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InP Membrane Based Broadband Regenerator for silicon-based optical interconnect applications

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Abstract: We demonstrate the use of a Membrane-InP-Switch(MIPS) on-silicon as a signal regenerator. A receiver sensitivity enhancement >2.5dB across the entire C-band and a tripling of Extinction Ratio(ER) for low ER signals at 1Gb/sec is demonstrated.

OCIS codes: (130.3120) Integrated optics devices; (200.6015) Signal regeneration

1. Introduction

Silicon photonics has seen increasing interest from industry [1,2] and academia [3-5] as a possible ultimate merging of CMOS and photonics on a unified platform. The basic passive building blocks needed to make integrated photonic circuits have been recognized already 20 years ago [6,7] and were demonstrated in recent years. Complementary functions such as light sources and detectors have also been achieved with the most successful demonstrations based on the heterogeneous/hybrid integration of III-V materials on top of silicon [4,5]. Yet another critical component being pursued is the electrical to optical convertor or modulator [8]. Demonstrated silicon modulators are limited by the properties of carriers in doped silicon and have therefore branched along two clear paths. For the realization of high speed and low voltage devices, solutions based on resonant cavities, and therefore narrow band in nature, have been used [9]. Where broad band operation was desired, Mach Zehnder Interferometer (MZI) structures have been built with typically a $V\pi L$ product of around 1-2 V·cm implying that modulators need either be very long or driven with high voltages in order to achieve a desired high extinction ratio (ER). Limiting the length and/or voltage of the MZI modulators results in poor ER, which in turn lowers the receiver sensitivity. It is therefore desirable to find a low power method for increasing the ER (regeneration) in the silicon circuit. Recently we have reported on a new device based on an ultra thin Membrane InP Switch on Silicon called the MIPS [10] which can precisely fulfill this function.

In this paper we demonstrate how the MIPS can be used as a passive signal regenerator for boosting the ER of low ER signals through the principal of saturable absorption. Tripling of the ER for low ER signals at 1 Gb/sec is shown and lowering of the required power at the receiver by more than 2.5dB is shown across the C-band. The demonstrated performance enhancement achieved with the heterogeneously integrated MIPS device on an SOI platform can enable the shortening of MZI Si structures or alternatively the lowering of their required modulation driving voltages.

2. MIPS description and typical characteristics

The InP membrane switch is made by adhesive bonding of a thin (<100 nm) III-V layer consisting of 3 quantum wells (QWs) and further post-processing of the membrane to leave a 2 μm wide and 150 μm long InP stripe on top of an SiO_2 dielectric. The optical signals are horizontally coupled using a polymer inverted taper coupler into the SOI and then transferred from the SOI waveguide to the InP switch structure by using an inverted taper with appropriate lengths in both the SOI and InP layers.

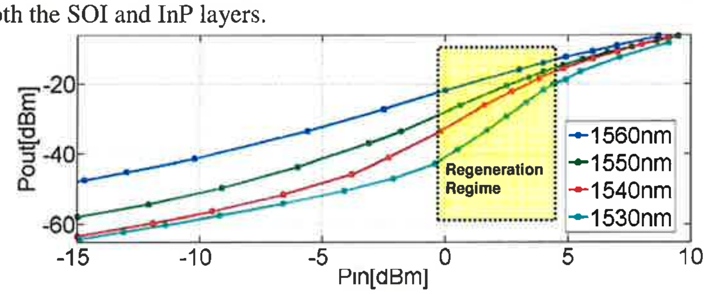

Figure 1: MIPS Pin-Pout characteristics showing the large slope in the regeneration regime

The InGaAs QWs are designed with a band gap of 1.58 μm. Light absorption is critically dependent on the wavelength [10] and since the membrane has such a small volume (QW layers: 7.2 μm^3, total structure: 30 μm^3) the P_{in} to P_{out} characteristics exhibit two distinct regimes (see figure 1). For low optical powers linear absorption dominates the behavior while for high input power, quick bleaching on the material results in a slope larger than one and hence a regeneration action. In addition, the further away from the band-edge the more pronounced the slope becomes in the regeneration regime.

3. MIPS operation as regenerator

From the slopes in figure 1 it is visible that in the regeneration regime a ΔPin to ΔPout ratio of 3:1 or more can be obtained. This suggests that the extinction ratio can be greatly increased by injecting a small ER signal with the appropriate optical power (as can also be seen in figure 2C). To test the MIPS regenerator an optical input signal modulated with a 2^{31}-1 PRBS sequence and varying extinction ratios was used. Two different scenario's were tested: operation at a 2dB input ER (figure 2A) and operation at 5dB ER (figure 2B). For both cases the measured receiver sensitivity can be improved by at least 2.5dB with the best results achieved for 2dB input ER at 1530nm where the obtained receiver sensitivity improvement was 4.5dB. Additional characterization (not included) showed that even steeper Pin Vs Pout curves can be obtained for shorter wavelengths, Therefore a QW epitaxy engineered with a band edge at 1.6 µm for example should yield >4dB enhancement across the C-band.

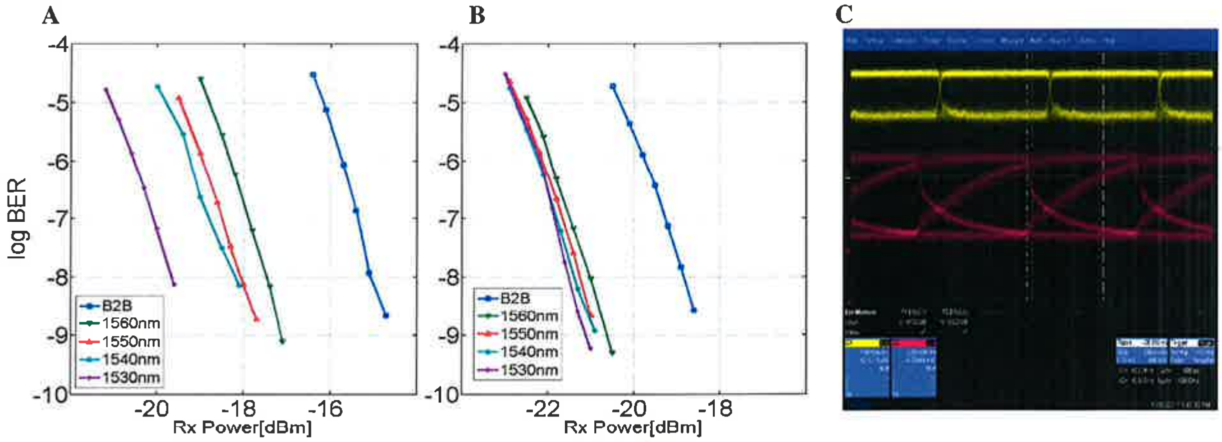

Figure 2: (A) Measured BER Vs Rx power for an input ER of 2dB; (B) Measured BER Vs Rx power for an input ER of 5dB; (C) 3x ER improvement at 1530nm

4. Discussion

It is clear that the operation speed of the device is limited by the carrier lifetime. The effective carrier lifetime can be decreased by sweeping the carriers out of the active region through the application of an electrical field. This can be done either in a p-i-n configuration or in a metal-semiconductor-metal configuration. Alternatively, the carrier lifetime can be reduced by ion implantation in the active regions. Reducing the carrier lifetime of course has an adverse effect on the required signal power for substantial bleaching of the multi-quantum well absorption, which is an intrinsic trade-off for this device.

5. Conclusions

We demonstrated the tripling of the ER for low ER signals using a passive MIPS device. ER improvements from 2 dB to 6 dB and from 5dB to 13dB at 1 Gb/sec were measured and the resulting receiver sensitivity has been improved by at least 2.5dB across the C-band. All values mentioned in this paper are for optical powers in the fiber leading to and from the MIPS device, which indicates that the regeneration action occurs in the chip for sub-milliwatt power levels. Many options exist to reduce the carrier lifetime which would pave the way to higher speed operation.

6. References

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A 23 GHz Ge/SiGe multiple quantum well electro-absorption waveguide modulator is demonstrated with 10 dB extinction ratio (ER). 9 dB ER is achieved with 1V swing with energy consumption limited to 108 fJ per bit.

12:00 PM – 1:30 PM LUNCH BREAK

1:30 PM - 3:30 PM
Session MB: HYBRID PHOTONICS
Session Chair: Rena Huang, Rensselaer Polytechnic Institute, Troy, NY, USA

MB1 1:30 PM - 2:00 PM (Invited)

Hybrid Silicon / III-V Sources for Optical Interconnects, J. E. Bowers, Martijn J.R.Heck, and Sudharsanan Srinivasan, *University of California - Santa Barbara, Santa Barbara, CA, USA;* Di Liang, *Hewlett Packard Laboratories, Santa Barbara, CA, USA*

Single-frequency hybrid silicon compact DFB and microring lasers are presented, showing the potential of this technology for future energy-efficient transmitters in wavelength multiplexed optical interconnects.

MB2 2:00 PM - 2:15 PM

Highly-Efficient, Low-Noise Si Hybrid Laser using Flip-Chip Bonded SOA, S. Tanaka, S.-H. Jeong, S. Sekiguchi, T. Kurahashi, Y. Tanaka and K. Morito, *Fujitsu Laboratories Ltd., Atsugi, Kanagawa, Japan*

We developed a Si hybrid laser integrating Si wavelength filter and flip-chip bonded SOA. A high-output-power of 14.4 mW and wall-plug efficiency of 6.2% were obtained together with a low RIN level of <-135 dB/Hz.

MB3 2:15 PM - 2:30 PM

InP Membrane Based Broadband Regenerator for silicon-based Optical Interconnect Applications, O. Raz, *Eindhoven University of Technology, Eindhoven, The Netherlands*, M. Tassaert, G. Roelkens, *Ghent University, Gent, Belgium* and H. J. S. Dorren, *Eindhoven University of Technology, Eindhoven, The Netherlands*

We demonstrate the use of a Membrane InP Switch (MIPS) on-silicon as a signal regenerator. A receiver sensitivity enhancement > 2.5dB across the entire C-band and a tripling of Extinction Ratio (ER) for low ER signals at 1 Gb/sec is demonstrated

MB4 2:30 PM - 2:45 PM

1.3μm Hybrid Silicon Electroabsorption Modulator, Y. Tang, J. D. Peters and J. E. Bowers, *University of California - Santa Barbara, Santa Barbara, CA, USA*

A high speed, efficient hybrid silicon electroabsorption modulator working at 1.3μm is demonstrated. This device has a bandwidth of 32GHz, an extinction ratio of over 5dB/V across 30nm wavelength span and a footprint of 150μmx350μm.

MB5 2:45 PM - 3:00 PM

Hybrid Chip-Scale Optical Interconnects Using Multiple Quantum Well Devices Bonded to Silicon, R. Nair, T. Gu, and M. W. Haney, *University of Delaware, Newark, DE, USA*

A hybrid MQW-device-based chip-scale optical interconnect is demonstrated. Novel small-footprint couplers are fabricated with gray-scale lithography to enable high-density fabrics and low-capacitance devices, with sub-pJ/b link performance. Contrast ratio and refined coupler results are presented.

MB6 3:00 PM - 3:15 PM

Compact High–Speed InP Microdisk Modulators Heterogeneously Integrated on a SOI Waveguide, J. Hofrichter, A. La Porta, T. Morf, B.-J. Offrein, *IBM Research, Rueschlikon, Switzerland*, P. Mechet, G. Morthier, *Ghent University, Gent, Belgium*, T. de Vries, H. J. S. Dorren and O. Raz, *Eindhoven University of Technology, Eindhoven, The Netherlands*

We present a compact, low–power, high–speed indium phosphide based microdisk modulator heterogeneously integrated on a silicon–on–insulator waveguide. We demonstrate bit–error rates below 10^{-9} and open eyes up to 10 Gb/s.

MB7 3:15 PM - 3:30 PM

Micro-Ring Resonator based Electro-Absorption Modulators on the Hybrid III-V on Silicon Platform, S. Srinivasan, *University of California - Santa Barbara, Santa Barbara, CA, USA*, D. Liang, M. Fiorentino, R. G. Beausoleil, *HP Laboratories, Palo Alto, CA, USA* and J. E. Bowers, *University of California - Santa Barbara, Santa Barbara, CA, USA*

We demonstrate a novel compact hybrid silicon microring electro-absorption modulator. A two-anode design is employed. 10 dB static extinction ratio and 60 fJ/bit energy consumption of the intrinsic device capacitance are observed.

3:30 PM – 4:00 PM EXHIBITS/COFFEE BREAK (ZIA A-B)

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In addition, all attendees have the option to participate in working groups to discuss and design a conceptual solution to a predefined design problem. This problem is intended to promote interactions between the participants and provide an overall focus to the meeting. This year the problem sessions will be held on the afternoon of Sunday, May 5th and will feature a problem related to social networks. The problem session is a great way to meet people with skills that complement yours, and are a lot of fun. We urge you to consider arriving on Sunday, May 5th at 1pm so you can participate.

We would like to personally thank each of the Program Chairs and the Program Committee Members who have volunteered and invested their time putting together this conference. We also want to thank the invited speakers for giving us their perspectives on the challenges and opportunities for new and emerging interconnect technologies and architectures. We believe that the combined efforts of the organizers and speakers will launch this conference why this conference series has achieved its esteemed reputation. Finally, we want to express our sincere appreciation to the Photonics Society staff for their professional organization and arrangements for this conference.

Have a great time!

Ashok Krishnamorthy and John Shalf

Optical Interconnects Conference General Chairs

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