1-μm InAs quantum dot micro-disk lasers directly grown on exact (001) Si

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Abstract: *Capitalizing on our novel epitaxial processes, we demonstrate subwavelength micro-disk lasers as small as 1 μm in diameter on exact (001) silicon substrates. Under continuous wave optical pumping at 10 K, low thresholds down to 35 μW were obtained together with a high spontaneous emission factor of 0.3.*

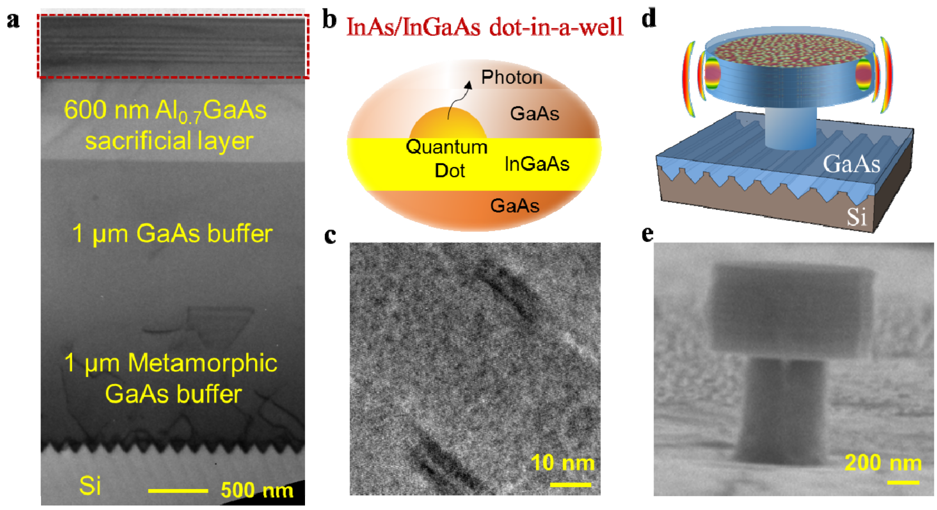
Keywords: *subwavelength, microdisk laser, III-V heteroepitaxy*

1. Introduction

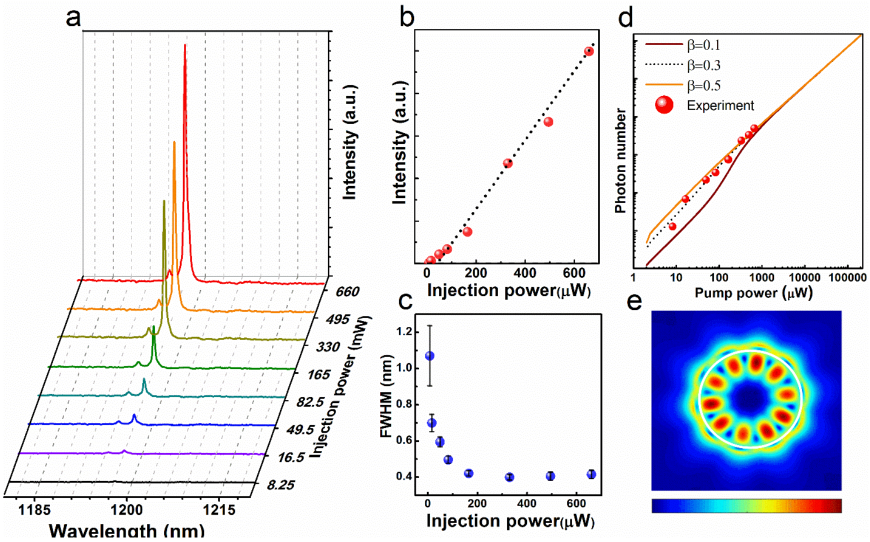
Similar to the scaling of transistors, miniaturization of efficient, compact and integrable laser sources on the well-established complementary metal–oxide–semiconductor (CMOS) platform can lead to numerous applications. The recent reported high-performance quantum dot (QD) lasers grown on Ge-on-Si and directly on Si substrates forecast the feasibility and enormous potential for on-chip lasers.[1,2] However, the current focus has been primarily placed on the realization of conventional laser performance on silicon. For power considerations, micro-fabricated whispering gallery mode cavities offer unique advantages in high quality factor, small footprint, low threshold and low power consumption[3]. However, shrinking the size to subwavelength scale is very challenging due to the high radiation loss and limited gain medium. Situation gets more serious for GaAs related materials which possess a high surface recombination velocity. As a result, there are only limited reports of micron-scale lasers on GaAs substrates.[4] To our knowledge, no lasers on Si in the scale of subwavelength has ever been reported, either by bonding or direct epitaxy.

2. Technical Work Preparation

In this work, we start with a high crystalline quality GaAs-on-Si template without any Ge related absorptive buffers or offcut angle using metal-organic chemical vapor deposition (MOCVD).[5,6] A typical five-layer InAs/InGaAs dot-in-a-well (DWELL) structure overgrown on the template by molecular beam epitaxy (MBE) was adopted as active region.[7]



A schematic illustration of the epitaxial layers and QDs active region are shown in Fig. 1(a) and Fig. 1(b) respectively. A high resolution transmission electron microscope (TEM) image in Fig. 1(c) reveals the typical dot size, which has a diameter of ~21 nm and height of ~6 nm. By combing the colloidal lithography, dry-etching and subsequent wetetching, micro-disk lasers (MDLs) were fabricated with straight vertical etching profile, smooth sidewall surface, and circular shape. A schematic of the device is shown in Fig. 1(d), and a 90° tilted scanning electron microscope (SEM) image of a fabricated disk can be seen in Fig. 1(e).



Using a micro-photoluminescence (μPL) system in a surface-normal pump/collection configuration, subwavelength MDLs as small as 1 μm in diameter were demonstrated with low thresholds down to 35 μW at 10 K. The typical lasing spectra with progressively higher optical pumping is presented in Fig. 2(a), a distinct peak at 1197 nm began to appear at the pump power of 16.5 μW. The peak increased sharply in intensity and sharpened once the threshold was exceeded, which is a clear sign of lasing. Lasing behavior was further evidenced by the clear kink in the light-out/light-in (LL) curve shown in Fig. 2(b), and narrowing of the linewidth presented in Fig, 2(c). Threshold was extracted to ~35 μW. In Fig. 2(d), The spontaneous emission factor (β) was extracted to be 0.3 by fitting the experimental data to a semiconductor cavity-QED model.[8] In Fig. 2(e), the lasing mode was identified to be $TE_{1,5}$ according to finite-difference time-domain (FDTD) simulation.

3. Conclusion

To conclude, ultra-small microdisk lasers down to subwavelength scale has been direct integrated on commercial compatible silicon substrates. The small power consumption together with the small footprint mark a major advancement towards fully integrated silicon photonics for on-chip optical communications.

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