

Demonstration of 80 Gbps NRZ-OOK Electro-Absorption Modulation of InP-on-Si DFB Laser Diodes

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Abstract: High-speed electro-absorption modulation of a heterogeneously integrated InP-on-Si DFB laser diode is used for the transmission of an 80 Gbps NRZ-OOK signal over 2 km of NZ-DSF link below the hard-decision forward-error-correction threshold.

OCIS codes: (140.3490) Lasers, distributed-feedback, (130.0250) Optoelectronics, (060.4510) Optical communications.

1. Introduction

Heterogeneous integration of III-V membranes on silicon, or silicon-on-insulator, is regarded as one of the few viable approaches to realize integrated sources for silicon photonics. A good candidate for optical data-communication applications is the distributed-feedback (DFB) laser diode, thanks to its stable single mode behavior with large side mode suppression. A characteristic of great importance for data-communication is the maximum modulation speed of the transmitters. In recent years, several state-of-the-art results have been reported for both monolithic InP devices and heterogeneously integrated InP-on-Si devices. These were realized using different modulation schemes: non-return-to-zero on-off-keying (NRZ-OOK), 4-level pulse amplitude modulation (PAM-4) and electrical duobinary (EDB). As an example, a 100 Gbps NRZ GeSi electro-absorption modulator implemented on a silicon photonic platform was shown in [1]. For III-V-on-silicon devices, 56 Gbps NRZ-OOK electro-absorption modulation was demonstrated from both sides of the laser [2]. In [3], an InP distributed Bragg reflector (DBR) laser was used for the generation of 112 Gbps PAM-4. Furthermore, an InP-based double-side electro-absorption modulated DFB laser has been used for 2 x 56 Gbps PAM-4 [4]. For III-V-on-silicon devices, 25 Gbaud PAM-4 was demonstrated [2], and the same design was used for 100 Gbps EDB [5]. Although the bandwidth of direct modulation can be relatively high [3], modulation at high frequencies often comes with a large chirp. Electro-absorption modulation suffers less from this problem and its bandwidth is limited only by the RC-constant of the modulator. In this paper, we report on the NRZ-OOK electro-absorption modulation of a heterogeneously integrated III-V-on-silicon DFB laser at 80 Gbps. We briefly discuss the design and fabrication of the externally modulated laser diode (EML). We also show that the bit-error-rate (BER) is substantially below the 7% hard-decision forward-error-correction (HD-FEC) threshold, both in back-to-back configuration as well as after transmission over 2 km of non-zero dispersion-shifted-fiber (NZ-DSF).

2. Design and fabrication

The top-view of the EML structure and the InP epitaxial layer stack design parameters are shown in Fig. 1. The taper structure used for coupling the light from the III-V-on-silicon DFB laser to the silicon waveguide is used as an EAM. The device is similar to that of [2], but with each taper section cut in two halves. The sections are electrically isolated from each other during fabrication, by wet-etching the top p-InGaAs contact layer, and dry-etching around 200 nm of the p-InP layer. The length of the etched region was 30 μm instead of 7 μm in [2]. High resistance between the sections minimizes the leakage current from one section to the other. In our laser, the resistance between the EAM and the laser section is 6 k Ω .

The active laser section is 500 μm long and 2 μm wide. The EAM sections are each 50 μm long. The full taper length is around 150 μm long. The width of the taper goes from 2 μm down to 0.7 μm . The InP epitaxial structure is

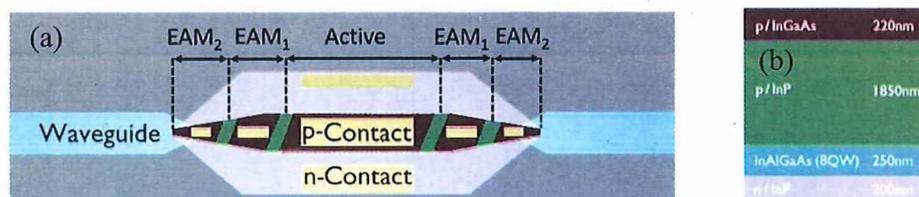


Fig. 1. (a) Top-view of the fabricated InP-on-Si EML showing the III-V-on-Si DFB and tapers used as EAM, and (b) the InP epitaxial layer stack design parameters.

bonded on a 400 nm thick Si waveguide (3.5 μm wide) that has a 500 μm long DFB grating etched 190 nm deep, with a period of 248 nm and duty cycle of 50%. A quarter-wave shifted section is located in the center of the grating. The detailed fabrication steps are reported in [6].

In principle, either of the EAM sections can be used to modulate the light. However, in the first EAM section, the light is confined more to the III-V waveguide, while in the second EAM section, the light is confined more to the silicon waveguide. Therefore, more light will be absorbed when reverse biasing the first EAM section, and a higher extinction ratio is expected. In this paper, we focus on modulating the first EAM section, while not pumping the second EAM section. If the lasing wavelength is close enough to the bandgap wavelength, reverse biasing of this section will result in a significant extinction with low insertion loss.

3. Characterization

The measured 3-dB modulation bandwidth of the device was found to be 33 GHz. Data transmission experiments were performed to investigate the large signal modulation performance of the EML. An electrical signal is generated with a Keysight M8196A Arbitrary Waveform Generator (AWG). This electrical signal is amplified by a 50 GHz RF electrical amplifier (SHF-S807). The data signal is superimposed on a negative bias voltage using a bias tee. An L-band Erbium Doped Fiber Amplifier (EDFA) is used to boost the optical signal. The amplified spontaneous emission from that EDFA is filtered out using a variable-bandwidth optical tunable filter. The resulting optical signal is fed to the photodetector, and finally, the output electrical signal is fed to a Keysight DSAZ634A Real-Time Oscilloscope. A raised-cosine filter with $\alpha = 0.1$ is used to shape the transmitted pulse. Using the built-in channel de-embedding function of the AWG, transmission of a 80 Gbps NRZ-OOK Pseudorandom-Binary-Sequence (PRBS) with a word length of 2^7-1 was verified, as shown in Fig. 2 (a, b) for back-to-back configuration, and after transmission over a 2 km long NZ-DSF link, respectively.

The voltage swing applied to the EAM is about 1.8 Vpp. The stage temperature was fixed at 15°C. The laser was operating at a bias current of 49 mA and an EAM reverse bias of -0.7 V. The lasing wavelength was 1570.6 nm. The optical bandwidth of the optical tunable filter was 1 nm. The received optical power was 5 dBm (note that no trans-impedance amplifier was present at the receiver). The recoded BER was around $1.5 \cdot 10^{-4}$, which is below the KP4-FEC threshold. Measurement of the BER vs. received power for this laser is shown in Fig. 2 (c). 80 Gbps PRBS transmission with a word length of (2^7-1) with a BER lower than the 7% HD-FEC threshold is possible for a received power less than 0 dBm.

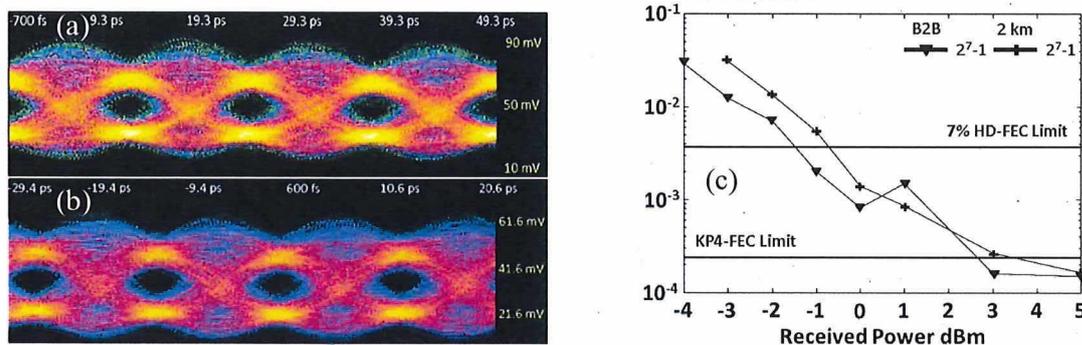


Fig. 2. Sub-HD-FEC transmission at 80 Gbps (a) in back-to-back configuration, and (b) with 2 km NZ-DSF link, for a PRBS pattern of length 2^7-1 . (c) Bit-error-rate vs. received power showing sub-HD-FEC operation for 80 Gbps for a received power below 0 dBm.

4. Conclusions

Electro-absorption modulation of InP-on-Si DFB laser diodes is demonstrated. Transmission of an 80 Gbps NRZ-OOK signal is shown for both back-to-back configuration and for a 2 km long NZ-DSF link between the transmitter and the receiver, with a BER below the 7% HD-FEC threshold.

5. References

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- [2] A. Abbasi et al., "III-V-on-Silicon C-band High-Speed Electro-Absorption Modulated DFB Laser," JLT, 36(2), (2018).
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Marriott
Salon I & II

CLEO: QELS-Fundamental Science

16:30–18:30

FTh4M • Hyperbolic Photonics Media
President: Moussa N'Gom Rensselaer
Polytechnic Institute, USA

FTh4M.1 • 16:30

Intersubband Plasmons Induced Negative Refraction at mid-IR Frequency in Heterostructured Semiconductor Metamaterials, Mario Ferraro¹, Adrian Hierro², Miguel Montes Bajo², Julen Tamayo-Arriola², Maxime Hugues¹, Jose Ulloa², Massimo Giudici³, Jean Michel Chauveau¹, Patrice Genevet¹; ¹CRHEA-CNRS, France; ²ISOM-Universidad Politécnic de Madrid, Spain; ³InPhyNi-CNRS, France. We theoretically and experimentally demonstrate negative refraction in a semiconductor system operating at mid-infrared wavelengths. Such effect is generic and realized by electrons quantum confinement in quantum wells, acting as an adjustable resonance.

FTh4M.2 • 16:45

Enhanced Radiative Emission of MQW by Resonant Modes of Hyperbolic Metamaterial Resonator, Kun-Ching Shen¹, Lung-Hsing Hsu¹, Din Ping Tsai¹, Hao-Chung Kuo², Chien-Chung Lin², Yuh-Jen Cheng¹; ¹Academia Sinica, Taiwan; ²National Chiao Tung Univ., Taiwan. We report the use of resonant modes of a hyperbolic metamaterial cube made of multiple metal/dielectric layer structure to enhance the radiative emission of multiple quantum wells. The mode analysis and photoluminescence will be discussed.

FTh4M.3 • 17:00

Field Enhancement and Ultrafast Plasmonics In Nonlocal Transitional Metamaterials, Brian Wells², Margoth Cordova Castro³, Anatoly Zayats³, Viktor A. Podolskiy¹; ¹Univ. of Massachusetts Lowell, USA; ²Univ. of Hartford, USA; ³King's College London, UK. We analyze spatial and temporal optical response of plasmonic nanocone arrays, relate the strong enhancement of local intensity to excitation of nonlocal plasmonic modes supported by the composites, and discuss potential applications in ultrafast nonlinear optics and plasmonics.

Marriott
Salon III

CLEO: Science & Innovations

16:30–18:30

STh4N • High-Speed Optical Interconnects
President: Jonathan Bradley McMaster Univ.,
Canada

STh4N.1 • 16:30

Demonstration of 80 Gbps NRZ-OOK Electro-Absorption Modulation of InP-on-Si DFB Laser Diodes, Mahmoud Shahin¹, Javad Rahimi Vaskasi¹, Joris van Kerrebrouck¹, Amin Abbasi², Kasper Van Gasse¹, Muhammad Muneeb¹, Laurens Breyne¹, Peter Ossieur¹, Xin Yin¹, Johan Bauwelinck¹, Gunther Roelkens¹, Geert Morthier¹; ¹Ghent Univ., Belgium; ²Antwerp space, Belgium. High-speed electro-absorption modulation of a heterogeneously integrated InP-on-Si DFB laser diode is used for the transmission of an 80 Gbps NRZ-OOK signal over 2 km of NZ-DSF fiber below the hard-decision forward-error-correction threshold.

STh4N.2 • 16:45

Waveguide Integrated CVD Graphene Photo-Thermo-Electric Detector With >40GHz Bandwidth, Simone Marconi^{2,1}, Vaidotas Miseikis³, Marco Angelo Giambra¹, Alberto Montanaro¹, Vito Sorianello¹, Camilla Coletti^{3,4}, Marco Romagnoli¹; ¹Photonic Networks and Technologies Lab - CNIT, Italy; ²Tecip Inst. - Scuola Superiore Sant'Anna, Italy; ³Graphene Labs, Istituto Italiano di Tecnologia, Italy; ⁴Center for Nanotechnology Innovation @NEST, Istituto Italiano di Tecnologia, Italy. We demonstrated a CVD Graphene near-infrared photodetector based on the photo-thermo-electric effect integrated on a Si₃N₄ waveguide. The device is based on a split-gate induced pn junction working at zero bias and with bandwidth >40GHz.

STh4N.3 • 17:00 Invited

Low Power Analog Coherent Links for Next-Generation Datacenters, Clint Schow¹; ¹Univ. of California Santa Barbara, USA. Ever-increasing bandwidth demand in datacenter networks makes a move to coherent links seem inevitable. An "analog coherent" approach using optical phase locked loops can enable low-power consumption, expanded link budgets, low-latency, and future bandwidth scalability.

Marriott
Salon IV

16:30–18:30

STh4O • Epitaxial Materials & Strain Engineering
President: Oana Malis; Purdue Univ., USA

STh4O.1 • 16:30

Transparent Displays Using Strain-Engineered Nanopillar Light-Emitting Diodes, Kunook Chung¹, Jingyang Sui¹, Pei-cheng Ku¹; ¹Univ. of Michigan, USA. Using local strain engineering, we fabricated monolithically integrated and individually addressable RGB pixels and showed feasibility for a transparent microdisplay.

STh4O.2 • 16:45

Uniformly Tensile-strained Germanium Enabled by a Recessed Nitride Stressor for Efficient Integrated Photodetectors at Longer Wavelengths, Yiding Lin^{1,2}, Danhao Ma³, Rui-Tao Wen³, Kwang Hong Lee², Xin Guo¹, Jin Zhou¹, Hong Wang¹, Chuan Seng Tan^{1,2}, Jurgen Michel^{2,3}; ¹Nanyang Technological Univ., Singapore; ²Low Energy Electronic Systems (LEES), Singapore-MIT Alliance for Research and Technology, Singapore; ³Materials Science and Engineering, MIT, USA. Germanium photodetector, formed with a self-aligned dry etching method, together with a tensile silicon nitride sidewall stressor, exhibits a strain profile with improved uniformity and a ~2× enhancement on the quantum efficiency at the L-band.

STh4O.3 • 17:00

Ultrawide Strain Tuning of Luminescence from Mechanically Stressed InGaAs Nanomembranes, Xiaowei Wang¹, Xiaorui Cui², Abhishek Bhat², Donald Savage², John Reno³, Max Lagally², Roberto Paiella¹; ¹Boston Univ., USA; ²Univ. of Wisconsin - Madison, USA; ³Sandia National Labs, USA. We investigate the tunability of semiconductor light emission based on the use of nanomembranes under external mechanical stress. Active tuning of the InGaAs emission spectrum over an ultrawide wavelength range (> 250 nm) is demonstrated.

Thursday, 16:30–18:30