InGaAs Quantum Dot Microtube Nanoscale Lasers on GaAs and Si

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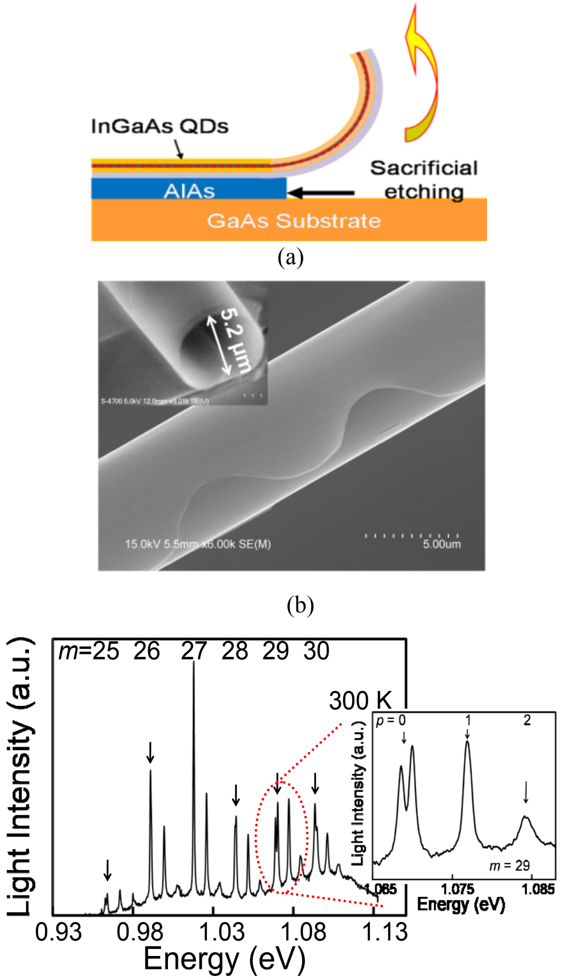
A critical, yet missing technology for future chip-level optical communications is a high performance and highly reliable laser on Si. Conventional III-V semiconductor lasers on Si have been limited, to a large extent, by the generation and propagation of dislocations. We have recently developed free-standing InGaAs/GaAs quantum dot (QD) microtube coherent light sources that may fundamentally eliminate such problems. Such microtubes are formed by self-rolling of coherently strained InGaAs/GaAs QD heterostructures through controlled release from their host substrates [1-3]. We have achieved, for the first time, coherent emission from single rolled-up QD microtubes on Si, with emission wavelengths in the spectral range of 1.1 ~ 1.3 μm and an intrinsic linewidth of less than 0.5 nm. Moreover, we have demonstrated that the 3-dimensionally confined optical modes can be exactly tailored by varying the microtube geometry.

The InGaAs/GaAs QD heterostructure consists of a 20 nm $In_{0.18}Ga_{0.82}As$ and 30 nm GaAs layer as well as two $In_{0.5}Ga_{0.5}As$ QD layers embedded in the GaAs matrix. Microtube formation was initiated with the selective etching of the AlAs sacrificial layer, due to the relaxation of strain in the InGaAs/GaAs bilayer (Fig. 1(a)). The SEM image of a QD microtube on GaAs is shown in Fig. 1(b). The measured tube diameter, shown in the inset of Fig. 1(b), is ~ 5.2 μm. Such microtubes can be subsequently transferred on Si substrates using a recently developed substrate-on-substrate transfer technique [3].

Emission characteristics of InGaAs/GaAs QD microtubes were studied using micro-photoluminescence spectroscopy at 300 K. A typical emission spectrum under an excitation power of 30 μW is illustrated in Fig. 1(c). There are six groups of eigenmodes, with the lowest energy mode in each group arising predominantly from optical resonance around the tube periphery. The corresponding azimuthal numbers (m = 25 to 30) are shown in Fig. 1(c). Additionally, associated with each azimuthal mode m is a group of optical resonance modes with different axial field distributions (inset of Fig. 1(c)), which are directly related to light localization along the tube axis due to the presence of corrugations (Fig. 1(b)). Evidently, by varying the tube geometry, an exact tailoring of the 3-dimensionally confined optical modes can be achieved. A minimum intrinsic linewidth of ~ 0.4 nm is derived, corresponding to a Q-factor of ~ 3,000. It is important to note that such a relatively high Q-factor is achieved in a single wall microtube, with a wall thickness of merely ~ 50 nm.

Detailed characterization and analysis of the 3-dimensionally confined optical modes, as well as the achievement of electrically pumped nanoscale coherent light sources on Si, will be presented.



(a)

(b)

(c)

Fig. 1 (a) Illustration of the formation of InGaAs/GaAs QD microtubes; (b) SEM image of a QD microtube and the cross-sectional view (inset); (c) Emission spectrum of a freestanding QD microtube at an excitation power of ~ 30 μW at room tempeature. A detailed view of the eigenmodes assoicated with azimuthal mode number m = 29 is shown in the inset, wherein the axial mode numbers (p) are also identified.

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