

Hybrid Silicon Evanescent Photonic Integrated Circuit Technology

John E. Bowers^a, Alexander W. Fang^a, Hyundai Park^a, Richard Jones^b, Oded Cohen^c, and Mario J. Paniccia^b

^aUniversity of California Santa Barbara, ECE Department, Santa Barbara, CA 93106, USA

^bIntel Corporation, 2200 Mission College Blvd, SC-12-326, Santa Clara, CA 95054, USA

^cIntel Corporation, SBI Park Har Hotzvim, Jerusalem, 91031, Israel

Email: bowers@ece.ucsb.edu

(Invited Paper)

Abstract: The hybrid silicon evanescent device platform utilizes III-V gain materials bonded to passive silicon waveguides. In this paper, we discuss this device platform, and present hybrid silicon evanescent laser and amplifier device results.

1. Introduction

The area of silicon photonics has received much attention from the research community in recent years because of its potential to provide a low cost photonic platform. There have been great advances in the areas of lasers and amplifiers, however due to silicon's indirect bandgap, these devices rely on physical effects other than the conventional band-to-band electron-light interactions for stimulated emission, such as the Raman effect, and are limited to optical pumping and long device lengths [1, 2]. Others have taken the approach of aligning and bonding pre-fabricated III-V active devices to individual waveguides fabricated on a silicon platform. This approach has the benefit of using electrically pumped active devices on a silicon platform, but since the III-V devices are aligned and bonded individually, the time and cost of manufacturing limits the total number of lasers that can be bonded on a single wafer. Moreover, limited alignment accuracy causes coupling loss variation and large reflection between the III-V active devices and the silicon waveguides. Recently, we demonstrated an electrically pumped hybrid silicon evanescent laser [3], where un-patterned III-V gain materials are bonded without sophisticated alignment to waveguides fabricated on silicon-on-insulator (SOI). The optical mode is defined by and lies primarily in the silicon waveguide with a small percentage lying in the III-V gain layers. This approach allows for the fabrication of hundreds of electrically driven lasers, amplifiers, and other active photonic devices in a single bond step on a silicon substrate. We report here results on silicon evanescent lasers and amplifiers.

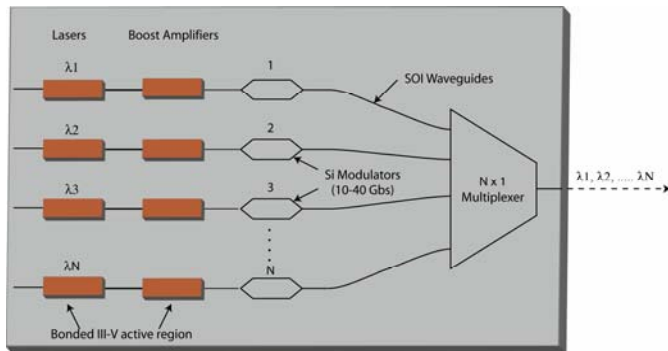


Fig. 1. Hybrid silicon evanescent transponder

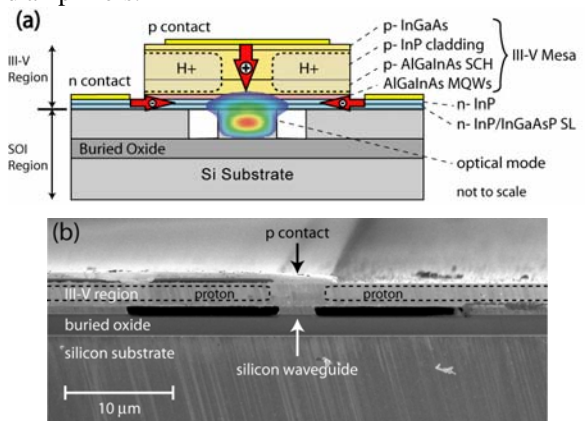


Fig. 2. a) Device cross section schematic. b) SEM photograph of a fabricated silicon evanescent laser

Figure 1 shows a schematic of an integrated WDM transponder concept based on the hybrid silicon evanescent device platform. Each transponder channel consists of a single wavelength hybrid silicon evanescent laser coupled through a hybrid silicon evanescent boost amplifier and high speed silicon modulator. These individual channels are multiplexed together with a silicon arrayed waveguide grating, and all these devices can all be fabricated with a alignment free, single-bond, process. Since the optical mode characteristics are defined by the silicon waveguide processing, the modal characteristics for each type of device can be engineered independently for the optimal performance. For example, the laser section can be designed to have higher modal gain for optimized thresholds while the amplifiers can be designed to have lower modal gains to achieve higher saturation powers. Coupling between active and passive sections in the integrated chip needs to be considered to maintain high coupling

efficiency and minimization of reflections from these junctions. In addition, the tailoring of the lasing wavelength of the hybrid silicon evanescent laser can be achieved by laying out the silicon waveguide in ring topographies or etching gratings in the silicon waveguides to form DFB or DBR lasers.

2. Device Structure and Fabrication

The device (Fig 2) consists of a silicon waveguide fabricated on an SOI wafer with a III-V epitaxial layer structure bonded to the top surface through a low temperature (300 °C) oxygen plasma assisted bonding process [4]. This bonding process allows for the scalability to large bonding sizes while preserving the properties of other CMOS silicon devices that may have been fabricated on the SOI wafer prior to bonding.

The III-V layer structure consists of an n region, multiple quantum well region, and p region. After bonding, the InP substrate is etched off and the transferred III-V epitaxial layer structure is processed in order to control the flow of current to the active region for efficient optical light generation. First, mesas are etched in order to access the n regions along with subsequent n and p contact metal definition, deposition, and lift-off. Next, the sides of the mesa are electrically insulated by proton implantation leading to a current flow channel in the center of the mesa to optimize the optical-mode overlap with the gain profile and. A full description of the device structure and fabrication flow can be found in reference [3].

3. Experimental Results

Figure 3 shows a family of LI curves for an 860 μm long hybrid silicon evanescent laser at various device stage temperatures. The laser has a waveguide width and height of 2.5 μm and 0.76 μm respectively. The maximum operating temperature of the laser is 40 °C with a maximum single sided fiber coupled power of 1.8 mW [2].

Figure 4 shows the gain spectra of a 1.36 mm long hybrid silicon evanescent amplifier for drive currents of 50 mA to 200 mA. The amplifiers have a waveguide width and height of 2 μm and 0.76 μm , respectively. The devices show a maximum chip gain 13 dB.

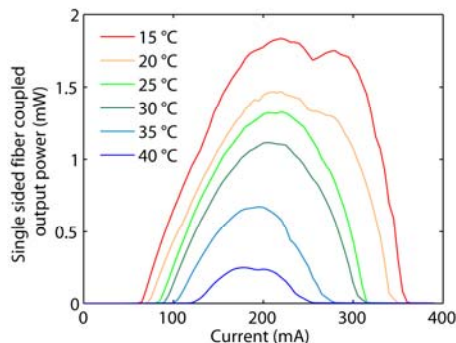


Fig. 3. LI curves of a 860 μm long and 2.5 μm wide laser with different temperatures [3].

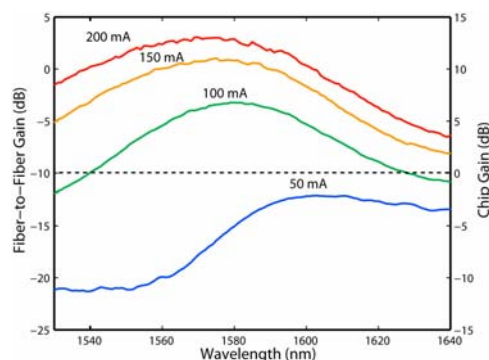


Fig. 4. Gain spectra of a 1.36 mm long and 2 μm wide amplifier with different currents.

4. Conclusion

The hybrid silicon evanescent based active photonic devices provide a platform to create electrically driven photonic integrated circuits on silicon. The demonstration of lasers with output powers of 1.8 mW and amplifiers with 13 dB of on chip gain show performance suitable for communications such as chip-to-chip and board to board optical interconnects.

The UCSB research was supported by by DARPA contracts W911NF-05-1-0175 and W911NF-04-9-0001, and by Intel.

- [1] H. Rong, Y.-H. Kuo, S. Xu, A. Liu, R. Jones, M. Paniccia, O. Cohen, and O. Rada, "Monolithic integrated Raman silicon laser," *Optics Express*, Vol. 14, Issue 15, pp. 6705-6712 (2006)
- [2] R. Jones, H. Rong, A. Liu, A. W. Fang, M. J. Paniccia, D. Hak, and O. Cohen, "Net continuous wave optical gain in a low loss silicon-on-insulator waveguide by stimulated Raman scattering," *Opt. Express* 13, 519-525 (2005).
- [3] A. W. Fang, H. Park, O. Cohen, R. Jones, M. J. Paniccia, and J. E. Bowers, "Electrically pumped hybrid AlGaInAs-silicon evanescent laser," *Opt. Express* 14, 9203-9210 (2006)
- [4] D. Pasquariello, et. al., *IEEE J. Sel. Topics Quantum Electron.* 8, 118-131, (2002).