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2:15pm – 2:30pm

Intrinsic temperature sensitivities of 1.3μm GaInNAs/GaAs, InGaAsP/InP and AlGaInAs/InP-based semiconductor lasers

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Abstract

The apparent temperature stability of GaInNAs-based lasers is attributed to significant defect current. By removing this current, GaInNAs devices have a similar temperature dependence to InGaAsP devices whilst AlGaInAs devices are more thermally stable.

Summary

InGaAsP and AlGaInAs grown on InP and GaInNAs grown on GaAs are three important material systems for lasers operating at 1.3 μm for optical fibre communications. InGaAsP/InP-based devices have dominated the market for emission at 1.3μm through to 1.55μm primarily due to the relative ease of growing high quality layers. It is however, an intrinsically inefficient material and exhibits a very temperature sensitive threshold current. AlGaInAs/InP-based lasers have aroused interest, primarily for 1.3μm emission due to the higher conduction band offset which gives rise to a reduced temperature sensitivity. This makes it particularly attractive for the metro market where cooler-less operation is highly desirable. The demand for ever cheaper components has led to wide interest in developing vertical cavity surface emitting lasers (VCSELs) at 1.3μm. The significant advantages of using GaAs-based material for VCSELs has led to concentrated efforts to produce 1.3μm active regions based upon GaAs. Of the GaAs-based technologies, GaInNAs/GaAs has emerged as a leading material system for the production of VCSELs. Due to the larger electron confinement, the GaInNAs system is also expected to show an improved temperature stability with some devices reportedly exhibiting characteristic temperatures (T_o) in excess of 200K[1].

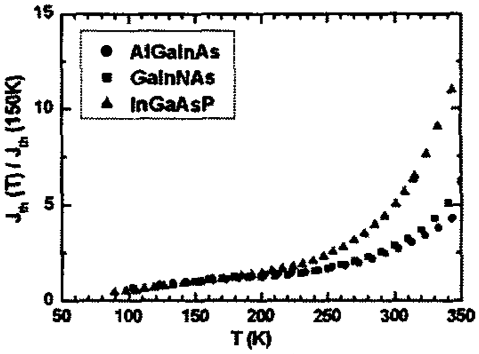

Figure 1 Temperature dependence of J_{th} (normalised at 150K) for 1.3μm InGaAsP, AlGaInAs and GaInNAs lasers.

In Figure 1, we show a comparison of the temperature dependence of the threshold current density, J_{th}, (normalised at 150K) for InGaAsP, AlGaInAs and GaInNAs devices. The corresponding T_o values for the devices, around room temperature are; 60K (InGaAsP), 100K (AlGaInAs) and 90K (GaInNAs). Clearly, the InGaAsP devices have the strongest temperature sensitivity around room temperature whilst the AlGaInAs and GaInNAs devices have a much lower temerature variation, corresponding to the higher T_o values. It has previously been shown that the severe temperature sensitivity of InGaAsP devices is associated with severe Auger recombination over the operating temperature range of interest[2]. Whilst Auger recombination also occurs in AlGaInAs devices, it is less significant accounting for only ~20% J_{th} at room temperature. The improved thermal performance of AlGaInAs devices is therefore due to the dominance of radiative recombination which, relative to Auger recombination, is much less temperature sensitive. In order to determine the importance of different recombination mechanisms in the GaInNAs devices, we measure the spontaneous emission emanating from a window milled into the laser substrate. The integrated spontaneous emission, $L \propto n^2$ where n is the carrier density. Thus by measuring L as a function

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of the current, I, we can obtain the carrier density dependence of the current by plotting a graph of ln(I) versus ln($L^{1/2}$). In Figure 2 we make such a plot for the GaInNAs devices. At low current, the slope of 1 shows that the current $\propto n$. This is consistent with monomolecular (defect) related recombination. By extrapolating this to laser threshold, we find that defect related recombination accounts for approximately 50% of the threshold current. Thus, in this material one half of the current flowing at threshold gives rise to recombination via defect states. By repeating this measurement over a wide temperature range, the temperature variation of the defect-related current (J_{mono}) may be determined. In Figure 3, we re-plot the data shown in Figure 1, where for the GaInNAs devices we now plot (J_{th}-J_{mono}) to simulate the effect of having perfect material. Clearly, whilst removing the defect related current path is advantageous in terms of the overall device power consumption, it can be seen that it has a profound effect on the temperature dependence. In the absence of defect related recombination one can see that the GaInNAs devices are very temperature sensitive with a T_o around room temperature of 60K. This is very similar to the value obtained for InGaAsP. These data therefore suggest that by improving the material quality of the GaInNAs lasers, the temperature sensitivity will increase. The temperature sensitivity of GaInNAs lasers is largely determined by Auger recombination[3] and by removing the defect-related current path, the Auger recombination becomes considerably more significant.

Further evidence for this can be obtained from the literature. In Figure 4 we plot the variation of T_o as a function of J_{th} per QW corresponding to published GaInNAs device characteristics. From this plot one can see that the devices with a low J_{th} generally have a low T_o. Conversely, the devices with the higher T_o values have correspondingly high threshold current densities. These results are consistent with our measurements which show that defect-related recombination gives rise to an artificially high T_o in GaInNAs lasers.

In summary, GaInNAs based lasers at 1.3μm offer considerable advantages over InP-based material for the production of VCSELs. For edge-emitting lasers, where the use of a GaAs substrate is less critical, AlGaInAs-based active regions may offer intrinsically more stable operation with temperature changes. Further results pertaining to the temperature dependence of these lasers will be presented.

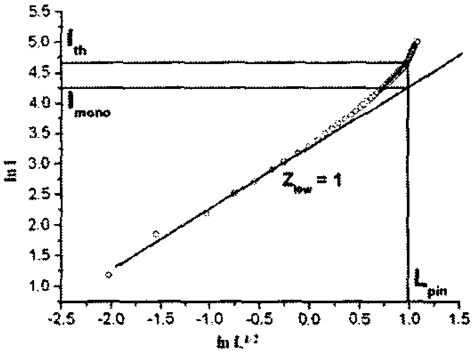

Figure 2 *Determination of defect-related current from spontaneous emission measurements.*

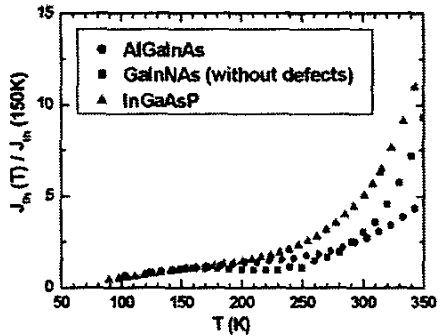

Figure 3 *Temperature dependence of J_{th} (normalised at 150K) for 1.3μm GaInNAs lasers (without defects) compared with InGaAsP, AlGaInAs.*

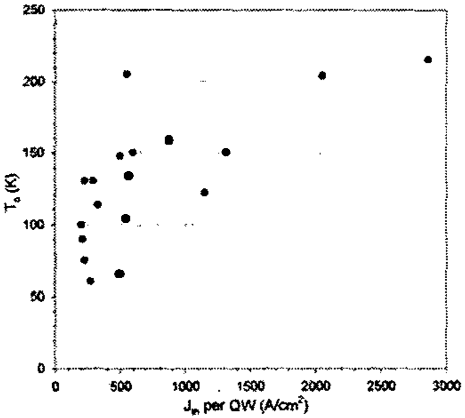

Figure 4 *Variation of T_o with J_{th}/QW for GaInNAs lasers (taken from literature).*

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[1] S Sato et al, IEEE Phot. Tech. Lett., 11, pp.1560-1562, 1999.

[2] Phillips et al, IEEE J. Sel. Top. Quant. Electr., 5, pp. 401-412, 1999.

[3] Fehse et al, IEEE J. Sel. Top. Quant. Electr., 8, pp. 801-810, 2002.