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Silicon photonics transceivers with integrated hybrid lasers

J-M Fédéli[1], L Virot[1,2,3], G.H. Duan[5], L Vivien[2], D. Thomson[6], J-M Hartmann[1], C.Jany[5], P.Grosse[1], A. Le Liepvre[5], W.Bogaerts[4], G.T.Reed[6], D.Van Thourhout[4], F.Lelarge[5],

[1]CEA, LETI, Minatec Campus, 17 rue des Martyrs, F-38054 Grenoble, France
[2]Institut d'Electronique Fondamentale (IEF), Univ. Paris-Sud, CNRS, Bât 220, F-91405 Orsay France
[3]STMicroelectronics, Silicon Technology Development, Crolles, France
[4] Photonic Research Group,– Ghent University, Ghent, Belgium
[5] III-V Lab, a joint lab of Alcatel-Lucent Bell Labs France, Thales Research and CEA, Avenue A. Fresnel, 91767 Palaiseau, France
[6] ECS/ORC, University of Southampton, Southampton, Hampshire, UK
Phone: +33 4 3878 6879 E-mail: jean-marc.fedeli@cea.fr

1. Introduction

Submicron silicon photonics have generated an increasing interest in recent years, mainly for optical telecommunications or for optical interconnects in microelectronic circuits. The rationale of silicon photonics is the reduction of the cost and energy of communications systems through the integration of photonic components and an electronic integrated circuit (IC) on a common chip (telecommunications applications), or the enhancement of IC performances with the introduction of optics inside a high performance chip (core to core communications), or low cost sensors. By co-integrating optics and electronics on the same chip, high- functionality, high-performance and highly integrated devices can be fabricated with a well-mastered microelectronics fabrication process. The FP7 HELIOS project aims to combine a photonic layer with a CMOS circuit by using microelectronics fabrication processes. A first goal was to develop high performance generic building blocks for a broad range of applications: WDM sources by III-V/Si heterogeneous integration [1], fast modulators [2,3] and detectors [4], passive circuits and packaging. With these building blocks, a transmitter with an InP on Si laser and a 16 channel receiver have been assembled.

2. Receiver

This receiver is imaged in Figure 1: A 2D surface grating couples the light coming from a single mode fiber SMF fiber into the circuit and separates the two polarizations while transforming the TM polarization into TE. Identical 200GHz 16 channel AWGs receive the two input signals and demultiplex the guided TE modes. The two 16 output waveguides are then connected to 16 Ge photodiodes.

We have developed a self-aligned process for the fabrication of the waveguides using two photolithography steps with a 193 nm stepper and two Si dry etching steps for the fabrication of gratings and waveguides on optical SOI substrates from SOITEC (220nm Si on top of 2µm Buried OXide). Then cavities are defined for the selective epitaxial growth of Germanium. This is achieved by deposition of a silica layer which is etched at the end of waveguides. In order to achieve direct coupling, the silicon floor of the cavities is etched down to 50nm on top of the BOX. Germanium was then selectivity grown in the cavities and Chemical Mechanical Polishing used to adjust the thickness. A thick layer of silica was then deposited and windows opened in it down to the Ge layer underneath. In a self-aligned process, the doped regions (N and P) of the lateral PIN Ge photodetector were then defined by ion implantation of Phosphorus and Boron in the defined openings. The separation of the openings thus defines the width of the Ge intrinsic region. A 1µm thick SiO2 layer was then deposited and planarized before etching 400nm diameter holes in it. These holes were filled with Ti/W and planarized in order to get W vias. A Ti/TiN/AlCu metal stack was deposited on this flat surface. DUV 248nm lithography together with and Cl2 etching was used to fabricate the metallic pads.

The tests were performed on a 200mm wafer prober. Using basic spirals, the propagation losses were statistically measured on the wafers. For 480nm x 220nm cladded waveguides, the losses were found at 2.3 dB/cm. The 2D grating coupler was adapted from the Gent University design [5] to the self-aligned technology (Figure 2). Using 2x 2D couplers mounted face to face, the Polarization Dependant Loss (PDL), the spectral response could be measured. The optimal efficiency for the 2D grating coupler was experimentally found to be 15% (~8dB coupling losses) at 1550nm with a 3dB bandwidth of 55nm. The minimum PDL was measured at ~1dB at ~1550nm. The 16 channels AWG with 200GHz separation is also adapted from a design from Gent University [5] with the technology and with the introduction of some absorbing sections. To reduce the crosstalk, an enlarged strip waveguide is used for the array part. So the crosstalk levels were measured at -15 dB, and the minimum center-channel insertion losses around 2.8 dB.

The Ge photodiode is a butt coupled PIN lateral type of 10µm length. The photodiode sensitivity ~ 0.8 A/W. Capacitance is in the 10 fF range and dark current of the order of 20nA (-0.5V) as seen on figure 4. The typical photodiode was connected to a 2D grating coupler and the polarization of the incoming was randomly changed. For this demonstrator, a separation of 1µm was selected and the measured bandwidth is around 20GHz which is comfortable for 10GB/s operation and should be also enough for 25Gbit/s operation in new receivers.

The spectral characteristic of the receiver is shown in figure 2. With the losses and sensitivity of the basic blocks, the overall receiver sensitivity is in the order of 0.08 A/W with a channel separation of 1.6nm, corresponding to 200GHz. The 2D grating coupler is responsible for the highest loss of sensitivity and should be optimized. Other solutions such as inverse taper or 1D grating coupler with separation of TE and TM coupled to a polarization rotator could be more efficient

3. Transmitter

An integrated tunable laser and MZM (ITLMZ) chip which consists of a single mode hybrid III-V/silicon laser [1], a silicon Mach-Zehnder (MZ) modulator and an optical output coupler have been designed and characterized (figure 3). The single-mode hybrid laser includes an InP waveguide providing light amplification, and a ring resonator allowing to achieve a single mode operation. Two Bragg reflectors etched on silicon waveguides form the laser cavity. The MZ modulator is based on 220nm depletion type [2] and allows to modulate the output light emitted from the hybrid laser.

The fabrication process begins with 200mm SOI wafers incorporating a 400 nm thick silicon waveguide layer on a 2µm BOX. DUV 193nm lithography and HBR etching of 180 nm silicon, allow the definition of rib waveguides for the coupling between the bonded III-V and silicon waveguides. By etching 120 nm silicon layer in the 220 nm defined level, rib waveguides for modulators are fabricated. The third step is the lithography and etching of 50 nm silicon layer, necessary for 220 nm stripe waveguides for Bragg gratings and output couplers. Then different ion implantation steps are carried out in order to make ,p++,p , n and n++ doping for the modulators. An HDP oxide deposition on the wafers and a CMP are used to planarize the wafers. InP samples with the heterostructure are directly bonded to the planarized SOI wafer after the preparation of the surfaces. Then InP lasers are then processed, and metallization steps are performed for contacting the modulators, the heaters above ring resonators and the hybrid III-V/Si lasers. A NiCr material is deposited and etched above the ring resonator for the fabrication of heaters which thermally tune the resonance frequency of the ring resonator.

The laser threshold CW current is around 41 mA at 20°C and the output power coupled to the silicon waveguide is of around 1.8 mW for an injection current of 100 mA. The maximum output power is around 3 mW at 20°C, and the output power is higher than 0.5 mW at 60°C. Single mode operation with SMSR larger than 35 dB is achieved

With the increase of current, the temperature of the silicon waveguide and the surrounding materials increase, leading to increased mode effective index and hence a shift of the resonance wavelength. As a result, the selected cavity mode will jump to another one with the lowest threshold. Figure 4 plots the lasing wavelength as a function of the heating power and a wavelength tuning range of 7 nm was achieved.

The ITLMZ is tested by modulating one arm, at 10 Gb/s using a peuso-random binary sequence (PRBS) of a length of $2^7 – 1$. The BER measurement is performed for 8 different wavelengths by changing the injection current into the heater.

The extinction ratio of all those wavelengths varies from 6 to 10 dB. Figure 5 shows the BER curves for all the wavelengths and also a reference curve for a directly modulated laser, measured using a high sensitive receiver including an avalanche photodiode. One can see that several channels can achieve error free operation with BER < 10^{-9}. The power level difference to achieve the same BER among all channels is around 4 dB

Acknowledgements

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Figure 1. Image of the receiver

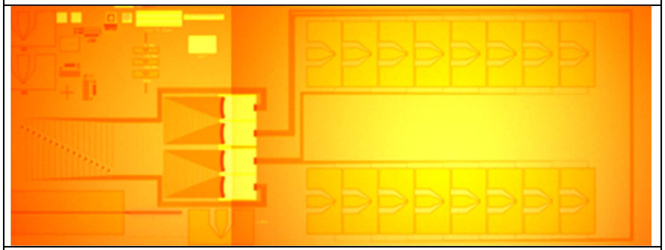

Figure 2. Photodiodes measurement after AWG.

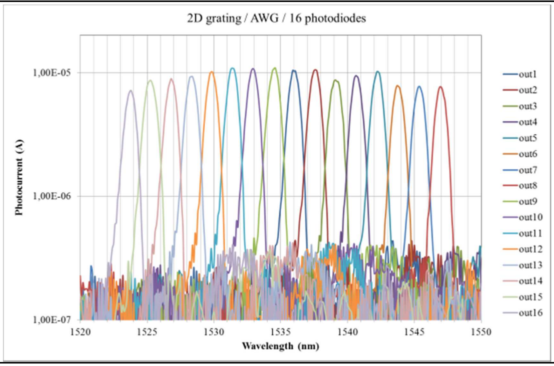

Figure 3. Image of the integrated tunable transmitter, incorporating a hybrid III-V/Si laser with wavelength tunability, and a silicon Mach-Zehnder modulator.

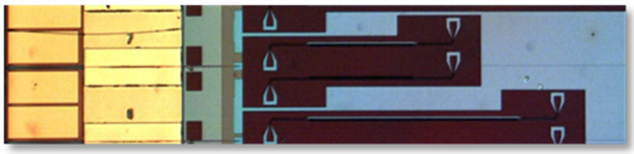

Figure 4. Lasing wavelength as a function of the heating power

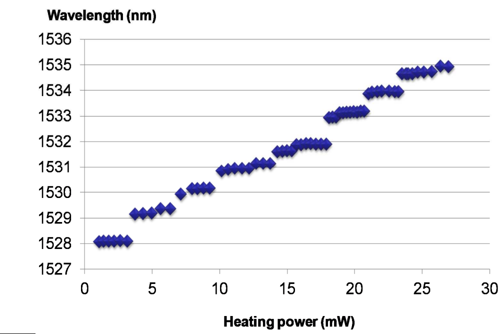

Figure 5. Bit error rate of the transmitter for different wavelength