ThB4
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Recombination and loss mechanisms in low-threshold InAs/GaAs 1.3 μm quantum dot lasers

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We show that even in quantum dot lasers with very low threshold current density (J_{th}=40-50 A/cm^2 at 300 K) the temperature sensitivity of the threshold current arises from nonradiative recombination which comprises ~60-70% of J_{th} at 300 K.

The 1.3 μm quantum dot lasers studied were 10 μm or 20 μm wide ridge dot-in-a-well structures with five stacked layers of InAs QDs within $Ga_{0.85}In_{0.15}As$ quantum wells separated by 50 nm GaAs barriers. The active region was embedded between $Al_{0.4}Ga_{0.60}As$ cladding layers and an $Al_{0.2}Ga_{0.8}As$ waveguide. The facets were as-cleaved and the cavity length was 3 mm. Both unamplified spontaneous emission, L, from a window milled in the substrate contact and the emission from the laser facet were investigated as functions of the injected current at different temperatures.

Fig.1 shows the temperature dependence of the threshold current density, J_{th}, and its radiative component, $J_{rad} \propto L$, normalised assuming that at low temperature J_{th} is totally radiative because it follows J_{th} closely below 180 K. The decrease in J_{th} with increasing temperature over this range is often observed in QD lasers and is attributed to an enhancement of carrier transport with increasing temperature allowing carriers to contribute more effectively to the lasing process. Above 200K, J_{th} increases strongly while J_{rad} remains almost temperature insensitive. The CW threshold current density of the lasers at 295 K was 44-55 A/cm^2 depending on the ridge width. The characteristic temperatures of J_{th} measured in CW and pulsed modes between 270 and 300 K were T_0=50 K and T_0=90 K, respectively. From the fit we see that at room temperature $J_{rad}(T)$ accounts for only ~30-40% of J_{th} in these lasers. Therefore the temperature sensitivity of the lasers must be due to a nonradiative recombination process.

Our previous study of 980 nm and 1.3 μm quantum dot lasers showed the importance of the loss process due to Auger recombination [1]. This mechanism can significantly decrease the temperature stability of the lasers studied in this work. Another possible loss mechanism is defect-related recombination in the wetting layer due to increasing thermal escape of carriers out of the dots. We observed emission from the wetting layer in the spontaneous emission spectra at threshold at 300 K although its amount is very small (integrated area of this region is about 0.7% of the total integrated emission). A quantitative investigation of the different recombination mechanisms is in progress and the results will be presented at the conference.

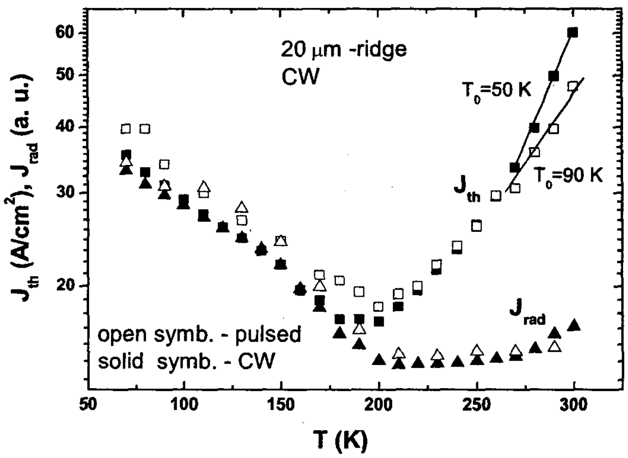

Fig. 1 Threshold current density and its radiative component versus temperature for the 20-μm ridge device

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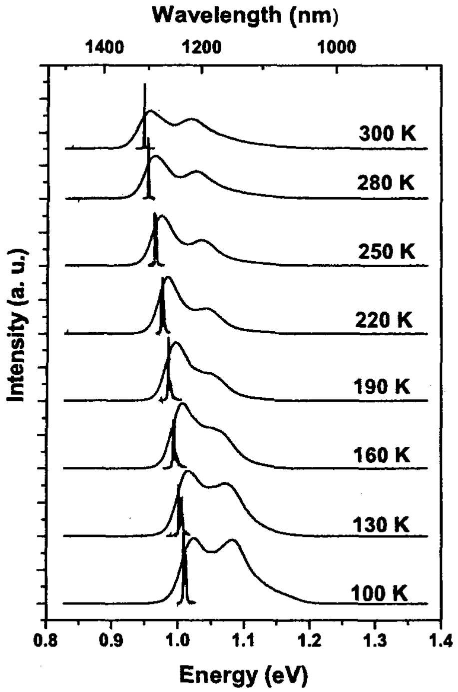

Fig.2 Spontaneous emission spectra at J_{th} and lasing spectra at different temperatures

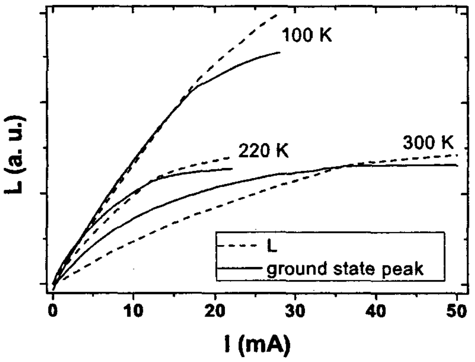

Fig.3 Integrated spontaneous emission (dashed lines) and maximum intensity of the ground state peak (solid line) as a function of injected current

Spontaneous emission spectra obtained at lasing threshold together with facet emission spectra above J_{th} at different temperatures are shown in Fig. 2. An increase of the intensity and narrowing of the spontaneous emission spectra at increasing temperature up to 200 K demonstrate the enhancement of carrier coupling between the dots and their recombination via the states with lower transition energies. A decrease of the emission intensity takes place above ~200 K, while the integrated spontaneous emission at the threshold current remains almost constant due to increasing emission from the excited states. The lasing line was very narrow in all the temperature range (5 meV at 100 K and 1 meV at 295 K) demonstrating the high homogeneity of the dots.

The integrated spontaneous emission, L, from the window vs current at different temperatures is shown in fig.3 by the dashed lines. The peak intensity of the ground state emission as a function of injected current, normalised to the value of L_{th} at each temperature, is plotted with solid lines. The integrated spontaneous emission pins better at higher temperatures. The pinning of ground state emission is better than that of the total spontaneous emission spectra and it pins almost ideally above 250 K. This shows that the emission from the excited states causes the poor overall pinning behaviour observed at higher temperatures, whilst the inhomogeneous carrier distribution at lower temperatures leads to a complete lack of pinning of both the total and ground state spontaneous emission. The lack of pinning of the excited state when the ground state is pinned by the stimulated emission is evidence of a bottleneck effect which prevents effective carrier thermalisation to the ground state where lasing occurs.

[1] I. P. Marko, A. D. Andreev, A. R. Adams, R. Krebs, J. P. Reithmaier, A. Forchel, "The Role of Auger Recombination in InAs 1.3 µm Quantum Dot Lasers Investigated Using High Hydrostatic Pressure", IEEE Journal of Selected Topics of Quantum Electronics, vol. 9, no. 5, 2003, pp.1300-1307.