Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp147-148

C-3-02

1.3µm Hybrid III-V on Silicon Transmitter Operating at 25Gb/s

Thomas Ferrotti[1,2,3], Benjamin Blampey[1], Hélène Duprez[1], Christophe Jany[1], Alain Chantre[2], Frédéric Boeuf[2], Christian Seassal[3] and Badhise Ben Bakir[1]

[1] Univ. Grenoble Alpes, CEA, LETI, MINATEC campus
17 rue des Martyrs, F-38054 Grenoble, France
Phone: +33-4-3878-0227 E-mail: badhise.ben-bakir@cea.fr
[2]STMicroelectronics
850 rue Jean Monnet, F-38926 Crolles, France
[3]Univ. de Lyon, Ecole Centrale de Lyon, CNRS, Institut des Nanotechnologies de Lyon-INL, UMR 5270, Ecully F-69134, France

Abstract

In this communication, we present the co-integration of a hybrid III-V/silicon Distributed Bragg Reflector (DBR) tunable laser at 1.3µm and a silicon Mach-Zehnder modulator (MZM) operating at 25Gb/s, forming a hybrid III-V/Silicon transmitter.

1. Introduction

In the last decade, silicon photonics devices have known fast developments, leading to a complete silicon photonic ‘toolbox’, including various components such as routing waveguides, surface grating couplers, modulators, and photo-detectors. All of these components are now fabricated at industrial levels in 300mm-Silicon photonics platforms [1].

However, since silicon is a poor light emitter due to its indirect bandgap, monolithically integrated optical sources on silicon are still missing to form a complete link. Commercial solutions are likely to rely on flip-chipped laser semiconductor diodes [2] whose light is coupled in the silicon photonic circuit using integrated or ball lenses [3-4].

The most mature approach to obtain wafer-level integrated lasers is based on molecular bonding of III-V materials on top of a patterned silicon-on-insulator (SOI) substrate. Several types of lasers based on this technology have already been demonstrated [5-6]. However these lasers are mostly demonstrated in stand-alone configurations, and few demonstrations of a complete transmitter have been published [7]. Therefore, we present our own hybrid III-V/silicon transmitter combining hybrid III-V/silicon laser and silicon modulator with a targeted data rate of 25Gb/s.

2. Transmitter description

Device structure

A top view of the device is provided on Fig. 1 (a). The transmitter associates a hybrid III-V/silicon Distributed Bragg Reflector (DBR) tunable laser and a silicon Mach-Zehnder modulator (MZM). A waveguide-to-fiber surface-grating coupler is located after the MZM to collect the modulated output signal.

The hybrid III-V/silicon laser uses a III-V epitaxy bonded above a silicon rib waveguide to provide optical gain, with a 100-nm-thick SiO2 layer between them [Fig 1 (b)]. The III-V active region is 700-µm-long and 5-µm-wide. The III-V epitaxy is based on intrinsic InGaAsP multiple quantum wells (MQW), designed to exhibit maximum gain around 1.3µm, and surrounded by n- and p-doped InP layers. Light coupling in the silicon is realized by adiabatic tapers patterned in the silicon rib waveguide. Those adiabatic tapers are 100-µm-long and are located at each side of the III-V waveguide. Their simulated coupling efficiency is above 90%. Feed-back is obtained by two Bragg gratings which are shallowly-etched (10-nm etch depth), 3-µm-wide, with a 50% duty-cycle. The two gratings are 150-µm and 700-µm long with a grating strength $\kappa=78cm^{-1}$, giving reflectivity of 70% and 99%, respectively. The period of these gratings is 195nm, to be centered on 1302.6nm.

The modulation effect in the silicon MZM is based on the depletion of a *p-n* junction in each arm of the interferometer, modifying its phase. The p- and n-doping concentrations are $4e17cm^{-3}$ and $6e17cm^{-3}$, respectively. These moderate concentrations have been chosen to offer the best trade-off between optical loss and phase shift efficiency. Several modulator lengths have been designed from to 2mm, as in Fig. 1 (a), to 6mm. Due to the lengths of the modulators, specific travelling-wave electrodes (TWE) have been designed to enhance the bandwidth, with a Signal-Ground-Signal (SGS) configuration.

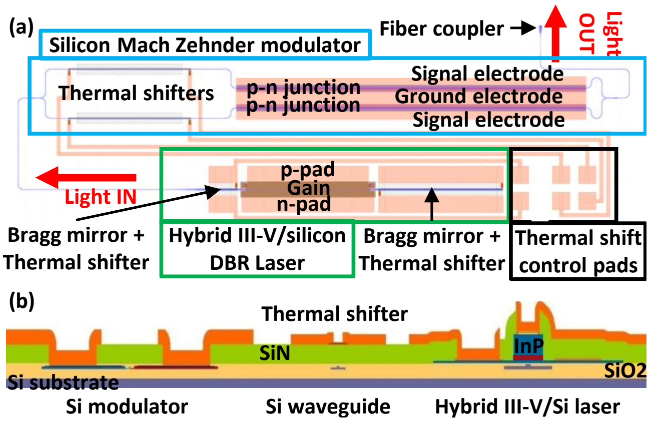

Fig. 1 (a) Top and (b) transversal views of the hybrid III-V/silicon transmitter.

Thermal shifters are also present in the hybrid transmitters. Resistive metal layers are used as heaters to change the silicon refractive index by a thermo-optic effect. Two pairs of heaters are located above undoped waveguides in the silicon MZM, and above the two Bragg reflectors. The first one is used to control the static phase difference between the MZM arms, and put it at quadrature ($\pi/2$ static phase difference). The second one is used to shift the peak wavelength of the reflectors, thus tuning the lasing wavelength.

Device fabrication

The hybrid III-V/silicon transmitters are fabricated on 8" high-resistivity SOI wafers from SOITEC, needed for RF performances. In the first steps, the silicon waveguides are patterned and doped by ion implantation to create the *p-n* junctions. Silicon contact regions are then silicided to reduce the contact resistance. After SiO_2 encapsulation, the wafer is planarized by chemical-mechanical polishing, leaving a planar surface for bonding. A 2" III-V wafer is bonded at room temperature on the SOI wafer. After having chemically removed the III-V substrate, leaving the laser epitaxy, the wafers are downsized from 8" to 3" to finish the processing in our III-V platform. The III-V waveguides are patterned by a combination of dry and wet etchings. Metallic n- and p-contact layers are defined using lift-off. The structure is encapsulated in SiN, which is opened to reach the laser and modulator contacts, contacted by larger metallic pads. Finally, a layer of NiFe is used to form the heaters. Fig.2 shows a top view of a fabricated transmitter, with scanning electron microscopic views of its different components.

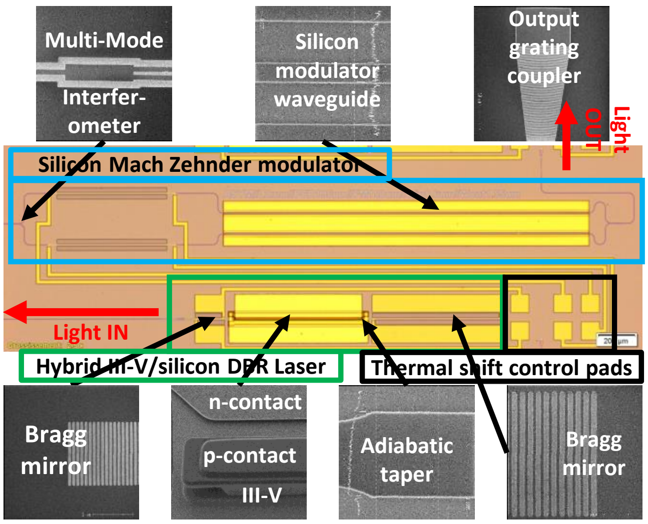

Fig. 2 Top view of the fabricated transmitter with scanning electron microscopic views of its different components.

3. Experimental results

Measurements of the transmitters on an optical spectrum analyzer can be seen on Fig. 3. Fig. 3 (a) shows the effect of the modulator thermal shifter, when the laser wavelength is fixed, while Fig. 3 (b) displays the thermal shift of the lasing wavelength for a maximum of 9nm. On both graphs, the laser spontaneous emission over the wavelength span permits to see the modulator spectrum with its interferences.

Open eye diagrams are reported on Fig. 4, and demonstrate the 25 Gb/s operation of our transmitter at 0km [Fig. 4 (a)] and 10km [Fig. 4 (b)]. A 4-mm-long modulator is used for this demonstration, in a dual drive configuration, with 2.5Vpp send on each arm of the silicon MZM. Both arms are biased at -1.25V, thus they receive NRZ signals in opposite phase, switching between 0 and -2.5V. For both measurements, the laser wavelength is 1303.5nm, and the modulators are set at quadrature using the thermal shifters. The measured extinction ratio is 4.7dB in both case, and no signal distortion is observed in the 10km case.

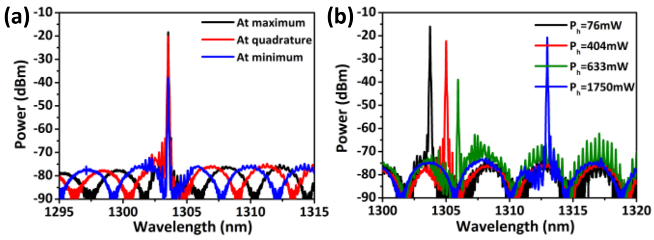

Fig. 3 Optical spectrums of the transmitter, for a laser bias current of 100mA. (a) Fixed laser wavelength, with different phase between the MZM arms. (b) Spectrum for a fixed modulator phase and different heating powers used to shift the Bragg reflectors.

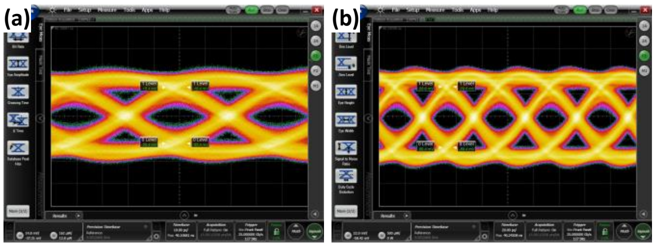

Fig. 4 25Gb/s eye diagrams of the hybrid III-V/Si transmitter: (a) Back-to-back, and (b) 10km transmission.

4. Conclusions

In this communication, we present a 25 Gb/s hybrid III-V/silicon transmitter at 1.3µm for silicon photonics. Future perspective work is focused on improving the integration of these hybrid transmitters on 300-mm-platform.

Acknowledgements

This work was supported by the French national program "programme d'Investissements d'Avenir, IRT Nano-elec, ANR-10-AIRT-05". Authors acknowledge A. Myko, K. Ribaud, P. Grosse and O. Lemonnier for valuable help in the measurement setup mounting, and also J. Harduin, K. Hassan, L. Sanchez, T. Card and R. Thibon for their help in the fabrication processes.

References

[1] F. Boeuf *et al.*, J. of Light. Technology **34** (2016), 286.
[2] T. Pinguet *et al.*, *Group IV Photonics Conference* (2015), 21.
[3] T. Suzuki *et al.*, *Group IV Photonics Conference* (2015), 27.
[4] B. Snyder *et al.*, J. of Light. Technology **31** (2013), 3934.
[5] B. Ben Bakir *et al.*, Opt. Express **19** (2011), 10317.
[6] H. Duprez *et al.*, Opt. Express **23** (2015), 8489.
[7] A. Alduino *et al.*, *Integrated Photonics Research, Silicon, and Nanophotonics Conference* (2010), PDIWI5.