On the thermal stability of 1.3μm GaAsSb/GaAs-based lasers

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Abstract – In spite of the almost ideal variation of the radiative current of 1.3μm GaAsSb/GaAs-based lasers, the threshold current, J_{th}, is high due to non-radiative recombination accounting for 90% J_{th} near room temperature. This also gives rise to low T_o values ~60K close to room temperature, similar to that for InGaAsP/InP.

GaAs-based vertical cavity surface emitting lasers (VCSELs) emitting close to 1.3μm are of considerable importance for the development of metro-area networks. There has been considerable effort devoted to the development of high quality GaAs based laser active regions which emit at 1.3μm. InAs quantum dots and GaInNAs based QWs have been the subject of extensive research, however their properties are far from ideal. Not only do the quantum dots exhibit a large size variation and thus a broad emission at 1.3μm but the threshold current density is highly temperature sensitive. As for GaInNAs it has been shown that even for the best devices available, approximately 50% of the threshold current at room temperature may be attributed to defect related recombination. An alternative is the use of GaAsSb/GaAs QWs. Lasers based upon this material have been successfully produced but remarkably little research has been undertaken to assess the carrier recombination and temperature dependent processes occurring in this material. This is perhaps all the more surprising given the wide uncertainly in the band alignment (type I versus type II) of the GaAsSb/GaAs interface for Sb~30-40% which will influence the device characteristics. The aim of this paper is to consider the characteristics of GaAsSb devices with the aim of learning more about their potential for use in 1.3μm VCSELs.

In this study we investigated devices processes from wafers grown by Solid Source MBE. The QW region consists of 3, 7nm $GaAs_{0.64}Sb_{0.36}$ QWs with 5nm GaAs spacers and GaAsP barriers for strain compensation. The wafers were fabricated into broad area stripe lasers with stripe widths of 100μm and a cavity length of 1mm. The devices were measured as-cleaved. Temperature dependence measurements were performed with a standard closed cycle cryostat set-up over the temperature range 60-300K.

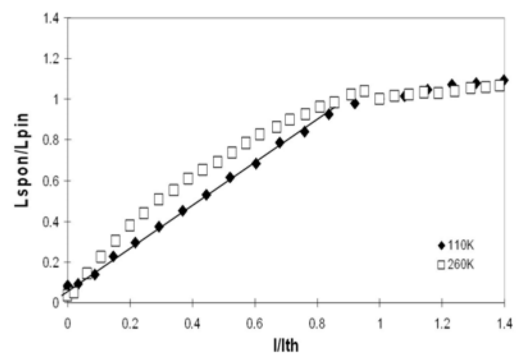

Figure 1 Integrated spontaneous emission versus current at T=110K and 260K

The integrated spontaneous emission (L_{spon}) versus current at two different temperatures, 110K and 260K, is shown in Fig. 1. At both temperatures, the integrated spontaneous emission pins at threshold due to the fact that the carrier density is prohibited from increasing by the lasing process. The two curves have been normalised to the value of L_{spon} at threshold, L_{pin}, so that the shape of both curves can be compared. At 110K, the L_{spon} versus current curve is linear suggesting that the primary current path flowing through the laser may be associated with radiative recombination. Furthermore, the fact that the curve remains linear down to the lowest currents suggests that defect-related recombination is minimal and that the material quality is high. In stark contrast, the sub-linear behaviour of the L_{spon} versus current curve at 260K suggests that a non-radiative process is present and that the process has a stronger dependence on the carrier density than the radiative current.

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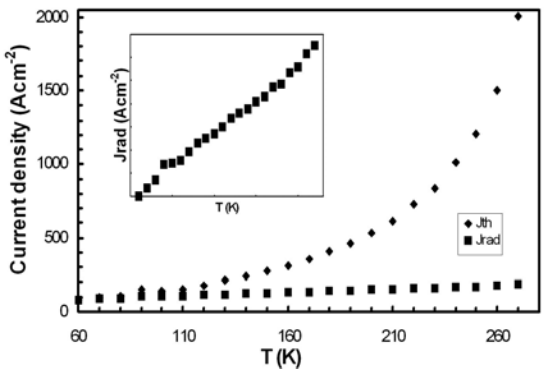

Figure 2 Measured J_{th} and J_{rad} as a function of temperature. Inset shows J_{rad} on an expanded scale.

In figure 2 we show the measured temperature dependence of the threshold current density, J_{th} (diamonds), for a GaAsSb device emitting at 1.27µm. Close to room temperature (RT) we observe J_{th} to be ~2kAcm^{-2}. We also find the devices are highly temperature sensitive with a characteristic temperature, T_o (derived from $1/T_o=d\ln J_{th}/dT$) of ~60K at RT, similar to that of typical InGaAsP/InP structures. Also shown is the temperature dependence of the radiative current density at threshold, J_{rad} (squares) determined from L_{pin}. We find that close to RT (270K) J_{rad} accounts for, at most, 10% of J_{th}. Clearly, non-radiative processes dominate, and account for at least ~90% J_{th} close to RT. Also J_{rad} has an ideal temperature dependence which is linear (inset Fig. 2), leading to the conclusion that the loss mechanisms must increase superlinearly with increasing temperature.

We investigated this further using high pressure techniques. The application of high hydrostatic pressure to semiconductor lasers causes an increase in the direct band gap and is an ideal way of investigating band gap dependent recombination mechanisms. The measured pressure dependence of the lasing energy is shown for the GaAsSb devices (inset Fig. 3). We find that the transition energy shifts by only 7.6meV/kbar. From a simple linear interpolation of the band gap pressure coefficients of the constituent binaries, GaAs (10.7meV/kbar) and GaSb (14.2meV/kbar) we would expect a shift for the GaAsSb QWs of ~11.9meV/kbar. The low measured pressure coefficient remains the subject of ongoing investigations but it is possible that strong band bending and/or recombination via delocalised electrons and holes could give rise to the lasing energy having a lower pressure dependence than the band gap, consistent with a type II band alignment.

Fig. 3 shows the measured room temperature normalized pressure dependencies of J_{th} for the GaAsSb devices (circles). Also shown is the ideal expected variation of $J_{rad}\propto E_g^2$ (line), where E_g is the band gap (taken from $E_g=hc/\lambda_{lasing}$). Clearly, J_{th} increases more rapidly with pressure than an ideal J_{rad} in particular at pressures above 4kbar. This behaviour suggests that either J_{rad} does not have an ideal pressure variation or that a non-radiative process is present. From the earlier temperature dependence measurements where a non-radiative process dominated at room temperature we conclude that the observed pressure dependence of J_{th} is due to non-radiative recombination. The strong increase in J_{th} with pressure may be attributed to indirect carrier leakage, perhaps into the L-minimum, although the

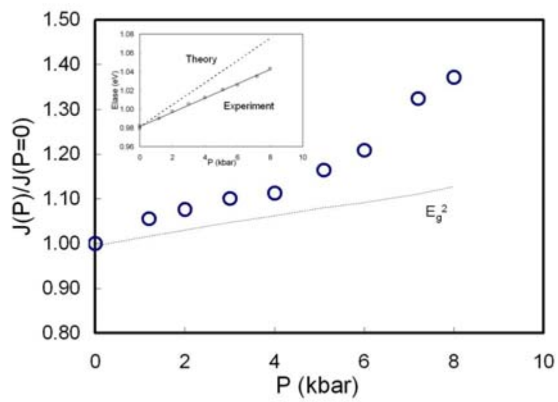

Figure 3 J_{th} as a function of pressure alongside 'ideal' E_g^2 dependence of J_{rad}. Inset shows predicted and measured lasing energy versus pressure.

exact mechanism for this requires further investigation. Due to the different pressure coefficients for GaAsSb and GaAs we also expect that the conduction band alignment becomes more type II like with increasing pressure. The conduction band offset increases approximately by 1meV/kbar. This would lead to a reduced gain for a given carrier density and hence, would tend to exacerbate processes such as Auger recombination or leakage and hence give rise to an increase in the threshold current as a function of pressure.

Whilst it is clear that non-radiative recombination dominates the performance of these devices at room temperature, additional experimental and theoretical evidence is required to identify the specific process responsible. This is vital if this material is to be exploited for the production of 1.3µm VCSELs as will be discussed further at the conference.