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Excited State Bilayer Quantum Dot Lasers at 1.3μm

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1. Introduction

Over recent years, considerable effort has been invested in developing 1.3 μm lasers based on InAs/InGaAs quantum dots (QDs) to the point of their current commercialization [1-3]. One of the main application areas is in optical communications. For GaAs based QD heterostructures, many of their attractive features (low cost, zero chirp, temperature insensitivity, and single photon emission) are particularly attractive at 1550nm. There is therefore continuing effort in extending the emission wavelength to this region. QD bilayers have been proposed as a route to achieving this. In the bilayer structure, two coupled (electronically *and* strain) QD layers allow the independent control of density (first "seed" layer), and emission wavelength (second QD layer). Each of the two QD layers may be grown under different conditions, with strain interaction from the smaller QDs in the seed layer fixing the QD density in the larger QDs of the second layer. The second layer may be grown at lower temperature with a slow deposition rate to achieve long wavelength emission [4, 5].

By contrast to quantum well lasers, the modulation dynamics of QD lasers is dominated by damping [6]. In order to achieve high modulation rates, low carrier scattering times to the lasing state and high saturated modal gain of the QDs is required. It has recently been demonstrated that the excited state of QDs exhibit much higher damping limited bandwidths as compared to ground-state lasers [7]. This enhancement was attributed to higher saturated gain (double) and lower scattering time (half) as compared to the ground state (GS). This is of course at the expense of higher operating currents. However, in that report the ground state emission was ~1.3 μm whilst the excited state (ES) was at 1.2 μm making such excited state QD lasers impractical for optical communications applications.

In this paper we report on the fabrication of QD bilayer materials where excited state lasing is demonstrated between 1.26 μm and 1.33 μm. This is achieved by using QD material consisting of 5x bilayer QDs with GaAs caps and 5x bilayer QDs with InGaAs cap layers. In addition to laser characterization, detailed analysis of the laser material and comparison to commercial QD material operating with ground-state emission at 1.3 μm is provided by multi-section laser characterization and detailed I-V measurements both in forward and reverse bias.

2. Experiment

The laser structures described here are shown schematically in Fig. 1. Growth was carried out on n+ GaAs(100) substrates by MBE and is described in detail elsewhere [4]. The active region for all structures was located in a 500nm undoped GaAs layer sandwiched between 1500nm $Al_{0.33}Ga_{0.67}As$ cladding layers. A 400 nm p-type GaAs:Be contact layer was grown to complete the laser structure. The active region of the bilayer structure consists of five GaAs capped QD bilayers. We refer to this sample as the "GaAs capped bilayer" sample in the following. Each bilayer consists of a seed layer of QDs and a top emission layer. The areal density of these structures was 2.7 x 10^{10} cm^{-2}. The second structure discussed is identical to the GaAs capped bilayer sample except the top emission layer (second QD layer) is capped by 4 nm of $In_{0.18}Ga_{0.82}As$ before subsequent GaAs growth. We term this as the "InGaAs capped bilayer". Figure 2 shows normalised photoluminescence (PL) spectra from GaAs and InGaAs capped bilayer test samples. Ground state emission is observed at 1.35 μm (1.45 μm), and excited state emission at 1.26 μm (1.33 μm) for the GaAs capped (InGaAs capped) sample. Wafers were processed into broad area lasers for the multi-length analysis and multi-section devices for the variable stripe analysis [8]. Characteristics were measured

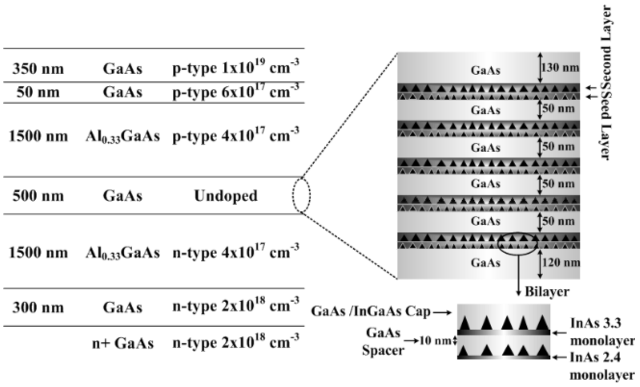

Fig. 1. Schematic Diagram Bilayer QD laser structures.

in pulsed regime (5µs pulsed duration, 1% duty cycle) to minimise thermal effects. All measurements were performed at a tile temperature of 300K.

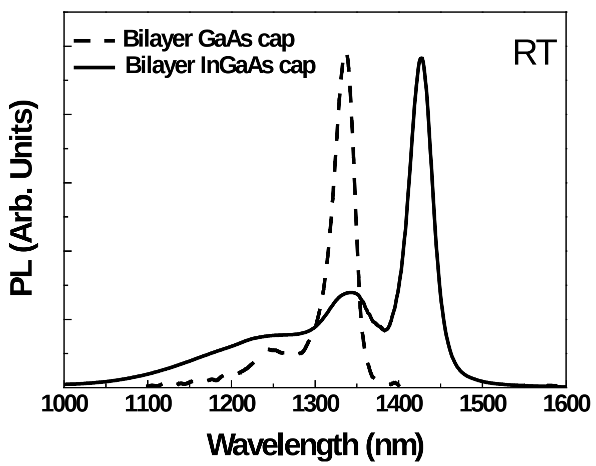

Fig. 2. Photoluminescence spectra from GaAs and InGaAs capped QD bilayer test samples.

Figure 3 shows electroluminescence (EL) spectra at room temperature for both sets of material at $1.2I_{th}$. The lasing from the excited state (ES1) is at 1.26 µm for the GaAs capped bilayer sample, and 1.33 µm for the InGaAs capped bilayer sample. EL peaks of the GS are ~30 dB lower in intensity than the lasing emission at these currents.

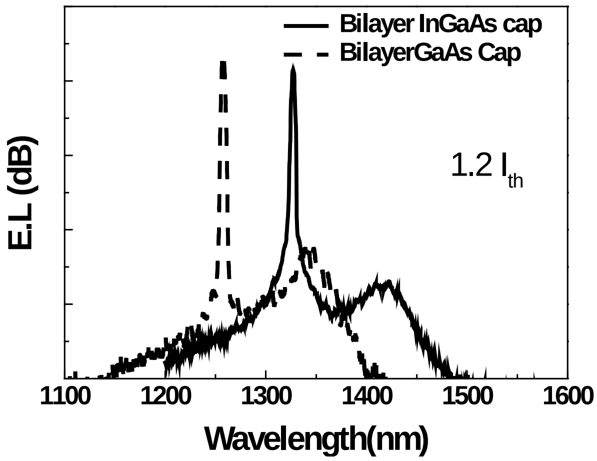

Fig. 3. Lasing spectra at $1.2I_{th}$ for 1 mm GaAs capped and 6mm InGaAs capped bilyar structures.

The gain spectrum may be determined as a function of current density by using multi-section devices. Figure 4 plots the peak modal gain of the excited state for both samples as a function of current density. The saturated gain for the GaAs and InGaAs capped bilayer samples are 18 and 12 cm^{-1}, respecitively. We note that the InGaAs capped bilayer sample demonstrated higher internal loss than the GaAs capped sample. The modal gain per QD of the GS and ES of the GaAs capped sample compares very favourably with commercial QD material operating at 1.28 µm. In addition to optical properties of the bilayer QDs, further comparison to conventional commercial QD material will be made through forward and reverse bias IV characterization.

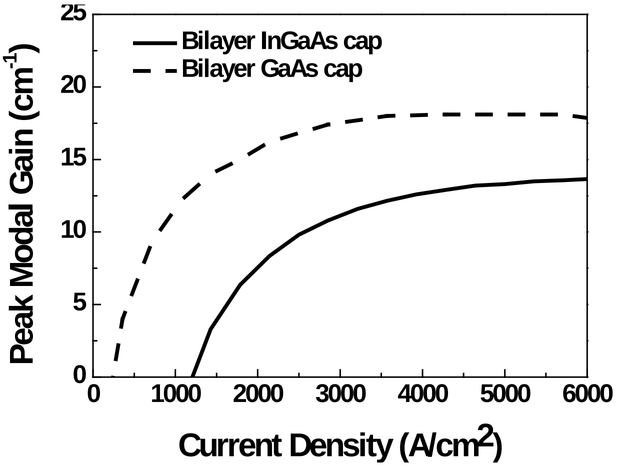

Fig. 4. Peak excited state gain for GaAs capped InGaAs capped bilayer structures obtained by multi-section gain measurements.

3. Conclusions

We present the realization of excited state QD lasers in the 1.31 µm region. GaAs capped and $In_{0.18}Ga_{0.82}As$ capped bilayer samples exhibit excited state lasing at 1.26 µm and 1.33 µm, respectively. This offers the opportunity for ultra-high modulation bandwidth GaAs based QD lasers. These materials allow the extension of GaAs based QD ground-state operating wavelengths to 1.45 µm, offering full coverage in the O and E-band.

Acknowledgements

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