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Citation: *AIP Conf. Proc.* **893**, 1431 (2007); doi: 10.1063/1.2730443

View online: <http://dx.doi.org/10.1063/1.2730443>

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Band Alignment and Carrier Recombination in GaAsSb/GaAs Quantum Wells

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Abstract. Using a combination of experimental and theoretical techniques, we investigated the band alignment and the carrier recombination processes occurring in GaAsSb/GaAs structures. We find that for Sb fractions ~30%, the band alignment is slightly type II. From studies on lasers based upon this material we show that at the high carrier densities required to achieve threshold, at room temperature, the devices are dominated by carrier leakage and non-radiative Auger recombination.

Keywords: GaAsSb, band alignment, carrier recombination, semiconductor laser, VCSEL, optical communications

PACS: 42.55.Px, 61.50.Ks, 72.20.Jv, 78.60.-b, 79.20.Fv, 85.35.Be

INTRODUCTION

GaAsSb/GaAs quantum wells are of significant technological interest as they allow the possibility to produce vertical cavity surface emitting lasers emitting at 1.3 μ m. However, there is still a lot of uncertainty concerning the basic material properties such as the band alignment of the GaAsSb/GaAs QW system (type I / type II) for Sb concentrations ~30-40% as required to achieve 1.3 μ m emission [1],[2]. Secondly, the role of non-radiative recombination processes such as Auger recombination, known to be important in the InGaAs(P)/InP system at similar band gaps, has yet to be quantified. Here we present a combination of spectroscopic and device studies together with preliminary theoretical calculations to determine the band alignment and the dominant recombination processes. Our results suggest that the GaAsSb/GaAs band alignment is slightly type II. However, this is shown to have little influence on device properties due to the Coulombic attraction between the delocalized electrons and holes. Using a combination of pressure and temperature dependence techniques, we also find that at the high carrier densities required for lasing operation, the current is dominated by non-radiative recombination through a combination of carrier leakage and Auger recombination.

LASER STRUCTURES AND EXPERIMENTS

The samples studied were in the form of semiconductor lasers. The active region of the samples consists of 3, 7nm GaAs_{0.64}Sb_{0.36} QWs within 5nm GaAs spacers and 8nm GaAsP barriers for strain compensation. The devices are measured as cleaved with cavity lengths of 500 μ m. To reduce Ohmic heating the devices were driven pulsed with a pulse width of 200ns and a 10kHz repetition rate. Temperature dependence measurements over the range of 60-300K were performed with a standard closed cycle cryostat set-up. Hydrostatic pressure measurements over the range 0-10kbar were performed using a gas compressor.

BAND ALIGNMENT

In order to investigate the nature of the band alignment and the extent to which the different radiative and non-radiative processes influence the

device characteristics, we performed spontaneous emission measurements whereby the light was collected in a direction perpendicular to the laser cavity through a window milled in the substrate of the lasers. This was to ensure that *pure* spontaneous emission was collected that had not been influenced by the effects of gain and/or loss along the laser cavity. This technique has been described in detail elsewhere [3] From those spontaneous emission spectra we observe a strong blue shift of the peak emission with excitation current (Figure 1). Also plotted is the equivalent data for a standard type I InGaAsP laser emitting at the same wavelength.

FIGURE 1. Comparison of the blue shift with excitation for the GaAsSb laser and an InGaAsP laser.

The shift for the GaAsSb/GaAs laser is much stronger and cannot be explained by band filling alone and is consistent with the carriers being delocalized and a type II band alignment. A comparably strong shift has also been observed in photoluminescence measurements of these structures [4]. Furthermore, utilizing self-consistent Schrodinger-Poisson calculations [5] in which the conduction band offset was treated as a free parameter, we observe that the peak emission shift with carrier density increases as one goes from a type I to a type II band alignment, consistent with our experimental findings

CARRIER RECOMBINATION

Figure 2 shows the measured temperature dependence of the threshold current (solid diamonds) and radiative current (open squares), the latter of which is determined from the spontaneous emission measurements [3]. It can be seen that the threshold current is very temperature sensitive whilst the radiative current maintains the ideal-like linear temperature dependence that one would expect for a QW [3] (see also inset). Thus, we conclude that at the typical carrier densities required for laser threshold, these 1.3μm GaAsSb/GaAs lasers are dominated by

non-radiative recombination, accounting for ~90% threshold current at room temperature. From pressure dependence measurements, described elsewhere [6] we find that this is due to a combination of electron leakage from the QWs into the barrier layers together with non-radiative Auger recombination.

FIGURE 2. Temperature dependence of the threshold current and the radiative current in the GaAsSb/GaAs lasers.

CONCLUSIONS

In summary, using a combination of experimental and theoretical techniques, we find that the band alignment of the GaAsSb/GaAs interface (for Sb fractions ~30%) is slightly type II. However, due to the Coulombic attraction between the electrons and holes, this has little effect on device performance. We also investigated the dominant carrier recombination processes in GaAsSb/GaAs lasers emitting close to 1.3μm. We find that at the high carrier densities required to achieve threshold, the current is dominated by carrier leakage from the QWs together with non-radiative Auger recombination.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge EPSRC (UK) for financial support.

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