010): Indexed yes
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Source-ID: 266724
Research output: Contribution to journal › Journal article – Annual report year: 2010 › Research › peer-review

High-index-contrast subwavelength grating VCSEL

In this article, we report our results on 980nm high-index-contrast subwavelength grating (HCG) VCSELs for optical interconnection applications. In our structure, a thin undoped HCG layer replaces a thick p-type Bragg mirror. The HCG
mirror can feasibly achieve polarization-selective reflectivities close to 100%. The investigated structure consists of a HCG mirror with an underneath /4-thick oxide gap, four p-type GaAlAs/GaAs pairs for current spreading, three InGaAs/GaAs quantum wells, and an n-type GaAlAs/GaAs Bragg mirror. The HCG structure was defined by e-beam lithography and dry etching. The current oxide aperture and the oxide gap underneath the HCG were simultaneously formed by the selective wet oxidation process. Compared to air-gap high contrast grating mirrors demonstrated elsewhere, our grating mirrors are particular since they are supported by thinner /4 aluminium oxide layer, and thus are mechanically robust and thinner than usual designs. Sub-milliamp threshold currents and single-transverse-mode operation was obtained. A hero device exhibited maximum singlemode output power of more than 4 mW at room temperature and 1 mw at 70°C, which are the highest values ever reported from the HCG structures. These results build a bridge between a standard VCSEL and a hybrid laser on silicon, making them of potential use for the realization of silicon photonics.

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Source-ID: 264020
Research output: Contribution to journal → Conference article – Annual report year: 2010 → Research → peer-review

Hybrid vertical cavity laser
A new hybrid vertical cavity laser structure for silicon photonics is suggested and numerically investigated. It incorporates a silicon subwavelength grating as a mirror and a lateral output coupler to a silicon ridge waveguide.

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Contributors: Chung, I., Mørk, J.
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Hybrid Vertical-Cavity Laser
The present invention provides a light source (2) for light circuits on a silicon platform (3). A vertical laser cavity is formed by a gain region (101) arranged between a top mirror (4) and a bottom grating-mirror (12) in a grating region (11) in a silicon layer (10) on a substrate. A waveguide (18, 19) for receiving light from the grating region (11) is formed within or to be connected to the grating region, and functions as an 5 output coupler for the VCL. Thereby, vertical lasing modes (16) are coupled to lateral in-plane modes (17, 20) of the in-plane waveguide formed in the silicon layer, and light can be provided to e.g. photonic circuits on a SOI or CMOS substrate in the silicon.
Numerical methods for modeling photonic-crystal VCSELs

We show comparison of four different numerical methods for simulating Photonic-Crystal (PC) VCSELs. We present the theoretical basis behind each method and analyze the differences by studying a benchmark VCSEL structure, where the PC structure penetrates all VCSEL layers, the entire top-mirror DBR, a fraction of the top-mirror DBR or just the VCSEL cavity. The different models are evaluated by comparing the predicted resonance wavelengths and threshold gains for different hole diameters and pitches of the PC. The agreement between the models is relatively good, except for one model, which corresponds to the effective index method. The simulation results elucidate the strength and weaknesses of the analyzed methods; and outline the limits of applicability of the different models.
Optimization of VCSELs for Self-Mixing Sensing

We have simulated the variations in optical output power from a vertical-cavity surface-emitting laser (VCSEL) subject to self-mixing feedback, which is very important for applications in sensing. In order to maximize the self-mixing signal for a given feedback we have optimized the epitaxial design of the VCSEL. The most important parameters are the number of quantum wells (gain), the number of Bragg mirrors (reflection), and the detector position.

Polymer-coated vertical-cavity surface-emitting laser diode vapor sensor

We report a new method for monitoring vapor concentration of volatile organic compounds using a vertical-cavity surface-emitting laser (VCSEL). The VCSEL is coated with a polymer thin film on the top distributed Bragg reflector (DBR). The analyte absorption is transduced to the electrical domain through modulation of the VCSEL output power as the polymer swell. We have investigated the responsivity of this technique experimentally using a plasma polymerized polystyrene coating and explain the results theoretically as a reflectance modulation of the top DBR.
Silicon-photonics light source realized by III-V/Si grating-mirror laser

A III–V/Si vertical-cavity in-plane-emitting laser structure is suggested and numerically investigated. This hybrid laser consists of a distributed Bragg reflector, a III–V active region, and a high-index-contrast grating HCG connected to an in-plane output waveguide. The HCG and the output waveguide are made in the Si layer of a silicon-on-insulator wafer by using Si-electronics-compatible processing. The HCG works as a highly-reflective mirror for vertical resonance and at the same time routes light to the in-plane output waveguide. Numerical simulations show superior performance compared to existing silicon light sources.
**Transverse-mode-selectable microlens vertical-cavity surface-emitting laser**

A new vertical-cavity surface-emitting laser structure employing a thin microlens is suggested and numerically investigated. The laser can be made to emit in either a high-power Gaussian-shaped single-fundamental mode or a high-power doughnut-shaped higher-order mode. The physical origin of the mode selection properties of the new structure is rigorously analyzed and compared to other structures reported in the literature. The possibility of engineering the emission shape while retaining strong single mode operation is highly desirable for low-cost mid-range optical interconnects applications as well as the compact optical trapping of high-refractive-index dielectric particles and low-refractive-index, absorbing, or metallic particles.

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Research output: Contribution to journal → Journal article – Annual report year: 2010 → Research → peer-review

**Acetone vapor sensing using a vertical cavity surface emitting laser diode coated with polystyrene**

We report theoretical and experimental on a new vapor sensor, using a single-mode vertical-cavity surface-emitting laser (VCSEL) coated with a polymer sensor coating, which can detect acetone vapor at a volume fraction of 2.5%. The sensor provides the advantage of standard packaging, small form-factor, mechanical stability and low cost when combined with a monolithically integrated photodiode detector.

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Source-ID: 251062
Research output: Chapter in Book/Report/Conference proceeding → Conference abstract in proceedings – Annual report year: 2009 → Research → peer-review
Advanced vectorial simulation of VCSELs with nano structures invited paper

The single-mode properties and design issues of three vertical-cavity surface-emitting laser (VCSEL) structures incorporating nano structures are rigorously investigated. Nano structuring enables to deliver selective pumping or loss to the fundamental mode as well as stabilizing the output polarization state. Comparison of three vectorial simulation methods reveals that the modal expansion method is suitable for treating the nano structured VCSEL designs.

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Contributors: Chung, I., Mørk, J.
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Selectively-pumped grating-mirror long-wavelength VCSEL

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The optical chip: high speed and diminutive size

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Publisher: DTU Fotonik
Time-resolved measurement of the light-current characteristic of a coated VCSEL diode in acetone vapour

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Event: Abstract from International Nano-Optoelectronics Workshop, Stockholm, Sweden and Berlin, Germany.

Vectorial analysis of dielectric photonic crystal VCSEL
A new vertical-cavity surface-emitting laser structure employing a dielectric photonic crystal mirror has been suggested and been numerically investigated. The new structure has a smaller threshold gain, a moderate strength of single-transverse-mode operation, a high quality of emission beam free from the scattering, and a potential of considerably increasing the single-mode output power.

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**Broadband subwavelength grating mirror and its application to vertical-cavity surface-emitting laser**
Various high-index-contrast sub-wavelength grating (HCG) mirror designs have been investigated. It reveals that transverse magnetic (TM-) and transverse electric (TE-) HCG reflect the incident fields in quite different ways and that the TM-HCG enables very thin gap below the grating. Based on these results, a new HCG VCSEL design with a thin oxide gap has been suggested. The thin oxide gap structure has a number of advantages including easier fabrication, better mechanical stability, and very strong single-mode properties.
Subwavelength grating-mirror VCSEL with a thin oxide gap

A new vertical-cavity surface-emitting laser (VCSEL) structure based on a subwavelength grating mirror and a thin oxide gap is suggested and numerically investigated. The structure is shown to exhibit similar threshold gain, suppression of higher order transverse modes, and polarization stability as a grating-mirror VCSEL reported in the literature based on a thick air gap. The thin oxide gap structure has a number of advantages including easier fabrication, better mechanical stability, and very strong single-mode properties.

General information
Publication status: Published
Organisations: Quantum and Laser Photonics, Department of Photonics Engineering
Contributors: Chung, I., Mørk, J., Gilet, P., Chelnokov, A.
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Finite-difference time-domain analysis of micro-lens integrated vertical-cavity surface-emitting lasers

General information
Publication status: Published
Organisations: Nanophotonics, Department of Photonics Engineering
Contributors: Chung, I., Lee, Y. T.
Publication date: 2007
Peer-reviewed: Yes
Source: orbit
Source-ID: 209644
Research output: Contribution to journal » Journal article – Annual report year: 2008 » Research » peer-review

Opto-VLSI-based reconfigurable free-space optical interconnects architecture
This paper presents a short-distance reconfigurable high-speed optical interconnects architecture employing a Vertical Cavity Surface Emitting Laser (VCSEL) array, Opto-very-large-scale-integrated (Opto-VLSI) processors, and a photodetector (PD) array. The core component of the architecture is the Opto-VLSI processor which can be driven by digital phase steering and multicasting holograms that reconfigure the optical interconnects between the input and output ports. The optical interconnects architecture is experimentally demonstrated at 2.5 Gbps using high-speed 1×3 VCSEL array and 1×3 photoreceiver array in conjunction with two 1×4096 pixel Opto-VLSI processors. The minimisation of the crosstalk between the output ports is achieved by appropriately aligning the VCSEL and PD elements with respect to the Opto-VLSI processors and driving the latter with optimal steering phase holograms.

General information
Publication status: Published
Organisations: Quantum and Laser Photonics, Department of Photonics Engineering, Edith Cowan University, Gwangju Institute of Science and Technology
Contributors: Aljada, M., Alameh, K., Chung, I., Lee, Y. T.
Publication date: 2007

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Research output: Chapter in Book/Report/Conference proceeding » Article in proceedings – Annual report year: 2007 » Research » peer-review

A method to tune the cavity-mode wavelength of resonant cavity-enhanced photodetectors for bidirectional optical interconnects
A method to tune the cavity-mode wavelength of resonant cavity-enhanced photodetectors (RCE-PDs) is proposed. The proposed method can enable monolithic integration of vertical-cavity surface-emitting lasers and RCE-PDs to be a cost-competitive choice for bidirectional optical interconnection by reducing the amount of component and packaging costs presently involved. The properly tuned cavity-mode wavelengths remain effectively aligned within a temperature range of -10 degrees C similar to 50 degrees C.
High Speed (2.5Gbps) reconfigurable inter-chip optical interconnects using opto-VLSI processors

Effect of outermost layers on resonant cavity enhanced devices

Effect of outermost layers on resonant cavity enhanced devices
Projects:

**VCSEL’S til medicinsk diagnosticering**
Ansbæk, T., PhD Student, Department of Photonics Engineering
Yvind, K., Main Supervisor
Chung, I., Supervisor
Larsson, D., Supervisor
Hvam, J. M., Examiner
Amann, M. C., Examiner
Birkedal, D., Examiner
Technical University of Denmark
01/11/2008 → 20/09/2012
Award relations: VCSEL’S til medicinsk diagnosticering
Project: PhD

**Ultrahigh-speed Si-integrated on-chip laser**
Tandukar, S., PhD Student, Department of Photonics Engineering
Chung, I., Main Supervisor
Ottaviano, L., Supervisor
Frandsen, L. H., Examiner
Almuneau, G., Examiner
Hammar, M., Examiner
Samfinansieret - Andet
15/11/2015 → 14/01/2019
Award relations: Ultrahigh-speed Si-integrated on-chip laser
Project: PhD

**Ultrahigh-speed hybrid III-C-on-Si lasers**
Topic, V., PhD Student, Department of Photonics Engineering
Chung, I., Main Supervisor
Ottaviano, L., Supervisor
Yvind, K., Examiner
Birkedal, D., Examiner
Bakir, B. B., Examiner
Samfinansieret - Andet
15/03/2015 → 14/02/2019
Award relations: Ultrahigh-speed hybrid III-C-on-Si lasers
Project: PhD

**Electrically pumped nanolaser for terabit communication**
Lupi, A., PhD Student, Department of Photonics Engineering
Yvind, K., Main Supervisor
Chung, I., Supervisor
Oxenløwe, L. K., Examiner
Birkedal, D., Examiner
Roelkens, G., Examiner
Eksternt finansieret virksomhed
15/03/2012 → 17/02/2016
Award relations: Electrically pumped nanolaser for terabit communication
Project: PhD

**Hybrid III-V-on-Si laser with ultralow energy consumption**
Taghizadeh, A., PhD Student, Department of Photonics Engineering
Chung, I., Main Supervisor
Mørk, J., Supervisor
Laurynenka, A., Examiner
High-speed Laser with Ultralow Energy Consumption for Silicon Photonics

This project aims to investigate and demonstrate a novel laser structure that appears as a very promising high-speed, ultralow-energy-consumption light source for silicon photonics. The laser structure differs from conventional designs in that the active material (III-V semiconductor) is incorporated into one of the mirrors, a so-called high-index-contrast grating mirror, which provides very strong field confinement within the grating. This allows ultra-small lasers with very efficient energy conversion of electrons to photons simultaneously with a high modulation bandwidth. At the same time, the laser can be integrated onto a silicon chip, allowing the realization of the long-time dream of integrating photonics and electronics on the same chip. In this integrated chip, one can exploit the properties of electrons for processing data and the properties of photons for transmitting data. This vision of silicon photonics is being actively pursued by companies like IBM and Intel, but the light source remains the critical component. Considerable interest shown by several companies reflects the potential of this innovative laser structure. The novel structure that we wish to investigate, however, has some fundamental challenges. Thus, a good understanding of the mode properties, the electrical transport and the thermal issues is needed. Also, the technology for integrating the active material (buried heterostructure) within the grating mirror needs to be developed. The project will thus rely on a close interaction between theory, design, fabrication and characterization. The knowledge gained in this project can form the background for research and development of a new class of ultra-small and highly-integrated photonic devices.

Chung, I., Project Manager, Quantum and Laser Photonics, Department of Photonics Engineering, Nanophotonics
Ran, Q., Project Participant, Quantum and Laser Photonics, Department of Photonics Engineering
Mørk, J., Project Participant, Quantum and Laser Photonics, Department of Photonics Engineering, Nanophotonics
NATEC: 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.

Hybrid vertical cavity laser
In the present invention, a new concept of hybrid laser diodes is suggested. In this laser structure, a light-generating active material that is made of compound semiconductor is integrated with a silicon electronics platform including a nano-structured mirror, in a novel way. This hybrid laser is predicted to have superior laser performance such as much higher output power and much lower power consumption, compared to existing laser technologies and known proposals. Thus, this hybrid laser will be a key building block for several important applications such as seen in Table 1: 1) Computers with optical interconnects, 2) optical data cable (e.g., USB 3.0), 3) much faster and cheap internet connections, and 4) portable diagnosis tool for diseases or chemicals. Practically, this hybrid laser has a potential to enable these applications, since it can be produced at low costs, exploiting mature silicon processing technologies.

Monomode surface emitting lasers
A vertical-cavity laser consists of a top mirror, an optical cavity containing a gain medium, and a bottom mirror. Its typical size is similar as a human hair. Light generated in the gain medium passes through the optical cavity and are reflected back to the cavity by the two mirrors. By repeating this cycle, the light is amplified and laser action starts. Due to this light generation mechanism, the properties of a laser is significantly influenced by the properties of the optical cavity and two mirrors. Gratings are one- or two-dimensional periodic structures mad of semiconductor or dielectrics. A one-dimensional grating looks like a barbecue grill and its typical size is 1/200 times thinner than a human hair. Specially designed gratings have high reflectivity adequate for laser mirrors. One of the important features of the grating mirror is that its reflection properties can be easily controlled by changing the grating design. Thus, using a grating mirror instead of a conventional mirror opens a unique way of designing laser properties through engineering the grating mirror, but also possibilities of...
many novel applications, which was not feasible with the conventional mirrors. In this project, the physics of the grating mirror and its effects on laser properties will be rigorously investigated. By using this understanding, two novel application devices will be optimized. For this aim, an advanced laser simulator will be developed for the first time.

Chung, I., Project Manager, Department of Photonics Engineering, Quantum and Laser Photonics

Mørk, J., Project Participant, Department of Photonics Engineering, Quantum and Laser Photonics

Laurynenka, A., Project Participant, Department of Photonics Engineering, Metamaterials

**Project ID:** 70477

**Forskningsrådene - Andre:** DKK2,150,000.00

**01/01/2009 → 31/12/2011**

**Award relations:** Thermo-electro-optical analysis of subwavelength grating-mirror VCSELs

**Project:** Research

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**Self-configurable optical links**

Peucheret, C., Project Manager, Department of Photonics Engineering

Jeppesen, P., Project Participant, Department of Photonics Engineering

Mørk, J., Project Participant, Department of Photonics Engineering

Chung, I., Project Participant, Department of Photonics Engineering

Seoane, J., Project Participant, Department of Photonics Engineering

Christensen, S. B., Contact Person, IPtronics A/S

Lysdal, H., Project Participant, IPtronics A/S

Johansen, E., Project Participant, IPtronics A/S

Keil, U., Project Participant, IPtronics A/S

**Project ID:** 70627

**Forsk. Private danske - Fonde:** DKK2,160,000.00

**01/02/2010 → 28/02/2012**

**Collaborators:** IPtronics A/S

**Award relations:** Self-configurable optical links

**Project:** Research

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**Activities:**

**Ohmic Contacts to n-Type InP for High-Speed Silicon-on-Chip Vertical-Cavity Lasers**

**Period:** 2 Jul 2018 → 6 Jul 2018

Vladimir Topic (Speaker)

Sushil Tandukar (Other)

Gyeong Cheol Park (Other)

Il-Sug Chung (Other)

**Department of Photonics Engineering**

**Description**

Poster presentation

**Degree of recognition:** International

**Related event**

**23rd OptoElectronics and Communications Conference**

**02/07/2018 → 06/07/2018**

Jeju, Korea, Republic of

**Activity:** Talks and presentations › Conference presentations

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**Ultrahigh-speed hybrid VCSEL for short-distance optical interconnects**

**Period:** 28 Aug 2017 → 1 Sep 2017

Vladimir Topic (Speaker)

Gyeong Cheol Park (Other)

Sushil Tandukar (Other)

Luisa Ottaviano (Other)

Il-Sug Chung (Other)

**Department of Photonics Engineering**
**Description**
Poster presentation  
Degree of recognition: International

**Related event**

*VI International School and Conference on Photonics*
**28/08/2017 → 01/09/2017**
Belgrade, Serbia
Activity: Talks and presentations › Conference presentations

**Annual Conference on Commercialization of Micro and Nano Systems**
**Period: 30 Aug 2009 → 4 Sep 2009**
Il-Sug Chung (Participant)
Department of Photonics Engineering  
Quantum and Laser Photonics

**Description**
Annual Conference on Commercialization of Micro and Nano Systems (COMS); 14: Acetone vapor sensing using a vertical cavity surface emitting laser diode coated with polystyrene

We report theoretical and experimental on a new vapor sensor, using a single-mode vertical-cavity surface-emitting laser (VCSEL) coated with a polymer sensor coating, which can detect acetone vapor at a volume fraction of 2.5%. The sensor provides the advantage of standard packaging, small form-factor, mechanical stability and low cost when combined with a monolithically integrated photodiode detector.

Place: Copenhagen, Denmark

**Related event**

*Annual Conference on Commercialization of Micro and Nano Systems*
**30/08/2009 → 04/09/2009**
Copenhagen, Denmark
Activity: Attending an event › Participating in or organising a conference