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Influence of Growth Temperature on Defect Density in 1.3μm GaInNAs-based lasers

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We show that the dramatic changes in threshold current density with changing active region growth temperature in 1.3μm GaInNAs-based lasers can be attributed nearly entirely to changes in the defect related monomolecular recombination current.

Lasers based upon GaInNAs/GaAs have become of major interest as an alternative to InGaAsP/InP. Better electron confinement is expected, because of the much larger conduction band offset and because wide-bandgap AlGaAs can be used to form the cladding regions. This both reduces carrier leakage and improves optical waveguiding. Most importantly, it also makes possible the fabrication of highly reflecting Bragg stacks and hence the production of 1.3μm wavelength vertical-cavity surface-emitting lasers for use in metro-area optical fibre communication.

In this paper we will describe investigations of the influence of the growth temperature of the active region on the magnitude of the main recombination mechanisms at lasing threshold of 1.3μm single quantum-well (SQW) GaInNAs/GaAs lasers grown by MBE. The laser structures used in this study are GaInNAs based SQW devices grown by molecular beam epitaxy (MBE) on n^+- GaAs substrates. The GaInNAs QWs have an In-content of about 30%, an N-content of about 1.6% and a width of 6.5 nm. Two nominally identical series were grown with the only difference being the growth temperature of the active region, T_g, which was set to be 422°C and 456°C respectively.

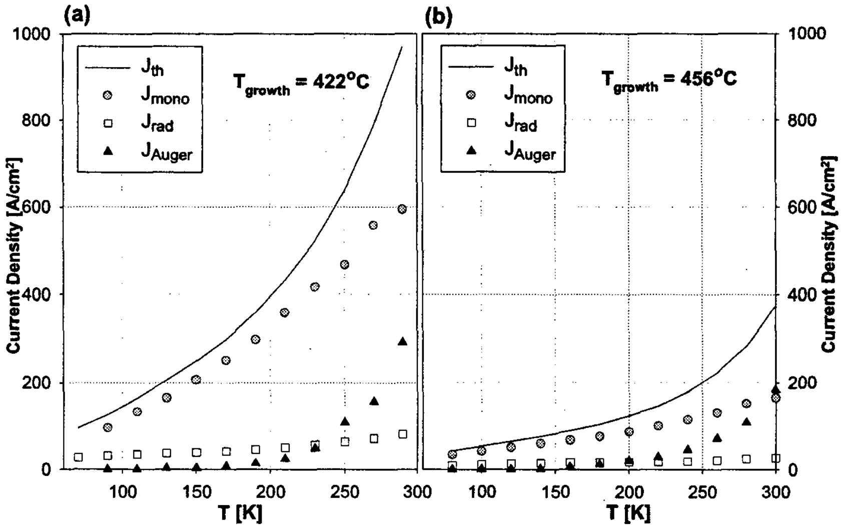

Figure 1 Current densities for the three main recombination processes versus temperature.

In figure 1 the current density (solid line), J_{th}, for an active region growth temperature T_g = 422°C (a) and T_g = 456°C (b) is plotted as a function of device temperature. Around room temperature (T=290K) we observe that $J_{th} \sim 970$ A/cm² for the low T_g lasers, while $J_{th} \sim 330$ A/cm² for the higher T_g devices. To determine which recombination processes are mainly responsible for this nearly factor 3 reduction in J_{th} we utilize a method, successfully applied before, which enables the experimental determination of the monomolecular-, radiative- and Auger-related current contributions to the threshold current by studying the integrated spontaneous emission rate from a window milled into the n-contact of the

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devices[1]. In figure 1 the resulting current densities at threshold versus temperature for the monomolecular current (grey circles), radiative current (open squares) and Auger current (closed triangles) are plotted for the SQW lasers with active region growth temperatures of $T_g = 422$°C (a) and $T_g = 456$°C (b). It can be seen that for the low T_g devices the monomolecular current contributes ~61% to the total threshold current at 290K for the low T_g lasers and ~48% for the high T_s devices. The total monomolecular current density is reduced by a factor of 3.8 from J_{mono}~600 A/cm^2 down to 160 A/cm^2 when increasing T_g from 422 °C to 456°C. The reduction in the Auger ($\propto n^3$) and radiative ($\propto n^2$) component is much less significant and can easily be explained with a slight variation in the threshold carrier density, n_{th}, between the two devices. However a slightly smaller n_{th} cannot explain the strong reduction in the monomolecular recombination ($\propto n$), which therefore requires a strongly decreased monomolecular recombination coefficient A with increasing growth temperature.

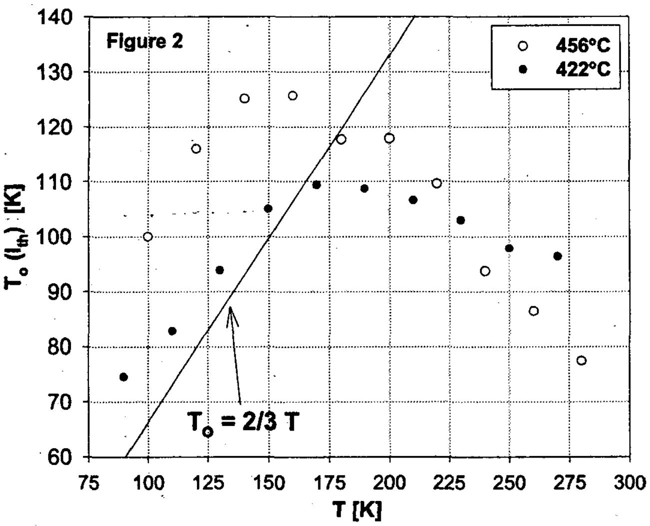

Figure 2 Variation of T_0 with temperature for the two growth temperature samples

These results are consistent with studies of the characteristic temperature, T_0, of the total threshold current, which is plotted in figure 2 as a function of temperature. Here the straight line indicates the expected behavior of the characteristic temperature of a purely monomolecular current, which for a QW can be deduced to be T_0 (I_{mono}) = 2/3 T assuming a simple free carrier capture process for a two dimensional electron gas. It can be seen that for temperatures below ~180 K, the T_0 for the low T_g laser (closed circles) follows closely the theoretical line for pure monomolecular current indicating that the device is dominated by defect related currents. This is consistent with the results presented in figure 1a. For T>180K in figure 1a the Auger component starts to increase leading to an increasing temperature sensitivity of J_{th}. This is reflected in the drop of T_0 (closed circles) for temperatures T>180K in figure 2. For the high T_g laser, T_0 (open circles) is slightly larger for T<180K. This is again consistent with the findings from figure 1b as the defect related contribution is less dominant and the lower temperature sensitivity of the radiative component (T_0=T for an ideal QW) increases the overall T_0. For T>180K the Auger current in figure 1b increases, leading to a drop of T_0 (open circles) in figure 2. It can be clearly observed that T_0 is decreasing much more strongly for the high T_g laser (open circles) than for the low T_g device (closed circles), leading to a cross over point at about 230K. Close to room temperature (280K) we find T_0(422°C) ≈ 95K and T_0(456°C) ≈ 77K. The lower T_0 of the high T_g laser is consistent with the higher relative Auger contribution (~45% for 456°C and ~30% for 422°C) to J_{th} due to lower defect related recombination. For Auger dominated threshold currents $T_0 < T/3$.

An interesting observation was made when comparing SQW and MQW lasers with nominally identical QWs. As expected when decreasing n_{th}, due to the larger modal gain the Auger current ($\propto n^3$) is reduced relatively to the radiative current ($\propto n^2$) when going from one to three wells However, the monomolecular contribution ($\propto n$) is reduced by approximately the same amount as the Auger component, which cannot be explained by a reduction in n_{th} alone but requires a further decrease in the coefficient A. The origin of this surprising effect is subject of ongoing investigations.

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[1] FEHSE, R., TOMIC, S., ADAMS, A.R., SWEENEY, S.J., O'REILLY, E.P., ANDREEV, A., RIECHERT, H., J. of Selected Topics in Quantum Electronics, Vol.9, No.4, Jul/Aug 2002