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Low Threshold and Record High TO (140 K) Long Wavelength Strained Quantum Well Lasers on InGaAs Ternary Substrates

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1. INTRODUCTION

Low threshold current and high characteristic temperature (T_0) 1.3 μm semiconductor lasers are strongly required for future optical interconnection and optical subscriber systems. The key technology for realizing them is to make the potential depth of quantum wells much deeper than that of conventional InGaAsP/InP systems. Larger optical gain and stronger optical confinement by deep potential quantum wells provide us low threshold lasers of excellent temperature characteristics, as is realized in 0.98 μm InGaAs/GaAs strained quantum well lasers[1]. Several technical approaches have been presented so far in order to make deep potential quantum wells emitting at 1.3 μm. Wide bandbap InAlGaAs barriers lattice-matched to InP[2], InAsP[3] and GaInNAs[4] quantum wells, and the InGaAs quantum wells on InGaAs graded buffer layers[5] have been employed.

Our approach to meet the requirement is the use of InGaAs ternary bulk substrates. Deep potential 1.3 μm quantum wells are possible on the InGaAs substrates whose indium content is between 0.25 and 0.3[1]. We previously fabricated the quantum well lasers on LEC-grown $In_{0.05}Ga_{0.95}As$ substrates[6-8] and on the $In_{0.21}Ga_{0.79}As$ substrates grown by multi-component zone growth method[9-13]. Photoluminescence at 1.3 μm was observed from the laser structure on $In_{0.26}Ga_{0.74}As$ substrates[14].

In this study, we have fabricated $In_{0.22}Ga_{0.78}As$ substrates and InGaAs/InAlGaAs strained quantum well lasers on them. The laser has lased at 1.225 μm with the low threshold current density of 176 A/cm^2. The T_0 of the laser has reached at 140 K, which is the highest value of ever reported for long wavelength semiconductor lasers.

2. FABRICATION

The grown $In_{0.22}Ga_{0.78}As$ bulk crystals were sliced along (100) orientation and mechanically polished. Surface damage was removed by wet chemical etching. Indium content of the substrates was checked by Bond method from the angle of (400) X-ray diffraction. The full width at half maximum (FWHM) of the rocking curve in the InGaAs substrates is 490 seconds, which is more than 20 times larger than that in GaAs as yet. The InGaAs substrates are n-doped because n-GaAs crystals were used in the growth. Electrical resistance of the InGaAs substrates is twice as large as that of a commercial Si-doped (2 X 10^{18} cm^{-3}) n-GaAs substrate. It is possible to form electrodes on the InGaAs substrate.

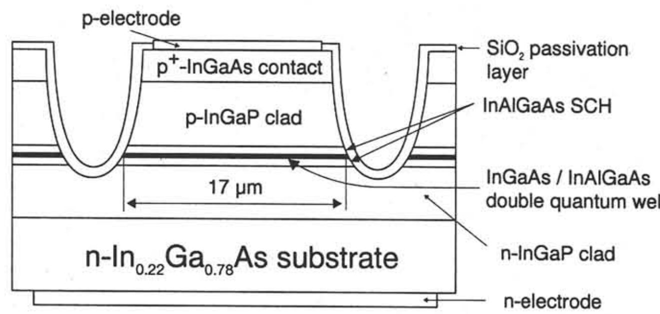

Fig. 1 Fabricated laser structure.

We fabricated 1.2 μm strained quantum well lasers on the InGaAs substrates because the indium content of the substrates is not enough to grow 1.3 μm quantum wells on them. Figure 1 shows the laser structure. A n-InGaP cladding layer (1.5 μm), an undoped double-quantum-well active layer sandwiched by 120-nm-thick InAlGaAs separate confinement heterostructure (SCH) layers, a p-InGaP cladding layer (1.5 μm) and a highly p-doped InGaAs contact layer (0.5 μm) were grown on the ternary substrates by metalorganic vapor phase epitaxy (MOVPE). The quantum wells consist of two 7-nm-thick InGaAs 1.32-%- compressively-strained quantum wells separated by a 10-nm-thick InAlGaAs barrier layer. The compositional wavelength of the InAlGaAs layers in the structure was set at 0.9 μm in order to make the potential wells deeper than those of the previous lasers[11-12]. Mesa stripes for carrier and optical confinement were defined by wet chemical etching. The width of active layers was 17 μm. Electrodes were formed on the p-InGaAs layer and the InGaAs substrate. 95 % high reflective (HR) layers were deposited on both facets of some devices. The fabricated laser chips were bonded on diamond heatsinks with junction side down.

3. MEASUREMENT

All measurements were carried out under pulsed condition. Figure 2 shows temperature dependence of current versus light output characteristics of the 600-μm-long laser with both facets HR-coated. The threshold current (I_{th}) at 20 °C is 18 mA and the corresponding threshold current density (J_{th}) is as low as 176 A/cm^2. The decrease of slope efficiency from 20 °C to 70 °C is only about 0.3 dB. This indicates that carrier overflow is suppressed owing to deep potential wells. Figure 3 show the lasing

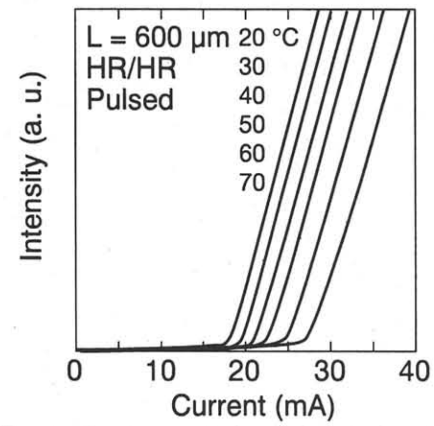

Fig. 2 Temperature dependence of current versus light output characteristics.

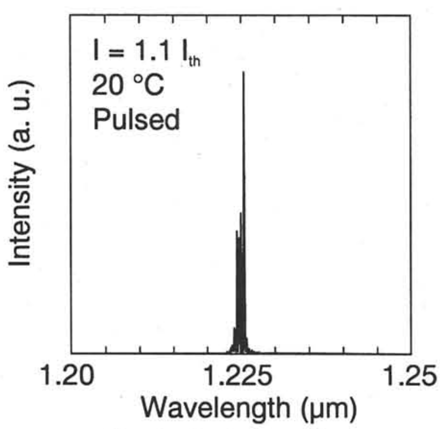

Fig. 3 Lasing spectrum.

spectrum at 20 °C under the injection level of 1.1 I_{th}. The lasing wavelength is 1.225 μm. Figure 4 is temperature dependence of the threshold current density. The T_0 in the temperature range from 20 °C to 50 °C is 140 K, which is the largest value of ever reported for long wavelength semiconductor lasers. These low threshold, temperature-insensitive efficiency, and high characteristic temperature have proven that InGaAs ternary substrates are very promising for fabricating the long wavelength lasers of excellent temperature characteristics. The characteristic temperatures of the devices strongly depend on the threshold current densities. The T_0 becomes lower in the device of higher J_{th}. A higher T_0 over 150 K is considered to be possible by increasing the number of quantum wells to obtain lower threshold. Further reduction of threshold would be possible by improving quality of the InGaAs substrates and applying wider bandgap cladding layers such as InAlAs.

4. CONCLUSION

We have fabricated the InGaAs ternary substrates and the 1.2 μm strained quantum well lasers on them. The low threshold current density of 176 A/cm^2 and the record high characteristic temperature of 140 K have been obtained in the fabricated laser. The 1.3 μm strained quantum well laser is possible on InGaAs ternary substrates by increasing their indium content to no less than 0.25.

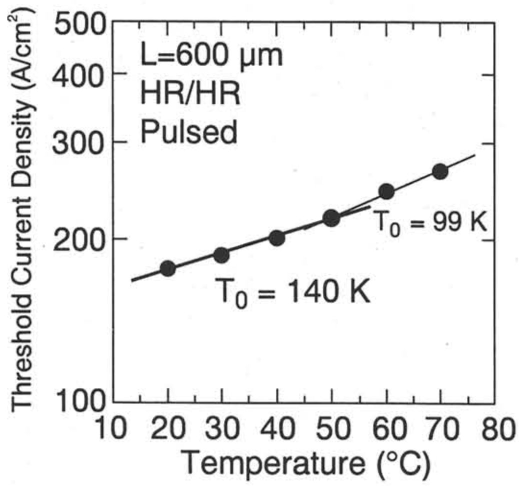

Fig. 4 Temperature dependence of J_{th}.

The characteristic temperatures of the devices strongly depended on the threshold current densities. So improvement in quality of $In_xGa_{1-x}As$ ($x > 0.25$) substrates and reducing threshold current density should enable the 1.3 μm strained quantum well lasers with high characteristic temperature over 150 K.

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