Red-emitting InGaN/GaN Quantum Dot Laser

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While high performance InGaN/GaN quantum well (QW) lasers have recently been demonstrated emitting in the shorter wavelengths of the visible spectrum (blue and green), longer (red-emitting) lasers have yet to be demonstrated in this material system. InGaN/GaN quantum dots (QDs) have important advantages over similar QWs in the context of laser performance including: stronger confinement and better electron/hole wavefunction overlap, smaller piezoelectric field and resulting quantum confined Stark effect (QCSE), and reduced recombination at dislocations due to spatial confinement of carriers [1,2]. We have recently demonstrated the first InGaN/GaN QD visible laser [3] with an emission wavelength in the green range (524 nm). The broad area laser was characterized by J_{th}=1.2 kA/cm^2 and a QCSE-induced peak shift of only 5nm in the emission peak from spontaneous emission to the peak of the lasing spectrum. Additionally, these nitride based lasers have excellent temperature stability, compared with other material systems emitting at long visible wavelengths[4]. We have measured T_0=233 K in these green emitting devices. We have also recently demonstrated lasers emitting at various other visible wavelengths, including in the blue (420 nm) [5]. Here we demonstrate, for the first time, a red-emitting (λ=635 nm) laser in the nitride system using InGaN/GaN QDs.

The red emitting QD laser heterostructure, shown schematically in Fig. 1(a) is grown on c-plane bulk GaN substrates having a defect density of ~1x10^5 cm^{-2} by plasma-assisted molecular beam epitaxy (PA-MBE). The GaN, AlGaN, and InGaN layers were grown at 740^{o}C, 770^{o}C and 590^{o}C, respectively, while the QDs were grown at 530^{o}C. The inset to Fig. 1(a) shows an atomic force microscopy image of an uncapped $In_{0.32}Ga_{0.68}N$/GaN QD layer, showing a dot density of 3 x 10^{10} cm^{-2}. X-ray diffraction measurements were done on a half laser sample (with the heterostructure grown through the quantum dot layers), as shown in Fig. 1(b), to determine the composition of the bulk $Al_{0.07}Ga_{0.93}N$ and $In_{0.02}Ga_{0.98}N$ layers, and also show strong superlattice peaks from the InGaN/GaN active region. To compensate for the reduced optical confinement at longer wavelengths due to the smaller index difference in the AlGaN/GaN heterostructure, $In_{0.18}Al_{0.82}N$ (lattice matched to GaN) was incorporated into the laser heterostructure. Material structural and optical characterization of the various layers will be presented.

Ridge waveguide lasers were fabricated with the facets cleaved along the m-plane. The facets were coated with dielectric DBRs (TiO_2/SiO_2) to enhance the facet reflectivity to ~0.7 and ~0.95 on each facet, respectively. Light-current characteristics are shown in Fig. 2(a) for a laser emitting at 635 nm, with a cavity length and width of 5 μm and 1 mm, respectively. The device has a threshold current density of 2.5 kA/cm^2, and was operated under continuous wave (CW) bias. The electroluminescence spectrum is shown in Fig. 2(b) at both 0.3 J_{th} and 1.1 J_{th}. The spectrums shows a QCSE induced peak wavelength shift of 11.6 nm, as shown in Fig. 2(c), which is significantly smaller than similar QW lasers at shorter wavelengths [6]. The peak modal gain is measured to be 35 cm^{-1} using Hakki Paoli [7] measurements, shown in Fig. 3(a) Light-current characteristics were performed on lasers of varying cavity lengths ranging from 0.6 to 1.6 mm. Figures 3(b) and (c) show the variation of η_d^{-1} with cavity length, and the variation of the measured J_{th} with inverse cavity length, respectively. From these measurements, an internal quantum efficiency of 36% and a differential gain of 2.2x10^{-17} cm^2 are calculated.

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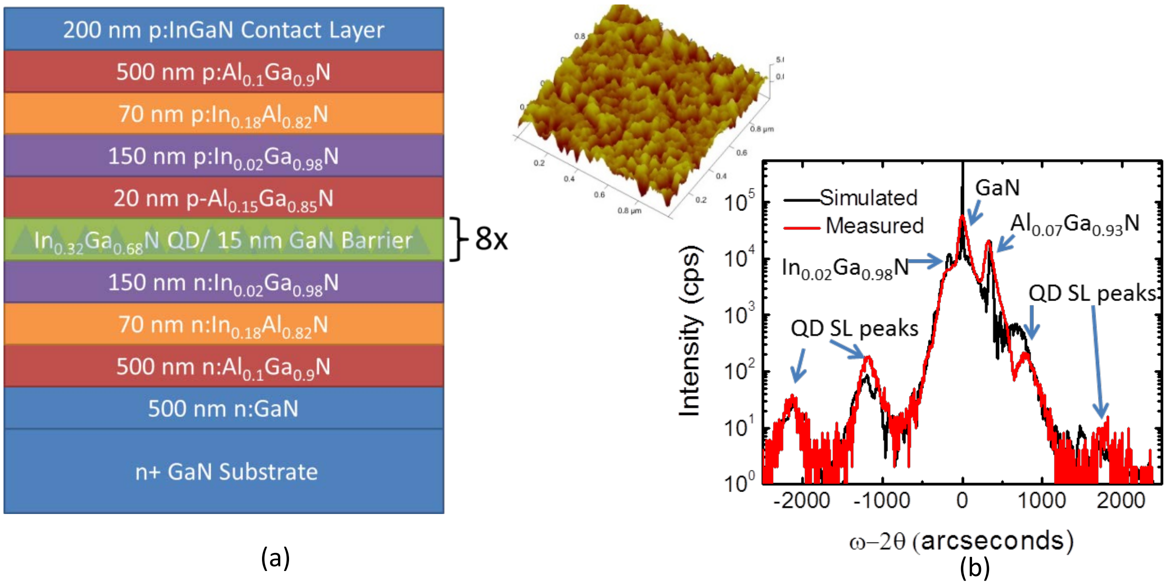

Figure 1 (a) Laser heterostructure incorporating the red emitting quantum dots, with an AFM of the dots shown in the inset; (b) XRD of the half-laser structure with simulated fit of the XRD.

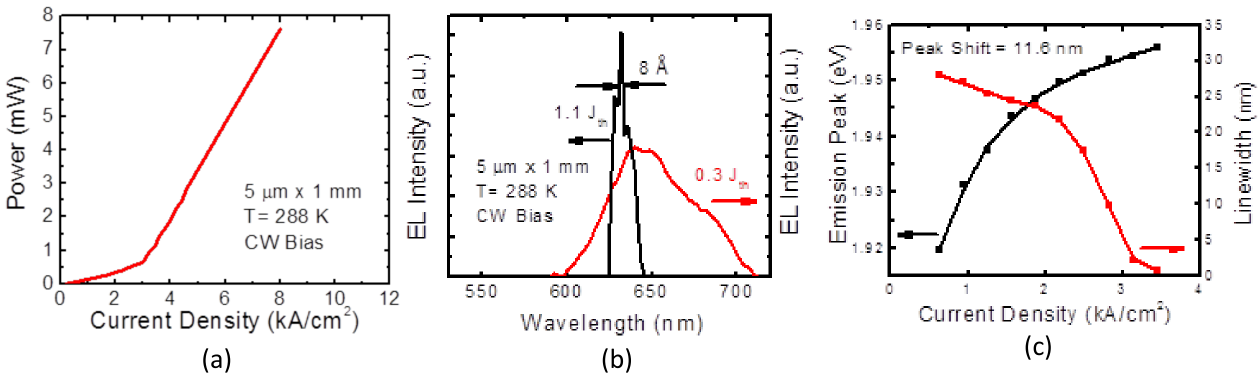

Figure 2 (a) Light-current characteristics of the red-emitting laser; (b) device spectrum above and below threshold; and (c) peak emission shift and linewidth with injection

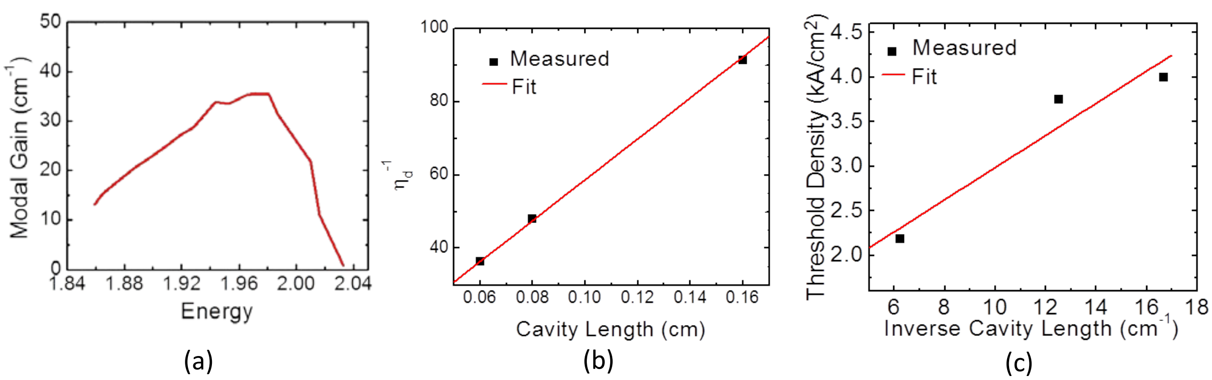

Figure 3 (a) Modal gain measured using the Hakki Paoli technique (b) dependence of η_i^{-1} with cavity length and (c) dependence of J_{th} with inverse cavity length.