B-2-1 (Invited)

Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp476-477

Hybrid III-V on Silicon Lasers

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Abstract

In this communication, we describe the III-V on Silicon hybrid platform for photonic integrated circuits and the recent advances on hybrid lasers and transmitters.

1. Introduction

Silicon photonic devices and integrated circuits have considerably increased in manufacturing maturity, being recently transferred from research to industrial foundries for the commercialization of high speed electro-optical transceivers. The development of 300mm-Silicon photonics platforms was recently reported with a broad set of integrated devices, including surface grating couplers, modulators, photo-detectors [1] and Wavelength Division Multiplexing (WDM) devices [2]. The opportunity to tightly integrate the Silicon Photonic Integrated Circuits (Si-PIC) with their driving and reading CMOS-Electronic Integrated Circuitries (CMOS-EIC) leverages transceivers performances.

In the absence of a practical laser source achievable directly in Silicon or other group IV materials, Si-photonic transmitters must be made by hybrid integration with III-V gain materials. One commercial solution makes use of external bulk-InP-processed-laser-dies [3]. The laser light is coupled into the PIC by means of a lens which is followed by an optical isolator, and a mirror for directing the light onto a surface grating coupler in the Si-PIC. Other approaches consist in butt-coupling a III-V Reflective Semiconductor Optical Amplifier (R-SOA) to the Si-PIC waveguide that comprises a Bragg-mirror for defining the laser cavity [4]. This forms an external-cavity Distributed Bragg Reflector (DBR) laser, with reported Waveguide-Coupled Wall-Plug-Efficiencies (WC-WPE) for the uncooled lasers of up to 9.5% at powers of 6 mW. But this technique does not allow wafer-level integration of the lasers.

A particularly promising approach instead is based on molecular bonding of III-V materials on top of a patterned Si-on-Insulator (SOI) substrate. This can be performed at the die or wafer level, depending on the application needs. Then, hybrid Si/III-V lasers are realized following a collective fabrication procedure, enabling complex photonic integrated systems onto the silicon platform. Using this technology, Fabry–Pérot, racetrack, distributed feedback and Bragg reflectors lasers were demonstrated [5-7].

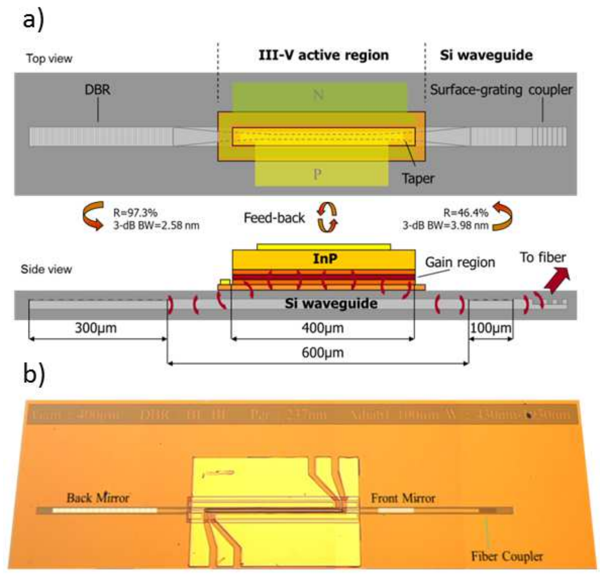

Fig. 1 a) Sketch up of a III-V on SOI DBR laser emitter including both top and side views. The III-V waveguide meant for light amplification and gain provider is superimposed over a silicon rib tapered waveguide enabling adiabatic coupling from/to the upper waveguide, light feedback through side DBRs and light collection to fiber via a surface grating coupler. (b) Optical microscope image of the fabricated device.

2. Device structure

The approach developed in our group at CEA-Leti exploits the adiabatic tapering of SOI as well as III-V waveguides in order to maximize the optical mode amplification in the III-V waveguide while maintaining a high coupling efficiency of photons to the silicon wires underneath, yielding significantly higher output power available for on-chip signal processing at low threshold currents.

The latest achievement in this sense is the fabrication of an electrically-driven III-V/SOI DBR laser emitting in the C-band endowed with adiabatic coupling to/from the silicon waveguides circuitry. A sketch of the architecture along with optical images of the fabricated device is reported in Fig. 1. Full description of the fabrication process and the optimized adiabatic coupling can be found in our earlier work [6] and references therein.

In detail, a III-V and an adiabatically-tapered silicon waveguide are vertically stacked by means of a 100-nm-thick silica bonding layer. The thickness of the bonding interface allows for relaxing fabrication constraints typical of evanescently-coupled structures where high control over the thin bonding layer (~5 nm) is required [5]. The 6-µm-wide top waveguide is essentially made up of an InGaAsP/InP-based heterostructure for carrier confinement and light amplification [6], while the resonator architecture is defined by a 600-µm-long silicon rib waveguide endowed with adiabatic tapers for mode coupling to the III-V waveguide terminated at both ends by DBRs with different reflectivity and a surface-grating for fiber coupling measurements. The shallowly-etched 10-µm-wide DBRs are characterized by a 10-nm etch depth, and 50% duty-cycle. Optimized for achieving enhanced modal control and large Side Mode Suppression Ratio (SMSR), the two DBRs are 300-µm and 100-µm-long with a grating strength $\kappa = 83\ cm^{-1}$ showing modal reflectivities of 97.3% and 46.4%, respectively.

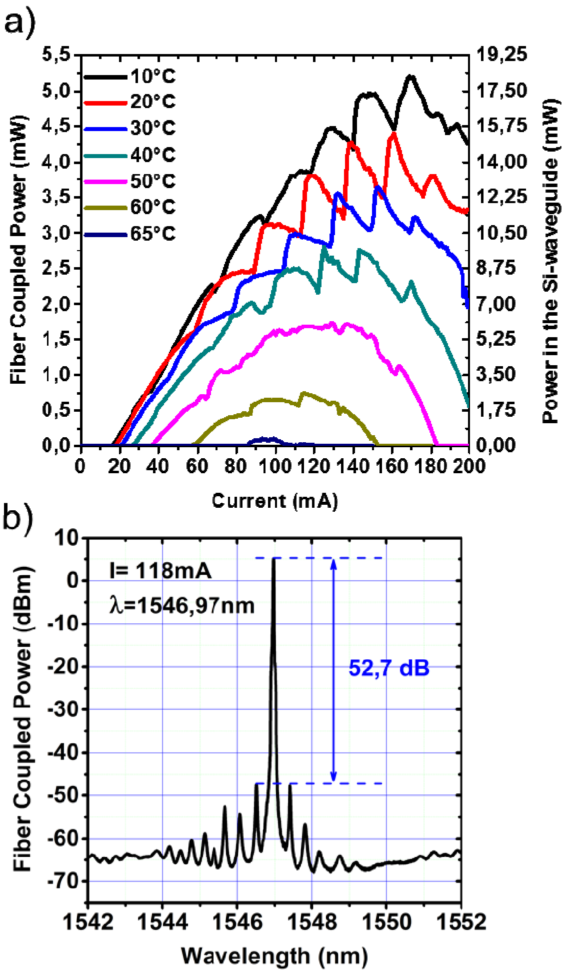

Fig. 2 a) *L-I* characteristics of the hybrid DBR laser for different temperatures. b) Lasing spectrum measured at a bias current of 118 mA.

3. Experimental results.

Static and dynamic characterization of the hybrid DBR laser via electrical probing was performed collecting the optical signal through a multi-mode fiber aligned over the laser grating coupler and connected to an optical spectrum analyzer and a power-meter. As reported in Fig. 2-a, the III-V on SOI laser source shows continuous-wave lasing up to 65 °C with a minimum current threshold (I_{th}) of 17 mA and maximum uncooled output power above 15 mW at 160 mA of driving current, resulting in a remarkable differential quantum efficiency of 13.3%. In addition, the laser diodes are characterized by a turn-on voltage of 1 V and a series resistance of 7.5 Ω. A SMSR greater than 50 dB at high driving current is achieved as shown in Fig. 2-b.

The electro-optic (EO) small-signal modulation response obtained for driving currents between 6 x I_{th} and 8 x I_{th} indicates a 3-dB bandwidth above 7.2 GHz, while open-eye diagrams reported in Fig. 3 confirm 5 Gb/s and 12.5 Gb/s on-off keying (OOK) direct modulation at room temperature and 160 mA of bias current in a back-to-back configuration for a 2^{15}-1 pseudo-random bit sequence (PRBS) with 17 mW RF power.

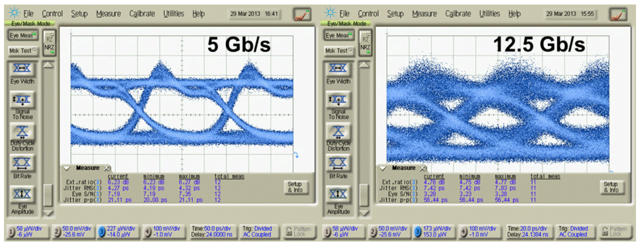

Fig. 3 Eye diagrams of the directly modulated DBR laser at 5 Gb/s and 12.5 Gb/s.

3. Conclusions

In this communication, we present and discuss the latest developments concerning the use of high-index-contrast SOI platform for the III-V long-wavelength hybrid laser integration on SOI. Enlarging the overview toward device maturity, we present hybrid DBR lasers featuring top-notch performances in terms of modal selectivity, output power, OOK high-speed modulation, and power efficiency.

Acknowledgements

This work was supported by the French national program “programme d’Investissements d’Avenir, IRT Nanoelec, ANR-10-AIRT-05”.

References

[1] F. Boeuf *et al.*, *IEEE International Electron Devices Meeting* (2013) 13.3.1-13.3.4.
[2] D. Fowler *et al.*, *Optical Fiber Communication Conference* (2014) Th2A.22.
[3] P. De Dobbelaere *et al.*, *Semiconwest* (2013).
[4] A. J. Zilkie *et al.*, Opt. Express **20** (2012) 23456.
[5] M. Heck *et al.*, J. Sel. Top. Quant. Electron. **17** (2011) 333.
[6] B. Ben Bakir *et al.*, Opt. Express **19** (2011) 10317.
[7] A. Descos *et al.*, ECOC *39th European Conference and Exhibition on Optical Communication*, **1, 3** (2013) 22.