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The influence of p-doping on the temperature sensitivity of 1.3μm Quantum Dot lasers

N. F. Massé, I. P. Marko, S. J. Sweeney, A. R. Adams,
Advanced Technology Institute, School of Electronic and Physical Sciences, University of Surrey, Guildford, Surrey GU2 7XH, United Kingdom
N. Hatori, M. Sugarawa
Optical Semiconductor Devices Lab. Fujitsu Laboratories LTD. 10-1 Morinosato-Wakamiya, Atsugi, 243-0197 Japan
n.masse@surrey.ac.uk

We find that non-radiative recombination plays an important role in p-doped quantum-dot lasers. Along with carrier thermalisation effects, this is responsible for the temperature insensitive operation as observed around room temperature in these lasers.

Temperature insensitive and thus cost effective lasers operating at 1.3 μm are of major interest for short range and ultra-fast telecommunication systems as silica optical fibers present a minimum of dispersion at this wavelength. Quantum Dot (QD) lasers have attracted much attention since Arakawa's prediction[1] in 1982 that superior performances may be obtained by confining the carriers in three dimensions. In particular, the possibility of an infinite T_o drove a great deal of research activity. In spite of the success of many groups in producing low threshold QD lasers at wavelengths including 1.3μm, an infinite T_o has remained elusive. However, recent reports of p-doped QD lasers have demonstrated a QD laser with a very low temperature sensitivity and a high modulation bandwidth of 10 Gb/s operating up to high temperature[2].

In this work we have concentrated on understanding the nature of carrier recombination in p-doped QD lasers and the extent to which different carrier recombination processes contribute to the temperature sensitivity of the devices. To do this we compare the recombination processes in both p-doped and intrinsic QD lasers with room temperature emission wavelengths close to 1.3 μm. We measured threshold densities of approximately 200 and 100 A/cm^2 for 1mm long p-doped and intrinsic devices, respectively at room temperature. Temperature and pressure dependent measurements of both the threshold current (I_{th}) and radiative current (I_{rad}) have been undertaken in order to separate the different recombination processes which occur in these devices. The radiative current is determined from the measured spontaneous emission collected from a window milled into the substrates of the lasers.

The temperature dependence of the intrinsic devices shows that I_{rad} remains relatively temperature stable, as predicted by Arakawa *et al.* Up to T=200 K it can be seen that I_{th}=I_{rad}. However, above this temperature I_{th} increases dramatically such that by room temperature, I_{th}>>I_{rad}. This has been attributed to non-radiative Auger recombination[3].

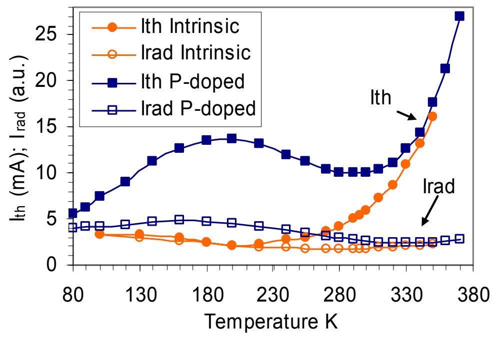

Figure 1: Variation of I_{th} and I_{rad} with temperature in intrinsic and p-doped 1 mm long devices

In the p-doped devices, non-radiative processes arise even at low temperature where we find that I_{th} and I_{rad} have quite different temperature dependencies. We find that I_{th} has a complicated temperature dependence with a temperature insensitive region from ~270K to ~310K. This we believe is due to the thermalisation of carriers between the dots of different sizes which causes the decrease in I_{th} (and I_{rad}) above ~200K. Coupled with a strongly temperature sensitive non-radiative current around room temperature,

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this gives rise to the plateau in I_{th} as seen between 270 and 310K.

In order to obtain more information about the non-radiative recombination processes, high hydrostatic pressure measurements have been performed enabling us to study the band gap dependence of the recombination currents.

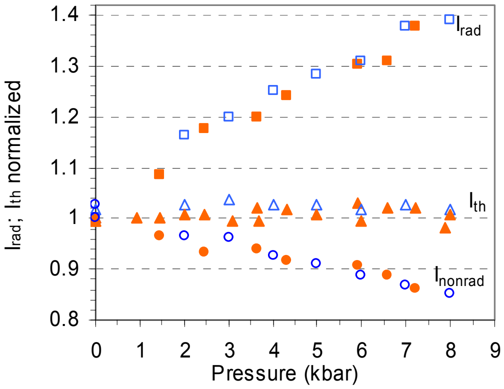

Figure 2: Pressure dependence of I_{th}, I_{rad} and $I_{non\text{-}rad}$ for 1 mm (solid symbols) and 0.5 mm (open symbols) intrinsic QD devices.

In the undoped devices (Figure 2), the normalized I_{th} remains constant over the whole pressure range studied. The magnitude of the radiative and non-radiative components of I_{th} can be estimated from the temperature dependence of I_{th} and I_{rad} assuming that $I_{th}=I_{rad}$ at low temperature as previously shown in Figure 1. The pressure dependence of I_{rad} is found to be in good agreement with previous measurements performed on QD devices[4]. This allows us to experimentally determine the pressure dependence of the non radiative current. We find that the non-radiative current decreases with pressure and is consistent with the strong presence of Auger recombination.

In the p-doped devices (Figure 3), the pressure dependence of I_{rad} is found to be similar to that of the intrinsic devices. However, in contrast we find that I_{th} *increases* with pressure at room temperature. Using a similar analysis to the intrinsic devices, these results suggest that a pressure independent current path such as defect related recombination plays an important role in the p-doped devices and makes a significant contribution in I_{th} at room temperature.

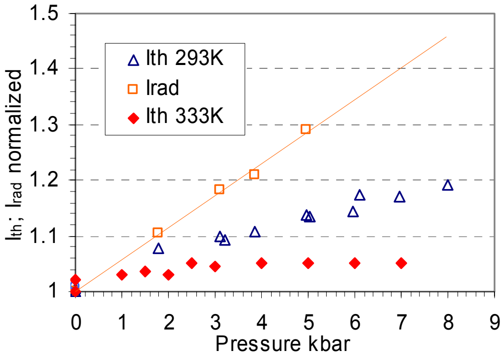

Figure 3: Pressure dependence of I_{th} at RT and 333 K and I_{rad} at RT.

At 333K, the rate of increase of I_{th} with pressure is found to be smaller than at 293K. This is consistent with Auger recombination playing an increasingly important role in these devices at higher temperatures. Due to the complexity of the effects, further investigations will be continued to confirm and eventually quantify the magnitude of the different recombination paths.

To conclude, we have studied the recombination processes in 1.3 µm intrinsic and p-doped quantum dot lasers for optical communications. The p-doped devices show an infinite T_0 around room temperature. By understanding the competition between radiative and non-radiative processes in the p-doped devices, we hope to determine optimal structures which could widen the already appreciable range of temperature insensitive operation. This together with the high speed of these devices promises exciting developments in this area for which a detailed knowledge of the basic device physics is essential.

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