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IEEE photonics Society

PROGRAM

November 17th-18th, 2016
Ghent University
Ghent, Belgium

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PHOTONICS RESEARCH GROUP

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Thursday November 17th

17:30 – 18:30 Registration

Plenary session (location: Refter, chair: Prof. Peter Bienstman)
18:30 – 18:45 Welcome by Prof. Peter Bienstman
18:45 – 19:30 Plenary talk by Prof. Eli Kapon (EPFL, Switzerland)
19:30 – 20:15 Plenary talk by Dr. Jeroen Koelemeij (VU Amsterdam, The Netherlands)

20:15 – 21:45 Poster session (odd numbers) (location: Kapittelzaal)

Friday November 18th

08:30 – 09:00 Registration

Plenary session (location: Refter, chair: Prof. Gunther Roelkens)
09:00 – 09:45 Plenary talk by Dr. Chris Broderick (University of Bristol, U.K.)
09:45 – 10:30 Plenary talk by Prof. Guy Millot (University of Bourgogne, France)

10:30 – 11:00 Coffee break (location: Kapittelzaal)

11:00 – 12:00 Oral presentations session (1)

	Session Title: High speed integrated devices location: Refter chair: Prof. Geert Morthier	**Session Title: Sensing** location: Zaal Rector Vermeylen chair: Prof. Sonia Garcia-Blanco
11:00	**Monolithically integrated widely tunable laser and electro-absorption modulator in a generic InP integration platform** Marija Trajkovic[1,2], Sylwester Latkowski [1], Helene Debregeas[2], Kevin A. Williams[1], and Xaveer J. M. Leijtens[1] *[1] Eindhoven University of Technology* *[2] III-V Lab*	**On-chip near field fluorescence excitation and detection with nanophotonic waveguides for improved bulk background suppression in bio-sensing** M. Mahmud-Ul-Hasan, P. Neutens, L. Lagae, and P. V. Dorpe *IMEC, KU Leuven*

11:15	**Cost-effective, compact and high-speed integrable multi-mode interference modulator** Daan Lenstra[1], Weiming Yao[1], Simone Cardarelli[1], and Jan Mink [2] *[1] Eindhoven University of Technology* *[2] VTEC*	**Al2O3 miroring resonators as a novel refractive index sensor platform** Michiel de Goede, Meindert Dijkstra, and Sonia García Blanco *University of Twente*
11:30	**Toward Si photonics based transceivers using directly modulated heterogeneously integrated DFB lasers** Amin Abbasi, Hongtao Chen, Jochem Verbist, Xin Yin, Johan Bauwelinck, Gunther Roelkens, and Geert Morthier *Ghent University – IMEC*	**Isotachophoresis preconcentration device for improved LOD of common pollutants in drinking water** Miquel Castellote, Pablo Muñoz, Cedric Noordam, Vasileios A. Papadimitriou, Jos Quist, Serge G. Lemay, Jan C. T. Eijkel, and Sonia García Blanco *University of Twente*
11:45	**Intuitive Analytical Model Relating Electrical Crosstalk in Mach-Zehnder Modulators to Performance Degradations** Weiming Yao[1], Meint K. Smit[1], and Michael J. Wale[1,2] *[1] Eindhoven University of Technology* *[2] Oclaro Technology Ltd.*	**Fiber Bragg gratings inscription in doped PMMA polymer optical fiber by 400 nm femtosecond laser pulses** Xuehao Hu, Damien Kinet, Patrice Mégret, and Christophe Caucheteur *University of Mons*

12:00 – 13:30 Poster session (even numbers) + walking lunch (location: Kapittelzaal)

13:30 – 14:30 Oral presentations session (2)

	Session Title: Integrated lasers location: Refter chair: dr. Xaveer Leijtens	**Session Title: NLO & materials** location: Zaal Rector Vermeylen chair: prof. Pascal Kockaert
13:30	**Discretely tunable III-V/SOI SG-DFB laser** Sören Dhoore, Gunther Roelkens, and Geert Morthier *Ghent University – IMEC*	**Ultrafast Optical Kerr Effect method to characterize the third order optical nonlinearity of graphene** E. Dremetsika[1], B. Dlubak[2], S.P. Gorza[1], C. Ciret[1], M.B. Martin[3], S. Hofmann[3], P. Seneor[2], D. Dolfi[2], S. Massar[1], Ph. Emplit[1], and P. Kockaert[1] *[1] Université libre de Bruxelles* *[2] Unité Mixte de Physique CNRS/Thales* *[3] University of Cambridge*
13:45	**Modeling and characterization of unidirectional device for feedback insensitive laser** T.T.M. van Schaijk, D. Lenstra, and E.A.J.M. Bente *Eindhoven University of Technology*	**Characterization of graphene-covered SiN waveguide using four-wave mixing** Koen Alexander, Bart Kuyken, and Dries Van Thourhout *Ghent University – IMEC*
14:00	**Er-doped potassium double tungstate channel waveguides with high optical gain** Sergio A. Vázquez-Córdova[1], Shanmugam Aravazhi[1], Christos Grivas[2], Yean-Sheng Yong[1], Sonia M. García Blanco[1], Jennifer L. Herek[1], and Markus Pollnau[1,3] *[1] University of Twente* *[2] University of Southampton* *[3] Royal Institute of Technology*	**Design of Thin Film Stacks for Non-Destructive Electro-Optical Characterizations by Spectroscopic Ellipsometry** Min-Hsiang Mark Hsu, Marianna Pantouvaki, Clement Merckling, Joris Van Campenhout, Philippe Absil, and Dries Van Thourhout *Ghent University – IMEC*

14:15	**A stabilized integrated ring laser for high resolution fiber based sensing** S. Andreou, S. Latkowski, and E.A.J.M. Bente *Eindhoven University of Technology*	**Distributed measurement of supercontinuum generation along highly nonlinear optical fibers** R. Hontinfinde, P.Megret, and M.Wuilpart *University of Mons*

14:30 – 15:00 Coffee break (location: Kapittelzaal)

15:00 – 16:15 Oral presentations session (3)

	Session Title: Sub-systems &systems location: Refter chair: prof. Chigo Okonkwo	**Session Title: Quantum Optics & dynamical systems** location: Zaal Rector Vermeylen chair: prof. Guy Verschaffelt
15:00	**Optical Label Switched Add-Drop Node for Low Latency and High Capacity Data Center Interconnect Metro Networks** W. Miao, J. van Weerdenburg, R. van Uden, H. de Waardt, T. Koonen, C. Okonkwo, and N. Calabretta *Eindhoven University of Technology*	**New materials for Single Photon Emission from Colloidal Quantum Dots** V. Chandrasekaran, D. Dupont, M. D. Tessier, Z. Hens, and E. Brainis *Ghent University*
15:15	**System Performance Assessment of a Monolithically Integrated WDM Cross-Connect Switch for Optical Data Centre Networks** N. Calabretta, W. Miao, K. Prifti, and K. Williams *Eindhoven University of Technology*	**Quantum sensing with a hybrid silicon nitride / diamond photonics platform** N. Verellen, B. Van de Vel, S. Philips, T. Hantschel, and P. Van Dorpe *IMEC*

15:30	**On-Board Optics and Compact Switches for Mega-Size Data Center Networks** Gonzalo Guelbenzu, and Oded Raz *Eindhoven University of Technology*	**Directional antennas with embedded single photon emitters** N. Verellen, S. Philips, J. Li, and P. Van Dorpe *IMEC*
15:45	**A 2x50 Gb/s PAM-4 driver IC integrated with a 1.5-µm VCSEL array** Wouter Soenen[1], Silvia Spiga[2], Renato Vaernewyck[1], Xin Yin[1], and Johan Bauwelinck[1] *[1] Ghent University – iMinds – IMEC* *[2] Technical University of Munich*	**Photonic information processing using multi-mode semiconductor lasers with delayed feedback** K. Harkhoe, and G. Van der Sande *Vrije Universiteit Brussel*
16:00	**A 1310 nm sub-5V Ge APD based optical receiver in a silicon platform for 32 Gbps PAM-4 transmission over 40 km** J. Verbist, H. Chen, B. Moeneclaey, X. Yin, J. Bauwelinck, and G. Roelkens *Ghent University – IMEC*	**Laser speckle reduction using micro-structured screens** Jael Pauwels, and Guy Verschaffelt *Vrije Universiteit Brussel*

16:15 – 16:45 Closing ceremony with poster award (location: Refter)

Abstracts

1A1. Monolithically integrated widely tunable laser and electro-absorption modulator in a generic InP integration platform

Marija Trajkovic[1,2], Sylwester Latkowski [1], Helene Debregeas[2], Kevin A. Williams[1], and Xaveer J. M. Leijtens[1]

[1] *Eindhoven University of Technology*

[2] *III-V Lab*

The operation of the identical active layer stack widely tunable laser and electro-absorption modulator will be presented. We have designed, fabricated and characterized this device for the first time in the COBRA generic integration platform for the operation at 1.55 µm. The tuning of the laser is achieved using a three stage voltage-controlled, intra-cavity Mach-Zehnder interferometer filters. The modulator's small footprint of 100 µm yielded a 9.4 dB static extinction ratio and together with its electro-optical bandwidth of 13.5 GHz allowed on-off-keyed data modulation for bit rates up to 10 Gbps.

1A2. Cost-effective, compact and high-speed integrable multi-mode interference modulator

Daan Lenstra[1], Weiming Yao[1], Simone Cardarelli[1], and Jan Mink [2]

[1] *Eindhoven University of Technology*

[2] *VTEC*

The transmission through a symmetric 1x1 multi-mode interference (MMI) waveguide can be substantially suppressed by introducing a small asymmetry in the core refractive index. This can be achieved by applying a voltage in reversed bias to half of the waveguide in the lateral direction, so as to involve the anti-symmetric lateral mode, which in the unbiased situation would not participate. Typical plots will be shown for the calculated transmission as a function of the refractive index change.

1A3. Toward Si photonics based transceivers using directly modulated heterogeneously integrated DFB lasers

Amin Abbasi, Hongtao Chen, Jochem Verbist, Xin Yin, Johan Bauwelinck, Gunther Roelkens, and Geert Morthier

Ghent University – IMEC

High speed directly modulated single mode lasers are becoming important optical components in the short reach communication. On the other hand, Si photonics opens up new opportunities to explore the transceivers for the short reach applications. We have fabricated a heterogeneously integrated DFB laser on a Si photonic circuit as a transmitter. For the receiver, a low voltage Si waveguide-coupled Ge avalanche photodetector has been used. We have successfully demonstrated error free transmission of a 10 Gb/s NRZ-OOK signal over 20 km single mode fiber using a silicon on insulator (SOI) based transmitter and receiver.

1A4. Intuitive Analytical Model Relating Electrical Crosstalk in Mach-Zehnder Modulators to Performance Degradations

Weiming Yao[1], Meint K. Smit[1], and Michael J. Wale[1,2]
[1] *Eindhoven University of Technology*
[2] *Oclaro Technology Ltd.*

WDM transmitters are increasingly realized as photonic integrated circuits where arrays of lasers and modulators are monolithically integrated in a parallel channel architecture. With increasing integration density electrical crosstalk emerges as a phenomenon that impairs transmitter performance. We present an intuitive analytical description of how coupling inside and between Mach-Zehnder modulators can affect their dynamic extinction ratio and introduce power penalties to the transmission. Based on the model we derive a crosstalk threshold of around -30 dB above which degradation starts to become visible. The results will be useful in establishing design rules to avoid crosstalk induced impairments.

1B1. On-chip near field fluorescence excitation and detection with nanophotonic waveguides for improved bulk background suppression in bio-sensing

M. Mahmud-Ul-Hasan, P. Neutens, L. Lagae, and P. V. Dorpe
IMEC, KULeuven

Fluorescence is a widely used transduction mechanism in bio-imaging, sensing or physical chemistry characterization applications. The ability to selectively excite desired molecules without generating considerable bulk background from nearby molecules is very important for all these applications. We propose a waveguide based platform to improve the surface and bulk fluorescence separation by combining near-field excitation and near-field collection. A reduction by half in effective 1/e decay length was found experimentally. The Surface and bulk fluorescence separation has been experimentally characterized by attaching a fluorescent dye (atto-633) on waveguide surface using CLICK Chemistry and a different dye (atto-725) as bulk background. Finally, an analytical model is derived to find the optimum device efficiency and validated experimentally.

1B2. Al2O3 mirroring resonators as a novel refractive index sensor platform

Michiel de Goede, Meindert Dijkstra, and Sonia García Blanco
University of Twente

Microring resonators are of great interest for refractive index sensors. Traditionally, they are realized on a SOI, Si3N4 or SiON platform. Al2O3 is an interesting alternative platform for optical refractive index sensors, since it can incorporate gain by rare-earth ion doping. This could compensate for the resonator losses and increase their sensitivity. Here, we present undoped Al2O3 microring resonators with a quality factor of 35000 that can be used as both a bulk refractive index sensor and a surface sensor.

1B3. Isotachophoresis preconcentration device for improved LOD of common pollutants in drinking water

Miquel Castellote, Pablo Muñoz, Cedric Noordam, Vasileios A. Papadimitriou, Jos Quist, Serge G. Lemay, Jan C. T. Eijkel, and Sonia García Blanco
University of Twente

Real-time monitoring of common pollutants in drinking water is highly desired, given the important consequences of a contamination event. Coated SERS substrates have been successfully used to detect micromolar concentrations of different anions often present in water. However, the limit of detection still needs to be improved by a factor of 10^4 in the worst case. A microfluidic preconcentration device is fabricated as a possible approach. This device can concentrate and separate the analytes of interest using isotachophoresis (ITP). Here we employed fluorescence to demonstrate the principle of operation whereas coupling with Raman spectroscopy is proposed for the final application.

1B4. Fiber Bragg gratings inscription in doped PMMA polymer optical fiber by 400 nm femtosecond laser pulses

Xuehao Hu, Damien Kinet, Patrice Mégret, and Christophe Caucheteur
University of Mons

In this paper, we report photo-inscriptions of uniform Bragg gratings in both step-index and microstructured polymer optical fibers. The Bragg grating inscriptions were performed by a femtosecond laser emitting at 400 nm and the phase mask technique. The photosensitive dopants in both fibers are trans-4-stilbenemethanol (TS) and benzyl dimethyl ketal (BDK), respectively, which enable Bragg gratings to reach saturation in slightly more than 1 minute (reflectivity 84%) for the step-index fiber and in ~20 seconds (reflectivity 40%) for microstructured fibers.

2A1. Discretely tunable III-V/SOI SG-DFB laser

Sören Dhoore, Gunther Roelkens, and Geert Morthier
Ghent University – IMEC

Discrete wavelength tuning with a heterogeneously integrated III-V/SOI sampled grating distributed feedback (SG-DFB) laser is demonstrated. The laser device is tunable over a wavelength range larger than 55 nm in wavelength steps of 5 nm and only employs two injection currents. A maximum fiber-coupled output power of -1.8 dBm is obtained as well as a high side mode suppression of more than 33 dB for all wavelength channels. The demonstrated laser is expected to find application in future flexible optical network architectures.

2A2. Modeling and characterization of unidirectional device for feedback insensitive laser

T.T.M. van Schaijk, D. Lenstra, and E.A.J.M. Bente
Eindhoven University of Technology

External optical feedback (EOF) is difficult to avoid in integrated lasers since conventional isolators are incompatible with integration technology. The tandem phase modulators proposed by Doerr et al. are a promising alternative isolator and can be combined with integration. A theoretical analysis for the operation of this component, together with experimental results from a tandem phase modulator operating at 600MHz will be presented and discussed. Device performance is found to be capable of drastically reducing EOF effects on an integrated laser.

2A3. Er-doped potassium double tungstate channel waveguides with high optical gain

Sergio A. Vázquez-Córdova[1], Shanmugam Aravazhi[1], Christos Grivas[2], Yean-Sheng Yong[1], Sonia M. García Blanco[1], Jennifer L. Herek[1], and Markus Pollnau[1,3]
[1] *University of Twente*
[2] *University of Southampton*
[3] *Royal Institute of Technology*

We report on the optical gain properties of channel waveguides patterned into layers of KGdxLuyEr1-x-y(WO4)2 grown by liquid phase epitaxy onto undoped KY(WO4)2 substrates. Internal net gain is experimentally demonstrated, with a maximum of ~11 dB/cm at the peak wavelength of 1534.7 nm. Overgrowth of the active waveguide by an undoped KY(WO4)2 layer would reduce the propagation losses and improve the gain to ~14 dB/cm. A systematic investigation of gain is performed for five different erbium concentrations in the range from 0.75 to 10 at.%. Experimental and simulated results for all samples are compared, revealing good agreement.

2A4. A stabilized integrated ring laser for high resolution fiber based sensing

S. Andreou, S. Latkowski, and E.A.J.M. Bente
Eindhoven University of Technology

We present an implementation of the Pound-Drever-Hall locking technique on a monolithically integrated single frequency tunable ring laser fabricated using InP active-passive integration technology. The ring laser which is based on three cascaded asymmetric Mach-Zehnder interferometers is locked to a fibre Fabry-Perot interferometer with 1 MHz full-width at half-maximum. The electric feedback signal is fed to a separate intra-cavity electro-refractive modulator which controls the wavelength of the lasing mode. We demonstrate the laser wavelength stabilization on long time scales and explain how we intend to use such an integrated stabilised laser in a fibre based sensing system.

2B1. Ultrafast Optical Kerr Effect method to characterize the third order optical nonlinearity of graphene

E. Dremetsika[1], B. Dlubak[2], S.P. Gorza[1], C. Ciret[1], M.B. Martin[3], S. Hofmann[3], P. Seneor[2], D. Dolfi[2], S. Massar[1], Ph. Emplit[1], and P. Kockaert[1]

[1] *Université libre de Bruxelles*

[2] *Unité Mixte de Physique CNRS/Thales*

[3] *University of Cambridge*

With its high and broadband optical nonlinearity, graphene appears to be a promising candidate for integrated photonics. Here, we report on the use of the ultrafast optical Kerr effect method with optical heterodyne detection (OHD-OKE) for the characterization of the third order optical nonlinearity of monolayer CVD graphene on quartz at telecom wavelength. Our measurements show that the nonlinear refractive index of graphene is negative, in contrast to previously reported results. We also performed measurements of the nonlinear absorption of graphene and we studied the temperature dependence of the nonlinearity, as well as the relaxation time of the OHD-OKE signal.

2B2. Characterization of graphene-covered SiN waveguide using four-wave mixing

Koen Alexander, Bart Kuyken, and Dries Van Thourhout

Ghent University – IMEC

It has been demonstrated, both theoretically and experimentally, that graphene has a strong optical nonlinearity. However, there remain strong discrepancies between the different reported experimental values of the nonlinear refractive index n2. These can in part be attributed to the different optical pulse durations used in different pulse-probe and Z-scan experiments and to the strong temporal dependence of n2. In this work, we performed four-wave mixing, cross-phase and cross-amplitude experiments on SiN waveguides covered with a single layer of graphene. Using these results, we estimated the nonlinear optical response with a high temporal and frequency resolution.

2B3. Design of Thin Film Stacks for Non-Destructive Electro-Optical Characterizations by Spectroscopic Ellipsometry

Min-Hsiang Mark Hsu, Marianna Pantouvaki, Clement Merckling, Joris Van Campenhout, Philippe Absil, and Dries Van Thourhout

Ghent University – IMEC

Spectroscopic ellipsometry (SE) is a general and non-destructive tool to characterize the optical properties of thin films. However, most commercial SE do not provide an additional signal amplifier, making it very challenging to investigate minor but crucial changes in thin-film layers such as those induced by the electro-optical effect (EO). Therefore, in this work, we develop a transfer matrix method (TMM) to design the transparent electrode in terms of material choice and thickness to achieve an EO measurement by SE with high resolution of index change (delta n). Based on our models, a delta n resolution of 5e-5 for the EO-effect in BaTiO3 grown on Si(001) using molecular-beam-epitaxy has been successfully demonstrated.

2B4. Distributed measurement of supercontinuum generation along highly nonlinear optical fibers

R. Hontinfinde, P.Megret, and M.Wuilpart
University of Mons

Supercontinuum is the spectral broadening of an intense light arising from the interplay between several nonlinear optical effects. In this paper, a non-destructive optical time domain reflectometry set-up is proposed to measure the spatial evolution of the spectral broadening induced along an optical fiber. The method is based on the measurement of the Rayleigh backscattered signals generated by the various components of the spectral broadening. The system was experimentally tested on highly nonlinear fibers. The experimental data obtained with the proposed method were in good agreement with the optical spectra measured by an optical spectrum analyzer at the fiber outputs.

3A1. Optical Label Switched Add-Drop Node for Low Latency and High Capacity Data Center Interconnect Metro Networks

W. Miao, J. van Weerdenburg, R. van Uden, H. de Waardt, T. Koonen, C. Okonkwo, and N. Calabretta
Eindhoven University of Technology

We investigate an optical label-switched add-drop node for data center interconnect metro networks. The switching node is capable of dynamically handling high-capacity waveband traffic within sub-microsecond switching latency. Experiments using prototyped nodes show 20ns dynamic switching for per-channel and 112Gb/s DP-QPSK traffic. Scalability in terms of the number of wavebands and crossed nodes is studied in a 25km looping set-up. Results show potential scalability up to 15 nodes and Terabit/s capacity with limited performance degradation.

3A2. System Performance Assessment of a Monolithically Integrated WDM Cross-Connect Switch for Optical Data Centre Networks

N. Calabretta, W. Miao, K. Prifti, and K. Williams
Eindhoven University of Technology

The system performance of a photonic integrated WDM cross-connect switch including SOA based wavelength selective switch is experimentally assessed. The results show nanoseconds wavelength, space, and time switching operation for 10 Gb/s, 20 Gb/s, and 40 Gb/s data packets and error-free dynamic switching has been achieved with less than 2dB power penalty. The capability of supporting multiple 40 Gb/s WDM channels indicates the potential of the cross-connect switch to further scale to higher capacity and port count in optical data center networks.

3A3. On-Board Optics and Compact Switches for Mega-Size Data Center Networks

Gonzalo Guelbenzu, and Oded Raz
Eindhoven University of Technology

We present the new compact hybrid switch with densely integrated on board optical modules. We show that four such switches can be packed into a single 1RU19 box, and operate with moderate power consumption. The integrated box can be easily thermally managed with forced air cooling thanks to the substitution of the front panel pluggable transceivers by on board optics modules. Further, by introducing a programmable power control and relying on an SDN controller, we suggest that the integrated box can be used in different power modes saving considerable power when scaling to mega size data centers.

3A4. A 2x50 Gb/s PAM-4 driver IC integrated with a 1.5-µm VCSEL array

Wouter Soenen[1], Silvia Spiga[2], Renato Vaernewyck[1], Xin Yin[1], and Johan Bauwelinck[1]
[1] Ghent University – iMinds – IMEC
[2] Technical University of Munich

Currently available optical datacenter transceivers exploit four lanes of 25 Gb/s to satisfy the 100 Gigabit Ethernet standard. Transitioning to PAM-4 modulation could extend the data rate while still using existing interfaces or optical devices. To evaluate the feasibility, we have designed a dual-channel PAM-4 driver IC in 130 nm SiGe BiCMOS, featuring a 4-tap symbol-spaced equalizer to drive a 1.5 µm VCSEL array. Both channels achieve a back-to-back BER below 1E-6 at 50 Gb/s. With 430 mW per channel, the presented VCSEL transmitter can be an efficient alternative to double the lane rate across single-mode fiber.

3A5. A 1310 nm sub-5V Ge APD based optical receiver in a silicon platform for 32 Gbps PAM-4 transmission over 40 km

J. Verbist, H. Chen, B. Moeneclaey, X. Yin, J. Bauwelinck, and G. Roelkens
Ghent University – IMEC

Avalanche photodetectors detectors (APDs) integrated in a silicon photonics platform can significantly improve the link budget of optical interconnects by boosting the optical receiver sensitivity compared to conventional p-i-n photodetectors at CMOS-friendly bias voltages. We demonstrate a silicon based receiver consisting of a low-voltage (<5V) 1310 nm Ge APD and a low-power BiCMOS transimpedance amplifier. The receiver offers a sensitivity improvement of ~6dB for 32 Gbps PAM-4 transmission over >40 km with a commercially available direct-modulated DFB laser as transmitter, allowing a 4 times higher split ratio in FTTx passive optical networks for the same link budget.

3B1. New materials for Single Photon Emission from Colloidal Quantum Dots

V. Chandrasekaran, D. Dupont, M. D. Tessier, Z. Hens, and E. Brainis
Ghent University

Colloidal quantum dots (QDs) are considered as a cost-effective alternative for optoelectronic applications compared to epitaxial QDs because of its economic & versatile method of synthesis and room temperature operation. CdSe based quantum dots are extensively studied for single photon emission and here we show the similar observation for our flash synthesis of QDs. The newly synthesized InP based QDs are also observed to be photostable and seems to be a good single photon emitter with narrow emission linewidth. Such QDs show great promise to be integrated onto a chip as single photon sources for quantum information based devices.

3B2. Quantum sensing with a hybrid silicon nitride / diamond photonics platform

N. Verellen, B. Van de Vel, S. Philips, T. Hantschel, and P. Van Dorpe
IMEC

Diamond nitrogen vacancy (NV) centers enable to extend the frontiers of detection and imaging techniques beyond classical limits. This unique quantum sensor can be optically initialized and read-out by means of optically detected magnetic spin resonance (ODMR). Large-scale and cost-effective integration in diamond is hampered by the lack of chip-scale high quality substrates. We experimentally demonstrate the integration of diamond NV centers into a silicon nitride photonic circuit and provide the first ODMR magnetic field sensing using a mature technology platform. Nano-analytic applications range from life sciences to material science. Being a solid-state qubit, establishing a platform to interface with NV centers is essential for the development of quantum information technologies.

3B3. Directional antennas with embedded single photon emitters

N. Verellen, S. Philips, J. Li, and P. Van Dorpe
IMEC

In nanophotonics applications where every photon counts, one immediately benefits from directed photon routing (wavefront engineering) for efficient photon collection. We present the design of all-dielectric antennas that enable unidirectional emission of embedded quantum emitters. These could be single photon sources such as the nitrogen, silicon or germanium vacancy centers in diamond. The extraordinary emission properties of these dielectric antennas are the result of clever phase control of interfering electric and magnetic multipoles. Application can be found in solid-state quantum information processing and optical quantum sensing.

3B4. Photonic information processing using multi-mode semiconductor lasers with delayed feedback

K. Harkhoe, and G. Van der Sande
Vrije Universiteit Brussel

Optical implementations of reservoir computing systems have shown great promise. They can be implemented using semiconductor lasers subject to delayed feedback. Currently, these systems rely on long delay lines, which are hard to integrate on chip. We propose to use semiconductor lasers with multiple longitudinal modes to distribute the computational power over more than one optical wavelength. As such, both the delay line can be shortened and the processing speeds will increase. Due to complex modal interactions, better computational performance on several benchmark tasks are obtained compared to single mode systems and this for a wide range of mode separations.

3B5. Laser speckle reduction using micro-structured screens

Jael Pauwels, and Guy Verschaffelt
Vrije Universiteit Brussel

We report on a novel speckle reduction scheme using microlens-arrays as screen material for application in laser-based projection systems. The speckle is reduced when the laser's spatial coherence area on the microlens-array screen is smaller than the microlens footprint. Resultantly, the fields emitted by the different microlenses cannot interfere in the observer plane and thus no speckle is created. We experimentally test this scheme, demonstrating that microlens arrays with a regular and irregular surface structure show promising results. The experimental results correspond well with a model we constructed, giving us more insight into the different effects influencing the speckle contrast.

P1. 2D beam-steered Indoor Optical Wireless Network

C. W. Oh[1], R. van der Linden[1,2], G. Sutorius[3], K. A. Mekonnen[1], and A. Perez Oliveros[1]
[1] *Eindhoven University of Technology*
[2] *Genexis B.V.*
[3] *Keysight Technologies*

With the proliferation of connected devices and continuing rise in interconnectivity among people and machines, the radio spectrum congestion is becoming a concern. Optical wireless communication is seen as a potential solution. By means of simple intensity modulation direct detection transceivers, we demonstrate a two-dimensionally steered free-space transmission system with 4-PAM modulation. We present the measured results of the channel performance which achieved up to 32 Gbps. The system's performance is only limited by its simple 10 GHz.

P2. Self-consistent theory of locking of semiconductor lasers

Daan Lenstra
Eindhoven University of Technology

In coupled lasers the effective coupling depends on the individual inversions in each constituent laser. Therefore, locking of coupled lasers defines a nonlinear problem that requires self-consistent treatment. Here we report on a general study of the frequency locking of two Fabry-Perot lasers using a self-consistent rate-equation approach. Application of the theory to the coupled cavity quantum-well semiconductor lasers yields very good agreement with measurements.

P3. PT symmetry in a side-coupled resonator structure for broadband unidirectional invisibility

N. Rivolta, and B. Maes
University of Mons

We analyze the scattering properties of a Parity-Time (PT) symmetric structure made of a waveguide and a finite chain of side-coupled resonators. 1D PT-structures exhibit unidirectional invisibility, meaning unit-transmission and zero-reflection for incidence from one direction. The side-coupled nature of our structure provides for different features than the traditional PT Bragg grating, which we explore rigorously. For example, we can achieve a broadband unidirectional invisibility with only two resonators, and we observe rich dispersions for the unidirectional invisibility with four resonators.

P4. From spider webs to a fibre-optic chemical sensor

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From the spider's perspective, silk is not only a building material but also a safety net, a weapon and a sensory organ to detect the presence of prey on its web. For scientists, dragline silk - directly extracted from spiders - is a tough, biodegradable and biocompatible optical fibre. These protein optical threads are made up of millions of repetitive protein sequences and domains that, unlike its silica counterpart, can interact with a multitude of chemical species. In this communication, we will explore the potential of using spider silk as a new type of fibre optic chemical sensor.

P5. Biomarker detection using packaged plasmonic optical fiber

M. Loyez, C. Ribaut, S. Chevineau, J-C. Larrieu, P. Lambert, C. Caucheteur, and R. Wattiez

University of Mons

The biomarker detection is an essential step for early cancer diagnosis. In that way, this work presents the development of an innovative plasmonic optical fiber immunosensor. A gold-coated optical fiber with a photoinscribed Tilted Fiber Bragg Grating (TFBG) is embedded in a specifically designed packaging providing enough stiffness to penetrate into soft matters and human tissues. This biosensor is able to detect biomarkers thanks to the excitation of a surface plasmon wave. For the first time, we demonstrate the detection at a very low concentration in non-liquid polyacrylamide gels containing the target, which is an important milestone towards medical diagnosis.

P6. Switching plasmonic resonances via the hysteretic behavior of SmS piezoresistive thin films

Andreas Sousanis, Philippe F. Smet, and Dirk Poelman

Ghent University

SmS is a switchable chalcogenide which presents a pressure-induced semiconductor-metal transition, while the semiconducting state can be restored by annealing. This work reports on the tuneable plasmonic resonance in the system SmS-Au. Due to the non-spherical shape of gold metallic nanoparticles on top of semiconducting SmS, two resonances could be observed, since the different plasmonic modes interact differently with the SmS layer. Both a constant and a tuneable resonance wavelength were obtained. The switching behavior of SmS from the semiconducting to the metallic state and vice versa was accompanied by a reversible switching behavior of the plasmonic resonance modes.

P7. Fano resonance engineering in a slanted hyperbolic metamaterial cavity

Fabio Vaianella, and Bjorn Maes

University of Mons

We present the possibility to engineer Fano resonances in multilayered hyperbolic metamaterials based on a central slanted section. The key concept is interference between a propagating and a rarely analyzed evanescent mode inside the slanted section that allows for highly tunable resonances. The propagating mode can reach extremely high effective indices, making the realization of deeply subwavelength cavities as small as 5 nm possible. We determine that these phenomena cannot be described using effective medium theory. The developed resonances are very sensitive to any structural changes and could be useful for sensing applications.

P8. Long Term Evolution- Advanced Multiband Wired and Wireless Transmission over Thick-Core Plastic Optical Fiber for Short Distance Communications

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A high indoor traffic capacity is fundamental for the current Long Term Evolution-Advanced (LTE-A) and future 5G networks. Carrier aggregation and femto-cells are foreseen as major solutions to boost higher capacity. Therefore, an in-home widespread multiband wired backbone for LTE-A traffic is highly desirable. Plastic optical fibers (POFs) are an attractive medium to transport LTE-A for short distances. Especially for applications in in-home communications, POF shows remarkable advantages such as easy do-it-yourself fiber installation. This paper demonstrates the successful transmission of 9 OFDM 64-QAM LTE-A band signals over a 35 m long 1mm core diameter PMMA graded-index POF link and 3.5m line-of-sight anechoic chamber wireless transmission.

P9. Photorefractive crystals as brain-inspired photonic reservoir computing systems

F. Laporte, J. Dambre, P. Bienstman
Ghent Univeristy – IMEC

Inspired by holographic data storage, we simulate small photorefractive crystals containing a random index variation placed in a cavity through which a pulsed bit sequence is sent. The light scatters and interferes with subsequent bits. By using the reservoir computing paradigm, the light leaking out of the cavity is interpreted by a linear readout neural network layer. Using this setup, simple bit recognition tasks are performed. In particular, XOR tasks between two bits with a separation of up to 4 bits, between two neighboring bits with a delay of 5 bits and header recognition up to a header length of 5 bits are possible with a bit error rate smaller than 10-3.

P10. Semiconductor Surface Emitting Lasers For Entangled Photons Generation

Luc R Vanbever[1], Evgueni Karpov[1], and Krassimir Panajotov[2]
[1] *Université Libre de Bruxelles*
[2] *Vrije Universiteit Brussel*

We study the feasibility of using a resonant Vertical-Cavity Surface-Emitting Lasers (VCSELs) for the efficient generation of entangled photons. By taking advantage of the relatively high value of the third order non-linearity of the VCSEL, we focus on degenerate four-wave-mixing in the spontaneous regime. We calculate the two-photon production rate, the spectrum of the generated signal photons and the signal-idler cross-correlations. We determine how the production rate of the entangled photons is affected by the dispersion of the third order non-linear medium. Based on our results we identify the characteristics of a VCSEL that would be suitable for entangled photons generation.

P11. Frequency comb generation in a time-dependent graphene ribbon array

G. Altares Menendez, and B. Maes
University of Mons

Graphene ribbon lattices are known for the high tunability of their plasmonic resonances. These lattices couple very efficiently light to plasmonic modes. Here we use a time modulated graphene lattice that allows light, plasmonic resonances and time modulations to interact and generate frequency combs from a monochromatic pulse. We used numerical simulations and coupled mode theory models to connect the frequency comb features to the resonance and applied modulation properties. This mechanism permits highly tunable frequency comb generation in ranges from mid-infrared to far-infrared.

P12. Toward highly confined potassium double tungstate waveguides for laser applications

C.I. van Emmerik, S.M. Martinussen, J. Mu, M.A. Sefünç, M. Dijkstra, and S.M. García-Blanco
University of Twente

Very compact, power efficient, tunable on chip lasers that operate in different wavelength ranges are important for applications in optical sensing, spectroscopy, metrology and telecommunications. In the RENOS project (Rare Earth Novel On-chip Sources) the development of high-contrast rare-earth ion doped potassium double tungstate (RE:KY(WO4)2 or KYW) rib waveguides is proposed. Those waveguides are necessary to develop, in a later stage, compact ring resonators. In this work, a fabrication scheme to produce in a controllable and reproducible way such highly confined waveguides is proposed.

P13. Transfer Printing of Silicon-on-Insulator Devices on Silicon Nitride Waveguide Circuits: Design of Coupling Structures and Process Development

Grigorij Muliuk[1], Nan Ye[1], Sarah Uvin[1], Antonio Trindade[2], Chris Bower[3], Dries Van Thourhout[1], and Gunther Roelkens[1]
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The use of transfer printing technology to integrate active silicon photonic components on a silicon nitride waveguide circuit is proposed. Alignment tolerant coupling schemes were designed using full vectorial simulations. Adiabatic taper structures allow 80% coupling efficiency at 1 um misalignment for the O-band and 97% for the C-band. Compact directional coupler structures allow 80% efficiency for 1 um misalignment for both bands. We present first transfer-printing technology results. This includes the release, picking and printing of silicon coupons from an SOI source wafer to a silicon target wafer. The impact of stress in the silicon membrane on the transfer printing process is assessed.

P14. 48x10 Gb/s Cost-effective FPC-based Optical Transmitter For Optical Interconnect Using Mid-board connector

T. Li, R. Stabile and O. Raz
Eindhoven University of Technology

We use the broadside coupled differential pair structure on printed circuit board (PCB) to achieve a high-speed optical transmitter. Compared to edge coupled differential pair, this structure makes it possible to achieve more compact transceiver design with standard PCB technology, which leads to low cost. In this paper, the simulation of broadside coupled differential pair based design is presented. Based on the 3D simulation of this PCB by CST, we find that this broadside coupled differential structure can operate up to 20 GHz with a worst case loss of 3.42 dB. Finally, the broadside coupled differential pair based PCB for 10 Gbps transmitter is assembled as a preliminary prototype.

P15. Reflected power-based interrogation of plasmonic tilted fiber Bragg grating sensors

Á. González Vila, D. Kinet, P. Mégret, and C. Caucheteur
University of Mons

In this work an interrogation technique for plasmonic tilted fiber Bragg grating (TFBG) sensors is reported. The sensor under test is followed by a uniform FBG whose central wavelength matches the one of the surface plasmon resonance excitation. Light reflected backwards by the grating gets partially attenuated due to the coupling of the plasmon wave to the external medium. Thus, tiny changes in the refractive index of the medium around the sensor are translated into a power fluctuation. This method provides an interrogation way based on the use of the reflected spectrum, especially suitable for remote or in-vivo measurements.

P16. Hybrid-Polymer Photonic Microring Resonators for Biosensing Applications by Nanoimprint Lithography

R. Morarescu, N. T. Beneitez, J. Missinne, G.Van-Steenberge, P. Bienstman, and G. Morthier
Ghent University – IMEC

The motivation of our work was to fabricate using a new low cost method, large area of polymer microring resonators with a minimum number of process steps operating in the very-near infrared region (900 nm). Flexible soft molds using perfluoropolyether (PFPE)-based elastomers for high-resolution replica molding are explored in the imprinting process flow. Our optimized fabrication method results in generation of high-quality devices with Q factors up to 40 000 and finesses up to F ~ 14.

P17. Polymer micro- and nanophotonic sensors realized using replication technologies

Jeroen Missinne, Nuria Teigell Beneitez, Marie-Aline Mattelin, Ahmed Elmogi, Erwin Bosman, and Geert Van Steenberge
Ghent University – IMEC

Polymers are transparent in the visible, mechanically flexible, cost-effective, and therefore attractive materials for optical sensors. Furthermore, high-quality micro- and nanophotonic structures can be realized in polymers using replication-based technologies. This paper will demonstrate single mode waveguide Bragg grating sensors realized using various polymers, and as such illustrate the capabilities of replication technologies both for fabricating microstructures (waveguides with typical cross-sectional dimensions of a few micron) and nanostructures (gratings with typical pitch of a few hundred nanometer) using these technologies. Furthermore, we illustrate that the sensor properties can easily be tuned by selecting the appropriate polymer material.

P18. Efficient grating couplers for Ge on Si and Ge on SOI platform at 5um

S. Radosavljevic, B. Kuyken, and G. Roelkens
Ghent University – IMEC

We present the design of fiber-to-chip grating couplers on germanium-on-silicon and germanium on silicon-on-insulator (SOI) waveguides in the 5 um wavelength range. The best TM and TE grating couplers for Ge on Si have a coupling efficiency of 39% and 18% respectively with 3dB bandwidths of 180 nm and 220 nm at a central wavelength of 5.3 um. The best grating couplers for Ge on SOI have a coupling efficiency of 70% for the TM mode and 60% for the TE mode. The higher coupling efficiency to Ge on SOI waveguides is attributed to the strong reflection at the Si/SiO2 interface, which can be optimized for maximum coupling efficiency.

P19. Optical event horizon in silicon-on-insulator waveguides

N. Poulvellarie, C. Ciret, and S.-P. Gorza
Université Libre de Bruxelles

We report on the first experimental evidence of an optical event horizon in a nanophotonic waveguide through the reflection of a weak pulse in the telecom C-band on a Near-IR intense pulse at 1850nm. The experiment takes advantages of the dispersion properties and the large Kerr nonlinearity of the waveguide to generate an optical event horizon. Compared with previous experiments in optical fibers, we have observed an efficient wavelength conversion on centimeter propagation distance at much lower peak power. The reflected pulse wavelength is 13nm apart from the probe pulse, in agreement with the phase matching condition governing this process.

P20. Design of the twin guide quantum well laser for Indium Phosphide membrane on Silicon platform

Vadim Pogoretskiy, Yuqing Jiao, Jos van der Tol, and Meint Smit
Eindhoven University of Technology

This work presents the design of an integrated twin guide quantum well membrane laser based on IMOS (Indium Phosphide Membrane On Silicon) platform. Laser is predicted to have a threshold current of 1 mA, small footprint of 100 um2. Layerstack is designed to be integrated with passive devices as well as the quantum well based electro-absorbtion modulator and photodetector.

P21. Influence of temperature on the transition cross-sections and the optical gain of highly Yb-doped potassium double tungstates

Y.S. Yong, S. Aravazhi, S.A. Vázquez-Córdova, J.L. Herek, S.M. García-Blanco, and M. Pollnau
University of Twente

We report the temperature dependence of transition cross-sections and optical gain in a high-ytterbium-concentration epitaxy layer of KYb0.57Gd0.43(WO4)2 grown on a KY(WO4)2 substrate for chip-scale waveguide amplifiers. The transition cross-sections strongly depend on crystal temperature via Boltzmann re-distribution and linewidth broadening at elevated temperatures. Consequently, the theoretical gain of an amplifier operating at 80 °C is limited to 67% of the gain at 20 °C. Nevertheless, numerical and experimental results show that >900 dB/cm of net gain is achievable at a pump wavelength of 933 nm and a signal wavelength of 981 nm without active thermal management, hence high-gain waveguide amplifiers operating without active cooling are feasible.

P22. Graphene devices for outperformed optical interconnects

Leili Abdollahi Shiramin, and Dries Van Thourhout
Ghent University – IMEC

Optical On-Off keying based on graphene has received great attention in the past years for communication applications. However most studied devices suffer from a low extinction ratio. Here we introduce a design based on the integration of graphene (two layers of graphene with a dielectric in between) on a silicon slot waveguide. It has an extinction ratio over 20 dB for a 100 um device length with an applied voltage about 6 Volt operating with TE polarized light. The insertion loss, another key parameter for optical switches, is only 1 dB for a high quality graphene.

P23. Aluminum-containing quantum wells in the COBRA Generic Photonic Integration Platform

F. Lemaître[1,2], H. Ambrosius[1], J. Decobert[2], F. Pommereau[2], and K. Williams[1]
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[2]*III-V Lab*

Aluminum-quaternary (Al-Q) quantum wells offer enhanced carrier confinement and the possibility of efficient uncooled operation for photonic integrated circuits. The technology has additionally been mastered in combination with selective area growth (SAG) technology at III-V Lab to tune the band gaps of AlInGaAs quantum well structures with wide variations in the band-edge across the wafer. In this work we incorporate Al-Q wells within the generic integration platform which uses epitaxial regrowth to combine active and passive devices. The challenge is to ensure minimal defect creation and oxidation during the regrowth. This work presents the fabrication of Al-Q chips by following the standard COBRA process. A comparison of Al-Q and the mature phosphorus-containing P-Q active sections will be presented to explore the advantages and challenges for incorporating Al-Q quantum wells.

P24. Grating couplers under flood illumination as a low-cost readout mechanism for photonic sensors

D. Martens, G. Dong, and P. Bienstman
Ghent University – IMEC

Grating couplers are a vital component for integrated photonics, as they provide an interface with the chip from anywhere on the surface. Conventionally, they are used with optical fibers, providing excellent power efficiency. The grating couplers are designed to match the size of the fiber mode. The alignment of the fiber to the chip requires high precision, rendering the couplers incompatible with applications where a low cost is crucial, like point-of-care biosensors. We present a reoptimization of grating couplers, for usage with a light source that illuminates an area much larger than the grating coupler, strongly reducing the required precision.

P25. Optical Design of a Novel Wide-Band Membrane Electro-Absorption Modulator Based on Bandfilling

J.P. van Engelen, L. Shen, G.C. Roelkens, Y. Jiao, M.K. Smit, and J.J.G.M. van der Tol
Eindhoven University of Technology

Recently we proposed a novel membrane electro-absorption modulator (EAM) based on the bandfilling induced absorption change in n-InGaAs. We now present the optical design and give a detailed analysis on the extinction ratio (ER) and insertion loss (IL). An improved design is given that yields an ER of 7.9 dB/100um and an IL of 1.9 dB/100um. This results in a modulation speed of 15 GHz for a device with a given ER of 7 dB, which makes it suitable for datacom applications.

P26. Optical coupler concept for wafer scale fabrication of adhesively bonded photonic and electronic circuits

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Wafer scale integration of photonics and electronics enables cost-effective realization of high-density and high-performance electro-optical modules. In this paper an optical coupler concept suitable for such integration technology is described by means of numerical simulations. Light from a vertically tapered indium phosphide waveguide is adiabatically expanded into the polymer structure, and subsequently butt-coupled into a standard single mode fiber. With this concept a simulated coupling loss of 0.82 dB can be achieved for a 2.4 mm long device.

P27. Low-loss slab waveguides in KY(WO4)2 fabricated by 12 MeV carbon ion irradiation

Raimond Frentrop, Manuel Díaz-Híjar, Victoria Tormo-Marquez, José Olivares, and Sonia M. García-Blanco

University of Twente

KY(WO4)2 is a very interesting material in integrated optics thanks to its excellent gain characteristics when doped with rare-earth ions and its relatively large non-linear index of refraction. The fabrication and characterization of slab optical waveguides in KY(WO4)2 by swift 12 MeV carbon ion irradiation using moderate fluences is presented. Losses as low as 2 dB/cm after annealing have been measured for an irradiation fluence of 1x1014 ion/cm2. Micro-Raman spectroscopy has been utilized as a tool to characterize the damage profile induced by the ions, which agrees qualitatively with the shape of the refractive index profile obtained from micro-reflectivity measurements.

P28. Design for hybrid SOI/Silicon Nitride high cooperatively optomechanical cavity

Paul Tiebot, Bart Kuyken, and Dries Van Thourhout

Ghent University – IMEC

We propose an optomechanical cavity design with greater than one cooperativity, based on an external high tensile stress SiN mechanical oscillator on top of a planarized SOI TM ring resonator. The high tensile stress SiN Beam based designed allowed for a very high mechanical quality factor. At the same time the TM mode and thin film deposition technic we can achieve nanometer size gaps between the mechanical resonator and the ring resonator leading to a strong optomechanical coupling Moreover, we investigate the use of electrostatic tuning in order to tune both optomechanical coupling, dissipative vs dispersive coupling ratio and FSR.

P29. Performance analysis of the DBRs in InP fabricated with DUV technology

Dan Zhao, Luc Augustin, Dzmitry Pustakhod, Jeroen Bolk, Kevin Williams, and Xaveer Leijtens

Eindhoven University of Technology

We present distributed Bragg reflectors (DBRs) in Indium-Phosphide (InP)-based platform fabricated with 193nm deep-ultraviolet (DUV) technology. This building block was developed to be compatible with the generic InP integration process. The parameter space of the DBRs and the impact of manufacturing tolerances were explored with numerical calculations. The DBRs were manufactured, characterized and compared to the simulated structures. A high-resolution optical frequency domain reflectometry (OFDR) method is applied to explore the fabrication accuracy and the properties of the DBRs.

P30. Strong quadratic coupling in slotted photonic crystal pair

Jesper Håkansson, and Dries Van Thourhout

Ghent University – IMEC

We present the design of a slotted photonic crystal compatible with CMOS fabrication techniques that is capable of state of the art position squared coupling. The confinement of the light into the slot together with the low weight, low frequency mechanical mode, gives a strong linear vacuum coupling rate. The design allows us to choose the optical splitting by means of the distance between the cavities and of an electro statically tunable slot width and gives a square vacuum coupling rate. This is interesting because a strong square coupling enables quantum non-demolition measurements of phonon numbers or squeezing the mechanical motion.

P31. Optical Gain with Colloidal Quantum Dots: From material photo-physics to integrated devices

Suzanne Bisschop, Pieter Geiregat, Tangi Aubert, Zeger Hens, Dries Van Thourhout, and Edouard Brainis

Ghent University – IMEC

Colloidal quantum dots (QDs) have emerged as a most attractive optical gain medium in recent years. They offer a broad gain spectrum that can be readily adjusted by exploiting size-dependent quantum confinement, a specific choice of QD material or the judicious formation of heterostructured core/shell QDs. Together with their suitability for solution-based processing, this makes them a most versatile gain medium for photonic integrated circuits. CdSe/CdS core/shell CQDs in particular have shown amplified spontaneous emission (ASE) and lasing under femtosecond and nanosecond pumping. However, to fully assess their potential for micro- and nanophotonics, a quantitative understanding of their gain characteristics is needed. Here, we show that the material gain of colloidal QDs can be determined through ultrafast transient absorption measurements on QD-dispersions, which is a key parameter for the design and optimization of future QD-based amplifiers and microlasers.

P32. Experimental Characterization of a Reflective Amplified Modulator for Analog Applications

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Eindhoven University of Technology

We present the analog characterization of a 35 GHz reflective electroabsorption modulator (REAM) monolithically integrated with a semiconductor optical amplifier (SOA). The device has a great potential as a low cost/consumption transmitter as it combines the high-speed modulation capabilities of a REAM with the amplification function of an SOA. Lossless operation over >40 nm range is measured. By optimizing the bias current of the SOA, higher modulation efficiency and larger operation range can be obtained. The dependence of the modulation efficiency and radio frequency gain on REAM bias voltage, input optical power and SOA bias current are investigated.

P33. Buried Heterostructure and Shallow Ridge lasers: a theoretical comparison

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Buried Heterostructure (BH) lasers have considerable advantages compared to shallow ridge (SR) lasers: higher current injection efficiency, energy efficiency, and better thermal dissipation. The reason is that the active region is surrounded on all sides by InP which has the function of confining charge carriers and tightly confining the optical field while efficiently dissipating heat. In this work, we present a model to quantify the improved current injection efficiency by analyzing the carrier distribution in BH and SR lasers. In particular, we focus on the effect which surface recombination and lateral carrier out-diffusion plays in BH and SR laser, respectively.

P34. 25 Gbit/s Duobinary and 4-PAM for Access Networks

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Access networks are no exception in the ever continuing increase in data rates. Due to the cost-sensitive nature of these networks it is of interest to be able to reuse the current 10G optics for the upgrade to higher data rates. Therefore, higher order modulation formats can be considered to transmit higher data rates through a reduced bandwidth. At the same time, complexity of the modulation format has to be kept low. In this paper we will present 25 Gbit/s transmission of Duobinary and 4-PAM modulation formats. Comparisons between the two modulation formats will be made.

P35. Imaging of photonic crystal cavity mode via refractive index sensing technique

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Silicon (Si) based integrated Photonic Crystal (PhC) cavities shows great promise for use in biosensing application, owing to their high Quality (Q) factor, low mode volume and Complementary metal oxide semiconductor (CMOS) compatibility. We experimentally map the PhC cavity mode by moving a silica nano-tip fiber near the back of cavity surface. The mode mapping is obtained by measuring intensity variation from top cavity surface which is induced by perturbation in local refractive index of the cavity due to nano-tip movement. The map of cavity turns out to be in excellent agreement with numerical prediction.

P36. A 64 Gb/s PAM-4 transimpedance amplifier in 0.13 um SiGe BiCMOS

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We present a transimpedance amplifier (TIA) for optical links, implemented in 0.13 um SiGe BiCMOS and capable of 64 Gb/s 4-level pulse-amplitude modulation (PAM-4) reception. Paired with a 0.55 A/W photodiode, a bit-error rate (BER) of 10^3 is achieved for 56 Gb/s (64 Gb/s) for average optical input powers between 8.4 dBm (7.0 dBm) and at least 1.6 dBm (1.7 dBm) by switching between a high and low gain mode, selected using an on-chip digital gain control circuit. The TIA consumes 150 mW and 134 mW in these respective modes, yielding a 2.34 pJ/b efficiency for 64 Gb/s.

P37. Low-loss highly tolerant vertical couplers for hybrid integration of Si3N4 and multimode polymer waveguides

Jinfeng Mu, Meindert Dijkstra, Yean-Sheng Yong, Sergio A. Vázquez-Córdova, and Sonia M. García-Blanco
University of Twente

In this paper, low-loss and highly fabrication tolerant vertical couplers are demonstrated for the integration of a polymer waveguide chip onto the Si3N4/SiO2 passive platform. The couplers are under multimode condition and assembled by using flip-chip bonding technique. The passively aligned vertical couplers have a lateral misalignment between polymer and Si3N4 waveguide cores of ±1.25 um. Successful operation has been experimentally demonstrated over a wide spectral window of 1480-1560 nm, with measured coupler losses below <0.8 dB for Si3N4 taper angles below 0.9°, showing good agreement with the calculated values. Furthermore, thermal shock test results indicate a robust coupling performance.

P38. Design of an intra-cavity SiN grating for integrated 850nm VCSELs

Sulakshna Kumari, Emanuel P. Haglund, Johan S. Gustavsson, Anders Larsson Gunther Roelkens, and Roel Baets
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A weakly etched grating placed inside a VCSEL cavity between the top and bottom DBR can couple out light into a waveguide connected to it. In this paper, the design of such an w intra-cavity Silicon Nitride (SiN) grating for hybrid 850nm VCSELs integrated on a SiN waveguide platform will be presented. This design enables the integration of polarization stable, single mode and energy efficient VCSELs on a SiN photonic integrated circuits (PIC).

P39. Design of a deep etched focusing subwavelength grating with a metallic reflector for InP membrane on Silicon platform

A.J. Millan Mejia, Y. Jiao, J.J.G.M. van der Tol, and M. Smit
Eindhoven University of Technology

In membrane photonic integration technologies, grating couplers are commonly used to couple light between the photonic integrated circuit and optical fibers. Hereby we present the design of a novel deep etched focusing subwavelength grating with a metallic reflector. This device is optimized for the InP membrane on silicon (IMOS) platform. The simulated coupling efficiency is as high as 76%, with the fiber tilted 10° from the surface normal. The use of a metal reflector makes the performance of the device independent of the underlying layer stack, providing flexibility and reliability to the platform.

P40. Switching Performance Assessment for High-capacity and Large-connectivity OPSquare Data Center Network

W. Miao, F. Yan, and N. Calabretta
Eindhoven University of Technology

The switching performance and scalability of the OPSquare data center network are investigated for different modulation formats, namely 425 Gb/s NRZ-OOK waveband, 28 Gb/s PAM4 and 40 Gb/s DMT traffic. By exploiting the fast WDM optical switching technology, the optical switch can achieve large port-count with lower broadcasting ratio and thus lower OSNR deterioration for the traffic. Experimental results show >8 dB input power dynamic range with <3 dB penalty for optical switches at scale of 64—64, which potentially enables a high-capacity and large-connectivity OPSquare data center network.

P41. Backscatter-Induced Transmission Noise and Length-Dependent Attenuation in Silicon Waveguides

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A standard process fabricated SOI waveguide is considered well behaved and understood. Surprisingly, we observed in 7cm-long waveguides sharp fluctuations of more than 15 dB in transmission spectrum, which we attribute to the interference between the guided mode and multiple backscatters on waveguide sidewalls. To understand how the backscattering and the fluctuation are related, we built a lumped-circuit waveguide model in CAPHE that includes backscattering and recaptured sharp fluctuations as measured. A relation between fluctuation statistics and backscattering strength is found, facilitating a derivation of backscattering from transmission measurements. Using our CAPHE model, we found the transmission attenuation rate non-constant when backscattering is considered. Rather unexpected, it is waveguide length dependent. Using Coupled-Power Theory, we well explained and qualitatively revised the theory to calculate the average waveguide transmission.

P42. Direct modulation and down scaling of laser sources in COBRA generic foundry platform

A. Higuera Rodriguez, W. Yao, and M. Smit
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We present an experimental study into the use of simple Fabry Perot lasers for integration in generic platforms. Such integrated FP lasers offer the advantage of freedom of placement anywhere on the chip and, easy integration with monitoring and control functions. They can play a role in short range data communications, they have a potential for 10 Gb/s direct modulation speed. We report first results on experimental realization of such lasers including eye diagrams and BER testing results.

P43. Incorporation of colloidal quantum dots into the gap of plasmonic bowtie antennas

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We demonstrate the deterministic incorporation of colloidal CdSe/CdS core-shell quantum dots emitting at 620 nm into the gap of plasmonic Ag bowtie antennas. The antennas were fabricated using a lift-off process employing electron beam lithography and electron gun evaporation of silver on a copper seed layer. Nano-patterning of the wet-chemically synthesized quantum dots was done using a previously devised lift-off process and a state-of-the-art electron beam lithography system for the alignment. Placing colloidal quantum dots in the gap of plasmonic antennas can significantly reduce their intrinsic radiative lifetime and hence increase the emission rate for the application as a room-temperature single-photon source.

P44. Phase shift control with active feedback

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We present a closed feedback loop approach to actively control the differential phase shift induced by a thermo-optic modulator in a silicon on insulator platform. We use an on-chip differential phase shift monitoring using integrated balanced photodiodes to generate the feedback signal to control the phase shifter. In addition to the optical circuit we use a control layer to analyse the feedback signal and adapt the electrical power applied in the thermo-optical phase shifter in order to achieve the desired phase shift.

P45. Embedded Opto-electronic Die Based on Wet Etched Silicon Interposer for 3D packaging with CMOS IC

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In this paper, we propose and fabricate a silicon interposer for 3D packaging of optical and electrical dies for parallel optical interconnections. With deeply wet etching of silicon, the cavity is formed for embedding and flip-chipping of photonics (VCSELs, PDs) and the openings for optical IOs are opened. The CMOS IC is flipped and bonded on the top of cavity, and the electrical interconnection are also design with impedance matched traces. Besides, the heat transfer is also simulated. Each channel of module is working at 10 Gb/s with error free operation.

P46. Optical beam steering functionality of an InP/InGaAsP based optical waveguide

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An optical beam steering device capable to control the beam position across the facet of an InP/InGaAsP chip is proposed and experimentally demonstrated. The beam steering is based on depletion effects occurring in a 14.5 μm wide waveguide by applying negative voltage to two p-electrodes placed on top of it. An adiabatic taper is connected to the waveguide to enable single lobe operation. The steering device has been co-integrated with a laser source at 1568 nm. The optical beam can be continuously moved in a total tuning range of 1 μm with a minimum applied voltage of -4V.