# Operational limits of high power quantum dot lasers

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Quantum dot (QD) lasers have attracted considerable recent attention in view of the interesting physics involved and the potential for wide range of applications. Operating characteristics of QD lasers are controlled by a number of factors. Here, the effects are discussed of nonuniformity of QDs, carrier-density-dependent internal loss in the waveguide, and excited states in QDs on the optical power of a laser.

In view of the variety and relative strength of contributing processes, the internal loss coefficient can range from below one to above several tens of reciprocal centimeters. Here, the maximum output optical power is discussed as a function of the effective cross section for internal absorption loss processes. The maximum power reduces to zero as the cross section approaches its largest tolerable value. The use of multiple layers of QDs is shown to significantly improve the laser output characteristics.

A general trend of the output power degradation with increasing nonuniformity of QDs has been discussed in [L. V. Asryan, S. Luryi, R. A. Suris, IEEE J. Quantum Electron. 39, 404 (2003)]. Here, the effect of nonuniformity of QDs on the shape of the light-current characteristic (LCC) is studied in the presence of carrier-density-dependent internal loss in the waveguide. A fascinating behavior of the LCC is revealed — two considerably different shapes of the LCC exist: "conventional" roll-over with single-branch (relatively uniform QDs), and roll-over with two-branches (nonuniform QDs). According to the theoretical model developed here, the quenching of lasing at a nonvanishing output power, often observed experimentally, can suggest the presence of high carrier-density-dependent internal loss and/or large QD-parameter dispersion.

In actual QDs, excited states are present in addition to the ground-state. For a direct capture of carriers from the waveguide into single-state QDs, the optical power of a laser has been calculated in [L. V. Asryan, S. Luryi, R. A. Suris, Appl. Phys. Lett. 81, 2154 (2002); IEEE J. Quantum Electron. 39, 404 (2003)]. Here, indirect capture into the QD ground-state, which occurs via the QD excited-state, is discussed. Such a capture places a fundamental limitation on ground-state lasing. As a consequence of a two-step capture into the lasing state in a QD, the output power saturates with increasing injection current. It is the transition from the excited- to ground-state that finally controls the carrier supply to the lasing ground-state and strongly limits the output power. The saturation power is discussed as a function of the transition time. The longest, cut-off time exists, beyond which no ground-state lasing is possible. The existence of the longest transition time is another manifestation of the critical dependence of the laser characteristics on the QD structure parameters, which has been revealed earlier [L. V. Asryan, R. A. Suris, Semicond. Sci. Technol. 11, 554 (1996); L. V. Asryan, S. Luryi, R. A. Suris, IEEE J. Quantum Electron. 39, 404 (2003).].

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