Avalence force field-Monte Carlo algorithm for quantum dot growth modeling

We present a novel kinetic Monte Carlo version for the atomistic valence force fields algorithm in order to model a self-assembled quantum dot growth process. We show our atomistic model is both computationally favorable and capture more details compared to traditional kinetic Monte Carlo models based on continuum elastic models. We anticipate the model will be useful to experimentalists in understanding better the growth dynamics of quantum dot systems.
Demonstration of a self-pulsing photonic crystal Fano laser

The semiconductor lasers in use today rely on various types of cavity, making use of Fresnel reflection at a cleaved facet', total internal reflection between two different median, Bragg reflection from a periodic stack of layers(3-8), mode coupling in a high contrast grating(9,10) or random scattering in a disordered medium'. Here, we demonstrate an ultrasmall laser with a mirror, which is based on Fano interference between a continuum of waveguide modes and the discrete resonance of a nanocavity. The rich physics of Fano resonances(12) has recently been explored in a number of different photonic and plasmonic systems(13,14). The Fano resonance leads to unique laser characteristics. In particular, because the Fano mirror is very narrowband compared to conventional laser mirrors, the laser is single mode and can be modulated via the mirror. We show, experimentally and theoretically, that nonlinearities in the mirror may even promote the generation of a self-sustained train of pulses at gigahertz frequencies, an effect that has previously been observed only in macroscopic lasers(15-18). Such a source is of interest for a number of applications within integrated photonics.
Enhancing Optical Forces in InP-Based Waveguides

Cantilever sensors are among the most important microelectromechanical systems (MEMS), which are usually actuated by electrostatic forces or piezoelectric elements. Although well-developed microfabrication technology has made silicon the prevailing material for MEMS, unique properties of other materials are overlooked in this context. Here we investigate optically induced forces exerted upon a semi-insulating InP waveguide suspended above a highly doped InP: Si substrate, in three different regimes: the epsilon-near-zero (ENZ), with excitation of surface plasmon polaritons (SPPs) and phonons excitation. An order of magnitude amplification of the force is observed when light is coupled to SPPs, and three orders of magnitude amplification is achieved in the phonon excitation regime. In the ENZ regime, the force is found to be repulsive and higher than that in a waveguide suspended above a dielectric substrate. Low losses in InP: Si result in a big propagation length. The induced deflection can be detected by measuring the phase change of the light when passing through the waveguide, which enables all-optical functioning, and paves the way towards integration and miniaturization of micro-cantilevers. In addition, tunability of the ENZ and the SPP excitation wavelength ranges, via adjusting the carrier concentration, provides an extra degree of freedom for designing MEMS devices.

General information

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Organisations: Department of Photonics Engineering, Plasmonics and Metamaterials, Nanophotonic Devices, Centre of Excellence for Silicon Photonics for Optical Communications, Technical University of Denmark
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Number of pages: 8
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Experimental demonstration of a Fano laser based on photonic crystals

Conventional semiconductor laser mirrors are based on Fresnel reflection [1], Bragg reflection [2, 3] or total internal reflection [4]. Here we demonstrate a new laser concept using photonic crystals (PhC), with a mirror based on Fano interference between a waveguide continuum and a discrete resonance of a nanocavity [5]. We show that the very narrowband feature of the Fano resonance [6] can lead to single mode lasing. In addition, when combined with optical nonlinearity, the highly dispersive feature of the Fano resonance can promote self-pulsations at gigahertz frequencies [7], which was previously observed only in macroscopic lasers [8].

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Fabrication and experimental demonstration of photonic crystal laser with buried heterostructure

Development of ultra-small and efficient laser sources for photonic integrated circuits is one of the main cornerstones in achieving the requirements imposed for on-chip optical interconnects [1]. The InP photonic crystal (PhC) platform with selectively embedded gain medium [2] is a promising way of separating active light amplification regions from passive regions for light propagation without induced absorption losses and surface recombination. The main focus of this work is the fabrication and experimental demonstration of a buried heterostructure (BH) photonic crystal laser bonded to a silicon wafer, illustrating the effective single-platform active-passive material integration method.

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High Q gallium nitride microring resonators
Summary form only given. Gallium nitride (GaN) is a promising material for nonlinear microresonators. It has large intrinsic $\chi(2)$ and $\chi(3)$, excellent thermal properties and a relatively large bandgap [1] and can be used for example for parametric conversion and frequency doubling [2]. Furthermore it is quite resilient and can withstand high temperatures and power. In this paper, we demonstrate GaN microring resonators with a quality factor (Q) larger than 105, which, to the best of our knowledge, is the highest demonstrated Q for microring resonators in a pure GaN platform [3].

General information
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Hybrid Si-on-chip Lasers with Nano Structures

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Lasers, switches and non-reciprocal elements based on photonic crystal Fano resonances

We discuss the realization of active photonic devices exploiting Fano resonances in photonic crystal membranes.

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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, Technical University of Denmark
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Mid-IR optical properties of silicon doped InP

InP is one of the most important materials for optoelectronics as a direct bandgap semiconductor, which can also be regarded as a low loss alternative plasmonic material for mid-infrared (mid-IR). The InP films studied in this work were grown by metal-organic vapor phase epitaxy (MOVPE). The effect of growth conditions on the optical and electrical properties of silicon doped InP (InP:Si) in the wavelength range from 3 to 40 μm was studied. The carrier concentration of up to $3.9 \times 10^{19}$ cm$^{-3}$ is achieved by optimizing the growth conditions. The dielectric function, effective mass of electrons and plasma frequency were determined by Fourier transform infrared spectroscopy (FTIR) for different carrier density levels. The plasma frequency can be tuned effectively via doping from 18.43 to 50.5 THz. Based on the experimental results, a semi-empirical formula for the plasma frequency, as a function of carrier concentration, is derived. Comparison to other semiconductors shows superior plasmonic performance of InP:Si in terms of propagation length and surface confinement.

On the high characteristic temperature of an InAs/GaAs/InGaAsP QD laser with an emission wavelength of ~1.5 μm on an InP substrate

We report on a study of lasers with an emission wavelength of about 1.5 μm and high temperature stability, synthesized on an InP (001) substrate. Self-organized InAs quantum dots capped with a thin GaAs layer are used as the active region of the laser. A quaternary InGaAsP solid solution with a band-gap width of 1.15 eV serves as the waveguide/matrix layer. A high characteristic temperature of the threshold current, $T_0 = 205$ K, is reached in the temperature range 20–50°C in ridge-waveguide laser diodes. A correlation between the values of $T_0$ and the band-gap width of the waveguide layers is found.
Photonic crystal Fano lasers and Fano switches

We show that Fano resonances can be realized in photonic crystal membrane structures by coupling line-defect waveguides and point-defect nanocavities. The Fano resonance can be exploited to realize optical switches with very small switching energy, as well as Fano lasers, that can generate short optical pulses.

Photonic crystal Fano resonances for realizing optical switches, lasers and non-reciprocal elements

We present our work on photonic crystal membrane devices exploiting Fano resonance between a line-defect waveguide and a side coupled nanocavity. Experimental demonstration of fast and compact all-optical switches for wavelength-conversion is reported. It is shown how the use of an asymmetric structure in combination with cavity-enhanced nonlinearity can be used to realize non-reciprocal transmission at ultra-low power and with large bandwidth. A novel type of laser structure, denoted a Fano laser, is discussed in which one of the mirrors is based on a Fano resonance. Finally, the design, fabrication and characterization of grating couplers for efficient light coupling in and out of the indium phosphide photonic crystal platform is discussed.

Specific features of waveguide recombination in laser structures with asymmetric barrier layers

The spatial distribution of the intensity of the emission caused by recombination appearing at a high injection level (up to 30 kA/cm²) in the waveguide layer of a GaAs/AlGaAs laser structure with GaInP and AlGaInAs asymmetric barrier layers
is studied by means of near-field scanning optical microscopy. It is found that the waveguide luminescence in such a laser, which is on the whole less intense as compared to that observed in a similar laser without asymmetric barriers, is non-uniformly distributed in the waveguide, so that the distribution maximum is shifted closer to the p-type cladding layer. This can be attributed to the ability of the GaInP barrier adjoining the quantum well on the side of the n-type cladding layer to suppress the hole transport.
Towards Ultra-High Q Microresonators in High-Index Contrast AlGaAs-On-Insulator

We demonstrate an AlGaAs-on-insulator microresonator with intrinsic Q as high as 690,000. We optimized the fabrication and investigated the impact of waveguide dimension on the Q in such a high-index contrast platform.

Высокая характеристическая температура лазера на квантовых точках InAs/GaAs/InGaAsP с длиной волны излучения около 1.5 мкм, синтезированного на подложке InP

We report on high temperature stability of a near-1.5 µm laser synthesized on an InP (001) substrate. Self-organized InAs quantum dots capped with a thin GaAs layer were used as an active region of the laser. An InGaAsP quaternary alloy having the bandgap energy of 1.15 eV was utilized as a waveguiding/matrix layer. A high characteristic temperature of the threshold current of $T_0 = 205$ K, evaluated in the temperature range of 20–50°C, was achieved in ridge waveguide laser diodes. A correlation of $T_0$ values with the bandgap energy of the waveguiding layer was found.
Temperature characteristics of InAs/InGaAsP quantum dot (QD) lasers synthesized on InP (001) substrate are presented. The lasers demonstrate high temperature stability: a threshold current characteristic temperature as high as 205 K in the temperature range between 20 to 50°C was measured. Lasing wavelength of 1.5 μm was achieved by covering QDs with 1.7 monolayers of GaAs.
Lasing action in semiconductors, Design of specific laser systems, Semiconductor lasers, gallium arsenide, III-V semiconductors, indium compounds, monolayers, quantum dot lasers, semiconductor quantum dots, InAs-InGaAsP-InP quantum dot laser, temperature stability, InP (001) substrate, threshold current, lasing wavelength, GaAs monolayers, temperature 205 K, temperature 20 degC to 50 degC, wavelength 1.5 mum, InAs–InGaAs–InP
An Ultra-Efficient Nonlinear Platform: AlGaAs-On-Insulator

The combination of nonlinear and integrated photonics enables applications including optical signal processing, multi-wavelength lasers, metrology, spectroscopy, and quantum information science. Silicon-on-insulator (SOI) has emerged as a promising platform [1, 2] due to its high material nonlinearity and its compatibility with the CMOS industry. However, silicon suffers two-photon absorption (TPA) in the telecommunication wavelength band around 1.55 µm, which hampers its applications. Different platforms have been proposed to avoid TPA in the telecom wavelength range such as Si3N4 and Hydex [3]. Though tremendous technological work in those platforms have greatly improved device performances, the relatively low intrinsic material nonlinearities of those materials limit device performances concerning efficiency. Therefore, an integrated nonlinear platform that combines a high material nonlinearity, a high-index contrast as SOI, and low linear and nonlinear losses is highly desired. Aluminium gallium arsenide (AlGaAs) was early identified as a promising candidate and even nominated as “the silicon of nonlinear optical material” [4] when operated just below half its bandgap energy. It offers a nonlinear index (n2) on the order of 10−17 W/m2 and a high refractive index (n ≈3.3), a large transparency window (from near- to mid-infrared), and the ability to engineer the material bandgap to mitigate TPA [5]. In this presentation, we introduce AlGaAs-on-insulator (AlGaAsOI) platform which combines both strong nonlinear light-matter interaction induced by high-index contrast layout and the potential to fabricate complex designs similar to what is done in silicon-on-insulator photonics. We demonstrate low loss (~ 1.4 dB/cm) nanowaveguides with an ultra-high nonlinear coefficient (~660W−1m−1 ) and microring resonators with quality factors on the order of 105 [6]. The large effective nonlinearity of such platform enables efficient nonlinear processes such as high-speed optical signal processing [7], supercontinuum generation, and Kerr frequency comb generation [8]. Moreover, the required operation power for signal generation processes such as optical parametric oscillation in the AlGaAsOI platform is well within the range of standard on-chip light sources. In line with the fast-growing hybrid integration trend to combine different materials in multiple levels on a single CMOS compatible chip, the AlGaAsOI platform is very promising for realizing a compact fully-integrated multi-wavelength light source for high bandwidth optical interconnects.

Broadband and Efficient Dual-Pump Four-Wave Mixing in AlGaAs-On-Insulator Nano-Waveguide

We characterize dual-pump four-wave-mixing in AlGaAs-on-insulator nano-waveguides and demonstrate an output conversion efficiency as high as -8.5 dB at 155-mW pump power. The idler optical signal-to-noise ratio is above 25 dB over a 26-nm bandwidth.
Broadband and efficient dual-pump four-wave-mixing in AlGaAs-on-insulator nano-waveguides

We characterize dual-pump four-wave-mixing in AlGaAs-on-insulator nano-waveguides and demonstrate an output conversion efficiency as high as −8.5 dB at 155-mW pump power. The idler optical signal-to-noise ratio is above 25 dB over a 26-nm bandwidth.

Characterization of a Wavelength Converter for 256-QAM Signals Based on an AlGaAs-On-Insulator Nano-waveguide

High efficiency and broadband wavelength conversion in a 9-mm AlGaAs-On-Insulator waveguide is shown to provide high-quality (OSNR > 30 dB) idler generation over a 28-nm bandwidth enabling error-free conversion of 10-GBd 256-QAM with OSNR penalty below 2.5 dB.
Efficient frequency comb generation in AlGaAs-on-insulator
The combination of nonlinear and integrated photonics enables Kerr frequency comb generation in stable chip-based microresonators. Such a comb system will revolutionize applications, including multi-wavelength lasers, metrology, and spectroscopy. Aluminum gallium arsenide (AlGaAs) exhibits very high material nonlinearity and low nonlinear loss. However, difficulties in device processing and low device effective nonlinearity made Kerr frequency comb generation elusive. Here, we demonstrate AlGaAs-on-insulator as a nonlinear platform at telecom wavelengths with an ultra-high device nonlinearity. We show high-quality-factor (Q > 105) micro-resonators where optical parametric oscillations are achieved with milliwatt-level pump threshold powers, which paves the way for on-chip pumped comb generation.

Highly doped InP as a low loss plasmonic material for mid-IR region
We study plasmonic properties of highly doped InP in the mid-infrared (IR) range. InP was grown by metal-organic vapor phase epitaxy (MOVPE) with the growth conditions optimized to achieve high free electron concentrations by doping with silicon. The permittivity of the grown material was found by fitting the calculated infrared reflectance spectra to the measured ones. The retrieved permittivity was then used to simulate surface plasmon polaritons (SPPs) propagation on flat and structured surfaces, and the simulation results were verified in direct experiments. SPPs at the top and bottom interfaces of the grown epilayer were excited by the prism coupling. A high-index Ge hemispherical prism provides efficient coupling conditions of SPPs on flat surfaces and facilitates acquiring their dispersion diagrams. We observed diffraction into symmetry-prohibited diffraction orders stimulated by the excitation of surface plasmon-polaritons in a periodically structured epilayer. Characterization shows good agreement between the theory and experimental results and confirms that highly doped InP is an effective plasmonic material aiming it for applications in the mid-IR wavelength range.
Low-loss high-confinement waveguides and microring resonators in AlGaAs-on-insulator

AlGaAs is a promising material for integrated nonlinear photonics due to its intrinsic high nonlinearity. However, the challenging fabrication of deep etched AlGaAs devices makes it difficult to realize high-performance devices such as low-loss dispersion engineered waveguides and high quality microring resonators. Here, we report a process to make high-quality AlGaAs-on-insulator (AlGaAsOI) wafers where high confinement waveguides can be realized. Using optimized patterning processes, we fabricated AlGaAsOI waveguides with propagation losses as low as 1 dB/cm and microring resonators with quality factors up to 350,000 at telecom wavelengths. Our demonstration opens new prospects for AlGaAs devices in integrated nonlinear photonics.
Nonlinear Optics in AlGaAs on Insulator

AlGaAs on insulator is a powerful nonlinear platform sporting a high effective nonlinearity and the possibility to fabricate complex designs. We will present low loss waveguides enabling efficient optical signal processing and Kerr comb generation.

General information
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Optically pumped 1550nm wavelength tunable MEMS VCSEL
The paper presents the design and fabrication of an optically pumped 1550nm tunable MEMS VCSEL with an enclosed MEMS. The MEMS is defined in SOI and the active material, an InP wafer with quantum wells are bonded to the SOI and the last mirror is made from the deposition of dielectric materials. The design brings in flexibility to fabricate MEMS VCSELs over a wider range of wavelengths. The paper discusses results from the simulations and bonding results from fabrication. The device will push the boundaries for wavelength sweep speed and bandwidth.

Phase-sensitive Four-wave Mixing in AlGaAs-on-Insulator Nano-waveguides
Phase-sensitive four-wave mixing is experimentally demonstrated in a 5-mm long AlGaAsOI nano-waveguide. More than 7 dB of phase-sensitive extinction ratio are reported without neither using active biasing nor polarization-assisted schemes. Measurements show a good match with numerical predictions.
Silicon doped InP as an alternative plasmonic material for mid-infrared

Silicon-doped InP is grown on top of semi-insulating iron-doped and sulfur-doped InP substrates by metalorganic vapor phase epitaxy (MOVPE), and the growth parameters are adjusted to obtain various free carrier concentrations from $1.05 \times 10^{19}$ cm$^{-3}$ up to $3.28 \times 10^{19}$ cm$^{-3}$. Midinfrared (IR) reflection spectra of the samples with different carrier concentrations are used to retrieve pertaining dielectric functions as the key factor for understanding plasmonic behavior of InP:Si in the mid-IR wavelength range.

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Single-Source AlGaAs Frequency Comb Transmitter for 661 Tbit/s Data Transmission in a 30-core Fiber

We demonstrate an AlGaAs-on-insulator nano-waveguide-based frequency comb with high OSNR enabling a single-source to fully load a 9.6-km heterogeneous 30-core fibre with 661 Tbit/s data achieved by 30xcores, 80xWDM, 40 Gbaud, and PDM-16QAM

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Supercontinuum Generation in AlGaAs-On-Insulator Nano-Waveguide at Telecom Wavelengths

We characterize pulse spectral broadening in an AlGaAs-on-insulator nano-waveguide at telecom wavelengths. We obtain a supercontinuum over 500 nm (30-dB bandwidth) with 410-fs pulses and self-phase modulation broadening covering the C-band with 1.1-ps pulses.

Surface Plasmons on Highly Doped InP

Silicon doped InP is grown by metal-organic vapor phase epitaxy (MOVPE) using optimized growth parameters to achieve high free carrier concentration. Reflectance of the grown sample in mid-IR range is measured using FTIR and the result is used to retrieve the parameters of the dielectric function. The derived dielectric function is used to simulate the excitation of surface plasmons by a diffraction grating made of the grown material. The grating structure is fabricated using standard nanofabrication techniques. Spectral features from the grating agree well with the simulations and show sp coupling at predicted angles of incidence and wavelengths.
Threshold Characteristics of Slow-Light Photonic Crystal Lasers

The threshold properties of photonic crystal quantum dot lasers operating in the slow-light regime are investigated experimentally and theoretically. Measurements show that, in contrast to conventional lasers, the threshold gain attains a minimum value for a specific cavity length. The experimental results are explained by an analytical theory for the laser threshold that takes into account the effects of slow light and random disorder due to unavoidable fabrication imperfections. Longer lasers are found to operate deeper into the slow-light region, leading to a trade-off between slow-light induced reduction of the mirror loss and slow-light enhancement of disorder-induced losses.

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Scopus rating (2010): SJR 6.418 SNIP 2.764
Web of Science (2010): Indexed yes
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Scopus rating (2009): SJR 6.342 SNIP 2.94
Web of Science (2009): Indexed yes
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 frequencies 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 avery small heat generation at high bitrates, which are highly desirable for both on-chip and off-chip applications.

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Vertical-cavity laser with a novel grating mirror

Hybrid III-V on silicon (Si) 'vertical cavity lasers' (hybrid VCLs), which can emit light laterally into a Si waveguide, are fabricated and investigated. The Si-integrated hybrid VCL consists of a top dielectric Bragg reflector (DBR), a III-V active layer, and a bottom high contrast grating (HCG) mirror formed in the Si layer of a Si-on-insulator (SOI) wafer. The hybrid VCLs have a promising potential for very high-speed operation and low energy consumption, which is ideal for optical interconnects as well as large data center applications. For the experimental demonstration of hybrid VCLs, CMOS-compatible fabrication processes are designed and developed. These include a low-temperature direct wafer bonding process for integrating III-V layers onto a SOI wafer, as well as two types of DBR formation processes: a lift-off process and an etch-back process. Based on these, two versions of optically-pumped hybrid VCLs have been fabricated. The first version of hybrid VCL is designed for demonstrating in-plane emission into a Si waveguide. The in-plane emission is enabled by the bottom HCG abutting the Si waveguide, which not only functions as a highly reflective mirror but also routes the light from the vertical cavity laterally into the Si waveguide. The measured inplane emission proves the lasing action with a side-mode suppression ratio (SMSR) of 27.5 dB at a peak wavelength of 1486 nm. The threshold pumping power corresponds to a current injection of 1.1 mA. A signature of highly anisotropic cavity dispersion has been observed and discussed, which is unique for HCG-based vertical cavities. The second version proves the potential for high-speed operation of hybrid VCL structure. In the hybrid VCL structure, the effective cavity length is substantially reduced by using a dielectric DBR and a TM-HCG with a very short evanescent tail. This reduces the photon lifetime of the laser cavity significantly without reducing the mirror reflectivity, leading to a very high intrinsic speed. A 3 dB frequency of 27.2 GHz was measured at a pumping power corresponding to a current injection of 0.7 mA. Since the pumping power was limited by the setup, the 3 dB frequency could be even higher. At this pumping level, the SMSR was about 49 dB and the lasing wavelength was 1541 nm. It was noteworthy that a modulation current efficiency factor (MCEF) of 42.1 GHz/mA1/2, which is 3 times greater than the cutting edge 850 nm VCSEL. Besides, this large MCEF is desirable for significantly lowering the injection current at a given target speed, which implies the amount of heat generation can potentially be reduced by 2 orders of magnitude than the 850 nm VCSELs.

Last, a new type of grating reflector, referred to as hybrid grating (HG) is analyzed and demonstrated, which may improve the heat dissipation efficiency of HCG-based hybrid VCL structures. The HG mirror consisting of a bottom grating and a high-refractive-index cap layer integrated on the grating can provide a stop band even broader than HCG. The interaction
between the cap and the bottom grating results in strong Fabry-Perot (FP) resonance as well as weak guided mode (GM) resonance. Most of the reflected power come from the FP resonance while the GM resonance performs a crucial role in achieving a reflectance of almost 100% as well as broadening the stopband as wide as 300 nm.

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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
Authors: Park, G. C. (Intern), Chung, I. (Intern), Semenova, E. (Intern)
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**A Highly Efficient Nonlinear Platform: AlGaAs-On-Insulator**

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Organisations: Department of Photonics Engineering, Nanophotonic Devices
Authors: Pu, M. (Intern), Ottaviano, L. (Intern), Semenova, E. (Intern), Yvind, K. (Intern)
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Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2015

**AlGaAs-On-Insulator Nanowire with 750 nm FWM Bandwidth, -9 dB CW Conversion Efficiency, and Ultrafast Operation Enabling Record Tbaud Wavelength Conversion**
We present an AlGaAs-on-insulator platform for integrated nonlinear photonics. We demonstrate the highest reported conversion efficiency/length/pump-power, ultra-broadband fourwave mixing, and first-ever wavelength conversion of 1.28-Tbaud serial data signals in a 3-mm long dispersion-engineered AlGaAs nano-waveguide

**General information**
State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, High-Speed Optical Communication
Authors: Pu, M. (Intern), Ottaviano, L. (Intern), Semenova, E. (Intern), Vukovic, D. (Intern), Oxenløwe, L. K. (Intern), Yvind, K. (Intern)
Number of pages: 3
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Publisher: IEEE
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Conference: Optical Fiber Communications Conference and Exposition 2015, Los Angeles, CA, United States, 22/03/2015 - 22/03/2015
AlGaAs-On-Insulator nonlinear photonics
We present an AlGaAs-on-insulator platform for integrated nonlinear photonics. We demonstrate the highest reported conversion efficiency and ultra-broadband four-wave mixing for an integrated platform around 1550nm.

Diode lasers with asymmetric barriers for 850 nm spectral range: experimental studies of power characteristics
It is demonstrated that the use of asymmetric barrier layers in a waveguide of a diode laser suppress non-linearity of light-current characteristic and thus improve its power characteristics under high current injection. The results are presented for 850-nm AlGaAs/GaAs broad-area lasers with GaInP and AlInGaAs asymmetric barriers.
Highly Efficient Four-Wave Mixing in an AlGaAs-On-Insulator (AlGaAsOI) Nano-Waveguide

We propose an AlGaAs-on-insulator platform for nonlinear integrated photonics. We demonstrate highly efficient four-wave mixing in a 3-mm long AlGaAs-on-insulator nanowaveguide. A conversion efficiency of -21.1 dB is obtained with only 45-mW pump.

Bibliographical note
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Main Research Area: Technical/natural sciences
Conference: 2015 Conference on Lasers and Electro-Optics 2015 (CLEO), San Jose, CA, United States, 10/05/2015 - 10/05/2015

DOIs:
10.1364/cleo_si.2015.stu1i.3
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Highly Sensitive Photonic Crystal Cavity Laser Noise Measurements using Bayesian Filtering
We measure for the first time the frequency noise spectrum of a photonic crystal cavity laser with less than 20 nW of fiber-coupled output power using a coherent receiver and Bayesian filtering.

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, a 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 saturation.
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.

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Scopus rating (2016): CiteScore 8.71 SJR 4.151 SNIP 3.583
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Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 5.019 SNIP 4.568 CiteScore 8.62
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Scopus rating (2013): SJR 5.155 SNIP 4.864 CiteScore 9.26
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BFI (2012): BFI-level 1
Scopus rating (2012): SJR 5.159 SNIP 3.679 CiteScore 7.59
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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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Scopus rating (2008): SJR 2.615 SNIP 3.187
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Source: PublicationPreSubmission
III-V/SOI vertical cavity laser structure for 120 Gbit/s speed

Ultrashort-cavity structure for III-V/SOI vertical cavity laser with light output into a Si waveguide is proposed, enabling 17 fJ/bit efficiency or 120 Gbit/s speed. Experimentally, 27-GHz bandwidth is demonstrated at 3.5 times of threshold. © 2015 OSA.

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.

III-V/SOI vertical cavity laser with in-plane output into a Si waveguide
Improvement of power characteristics in 850 nm quantum well laser with asymmetric barriers

Power and spectral characteristics of lasers with asymmetric barrier layers (ABLs) and a wide waveguide are studied. The use of ABLs reduces the saturation of light-current characteristic, associated with the parasitic recombination in the waveguide.

On the optimization of asymmetric barrier layers in InAlGaAs/AlGaAs laser heterostructures on GaAs substrates

Band offsets at the heterointerface are calculated for various combinations of InAlGaAs/AlGaAs heteropairs that can be synthesized on GaAs substrates in the layer-by-layer pseudomorphic growth mode. Patterns which make it possible to obtain an asymmetric barrier layer providing the almost obstruction-free transport of holes and the highest possible barrier height for electrons are found. The optimal compositions of both compounds ((InAlGaAs)-Al-0.232-Ga-0.594-As-0.174/(AlGaAs)-Ga-0.355-As-0.645) at which the flux of electrons across the barrier is at a minimum are determined with consideration for the critical thickness of the indium-containing quaternary solid solution.
Overcoming doping limits in MOVPE grown n-doped InP for plasmonic applications

Effect of the growth parameters on carrier concentration in MOVPE grown silicon-doped InP is studied. The dopant flow, V/III ratio and substrate temperature are optimized by considering the origin of the doping limits. In addition, two different group V precursors, namely PH3 and TBP, are compared. The carrier concentration profile is measured using electrochemical capacitance-voltage (ECV) profilometry and the total concentration of silicon atoms is measured by secondary ion mass spectroscopy (SIMS) in order to evaluate the amount of Si atoms contributing as donors. The electron concentration about 4×10¹⁹cm⁻³ is achieved. Optical properties of the samples are investigated by Fourier transform infrared reflection (FTIR) spectroscopy and are fitted by a Drude-Lorentz function.

General information
State: Published
Organisations: Department of Photonics Engineering, Plasmonics and Metamaterials, Structured Electromagnetic Materials, Nanophotonic Devices
Authors: Panah, M. E. A. (Intern), Xiao, S. (Intern), Lavrinenko, A. (Intern), Semenova, E. (Intern)
Number of pages: 4
Publication date: 2015
Slow-light effects in photonic crystal membrane lasers
In this paper, we present a systematic investigation of photonic crystal cavity laser operating in the slow-light regime. The dependence of lasing threshold on the effect of slow-light will be particularly highlighted.

Suppression of sublinearity of light–current curve in 850 nm quantum well laser with asymmetric barrier layers
An AlGaAs/GaAs quantum well (QW) laser is fabricated with GaInP and AlGaInAs asymmetric barrier layers (ABLs) and its light–current characteristic (LCC) is compared with that of a reference conventional QW laser without ABLs. It was found that the use of the ABLs suppresses the sublinearity of the LCC at high current densities. As a result, the maximum lasing power of 9.2 W, being limited by catastrophic optical mirror damage, is achieved at a considerably lower operating current in the laser with ABLs as compared to the reference laser (12.5 against 20.2 A). The ABL effect is associated with the suppression of the parasitic recombination in the optical confinement layer, as confirmed by a decrease of the intensity of the spontaneous emission from the layer.
Tailoring quantum structures for active photonic crystals

This work is dedicated to the tailoring of quantum structures, with particular attention to the integration of selective area grown (SAG) active material into photonic crystal (PhC) slabs. The platform based on active PhC is vital to the realization of highly efficient elements with low energy consumption for on-chip and chip-to-chip optical communication. In order to develop metal-organic vapor phase epitaxial selective area etching and growth, a mask was fabricated in the HSQ e-beam resist including optimization of exposure and development conditions. By use of CBr4 as an etchant, in situ etching demonstrated various trench profiles along the [0-1-1] and [0-11] crystallographic directions. Selectively grown InGaAs/InP quantum wells (QWs) possessed distinct geometrical and optical properties in the cases of directly grown InGaAs and when an InP buffer was deposited underneath. The fabrication process for the incorporation of an SAG material into needle-shaped specimens for transmission electron microscopy or into PhC amplifiers was optimized to improve the alignment accuracy to below 100 nm. Micro-photoluminescence measurements of SAG QW showed a large wavelength red-shift (over 100 nm) compared to the unpatterned area and between the structures oriented along the [0-1-1] and [0-11] directions. Strong wavelength dependence with variations of the mask width of a few μm and opening sizes of hundreds of nanometers was observed. Incorporation of an active medium into PhC structures has showed promising results; in particular, the emission control of SAG QW matched the operating wavelength of photonic crystals. A strong photoluminescence signal in the slow light regime with the group index of 18 was demonstrated.

The effect of asymmetric barrier layers in the waveguide region on power characteristics of QW lasers

Current-voltage and light-current characteristics of quantum-well lasers have been studied at high drive currents. The introduction of asymmetric barrier layers adjacent to the active region caused a significant suppression of the nonlinearity in the light-current characteristic and an increase in the external differential efficiency. As a result, the maximum wallplug efficiency increased by 9%, while the output optical power increased by 29%.
Thermal analysis of line-defect photonic crystal lasers

We report a systematic study of thermal effects in photonic crystal membrane lasers based on line-defect cavities. Two material platforms, InGaAsP and InP, are investigated experimentally and numerically. Lasers with quantum dot layers embedded in an InP membrane exhibit lasing at room temperature under CW optical pumping, whereas InGaAsP membranes only lase under pulsed conditions. By varying the duty cycle of the pump beam, we quantify the heating induced by optical pumping in the two material platforms and compare their thermal properties. Full 3D finite element simulations show the spatial temperature profile and are in good agreement with the experimental results concerning the thermal tolerance of the two platforms.

General information

We present a record-low threshold power of 7 mW at ~1.55 µm for on-chip optical parametric oscillation using a high quality factor micro-ring-resonator in a new nonlinear photonics platform: AlGaAs-on-insulator

Butt-joint integration of active optical components based on InP/AlInGaAsP alloys

We demonstrate all-active planar high quality butt-joint (BJ) integration of a QW Semiconductor Optical Amplifier (SOA) and MQW Electro-Absorption Modulator (EAM) based on an InP/AlInGaAsP platform. The degradation of the optical properties in the vicinity of ~1 μm to the BJ interface was determined by means of μPL measurements.


We present a record-low threshold power of 7 mW at ~1.55 µm for on-chip optical parametric oscillation using a high quality factor micro-ring-resonator in a new nonlinear photonics platform: AlGaAs-on-insulator

Butt-joint integration of active optical components based on InP/AlInGaAsP alloys

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Organisations: Department of Photonics Engineering, Nanophotonic Devices, High-Speed Optical Communication
Authors: Pu, M. (Intern), Ottaviano, L. (Intern), Semenova, E. (Intern), Oxenløwe, L. K. (Intern), Yvind, K. (Intern)
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Source-ID: 108590197
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

Butt-joint integration of active optical components based on InP/AlInGaAsP alloys

We demonstrate all-active planar high quality butt-joint (BJ) integration of a QW Semiconductor Optical Amplifier (SOA) and MQW Electro-Absorption Modulator (EAM) based on an InP/AlInGaAsP platform. The degradation of the optical properties in the vicinity of ~1 μm to the BJ interface was determined by means of μPL measurements.

General information
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Organisations: Nanophotonic Devices, Department of Photonics Engineering
Authors: Kulkova, I. (Intern), Kuznetsova, N. (Intern), Semenova, E. (Intern), Yvind, K. (Intern)
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Conference: 26th International Conference on Indium Phosphide and Related Materials, Montpellier, France, 11/05/2014 - 11/05/2014
Crystallographic dependent in-situ CBr4 selective nano-area etching and local regrowth of InP/InGaAs by MOVPE

Selective area etching and growth in the metalorganic vapor phase epitaxy (MOVPE) reactor on nano-scale structures have been examined. Using different mask orientations, crystallographic dependent etching of InP can be observed when carbon tetrabromide (CBr4) is used as an etchant. Scanning Electron Microscopy (SEM) investigation of etch profiles showed formation of a U-shaped groove along the [01̄1̄] direction, terminated by (111)B planes with an ~15nm (100) plateau and transitional (311)B planes, developed in a self-limiting manner. In the perpendicular direction [01̄1] etching with a dominant lateral component driven by fast etched (111)A and (311)A side planes was observed. A directly grown single InGaAs QW in the etched grooves demonstrated different QW profiles: a crescent-shaped on (311)B and (100) planes (along the [01̄1̄] direction) and two separated quarter-circle curvatures grown preferably on (311)A along [01̄1].

Room temperature micro-photoluminescence measurements indicated a wavelength red-shift in over 125nm along [01̄1] comparing to [01̄1], which is related to both growth enhancement and composition variation of the grown material.

General information
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Organisations: Department of Photonics Engineering, Nanophotonic Devices, Center for Electron Nanoscopy, St. Petersburg Academic University
Authors: Kuznetsova, N. (Intern), Kulkova, I. (Intern), Semenova, E. (Intern), Kadkhodazadeh, S. (Intern), Kryzhanovskaya, N. (Ekstern), Zhukov, A. (Ekstern), Yvind, K. (Intern)
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Scopus rating (2016): SJR 0.735 SNIP 1.175 CiteScore 1.69
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Scopus rating (2013): SJR 0.831 SNIP 1.221 CiteScore 1.78
ISI indexed (2013): ISI indexed yes
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Scopus rating (2012): SJR 0.956 SNIP 1.246 CiteScore 1.68
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Epitaxial growth of quantum dots on InP for device applications operating at the 1.55 μm wavelength range

The development of epitaxial technology for the fabrication of quantum dot (QD) gain material operating in the 1.55 μm wavelength range is a key requirement for the evolution of telecommunication. High performance QD material demonstrated on GaAs only covers the wavelength region 1-1.35 μm. In order to extract the QD benefits for the longer telecommunication wavelength range the technology of QD fabrication should be developed for InP based materials. In our work, we take advantage of both QD fabrication methods Stranski-Krastanow (SK) and selective area growth (SAG) employing block copolymer lithography. Due to the lower lattice mismatch of InAs/InP compared to InAs/GaAs, InP based QDs have a larger diameter and are shallower compared to GaAs based dots. This shape causes low carrier localization and small energy level separation which leads to a high threshold current, high temperature dependence, and low laser quantum efficiency. Here, we demonstrate that with tailored growth conditions, which suppress surface migration of adatoms during the SK QD formation, much smaller base diameter (13.6nm versus 23nm) and an improved aspect ratio are achieved. In order to gain advantage of non-strain dependent QD formation, we have developed SAG, for which the growth occurs only in the nano-openings of a mask covering the wafer surface. In this case, a wide range of QD composition can be chosen. This method yields high purity material and provides significant freedom for reducing the aspect ratio of QDs with the possibility to approach an ideal QD shape.

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Organisations: Department of Photonics Engineering, Nanophotonic Devices, Center for Electron Nanoscopy, Programmable Phase Optics, Department of Micro- and Nanotechnology, Nanointegration, Amphiphilic Polymers in Biological Sensing, University of Rome
Number of pages: 9
Publication date: 2014
High-quality MOVPE butt-joint integration of InP/AlGaAs/InGaAsP-based all-active optical components

In this paper, we demonstrate the applicability of MOVPE butt-joint regrowth for integration of all-active InP/AlGaAs/InGaAsP optical components and the realization of high-functionality compact photonic devices. Planar high-quality integration of semiconductor optical amplifiers of various epi-structures with a multi-quantum well electro-absorption modulator has been successfully performed and their optical and crystalline quality was experimentally investigated. The regrown multi-quantum well material exhibits a slight bandgap blue-shift of less than 20 meV, when moving away from the regrowth interface. In closest vicinity to the mask, the growth profile revealed a bent-up shape which is associated with an increase in the bandgap energy resulting from the combined effect of growth rate suppression and higher Ga concentration. This increase in bandgap energy makes the interface partially transparent (thus beneficial
for unaffected light transmission) and forces carriers away from possible interfacial defects. The internal reflectivity below 2.1×10^{-5} ensures minimization of detrimental intracavity feedback.

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**Organisations:** Department of Photonics Engineering, Nanophotonic Devices, Center for Electron Nanoscopy, Department of Physics, Quantum Physics and Information Technology

**Authors:** Kulkova, I. (Intern), Kadkhodazadeh, S. (Intern), Kuznetsova, N. (Intern), Huck, A. (Intern), Semenova, E. (Intern), Yvind, K. (Intern)

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- Scopus rating (2014): SJR 0.795 SNIP 1.184 CiteScore 1.69
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- Scopus rating (2013): SJR 0.831 SNIP 1.221 CiteScore 1.78
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- Scopus rating (2012): SJR 0.956 SNIP 1.246 CiteScore 1.68
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- BFI (2011): BFI-level 1
- Scopus rating (2011): SJR 0.96 SNIP 1.425 CiteScore 1.89
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- Scopus rating (2010): SJR 1.163 SNIP 1.206
- Web of Science (2010): Indexed yes
- BFI (2009): BFI-level 1
- Scopus rating (2009): SJR 1.068 SNIP 1.202
- BFI (2008): BFI-level 1
- Scopus rating (2008): SJR 1.161 SNIP 1.236
- Web of Science (2008): Indexed yes
- Scopus rating (2007): SJR 1.237 SNIP 1.32
- Web of Science (2007): Indexed yes
- Scopus rating (2006): SJR 1.001 SNIP 1.211
- Scopus rating (2005): SJR 1.105 SNIP 1.403
- Scopus rating (2004): SJR 1.211 SNIP 1.292
- Scopus rating (2003): SJR 0.956 SNIP 1.11
- Web of Science (2003): Indexed yes
- Scopus rating (2002): SJR 1.16 SNIP 1.262
- Scopus rating (2001): SJR 1.108 SNIP 1.067
Improvement of light-current characteristic linearity in a quantum well laser with asymmetric barriers

The effect of asymmetric barriers on the light-current characteristic (LCC) of a quantum well laser was studied theoretically and experimentally. It is shown that the utilization of asymmetric barriers in a waveguide prevents the nonlinearity of LCC and, consequently, allows rising of the maximum output power.

Material Engineering for Monolithic Semiconductor Mode-Locked Lasers

This thesis is devoted to the materials engineering for semiconductor monolithic passively mode-locked lasers (MLLs) as a compact energy-efficient source of ultrashort optical pulses. Up to the present day, the achievement of low-noise sub-picosecond pulse generation has remained a challenge. This work has considered the role of the combined ultrafast gain and absorption dynamics in MLLs as a main factor limiting laser performance. An independent optimization of MLL amplifier and saturable absorber active materials was performed. Two promising approaches were considered: quantum dot (QD) or single quantum well (QW) amplifier in tandem with a fast multi-QW electroabsorption modulator (EAM) based on the InP/AlGaInAs/InGaAsP platform for operation in the 1.55 μm telecommunications range.

A butt-joint MOVPE regrowth technique was established for monolithic integration showing high crystalline quality and low internal reflection compatible with the severe requirements of monolithic MLLs. Experimental characterization of static material parameters of the fabricated devices revealed QW-like gain behavior of a self-assembled InAs/InP QD material and low internal efficiency which limited its application in MLLs. Improved QW laser performance was demonstrated using the asymmetric barrier layer approach. The analysis of the gain characteristics showed that the high population inversion beneficial for noise reduction cannot be achieved for 10 GHz QW MLLs and would have required lowering the modal gain or utilizing an extended cavity design. The offset QW design was introduced. The performance of 10 GHz passively MLLs consisting of integrated QW gain section with MQW EAM was demonstrated to allow for 890 fs pulse generation with reduced timing jitter compared to non-integrated QW MLLs owing to the fast EAM recovery.
Nonplanar nanoselective area growth of InGaAs/InP

In this study, we have investigated metal-organic vapor phase epitaxial nano-patterned selective area growth of InGaAs/InP on non-planar (001) InP surfaces. Due to high etching resistance and the small molecular size of negative tone electron beam HSQ resist, the protection mask formed in HSQ has small feature sizes in ten nanometers scale and allow realization of in-situ etching. As was observed in the SAG regime, in-situ etching of InP by carbon tetrabromide leads to formation of self-limited structures. By altering etching time, the groove shape can be changed from a triangular trench to a trapeze. Another appealing aspect of in situ etching is that the shape of InGaAs can be tuned from a crescent to a triangular or a line by varying growth parameters. Quantum well wires can be fabricated by growing directly in the bottom of V-shaped groove. In addition, changes of mask orientations lead to anisotropic or isotropic character of etching. The investigated technique of nano-patterned selective area growth allows obtaining different profiles of structures and different quantum structures such as quantum well or wires in the same growth run. To investigate the shape and crystalline quality of the active material, the cross-sectional geometry was observed by field emission scanning electron microscopy and scanning transmission electron microscopy. The optical properties were carried out at room temperature using micro-photoluminescence setup. The results showed different deposition rates for openings oriented along [0-11] and [0-1-1] directions with higher rate along [0-1-1]. The fabricated active material was incorporated into photonic crystal waveguides.
Slow-light-enhanced gain in active photonic crystal waveguides

Passive photonic crystals have been shown to exhibit a multitude of interesting phenomena, including slow-light propagation in line-defect waveguides. It was suggested that by incorporating an active material in the waveguide, slow light could be used to enhance the effective gain of the material, which would have interesting application prospects, for example enabling ultra-compact optical amplifiers for integration in photonic chips. Here we experimentally investigate the gain of a photonic crystal membrane structure with embedded quantum wells. We find that by solely changing the photonic crystal structural parameters, the maximum value of the gain coefficient can be increased compared with a ridge waveguide structure and at the same time the spectral position of the peak gain be controlled. The experimental results are in qualitative agreement with theory and show that gain values similar to those realized in state-of-the-art semiconductor optical amplifiers should be attainable in compact photonic integrated amplifiers.

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Web of Science (2018): Indexed yes
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.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, Nanophotonics Theory and Signal Processing
Authors: Ansbæk, T. (Intern), Chung, I. (Intern), Semenova, E. (Intern), Yvind, K. (Intern)
Pages: 365-367
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Main Research Area: Technical/natural sciences

Publication information
Journal: IEEE Photonics Technology Letters
Volume: 25
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BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Web of Science (2016): Indexed yes
Scopus rating (2016): CiteScore 2.52 SJR 1.018 SNIP 1.279
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.263 SNIP 1.327 CiteScore 2.62
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.461 SNIP 1.614 CiteScore 2.78
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.487 SNIP 1.547 CiteScore 2.95
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.623 SNIP 1.706 CiteScore 2.46
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.51 SNIP 2.012 CiteScore 2.48
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.474 SNIP 1.623
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.775 SNIP 1.804
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.081 SNIP 1.818
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.345 SNIP 1.566
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 2.112 SNIP 1.884
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.97 SNIP 2.454
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 3.286 SNIP 2.716
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 3.44 SNIP 2.467
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 3.566 SNIP 2.117
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 3.519 SNIP 1.678
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 2.345 SNIP 1.202
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 2.44 SNIP 1.302

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Publication: Research - peer-review › Journal article – Annual report year: 2013
Crystallographic dependence of the lateral undercut wet etch rate of Al<sub>0.5</sub>In<sub>0.5</sub>P in diluted HCl for III-V sacrificial release

The authors investigated the use of InAlP as a sacrificial layer lattice-matched to GaAs when diluted hydrochloric acid is used for sacrificial etching. They show that InAlP can be used to fabricate submicrometer air gaps in micro-opto-electromechanical systems and that a selectivity toward GaAs larger than 500 is achieved. This selectivity enables fabrication control of the nanometer-size structures required in photonic crystal and high-index contrast subwavelength grating structures. The crystallographic dependence of the lateral etch rate in InAlP is shown to be symmetric around the (110) directions where an etch rate of 0.5 μm/min is obtained at 22°C in HCl:2H2O. Since the etch rate in the (100) directions exceeds by ten times that of the (110) directions, InAlP may be used in sacrificial release of high-aspect ratio structures. Free-hanging structures with length to air-gap aspect ratios above 600 are demonstrated by use of critical point drying following the sacrificial etch.

General information
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Organisations: Department of Photonics Engineering, Nanophotonic Devices, Experimental Surface and Nanomaterials Physics, Department of Micro- and Nanotechnology, Silicon Microtechnology, Center for Individual Nanoparticle Functionality
Authors: Ansbæk, T. (Intern), Semenova, E. (Intern), Yvind, K. (Intern), Hansen, O. (Intern)
Number of pages: 4
Pages: 011209
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Main Research Area: Technical/natural sciences

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Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.08 SJR 0.444 SNIP 0.499
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.345 SNIP 0.379 CiteScore 0.66
BFI (2014): BFI-level 1
Web of Science (2014): Indexed yes
Scopus rating (2014): SJR 0.312 SNIP 0.368 CiteScore 0.61
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.432 SNIP 0.523 CiteScore 0.83
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Web of Science (2012): Indexed yes
Scopus rating (2012): SJR 0.631 SNIP 0.689 CiteScore 0.85
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Web of Science (2011): Indexed yes
Scopus rating (2011): SJR 0.862 SNIP 0.86 CiteScore 1.22
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Web of Science (2010): Indexed yes
Scopus rating (2010): SJR 0.906 SNIP 0.862
BFI (2009): BFI-level 1
Web of Science (2009): Indexed yes
Scopus rating (2009): SJR 0.932 SNIP 0.95
BFI (2008): BFI-level 1
Web of Science (2008): Indexed yes
Scopus rating (2008): SJR 1.001 SNIP 0.947
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.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonics Theory and Signal Processing, Nanophotonic Devices
Authors: Park, G. C. (Intern), Semenova, E. (Intern), Chung, I. (Intern)
Pages: B90-B91
Publication date: 2013

Host publication information
Title of host publication: iNOW 2013 : International Nano-Optoelectronics Workshop
Main Research Area: Technical/natural sciences
Source: dtu
Source-ID: u::10718
Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

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 verticalcavity 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 around an emission wavelength of 1060 nm with 0.9 mW output power.
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.

General information

State: Published
Organisations: Department of Photonics Engineering, Nanophotonics Theory and Signal Processing, Nanophotonic Devices
Authors: Chung, I. (Intern), Park, G. C. (Intern), Ran, Q. (Intern), Semenova, E. (Intern), Yvind, K. (Intern), Mørk, J. (Intern)
Number of pages: 1
Publication date: 2013

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Main Research Area: Technical/natural sciences
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Invited paper.
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Source-ID: u::10719
Publication: Research - peer-review » Conference abstract in proceedings – Annual report year: 2014

41 GHz and 10.6 GHz low threshold and low noise InAs/InP quantum dash two-section mode-locked lasers in L band

This paper reports recent results on InAs/InP quantum dash-based, two-section, passively mode-locked lasers pulsing at 41 GHz and 10.6 GHz and emitting at 1.59 μm at 20 degrees C. The 41-GHz device (1 mm long) starts lasing at 25 mA
under uniform injection and the 10.6 GHz (4 mm long) at 71 mA. Their output pulses are significantly chirped. The 41-GHz laser exhibits 7 ps pulses after propagation in 60 m of a single-mode fiber. The 10.6-GHz laser generates one picosecond pulses with 545 m of a single-mode fiber. Its single side-band phase noise does not exceed -80 dBc/Hz at 100 kHz offset, leading to an average timing jitter of 800 fs.

**General information**

State: Published
Organisations: Department of Photonics Engineering, Nanophotonics, Nanophotonic Devices, Universite europeenne de Bretagne, Technical University of Denmark
Authors: Dontabactouny, M. (Ekstern), Piron, R. (Ekstern), Klaime, K. (Ekstern), Chevalier, N. (Ekstern), Tavernier, K. (Ekstern), Loualiche, S. (Ekstern), Le Corre, A. (Ekstern), Larsson, D. (Intern), Rosenberg, C. (Forskerdatabase), Semenova, E. (Intern), Yvind, K. (Intern)
Pages: -
Publication date: 2012
Main Research Area: Technical/natural sciences

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- BFI (2018): BFI-level 1
- Web of Science (2018): Indexed yes
- BFI (2017): BFI-level 1
- Web of Science (2017): Indexed yes
- BFI (2016): BFI-level 1
- Scopus rating (2016): CiteScore 1.72 SJR 0.632 SNIP 0.815
- 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
- Scopus rating (2014): SJR 1.005 SNIP 1.18 CiteScore 2.04
- Web of Science (2014): Indexed yes
- BFI (2013): BFI-level 1
- Scopus rating (2013): SJR 1.165 SNIP 1.317 CiteScore 2.24
- ISI indexed (2013): ISI indexed yes
- Web of Science (2013): Indexed yes
- BFI (2012): BFI-level 1
- Scopus rating (2012): SJR 1.305 SNIP 1.294 CiteScore 2.13
- ISI indexed (2012): ISI indexed yes
- Web of Science (2012): Indexed yes
- BFI (2011): BFI-level 1
- Scopus rating (2011): SJR 1.373 SNIP 1.318 CiteScore 2.24
- ISI indexed (2011): ISI indexed yes
- Web of Science (2011): Indexed yes
- BFI (2010): BFI-level 1
- Scopus rating (2010): SJR 1.47 SNIP 1.195
- Web of Science (2010): Indexed yes
- BFI (2009): BFI-level 1
- Scopus rating (2009): SJR 1.518 SNIP 1.238
- Web of Science (2009): Indexed yes
- BFI (2008): BFI-level 1
- Scopus rating (2008): SJR 1.667 SNIP 1.338
- Web of Science (2008): Indexed yes
- Scopus rating (2007): SJR 1.708 SNIP 1.395
Effect of Asymmetric Barrier Layers in the Waveguide Region on the Temperature Characteristics of Quantum Well Lasers

The temperature sensitivity of the threshold-current density in quantum-well lasers is studied and the factors affecting the characteristic temperature and its dependence on optical losses are analyzed. It is shown that the inclusion of asymmetric potential barriers (one barrier on each side of the quantum well), which prevent the formation of bipolar carrier population in the waveguide region and lead to weakening of the temperature dependences of the transparency-current density, the gain-saturation parameter and, consequently, to a higher characteristic temperature for both long- and short-cavity laser diodes.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, St. Petersburg Academic University, Virginia Polytechnic Institute and State University, Russian Academy of Sciences
Authors: Zhukov, A. E. (Ekstern), Asryan, L. V. (Ekstern), Shernyakov, Y. M. (Ekstern), Maximov, M. V. (Ekstern), Zubov, F. I. (Ekstern), Kryzhanovskaya, N. V. (Ekstern), Yvind, K. (Intern), Semenova, E. (Intern)
Pages: 1027-1031
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Semiconductors
Volume: 46
Issue number: 8
ISSN (Print): 1063-7826
Ratings:
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Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Enhanced Gain in Photonic Crystal Amplifiers

We experimentally demonstrate enhanced gain in the slow-light regime of quantum well photonic crystal amplifiers. A strong gain enhancement is observed with the increase of the group refractive index, due to light slow-down. The slow light enhancement is shown in an amplified spontaneous emission study of a 1 QW photonic crystal amplifier. Net gain is achieved which enables laser oscillation in photonic crystal micro cavities. The ability to freely tailor the dispersion in a semiconductor optical amplifier makes it possible to raise the optical gain considerably over a certain bandwidth. These results are promising for short and efficient semiconductor optical amplifiers. This effect will also benefit other devices, such as mode locked lasers.

General information

State: Published
Organisations: Department of Photonics Engineering, Nanophotonics Theory and Signal Processing, Nanophotonic Devices, Nanophotonics
Authors: Ek, S. (Intern), Semenova, E. (Intern), Hansen, P. L. (Intern), Yvind, K. (Intern), Mørk, J. (Intern)
Number of pages: 4
Publication date: 2012
High-speed photodetectors in a photonic crystal platform

We demonstrate a fast photodetector (f3dB > 40GHz) integrated into a high-index contrast photonic crystal platform. Device design, fabrication and characterization are presented.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, Nanophotonics, Universite europeenne de Bretagne, University of Ferrara
Authors: Ottaviano, L. (Intern), Semenova, E. (Intern), Schubert, M. (Intern), Yvind, K. (Intern), Armaroli, A. (Ekstern), Bellanca, G. (Ekstern), Trillo, S. (Ekstern), Nguyen, T. N. (Ekstern), Gay, M. (Ekstern), Bramerie, L. (Ekstern), Simon, J. (Ekstern)
Number of pages: 2
Publication date: 2012

Improvement of temperature-stability in a quantum well laser with asymmetric barrier layers

We fabricated and tested a quantum well laser with asymmetric barrier layers. Such a laser has been proposed earlier to suppress bipolar carrier population in the optical confinement layer and thus to improve temperature-stability of the threshold current. As compared to the conventional reference laser structure, our laser with asymmetric barrier layers demonstrates reduced internal optical loss, lower threshold current density at elevated temperatures, and higher characteristic temperature (143 vs. 99K at 20 degrees C).

General information
State: Published
Organisations: Nanophotonic Devices, Department of Photonics Engineering, St. Petersburg Academic University, Abraham F. Ioffe Institute, Virginia Polytechnic Institute and State University
Authors: Zhukov, A. E. (Ekstern), Kryzhanovskaya, N. V. (Ekstern), Zubov, F. I. (Ekstern), Shernyakov, Y. M. (Ekstern), Maximov, M. V. (Ekstern), Semenova, E. (Intern), Yvind, K. (Intern), Asryan, L. V. (Ekstern)
Pages: 021107
Publication date: 2012
Main Research Area: Technical/natural sciences
Publication information
Individual optimization of InAlGaAsP-InP sections for 1.55-μm passively mode-locked lasers
We present integrated single QW semiconductor optical amplifier and MQW electroabsorber modulator based on InAlGaAsP-InP materials for application in a monolithic mode-locked laser. Optimized structures with high-quality butt-joint interfaces are demonstrated.

Nano-selective area growth of InGaAs/InP using CBr4 in-situ etching
We are investigating the conditions for nano-patterned selective area epitaxial growth using e-beam lithography on HSQ resist and in-situ etching in the MOVPE reactor.
Slow-light enhancement of spontaneous emission in active photonic crystal waveguides

Photonic crystal defect waveguides with embedded active layers containing single or multiple quantum wells or quantum dots have been fabricated. Spontaneous emission spectra are enhanced close to the bandedge, consistently with the enhancement of gain by slow light effects. These are promising results for future compact devices for terabit/s communication, such as miniaturised semiconductor optical amplifiers and mode-locked lasers.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonics Theory and Signal Processing, Nanophotonic Devices
Authors: Ek, S. (Intern), Chen, Y. (Intern), Semenova, E. (Intern), Hansen, P. L. (Intern), Yvind, K. (Intern), Mørk, J. (Intern)
Pages: 82731A
Publication date: 2012
Conference: SPIE Photonics West : Advances in Slow and Fast Light V, Santa Barbara, CA, United States, 22/01/2012 - 22/01/2012
Main Research Area: Technical/natural sciences

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Journal: Proceedings of SPIE--the international society for optical engineering
Volume: 8273
Issue number: 1
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BFI (2018): BFI-level 1
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BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 0.42 SNIP 0.245
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.187 SNIP 0.224 CiteScore 0.3
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.188 SNIP 0.231 CiteScore 0.3
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.2 SNIP 0.259 CiteScore 0.26
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.194 SNIP 0.243 CiteScore 0.27
ISI indexed (2012): ISI indexed no
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.197 SNIP 0.264 CiteScore 0.31
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.208 SNIP 0.241
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.211 SNIP 0.271
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.222 SNIP 0.289
Web of Science (2008): Indexed yes
Active III-V Semiconductor Photonic Crystal Waveguides

We experimentally demonstrate enhanced amplified spontaneous emission in a quantum well III-V semiconductor photonic crystal waveguide slab. The effect is described by enhanced light matter interaction with the decrease of the group velocity. These are promising results for future compact devices for terabit/s communication, such as miniaturised semiconductor optical amplifiers and mode-locked lasers.

Enhanced Gain in Slow-Light Photonic Crystal Waveguides with Embedded Quantum Dots

We experimentally demonstrate enhanced gain in the slow-light regime of quantum dot photonic crystal waveguide slabs. These are promising results for future compact devices for terabit/s communication, such as compact optical amplifiers and mode-locked lasers.
InAs/InGaAsP Quantum Dots Emitting at 1.5 μm for Applications in Lasers
In this work the epitaxial growth of InAs quantum dots (QDs) in an InGaAsP matrix on an InP wafer is described. A new approach to shift the emission wavelength to the 1.5μm region using deposition of a thin GaAs capping layer on top of the QDs is suggested and exploited. Laser structures based on 5 layers of such dots as the gain material demonstrate lasing in continuous wave regime at 1.5 μm wavelength at room temperature.

Investigating the chemical and morphological evolution of GaAs capped InAs/InP quantum dots emitting at 1.5μm using aberration-corrected scanning transmission electron microscopy
The emission wavelength of InAs quantum dots grown on InP has been shown to shift to the technologically desirable 1.5μm with the deposition of 1–2 monolayers of GaAs on top of the quantum dots. Here, we use aberration-corrected scanning transmission electron microscopy to investigate morphological and compositional changes occurring to the quantum dots as a result of the deposition of 1.7 monolayers of GaAs on top of them, prior to complete overgrowth with InP. The results are compared with theoretical models describing the overgrowth process.
Metal organic vapor-phase epitaxy of InAs/InGaAsP quantum dots for laser applications at 1.5 μm

The epitaxial growth of InAs/InGaAsP quantum dots (QDs) for emission around 1.5 μm by depositing a thin layer of GaAs on top of the QDs is presented in this letter. The influence of various growth parameters on the properties of the QDs, in particular, size, shape, chemical composition, and emission wavelength are investigated. Continuous wave lasing
in ridge waveguide QD laser structures in the 1.5 μm wavelength range is demonstrated. VC 2011 American Institute of Physics. [doi:10.1063/1.3634029]

**General information**

State: Published
Organisations: Nanophotonic Devices, Department of Photonics Engineering, Center for Electron Nanoscopy
Authors: Semenova, E. (Intern), Kulkova, I. (Intern), Kadkhodazadeh, S. (Intern), Schubert, M. (Intern), Yvind, K. (Intern)
Pages: 101106
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- Web of Science (2018): Indexed yes
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- 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
- 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
- BFI (2011): BFI-level 2
- 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
- BFI (2008): BFI-level 2
- Scopus rating (2008): SJR 2.934 SNIP 1.83
- Web of Science (2008): Indexed yes
- Scopus rating (2007): SJR 3.039 SNIP 1.913
- Web of Science (2007): Indexed yes
- Web of Science (2006): Indexed yes
- Scopus rating (2005): SJR 3.709 SNIP 2.382
Quantitative strain mapping of InAs/InP quantum dots with 1 nm spatial resolution using dark field electron holography

The optical properties of semiconductor quantum dots are greatly influenced by their strain state. Dark field electron holography has been used to measure the strain in InAs quantum dots grown in InP with a spatial resolution of 1 nm. A strain value of 5.4%±0.1% has been determined which is consistent with both measurements made by geometrical phase analysis of high angle annular dark field scanning transmission electron microscopy images and with simulations.

General information
State: Published
Organisations: Center for Electron Nanoscopy, Nanophotonic Devices, Department of Photonics Engineering, Commissariat Energie Atomique, FEI France
Authors: Cooper, D. (Intern), Rouviere, J. (Ekstern), Béché, A. (Ekstern), Kadkhodazadeh, S. (Intern), Semenova, E. (Intern), Yvind, K. (Intern), Dunin-Borkowski, R. E. (Intern)
Pages: 261911
Publication date: 2011
Main Research Area: Technical/natural sciences

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Volume: 99
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BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
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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
Towards quantitative three-dimensional characterisation of buried InAs quantum dots

InAs quantum dots grown on InP or InGaAsP are used for optical communication applications operating in the 1.3 – 1.55 μm wavelength range. It is generally understood that the optical properties of such dots are highly dependent on their structural and chemical profiles. However, morphological and compositional measurements of quantum dots using transmission electron microscopy can be ambiguous because the recorded signal is usually a projection through the
thickness of the specimen. Here, we discuss the application of scanning transmission electron microscopy tomography to
the morphological and chemical characterisation of surface and buried quantum dots. We highlight some of the challenges
involved and introduce a new specimen preparation method for creating needle-shaped specimens that each contain
multiple dots and are suitable for both scanning transmission electron microscopy tomography and atom probe
tomography.

**General information**
State: Published
Organisations: Center for Electron Nanoscopy, Nanophotonic Devices, Department of Photonics Engineering, Chalmers
University of Technology
Authors: Kadkhodazadeh, S. (Intern), Semenova, E. (Intern), Schubert, M. (Intern), Thuvander, M. (Ekstern), Stiller, K. M.
(Ekstern), Yvind, K. (Intern), Dunin-Borkowski, R. E. (Intern)
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Main Research Area: Technical/natural sciences

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  - Web of Science (2016): Indexed yes
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  - Scopus rating (2015): SJR 0.24 SNIP 0.373 CiteScore 0.35
  - Web of Science (2015): Indexed yes
  - BFI (2014): BFI-level 1
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  - Web of Science (2014): Indexed yes
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  - BFI (2012): BFI-level 1
  - Scopus rating (2012): SJR 0.28 SNIP 0.354 CiteScore 0.33
  - ISI indexed (2012): ISI indexed no
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  - Scopus rating (2011): SJR 0.292 SNIP 0.352 CiteScore 0.43
  - ISI indexed (2011): ISI indexed no
  - BFI (2010): BFI-level 1
  - Scopus rating (2010): SJR 0.288 SNIP 0.344
  - Web of Science (2010): Indexed yes
  - BFI (2009): BFI-level 1
  - Scopus rating (2009): SJR 0.253 SNIP 0.321
  - BFI (2008): BFI-level 1
  - Scopus rating (2008): SJR 0.265 SNIP 0.294
  - Web of Science (2008): Indexed yes
  - Scopus rating (2007): SJR 0.257 SNIP 0.39
  - Web of Science (2007): Indexed yes
  - Scopus rating (2006): SJR 0.267 SNIP 0.284
  - Web of Science (2006): Indexed yes
Towards quantitative three-dimensional characterisation of InAs quantum dots

InAs quantum dots (QDs) grown on InP or InGaAsP are used for optical communication applications operating in the 1.3 – 1.55 μm wavelength range. It is generally understood that the optical properties of such QDs are highly dependent on their three-dimensional structural and chemical profiles. Whilst conventional transmission electron microscopy (TEM) techniques can be used to study capped QDs in plan-view or cross-sectional geometries, the resulting images can provide ambiguous information about their three-dimensional properties. Here, we describe an approach for investigating the applicability of both high-angle annular dark-field (HAADF) scanning transmission electron microscopy (STEM) tomography and atom probe tomography (APT) to the study of surface and buried InAs/InGaAsP QDs grown by metal organic vapour phase epitaxy (MOVPE). Electron tomography was carried out in an FEI Titan TEM instrument operated at 300 kV. TEM specimens were prepared in plan-view geometry using mechanical grinding, polishing and Ar ion milling. Both original HAADF STEM images and final tomographic reconstruction of surface QDs suggest an elongated hexagonal shape for the bases of the QDs (Figure 1). The elongation direction was determined to be [110], using selected area electron diffraction and atomic force microscopy. The HAADF STEM images also suggest that surface QDs have a double-terraced geometry, with steeper facets around their bases and shallower facets close to their tops. This geometry is consistent with a theoretical model of InAs QDs formed on an InGaAs substrate that is lattice matched to InP [1] shown in Figure 1(b). Despite the large inner detector semi-angle used (approximately 50 mrad), strong diffraction effects were present in the original tilt series of HAADF STEM images, resulting in departure from the projection requirement for electron tomography, which states that the recorded intensity should be a monotonic function of a property of the object [2]. These diffraction effects are likely to be associated with diffraction and may lead to artefacts in the tomographic reconstruction. The same tomographic analysis was applied to a buried InAs/InGaAsP QD (Figure 1(d) and (e)). The buried QD appears to be elongated along the [110] direction, although not as strongly as the surface QD. Similarly, the faceting that is clearly visible in both the original HAADF STEM images and the final reconstruction of the surface QD, is not as pronounced for the buried QD. This difference may result from chemical intermixing between the buried QD and the capping material during overgrowth. A limiting constraint in STEM tomography of thin film specimens is the limited tilt range available before the specimen becomes too thick for imaging. This limitation can, in principle, be overcome by fabricating needle-shaped specimens using focused ion beam (FIB) milling, in order to allow unlimited tilting without significant increase in projected specimen thickness. However, FIB milling can introduce considerable damage into III-V semiconductors, including amorphisation and Ga ion implantation [3]. We have fabricated needle-shaped specimens that are 100 nm in diameter, using reactive ion etching, selective wet etching and critical point drying in plan-view geometry (Figure 2). The choice of a plan-view geometry for the needles means that each specimen will contain several QDs. The needles can either be detached from the substrate by cleaving (Figure 2(b)) or lifted out and mounted onto suitable grids using a micro-manipulator in the FIB with minimal additional damage (Figure 2(c)). Significantly, in addition to their suitability for electron tomography, these specimens can be used for APT, for which needle-shaped specimens with sharp tips (narrower than 100 nm) are required. Our ongoing experiments involve the application of both HAADF STEM tomography and APT to the same QD, in order to better understand its morphology and composition. A comparison between reconstructions obtained using both techniques will also assist in the evaluation and mitigation of potential artefacts that are present when using each technique.
This paper reports the fabrication and the characterisation of a 10 GHz two-section passively mode-locked quantum dash laser emitting at 1.59 μm. The potential of the device's mode-locking is investigated through an analytical model taking into account both the material parameters and the laser geometry. Results show that the combination of a small absorbing section coupled to a high absorption coefficient can lead to an efficient mode-locking. Characterisation shows mode-locking operation though output pulses are found to be strongly chirped. Noise measurements demonstrate that the single side band phase noise does not exceed -80 dBc/Hz at 100 kHz offset leading to an average timing jitter as low as 800 fs. As compared to single QW lasers these results constitute a significant improvement and are of first importance for applications in optical telecommunications.
Lambda shifted photonic crystal cavity laser
We propose and demonstrate an alternative type of photonic crystal laser design that shifts all the holes in the lattice by a fixed fraction of the targeted emission wavelength. The structures are realized in InGaAsP =1.15 with InGaAsP quantum wells =1.52 as gain material. Cavities with shifts of 1/4 and 3/4 of the emission wavelength were fabricated and characterized. Measurements show threshold behavior for several modes at room temperature. Both structures are simulated using a finite difference time domain method to identify the resonances in the spectra and calculate the mode volume of the dominant mode.

General information
State: Published
Organisations: Nanophotonic Devices, Department of Photonics Engineering, Nanophotonics Theory and Signal Processing
Authors: Schubert, M. (Intern), Skovgård, T. S. (Intern), Ek, S. (Intern), Semenova, E. (Intern), Hvam, J. M. (Intern), Yvind, K. (Intern)
Pages: 191109
Publication date: 2010
Main Research Area: Technical/natural sciences

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Web of Science (2018): Indexed yes
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Web of Science (2017): Indexed yes
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Scopus rating (2016): CiteScore 2.67 SJR 1.132 SNIP 0.996
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Scopus rating (2015): SJR 1.085 SNIP 0.983 CiteScore 2.47
Web of Science (2015): Indexed yes
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Scopus rating (2014): SJR 1.799 SNIP 1.462 CiteScore 3.25
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.149 SNIP 1.652 CiteScore 3.77
ISI indexed (2013): ISI indexed yes
Quarter-lambda-shifted photonic crystal lasers

A new design for photonic crystal lasers is proposed and realised. It allows an intuitive design for ultralow mode volume and high Q cavities which can be realized in a connected membrane structure.

General information
State: Published
Organisations: Nanophotonic Devices, Department of Photonics Engineering, Nanophotonics Theory and Signal Processing
Authors: Schubert, M. (Intern), Skovgård, T. S. (Intern), Ek, S. (Intern), Semenova, E. (Intern), Hvam, J. M. (Intern), Yvind, K. (Intern)
Publication date: 2010
Main Research Area: Technical/natural sciences
Projects:

**III-V Nanowire Selective Area MOVPE Growth for High Efficiency Solar Cell**
Department of Photonics Engineering  
Period: 01/01/2018 → 31/12/2020  
Number of participants: 3  
Phd Student:  
Lebedkina, Elizaveta (Intern)  
Supervisor:  
Canulescu, Stela (Intern)  
Main Supervisor:  
Semenova, Elizaveta (Intern)

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

**Tailored nanoscale optical materials and devices**
Department of Photonics Engineering  
Period: 01/08/2015 → 31/07/2018  
Number of participants: 4  
Phd Student:  
Sakanas, Aurimas (Intern)  
Supervisor:  
Mørk, Jesper (Intern)  
Semenova, Elizaveta (Intern)  
Main Supervisor:  
Yvind, Kresten (Intern)

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

**Developing of Superior Quantum Dot Gain Material for 1.5-1.6 um Wavelenght Range**
Department of Photonics Engineering  
Period: 15/03/2015 → 14/03/2018  
Number of participants: 4  
Phd Student:  
Shikin, Artem (Intern)  
Supervisor:  
Almdal, Kristoffer (Intern)  
Yvind, Kresten (Intern)  
Main Supervisor:  
Semenova, Elizaveta (Intern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Eksternt finansieret virksomhed
Developing of III-V epitaxy of highly efficient quantum dot gain material to the silicon platform

Department of Photonics Engineering
Period: 01/10/2014 → 31/03/2018
Number of participants: 4
Phd Student: Viazmitinov, Dmitrii (Intern)
Supervisor: Frandsen, Lars Hagedorn (Intern)
Yvind, Kresten (Intern)
Main Supervisor: Semenova, Elizaveta (Intern)

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

Block Copolymer Precursors for Chemical Nanopatterning of Graphene

Department of Micro- and Nanotechnology
Period: 15/07/2014 → 07/12/2017
Number of participants: 6
Phd Student: Wang, Zhongli (Intern)
Supervisor: Almdal, Kristoffer (Intern)
Main Supervisor: Ndowi, Sokol (Intern)
Examiner: Semenova, Elizaveta (Intern)
Jannasch, Patric (Ekstern)
Posselt, Dorthe (Ekstern)

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

Relations
Publications:
Nanopatterning of graphene guided by block copolymer self-assembly
Project: PhD

Design and fabrication of mid-infrared plasmonic materials based on highly doped III-V semiconductors

Department of Photonics Engineering
Period: 15/02/2014 → 23/08/2017
Number of participants: 6
Phd Student: Panah, Mohammad Esmail Aryae (Intern)
Supervisor: Semenova, Elizaveta (Intern)
Main Supervisor: Lavrinenko, Andrei (Intern)
Examiner: Yvind, Kresten (Intern)
Bordo, Vladimir G. (Ekstern)
Engheta, Nader (Ekstern)
Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

QUantum dot Energy level Engineering for laser applicatIoNs on InP and Si platforms
This project is dedicated to the research of quantum dot (QD) epitaxial growth on both indium phosphide (InP) and silicon (Si) based platforms with the aim of creating superior gain material emitting in the 1.5-1.6 μm wavelength range. The majority of the proposed research is quite fundamental but will have noticeable impact to device applications for our everyday life in the near future. Diverse areas like telecommunication, optical coherence tomography including medical applications, sensing, computer and network clock-distribution, THz generation, and metrology can benefit from the materials investigated.

The projected research covers two directions. The first is the development of QDs which possess desired electronic and optical properties in the InP based material system, i.e. tailoring the energy level structure and wave functions in the dots. Manipulating the shape, chemical composition and surroundings of the nanostructures is the key to achieving the set goals. In the frame of the project I will implement two different approaches to design and grow high optical quality arrays of QDs. Those approaches are self-assembled quantum dot growth and selective area growth using block copolymer lithography. The second direction of the research is the deployment of the highly efficient QD gain material to a silicon platform. The development of epitaxial growth technology of III-V materials on Si combines the benefits of high optical quality III-V QD gain material with low cost silicon photonics, which is a key platform to push towards increased integration, higher speed and lower energy consumption.

Department of Photonics Engineering
Nanophotonic Devices
Center for Nanostructured Graphene
Department of Micro- and Nanotechnology
Amphiphilic Polymers in Biological Sensing
Center for Electron Nanoscopy
DTU Danchip
Period: 01/06/2013 → 31/08/2017
Number of participants: 9
Acronym: QUEENs
Number of related Ph.D. students: 2
Project participant:
Yvind, Kresten (Intern)
Almdal, Kristoffer (Intern)
Kadkhodazadeh, Shima (Intern)
Ottaviano, Luisa (Intern)
Willatzen, Morten (Intern)
Barettin, Daniele (Ekstern)
Phd Student:
Viazmitinov, Dmitrii (Intern)
Shikin, Artem (Intern)
Project Manager, academic:
Semenova, Elizaveta (Intern)

Vertical-cavity laser with a novel grating mirror
Department of Photonics Engineering
Period: 15/02/2013 → 15/06/2016
Number of participants: 6
Phd Student:
Park, Gyeong Cheol (Intern)
Supervisor:
Semenova, Elizaveta (Intern)
Main Supervisor:
Chung, Il-Sug (Intern)
QDLaser: Development of novel quantum dot based materials for compact laser devices for potential

The goal of the project is the development of portable, low-cost, reliable and highly-efficient ultrashort pulse (down to 100 fs) laser sources based on quantum dot (QD) material working in the spectral range 1.0-1.6 microns. This new generation of QD based mode-locked lasers has to become an alternative to the conventionally used ultrafast solid-state lasers, which are very expensive, cumbersome and complex to operate. The proposed research has a very high practical significance because it creates the possibility for evolution in different science and medical areas, in particular, advanced telecommunication, terahertz generation, optical sampling, biophotonics, non-invasive medical diagnosis and therapeutics.

By placing a primary emphasis on novel materials, devices and system designs, this project will encompass a range of challenging and cutting-edge research directions that exploit QD-based semiconductor structures. The work in the frame of this project will mainly be focused on epitaxial growth of QD-based laser structures. It will be devoted to the optimisation of the epitaxial growth procedure, testing optical, structural and transport measurements and working on the design of epitaxial structure and design of the final devices. This research is in the area of interest of the host organisation and is interdependent with other projects running at the department. I will closely collaborate with other researchers in the fields of laser device design, laser characterisation and discuss results at every stage of the project. Moving to DTU, I bring all of my knowledge gained during my PhD and postdoctoral research work in Russia and France, which will lead to new scientific achievements at DTU. My connections to international scientists will increase the collaboration of DTU with other European and Russian Universities as well.
**Nanoscale semiconductor optical devices**
Department of Photonics Engineering  
Period: 01/09/2010 → 18/06/2015  
Number of participants: 6  
Phd Student:  
Kuznetsova, Nadezda (Intern)  
Supervisor:  
Semenova, Elizaveta (Intern)  
Main Supervisor:  
Yvind, Kresten (Intern)  
Examiner:  
Malureanu, Radu (Intern)  
Cirlin, George (Ekstern)  
Kardynal, Beata (Intern)  

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Institut/centerfinansieret  

**Relations**  
Publications:  
Tailoring quantum structures for active photonic crystals  
Project: PhD

**Femtosecond semiconductor lasers**  
Department of Photonics Engineering  
Period: 01/08/2010 → 24/09/2014  
Number of participants: 7  
Phd Student:  
Kulkova, Irina (Intern)  
Supervisor:  
Larsson, David (Intern)  
Semenova, Elizaveta (Intern)  
Main Supervisor:  
Yvind, Kresten (Intern)  
Examiner:  
Tafur Monroy, Idelfonso (Intern)  
Avrutin, Eugene (Ekstern)  
Decobert, Jean (Ekstern)  

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

**Femtosecond semiconductor LASers Harnessed**  
Nanophotonic Devices  
Department of Photonics Engineering  
University of Cambridge  
Period: 01/09/2009 → 31/10/2012  
Number of participants: 6  
Mode-locked lasers, Semiconductor optoelectronics, Ultrafast dynamics, Nanotechnology  
Acronym: FLASH  
Project ID: 70488  
Contact person:  
Yvind, Kresten (Intern)  
Penty, Richard (Ekstern)
Project participant:
Kim, Jong Min (Intern)
Semenova, Elizaveta (Intern)
Mørk, Jesper (Intern)
Hvam, Jørn Marcher (Intern)

Financing sources
Source: Forskningsrådene - Andre
Name of research programme: Forskningsrådene - Andre
Amount: 5,291,888.00 Danish Kroner

Project
Governing the speed of light
The GOSPEL project aims at developing new, highly effective technologies for enabling slow and fast light propagation as a tunable feature in photonic devices. In fact, controlling the speed of light offers a solution to a necessary, and often missing, functionality in broadband ICT systems: a time-delay/phase-shift line. The proposed research will address three slow and fast light device platforms: linear and nonlinear semiconductor photonic crystal waveguides with position controlled embedded quantum dots, active semiconductor waveguides based on quantum dots and advanced, specifically engineered optical fibers. These technologies will be harnessed in microwave and millimeter wave applications, such as: true time delay antenna feed systems for radars and ultra wide band wireless communication; complex microwave filters; high spectral purity opto-electronic oscillators and electro optical sampling systems. This project gathers world leading experts in microwave photonics and semiconductor and fiber technologies, under a unified vision of the role that slow and fast light can play in advanced microwave applications. The project tackles several key challenges of the 7th Framework Work programme in the ICT domain and represents a significant step towards the removal of a major roadblock, i.e. the lack of practical, tunable, broadband, low distortion time-delay/phase-shift lines for microwave signals. This elemental component, besides enabling several applications, can ease the convergence of photonics and electronics and can attribute new functions to photonic devices. The proposed fundamental research will produce new results in multi-disciplinary topics like semiconductor physics, quantum dots, photonic crystal design and fiber technology and it will also represent a significant advancement across many sectors of ICT.

Department of Photonics Engineering
Period: 01/09/2008 → 31/12/2011
Number of participants: 9
Acronym: GOSPEL
Project ID: 70445
Project participant:
Gregersen, Niels (Intern)
Yvind, Kresten (Intern)
Kristensen, Philip Trøst (Intern)
Hansen, Per Lunnemann (Intern)
Semenova, Elizaveta (Intern)
Xue, Weiqi (Intern)
Pu, Minhao (Intern)
Larsson, David (Intern)
Project Manager, organisational:
Mørk, Jesper (Intern)

Financing sources
Source: Forsk. EU - Rammeprogram
Name of research programme: Forsk. EU - Rammeprogram
Amount: 2,380,000.00 Danish Kroner

Activities:
Presentation title: "A valence force field-Monte Carlo algorithm for quantum dot growth modeling".
Period: 24 Jul 2017 → 28 Jul 2017
Shima Kadkhodazadeh (Other)
Elizaveta Semenova (Other)
Morten Willatzen (Other)
Alessandro Pecchia (Other)
Matthias Auf de Maur (Other)
Daniele Barettin (Speaker)

Center for Electron Nanoscopy
DTU Danchip
Department of Photonics Engineering
Nanophotonic Devices
Centre of Excellence for Silicon Photonics for Optical Communications

Degree of recognition: International
Documents:
nusod17paper59
Links:

Related event

17th International Conference on Numerical Simulation of Optoelectronic Devices (NUSOD17)
24/07/2017 → 28/07/2017
Kgs. Lyngby, Denmark
Activity: Talks and presentations › Conference presentations