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Single-layer InAs/InP (100) quantum-dots on well laser and mid-infrared emission

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Abstract— We report a single layer InAs/InP (100) quantum dot (QD) laser operating in continuous wave mode at room temperature on the QD ground state transition grown by metal organic vapor phase epitaxy. The necessary high QD density is achieved by growing the QDs on a thin InAs quantum well (QW). This QDs on QW laser exhibits a high slope efficiency and a lasing wavelength of 1.74 µm. An extremely long-wavelength emission centered at 2.46 µm at 6 K is also observed from such QDs on QW structure.

Keywords- III-V semiconductors; semiconductor quantum dots; semiconductor lasers; mid-infrared emission

I. INTRODUCTION

InAs/InP (100) quantum dot (QD) lasers operating in continuous wave (CW) mode at room temperature (RT) on the QD ground state (GS) transition require multiple stacked QD layers for sufficient gain [1-2]. A single layer InAs QD laser was reported on InP (311)B where the QD density is higher than on InP (100) [3]. Here we report a single layer InAs/InP (100) QD laser operating in CW mode at RT on the QD GS transition and an extremely long-wavelength emission centered at 2.46 µm at 6 K.

II. DEVICE FABRICATION

The QD lasers were grown by low-pressure metalorganic vapor-phase epitaxy (MOVPE) on n-type InP (100) substrates using trimethyl-indium (TMI), trimethyl-gallium (TMG), tertiarybutyl-arsine (TBA), and tertiarybutyl-phosphine (TBP) as gas sources. The InAs QDs on QW structures and conventional InAs QDs for reference were placed in the center of a 500 nm thick lattice-matched InGaAsP waveguide core with a RT band gap at $\lambda_{Q}=1.25$ µm (Q1.25). For the InAs QDs on QW structure, a 1.6 nm-thick InAs QW was formed under metal stable conditions [4]. 1 ML InAs was deposited for QD formation which is already sufficient due to a large amount of surface segregated In on the InAs QW [6].

III. RESULTS

A. Single-layer InAs/InP(100) QD laser

Fig. 1 (a) and (b) show schematic drawing of the InAs QDs on QW structure and the InAs QDs grown with GaAs interlayer. Fig. 1 (c) and (d) are the atomic force microscopy (AFM) images of the QDs corresponding to the structures in Fig. 1 (a) and (b). The QD density is increased 5 ~ 6 times in the presence of the InAs QW from 6 x 10⁹ cm⁻² for the QDs on Q1.25 to 3.4 x 10¹⁰ cm⁻². This increase of the QD density on the InAs QW is attributed to the large amount of strain and surface segregated In [6].

Fig. 2 (a) - (c) show the electroluminescence and lasing spectra of the single layer InAs QDs on QW laser and the five-fold and three-fold stacked InAs QD lasers taken in CW mode at RT. Fig. 2 (d) shows the electroluminescence of the single layer InAs QD laser. QD GS lasing is obtained for the single layer InAs QDs on QW laser with lasing wavelength of 1.74 µm and for the five-fold stacked InAs QD laser. Excited state (ES) lasing of the single layer InAs QDs on QW laser sets in with increasing injection current, confirming GS lasing at...
threshold, shown in Fig. 2 (a) at twice the threshold current ($I_{th}$). For the three-fold stacked InAs QD laser only lasing from ES is observed. For the single layer of InAs QDs lasing is not achieved.

Fig. 3 shows the single facet (as-cleaved) light output versus injection current curves of the four QD lasers. $I_{th}$ of the single layer InAs QDs on QW laser and the five-fold stacked InAs QD laser are comparable. For the three-fold stacked InAs QD laser $I_{th}$ density per QD layer is increased significantly to 0.97 kA/cm$^2$ from 0.46 kA/cm$^2$ for the five-fold stacked InAs QD laser due to the three-fold degeneracy of the ES. The slope efficiency of the single layer InAs QDs on QW laser is larger than that of the five-fold stacked InAs QD laser. This is attained by the high density QDs on QW, the related larger confinement factor for the single layer QDs on QW due to their location in the center of the waveguide (see insets in Fig. 2), and a better carrier injection into this single layer.