High-strain InGaAs/GaAs quantum well grown by MOCVD

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High-strain InGaAs/GaAs quantum wells (QWs) are grown by low-pressure metal-organic chemical vapor deposition (LP-MOCVD). Photoluminescence (PL) at room temperature is applied for evaluation of the optical property. The influence of growth temperature, V/III ratio, and growth rate on PL characteristic are investigated. It is found that the growth temperature and V/III ratio have strong effects on the peak wavelength and PL intensity. The full-width at half-maximum (FWHM) of PL peak increases with higher growth rate of InGaAs layer. The FWHM of the PL peak located at 1039 nm is 20.1 meV, which grows at 600 °C with V/III ratio of 42.7 and growth rate of 0.96 μm/h.

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High-quality InGaAs/GaAs quantum well (QW) is a key structure for many optoelectronic[1,2] and microelectronic[3,4] devices. High-strain InGaAs/GaAs structure laser diode has been investigated because of its large emitting wavelength range[5] and promising application in communication[6,7]. It has been reported that highly strained and high-quality epitaxial InGaAs/GaAs structures have been manufactured by molecular beam epitaxy[8] and metal-organic chemical vapor deposition (MOCVD)[9,10] techniques. Kim *et al.*[11] prepared InGaAs/GaAs strained multiple QWs (MQWs) by MOCVD. The detected MQW peaks by photocurrent and photoluminescence (PL) spectra were assigned to the fundamental excitonic transitions of electron–heavy hole and electron–light hole[11]. InGaAs/GaAs/AlGaAs QW structures grown at different temperatures by MOCVD using tertiarybutylarsine as group V source exhibited that the QW grown at 640 °C showed the highest PL intensity[12]. A double-QW structure was prepared on GaAs substrate by MOCVD, which showed room temperature luminescence at 1215 nm and spectral linewidth of 48 meV[13]. It was reported that a full-width at half-maximum (FWHM) of about 32 meV with wavelength of 1054 nm was obtained when a strain buffer layer (SBL) was inserted into an InGaAs/GaAs structure, which was grown with a V/III ratio of 100 and a growth rate of 3 μm/h[14]. It was also reported that when SBLs were inserted during InGaAs growth, the FWHM was decreased to 29 meV at a peak of 1069 nm[15]. For highly strained InGaAs double-QW structure, the FWHM decreased with higher growth rate due to lower density of defects, which was reported that the FWHM decreased to about 26 meV as the growth rate reached to about 2 μm/h[16]. Although the highly strained InGaAs/GaAs structure has been studied for many years, the reported PL peak FWHM is usually still larger than 25 meV. Here, we have investigated the impact of different growth conditions for InGaAs/GaAs QW PL property. The structure is $In_xGa_{1-x}As$ signal QW with a thicknesses of 10 nm sandwiched between 300 nm thick GaAs layers. All the samples were measured by an Accent RPM2000 Compound Semiconductor PL System at room temperature. By optimizing growth temperature, V/III ratio, and growth rate, a 20.1 meV FWHM with room temperature luminescence at 1039 nm was obtained, which was the narrowest FWHM for high-strain InGaAs/GaAs structure known to the best of our knowledge.

Trimethylindium (TMIn) and trimethylgallium were used as group III sources and arsine (AsH_3) was used as group V source. The growth parameters of the experiment are shown in Table 1. Sample S1 had a 10 nm QW layer, which was grown at 650 °C with a V/III ratio of 65 and a growth rate of 1.15 μm/h. Samples S2 and S3 were grown at 600 and 550 °C, respectively, with the other growth parameters same as sample S1. The V/IIII ratios of S4, S5, S6, and S7 were 55.5, 51.5, 42.7, and 34.2, respectively. For S8 and S9 samples, the QW growth rates were 1.38 and 0.96 μm/h, respectively.

The growth temperature has a significant effect on the crystal quality[17]. Indium atoms will become more active when temperature increases, so lower growth temperature helps keep more indium atoms in the QW layer, in which way the PL property is improved and the indium ratio increases resulting in a red-shift wavelength. Besides, there will be more adducts depositing on the substrate surface when the growth temperature is higher, in which way the quality of crystal lattice deteriorates.

Table 1. Growth Conditions of the Experiments

	S1	S2	S3	S4	S5	S6	S7	S8	S9
TMIn Ratio (Gas Phase) (%)	39	39	39	33	33	33	33	33	33
Growth Temperature (°C)	650	600	550	600	600	600	600	600	600
Growth Rate (μm/h)	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.38	0.96
V/III Ratio	65	65	65	55.5	51.5	42.7	34.2	42.7	42.7

Figure 1 shows the PL spectra of S1, S2, and S3. Figure 2 compares the PL intensities with FWHMs of InGaAs/GaAs QW structures grown at different temperatures. When the temperature is 550 °C, the PL shows the highest intensity. It has been reported that the incorporation efficiency of indium atoms increases with decreasing temperature, but InGaAs crystal quality will degrade when growth temperature is as low as 530 °C, because of decreasing AsH_3 cracking efficiency[18].

The V/III ratio has a strong impact on PL characteristic[10]. Increasing V/III ratio could reduce the surface migration length which improves the quality of InGaAs layer[19]. Figure 3 shows the PL spectra of samples grown at four different V/III ratios. The PL intensities and FWHMs of S4, S5, S6, and S7 are shown in Fig. 4. With V/III ratio increasing from 34.2 to 51.5, the FWHM decreases from 26 to 22.1 meV gradually. As V/III ratio is higher than 51.5, the FWHM tends to

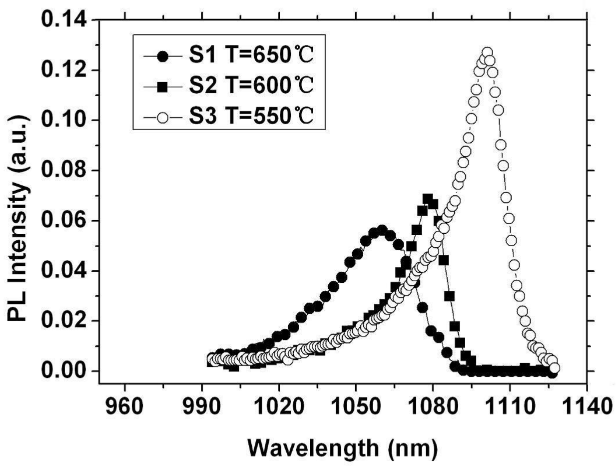

Fig. 1. PL spectrum of samples at different growth temperatures.

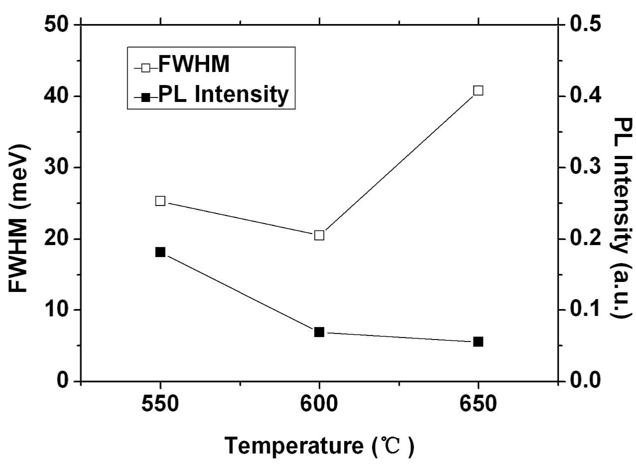

Fig. 2. PL FWHM and intensity of samples at different growth temperatures.

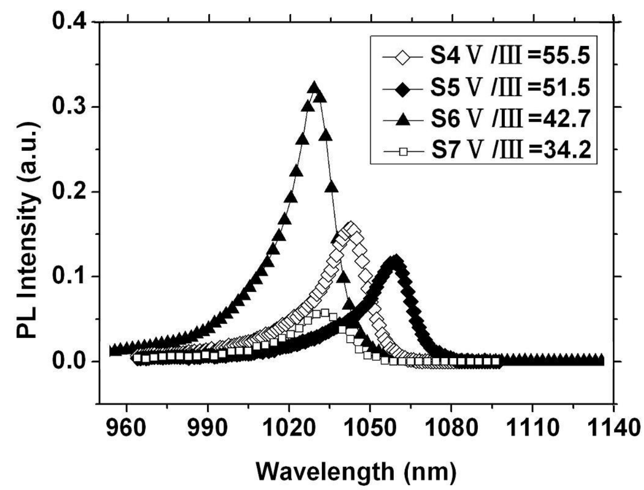

Fig. 3. PL spectra of samples grown at different V/III ratios.

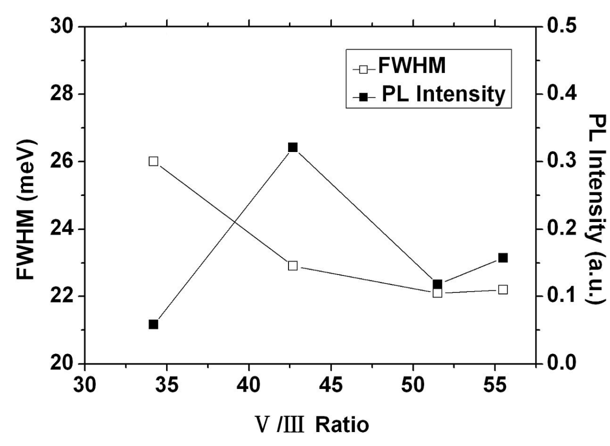

Fig. 4. PL FWHM and intensity of samples prepared at different V/III ratios.

be smooth. There is no further degradation of FWHM as V/III ratio increases to 55.5. The S6 sample which was grown with a V/III ratio of 42.7 exhibits the highest PL intensity of 0.32 meV as shown in Fig. 4, which is nearly double the intensity of sample grown with a V/III ratio of 55.5, three times of sample grown with a V/III ratio of 51.5 and five times of sample grown with a V/III ratio of 34.2. It was reported that when the V/III ratio was below 40, hillocks occurred on the surface because of the volatilization of As. The hillocks disappeared gradually with increase in the V/III ratio. In order to obtain smooth surface without hillocks, the V/III ratio needs to be kept near or above 40[20].

For high-strain InGaAs/GaAs QW structure, it has been reported that increasing growth rate caused decreasing diffusion length and resulted in the change of growth mode[21], which could improve the crystal quality. Figure 5 shows the PL spectra of InGaAs/GaAs structures prepared at different growth rates. Figure 6 shows the dependence between PL intensity and FWHM of samples S6, S8, and S9. As shown in Fig. 6, the FWHM increases from 20.1 to 24.1 meV as

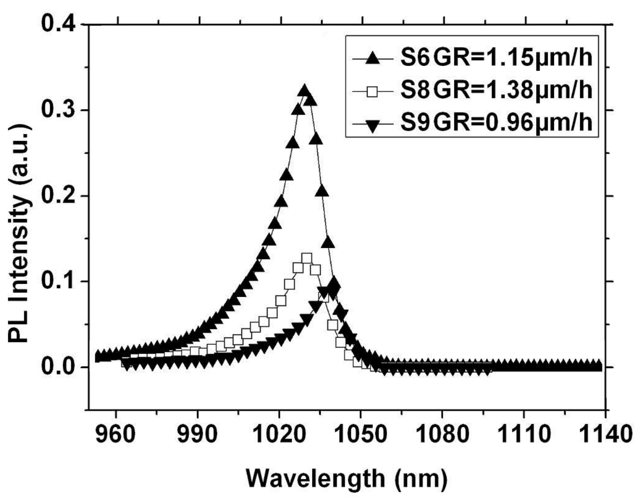

Fig. 5. PL spectra for samples prepared at different growth rates.

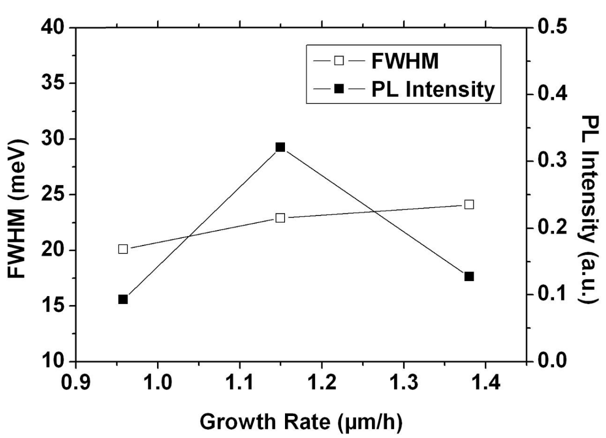

Fig. 6. PL FWHM and intensity of samples prepared at different growth rates.

growth rate increases from 0.96 to 1.38 μm/h, which indicates that the crystal quality degrades with increasing growth rate. The S6 sample shows the highest PL intensity, which is prepared with a growth rate of 1.15 μm/h. When the growth rate is decreased to 0.96 μm/h, the FWHM is decreased to 20.1 meV. The PL intensity does not show further improvement when growth rate reaches 1.38 μm/h. This might originate from the surface's overloading and the overflowing indium atoms diffusing into GaAs layers, in which way the interface quality deteriorates resulting in degradation of PL intensity.

In conclusion, the structure consisting of $In_xGa_{1-x}As$ signal QW sandwiched between GaAs layers is grown by low-pressure MOCVD. With decreasing growth temperature of InGaAs layer, the room temperature PL intensity improves and the wavelength exhibits a red-shift. The FWHM increases with higher growth rate. The sample grown at 600 °C, with the V/III ratio of 42.7 and an InGaAs growth rate of 1.15 μm/h shows the highest PL intensity. The narrowest FWHM of 20.1 is obtained from the sample emitting at 1039 nm, which is grown at 600 °C with the V/III ratio of 42.7 and a growth rate of 0.96 μm/h.

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