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Strain balancing of MOVPE InAs/GaAs quantum dots using $GaAs_{0.8}P_{0.2}$

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Abstract: *MOVPE growth of stacked InAs/GaAs QDs with and without $GaAs_{0.8}P_{0.2}$ strain balancing layers has been studied. The GaAsP layers reduce the accumulated strain whilst maintaining the electrical characteristics. This should enable closer stacking of QD layers leading to higher gain and improved laser performance.*

1. Introduction

Self-assembled InAs/GaAs quantum dots (QDs) have been studied intensively for a range of opto-electronic devices where high volumetric gain/absorption is required. The areal QD density is therefore an important factor, with state-of-the-art MBE grown structures exhibiting densities of $6x10^{10}cm^{-2}$. However, in conventional devices, accumulated strain limits the spacing between subsequent QD layers to ~35nm. Strain balancing enables closer vertical stacking of QD layers and provides a route to increase the volumetric density and device gain. However, this needs to be achieved without affecting the electrical and optical characteristics. Mesa diodes and broad area lasers were fabricated and tested electrically and optically. Transition electron microscopy (TEM) was used to give structural information.

2. Experimental Results and discussion

Self-assembled QD samples were grown by MOVPE on 2" GaAs (100) (3° Si n-doped) substrates. p-i-n devices with and without 5nm $GaAs_{0.8}P_{0.2}$ strain balance layers were grown for spacer thickness of 50, 30 and 20nm and five QD layers. X-ray diffraction analysis confirms that strain balancing is achieved for the samples with $GaAs_{0.8}P_{0.2}$. Wafers were fabricated into mesa diodes for optical access. Laser structures with nominally identical design, except for thicker (1.5μm vs 150 nm) $Al_{0.42}Ga_{0.38}As$ cladding layers, were fabricated into broad area devices.

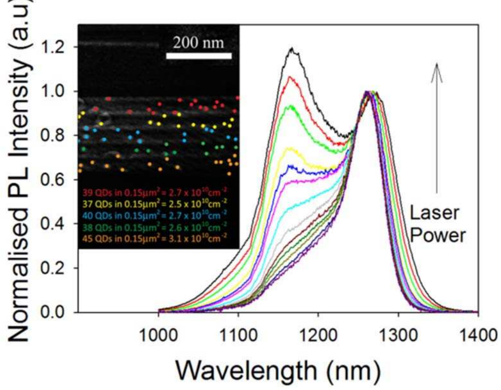

Fig 1: Room temperature power dependent PL. Fig 1(inset): Tilted TEM image.

Figure 1 shows room temperature normalised power dependent photoluminescence of a sample with 50nm separation between the QD layers. Ground state and excited state emission is observed at 1.27 and 1.165μm respectively. A relatively large state separation of 88meV is observed with a narrow inhomogeneous linewidth of 54meV. The inset to figure 1 shows a tilted TEM image. The inter-layer QD density varies from $2.5\text{-}3.1x10^{10}cm^{-2}$.

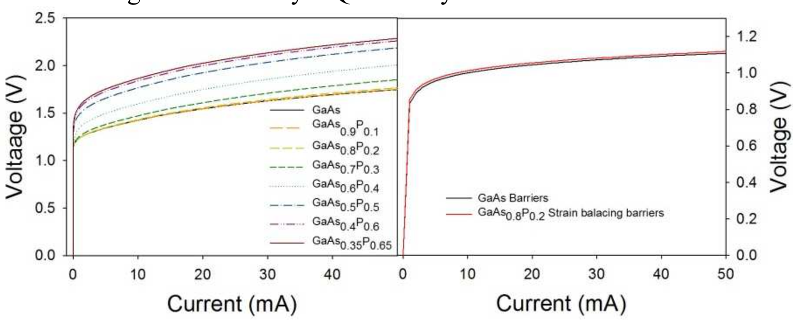

Fig 2(a): Modelled IV characteristics for varied phosphorus percentages. Fig. 2(b): Room temperature IV for a QD mesa diode.

Although the current MOVPE QD density is less than the best reported MBE value a critical advantage of MOVPE is the ability to grow As-P combinations allowing the introduction of Ga(As)P strain balancing layers to enable closer stacking and/or increased layer number. Other research groups have used GaP but this has a detrimental effect on the IV characteristics. [1] Figure 2(a) shows modeled IV characteristics for a double 7.6nm $In_{0.19}Ga_{0.81}As$ QW emitting at 0.98µm. A 5nm GaAsP barrier layer is placed between the two QWs. As the phosphorous content is increase from 0 to 20% there is no observable change in the IV characteristics. However, further increase from 20-65% results in significant degrading in the IV characteristics; both a higher turn-on voltage and increased internal resistance. Hence we have opted to achieve strain balance using $GaAs_{0.8}P_{0.2}$ layers. Figure 2(b) shows room temperature IV characteristics for a mesa diode with and without $GaAs_{0.8}P_{0.2}$ strain balancing layers. Minimal difference is observed supporting the conclusions of the modelling.

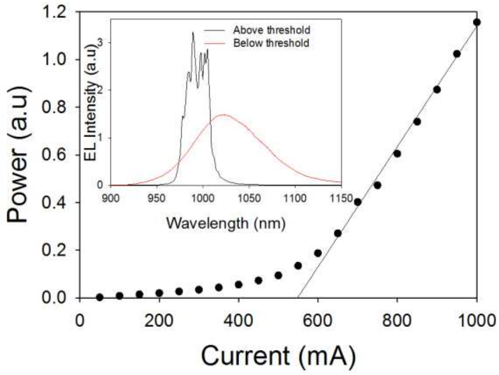

Fig 3: 50K power versus current of 30nm strain balanced broad area laser. Fig 3(inset): 50K EL spectra

Figure 3 shows preliminary results at 50K from a 30nm strained balanced laser which is fabricated into a 8mm by 30µm broad area Fabry-Perot device. A pulsed threshold current density of $230A/cm^2$ is achieved. The inset of figure 3 shows the spectra observed below threshold (200mA) and above threshold (1000mA). Narrowing of the spectra and multiple lasing modes are observed at 1µm. Comparison with an identical sample but without the $GaAs_{0.8}P_{0.2}$ strain balancing layers shows very similar threshold densities confirming that the inclusion of the $GaAs_{0.8}P_{0.2}$ strain balancing layers has no detrimental effects on device performance.

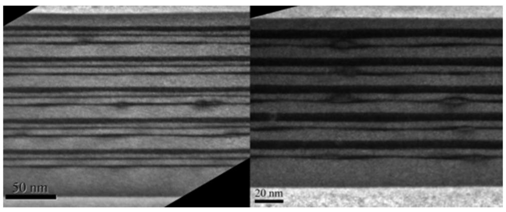

Fig. 4(a): TEM image of strain balanced 30nm spacing separation. Fig. 4(b): TEM image of strain balanced 20nm spacing separation.

Figure 4(a) and (b) show TEM images of the 30 and 20nm strain balanced structures. Structural integrity is maintained for the 20 nm structure giving us confidence that this approach will allow the close stacking of QD layers for optimised laser performance. We will present the latest results from the closely stacked QD lasers.

3. Conclusion

The development of long wavelength strain balanced InAs/GaAs QD lasers has been reported. The need for careful choice of the GaAsP barrier composition is noted. QD layers which simultaneously achieve 1.27µm at room temperature with areal densities of $\sim 3.1 \times 10^{10} cm^{-2}$ are achieved. Strain balanced lasers using $GaAs_{0.8}P_{0.2}$ are demonstrated. With preliminary results showing a 50K working broad area laser with a threshold current density of $230A/cm^2$. This technology provides a possible route to high gain optical devices and high absorption coefficient solar cells.

Acknowledgments

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References

[1] P. Lever, "InGaAs quantum dots grown with GaP strain compensation layers," *J. Appl. Phys.*, vol. 95, no. 10, p. 5710, May 2004.