Hybrid Silicon Microring Lasers

Daryl Spencer

Engineering Physics, University of Tulsa

NNIN REU Site: Nanotech@UCSB, University of California, Santa Barbara, CA

NNIN REU Principal Investigator(s): Dr. John Bowers, Electrical and Computer Engineering, University of California, Santa Barbara

NNIN REU Mentor(s): Dr. Di Liang, Electrical and Computer Engineering, University of California, Santa Barbara

Contact: daryl-spencer@utulsa.edu, bowers@ece.ucsb.edu, dliang@ece.ucsb.edu

Abstract:

We demonstrate a hybrid silicon microring laser device utilizing active indium phosphide (InP)-based epitaxial layers integrated on a silicon-on-insulator (SOI) substrate. The ring resonators exhibit compact structure with diameters of ≤ 50 μm. Laser emission is evanescently coupled to a Si waveguide and captured by on-chip photodetectors. Successful continuous-wave lasing has been observed with a minimum electrical pump current of ~ 5 mA at 10°C and maximum power output > 500 μW at 20°C. Temperature dependent studies were also conducted up to a safe operating temperature of 65°C. Lasing at 1.53 μm shows good spectrum purity with a < 0.04 nm linewidth (limited by the resolution of the optical spectrum analyzer) and a 4.2 nm free spectral range at 20°C. Unidirectional lasing bistability, a unique characteristic of circular lasers, is also observed. The devices are a promising candidate for future applications in optical interconnects, memory, and all optical processing.

Introduction:

Silicon photonics is an important and progressive field for developing low-cost, high-speed optical devices on a Si substrate. Integrating on-chip optical interconnects with modern Si electronics can realize faster and more power efficient data communications in future microprocessors and other emerging applications.

Our research focused on developing a microring laser based on the hybrid silicon platform [1] developed by a joint effort between the University of California Santa Barbara and Intel Corporation. The hybrid silicon platform realizes active optical components on a well developed silicon manufacturing base. The goal of this project was to characterize the microring lasers across design parameters and optimize the fabrication procedure.

Device Layout:

Figure 1 shows the 3D schematic (a) as well as the 2D cross section (b) of the hybrid silicon microring laser. The ring resonator consisted of an active gain region: InAlGaAs-based quantum wells and a separate confinement heterostructure sandwiched by InP p-cladding and n-contact layer, which were then integrated through a wafer bonding technique onto an SOI substrate. The active region generated photons when electrical carriers were injected, which were guided along the ring resonator to achieve optical gain. The ring resonator had a compact structure with a variable radius, R, of ≤ 25 μm. The laser emission was evanescently coupled across a gap, s (50-500 nm), to a Si bus waveguide of width, w (600-1000 nm), for characterization via on-chip photodetectors.

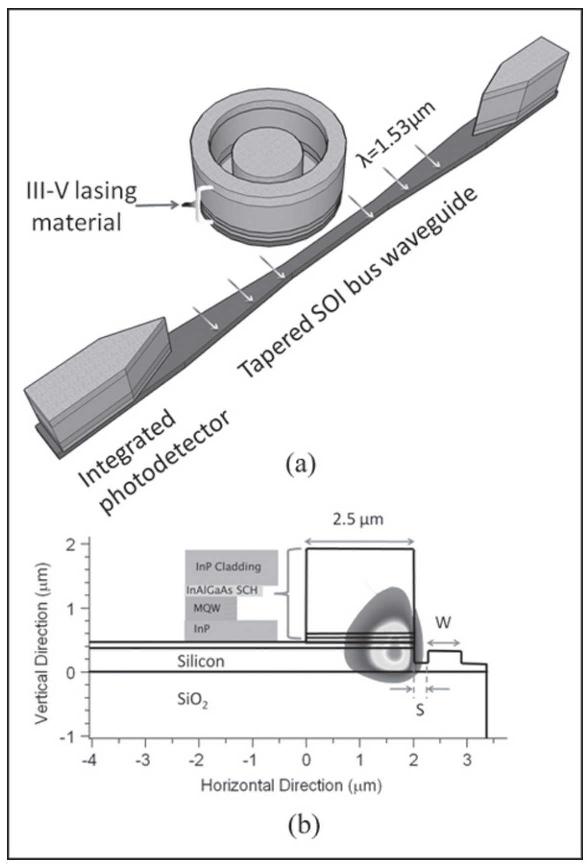

Figure 1: (a) 3D schematic ring resonator, waveguide, and photodetectors, and (b) 2D cross section with optical mode profile and epitaxial layers.

Results:

Figure 2 shows a typical continuous-wave, temperature-dependent output power vs. injected current (L-I) characteristic for devices

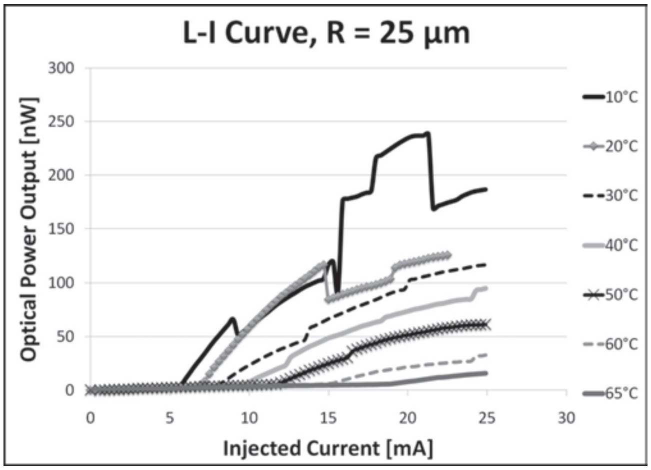

Figure 2: Detail of typical L-I curve for R = 25 µm devices.

with R = 25 μm. Once the required threshold was met, the output light power increased dramatically and was the sign of lasing. Successful lasing was achieved at thresholds as low as 5.4 mA (R = 12.5 μm, s = 250 nm, w = 600 nm) at 10°C and output light power > 500 μW (R = 25 μm, s = 50 nm, s = 600 nm) at 20°C. Experiments increasing the coupling gap from 50 nm to 500 nm showed a trend of decreasing threshold (I_{TH}) with a reduction of out-coupled power collected at the photodetectors. The maximum lasing temperature was recorded under safe operating conditions of up to 25 mA pump current, and yielded a maximum temperature of 65°C. Devices fabricated with a coupling gap of 500 nm had too low of a optical power coupled to the waveguide to be consistently measured with the photodetectors.

Figure 3 shows the primary longitudinal mode in the lasing spectrum collected from the silicon waveguide. Full-width at half-maximum is < 0.04 nm (limited by the resolution of the optical spectrum analyzer) and the free spectral range between higher order modes is 4.2 nm (not shown), which agrees well with a predicted value of 4.3 nm.

Figure 4 shows the L-I curves for unidirectional lasing, a feature unique to ring/disk resonators. Without introducing nonreciprocal gain or loss in the resonator cavity, lasing was observed in both clock-wise (CW) and counter-clock-wise (CCW) simultaneously. In order to break the balance, the right photodetector (PDR) was forward-biased as a light source at 500 mV to force laser emission in a CW direction. The output was measured at the left photodetector (PDL) as the pump current was increased. When threshold was reached, it was clear that the majority of the laser emission was detected at the PDL, thus demonstrating unidirectional lasing.

Conclusions:

We have demonstrated a compact hybrid silicon microring laser with low threshold down to 5.4 mA and output power > 500 μW at 10°C. Good spectrum purity was observed with a linewidth < 0.04 nm and a free spectral range of 4.2 nm. Additionally, unidirectional lasing was achieved utilizing the on chip photodetectors and unique geometry of the ring resonator.

These results show that the hybrid silicon microring laser is a promising candidate for optical interconnects, memory, and all optical processing.

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References:

[1] A. W. Fang, H. Park, O. Cohen, R. Jones, M. J. Paniccia, and J. E. Bowers, "Electrically pumped hybrid AlGaInAs-silicon evanescent laser," OE 14, 9203-9210, (2006).

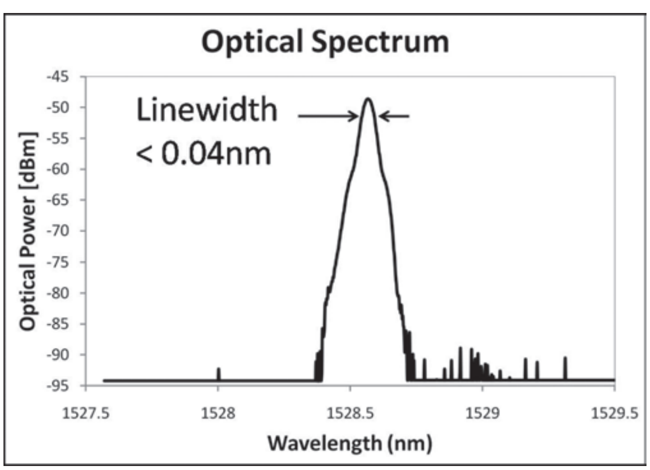

Figure 3: 1st order mode lasing spectrum and measured linewidth.

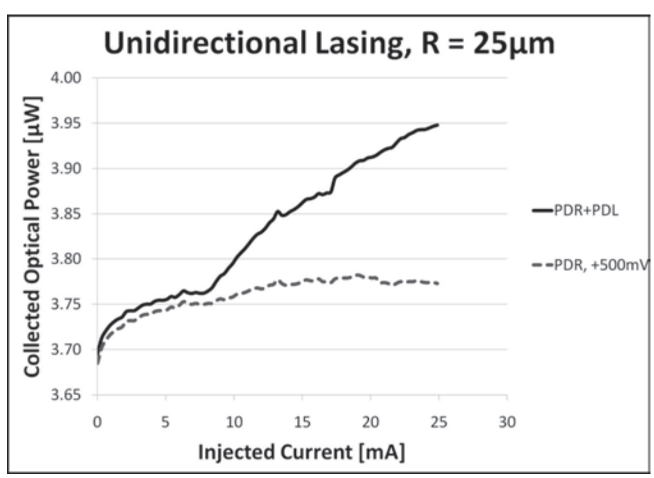

Figure 4: Unidirectional lasing in the microring structure.