1.3 μm quantum-dot micro-disk lasers directly grown on (001) silicon

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***Abstract* — We report growth and room temperature continuous wave operation of InAs quantum-dot microdisk lasers grown on nominal (001) silicon substrates. The active structure containing five layers of InAs/GaAs quantum dots was grown by MBE on a GaAs-on-v-grooved-Si (GoVS) template produced by MOCVD. Microdisk lasers with 4 μm diameters showed continuous wave lasing at room temperature with thresholds on the order of hundreds of microwatts. A statistical comparison with identical lasers on native GaAs substrates shows that average threshold values for the two cases are within 40% of each other despite four orders of magnitude difference in dislocation density.**

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

On-chip light sources on silicon are necessary to meet techno-economic requirements of low cost, high device/bandwidth density, and low power consumption for high volume applications such as data communication [1]. III-V integration on silicon by epitaxial growth is the de facto lowest cost solution compared to other methods such as flip chip bonding, die/wafer bonding, or external coupling [1, 2]. There has been significant research lately on III-V quantum dot lasers epitaxially grown on silicon, which can be efficient light emitters even given a high dislocation density [2, 3]. To meet the other requirements of low power consumption and high-density devices, quantum dot enabled micro/nanolasers are attractive due to their robustness against surface recombination currents that dominate at small device sizes, as well as much-reduced transparency/threshold current densities over quantum wells [2]. Here we report the room temperature continuous wave operation of optically pumped microdisk lasers with very compact size and low thresholds directly grown on (001) silicon for low cost manufacturing.

A GaAs buffer was first grown on v-groove patterned (001) silicon by an Aixtron AIX-200/4 MOCVD. The silicon substrate used was a nominal (001) wafer compatible with standard CMOS processing. A highly ordered, regular array of planar GaAs nanowires were first formed, and subsequently coalesced to form a standard planar film with a dislocation and stacking fault density of 10^8 cm^{-2}[3]. The remaining structure, comprising of a 1um GaAs buffer, a 600-nm $Al_{0.7}Ga_{0.3}As$ sacrificial layer, and a 500-nm disk region, was grown in a Gen II MBE system. The active region consisted of five 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 37.5 nm GaAs barriers and enclosed by outer 50 nm thick $Al_{0.4}Ga_{0.6}As$ barriers (see Fig 1). MBE growth temperatures were 505 °C for the active region and 600 °C for GaAs/AlGaAs as detected by a pyrometer. The same active structure was also grown on a GaAs substrate for comparison.

Microdisk lasers with 4 μm diameters were fabricated by dry-etching pillars on the as-grown epi and selectively etching the sacrificial $Al_{0.7}Ga_{0.3}As$ layer (see Fig 2). The fabricated devices were characterized in a surface-normal pump/collection micro-photoluminescence (μPL) system at room temperature. Fig. 3a shows a representative set of spectra measured from a 4-μm diameter micro-disk on silicon with progressively higher pump power from a 532 nm CW diode laser. A distinct lasing peak appears at 1308 nm and increases sharply in intensity, signifying the transition from spontaneous emission to lasing. Fig. 3d &e present the histograms of the lasing wavelength for each measured micro-disk on the GoVS template and GaAs substrate, respectively. The threshold for the micro-disk lasers on the GoVS template ranges from 130 μW to 410 μW, with an average value of 250 μW, approximately 1.4 times of the average value for lasers on the GaAs substrate (180 μW). The average threshold of micro-disk on GoVS corresponds to 50 μW per QD layer, comparable to the best-reported values for InAs QD micro-disk lasers with the same cavity size on GaAs in the literature.

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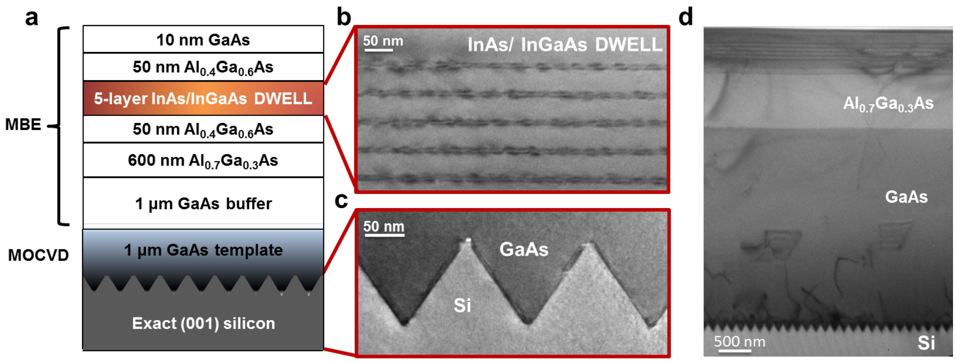

Figure 1. a, Schematic of the as-grown structure of micro-disk lasers. **b-d,** Cross-sectional TEM images of the quantum dots (b), V-grooved structure (c), and entire epi stack (d).

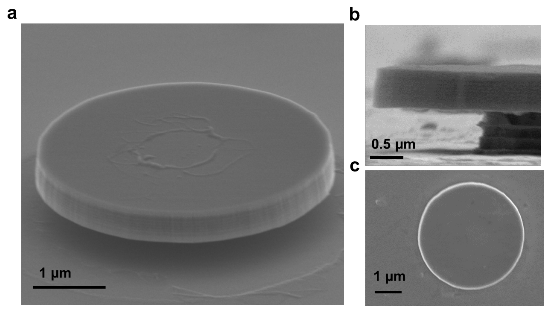

Figure 2. a, 70° tilted view of the disk. **b,** a zoom-in view of a 90° tilted SEM image of a fabricated microdisk, revealing smooth sidewall. **c,** top-down view of the disk, showing circularity.

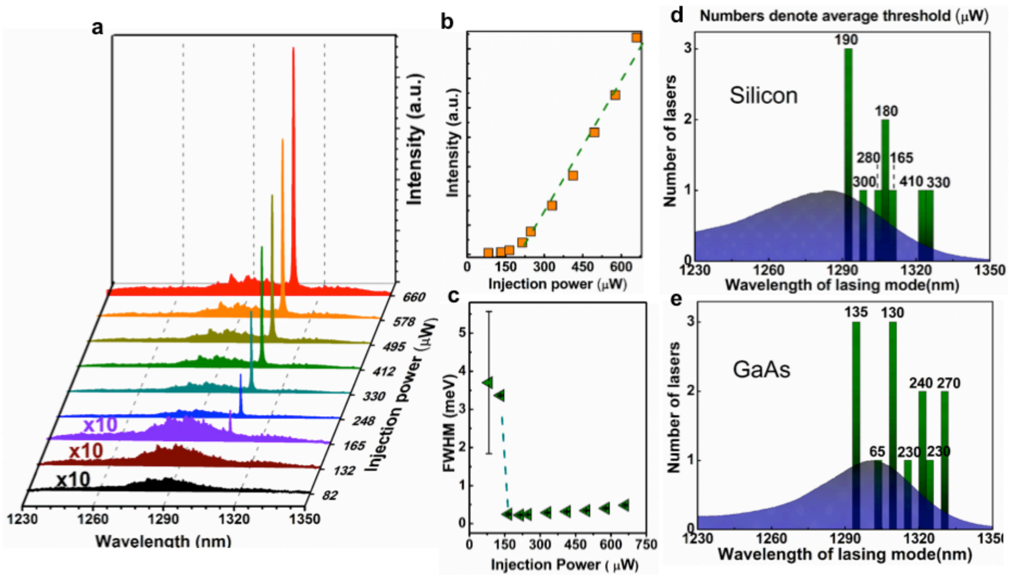

Figure 3 a, RT PL spectra of a microdisk on silicon taken at increasing pump powers. **b, c,** Integrated photoluminescence intensity (b) and linewidth (c) of the dominant mode as a function of pump power for the device in (a). **d, e,** Histograms of the lasing wavelength for all measured devices on Silicon (d) and GaAs (e), respectively. The average lasing threshold of the devices within each histogram bar is denoted by the number displayed on top of it. The normalized photoluminescence spectra of the un-processed sample are superimposed in blue.