Electrically pumped continuous wave 1.3 µm quantum dot lasers epitaxially grown on on-axis (001) Si

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Abstract: *We demonstrate 1.3 µm quantum dot lasers grown directly on (001) silicon substrates without offcut or germanium layers, with thresholds down to 30 mA and lasing up to 90°C. Measurements of relative intensity noise versus feedback show 20 dB higher tolerance to reflections compared to quantum well lasers on silicon.*
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1. Introduction

III-V quantum dot lasers epitaxially grown on silicon are a promising monolithic light source for silicon photonics that can be manufactured at scale with low cost [1-3]. Integration with existing silicon foundry process flows will be critical to supporting high volume integrated silicon photonic applications requiring on-chip lasers. We have previously demonstrated, along with other groups, high performance continuous wave quantum dot lasers epitaxially grown on silicon, however these past works all utilized intentionally offcut silicon substrates to suppress anti-phase domains [2-3]. The offcut substrates are incompatible with standard silicon CMOS process flows and are more expensive than nominal (001) silicon; thus, high performance III-V light sources on on-axis (001) silicon are needed. Here, we demonstrate the first continuous wave electrically pumped III-V laser on (001) silicon substrates without offcut.

2. Laser Design, Growth and Fabrication

The substrate used was a 775 µm thick on-axis (001) p-doped Si substrate, with 200nm thick n-doped Si homo-epitaxial buffer and a subsequent 45 nm thick n-doped GaP nucleation layer deposited by NAsP III-V GmbH. A GaAs/AlGaAs GRINSCH laser with 7 layers of p-modulation doped InAs/GaAs quantum dots as the active region was then grown in MBE, following the conditions reported in [4]. The threading dislocation density in the material was measured to be ~3×10^{8} cm^{-2} by plan-view electron channeling contrast imaging. The as grown material was processed into deeply etched ridge waveguide lasers using standard dry etching and metallization techniques. Laser facets were created by cleaving or polishing. All measurements were performed in continuous wave (CW) operation.

3. Results

Figure 1a shows room temperature photoluminescence comparison of the as grown laser material on GaP/Si to a reference structure grown on GaAs. Both samples show a similar peak wavelength of ~1280nm, while the laser on GaP/Si has a relative peak intensity of ~57% compared to the reference sample on GaAs. Figure 1b shows CW light-current (LI) comparisons of five broad area lasers (2 mm x 20 μm^2) on GaAs to five on GaP/Si, all without facet coatings. The lowest threshold current (densities) of the aforementioned devices is 190 mA (475 A/cm^2) for lasers on GaAs, and 345 mA (862 A/cm^2) for GaP/Si. As shown in the same figure, single facet output powers up to 110 mW were obtained from the lasers on GaP/Si.

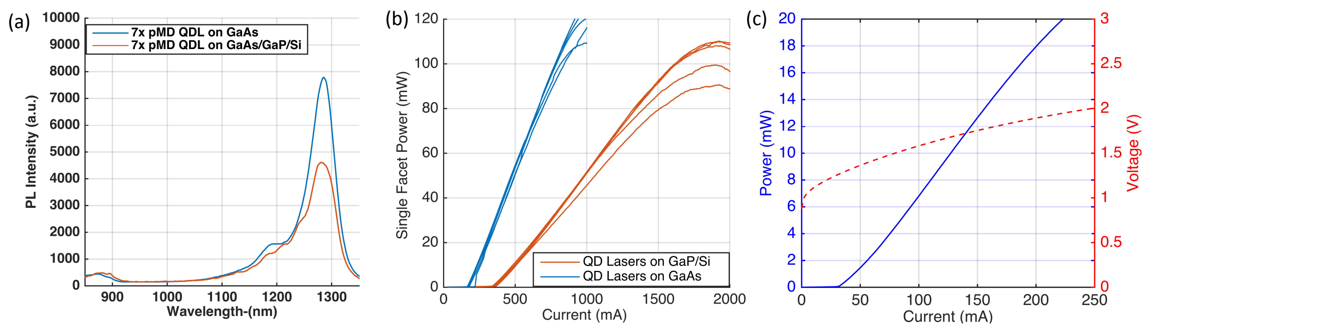

Fig. 1. (a) RT photoluminescence comparison of the as-grown laser stack on GaP/Si to a reference laser grown on GaAs substrate under incident pump power density of 18 W/cm^2. (b) RT light versus current comparisons of 2mm xy 20 µm broad area lasers without facet coatings on GaAs (blue) and GaP/Si (red). Five devices of each type are shown. (c) RT light-current-voltage curve for an HR/HR coated (95/55) 750x4 μm^2 laser with a threshold of 32 mA.

Narrow ridge waveguide lasers were fabricated using facet polishing of shorter cavities followed by high-reflection coating (95/55). Figure 1c shows room temperature light-current-voltage (LIV) measurements of a 750x4 μm^2 device with a 32 mA threshold and slope efficiency of 0.106 W/A. A plot of the threshold current versus ridge width for 68 different lasers with cavity lengths ranging from 750 to 1500 µm is shown in Figure 2a. The threshold decreases as expected for smaller cavities, with the lowest threshold being 30 mA. We hypothesize that the statistical scatter is mostly due to chipping of facet material from the high aspect ratio waveguides during the polishing process, as confirmed by visual inspection. Figure 2b demonstrates high temperature continuous wave operation of a longer device (1500x3.5 µm^2) up to 90^{o}C. Figure 2c shows a typical room temperature lasing spectrum. The lasing wavelength of 1280nm matches closely with the measured photoluminescence peak.

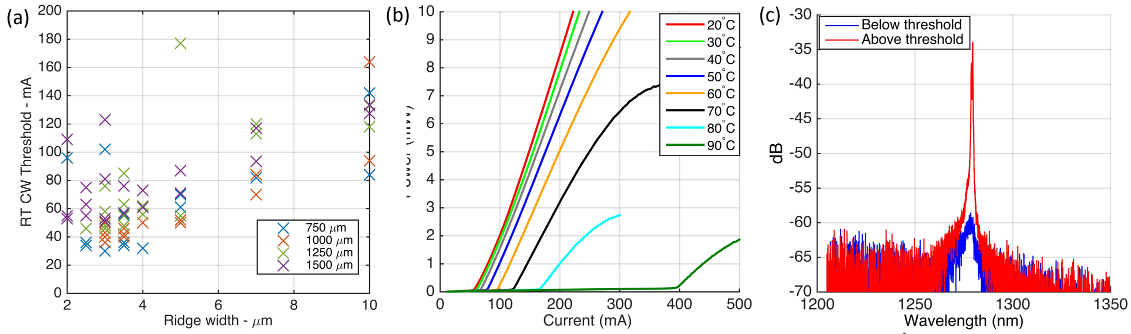

Fig. 2. (a) Threshold current for various cavity sizes. (b) Continuous wave lasing up to 90^{o}C by a 1500x3.5 µm^2 device. (c) Electroluminescence spectra near and above threshold at room temperature demonstrating ground state lasing at 1280 nm.

For application as an on-chip light source, these lasers may be subject to unwanted feedback due to process imperfections or interface reflections when integrated in a photonic integrated circuit. Due to highly damped relaxation oscillations and low α factors, quantum dot lasers should be more stable in the presence of optical feedback compared to quantum wells lasers. We compare relative intensity noise (RIN) of quantum dot lasers epitaxially grown on silicon to heterogeneously integrated quantum well lasers on silicon for different feedback levels in Figure 3. The low frequency RIN at 100 MHz for the quantum well laser shows up to a 30 dB increase with increasing feedback levels (Figure 3a). On the other hand, RIN for the quantum dot laser only increases by 10 dB within the same measurement range (Figure 3b). For a common RIN level of -135 dBc/Hz, the quantum dot laser requires 20 dB stronger feedback (-10 dB) compared to the quantum well laser (-30 dB).

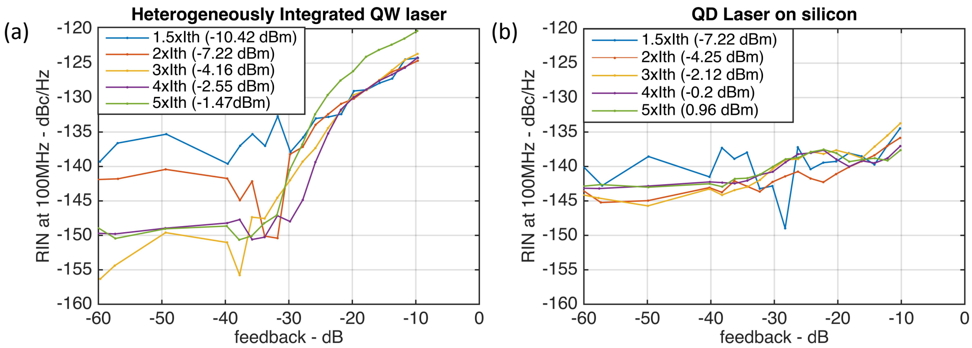

Fig. 3. RIN at 100 MHz versus feedback at five bias currents for a) a heterogeneously integrated quantum well laser on silicon with a 1.05 mm long gain section and 4 µm wide current channel. b) A 1mm long by 3 µm wide quantum dot laser on silicon.

4. CONCLUSION

We have presented the first electrically pumped continuous wave III-V quantum dot lasers epitaxially grown on on-axis (001) silicon without offcut or germanium layers. These devices show thresholds down to 30 mA, lasing to 90^{o}C, output powers up to 110 mW, and 20 dB higher tolerance to feedback compared to quantum well lasers. These results demonstrate the compatibility of high performance monolithic III-V light sources with foundry compatible silicon substrates, and their suitability for use as integrated on-chip light sources.

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