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MBE Growth of High Power Quantum Dot Superluminescent LEDs

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Abstract: - In this paper we demonstrate record high output powers for 1.3μm quantum dot superluminescent diodes through an improvement in growth conditions. Such devices exhibit 40mW CW output powers with emission bandwidths of 21nm.

Introduction: -

Superluminescent LEDs (SLEDs) are of growing interest for applications requiring a high output power and broad emission band. Application of significant interest is Optical Coherence Tomography, which requires high output power (>10mW) for millimetre range penetration depth [1]. Operating wavelengths of 1050 nm and 1300 nm are required corresponding to the minimum in dispersion and loss for skin tissue, respectively. The growth of high quality, long wavelength QD structures is technologically difficult as InAs QDs are typically grown at a low temperature, and in order to achieve long wavelengths low temperature InGaAs barrier layers capping the QDs are required (DWELL, dot –in-well). Previously we reported low threshold current density, 1.31μm InAs/GaAs QD lasers incorporating a high temperature growth step for GaAs barrier layers separating the DWELLs [2]. In this paper we present improved growth parameters for high power QD SLEDs, where the thickness of the low temperature GaAs following DWELL deposition is reduced from 15 nm to 2nm in thickness. We demonstrate a ~4 fold increase in SLED CW output power leading to 40mW output powers with a spectral linewidth of 21nm at 1A drive current. This correlates with a concomitant reduction in the threshold current density (J_{th}) of laser diodes, and a reduction in reverse leakage current and increase in breakdown voltage for mesa diodes.

Device Growth and Fabrication: -

For both of our devices optical confinement was achieved using 1500nm $Al_{0.4}Ga_{0.6}As$ cladding layers. The DWELL layer consisted of 3.0 monolayers (MLs) of InAs grown on 2nm of $In_{0.15}Ga_{0.85}As$ covered by 6nm of $In_{0.15}Ga_{0.85}As$. Seven InAs/InGaAs DWELLs were separated by 50nm GaAs barriers and embedded between 150nm separate confinement hetero-structure GaAs layers. The DWELL layers were delta p-doped with 12 Be acceptors per QD. To reduce the detrimental effects associated with the low growth temperature we utilised two indium cells [3]. Areal dot density of $3.5\text{x}10^{10}\text{cm}^{-2}$ per layer was measured by atomic force microscopy on uncapped structures. A VG Semicon V90H molecular beam epitaxy system was used to grow the SLED structures on a Si doped GaAs (110) substrate. We investigated two samples, for both structures the growth temperatures were T_{growth}= 620°C for the AlGaAs and T_{growth}=510°C for the In containing layers. The samples differed only in the temperature ramp of the barrier layers between DWELL layers. One structure incorporated our standard low temperature GaAs barrier layer (SLTBL) utilised for 1.3 μm laser structures (15nm T_{growth}=510°C, 35nm T_{growth}=620°C), and the other with a thin low temperature barrier layer (TLTBL) (2nm T_{growth}=510°C, 48nm T_{growth}=620°C). The SLED ridges were tilted by 8^0 from the normal to the as-cleaved facet. The results shown here are for SLED ridges, which are 15μm wide. CW and pulsed measurements showed similar trends, though CW results are described here.

Result and Discussion: -

Figure 1 shows the room temperature CW current-power response for SLTBL and a TLTBL SLED devices of cavity length 8mm. At all current densities the plot shows ~4 fold increase in output power for the TLBTL SLED compared to the SLTBL SLED at room temperature. The "threshold" current for superluminescence is observed to be smaller for the TLTBL sample than the SLTBL device. For an injection of 1Amp CW current the TLTBL SLED gives an output power over 40mW and a spectral bandwidth of 21nm. Figure 2 shows the leakage current as a function of reverse bias voltage plot for mesa diodes of 50μm radius. At all reverse biases the leakage current is lower for the TLTBL compared to that of SLTBL; also the reverse breakdown voltage is higher for the TLTBL material. This is indicative of device quality and is attributed to the existence of fewer defects.

Threshold current densities of SLTBL and TLTBL laser devices are plotted as a function of reciprocal cavity length in Fig. 3. For all lengths the threshold current density is lower for the TLTBL lasers, which yields very low transparency current density (J_0) for TLTBL. The possible explanation for this behaviour is either a more efficient use of injected carriers, which indicates high internal quantum efficiency (η_d) or a longer carrier lifetime. η_d measured for TLTBL and SLTBL lasers are ~80% and ~40% respectively.

Figure 4 shows the CW room temperature electroluminescence spectra for both types of devices. At low carrier densities FWHM of 26nm and 22 nm are measured for the SLTBL and TLTBL devices respectively. The ground state peak emission wavelength for the TLTBL device is 1267nm whereas that for the LBTL is 1315nm. The blue shift in emission wavelength is attributed to annealing of the QDs during growth, leading to a reduction in indium composition within the QDs due to out diffusion of indium into the barrier.

Conclusion: -

In conclusion, we have demonstrated the effect of the growth parameters on the output power of QD SLEDs. By reducing the thickness of the barrier layer that is grown at low growth temperatures, a significant increase in output power is observed, at the expense of a shift in the emission wavelength. This phenomena correlates with a reduction in J_0 for lasers and reduced reverse leakage current. We shall discuss the origin of this improvement and strategies for retaining true 1.3µm emissions.

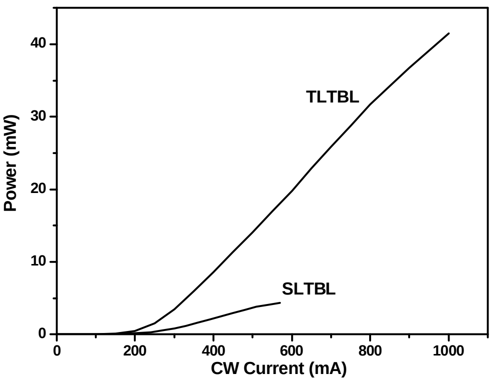

Fig 1. Room temperature Light-Current response for 8mm long 15µm wide TLTBL and LBTL SLED.

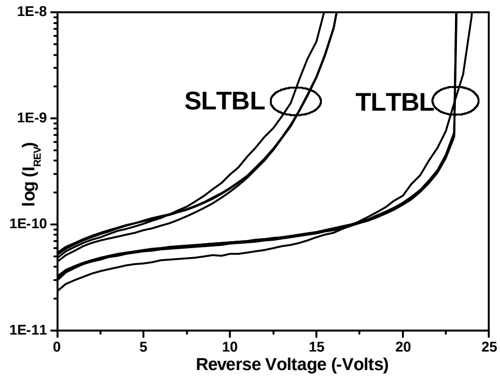

Fig 2. Leakage current plot as a function of the reverse bias voltage as a function of reverse voltage.

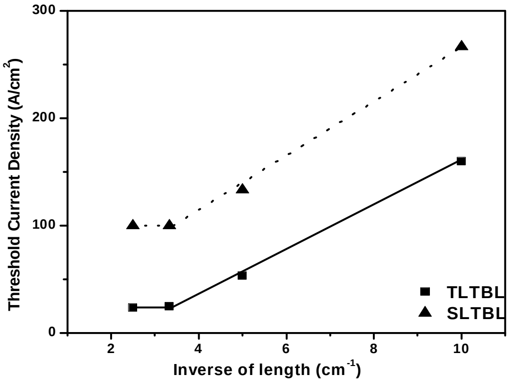

Fig 3. Threshold current densities for TLTBL and SLTBL lasers plotted as a function of reciprocal cavity length.

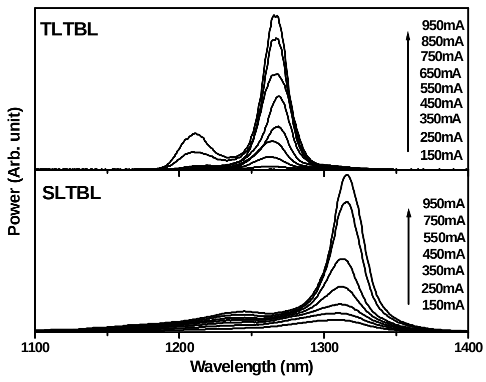

Fig 4. Electroluminescence spectra for a TLTBL and a LBTL SLEDs as a function of CW injection current.

References: -

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