AIP Conference Proceedings

# The Influence of Auger Processes on Recombination in LongWavelength InAs/GaAs Quantum Dots

I. P. Marko, A. D. Andreev, S. J. Sweeney, A. R. Adams, R. Krebs et al.

Citation: AIP Conf. Proc. **772**, 681 (2005); doi: 10.1063/1.1994289

View online: http://dx.doi.org/10.1063/1.1994289

View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=772&Issue=1

Published by the American Institute of Physics.

---

# The Influence of Auger Processes on Recombination in Long-Wavelength InAs/GaAs Quantum Dots

I. P. Marko[1], A. D. Andreev[1], S. J. Sweeney[1], A. R. Adams[1], R. Krebs[2],
S. Deubert[2], J. P. Reithmaier[2], A. Forchel[2]

[1]*Advanced Technology Institute, University of Surrey, Guildford, Surrey, GU2 7XH, UK*
[2]*Technische Physik, Universität Würzburg, Am Hubland, D-97074, Würzburg, Germany*

**Abstract.** Analysis of the temperature dependencies of the threshold current and of the unamplified spontaneous emission in 0.98-µm and 1.3-µm InAs/GaAs quantum dot lasers as well as high hydrostatic pressure studies show that the recombination and loss mechanisms are wavelength dependent. The results indicate that the temperature dependence of the threshold current is due to two non-radiative recombination processes. Auger recombination is very important in the 1.3-µm devices at room temperature and causes their temperature sensitivity. In the 980 nm lasers Auger recombination is negligible, but thermal escape of carriers out of the dots followed by defect related recombination leads to an increase of the threshold current with temperature.

## INTRODUCTION

It has been predicted that if the electrons can be confined to a single discrete atomic like level in quantum dot (QD) lasers, they will not suffer large thermal broadening and the threshold current will be temperature insensitive. However, despite the growth of very good self-assembled layers of quantum dots, the longer wavelength lasers with the low threshold currents required for optical communication are still temperature sensitive [1]. Therefore it is very important to understand the physical mechanisms responsible for QD laser operation and their temperature performance.

## RESULTS AND DISCUSSION

InAs quantum dot lasers with emission wavelengths near 980 nm and 1.3 µm at room temperature with similar waveguide and cladding structures [2, 3] were studied using measurements of stimulated and of unamplified spontaneous emission as a function of temperature and while applying high hydrostatic pressure [3]. The 1.3 µm lasers were symmetrically or asymmetrically designed "dot in a well" (DWELL) structures [2].

The threshold current density, $J_{th}$, and its radiative component, $J_{rad}$, which is proportional to the integrated spontaneous emission at threshold, of different QD lasers are shown in Fig. 1. We observed that $J_{rad}$ is much less temperature sensitive than the total threshold current, demonstrating that there must be at least one temperature sensitive non-radiative loss process. The characteristic temperature, $T_0$, of $J_{th}$ was $T_0$=110-130 K and $T_0$=40 K in the 980 nm lasers and in the 1.3 µm lasers, respectively, indicating that the recombination mechanisms in these lasers are different and most probably wavelength dependent. An asymmetric design of the active region of 1.3 µm lasers significantly decreased $J_{th}$, but did not increase $T_0$. It was also found that in the 1.3 µm devices there is a non-radiative loss process that decreases strongly with increasing hydrostatic pressure, p. Hydrostatic pressure allows the band gap, $E_g$, to be varied at constant temperature while keeping all other basic properties of the structure effectively unchanged. This allows the relative importance of different recombination mechanisms to be determined. The mechanisms we considered are: i) electron leakage via the AlGaAs cladding layers, ii) intervalence band

CP772, *Physics of Semiconductors: 27th International Conference on the Physics of Semiconductors,*
edited by José Menéndez and Chris G. Van de Walle

absorption, iii) thermal excitation from the dots and subsequent non-radiative recombination, probably via defects and iv) Auger recombination.

Normalised pressure dependencies of $I_{th}$ for different QD structures are given in Fig. 2. The increase in $I_{th}$ with p in the 980 nm QDs can be fitted by assuming that the difference between $J_{th}$ and $J_{rad}$ in Fig 1 is due to process iii) together with a small (0.06%) of process i). Process iii) is pressure independent but gives rise to the strong temperature dependence of $J_{th}$ in Fig 1. On the other hand process i) does not affect the temperature dependence at atmospheric pressure but explains the high-pressure behavior. Processes i) and iii) are expected to be much smaller in the 1.3 µm QD lasers since the quasi Fermi level separation at lasing is less. Also in both 1.3-µm laser types $I_{th}$ decreases strongly with increasing pressure. The only process, which behaves in this way and can also explain the temperature behavior is Auger recombination [3].

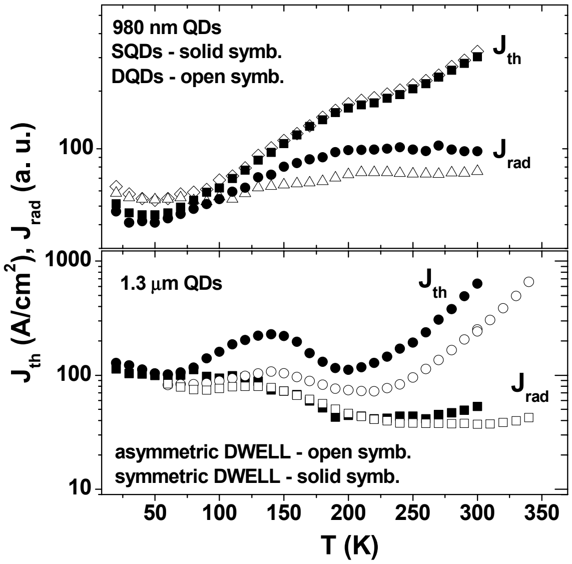

**FIGURE 1.** Temperature dependencies of the threshold current density, $J_{th}$, and its normalized radiative component, $J_{rad}$, for the 980 nm QD lasers with single (SQDs) and double layers of QDs (DQDs), and for the 1.3 µm QD lasers with dots grown symmetrically and asymmetrically in the well.

To estimate the contribution of Auger recombination in different lasers, we fit experimental results in fig. 2 using a simple theoretical model, assuming that $I_{th}=I_{rad}+I_{Aug}$ and that the radiative component increases as $E_g^2$ [3]. An Auger component is required corresponding to 60% and 70% of the threshold current in the asymmetric and symmetric devices respectively.

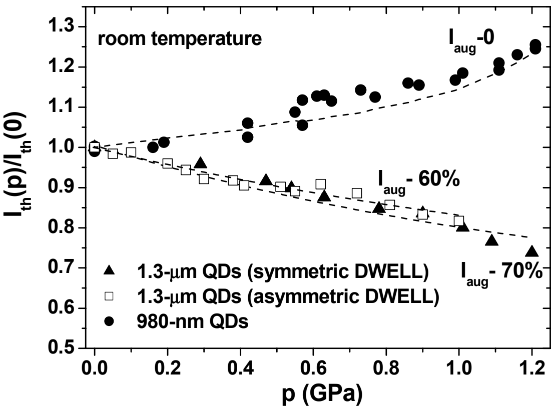

**FIGURE 2.** Normalised threshold current $I_{th}(p)/I_{th}(0)$ vs pressure for the 980 nm QD laser with one layer of QDs and for the 1.3 µm lasers. Dashed curves are the theoretical fits as described in the text.

In conclusion, the importance of Auger recombination in 1.3 µm QD devices may explain their strong temperature dependence, just as was observed in quantum well 1.3 µm devices. Further understanding of Auger process in quantum dots would be very helpful in design of more temperature insensitive quantum dot lasers.

## ACKNOWLEDGMENTS

The authors gratefully acknowledge EPSRC for financial support.

## REFERENCES

1. R. Fehse, I. Marko, A. R. Adams, IEE Proc. Circuits, Devices and Systems, **150** (6), 2003, pp.521-528.
2. R. Krebs, S. Deubert, J. P. Reithmaier, A. Forchel, IEEE J. Cryst. Growth, **251**, 2003, pp. 742-747.
3. I. P. Marko, A. D. Andreev, A. R. Adams, R. Krebs, J. P. Reithmaier, A. Forchel, IEEE J. Select. Topics Quant. Electr., **9** (5), 2003, pp. 1300-1307.