

# Excited states and optical power of ground-state emission in quantum dot lasers with asymmetric barrier layers

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**Abstract:** Continuous-wave power of ground-state emission in quantum dot lasers with asymmetric barrier layers is studied. Unlike conventional lasers, the power is virtually unaffected by excited-to-ground state relaxation delay of carriers in quantum dots. © 2021 The Authors

Semiconductor lasers present an important component for various applications ranging from telecommunication to medical uses. Conventional semiconductor lasers with a low-dimensional active region [Fig. 1(a)] suffer from parasitic electron-hole recombination that occurs in the optical confinement layer (OCL) [1-4]. To suppress this recombination outside the laser active region, two alternative approaches were proposed [5-12] – one based on double tunneling-injection (injection of both electrons and holes) into the quantum-confined active region and the other using asymmetric barrier layers (ABLs).

Here we discuss the optical output of quantum dot (QD) lasers with ABLs. In such lasers, the active layer with QDs is clad on each side by a thin barrier layer [Fig. 1(b)]. The barrier layers are designed in such a way that they prevent from building up bipolar carrier (i.e., both electron and hole) population in the OCL. As a result of this, the parasitic electron-hole recombination in the OCL is suppressed in ABL QD lasers.

As in conventional QD lasers [13], the QDs in ABL lasers may contain excited states in addition to the ground state. In this work, the optical power of ground-state emission in ABL QD lasers is studied in the presence of excited states in QDs. The most dramatic situation is considered in which the charge carriers injected into the OCL are not directly captured into the lasing ground state in QDs – they are first captured from the OCL into the excited state in QDs and then they relax from the excited state to the ground state [Fig. 1(b)].

The rate equations model is used for the layered structures shown in Fig. 1. The electron and hole populations in the OCL, excited-state and ground-state in QDs, and the optical power are calculated as a function of the injection current.

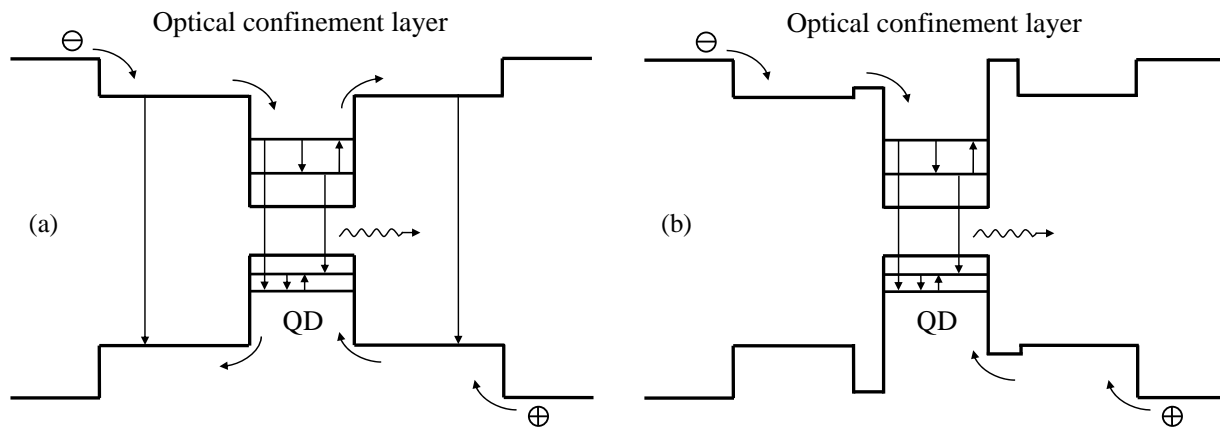


Fig. 1. Schematic energy band diagrams: (a) conventional QD laser, (b) ABL QD laser.

Fig. 2 shows the power of ground-state emission against the injection current density in (a) conventional and (b) ABL QD lasers. As seen from Fig. 2(a), the output power saturates with pumping in the conventional laser [the dashed line in (a) shows the saturation value]. The saturation is due to the combination of two effects – relaxation delay of charge carriers from the excited- to ground-state in QDs and parasitic electron-hole recombination in the OCL. As opposed to conventional QD lasers, the power of ground-state emission continues to increase with increasing injection current in the ABL laser. As the other advantages of ABL lasers, this advantage for

continuous-wave high-power lasing of ABL QD lasers over the conventional QD lasers is due to efficient suppression of unwanted electron-hole recombination in the OCL in ABL QD lasers. Indeed, in this case, even in the presence of excited-to-ground state relaxation delay in QDs, a built up of carrier population of one type only may occur in each side of the structure – electrons in the left- and holes in the right-hand side in Fig. 2(b).

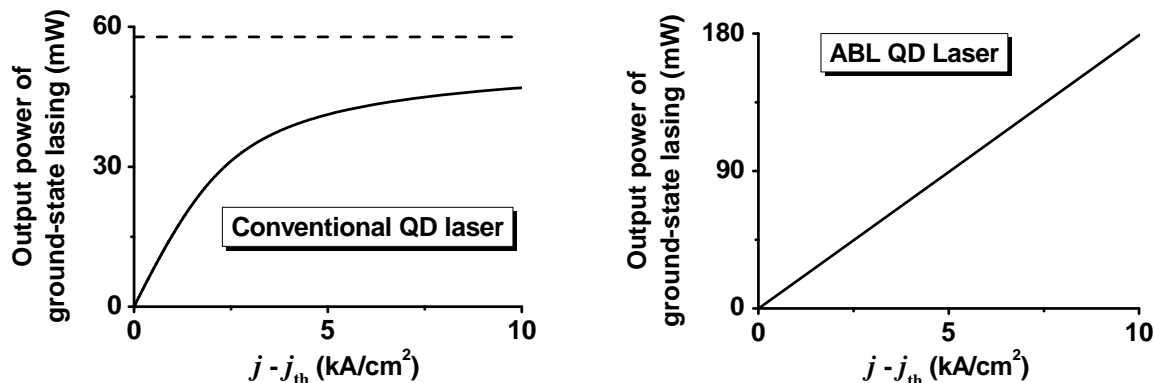


Fig. 2. Optical power of ground-state emission vs. excess of injection current density over threshold current density: (a) conventional QD laser, (b) ABL QD laser. The horizontal dashed line in (a) shows the saturation value of the power for ground-state emission in the reference conventional QD laser. The reference structure lasing near 1.55  $\mu\text{m}$  is considered [13, 14].

In conclusion, it is shown that, even in the most dramatic situation of indirect capture of charge carriers into the lasing ground state and unlike the conventional QD lasers, the continuous-wave power of ground-state emission in ABL QD lasers does not saturate with increasing pump current – instead, it increases almost linearly with injection current. This advantage for high-power lasing of ABL QD lasers over the conventional QD lasers is due to efficient suppression of unwanted electron-hole recombination in the OCL in ABL QD lasers.

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