Integrated Hybrid Silicon Evanescent Racetrack Laser and Photodetector

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Abstract: A hybrid silicon evanescent racetrack laser with integrated photodetectors has been demonstrated running continuous-wave (c.w.) at 1590 nm with a threshold, maximum output power, and maximum operating temperature of 175 mA, 29 mW and 60 C, respectively.

1. Introduction

Silicon photonics research has had many advancements with hopes to enable the introduction of integrated photonics in new applications due to silicon's low cost manufacturing infrastructure [1]. Recently, we demonstrated a hybrid AlGaInAs-silicon evanescent laser that fulfills the need for an electrically pumped laser source that can be integrated on a wafer scale with a silicon photonic platform [2]. The first hybrid laser demonstration relied on the dicing and polishing of straight hybrid waveguides to define a Fabry-Perot laser cavity. Here we describe a monolithic hybrid AlGaInAs-silicon evanescent laser based on a racetrack-resonator-topography[3]. The laser runs continuous-wave (c.w.) with a threshold of 175 mA, a maximum total output power of 29 mW and maximum operating temperature of 60 °C. Moreover, the integration of this laser with a hybrid AlGaInAs-silicon evanescent photodetector is used to measure the laser output [4].

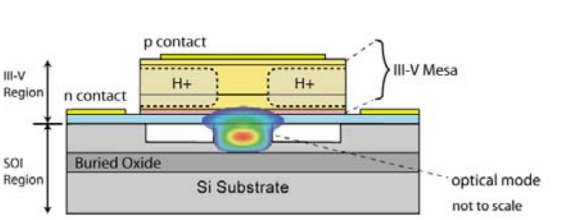
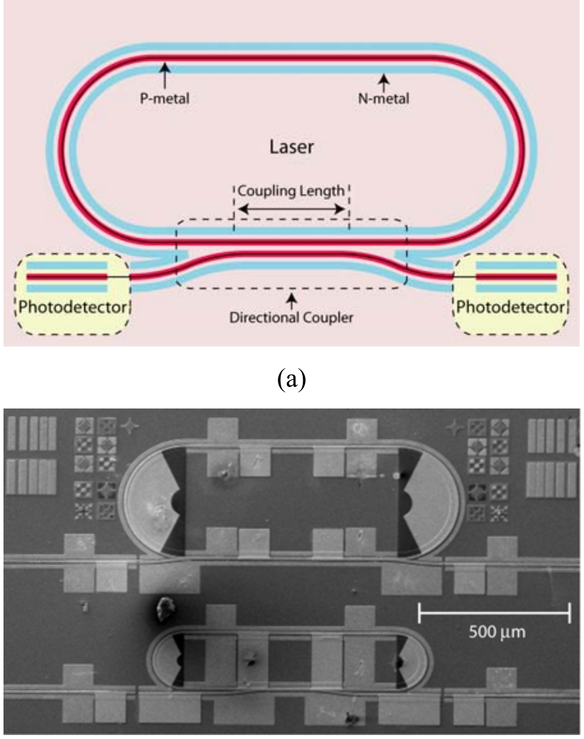


Fig. 1. The hybrid silicon-evanescent device cross section structure.

2. Device Structure and Fabrication

The hybrid AlGaInAs-silicon evanescent device cross section is shown in figure 1. The devices are fabricated using an AlGaInAs quantum well epitaxial structure that is bonded to a low-loss silicon rib waveguide. The silicon waveguide was fabricated with a final height, width, and rib-etch depth of 0.69 µm, 1.65 µm, and 0.5 µm, respectively. This results in a calculated overlap of the optical mode with the silicon waveguides and the quantum wells of 64 % and 4.2 %, respectively. The fabrication procedure and III-V epitaxial structure details can be found in Ref. [2].



(a)

(b)

Fig. 2. a) The layout of the racetrack resonator and the hotodetectors. b) A top view SEM micrograph of two racetrack resonator lasers. The racetrack resonator lasers on the top and bottom have radii of 200 and 100 microns, respectively

The laser layout is shown in Figure 2. It consists of a racetrack ring resonator with a straight waveguide length of 700 microns. A directional coupler is formed on the bottom arm by placing a bus waveguide 0.5 micron away from the racetrack. Four device designs were fabricated with varying ring radius, and coupler interaction lengths ($L_{interaction}$). Table 1 shows the device layout breakdown with the corresponding cavity lengths (L_{cavity}) and the computed coupling percentage to the bus waveguide. The laser power is collected into the two 440 micron long photodetectors. These photo-detectors have the same waveguide architecture as the hybrid laser, the only difference being that they are reverse biased to collect photo-generated carriers.

Radius	L_{cavity}	$L_{interaction}$	Computed Feedback Coupling
200 μm	2656 μm	600 μm	3 %
		400 μm	12.6%
100 μm	2028 μm	300 μm	36%
		100 μm	85%

Table 1, Ring dimensions and coupling parameters

3. Experiment and Results

The laser is driven by applying a positive bias voltage to the top p-probe contact while the optical power is measured by the two photodetectors on each side of the coupler. The photocurrent is measured while reverse biasing the photodetectors at -5V. We use a responsivity of 1.25 A/W such that the laser power values are on the conservative side. Since the testing of the lasers are done all on chip without polishing and dicing, the lasing spectrum is measured by collecting scattered light near the bends of the ring through a fiber probe.

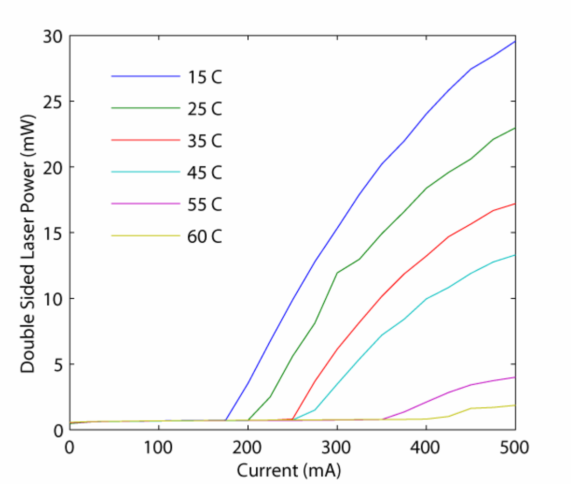


Fig. 3. The LI curve for a laser with radius R = 200 microns, and $L_{interaction}$ = 400 micons for various temperatures

Figure 3 shows the measured total c.w. laser output power which is the sum of the optical power measured at both detectors as a function of injected current for various operating temperatures ranging from 15 to 60 °C for the laser with a ring radius and coupling interaction length of 200 microns and 400 microns respectively. As can be seen from Fig. 3, the laser threshold is 175 mA with a maximum output power of 29 mW at 15 °C. The maximum power is limited by the available drive current to the device. The laser has a 60 °C maximum lasing temperature with a characteristic temperature of 55 K. The laser has a threshold voltage of 1.75V and a series resistance of 3.5 ohms.

The spectrum was measured with an HP 70952A optical spectrum analyzer with a resolution bandwidth of 0.1 nm. The lasing wavelength is 1592.5 nm with a 0.21 nm mode spacing corresponding to a group index of 3.67.

Radius	$L_{interaction}$	P_{max}	η_d	I_{th}	T_{max}
200 μm	600 μm	29 mW	13%	175 mA	60 C
	400 μm	27.5 mW	17%	175 mA	60 C
100 μm	300 μm	3.1 mW	12%	200 mA	65 C
	100 μm	7 mW	4.3%	150mA	65 C

Table 2: Max power, differential efficiencies, threshold currents and maximum operating temperatures

Table 2 shows the maximum output powers, differential efficiencies, threshold currents, and maximum output temperatures of the four device designs. The injection efficiency, modal loss, and g_o were found to be 70%, 15 cm^{-1}, and 1500 cm^{-1}, respectively. The additional bend loss for 200 micron and 100 micron bends were found to be 0 cm^{-1} and 50 cm^{-1}, respectively.

4. Conclusion

The integration of a racetrack laser with a photodetector on the hybrid silicon evanescent device platform demonstrates the potential to realize practical photonic integrated circuits on a silicon substrate. These two types of photonic devices are fabricated on a single active region design showing the flexibility of the hybrid silicon evanescent device platform. On-chip testing and characterization of the laser simplifies the testing by eliminating facet polishing and characterization uncertainties caused by coupling losses. We have demonstrated a monolithic laser with output powers up to 29 mW operating up to 60 C in the range of 1590nm. The integrated photodetector shows a responsivity of ~1.11 A/W.

Acknowledgments

We thank Intel & Jag Shah & Wayne Chang through DARPA for supporting this research through contracts W911NF-05-1-0175 and W911NF-04-9-0001.

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