Electrically pumped continuous wave III-V quantum dot lasers epitaxially grown on exact GaP/Si (001)

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***Abstract* — We report room temperature continuous wave operation of electrically pumped III-V semiconductor lasers epitaxially grown on exact (001) GaP/silicon substrates without offcut.**

Keywords—quantum dot lasers, silicon photonics, heteroepitaxy, III-V on silicon

III-V quantum dot lasers epitaxially grown on silicon are proving to be a promising light source for silicon photonics, with the potential to be manufactured at scale with low cost [1-3]. To fully capture their added value, these lasers should be compatible with existing silicon CMOS foundry process flows to enable their integration with other photonic devices on a common silicon substrate. We and other groups have previously demonstrated high performance continuous wave quantum dot lasers epitaxially grown on silicon [2-3]. These past works utilized intentionally offcut silicon substrates to suppress antiphase disorder arising from the III-V (polar) on silicon (non-polar) heteroepitaxy, and as such are not compatible with standard silicon CMOS processing, which requires nominal (001) silicon. Thus, high performance III-V lasers on exact (001) silicon are needed. To this end, we have previously demonstrated optically pumped microdisk lasers on patterned (001) silicon [4]. We now report the first demonstration of an electrically pumped quantum dot laser operating at room temperature in continuous wave operation grown on exact GaP/silicon substrates without offcut.

The epitaxial laser stack was grown on a GaP/Si (001) template provided by NAsP III-V GmbH. The original template was a 775 µm thick (001) on-axis 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 metal organic chemical vapor phase epitaxy. An InAs quantum dot laser embedded in a GaAs/AlGaAs GRINSCH waveguide was then grown in MBE (see Fig 1). The active region consisted of seven stacks of InAs quantum dot layers (2.75 MLs deposited at 0.11 ML/s, VIII ratio of 35) embedded in 8nm $In_{0.15}Ga_{0.85}As$ quantum wells, which were separated by partially p-doped GaAs barriers. MBE growth temperatures were 500 °C for the active region and 590 °C for GaAs/AlGaAs as detected by a pyrometer. The same active structure was also grown on a GaAs substrate for comparison. Figure 2 a&b shows an AFM comparison of quantum dots on GaAs substrates versus on GaP/Si substrates, revealing similar morphologies. Figure 2c shows a photoluminescence (PL) comparison of the two as-grown laser structures: while the peak wavelength is similar between the two, the intensity of the laser on GaP/Si is ~60% that of on GaAs.

The as grown material was then processed into deeply etched lasers with varying stripe widths using standard dry etching and metallization techniques. The Ti/Pt/Au p-contact was deposited on top of the etched mesa and AuGe/Ni/Au n-contact metal deposited on the exposed nGaAs layers. Laser cavities were formed by cleaving for the lasers on GaAs, and dicing + polishing for the lasers on GaP/Si. Fig. 3a shows room temperature continuous wave (CW) light-current (LI) curves of 2mm long by 20 µm wide broad area lasers on GaAs (I_{th} = 190 mA) and on GaP/Si (I_{th}=345 mA), with no extra high reflection coatings applied to the facets. The laser on GaP/Si has a saturated output power (single facet) of 110 mW. Figure 3b shows typical room temperature CW lasing spectra measured from a device on GaP/Si, showing the evolution of a lasing peak near 1280nm past lasing threshold.

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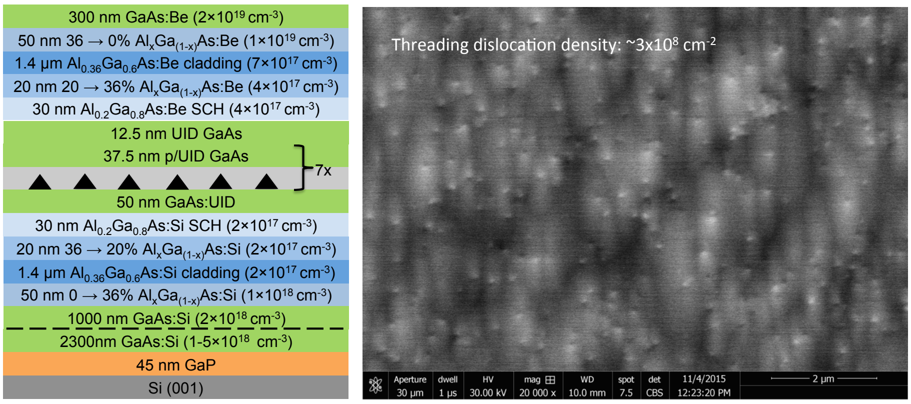

Figure 1. Left: Schematic of the as grown laser structure. **Right**: Electron channeling contrast imaging (ECCI) image taken at the surface of a GaP/Si template with 2300nm of GaAs grown on top (dashed line in left figure) revealing a threading dislocation density of ~$3x10^8$ cm^{-2}, the RMS roughness is > 5 nms.

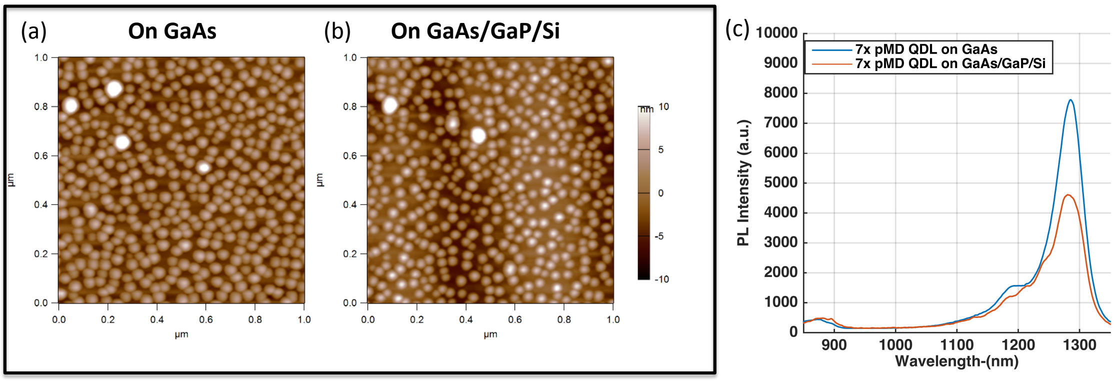

Figure 2. 1x1 μm^2 atomic force microscope (AFM) scans of InAs/GaAs quantum dots grown on **(a)** GaAs substrates and **(b)** GaP/Si substrates. **(c)** Room temperature photoluminescence comparison of QDs on GaAs vs GaP/Si under incident pump power density of 18 W/cm^2.

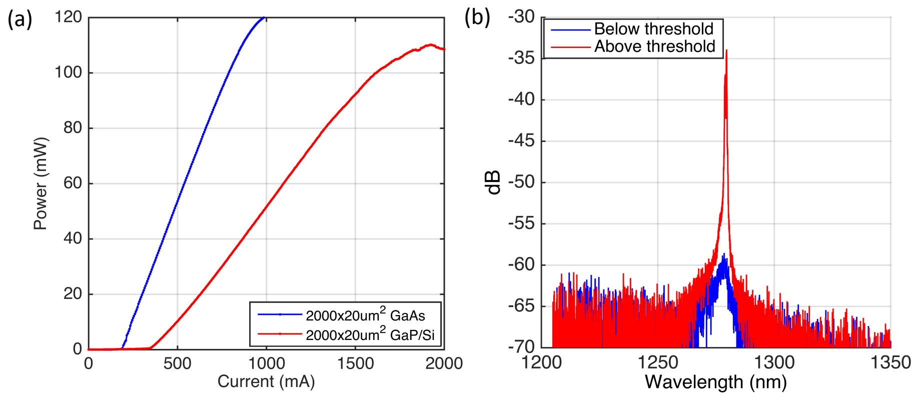

Figure 3 a, Room temperature CW LI curves of lasers on GaAs versus GaP/Si substrates. Threshold current (densities) are 190 mA (475 A/cm^2) for the laser on GaAs, and 345 mA (862 A/cm^2) for GaP/Si. **b,** Room temperature electroluminescence spectra below threshold (blue) and above threshold for a laser on GaP/Si, with a lasing wavelength of ~1.28 μm.