

Integrated Hybrid Lasers and Amplifiers on a Silicon Platform

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Abstract: An overview is given of the hybrid AlGaInAs-silicon platform where InP active and silicon passive components are integrated using wafer bonding. Hybrid optical amplifiers and lasers demonstrate the functionality this platform brings to silicon photonics.

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1. Introduction

CMOS processing has the ability to fabricate low cost optical components from silicon for high volume applications. While silicon can be regarded as an excellent material for passive optical components due to its low loss beyond $1.1\mu\text{m}$ and high index contrast with its native oxide, it is, unfortunately, a very poor light emitter. Due to silicon's indirect band gap, light emission is very inefficient [1] and currently the preferred method of integrating lasers with silicon chips is to align and then attach individual prefabricated lasers to silicon waveguides one at a time which is costly in terms of time and price as the number of lasers increases. Wafer bonding is an alternative strategy which allows the hybrid integration of different materials to take advantage of their different characteristics [2]. Here the light emission and amplification properties of AlGaInAs quantum wells are combined with low loss silicon passive components. Conventionally this is viewed as adding active functionality to silicon, but an alternative viewpoint is adding the passive capability of silicon, that is low loss and low cost waveguides to InP. Here an overview of our recent research into hybrid silicon devices specifically focusing on electrically pumped optical amplifiers and lasers will be given.

2. Discrete Devices

This hybrid platform lends itself to the fabrication of any active device conventionally fabricated from InP integrated with a silicon-on-insulator (SOI) waveguide. Examples of hybrid silicon devices that have been demonstrated are: 1550nm Photodetectors [3]; 1550nm optical amplifiers [4]; 1550nm Fabry-Perot [5] and ring lasers [6]; 1310nm Fabry-Perot lasers [7]; and 1550nm Mode-locked lasers [8]. A typical device cross-section is shown in Figure 1(a), the lower half of the waveguide comprises silicon and the upper half InP. Due to the similar refractive indices of silicon and the InP material and the thin (<5nm oxide) bonding interface the resultant hybrid waveguide can support a single mode that is guided by the silicon layer and can receive gain from the MQW layer. Key device properties are the optical mode overlap with the silicon waveguide as this dictates the hybrid mode shape and the overlap with the quantum well region as this determines the modal gain/loss [5].

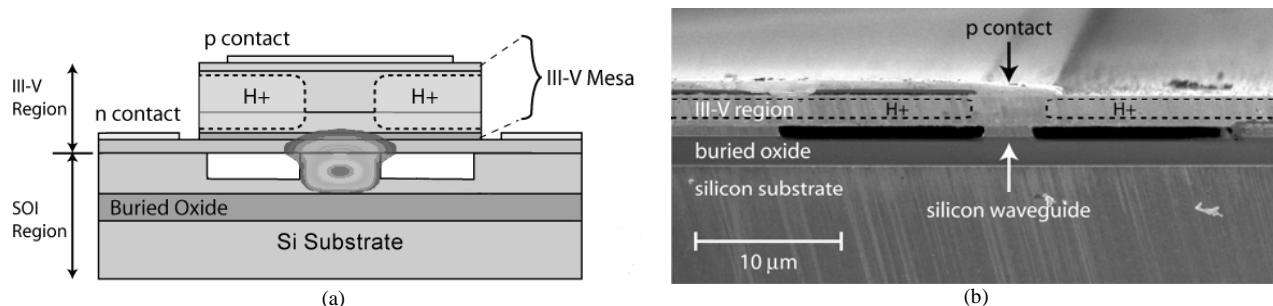


Figure 1 (a) Schematic cross-section of hybrid silicon waveguide, (b) Cross-section SEM of fabricated Hybrid silicon laser

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The key advantage of this architecture derives from bonding an unpatterned InP wafer to a silicon wafer already patterned with optical waveguides. As the InP wafer has not been processed there is no critical alignment needed before the low temperature plasma-assisted bonding step [2]. After bonding the InP substrate is removed and Mesa's are etched into the InP. n- and p-metal contacts are deposited and patterned and a proton implantation is used to insulate the edge of the mesa and reduce current spreading through the device, as shown in Figure 1(a). All the InP processing is done aligned to alignment marks on the silicon wafer resulting in active devices integrated with silicon waveguides using standard photo-lithography. By bonding sufficiently large InP die or wafers, many lasers and other active devices can be fabricated from a single bond step. A scanning electron micrograph (SEM) of the final device cross section is shown in Fig. 1(b); for more process information, see reference [3-8].

A good example of the value of this hybrid silicon platform is in the fabrication of optical amplifiers compatible with silicon photonics. Here 1.26mm long hybrid waveguides were angled polished and AR-coated to function as amplifier chips [4]. The silicon strip waveguide height is 0.76 μ m and its width is 2 μ m corresponding to an overlap of the optical mode with the quantum wells of 3.4%.

The amplifier gain as a function of bias current is shown in Figure 2(a). The maximum fiber-fiber gain for TE polarized light is 3dB corresponding to an on-chip gain of 13dB at a wavelength of 1575nm. Due to the compressive strain on the quantum wells these devices work predominantly on TE polarization with only 1dB on-chip gain for TM polarization. Figure 2(b) shows the on-chip gain as a function of chip output power, the 3-dB output saturation power is 11dBm which is higher than conventional semiconductor optical amplifiers due to the reduced mode overlap with the off-center, evanescently-coupled, quantum wells.

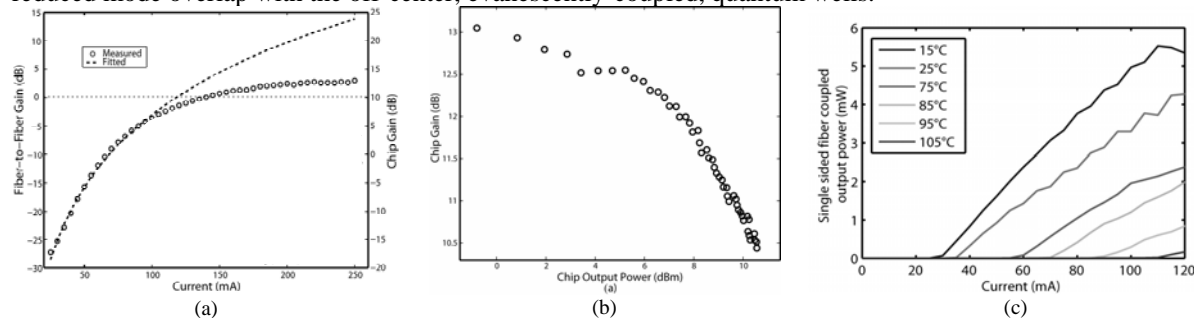


Figure 2: Hybrid silicon amplifier gain versus (a) bias current and (b) output power; (c) L-I curve for 1310nm F-P Hybrid silicon Laser

With amplification comes the possibility of lasing. Figure 2(c) shows the L-I curve for a hybrid silicon Fabry-Perot laser running at 1326nm [7]. Here the chip length was 860 μ m and facets that were polished but not coated. The silicon rib waveguides had a width, height, and rib etch depth of 2.5 μ m, 0.69 μ m and 0.52 μ m respectively. This laser supported two modes and lased with the higher order mode due to its higher overlap with MQW region of 10.5%. The laser threshold was 35mA with 6mW of power coupled into a single mode fiber (corresponds to 15.8mW single sided output power) at 15°C. The maximum lasing temperature of 105°C demonstrates that while the buried oxide layer of the SOI wafer is potentially problematic for heat dissipation it is not a barrier to high temperature lasing.

3. Uni-directional ring laser

Ring lasers offer convenient on-chip laser sources without the problem of polishing facets, or the complexity of retro-reflecting mirrors. However coupling between the degenerate clockwise and anti-clockwise modes results in instability and kinks in the L-I curve [9]. One way to force unidirectional lasing is to seed the cavity in the preferred direction with an external light source. Here we integrate an amplified spontaneous emission (ASE) seed with a ring laser to obtain unidirectional lasing with an on-chip power monitor using the hybrid silicon platform [6].

The ring laser is fabricated with silicon waveguide of width, height, and slab height of 1.65 μ m, 0.69 μ m and 0.19 μ m respectively. The calculated overlap of the optical mode with the silicon waveguide is 64 % while there is a 4.2 % overlap in the quantum wells. The evanescent couplers are fabricating from two 100 μ m long waveguides placed 0.6 μ m apart, resulting in 85% of light being fed back into the ring. The ASE source and power monitor were both fabricated from a 400 μ m straight hybrid waveguide. Reverse biasing a section resulted in it being a photo-detector, forward biasing it allowed it to emit spontaneous radiation and act as an ASE source. A top-down SEM of the integrated circuit is shown in Fig. 3. The responsivity of the photodetector was measured to be in the range of 1.25 - 1.11 A/W. This corresponds to a quantum efficiency between 97%-86%. We use a responsivity of 1.25 A/W such that the laser power values are on the conservative side. The detector dark current was measured to be 200 μ A.

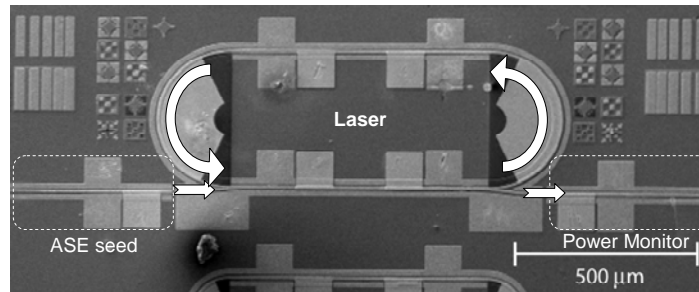


Fig. 3 Top view SEM of integrated ASE source, ring laser and power monitor

Fig. 4(a) shows the LI curve for the ring laser with different biases being applied to the ASE seed. With no seed bias, the ring laser output is very erratic due to mode hopping as the laser output switches between clockwise and anticlockwise lasing as the laser bias is varied. At 75mA ASE seed current, this LI becomes smoother, and at 100 mA, the anticlockwise propagating mode achieves stable unidirectional lasing. The laser runs continuous mode with a maximum output power of the ring laser is 2mW, with a threshold of 150mA. Fig. 4(b) shows the lasing spectrum of the ring laser. Due to its long, 2mm, cavity length it runs multi-mode at 1,592nm wavelength.

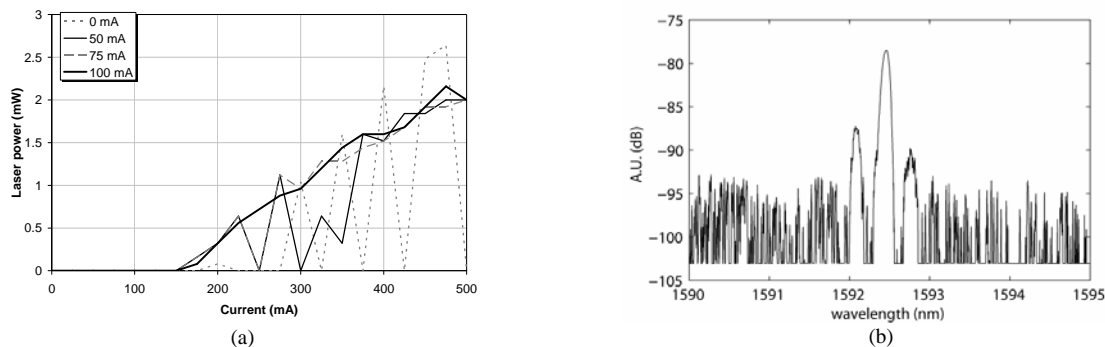


Fig 4 (a) L-I curve for ring laser as for 0; 50; 75 and 100mA bias on ASE seed. (b) Lasing spectrum of hybrid silicon ring laser

4. Conclusion

The hybrid AlGaInAs-silicon device platform is described. Active III-V devices such as lasers, amplifiers and photo-defectors can be integrated with silicon waveguides to combine the mature, low cost manufacturability of silicon with the functionality of InP. This wafer scale approach to integration will enable optical interconnects for high volume applications, such as around PCs and servers where their current price is too expensive.

5. References

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