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Fabrication of $In_{0.25}Ga_{0.75}As$/InGaAsP Strained SQW Lasers on $In_{0.05}Ga_{0.95}As$ Ternary Substrate

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***Abstract*— A uniform $In_{0.05}Ga_{0.95}As$ ternary substrate was grown by using liquid encapsulated Czochralski (LEC) technique with a method of supplying GaAs source material at a constant temperature, and InGaAs/InGaAsP strained single quantum well (SQW) lasers were fabricated on the substrate for the first time. The lasers lased at 1.03 μm and exhibited low threshold current density of 222 A/cm^2 and excellent characteristic temperature of 221 K, showing that the ternary substrate has a sufficient quality for laser fabrication.**

I. INTRODUCTION

HIGH performance laser emitting at 1.3 μm is strongly required for future applications to optical access systems and optical interconnection systems. Although recent progress in strained quantum well has enabled high performance quantum well lasers [1]–[3], the performances of 1.3 μm lasers on InP substrate are still unsatisfactory, and are much inferior to that of 0.98 μm lasers on GaAs substrate especially in the temperature characteristics. Characteristic temperature above 150 K as realized in 0.98 μm lasers has not been reported in 1.3 μm lasers to date. Concerning this problem, Ishikawa *et al.* recently reported that shallow potential well could be one of the major causes of poor temperature characteristics of 1.3 μm lasers on InP substrate [4]. If we could make much deeper potential well for 1.3 μm strained quantum well, the subband separation would be enlarged, and the electron overflow to SCH layers would be also reduced, resulting in higher optical gain and better temperature characteristics [4], [5]. From this point of view, the use of ternary $In_xGa_{1-x}As$ substrate is effective for the deep potential well in 1.3 μm lasers [5]. The ternary substrate allows us to use large bandgap barrier layer. In the last several years, Nakajima *et al.* have been challenging the growth of ternary bulk crystals, and they have developed the liquid encapsulated Czochralski (LEC) technique for the InGaAs ternary crystals with uniform composition [6]–[9]. However, the validity of the ternary crystals has not been verified in laser fabrication.

In this letter, we report the first fabrication of lasers on ternary substrate. We have grown a uniform ternary bulk crystal of $In_{0.05}Ga_{0.95}As$, and fabricated $In_{0.25}Ga_{0.75}As$/InGaAsP strained single quantum well (SQW) lasers on the ternary substrate. Low threshold current operation and excellent characteristic temperature were obtained in the lasers emitting at 1.03 μm. Although higher indium content of around 0.25 is required for realizing 1.3 μm lasers, we successfully confirmed the sufficient quality of the ternary substrate for laser fabrication as the first step.

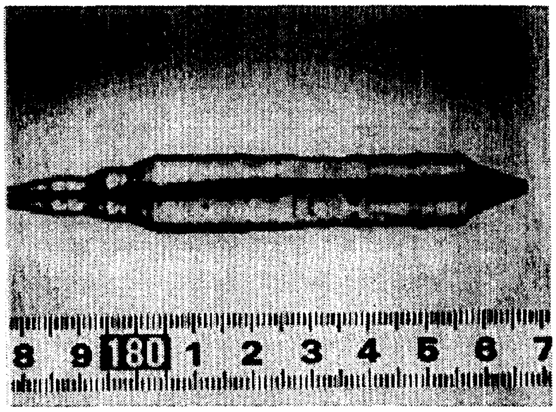

Fig. 1. $In_{0.05}Ga_{0.95}As$ ternary bulk crystal grown by using LEC technique with a method of supplying GaAs source material. The diameter is 1.5 cm, and the length is 6 cm. No impurity is introduced.

II. FABRICATION

For the growth of InGaAs ternary bulk crystals, control of the composition along the growth direction is one of the most critical problems. In the conventional LEC growth, the grown ternary bulk crystals must have some gradient on the composition because of the lack of melt refreshment during the growth. In order to overcome this problem, a new LEC growth technique with a method of supplying GaAs source material at a constant temperature has been developed [6], [7]. More recently, a double crucible method for further improvement in the controllability of the source supply in the LEC growth has been also introduced [8]–[9]. As shown in Fig. 1, a uniform $In_{0.05}Ga_{0.95}As$ bulk crystal with a diameter of 1.5 cm and a length of 6 cm was successfully obtained. The electrical and optical qualities of this crystal was confirmed to be as high as the LEC grown GaAs crystal on the market by the electrical and photoluminescence measurements. Exciton related spectra could be observed as strongly as for GaAs, and the mobility was about 5000 cm^2/V·s which was comparable to that of undoped GaAs [9]. We used this ternary bulk crystal for laser fabrication.

The ternary bulk crystal was sliced to substrates with a facet of (100)-orientation. On the ternary substrate, a laser structure

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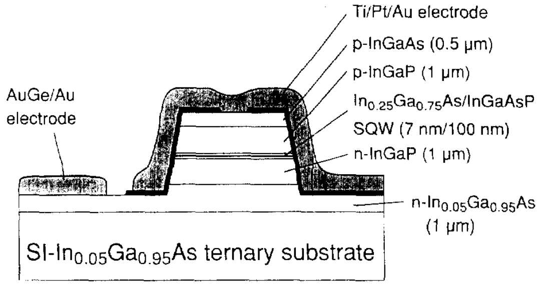

Fig. 2. Cross sectional view of $In_{0.05}Ga_{0.95}As$/InGaAsP SQW LD grown on SI-$In_{0.05}Ga_{0.95}As$ ternary substrate. Width of mesa-structure is 20 μm. Coplanar structure is employed.

shown in Fig. 2 was grown by MOVPE. An InGaAs buffer layer (1 μm), a n-InGaP cladding layer (1 μm), a nondoped InGaAs/InGaAsP active layer (~0.2 μm), a p-InGaP cladding layer (1 μm), and a p-InGaAs cap layer (0.5 μm) were successively grown on the ternary substrate. The active layer consists of 7 nm-thick $In_{0.25}Ga_{0.75}As$ strained SQW sandwiched by 100 nm-thick InGaAsP SCH layers ($\lambda_{SCH} = 0.845$ μm). After the growth, mesa-stripe of 20 μm width was formed by C_2H_6 reactive ion etching (RIE) for carrier and optical confinement. Calculated optical confinement factor for this structure is about 2%. Coplanar structure was employed for current injection because no impurity was intentionally introduced into the substrate at present. In the photoluminescence measurement at room temperature, we observed an emission peak at 1.03 μm, which just corresponded to the ground level of the $In_{0.25}Ga_{0.75}As$ strained SQW. The emission intensity was strong enough when compared with that of 0.98 μm lasers grown on GaAs substrate.

III. LASER CHARACTERISTICS

Fig. 3 shows light output and voltage versus injected current characteristics of a 600 μm-long laser under CW condition at 25°C, where both facets are as cleaved. The threshold current was 26.7 mA and the corresponding threshold current density was 222 A/cm^2. The maximum output power was larger than 60 mW, and the slope efficiency at the output power of 5 mW was as high as 0.29 mW/mA/facet. The differential resistance was about 3 Ω, which was almost constant above the threshold. The emission wavelength was 1.03 μm.

Fig. 4 shows the cavity length dependence of inversed differential quantum efficiency, where internal loss of the laser structure α_i and internal quantum efficiency η_i were estimated from several samples with different cavity lengths. The estimated α_i and η_i were 7.3 cm^{-1} and 58%, respectively, which were a little inferior to those of conventional SQW lasers. The mesa structure formed by dry-etching might lead to the degradation. Furthermore, the sidewall of the active layer covered by electrode metal might induce the increase of absorption loss. In fact, in the measurement of near field pattern, we observed the broadening of the emission over the whole stripe.

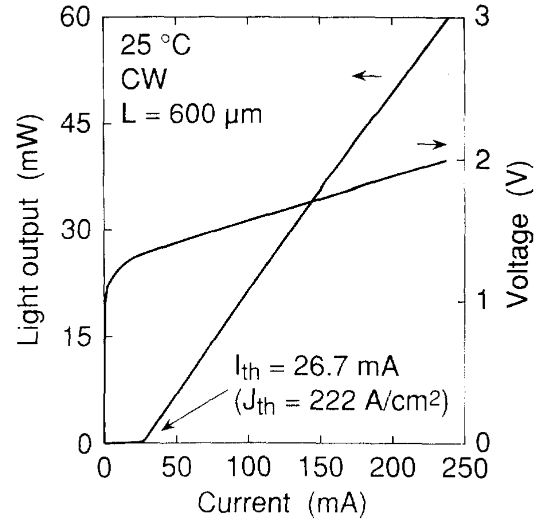

Fig. 3. Light output and voltage versus injected current characteristics at 25°C under CW condition. Cavity length is 600 μm, and both facets are as-cleaved.

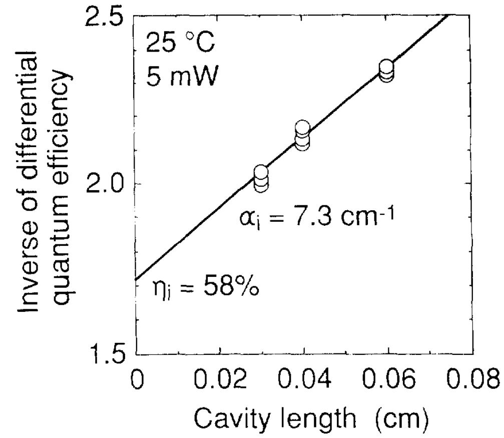

Fig. 4. Cavity length dependence of inversed differential quantum efficiency. α_i and η_i denote internal loss and internal quantum efficiency, respectively.

Temperature dependence of the threshold current was also measured in a 600 μm-long laser. As shown in Fig. 5, characteristic temperature T_0 was as high as 221 K in the range of 15°C to 65°C, which was comparable or superior to that of 0.98 μm laser on GaAs substrate. Low threshold current density operation enabled such an excellent temperature characteristic.

IV. CONCLUSION

We have grown a uniform $In_{0.05}Ga_{0.95}As$ ternary substrate by using LEC technique with a method of supplying GaAs source material at a constant temperature, and have fabricated InGaAs/InGaAsP strained single quantum well (SQW) lasers on the ternary substrate for the first time. The lasers exhibited low threshold current density of 222 A/cm^2 and excellent characteristic temperature of 221 K. Although the obtained lasing wavelength was 1.03 μm, these results indicate that the ternary substrate has a sufficient quality for laser fabrication.

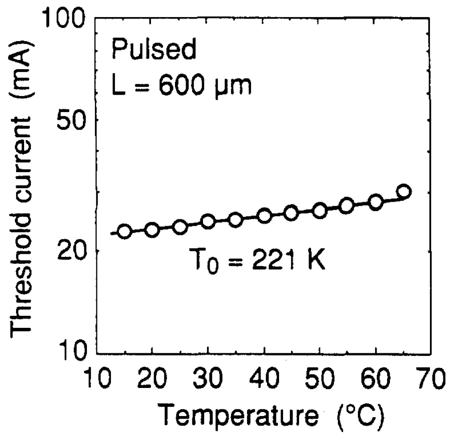

Fig. 5. Temperature dependence of threshold current. Characteristic temperature T_0 is 221 K in the temperature range of 15°C to 80°C.

Increased indium content will enable 1.3 μm lasers with excellent temperature characteristics.

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