Effect of stack number on the threshold current density in Quantum Dash/Dot lasers

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Abstract : We demonstrate the achievement of multiple stacked InAs quantum dash and quantum dot lasers. The threshold current density reaches a minimum value of 680 A.cm^{-2} for quantum dash lasers on InP (100) and 170 A.cm^{-2} for quantum dot lasers on InP (311)B. The wavelength varies from about 1.49µm to 1.58µm.

Experiment: The lasers were grown by gas source molecular beam epitaxy (GSMBE) on n-type (100) and (311)B InP wafers for QDH and QD respectively. The active region comprises multiple layer stacked QDHs (QDs) with a nominal deposition thickness of 0.6 nm InAs per layer. The QDH (QD) layers are separated by relatively thin barriers of 30 nm lattice-matched $In_{0.8}Ga_{0.2}As_{0.43}P_{0.57}$ quaternary ($Q_{1.18}$; λ_g=1.18 µm). The active region is embedded into the centre of a 320 nm $Q_{1.18}$ waveguide, providing optical confinement in the transverse direction by the refractive index contrast to the cladding layers. The core structure is surrounded by 500 nm low doped InP cladding layers on both sides. The top cladding is followed by a highly doped 2.5 µm InP and capped with a 150 nm InGaAs contact layer. All layers, except the QDH (QD) layers, are lattice matched to InP. The growth process of QDH (QD) was optimized by using the double-cap technique as well as controlling the arsenic flux[1]. The double-cap technique consists of a capping procedure in two steps. The first capping step is the deposition of a fixed small thickness, and the maximum height of the QDH (QD) is therefore controlled easily and reproducibly by the thickness of this first capping layer, thus allowing a reduction of the height dispersion. The QDH (QD) formation is followed by a growth interruption under group As_2 and P_2 fluxes, resulting in planarization of the surface due to effective As/P exchange. The second capping step is then carried out to complete the spacer layer. The reduction of the arsenic flux results in better morphology. Therefore, the emitting wavelength of the laser can be easily tuned in the range of 1.55 µm telecommunication wavelength. Moreover, a sharper gain curve can consequently be expected for the structure, which greatly eases the losses compensation. Figure 1 is a 1 × 1 µm^2 atomic force microscopy (AFM) image of uncapped QDHs structure containing 3 stacked layers. The morphology shows elongated QDHs with a mean height, width, and length of 2.2, 20, and 300 nm respectively. The surface density is 2×10^{10} cm^{-2}.

The broad area lasers were processed by a standard laser processing technique. The stripes of QDH lasers on InP (100) were patterned along [011] direction which is perpendicular to the dash elongated direction, with a width of 100 µm. The direction is chosen to obtain higher modal gain and thus lower threshold [2]. For QD lasers on InP (311)B, the stripes were along [01-1], as (01-1) planes are the only ones that can be cleaved to obtain cavity mirrors. The cavity length of QDH and QD lasers are 1.2 and 3.0 mm respectively, with both cleaved facets uncoated. The lasers were mounted on a copper block using silver epoxy. The laser diodes showed turn-on voltages at 0.7 V. The laser diodes are electrically injected by pulsed current with 500 ns pulse width and 2 kHz repetition rate.

Results: The lasing wavelengths of QDH lasers increase with stack number from 1.49 to 1.58 µm, resulting from inhomogeneous morphology during stacking. A gradual decrease of J_{th} with reduced stack number is confirmed, and a minimum J_{th} of 680 A.cm^{-2} is obtained for a double layer stacked QDH laser, depicted in Figure 2. Similar J_{th} trend is predicted in quantum wells [3]. For quantum dot lasers on (311)B, double stacked QD laser with ultra low J_{th} of 170 A.cm^{-2}

was demonstrated[4]. Moreover, lasing from a single QD layer as active region was obtained with a QD density of higher than 10^{11} cm^{-2} [5]. Unfortunately, the single QDH structure didn't give lasing at room temperature, probably due to the very low optical confinement factor and relatively low surface density of QDHs. For a very small number of stacked layers, the low value of optical confinement factor implies a strong increase of the threshold carrier density, and thus high pumping level is required to reach lasing. On the other side, for larger number of stacked layers, threshold carrier concentration approaches transparency carrier concentration, and J_{th} thus increases linearly with the number of stacks. At the minimum of the curve, a further reduction of J_{th} in QDH laser could be possible after optimizing the size fluctuation and surface density of the quantum structure.

Conclusion: Threshold current density and wavelength as a function of stack number are investigated in quantum dash and quantum dot lasers. The results show that the lowest J_{th} can be obtained at an intermediate stack number. This is attributed to the behaviour from the sum of current density in active region and in the waveguide region.

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Figures:

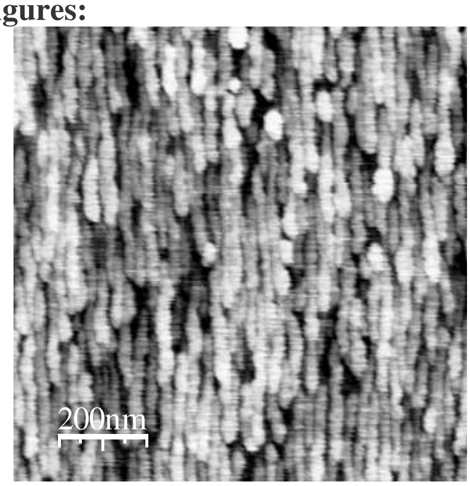

Figure 1

1 × 1 μm^2 AFM image of an uncapped three-fold stacked QDH layer.

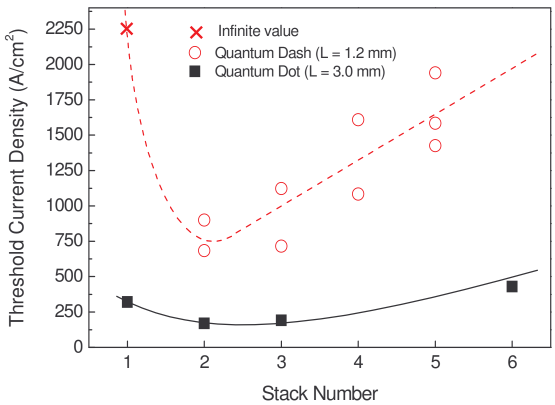

Figure 2

Threshold current density as a function of stack number for QDH (open circle) and QD (filled square). (The continuous line is a guide to eyes). For single stacked QDH laser, no lasing was observed, as J_{th} reaches infinite value.