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Low-Threshold Operation of Short-Wavelength Tensile-Strained QW AlGaInP Laser Diodes in 630-nm Band

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Theoretical investigations for the band structure of a strained-layer quantum well (QW) [1-2] have led to the improved performance of semiconductor lasers fabricated with several materials. In short-wavelength AlGaInP LDs, recent experiments [3-4] have shown the advantage of tensile strain besides compressive strain for low-threshold operation. A tensile-strained layer makes it possible to effectively design the oscillation wavelength of the 630-nm band with ternary QWs, although quaternary QWs are desirable to increase the carrier confinement in the case of a compressively-strained layer. However, the detailed design of tensile-strained QW structures for the further reduction in threshold currents has not yet been clarified. This paper examines the optimization for low-threshold operation of 630-nm band AlGaInP LDs, which can be used instead of a He-Ne gas lasers. We also provide a quantitative guide to the effective use of tensile strain in QW structures.

High performance of laser characteristics is expected by optimizing QW strain and quantum confinement simultaneously. We tried to increase the split between light-hole (lh) and heavy-hole (hh) subbands by introducing a large tensile strain for the wide QWs. This enables us to reduce the lh density of states and the threshold carrier density n_{th}. In this case, the oscillation wavelength should be retained in the same range because the overflow carriers from the active region cause excess current in proportion to the shorter wavelength.

The threshold current density J_{th} is compared for several tensile-strained QW structures with the wavelength of 635 nm. Here J_{th} is estimated as the total current density calculated from n_{th} and the excess carrier density. The carrier effective masses are determined by linear interpolation of the alloy composition. Figure 1 shows the calculated results for the dependence of J_{th} for each QW structure on QW numbers. These results suggest that J_{th} can be reduced by enlarging the width and decreasing the number of QWs with large tensile strain. Experimental results for the threshold currents I_{th} of three kinds of QW structures are shown in Fig. 2. These samples have the index-guided structure fabricated on 7°-off misoriented substrates [5-6] and almost the same optical confinement factor of the active region. The I_{th} in the SQW LDs is smaller than half of the unstrained MQW. The reduction in I_{th} which depends on the tensile-strained QW structure corresponds well to the tendency of the calculated results. The relative intensity of TE or TM polarization below threshold in three kinds of QW LDs is shown in Fig. 3. The relative intensity of TM polarization due to the electron-lh transition increases in accordance with a large tensile strain, while TE polarization due to the electron-hh is seen in the unstrained MQW. In the tensile-strained MQW LDs with a lattice mismatch of $\Delta a/a$ = -0.5%, the relative intensity and the split of hole subbands are not so large that the reduction in the lh density of states is insufficient. TM polarization intensifies due to the large split between lh and hh when $\Delta a/a$ = -1.1% is introduced for the SQW LDs whose QW width of 35 nm is as wide as the corresponding bulk layer. The low carrier density of states brings about low n_{th}, and also the larger heterobarrier which results in decreasing the excess carrier density. The lowest threshold current of 27.7 mA at 20°C was obtained among the tensile-strained SQW LDs as shown in Fig. 4. The oscillation wavelength was 629.5 nm at 5 mW. As a result, very low-threshold operation of 630-nm AlGaInP LDs, whose I_{th} is the lowest ever reported, is successfully attained by optimizing the tensile-strained QW structure.

References

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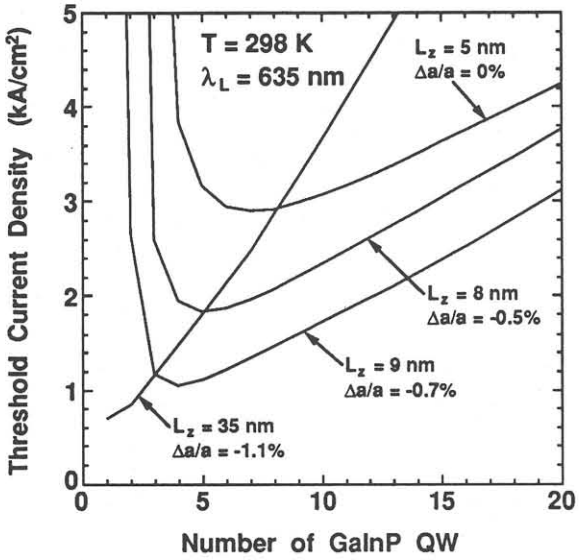

Fig. 1 Calculated results for threshold current density of AlGaInP LDs with various numbers of unstrained and tensile-strained QWs

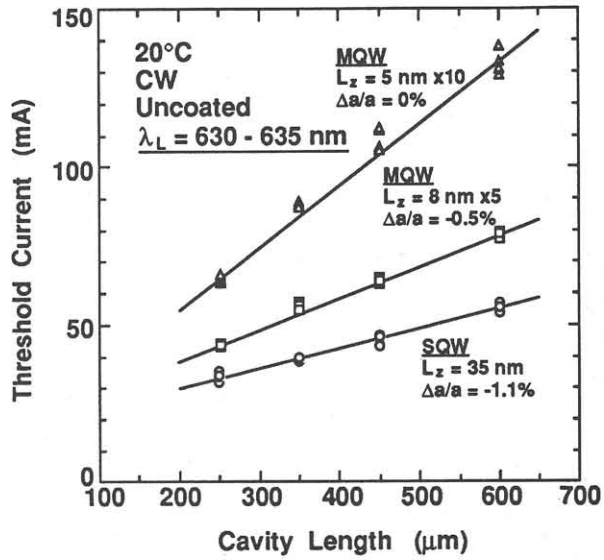

Fig. 2 Experimental results for dependence of the threshold currents of AlGaInP LDs with unstrained and tensile-strained QWs on cavity length

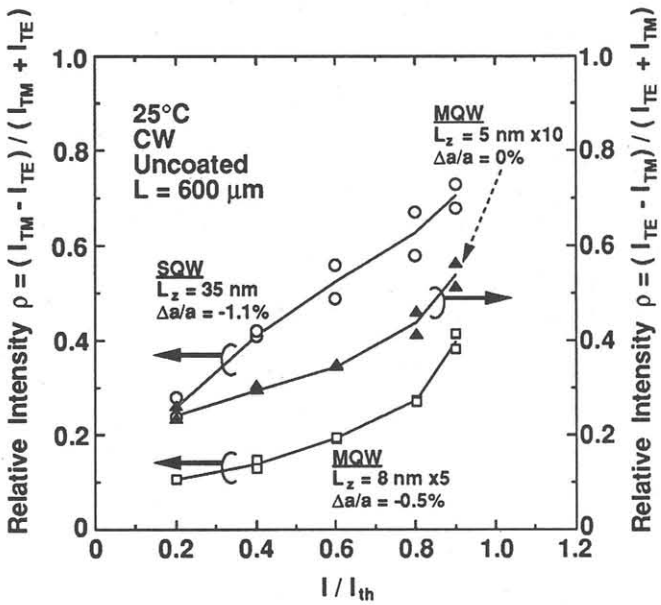

Fig. 3 Relative intensity ρ of TE or TM polarization in unstrained and tensile-strained QW LDs with respect to the ratio of injected current to threshold

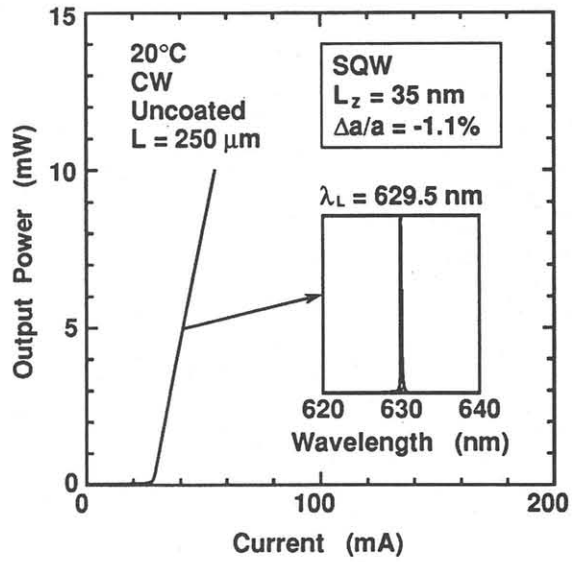

Fig. 4 Light output power vs injected current characteristics and longitudinal-mode spectra of a tensile-strained SQW LD with Δa/a = -1.1%