1310nm Silicon Evanescent Laser

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Abstract

An electrically pumped 1310 nm silicon evanescent laser (SEL) is demonstrated utilizing the hybrid silicon evanescent waveguide platform. The SEL operates continuous wave (C.W.) up to 105 °C with a threshold current of 30 mA and a maximum output power of 5.5 mW.

I. Introduction

Many significant advancements have been made towards the realization of lasers that are compatible with silicon [1,2,3,4,5]. However, due to silicon's indirect bandgap, several of these solutions have relied on optical pumping methods such as stimulated Raman scattering (SRS) [1,2], or have relied on complex heterogeneous integration of III-V materials [4,5]. Recently, silicon evanescent lasers (SEL) have been demonstrated in the 1550 nm regime [3,6]. These lasers utilize quantum wells bonded to a silicon waveguide to achieve evanescently coupled optical gain into the silicon mode. The optical mode of this hybrid waveguide lies in both the III-V region and silicon waveguide. The optical mode is defined by the silicon waveguide and no alignment is needed for this bonding process. This allows for a large number of SELs to be bonded to the silicon wafer through a single bonding step. We report here an SEL operating in the 1310 nm regime with a threshold current of 30 mA, a maximum output power of 5.5 mW, and C.W. operation up to 105 °C.

II. Device Structure and Fabrication

The SEL consists of a III-V active layer bonded to a silicon waveguide fabricated on a silicon-on-insulator (SOI) substrate, as shown in Figure 1. A set of silicon waveguides with a height h = 0.69 µm, rib etch depth d = 0.52 µm, and width w = 2.5 µm are patterned on the silicon before bonding.

The fabrication can be divided up into 4 major steps. First, the silicon waveguides are fabricated on the SOI wafer using standard projection lithography and dry etching techniques. Second, the III-V layer structure is transferred to the silicon wafer through low temperature wafer bonding process [7]. Third, the III-V region is processed to ensure efficient carrier injection to the active region. Finally, the sample is diced and polished, resulting in a total cavity length of 850 microns. A detailed description of the fabrication procedure can be found in references [3,6].

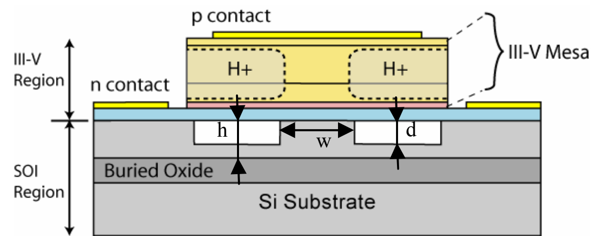

Figure 1. Silicon evanescent laser structure.

Table 1 shows the details of the III-V epitaxial structure. The AlGaInAs quantum wells are designed with a PL peak at 1303 nm. The quantum wells are located between a carrier blocking layer and a n-layer. The carrier blocking layer is designed to have a low valence band offset while maintaining a high conduction band offset [8]. This allows holes to flow past this layer from the p-mesa into the quantum wells while preventing electrons from flowing out of the quantum wells into the p mesa. A SCH layer and p-cladding layer are placed above the carrier blocking layer.

III-V Epitaxial growth layer structure

Name	Composition	Doping Concentration	Thickness
P contact layer	P-type $In_{0.53}Ga_{0.47}As$	1×10^{19} cm^{-3}	0.1 µm
Cladding	P-type InP	1×10^{18} cm^{-3}	0.5 µm
SCH	P-type $Al_{0.4055}Ga_{0.064}In_{0.5305}As$, 0.9 µm	1×10^{17} cm^{-3}	0.25µm
Electron Blocking Layer	$Al_{0.4764}Ga_{0.0189}In_{0.5047}As$	undoped	10 nm
Quantum Wells	$Al_{0.178}Ga_{0.1234}In_{0.6986}As$, 1.5 µm (8x)	undoped	7 nm
	$Al_{0.055}Ga_{0.292}In_{0.653}As$, 1 µm (9x)	undoped	9 nm
N layer	N-type InP	1×10^{18} cm^{-3}	110 nm
Super Lattice	N-type $In_{0.85}Ga_{0.15}As_{0.327}P_{0.673}$ (2x)	1×10^{18} cm^{-3}	7.5 nm
	N-type InP (2x)	1×10^{18} cm^{-3}	7.5 nm

Table 1. III-V epitaxial growth layer structure.

Figure 2(a) and 2(b) show the simulated fundamental and 2nd order transverse optical modes

of this structure for devices with 2.5 µm waveguide width. These modes are calculated by the film mode matching (FMM) method [9]. The quantum well confinement factor for the fundamental mode and 2nd order transverse mode are 2.2 % and 10.5 %, respectively. Since the 2nd order transverse mode has a higher confinement factor in the III-V region, it preferentially lases over the fundamental mode. The observed optical mode is as shown in Figure 2 (c).

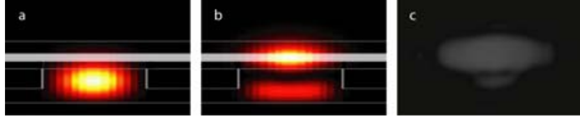

Figure 2 Optical mode simulation results of SEL and the measured mode: (a) simulated fundamental mode; (b) 2nd order transverse mode; (c) measured optical mode.

III. Experiments and results

The device is mounted on a thermal-electrical cooler and biased with a C.W. current source. We collect the light on one facet of our device with a single mode lensed fiber. On the other facet, we use an IR camera to image the lasing mode. The coupled power is then sent to a spectrum analyzer or photodetector. The coupling loss was measured to be ~4.6 +/- .8 dB.

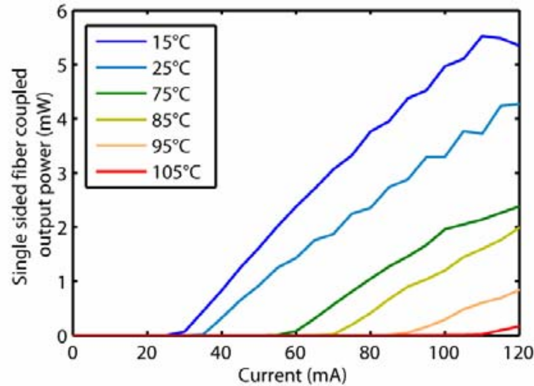

Figure 3. The single sided fiber coupled laser power output as a function of drive currents at different temperatures.

Figure 3 shows the measured C.W. laser output power from one facet as a function of the injected current for various temperatures ranging from 15 °C to 105 °C. As we can see from Figure 3, the threshold current is about 30 mA at 15 °C. The highest lasing temperature of our devices is 105 °C with a threshold current of 110 mA. This is 50 °C higher than the previous record [6]. Even though the cavity lengths are quite similar, the 15 °C threshold of 30 mA reported here is substantially lower than the 65 mA threshold reported in [3]. This can be attributed to the high active region confinement factor of the 2nd order transverse mode. The maximum single sided fiber coupled output power is 5.5 mW and the differential quantum efficiency is 8 %. Taking into account the coupling loss and light from both facets, we estimate the total output power and differential efficiency to be 31.6 mW and 46 %.

The voltage-current curve is shown in Figure 4. The turn on voltage at 15 °C is 1.2 V and the series resistance is 11.5 ohms.

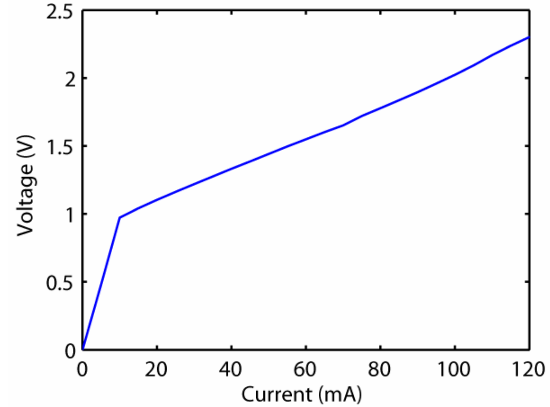

Figure 4 The V-I characteristic curve of SEL.

Figure 4 shows the measured lasing spectrum of the SEL under 100 mA drive current at 15 °C. The center wavelength is 1326 nm. The inset of Figure 4 shows a close up of the lasing spectrum, showing the Fabry-Perot modes. The mode spacing is measured to be 0.27 nm, which corresponds to a group index of 3.83.

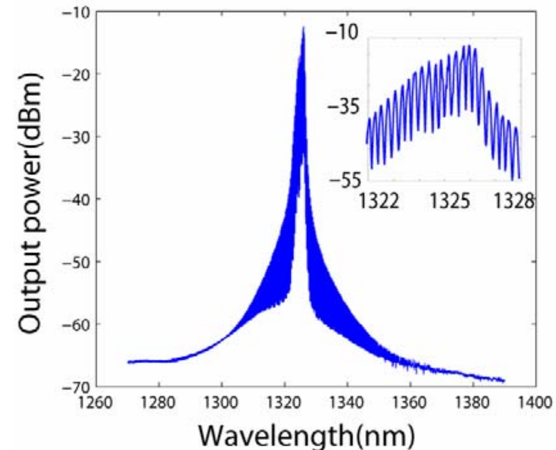

Figure 4. The spectrum of silicon evanescent laser under 100 mA driving current at 15 °C.

IV. Conclusions

An electrically pumped laser on silicon at 1310nm is important for silicon-based photonic integrated circuits. Here we demonstrate the first electrically pumped 1310nm SEL on silicon with a threshold current of 30mA and maximum single sided fiber coupled output power of 5.5mW. The single sided fiber coupled differential quantum efficiency is 8% and the maximum lasing temperature is 105 °C. This technology is applicable to semiconductor optical amplifiers [10] at 1310 nm, which is important because it is outside the wavelength range of erbium doped fiber amplifiers.

V. Aknowledgements

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