Growth of $In_{0.1}Ga_{0.9}As$ Single Crystal Plates and Fabrication of $In_xGa_{1-x}As/In_{0.1}Ga_{0.9}As$-Strained Quantum Wells (SQW)

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Abstract : We grew compositionally homogeneous platy single crystals of $In_{0.1}Ga_{0.9}As$ composition by the Traveling Liquidus Zone (TLZ) method. We also fabricated $In_XGa_{1-X}As$-SQWs on the $In_{0.1}Ga_{0.9}As$ substrate by the Metal Organic Vapor Epitaxy (MOVPE) method. In the photoluminescence (PL) measurement, we observed emission at 1.3 μm from the $In_{0.5}Ga_{0.5}As$/ $In_{0.1}Ga_{0.9}As$-SQW.

Key words : $In_XGa_{1-X}As$, Traveling Liquidus Zone method, Homogeneous single crystal, SQW

1. Introduction

Development of high speed and broad band optical communication system is being promoted for establishing global information. In the optical communication system, wavelengths of 1.3 μm and 1.55 μm are used. Although transmission loss in optical fibers is higher at 1.3 μm than at 1.55 μm, low cost fibers are available for 1.3 μm wavelength. The present laser using InP substrate for 1.3 μm needs a thermal control unit due to an insufficient confinement of carriers and large power output dependence on temperature. $In_XGa_{1-X}As$ is expected as a substrate which has the ability of effective carrier confinement. But the single crystal growth of homogeneous $In_XGa_{1-x}As$ is very difficult because the gap between the liquidus and the solidus in the InAs-GaAs system is very large (Fig.1). Therefore, we tried to grow $In_{0.1}Ga_{0.9}As$ thin plate (2mm in thickness) by the TLZ method, in order to obtain a large surface area for a laser substrate with suppressing convection.[1] The TLZ method has been proven to be useful for growing homogeneous $In_XGa_{1-x}As$ crystals when convection in their melts is suppressed. Furthermore, we fabricated $In_XGa_{1-x}As$- SQWs on the $In_{0.1}Ga_{0.9}As$ plate.

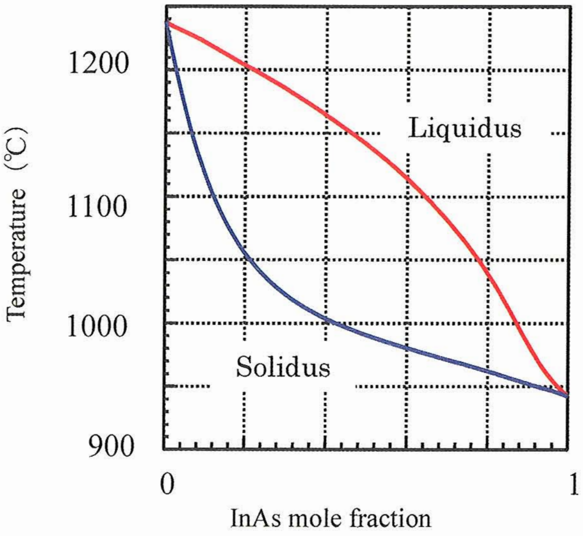

Fig. 1. Phase diagram of InAs-GaAs system.

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2. Principle of the TLZ method

The detail of the TLZ method has been described elsewhere,[2] we explain its essence briefly (Fig.2). The sample consists of a GaAs single crystal seed with (100) surfaces, an InAs crystal as a liquid former and a GaAs feed. The sealed sample is inserted and heated in an experimental furnace. InAs melts and forms a narrow melt zone. The TLZ method assumes the diffusion limited mass transport. The solidification occurs by the solute diffusion in the melt. The spontaneous growth rate (V) is given by

$$V=-D/(C_{LO}-C_{SO})\times(\partial C_L/\partial T)\times(\partial T/\partial Z) \qquad (1),$$

where D is the diffusion coefficient, C_{LO} and C_{SO} are the liquidus and the solidus concentrations at the freezing interface respectively, $(\partial C_L/\partial T)$ is a reciprocal of the liquidus slope and $(\partial T/\partial Z)$ is a temperature gradient. [2] [3] The sample is translated towards the lower temperature side in the furnace, synchronizing with a spontaneous crystal growth rate. The freezing interface is kept at the fixed position, and the crystallization temperature is kept constant. Thus, we can obtain homogeneous crystals.[2]

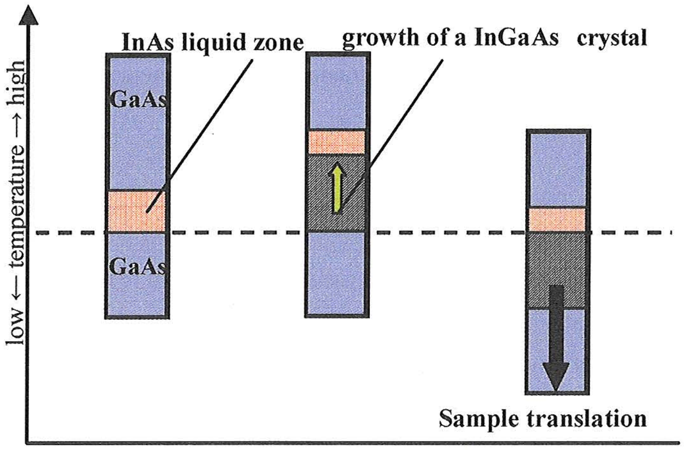

Fig. 2. Principle of the TLZ method.

3. Experiments

3-1. $In_xGa_{1-x}As$ Crystal growth

Grown crystals are platy, 2mm in thickness, 10mm in width and 40～60 mm in length. The temperature of initial solidifying interface was kept at the crystallization temperature of $In_{0.1}Ga_{0.9}As$. The sample was translated at the rate calculated by the equation (1). To confirm the composition profiles, a grown crystal was analyzed by electron probe micro-analyzer. To evaluate the crystallinity, X-ray rocking curves of (400) reflection and etch pit densities (EPD) measurements were carried out.

3-2. Fabrication of SQW

After polishing surfaces of grown crystal plates, strained $In_xGa_{1-x}As$(x=0.28-0.52) layers, sandwiched by $In_{0.1}Ga_{0.9}As$ barrier layers, were fabricated on the substrates by the MOVPE method (Fig.3). AsH_3, triethyl-galium and trimethyl-indium were used as feed gases. The buffer layer and the SQW layer were fabricated at 1023K and 823K, respectively. Flow gas pressure was 76 torr and the V/III ratio was 10. To evaluate the SQWs, cross section was observed by transmission electron microscope (TEM), and PL spectra measurements on the SQW layer were performed.

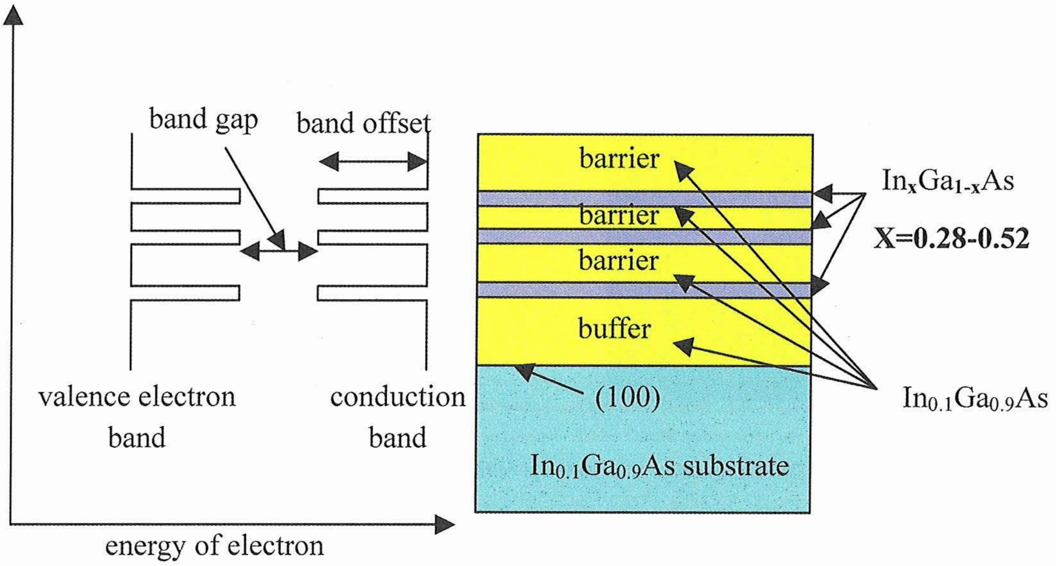

Fig. 3. Energy-band and Structure of $In_xGa_{1-x}As/In_{0.1}Ga_{0.9}As$-SQW.

4. Results and Discussion

4-1. $In_xGa_{1-x}As$ Crystal growth

Highly homogeneous crystals with InAs mole fraction $X=0.1\pm0.01$ were grown (Fig.4). Figure5 shows the back reflection Laue patterns obtained in the seed and grown crystal regions. It is clear that these patterns are similar, which means that seeding is successful. We can say that it is possible to grow large platy $In_{0.1}Ga_{0.9}As$ crystals with suppressing convection in their melts (2mm in thickness). The full width at half maximum (FWHM) measured by X-ray diffraction peak of $In_{0.1}Ga_{0.9}As$, was 0.041 degree as shown in Figure6. This was sufficiently low enough for substrate use, by comparing with X-ray diffraction peak of the GaAs seed. The average EPD of $In_{0.1}Ga_{0.9}As$ was $5\times10^4/cm^2$, which was good in comparison with GaAs used as a seed (Fig.7).

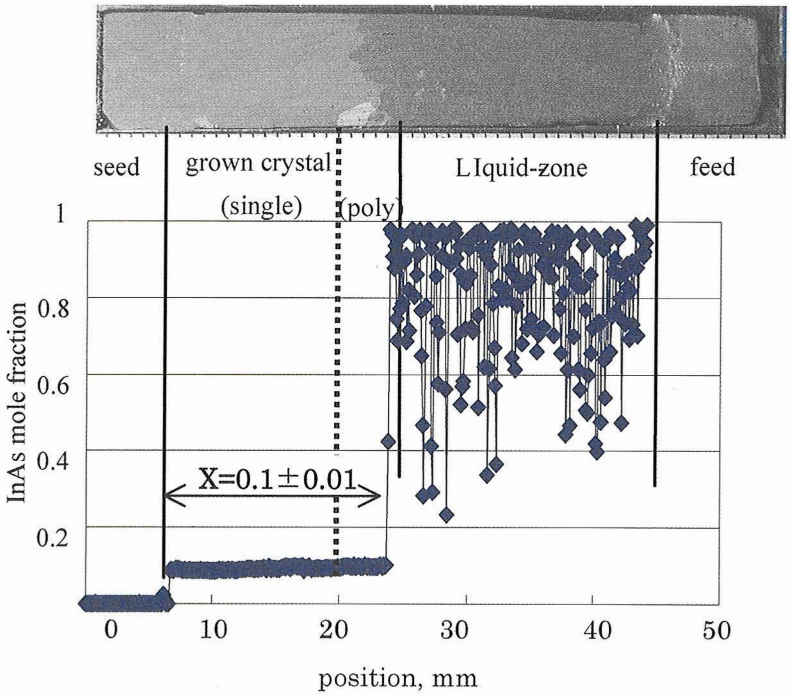

Fig. 4. Composition profiles of a grown crystal.

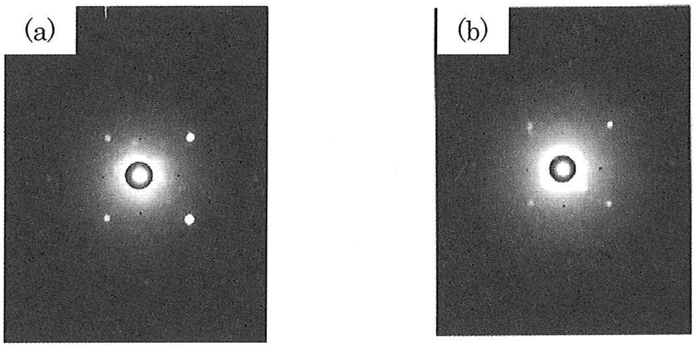

Fig. 5. X-ray back Laue diffraction patterns of (a) GaAs seed and (b) $In_{0.1}Ga_{0.9}As$ crystal.

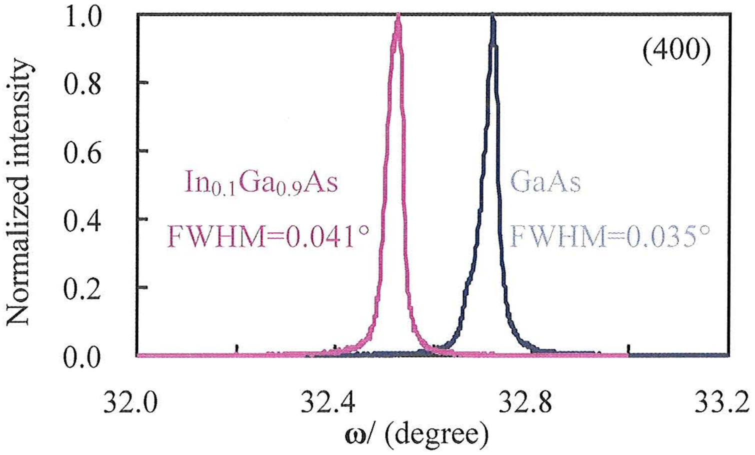

Fig. 6. X-ray diffraction peak profiles of $In_{0.1}Ga_{0.9}As$ crystal and GaAs seed for the (400) reflection.

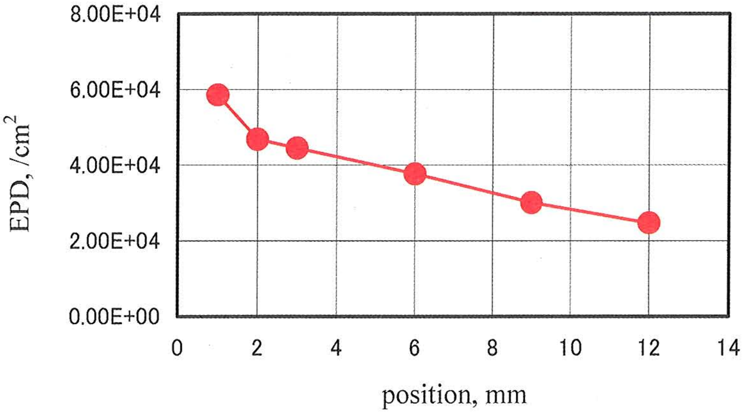

Fig. 7. EPD distribution in the grown $In_{0.1}Ga_{0.9}As$ crystal.

4-2. Fabrication of SQW

Figure8 shows the cross section of the SQW observed by TEM. The $In_xGa_{1-x}As$ strained well layer on the $In_{0.1}Ga_{0.9}As$ substrate is flat, which means that we successfully fabricated the SQW. In the PL measurement, we observed emissions from $In_xGa_{1-x}As$-SQWs (X=0.28, 0.45, 0.50, 0.52), especially 1.3 μm from the $In_{0.5}Ga_{0.5}As/In_{0.1}Ga_{0.9}As$-SQW (Fig.9). However, the FWHM of PL spectrum increased largely for the emission at 1.3 μm wavelength (Fig.10). This is probably due to excess strain, which is caused by the lattice mismatch between the $In_{0.1}Ga_{0.9}As$ substrate and $In_xGa_{1-x}As$ strained well layer.

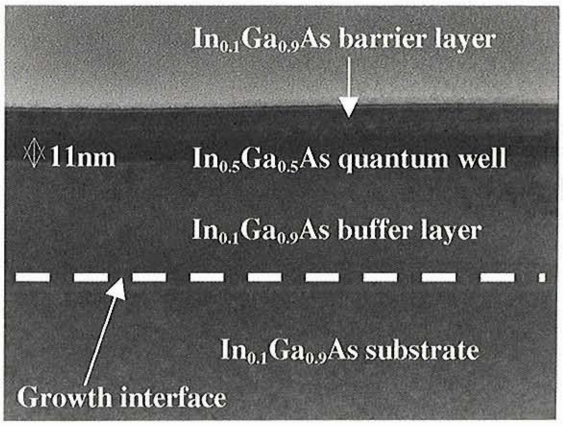

Fig. 8. Cross sectional view of SQW by TEM.

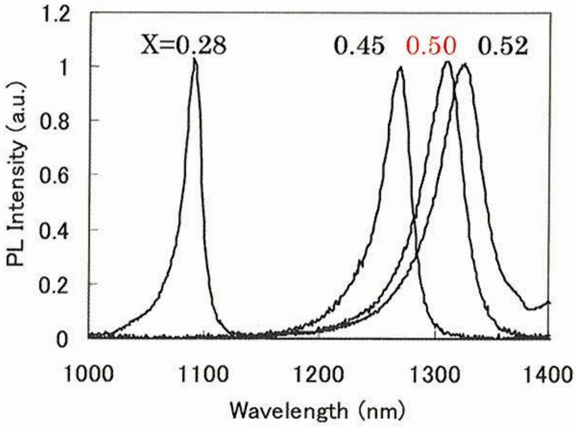

Fig. 9. PL spectra of $In_xGa_{1-x}As/In_{0.1}Ga_{0.9}As$-SQW.

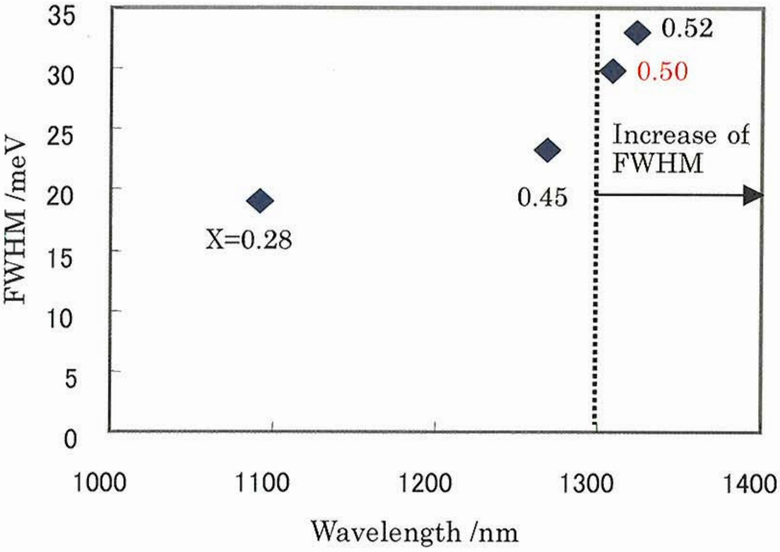

Fig. 10. Wavelength vs FWHM of PL spectra.

5. Conclusions

We grew large platy single crystals of homogeneous $In_{0.1}Ga_{0.9}As$ composition by the TLZ method, the fluctuation of InAs mole fraction was 0.1±0.01. By using these platy crystals as substrate, we fabricated $In_XGa_{1-X}As$-SQWs. The SQWs were evaluated by the measurements of PL spectra and the emission of target wavelength of 1.3 μm from the $In_{0.5}Ga_{0.5}As/In_{0.1}Ga_{0.9}As$ -SQW was observed. The FWHM of PL spectrum at 1.3 μm was broad due to excess lattice mismatch between the SQW layer and the $In_{0.1}Ga_{0.9}As$ substrate. We will further investigate experimental conditions to increase InAs mole fraction of a substrate, and aim at fabricating the SQW whose strain is suppressed to an acceptable level.

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