High performance InAs quantum dot lasers grown on on-axis (001) Si with low threading dislocation density

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InAs quantum dots (QDs) epitaxially grown on Si are promising for efficient, scalable, and reliable light source for Si-based photonic integrated circuits. The effective lateral carrier confinement in QDs makes themselves less sensitive to threading dislocations that inevitably occur from the growth of GaAs on Si. Most of the previous research on QD lasers on Si employed intentional off-cut (4-6 °) substrates to circumvent electrically active antiphase domains that arise at the polar/non-polar interface. To be fully compatible with CMOS foundries, on-axis Si substrates have been recently used via various growth techniques, but the QD laser performance has been considerably diminished mainly due to the high threading dislocation density (TDD).

In this work, we demonstrate high performance 1.3 μm quantum dot lasers epitaxially grown on on-axis (001) Si using molecular beam epitaxy [1]. Thermal cycle annealing and strained-layer superlattices were performed, and the TDD was reduced from ~3×10^{8} cm^{-2} to ~8×10^{6} cm^{-2} in the metamorphic GaAs buffer layer on Si. A sample with one QD layer for photoluminescence was grown, and a very small full-width at half-maximum of 28 meV was measured at room temperature (Figure 1-a). Uncapped QDs also revealed a highly homogeneous height distribution with a density of ~5.2×10^{10} cm^{-2}. The high quality GaAs/Si template enabled record-low threshold current of 6.2 mA (Figure 1-b) at 20 °C. Lifetime tests were performed at Intel Corp., and the devices revealed extrapolated mean-time-to-failure (double initial threshold current) of more than one million hours for CW operation at 35 °C, which is a record-long lifetime for any lasers grown on on-axis (001) Si.

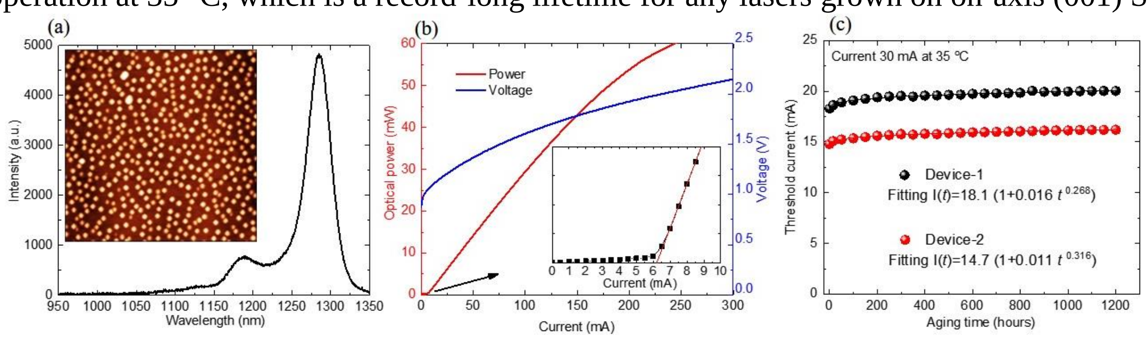

Figure 1 (a) RT PL spectra, and inset shows QDs from atomic force microscopy image. (b) light-current-voltage from a QD laser on Si. (c) Threshold currents vs. aging time.

[1] D. Jung, J. Norman, MJ Kennedy, C. Shang, B. Shin, Y. Wan, A. C. Gossard, J. E. Bowers, Appl. Phys. Lett. **111**, 122107 (2017).

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Supplementary Page

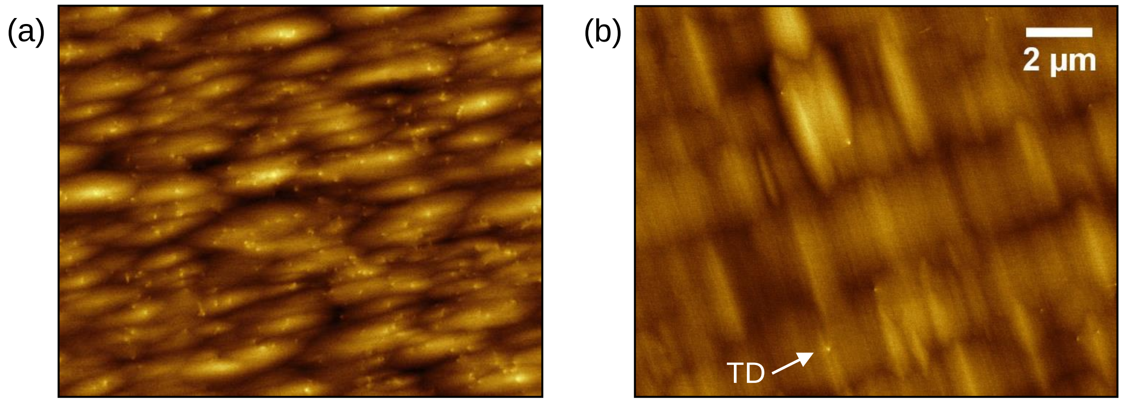

Figure 2 Electron channeling contrast images from (a) reference GaAs buffer and (b) optimized GaAs buffer grown on Si substrates. The two images have the same scale. The TDD is ~3×10^{8} cm^{-2} for the reference sample and 7×10^{6} cm^{-2} for the optimized one.

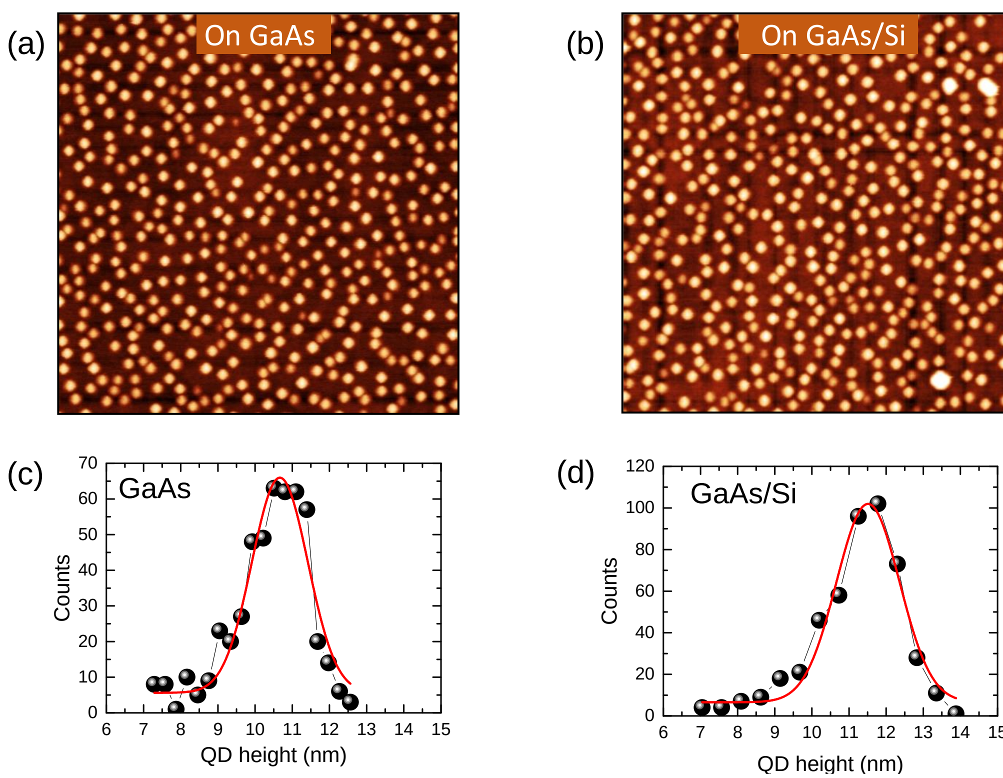

Figure 3 (a-b) show 1×1 μm^2 atomic force microcopy (AFM) images of InAs QDs grown on a native GaAs substrate and GaAs/Si template. The QD density is ~5.2×10^{10} cm^{-2} on GaAs and GaAs/Si both. Figure S1 (c-d) are the QD height distributions with Gaussian fittings. Note that the size distributions of the QDs grown on a GaAs wafer and GaAs/Si template are almost identical. The average height for GaAs sample is 10.7 nm with a standard deviation of 1.8 nm and for GaAs/Si template is 11.5 nm with a standard deviation of 2.0 nm.