Low Threshold Current Density InAs Quantum Dash Lasers on InP Using Double Cap Technique

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Abstract

Low threshold current density InAs quantum dash lasers is demonstrated by reducing the energy inhomogeneous broadening through an optimized double cap technique. A threshold current density for infinite cavity length of 225 A/cm^2 (~ 45 A/cm^2 per stack) is obtained from 5-stack laser structure. The characteristic temperature of 52 K is measured in the temperature range between 25 and 70 °C.

INTRODUCTION

Self-assembled quantum dash (QDH) and quantum dot (QD) lasers are expected to have superior performance, such as low threshold current density (J_{th}), high temperature stability, high modulation bandwidth, and ultrafast operation [1-3]. QDH structure exhibits clear linear polarization, which is an advantage to reduce the bit rate error in device operation. Mode-locking has recently been realized by QDH laser at 134 GHz [4]. Ultrafast mode-locked laser requires a short cavity length, and thus low threshold is an important issue. However, due to the inhomogeneous broadening of practical QDHs (QDs), the interesting features are limited. Long wavelength self-assembled InAs QDH grown on InP substrate have been explored to obtain wavelength emission of 1.55 µm for optical fibre communications, but the typical photoluminescence (PL) linewidth of InAs/InP QDH is more than 100 meV, much larger than that of InAs/GaAs material system, due to the difficulty to control As/P exchange [5,6]. Double cap technique is therefore developed to control the As/P exchange during QDH formation, with successful tuning of the emission wavelength into the range of 1.55 µm. In this letter we report room temperature operation InAs QDH laser on InP substrate with InGaAsP as optical waveguide, emitting around 1.58 µm. A low threshold current density for infinite length of 225 A/cm^2 is obtained. Internal quantum efficiency and internal optical losses is deduced to be 55 % and 7 cm^{-1} respectively.

EXPERIMENT

The QDH laser structures were grown by molecular beam epitaxy (MBE) on n-doped InP (100) substrate. The laser structure is based on a separate confinement waveguide design consisting of a 320 nm thick InGaAsP (Q1.18) lattice matched to InP substrate. The lower cladding consists of an InP substrate and a 600 nm thick InP layer. The upper cladding and contact layers are 2000 nm thick InP and 200 nm InGaAs respectively. In the centre of the waveguide core, the QDH active region consists of five stacked 2.1 MLs InAs dash layer with 20 nm Q1.18 as spacer layers. Importantly, after the formation of QD, a first cap of 2.2 nm thick Q1.18 is deposited, and then 30 sec growth interruption under As_2+P_2 flux is optimized. After that the rest of the spacer layer of Q1.18 is deposited to complete the technique, i.e. double cap technique [5]. The PL measurement is performed at RT and the signal is dispersed into a monochromator and collected by InSb detector. Broad area lasers are processed by a conventional lift-off processing technique. The QDH laser stripes are patterned along [011] direction with a width of 100 µm. The laser bars are cleaved into cavities with various lengths and both facets are left uncoated. The laser diodes are electrically pumped by pulsed current with 0.5 µs pulse width and 2 kHz repetition rate.

The growth process uses the double cap technique as well as the control of the arsenic flux to tune the wavelength and to optimize the density [5]. By this means, the emitting wavelength of the laser can be tuned to the 1.55µm spectral window. Figure 1 depicts the PL spectrum obtained at RT for 5-stack QDH. With this optimized double-cap growth condition, i.e. first cap thickness and growth interruption time, the result shows peak energy at 0.797 eV (corresponding to wavelength at 1.56 µm) and a narrow full width at half maximum (FWHM) of 62 meV. The energy inhomogeneous broadening is much lower than the typical value of 100 meV for QDH by conventional method. This indicates that the As/P exchange is better controlled of by optimizing the double cap technique.

Figure 2 depicts the J_{th} exponential dependency on the inverse cavity length. The current density for infinite length of 225 A/cm^2 is derived for the 5 stacked QDH laser, i.e. 45 A/cm^2 per QDH layer. This low value for QDH lasers indicates their potential to reach ultralow threshold and thus ultrafast operation in the future. The inset corresponds to the lasing spectrum under injection current density of 1.1 × Jth for a cavity length of 1.2 mm. The lasing wavelength is centered at 1.587μm, in accordance with the PL emission wavelength, indicating the lasing is from the ground state

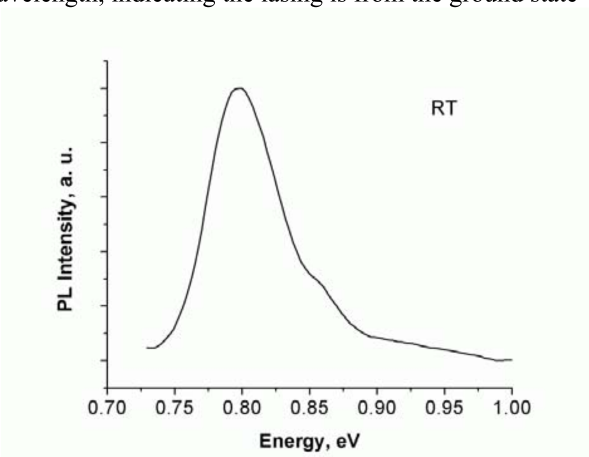

Fig. 1: PL spectrum taken at RT of 5-stack QDH structure.

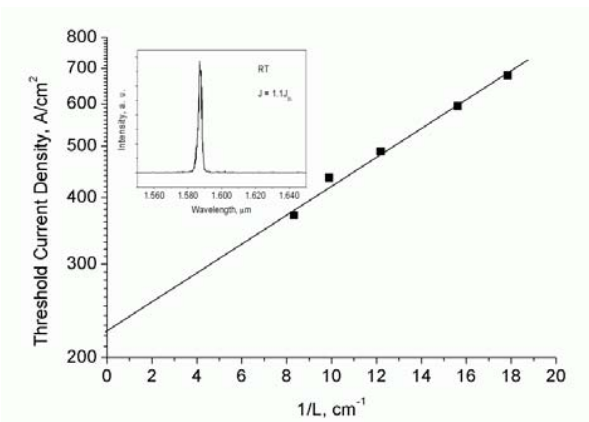

Fig. 2: J_{th} vs the reciprocal length taken at RT for 5-layer stacked QDH lasers. The inset shows a lasing spectrum at 1.1 × J_{th} for a cavity length of 1.2 mm.

The inverse external quantum efficiency ($1/\eta_{ext}$) as a function of the cavity length is plotted in Fig. 3. A linear fitting is performed according to:-

$$1/\eta_{ext} = 1/\eta_{int}[1+\alpha_{int}L/\ln(1/R)],$$

where η_{int} and α_{int} are respectively, the internal differential quantum efficiency and the internal optical loss, and R is the mirror reflectivity. The internal quantum efficiency (η_{int}) and internal optical loss (α_{int}) are extracted to be 55 % and 7 cm^{-1} respectively. The value of α_{int} is lower than the typical values of 10—20 cm^{-1} reported for QDH lasers grown by conventional capping technique [1,6]. This is believed to be a reflection of the material quality improvement through optimized double cap technique, confirmed also by the small PL linewidth mentioned above. Therefore, the less energy dispersion and the lower optical losses result in a lower threshold current, since the lower pumping level has to be reached for enough modal gain.

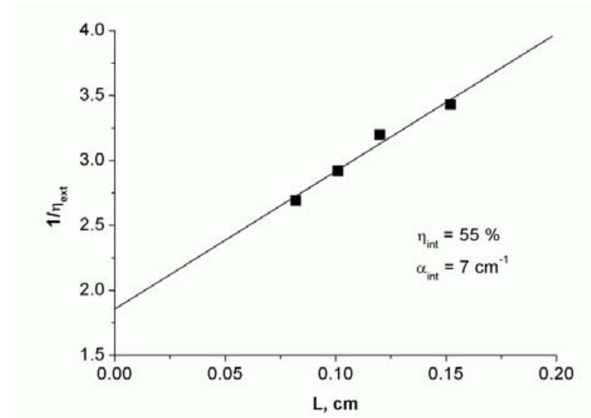

Fig. 3: Inverse external quantum efficiency vs cavity length taken at RT.

In addition, the temperature dependence of the J_{th} is plotted in Fig. 4 in the range from 25 to 70 °C. The characteristic temperature of the threshold (T_0) is determined to be 52 K. This value is similar to those reported in the literature. The relatively low T_0 originated from the low energy confinement of the Q1.18 barrier and the low band offset ratio of the conduction band.

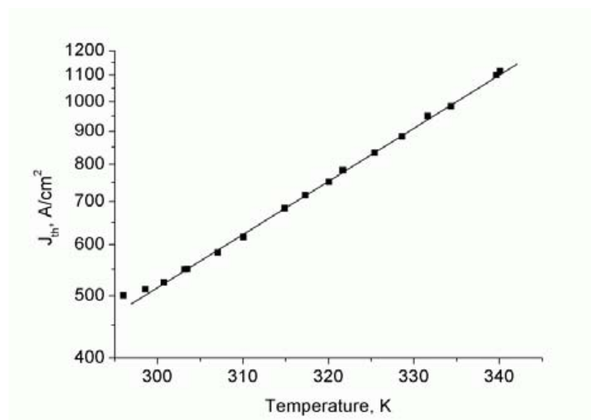

Fig. 4: J_{th} as a function of temperature for 5-stack QDH laser.

CONCLUSIONS

We have demonstrated quantum dash laser emitting at 1.58 μm grown by gas source MBE. Broad area lasers show a low threshold current density for infinite length of 225

A/cm^2 (45 A/cm^2 per dash layer). It results from the small energy inhomogeneous broadening and low internal optical loss. The characteristic temperature of 52 K is deduced in the temperature range between 25 and 70 °C.

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ACRONYMS

MBE: Molecular Beam Epitaxy
J_{th}: Threshold current density
PL: Photoluminescence
FWHM: Full Width at Half Maximum
RT: Room temperature