Silicon Evanescent Lasers and Amplifiers
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Abstract
The use of III-V based quantum wells bonded to silicon waveguides to form electrically pumped, hybrid silicon evanescent lasers and amplifiers on a silicon photonics platform is described.

I. Introduction
Laser sources and amplifiers are key elements for building photonic integrated circuits. Many efforts have been made to realize lasers on silicon, however due to it’s indirect band gap methods other than band-to-band electron transitions have been explored. Silicon Raman lasers [1, 2] and amplifiers [3] have been demonstrated but are limited to optically pumped operation. A hybrid approach, evanescent optical gain, utilizing III-V quantum wells bonded to silicon rib waveguides is discussed here. Recently we demonstrated optically pumped silicon evanescent lasers lasing at 1568 nm with a pump threshold of 23 mW and peak fiber coupled output power of 4.5 mW [4]. In this paper we discuss the device structure and design characteristics of electrically pumped silicon evanescent lasers (SEL) and silicon evanescent amplifiers (SEA)

II. Device Structure
Figure 1 shows the cross sectional structure of the proposed electrically pumped laser and amplifier. The III-V region consists of a p-InGaAs contact layer, a p-InP clad, an AlGaInAs separate confinement heterostructure (SCH) layer, 8 AlGaInAs quantum wells, an n-InP layer, and n-InP/n-InGaAsP super lattice (SL) layers. The quantum wells consist of alternating 7nm thick 1.5\textit{Q}-AlGaInAs well layers and 10nm thick 1.3\textit{Q}-AlGaInAs barrier layers. The thickness of the SCH layer is 0.25 \textmu m thick and the total thickness of n-layer including the InP and the SL layer is 0.15 \textmu m. The silicon waveguide is formed on an SOI wafer. These two regions are bonded together through low temperature oxygen assisted wafer bonding [5, 6] and the final structure is realized through subsequent backside processing of III-V region. Electrical current flows vertically through the mesa structure formed on the III-V region, and then flows laterally through n-InP and n-type SL layers.

Fig. 1. Cross sectional device structure.

The calculated silicon confinement factors and quantum well confinement factors are shown in Figure 2. The silicon waveguide dimensions are chosen carefully in order to achieve the desired confinement factors for a given device. High silicon confinement factors provide high coupling efficiency with passive devices while high quantum well confinement factors provide high optical gain. In general, wider and taller waveguides result in higher confinement in the silicon waveguide, while narrower and shorter waveguides result in higher confinement in the quantum well region.
III. Silicon evanescent lasers

Figure 3 and 4 represent the results from optically pumped silicon evanescent lasers demonstrated recently. The fabricated waveguides have a height of 0.7 µm and an etch depth of 0.6 µm with a variation of waveguide width from 1 µm to 5 µm. The specific structure of the III-V region is described in Ref. 4. In Fig. 3, the transition of the optical mode from the III-V region to the silicon region can be seen as the waveguide width increases. For 4 µm wide devices, the maximum fiber coupled output power is 4.5 mW and the maximum operating temperature is 60 °C as shown in Fig. 4. Several kinks in the figure are mainly due to the multimode behavior originated from the wide waveguide dimensions.

![Fig. 3. Measured mode profiles from optically pumped silicon evanescent lasers.](image)

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Figure 5 shows the calculated thresholds with different device lengths and facet reflectivity for electrically pumped lasers. The modeled waveguide dimensions have a height of 0.8 µm, a width of 1 µm, and an etch depth of 0.4 µm. With these waveguide dimensions, Γ_{QW} and Γ_{Si} are calculated to be 3 % and 75 % respectively and single mode operation is also ensured. The active region width is assumed to be 5 µm which corresponds to the actual optical mode width. The internal efficiency of the given epitaxial structure is simulated to be 80 % with Simwindows, a 1D drift and diffusion simulator. The calculation uses the material gain of g(N) = g_0 ln(N/N_t), where g_0 = 2000 cm^{-1} and N_t = 2 \times 10^{18} cm^{-3}. Modal losses are assumed to be 10 cm^{-1} and 20 cm^{-1} respectively. These characteristics are based on previous Hakki-Paoli measurements made on optically pumped silicon evanescent lasers [7]. A much lower threshold of 5 mA can be achievable with a facet reflectivity of 80%. Silicon distributed Bragg reflectors (DBR) could be fabricated outside of active regions to further increase the reflectivity and allowing single longitudinal mode lasing.

![Fig. 5. Calculated silicon and quantum well confinement factors. The silicon remaining after rib-etch (H – D) was kept constant at 0.5 µm.](image)

![Fig. 4. LL Curves for 4 µm wide device form optically pumped devices.](image)

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IV. Silicon Evanescent Amplifiers

Optical amplifiers are also key components to realize dense photonic integration by compensating for optical losses. The laser structure can be directly extended to the amplifier through anti-reflection coating or tilting the facet. The calculated amplifier gain is shown in Fig. 6 with different lengths of coating or tilting the facet. The calculated amplifier for optical losses. The laser structure can be directly realized to achieve high density active silicon photonic integrated circuits for telecommunications and optical interconnect applications.

IV. Conclusions

Electrically pumped silicon evanescent lasers and amplifiers are proposed here. We present their structure and simulations of their characteristics modeled from device parameters experimentally obtained from optically pumped silicon evanescent lasers. The realization of these devices will enable high density active silicon photonic integrated circuits for telecommunications and optical interconnect applications.

V. References