The influence of carrier density non-pinning on the output power of 1.55 μm lasers at high temperature

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Maximising the output power is of key importance in the development of lasers in many applications. When operating at several times laser threshold, the threshold current, I_{th}, and its temperature sensitivity, T_o (=$I_{th}(dI_{th}/dT)^{-1}$) are often ignored since optimisation schemes typically aim to minimise optical losses which degrade the differential quantum efficiency, η_d. In an ideal laser, the carrier density pins at threshold and hence, in principal, all of the injected current above threshold is available to produce stimulated emission. In this paper we show that this not the case since, under the high injection conditions required to achieve high powers, internal heating causes non-pinning of the carrier density due to increased thermal broadening of the Fermi distribution of carriers. This means that above laser threshold one has to inject a higher carrier density (n) to maintain the threshold gain condition. This non-pinning of the carrier density above I_{th} consequently leads to an increase in the recombination currents which constitute the threshold current. This is particularly problematic if Auger recombination dominates, due to its n^3 dependence and correspondingly strong temperature dependence, and results in significantly less current available to produce stimulated emission. We show that the degree of non-pinning can in fact be significant, and have a large impact on the maximum obtainable power through its effect on non-radiative recombination processes.

We analysed the importance of the temperature dependence of I_{th} and η_d on the maximum output power, P_{max}, of 1.55 μm 1% strained 4QW InGaAlAs based lasers. We studied the temperature dependence of light-current (LI) characteristics in pulsed and CW regimes up to T=365K and looked at how non-pinning and losses limit the output power. Fig.1 shows the variation of the facet emission and integrated spontaneous emission versus current at T=365K. One can see the heating effect in the CW regime gives rise to the typical roll-over plot and hence a limited P_{max}. Fig. 1 also shows the variation of the integrated spontaneous emission, L_{spon}, as measured from a window in the laser substrate. This provides a useful measure of how well the carrier density pins. Under CW operation (solid blue symbols) there is a significant increase in L_{spon} with current (compared to the pulsed measurement for which internal heating is negligible) highlighting the strong heating induced non-pinning of the carrier density. Fig. 2 shows calculated LIs for the ideal case, for which radiative recombination only occurs (hence T_0=T=365K) and for the case when T_0 is limited by an Auger process (T_0=77K, as measured in the range 290-365K). We also consider the effect of temperature dependent optical losses (dashed lines) based upon the measured temperature dependence of η_d. We note that whilst P_{max} is degraded due to the temperature dependence of η_d, due to non-pinning of the carrier density, non-radiative processes such as Auger recombination have a significant limiting effect on the maximum output power. Furthermore, when operating in a high loss regime, the maximum output power is strongly dependent on the extent to which non-radiative recombination controls T_o. These effects are observed at elevated temperatures across a broad range of 1.55 μm laser devices including conventional InGaAsP structures.

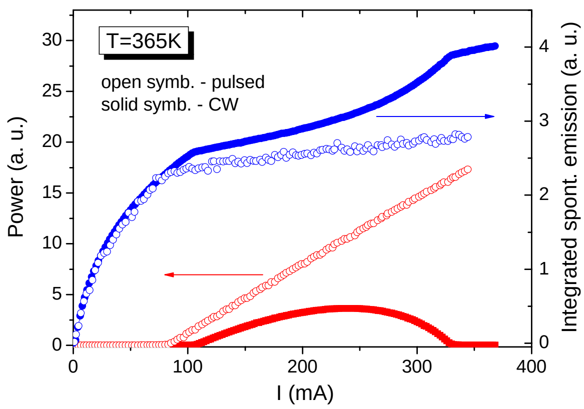

Fig. 1 Facet emission and integrated spontaneous emission from the window in pulsed and CW regimes at T=365K.

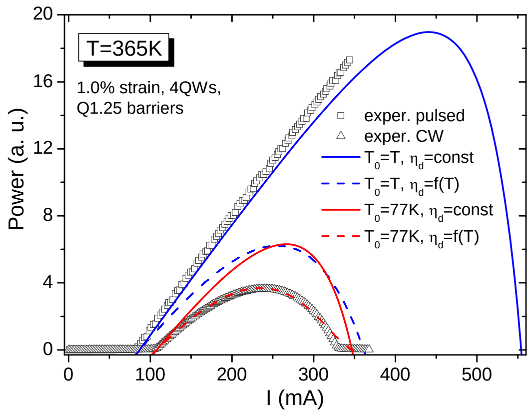

Fig. 2 Experimental and calculated light-current characteristics for different cases (assuming contribution of Auger recombination or/and temperature dependence of η_d).