A CW Mid-infrared Hybrid Silicon Laser at Room Temperature

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***Abstract* – We report the first CW room temperature mid-infrared (λ=2.0µm) laser heterogeneously integrated on silicon. Molecular (polymer-free) wafer bonding of InP to Si is employed. III-V tapers transfer light from a hybrid III-V/silicon optical mode into a Si waveguide mode. Polished Si facets form a Fabry-Pérot laser cavity.**

I. INTRODUCTION

Long wavelength silicon devices have been rapidly gathering attention in recent years. The mid-infrared regime, 2-20µm, is of particular interest for a variety of sensing and detection applications. Many of these applications will benefit from the low cost, compact device size, and commercial scalability enabled by integration in silicon photonic systems. Chemical bond spectroscopy, biological sensing (lab-on-a-chip), thermal imaging, gas detection and environmental monitoring, and astrophotonics are all important applications for silicon mid-infrared devices. Additionally, the 2-3µm spectral region has been shown to be advantageous for on-chip nonlinear optics for amplification and generation of light[i,ii].

Numerous mid-infrared silicon devices have been demonstrated to date [iii iv, v] including a preliminary demonstration of a 2.38µm, polymer adhesive bonded, pulsed hybrid silicon laser operating at 10ºC [vi]. However, in order to realize many of these applications in complete silicon photonic systems, room-temperature CW on-chip sources at mid-infrared wavelengths will be necessary. Here we demonstrate CW 2.0µm hybrid silicon lasers operating up to 35ºC and heterogeneously integrated with silicon waveguides.

II. DESIGN

A four well MQW laser diode structure suitable for hybrid silicon integration was epitaxially grown with MOCVD on an InP substrate by nLight for 2.0µm operation.

Silicon rib waveguides were photolithographically defined on 500nm SOI. The III-V material was bonded to the SOI by plasma-assisted wafer bonding and annealed at 300ºC for 60 minutes. The InP substrate was removed by mechanical lapping and chemical wet etching. III-V mesas were formed by methane/hydrogen/argon reactive ion etching (RIE) with a SiO_2 hard mask. Etch depth uniformity was improved by an intermediate 1:3 $HCl:H_3PO_4$ selective wet etch between RIE etch steps. Pd/Ge/Pd/Au was deposited on n-InP to form bottom contacts and Pd/Ti/Pd/Au was deposited on p-InGaAs to form top contacts. A current channel of varying widths was formed by proton implantation. Devices were electrically isolated with SiO_2, vias were etched, and probe metal was deposited.

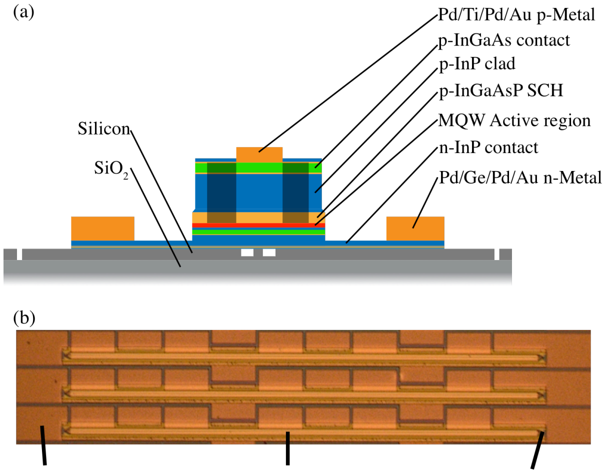

Figure 1: (a) Cross sectional schematic of hybrid silicon active region. Not shown: electric isolation and probe metal (b) Top-down microscope image of laser structures. Si waveguides are hidden under probe metal and bottom III-V n-layers.

Fig. 1 shows a cross-sectional schematic and top-down image of the devices. Silicon waveguides ranged from 0.5-3µm wide and were partially etched about 240nm deep. III-V mesas were 1mm or 2mm long and current channels were 4-6µm wide. 20µm long tapers terminated the III-V mesas. This transferred the hybrid III-V/silicon waveguide into a silicon waveguide on both sides of the III-V mesa. The devices were terminated with polished silicon facets forming a Fabry-Pérot laser cavity.

III. TESTING AND RESULTS

Laser diode bars were mounted on a temperature controlled copper block with thermal paste. A ThorLabs DET10D InGaAs detector was positioned directly at the laser end facet to collect light. Light vs. current curves are shown in fig. 2 for various substrate temperatures. Lasing occurred at temperatures up to 35ºC. Total single-facet output powers above 1mW and quantum differential efficiencies up to 0.5% were achieved at 20ºC.

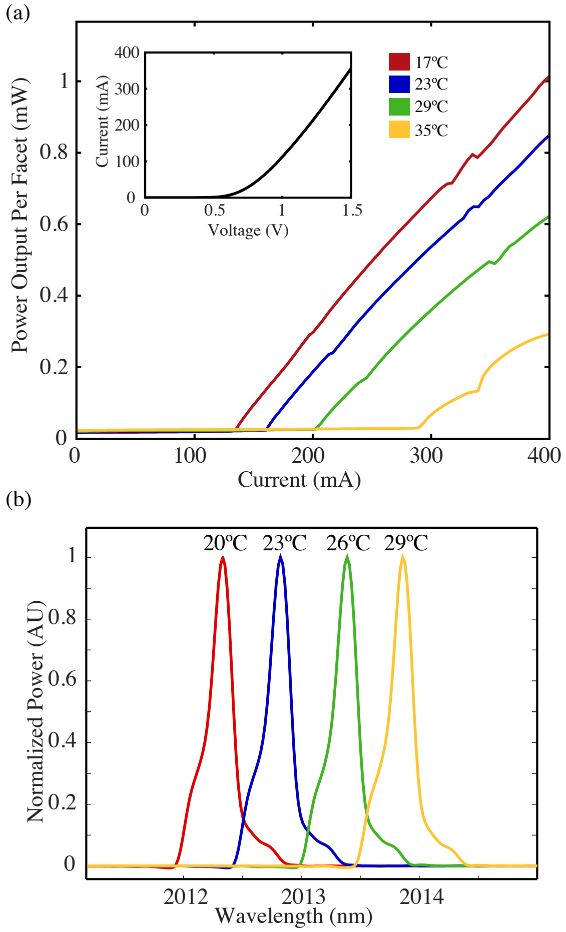

Figure 2: (a) Light-current plot for a laser at various substrate temperatures with a 24μm wide and 2mm long III-V mesa, 1.5μm wide Si waveguides, and 4μm wide current channel. Inset: Voltage-current characteristics for this device at 23ºC. (b) Optical spectrum for a 2mm laser diode driven at 450mA at various substrate temperatures. The power of each spectrum is individually normalized.

A glass lens was used to collimate the output light in order to observe the optical spectrum with a Bruker Vertex 70 FT-IR spectrometer. One device is shown in Fig. 2 with a peak wavelength at 20ºC of 2012.3nm. The single longitudinal mode behavior is likely attributed to reflections from the tapers resulting in coupled cavities. Other side modes are visible in the spectrum under certain drive current and temperature conditions.

Threshold currents at 20ºC varied from about 93-350mA. A histogram of threshold current densities for 54 devices is shown in Fig. 3.

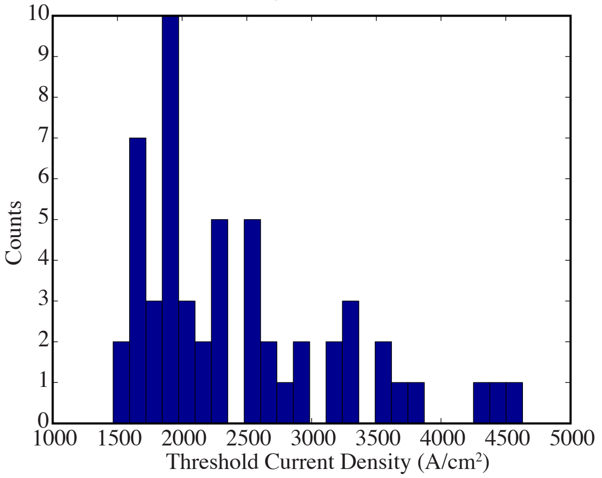

Figure 3: Histogram of threshold current densities for 54 lasers of various device geometries.

IV. CONCLUSIONS

We have demonstrated a 2.0µm continuous wave hybrid silicon laser operating up to 35ºC. Single-facet powers above 1mW and threshold currents as low as 93mA are observed.

V. ACKNOWLEDGMENTS

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