Silicon photonics transceivers with integrated hybrid lasers

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1. Introduction
Submicron silicon photonics have generated an increasing interest in recent years, mainly for optical telecommunication 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 performances, highly integrated and high-silicon photonics can be fabricated with a well-mastered microelectronics fabrication process. The FP7 HELIOS project aims to combine a photonics 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 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 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 selective epitaxial growth of Germanium. A Ge photodiode is a butt coupled PIN lateral type of 10μm length. The photodiode sensitivity ~ 0.8 A/W. Capacitance is in the 10 F 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 compatible for 10Gb/s operation and should be also enough for 25Gb/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 AW 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 220 nm depletion type [2] and allows to modulate the output light emitted from the hybrid laser.

The fabrication process begins with 200 nm SOI wafers incorporating a 400 nm thick silicon waveguide layer on a 2 µm 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 pseudo-random binary sequence (PRBS) of a length of 27 – 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

The research leading to these results has received funding from European Community’s under grant agreement n°224312 HELIOS.

References


