Hybrid Silicon Evanescent Lasers

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Silicon photonic platforms have been of great interest for the integration of photonic and electronic circuits on a silicon substrate. However, efficient light generation inside a silicon crystal has been the major obstacle due to the indirect bandgap characteristics of silicon. To overcome this problem, recently we demonstrated optically pumped hybrid silicon evanescent lasers, in which III-V based quantum wells are bonded to silicon rib waveguides [1]. This approach enables to build active silicon photonic devices by combining high optical gain of III-V materials with well developed silicon processing technology. The work presented here is a first step of the future development of the electrically driven silicon active photonic devices as well as the photonic integration with electrical circuitry on silicon-on-insulator (SOI) wafers.

The device structure is shown in Fig. 1. The structure can be divided into a III-V region and a silicon waveguide region. The III-V region is made up of the active region with five 7 nm thick AlGaInAs quantum wells under compressive strain (0.85 %) and 10 nm thick AlGaInAs barriers under tensile strain (-0.55 %). Unstrained 1.3 μm AlGaInAs absorber layers are placed on the both sides of the QWs to increase pump power absorption. A two period InP/1.1 μm InGaAsP superlattice (SL) is employed to inhibit the propagation of defects from the bonded interface to the QW region [2]. Finally a 110 nm thick n-doped InP spacer is used as a bonding interface to silicon. The silicon waveguide region incorporates a silicon rib waveguide with a 1 μm thick SiO_2 lower cladding layer. Figure 2 shows the index profile and the calculated band structure of the device. The transverse confinement factors of the silicon waveguide and the QWs can be manipulated by the silicon waveguide dimensions. In general more of the transverse optical mode is confined in silicon waveguide region with a wider or taller silicon waveguide. For the fabricated waveguide dimensions of a 0.7 μm height (H) and 0.6 μm rib-etch depth (D), silicon confinement factors (Γ_{Si}) are varied from 5 % to 51 % with waveguide width variation of 1 μm to 5 μm and correspondingly the QW's confinement factors (Γ_{QW}) are varied from 5 % to 4 % for five quantum wells as shown in Fig 3. The fabrication of the hybrid structure includes silicon rib waveguide formation on a SOI wafer and oxygen plasma assisted wafer bonding [3] and it is described specifically in Ref. [1].

The device is optically pumped by a 1250 nm fiber laser in a direction normal to the device structure. The laser output is collected into with a multimode fiber and subsequently characterized using a spectrum analyzer or photodetector. The TE/TM near-field images of the output mode are recorded on an IR camera through a polarizing beam splitter and an 80x lens at the opposite waveguide facet. Figure 4 shows the laser output power as a function of pump power and temperature for a 800 μm-long and 4 μm wide device. The device is operating with a threshold pump power of 23 mW, fiber-coupled maximum output power of 4.5 mW, and a slope efficiency of 3 % at 20 ºC. The threshold increases from 23 to 105 mW between 20 °C and 60 °C and the structure exhibits a temperature coefficient (T_0) of 27 K as shown in the inset. The kinks in the LL curves can be attributed to the multi mode lasing due to wide waveguide dimension. It is clearly shown that higher order modes are superimposed with a fundamental mode at the region II of the LL curve while only a fundamental mode is lasing at the region I. Figure 5 shows LL curves of a 1 μm wide device with a threshold of 120 mW and a slope efficiency of 0.5 % at 20 ºC. Due to the narrower waveguide dimensions, the fundamental mode is primarily confined in the III-V region and is lases without higher order modes. The device demonstrates a maximum output power of 0.9 mW. Fig. 6, shows the threshold pump power dependence on waveguide width at different temperatures. For devices wider than 2 μm, most of the optical mode is confined in the silicon waveguide and evanescently coupled into the III-V region. These devices also show lower threshold pump power than narrower devices due to low propagation loss in the silicon waveguide and thus reduced total internal loss.

[1] H. Park, et. al., Optical Fiber Communication Conference 2006, OWH2, (2006)
[2] A. Karim, et. al., *IEEE Photon. Technol. Lett.*12, 1438-1440, (2000).
[3] D. Pasquariello, et. al., *IEEE J. Sel. Topics Quantum Electron*. 8, 118-131, (2002).

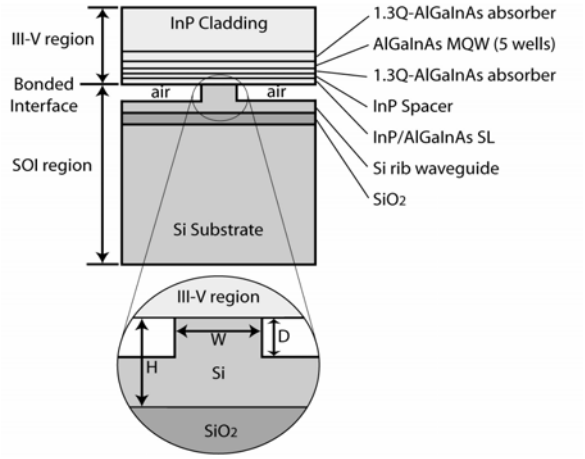

Fig. 1. Device structure.

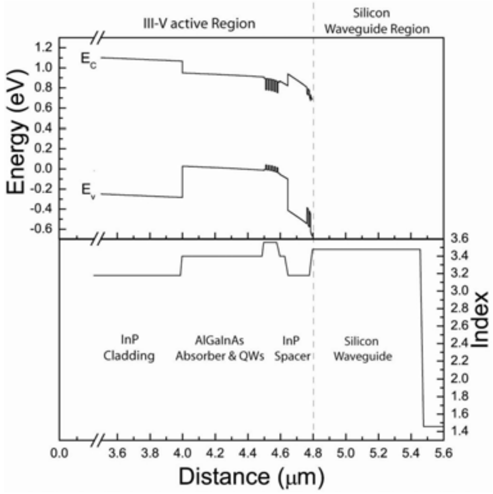

Fig. 2. III-V active region band diagram and index profile.

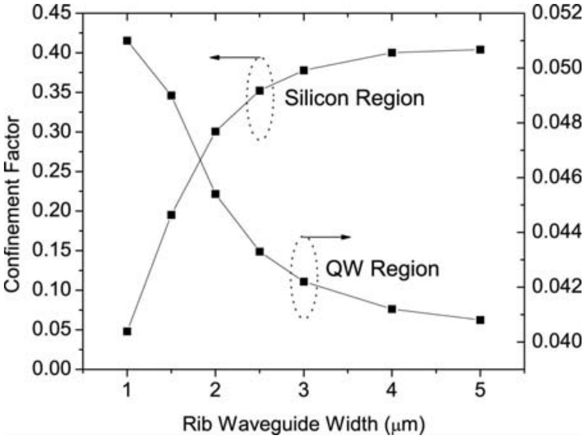

Fig. 3. Calculated confinement factors of fabricated devices.

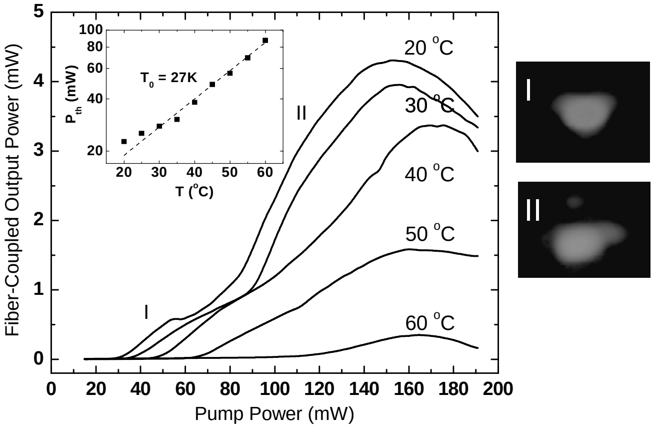

Fig. 4. LL curves and mode profiles of a 800 μm long and 4 μm wide device (inset) threshold vs temperature.

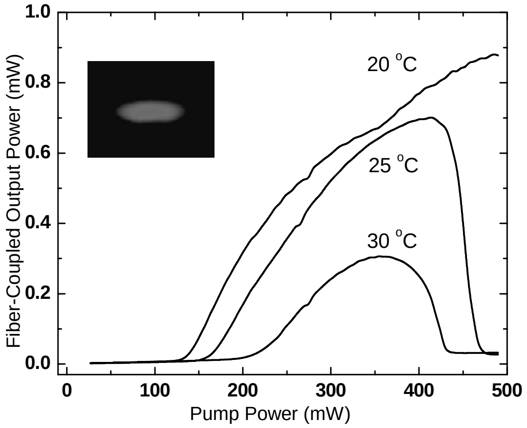

Fig. 5. LL curves and mode profiles of a 800 μm long and 1 μm wide device.

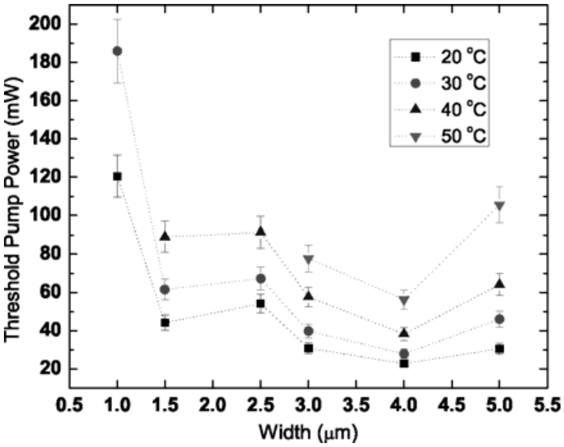

Fig. 6. Threshold pump power with different waveguide widths.