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Auger Recombination Suppression And Band Alignment In GaAsBi/GaAs Heterostructures

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Abstract. Using a combination of experimental and theoretical techniques we present the dependence of the bandgap E_g and the spin orbit splitting energy Δ_{so} , with Bi concentration in GaAsBi/GaAs samples. We find that the concentration at which $\Delta_{so} > E_g$ occurs at 9%. Both spectroscopic as well as first device results indicate a type I alignment.

Keywords: GaAsBi, band alignment, Auger recombination,
PACS: 71.20Nr, 72.20Jv, 78.55Cr, 78.60.Fi

INTRODUCTION AND SAMPLE DETAILS

The incorporation of Bismuth into III-V compounds such as GaAs shows interesting effects on the band structure due to the strong influence of Bismuth on both the band gap and spin-orbit splitting. Similar to the dilute nitrides the large difference in the size of the bismuth atom compared to arsenic leads to localised Bi-related cluster states and a band anti-crossing effect. Since the Bi-level is below the GaAs valence band edge this gives rise to valence band anti-crossing and an upward movement of the valence band edge. The resulting strong bandgap bowing is $\sim 80\text{meV/Bi}\%$. Furthermore, due to the large mass of the Bi atom, the spin orbit (SO) splitting energy, Δ_{so} , is enhanced. This means that one can essentially engineer the bandgap and the SO splitting energy by adding Bi (and possibly also N), with low (or zero) strain on GaAs substrates. This gives rise to promising properties for optoelectronic devices in the near and mid-infrared and has consequently attracted much interest.

With the GaAsBi(N) system it is possible to achieve a case where Δ_{so} is larger than the band gap. This is potentially very useful for optoelectronic devices as this should lead to a reduction in the hot-hole driven Auger current (CHSH) which causes the high temperature sensitivity of semiconductor lasers operating in the near infrared. In this paper we present first characterization of GaAsBi/GaAs samples with Bi concentrations from 2.3% to 10.4%. and GaAsBi pin diodes with Bi concentrations of 1.4% and 1.8% which have all been grown by MBE at low growth temperature necessary for Bi incorporation.

BANDGAP AND SPIN ORBIT SPLITTING

Figure 1: Bandgap and spin orbit splitting energy with Bi concentration for GaAsBi.

With a combination of theoretical and experimental techniques, we have determined the variation of band gap and SO splitting as a function of Bismuth composition in GaAsBi/GaAs samples. Using photomodulated reflectance (PR) we measured the variation of the bandgap and SO splitting for Bi concentrations of 2.3%, 4.5%, 8.5% and 10.4%. For Bi concentrations exceeding 9%, Δ_{so} is larger than the bandgap energy [1].

Using the valence band anti crossing (VBAC) model we are also able to fit and predict bandgap and Δ_{so} for even higher Bi fractions. The theory also enables us to calculate what would happen when both N and Bi are incorporated into GaAs. In this quaternary not only can

the bandgap and Δ_{so} be tuned but there is also large scope for band offset optimisation.

BAND ALIGNMENT AND DEVICE MEASUREMENTS

In the PR measurements we also observe a red-shift of the CB-SO transition which is even more prominent if we calculate the transitions for unstrained material. Under the assumption that Δ_{so} increases with atomic number, the SO band will move down with increasing Bi concentration. Since the CB-SO transition decreases this indicates that the CB also moves down with increasing Bi concentration but somewhat faster than the SO band. This has been confirmed by tight binding calculations [2]. With the valence band moving up due to the anti-crossing and the conduction band also moving down we find a type I alignment at the GaAsBi/GaAs heterointerface which is useful for device applications.

GaAsBi pin-diodes were also measured with low (up to 1.8%) Bi concentration [3]. From the temperature dependence we find evidence of non-radiative recombination at room temperature. To investigate this further we used high hydrostatic pressure. In the pressure dependent electroluminescence (Fig. 2) at 80K we observe the main transition increasing with pressure while at the same time emission from the GaAs₂ visible as a shoulder highlighted by the circle in Fig. 2, appears and increases with pressure.

Figure 2: Pressure dependence of electroluminescence of a GaAsBi pin diode. The circle highlights the GaAs emission and the arrow indicates the energy shift of the GaAsBi peak with pressure.

This increase in the GaAs emission implies that there is an increasing leakage current with pressure which can be explained by the fact that by applying high pressure the band alignment can be changed due to the different pressure coefficients of the materials. In this case the GaAsBi layer has a higher pressure coefficient than GaAs and hence the CB edge of the GaAsBi layer moves up quicker with pressure (as indicated by the arrow) than the CB edge of the GaAs. This means that with increasing pressure this leakage path becomes more significant; this also confirms that the initial alignment (at zero pressure) is type I with the conduction band edge of the GaAsBi being below the conduction band edge of the GaAs.

SUPPRESSION OF AUGER RECOMBINATION

In order to investigate the potential for Auger suppression we investigated the power-law dependence of

the photoluminescence (PL) intensity on pump power for different temperatures for samples above (10.4%) and below (8.5%) the cross-over. With decreasing temperature the band gap of the 10.4% increases and can be brought into resonance with Δ_{so} .

In Figure 3 the power dependence of the 8.5% and the 10.4% sample at room temperature and 150K are compared. The slope and the overall intensity for the 8.5% sample increases as expected suggesting less Auger recombination due to the decrease in temperature. For the 10.4% the slope stays the same suggesting that at the lower temperatures the Auger process (CHSH) that was suppressed at RT is activated at this lower temperature and so despite the lower temperature there is evidence for an increase in the Auger recombination coefficient.

Figure 3: Comparison of the change in the slope of the power dependence from RT to 150K for the 10.4% and the 8.5% sample.

CONCLUSIONS

A set of GaAsBi/GaAs samples with varying Bi concentrations was measured. From PR measurements and VBAC calculations we find that the interesting Bi concentration at which Δ_{so} is larger than the bandgap occurs at ~9%. From the spectroscopy we also find evidence for a type I alignment at the GaAsBi/GaAs interface which is confirmed by pressure dependent device measurements. From power dependent PL we find first indications for the possibility of CHSH Auger suppression for high Bi containing samples.

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