Optical Properties of Molecular-beam-epitaxy-grown InAs/InAlGaAs/InP Quantum Dots as 1.55 μm Emitters in Tunnel Injection Lasers

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Quantum dot (QD) layers as active material for lasers have not yet shown full potential, especially for telecom application. Although the theoretically predicted advantages of QD-based lasers, such as low sensitivity to temperature and low threshold currents, have been confirmed, there still exist two major obstacles limiting both their emission intensity and modulation speed. The first one is low carrier collection efficiency, related to small total volume of dots. It may be reduced with multiple QD layers, which however adversely affects other parameters of a laser and can increase the losses. The second one is directly related to the 3D confinement of carriers and resulting discreet ladder of states. The speed of modulation is limited by the carriers relaxation into the lowest energy state, requiring many phonon emission processes, which considerably increase its time. In order to alleviate this, the tunnel injection scheme has been proposed [1], where carriers are collected and thermalize within the injector quantum well (QW) and then tunnel to the lowest energy state of the neighbouring QD, with the assistance of lateral optical (LO) phonon. Practical realization of the device requires a careful design of its components. To achieve emission at 1.55 μm, InAs on InP material system should be used, allowing for the nucleation of large dots. However, in typical conditions of molecular beam epitaxy (MBE) it leads to the growth of high surface density, strongly elongated 3D islands, called quantum dashes, with very high inhomogeneity.

We present here the optical characterisation of symmetric structures of that kind grown by MBE - a novel family of QDs obtained thanks to the recent advances in InAs/InAlGaAs/InP growth [2], as candidates for emitters in tunnel injection lasers. The quantum-dot-like morphology of these nanostructures is confirmed in atomic force microscopy images. Photoluminescence (PL) measurements reveal strong emission from the ground state around 1.55 μm. The broadenings of the PL peaks are in the range of 20 meV – at least twice better than for quantum dashes and QDs of that material system fabricated by other techniques, evidencing improved homogeneity. It is important for the efficient injection of carriers, due to the required matching conditions for energy states in QW and QD layers. Polarization resolved PL showed the degree of linear polarization above 20%, which is unexpected for symmetric structures. In order to explain that result and to determine precisely the energy structure of levels confined in the QDs, we have performed calculations in an 8-band $\mathbf{k}\cdot\mathbf{p}$ model, with realistic geometries, strain and piezoelectricity effects included. The calculated energy level structure agrees with high excitation power PL spectra and proves that the obtained confined levels for holes and electrons can be matched by a single LO-phonon energy to the states in an InGaAlAs quantum well injector. The degree of polarization is understood as driven mainly by lateral coupling between dots (surface images show that dots gather in long chains) and some remaining asymmetry.

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[2] V. I. Sichkovsky, M. Waniczek and J. P. Reithmaier, *Appl. Phys. Lett.* **102**, 221117 (2013).