## Abstract

An asymmetric rate equation model which takes into account lasing from both the ground and excited states and distinguishes between electrons and holes is presented to analyse the simultaneous two-state lasing operation in a single-mode quantum dot laser. Under certain assumptions, the model is reduced to a simpler form in order to obtain simple mathematical expressions for the steady-state occupational probabilities for electrons and holes in the ground and in the excited states, as well as for the intensities of both modes, and relaxation oscillation frequencies in both single and dual lasing regimes.

From the expression of the steady state solutions, we can explain the role of the effective gain factor. Specifically, we show that the effective gain factor affects the threshold itself. Also, we show that larger values of the effective gain factor prevent the decrease of the ground state output power after the appearance of the excited state lasing.

We apply a linear stability analysis to the analytical solutions of the reduced model to clarify the relaxation oscillation dynamics in a single-mode quantum dot laser. By getting mathematical expressions for the relaxation oscillation frequencies in both single and dual lasing stable regimes at different time scales, we prove that the intradot time scales strongly affects the relaxation dynamics in the quantum dot laser.

Finally, a delay differential rate equation model is presented to support the multi-mode lasing operation in pulsed quantum dot lasers. The model is solved numerically to explain the experimentally observed power dropout of a quantum dot laser under pulsed current conditions. Specifically, we show that the large value of the linewidth enhancement factor in the proximity of the excited state threshold can explain the power dropout. Also, we introduce a bifurcation analysis of a slow passage through a Hopf bifurcation to clarify the power dropout.