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Origin of the High Temperature Performance Degradation of 1.5μm InGaAs(P)/InP Quantum Well Lasers

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Abstract

High temperature degradation of the efficiency of 1.5μm InGaAs(P) lasers is shown to be due to strong coupling between Auger recombination and internal absorption. This is explained using a simple analytical model.

Summary

Semiconductor lasers in the 1400-1600nm band are key components of telecommunications systems where they may be used as signal or pump sources. InGaAs(P)/InP is the traditional alloy used for the production of devices at these wavelengths, however, due to the strong temperature dependence of the threshold current (I_{th}) in these devices there is currently much activity in searching for an alternative, more thermally stable material. This will eliminate the requirement for thermoelectric cooling and lead to a significant component cost reduction. Most practical applications require stable operation over the temperature range, -20°C to +80°C. To assist in the development of thermally stable materials requires a detailed understanding of the thermal factors influencing device performance over this range. It has previously been demonstrated[1] that the strong increase in threshold current observed for 1.5μm InGaAs(P)/InP lasers is due to non-radiative Auger recombination such that at room temperature it accounts for ~80% I_{th} with the remaining 20% I_{th} due to radiative recombination.

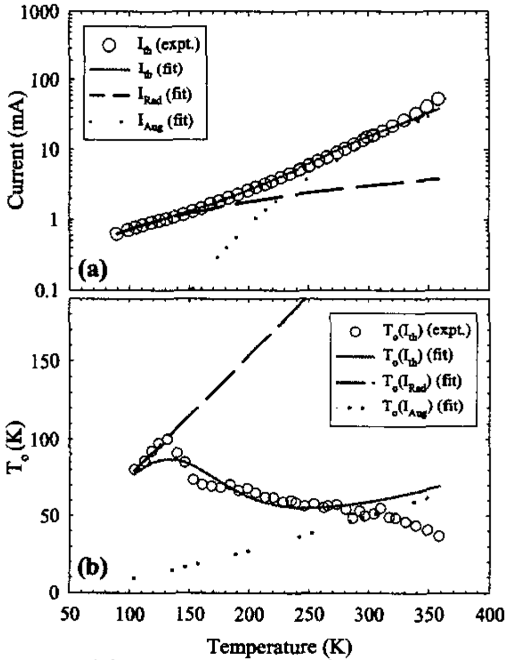

Figure 1 Simple transparency model fit to (a) I_{th} and (b) T_o for a 1.5μm InGaAs(P) device. Above 300K, the simple model underestimates I_{th} and hence overestimates T_o.

Using a combination of Auger- (I_{Aug}) and radiative-recombination (I_{Rad}) currents, one can obtain good agreement with the measured I_{th} from low temperatures up to room temperature (Figure 1a). However, for further increases in temperature it is clear that this model begins to fail and severely underestimate I_{th}. This is particularly evident from an equivalent plot of the characteristic temperature, T_o (figure 1b) where T_o is defined as $1/T_o=d(ln I)/dT$. In the simple model, it is assumed that the threshold carrier density, n_{th} is equal to the transparency carrier density, n_{tr}. Under the Boltzmann approximation, $I_{Rad}=Bn^2$ and $I_{Aug}=Cn^3$ where n is the carrier density, B is the bimolecular recombination coefficient and C is the Auger coefficient. For a quantum well, at *transparency*, $n \propto T$, where T is the absolute temperature. In addition we can write that $B \propto T^{-1}$ and $C=C_o\exp(-E_a/kT)$[1]. Consequently, at transparency, we derive expressions for the temperature dependencies of each current path as $T_o(I_{Rad})=T$ and $T_o(I_{Aug})=T/(3+E_a/kT)$[2]. Up to room temperature these expressions agree well with experiment. However they fail to predict the decrease in T_o observed above room temperature since both $T_o(I_{Rad})$ and $T_o(I_{Aug})$ continue to increase with increasing temperature.

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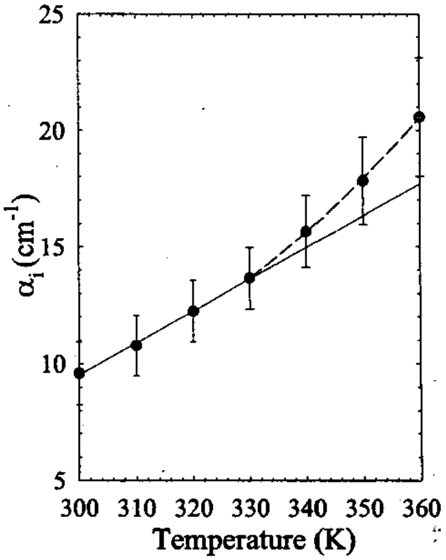

Figure 2 Measured variation of the internal absorption, α_i determined from differential efficiency measurements.

In Figure 2 we plot the temperature variation of the internal absorption, α_i, measured for the same devices as determined from the slope of the inverse differential efficiency versus cavity length. Over the temperature range 300-360K α_i increases from 10cm^{-1} to ~20cm^{-1} due to increasing inter-valence band absorption[3]. This manifests itself as both a decrease in the differential efficiency and a further increase in I_{th} (and hence a decrease in T_o). One can quantify the effect of α_i on I_{th} and T_o as follows. For a quantum well[4], assuming that the gain varies logarithmically with n, one can write that $n_{th}=n_{tr}\exp(g_{th}/g_o)$ where g_{th} is the threshold material gain and g_o is the gain coefficient. $g_{th}=(\alpha_i+\alpha_m)/\Gamma$ where α_m is the mirror loss and Γ is the optical confinement factor. At *threshold* we can write that $I_{Rad}=Bn_{tr}^2\exp\left(\frac{2}{\Gamma g_o}(\alpha_i+\alpha_m)\right)$ and $I_{Aug}=Cn_{tr}^3\exp\left(\frac{3}{\Gamma g_o}(\alpha_i+\alpha_m)\right)$. Assuming that α_m and g_o are approximately temperature insensitive and substituting our previously defined temperature variations of B, C and n_{tr} gives $T_o(I_{Rad})=\frac{T}{1+\frac{2T}{\Gamma g_o}\cdot\frac{d\alpha_i}{dT}}$ and $T_o(I_{Aug})=\frac{T}{3+\frac{E_a}{kT}+\frac{3T}{\Gamma g_o}\cdot\frac{d\alpha_i}{dT}}$ where $d\alpha_i/dT$ is the temperature dependence of α_i. Note that if $d\alpha_i/dT=0$, these expressions reduce to the simple form as discussed earlier. It is clear from these expressions how the increase in α_i with temperature couples strongly into the radiative, and in particular, the Auger recombination current[3].

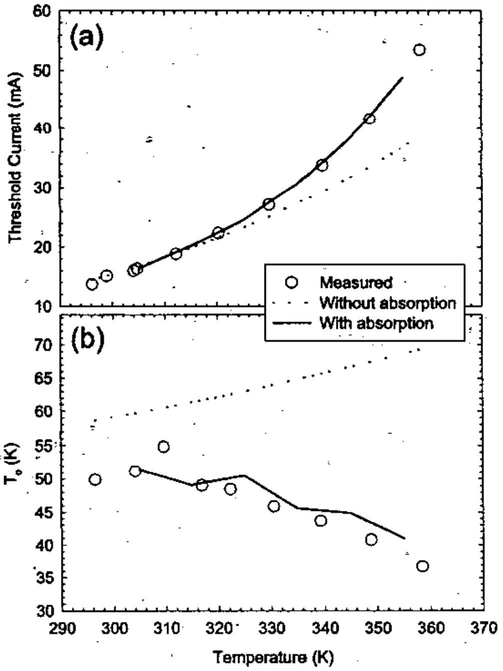

Figure 3 Measured and calculated variation of (a) I_{th} and (b) T_o. Good agreement is obtained when the effect of temperature dependent absorption is included.

From measurements of J_{th} versus cavity length we deduce that $g_o\approx4500$cm^{-1} over this temperature range. Furthermore from ref. 2, E_a=62meV and using a simple effective index model we calculate Γ=0.016 for this structure. Using these parameters together with the measured $\alpha_i(T)$, Figure 3 shows the measured I_{th} and T_o (circles) together with the calculated $I_{th}(T)$ and $(T_o(T)$ which includes the effect of temperature dependent absorption (solid line). For comparison, the dotted lines show the calculated I_{th} and T_o without including absorption. These data clearly show that temperature dependent absorption *coupled* with Auger recombination explains the dramatic fall off in T_o above room temperature and can readily be explained with a simple analytical model. These results highlight the extent to which Auger recombination degrades the performance of 1.5μm InGaAs(P) lasers and emphasises the importance of minimising absorptive losses in lasers operating in the Auger regime.

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[1] S. J. Sweeney et al, Phot. Tech. Lett., **10**, 1076 (1998).

[2] E. P. O'Reilly and M. Silver, Appl. Phys. Lett., **63**, 3318 (1993).

[3] A. R. Adams et al, Semi. Sci. Tech., **2**, 761 (1987).

[4] P. W. A. McIlroy et al, Jour. Quant. Elect., **21**, 1958 (1985).