Hybrid AlGaInAs-silicon evanescent racetrack laser

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(Invited Paper)

Abstract: We describe an on chip racetrack laser integrated with two photodetectors on the AlGaInAs hybrid silicon evanescent device platform.

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Silicon photonics research has seen great advancements in recent years with its focus on the basic building blocks of photonic integrated circuits (i.e. lasers, modulators, photodetectors, and others [1-6]). 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 [7]. This device consists of a III-V epitaxial structure bonded to a silicon waveguide to make a hybrid waveguide such that its optical mode lies primarily in the silicon region with a small portion of the mode overlapping the quantum wells of the III-V structure for optical gain. The optical mode characteristics are predominately defined by the silicon waveguide processing. Bonding can be performed without critical alignment. Here we discuss a monolithic hybrid AlGaInAs-silicon evanescent laser based on a racetrack-resonator-topography integrated with two silicon evanescent photodetectors[8]. 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 ^{o}C.

The hybrid AlGaInAs-silicon evanescent device cross section is shown in Fig. 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. The III-V epitaxial structure is grown on an InP substrate and its details can be found in Ref. [7]. The calculated overlap of the optical mode with the silicon waveguides is 64 % while there is a 4.2 % overlap in the quantum wells. The laser consists of a racetrack resonator with a directional coupler placed on the bottom of the two straight waveguide sections (Figure 2). The racetrack radius, directional coupler length and total cavity length were, 200 μm, 400 μm, and 2656 μm, respectively. Two photodetectors are located at the two ends of the directional coupler to collect light from the clockwise and counter clockwise propagating laser modes.

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. 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. The entire silicon chip is mounted on a TEC controller which allows the operating temperature of the laser to be varied from 0 °C to 80 °C.

The responsivity of the photodetectors was measured by dicing and polishing a discrete detector in the same chip and launching a laser light into the detector through a lensed fiber. We measure the photodetector responsivity 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 in the remainder of this paper such that the laser power values are on the conservative side. The detector dark current was measured to be 200 μA.

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. 4, 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 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.

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. Single wavelength lasing sources should be achievable by reducing the cavity length of these lasers to ~50 microns long or utilizing gratings to form DBR lasers.

Acknowledgments

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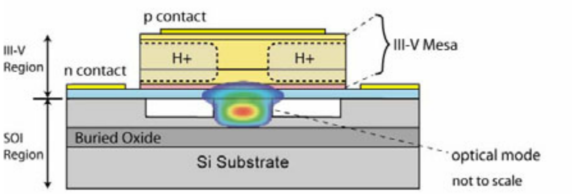

Fig. 1. The hybrid silicon-evanescent device cross section structure.

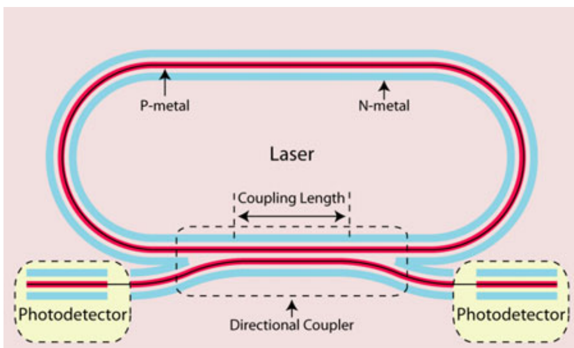

Fig. 2. The layout of the racetrack resonator and the photodetectors.

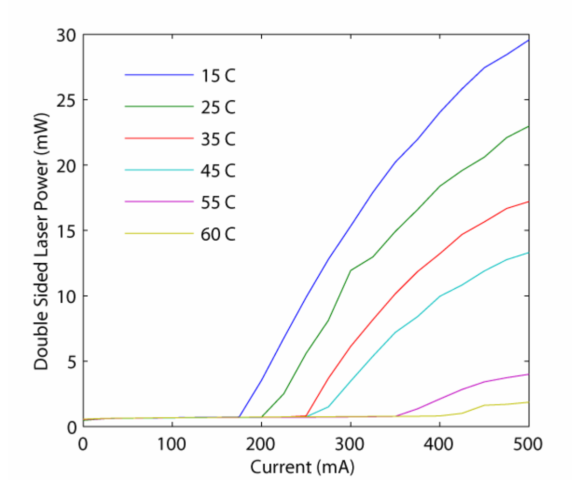

Fig. 3. The LI curve for a racetrack laser for various temperatures

1. G. T. Reed, “The optical age of silicon.” Nature **427**, 615−618 (2004).
2. O. Boyraz, & B. Jalali, “Demonstration of a silicon Raman laser,” Opt. Express **12**, 5269 (2004).
3. S. G. Cloutier , P. A. Kossyrev, & J. Xu, “Optical gain & stimulated emission in periodic nanopatterned crystalline silicon.” Nature Materials **4**, 887, (2005).
4. A. Liu, L. Liao, D. Rubin, H. Nguyen, B. Ciftcioglul, Y. Chetrit, N. Izhaky, and M. Paniccia, “High-speed optical modulation based on carrier depletion in a silicon waveguide,” Opt. Express **15**, 660-668 (2007)
5. V. R. Almeida, C. A. Barrios, R. R. Panepucci, M. Lipson, “All-optical control of light on a silicon chip,” Nature **431**, 1081-1084 (2004)
6. J. Liu, D. Pan, S. Jongthammanurak, K. Wada, L. C. Kimerling, and J. Michel, "Design of monolithically integrated GeSi electro-absorption modulators and photodetectors on a SOI platform ," Opt. Express **15**, 623-628 (2007)
7. 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)
8. A. W. Fang, R. Jones, H. Park, O. Cohen, O. Raday, M. J. Paniccia, and J. E. Bowers, "Integrated AlGaInAs-silicon evanescent race track laser and photodetector," Opt. Express **15**, 2315-2322 (2007)