Temperature sensitivity of 1.55µm (100) InAs/InP-based Quantum Dot Lasers

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Semiconductor lasers with quantum dot (QD) based active regions have generated a huge amount of interest for applications including communications networks due to their anticipated superior physical properties due to three dimensional carrier confinement. For example, the threshold current of ideal quantum dots is predicted to be temperature insensitive [1]. We have investigated the operating characteristics of 1.55 µm InAs/InP (100) quantum dot lasers focusing on their carrier recombination characteristics using a combination of low temperature and high pressure measurements. By measuring the intrinsic spontaneous emission from a window fabricated in the n-contact of the devices we have measured the radiative component of the threshold current density, J_{rad}. We find that J_{rad} is itself relatively temperature insensitive (Fig. 1). However, the total threshold current density, J_{th}, increases significantly with temperature leading to a characteristic temperature T_0~72K around 220K-290K. From this data it is clear that the devices are dominated by a non -radiative recombination process which accounts for up to 94% of the threshold current at room temperature (Fig. 1).

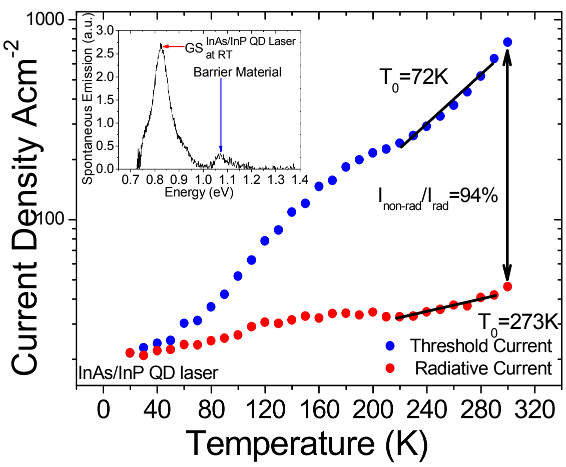

Fig. 1. Temperature dependence of J_{th} and J_{rad} as function of temperature. Inset shows spontaneous emission spectrum from QDs

Different carrier recombination processes have distinctive dependencies on the band gap, therefore hydrostatic pressure provides a robust tool to study the dominating processes since it allows one to reversibly vary the band gap of an operating device in the absence of other compositional changes [2, 3]. Fig. 2 shows that the lasing energy increases (reversibly) with pressure in the QD lasers with a pressure coefficient that is temperature insensitive, ~8meV/kbar.

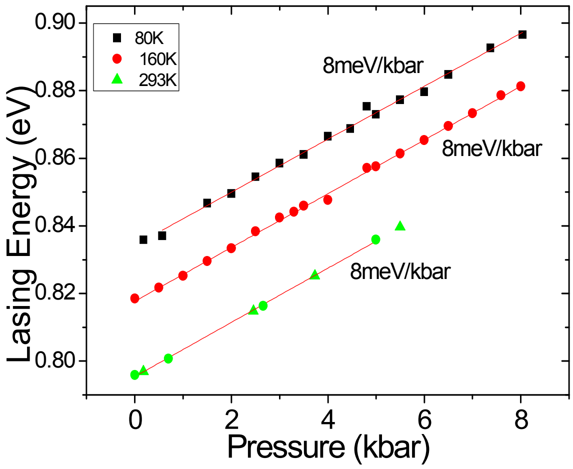

Fig. 2. Dependence of lasing energy on hydrostatic pressure and temperature for a quantum dot laser

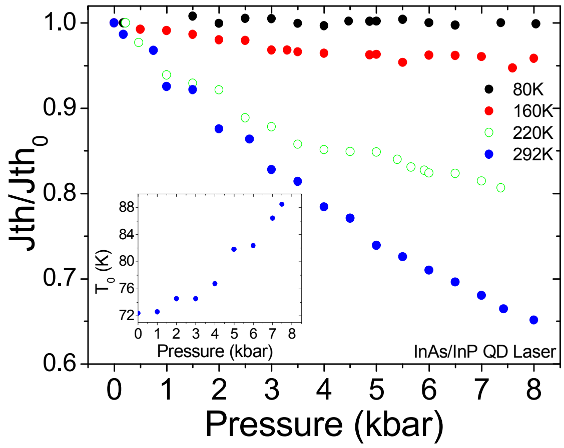

Fig. 3. Variation of J_{th} with temperature and pressure for the QD lasers and an inset showing T_o as function of pressure.

In Fig. 3, we plot the corresponding pressure and temperature dependence of the threshold current, normalised at atmospheric pressure. At room temperature, a strong decrease in threshold current is observed with increasing pressure, consistent with Auger recombination dominating as per previous findings on 1.55 µm (311B) InAs/InP [2] and 1.33 µm InAs/GaAs [3] QD lasers. With decreasing temperature, the rate of decrease in threshold current with pressure reduces. This is exactly as one would expect due to the reduced importance of Auger recombination at lower temperature, as evidenced from the temperature dependence data in Fig. 1. From these data it is clear that the thermal behaviour of these QD lasers is dominated under ambient conditions by Auger recombination.

In summary, we have investigated the temperature sensitivity of recombination processes in 1.55 µm InAs/InP QD laser grown on (100) InP substrate using temperature dependent measurements on J_{th} and J_{rad} and hydrostatic pressure measurements of J_{th} and lasing wavelength to determine the dominant recombination processes. The temperature behaviour of J_{th} and J_{rad} and decrease in J_{th} with increasing pressure indicates that these devices are dominated by NR recombination processes which decrease strongly with increasing pressure and also decrease with decreasing temperature. The presence of NR recombination processes is consistent with the temperature dependence characteristics observed in Fig. 1 and Fig. 3. Therefore we conclude that Auger process is dominant NR recombination processes in these devices at RT.

References:

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