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Strained Double-Quantum-Well Lasers Emitting in 1.2 μm Region Grown on $In_{0.21}Ga_{0.79}As$ Ternary Substrates

K. Otsubo, H. Shoji, T. Kusunoki, T. Suzuki, T. Uchida and H. Ishikawa

Fujitsu Laboratories Ltd., 10-1 Morinosato-Wakamiya, Atsugi 243-01, Japan
Phone : +81-462-50-8249, Fax : +81-462-48-5193, E-Mail : kotsubo@flab.fujitsu.co.jp

Strained double-quantum-well lasers have been fabricated on $In_{0.21}Ga_{0.79}As$ ternary substrates grown by a new method. Though the quality of the substrate is not mature enough according to X-ray measurement, the device has lased at 1.219 μm with the threshold current density of 355 A/cm^2 under room temperature cw condition. The experimental performance has shown good agreement with calculated results. It has been predicted that the use of wider band-gap barrier should enable characteristic temperature higher than 150 K.

1. INTRODUCTION

1.3 μm semiconductor lasers are highly attractive light sources for future optical access and interconnection systems. Low threshold current and high characteristic temperature are strongly required for the lasers to be applicable in those fields. Improved characteristics in 1.3 μm strained quantum-well lasers have been reported so far[1]-[4], but achieving high characteristic temperature over 150 K, as is realized in 0.98 μm InGaAs strained quantum-well lasers on GaAs substrates, is considered to be impossible in InP-based system.

Ishikawa's theoretical investigation predicts that deep potential wells in the 0.98 μm InGaAs strained quantum-well lasers end up with their large optical gain and high characteristic temperature[5]. The use of the InGaAs substrates whose lattice constants are between those of GaAs and InP should enable deep potential strained quantum-wells at 1.3 μm. The desirable indium content of the ternary substrates is over 0.25 for our purpose.

$In_{0.05}Ga_{0.95}As$ substrates were previously grown by a double crucible liquid encapsulated Czochralski (LEC) method[6]-[8] and strained single-quantum-well lasers were fabricated on them[9]. They showed excellent characteristic temperature of 221 K, but the lasing wavelength was 1.03 μm because of the lack of indium content of the substrates. Increasing indium content of InGaAs bulk crystal up to more than 0.2 by LEC growth technique is very difficult because of large segregation of Ga in InGaAs material system, which results in unendurably continuous supply of GaAs source material under precisely controlled temperature during the crystal growth.

In this study, we have fabricated $In_{0.21}Ga_{0.79}As$ substrates by a new method and InGaAs strained double-quantum-well lasers on them. The quality of the substrate has been examined by X-ray diffraction measurement. The fabricated laser has lased at 1.219 μm and the lasing wavelength has become closer to 1.3 μm owing to the increased indium content of the substrates. Comparison of measured threshold current density and characteristic temperature with calculated performance has been carried out.

2. FABRICATION

The $In_{0.21}Ga_{0.79}As$ substrates have been grown by a new multi-component zone-growth method developed by Suzuki et al. [10]-[11]. This method no longer needs continuous supply of GaAs source material. The grown InGaAs 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 the angle of (400) X-ray diffraction and energy dispersive X-ray (EDX) analysis. The estimated indium contents from the both methods coincided. Figure 1 shows X-ray rocking curves of the fabricated $In_{0.21}Ga_{0.79}As$ substrate and a commercial GaAs substrate. The full width at half maximum (FWHM) of the rocking curve in $In_{0.21}Ga_{0.79}As$ substrate is 410 seconds, which is about 20 times larger than that in the GaAs as yet. The growth method is still being developed and we believe that $In_xGa_{1-x}As$ ($x > 0.25$) can be obtained by this method.

Figure 2 shows the fabricated laser structure. A n-InGaAs buffer layer (1 μm), a n-InGaP cladding layer (1 μm), an undoped double-quantum-well active layer sandwiched by

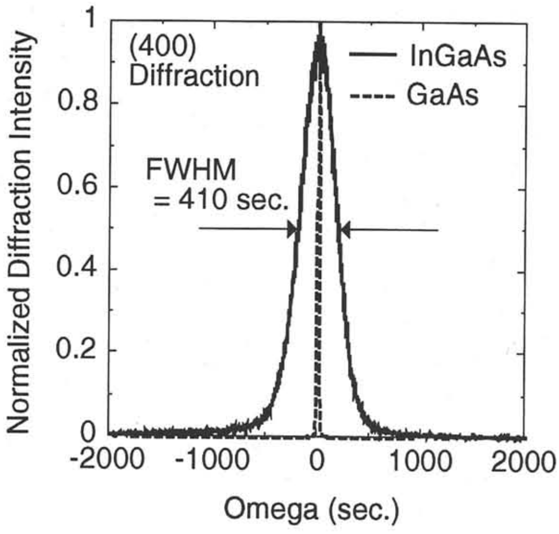

Figure 1: X-ray rocking curves of the $In_{0.21}Ga_{0.79}As$ substrate and a GaAs substrate.

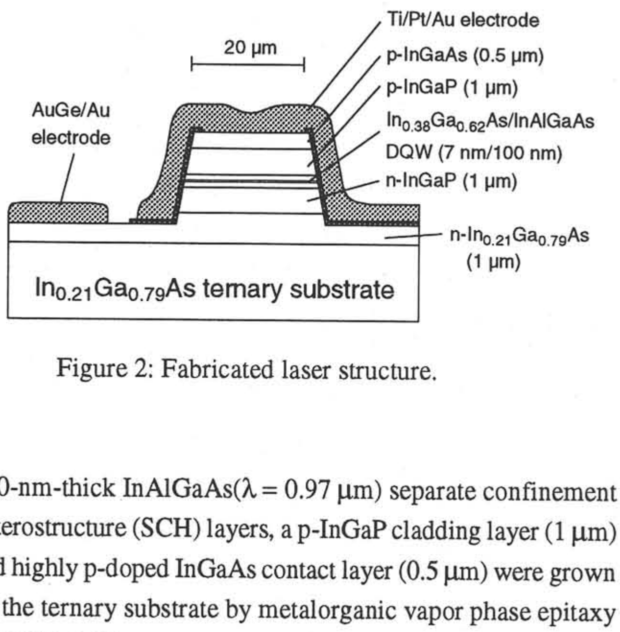

Figure 2: Fabricated laser structure.

100-nm-thick InAlGaAs($\lambda = 0.97$ μm) separate confinement heterostructure (SCH) layers, a p-InGaP cladding layer (1 μm) and highly p-doped InGaAs contact layer (0.5 μm) were grown on the ternary substrate by metalorganic vapor phase epitaxy (MOVPE). The structure of the active layer has two 7-nm-thick $In_{0.38}Ga_{0.62}As$ compressively-strained (1.19 %) quantum-wells separated by a 10-nm-thick InAlGaAs($\lambda = 0.97$ μm) barrier layer. Wide band-gap barrier and SCH layers are required to realize deep potential quantum-wells. In this case, InAlGaAs and InGaAsP lattice-matched to the ternary substrate are the candidates for them. There exists a miscibility gap in the growth of the InGaAsP layers whose compositional wavelength is shorter than ~1 μm, so InAlGaAs layers were chosen for the purpose. 20-μm-wide mesa stripes for carrier and optical confinement were defined by C_2H_6 reactive ion etching (RIE). Electrodes were coplanarly formed because impurity was not introduced to the substrates. The laser chips were bonded on diamond heatsinks.

3. MEASUREMENT AND DISCUSSION

Light output and voltage versus injected current characteristics of the 900-μm-long laser with as-cleaved facets are shown in Fig. 3. Measurement was carried out under 25 °C cw condition. The threshold current is 63.9 mA, which corresponds to the threshold current density (J_{th}) of 355 A/cm^2. The maximum output power is over 8 mW and the slope efficiency is 0.1 W/A/facet at 2 mW. Figure 4 shows the lasing spectrum at 1 mW. The lasing wavelength is 1.219 μm, which far exceeds the result of our previous work[9] and has become closer to 1.3 μm owing to the increased indium content of the substrate from 0.05 to 0.21.

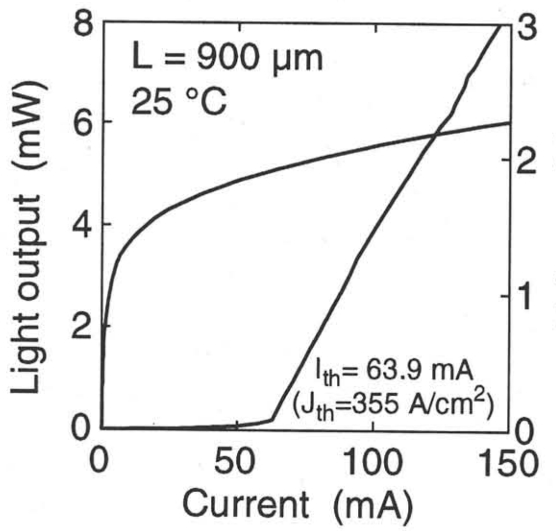

Figure 3: Light output and voltage versus injected current characteristics under 25 °C cw condition.

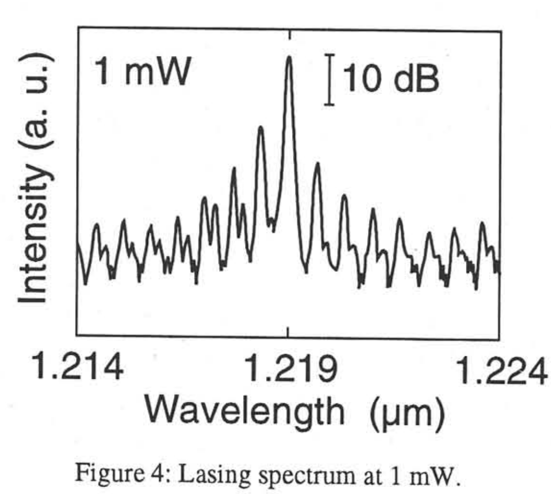

Figure 4: Lasing spectrum at 1 mW.

Figure 5 shows calculated dependences of threshold current density and characteristic temperature on compositional wavelength of barrier layer. We calculated optical gain for our laser structure as a function of sheet carrier density, taking the effect of carriers in the SCH layers into account[12]. Then we estimated the threshold current density and characteristic temperature from the theoretical optical gain. Auger nonradiative recombination is not considered in the calculation. Measured characteristic temperature of the device is 84 K and the best experimental result of J_{th} is 280 A/cm², which are also indicated in Fig. 5. They show good agreement with the theoretical values. We employed the barrier layers whose compositional wavelength is 0.97 μm because crystal growth condition of wider bandgap InAlGaAs layers has not been established at that time. According to the calculation, achievement of the characteristic temperature over 150 K should be possible by making compositional wavelength of barrier layers shorter than 0.9 μm.

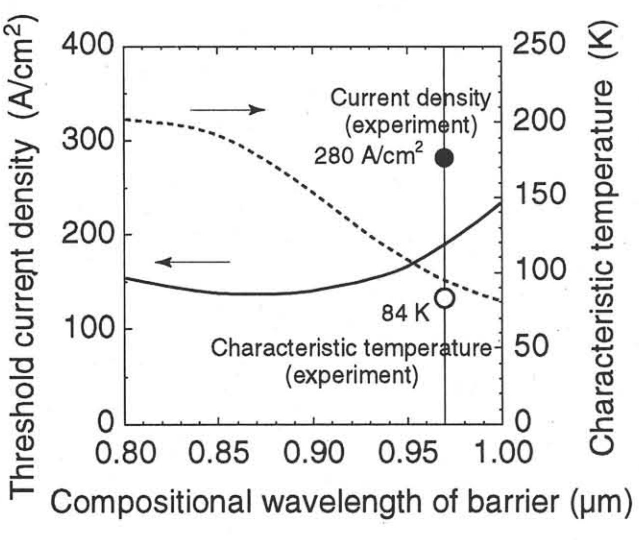

Figure 5: Calculated dependences of the threshold current density (solid curve) and characteristic temperature (dashed curve) on compositional wavelength of the barrier layer. The experimental results are shown with solid (threshold current density) and open (characteristic temperature) circles.

4. CONCLUSION

In conclusion, we have fabricated InGaAs strained quantum-well lasers on $In_{0.21}Ga_{0.79}As$ ternary substrates. The InGaAs substrates have been grown by a new multi-component zone-growth method and those of high indium content of 0.21 have been obtained, which it is difficult to grow by a LEC growth technique. The FWHM of X-ray rocking curve of the ternary substrate has been much wider than that of a GaAs substrate. The lasers have lased at 1.219 μm with the threshold current density of 355 A/cm² under room temperature cw condition and the experimental results have shown good agreement with the calculated ones, in spite of the quality of the substrate. The growth method of the substrate we used is now under development, and we believe that the use of $In_xGa_{1-x}As$ ($x > 0.25$) substrates with wider bandgap ($\lambda <$ 0.9 μm) barrier should enable 1.3 μm quantum-well lasers with characteristic temperature higher than 150 K.

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