Effect of Growth Parameters on Composition Distribution in Superlattice-in-Well Structure by Submonolayer Deposition Technique

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The superlattice-in-well structures were grown using a cycled submonolayer AlGaAs/GaAs deposition technique. The optical quality of Al–Ga interdiffusion in AlGaAs/GaAs superlattice was investigated by measuring the photoluminescence of samples grown at temperature from 610°C to 630°C. Results show that Al composition can be modulated under some growth temperature or period. Effect of the growth interrupt in the growth process of superlattice on film optical quality is also discussed. Especially, the role played by the period of superlattice in the process of obtaining high quality film material with low composition is investigated in detail.

PACS numbers: 81.15.Hi, 68.55.Ln, 68.65.Fg, 68.65.Cd

1. Introduction

The potential of superlattice for the optoelectronic devices is due to the fact that energy band structure can be modulated by changing the period and distribution [1]. The high quality film for future optoelectronics devices requires the precise control of the thickness and composition [2, 3]. Submonolayer deposition technique has attracted considerable investigation interest for implementing atom layer controllable growth [4]. At the same time, this approach results in a significant increase in component intermixing in the process of superlattice preparing due to the diffusion length shortening. Tremendous research effort has been focused to optimize the performance of electronic and optoelectronic devices by post-growth diffusion technology [5–11], while less attention has been paid to *in situ* diffusion in superlattice with barrier layers of submonolayer thickness.

In this paper, the superlattice-in-well structures were grown using a cycled submonolayer AlGaAs/GaAs deposition technique. These quantum wells are composed of alternating $Al_xGa_{1-x}As/GaAs$ layers with submonolayer thickness. The effect of growth temperature and period on composition was analyzed in detail. At the same time, Al–Ga interdiffusion process in AlGaAs/GaAs superlattice can be used to produce low content Al composition. It is possible for extending the technology to other complicated semiconductor systems.

2. Experiment investigation

The samples are prepared on the undoped GaAs (100) wafers in Riber32 compact 21 solid source MBE system equipped with a valved cracker cell for arsenic. We use the valve for a precise and immediate control of the arsenic flux. During growth of the AlGaAs layer, growth temperature is calibrated by infrared pyrometer. After loading into the growth chamber, the samples were slowly heated to 580°C to remove surface oxide. The GaAs buffer layer was grown at 580°C followed by a 15 nm thick AlAs/GaAs short-period superlattice (SL). The structure consisted of an undoped 0.2 μm thick $Al_{0.37}Ga_{0.63}As$ core containing 7 nm thick quantum well. The part of quantum well was formed by alternate deposition submonolayer $Al_{0.14}Ga_{0.86}As$ and GaAs for several times. The core was sandwiched between a 1.5 μm thick $Al_{0.4}Ga_{0.7}As$ lower carrier confinement layer and a 0.9 μm thick $Al_{0.4}Ga_{0.7}As$ super carrier confinement layer. The scheme of sample structure is shown in Fig. 1. The core structures were grown at the different growth temperature. In the photoluminescence (PL) measurement, samples were excited with the Ar$^+$ laser 514.5 nm line. The PL spectra were detected with InGaAs detector.

GaAs cap 10 nm	
$Al_{0.4}Ga_{0.6}As$ 900 nm	
$Al_{0.37}Ga_{0.63}As$ 200 nm	
$Al_{0.14}Ga_{0.86}As$	$\times 30$
GaAs	
$Al_{0.37}Ga_{0.63}As$ 200 nm	
$Al_{0.4}Ga_{0.6}As$ 1500 nm	
AlAs	$\times 10$
GaAs	
GaAs buffer 300 nm	
Sub. SI–GaAs(100)	

Fig. 1. Scheme of the superlattice-in-well structures. Sub SI-GaAs(100) represented semi-insulating GaAs(100) substrate.

3. Results and discussion

Figure 2 shows room temperature PL spectra of sample (a) (grown at 610°C), sample (b) (630°C) and sample (c) (650°C), respectively. The excitation power of PL is the same for three samples. The full width at half maximum (FWHM) value is about 0.14 eV, which indicates good optical quality of the samples. The PL intensity of the samples (a) and (c) are slightly weaker than that of the sample (b). The increase in peak intensity at 630°C is probably due to the reduction of the nonradiative defects in the quantum well. For the high growth temperature (650°C), the decrease in the peak intensity is due to the increase in the Al composition in the quantum well rather than the reduction of the quantum confinement. This is because the Al–Ga interdiffusion was influenced little at the temperature near 650°C, which had little effect to the variation of the quantum well width. That is to say, the quantum confinement of quantum well had little change as the growth temperature increases. The PL peak related to the superlattice-in-well of sample (c) is blue-shifted compared to sample (a) and (b). This could be ascribed to a decrease in the quantum well confined potential [12]. However, the Al–Ga interdiffusion does not take place between quantum wells and barriers even at the temperature 650°C. This is because the intrinsic GaAa/AlGaAs heterostructure shows the well thermal stability at the temperature 650°C [9, 13]. The Al–Ga interdiffusion coefficient is proportional to the concentration of the triply-charged column III vacancy [9, 11, 14]. Ga desorption is believed to enhance interdiffusion by introducing column III vacancy in GaAs layer growth process, at the same time, Ga concentration is decreased as the growth temperature increases, which can result in the increase in the Al concentration. The energy shift of PL emission can be attributed to Al concentration changing in the growth process of SL, not the changing of confinement energy of quantum well due to the diffusion between quantum well and barrier, as the growth temperature was elevated to 650°C.
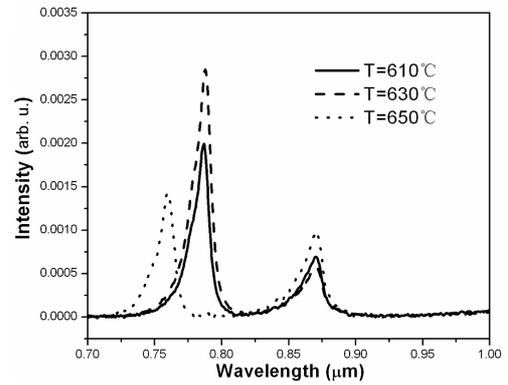
Fig. 2. The PL spectra of the SL samples with the different growth temperature: (a) 610°C, (b) 630°C, (c) 650°C.
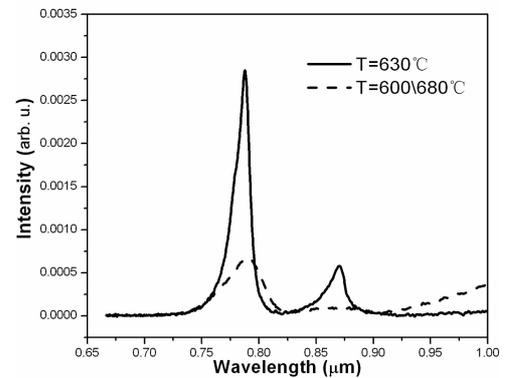
Fig. 3. The PL spectra of the SL samples with the same growth temperature. (d) 630°C, with the alternate changing growth temperature, GaAs at 630°C and AlGaAs at 680°C.

As we all know, high qualities of GaAs and AlGaAs layers are corresponding to the different optimal growth temperature, usually, GaAs to 580°C and AlGaAs to 680°C. Thus, the effects of growth temperature on the optical quality of GaAs/AlGaAs SL are further investigated. When the substrate temperature is changed, a growth interruption occurs between GaAs and AlGaAs. Figure 3 shows the PL spectra of sample (d), which is compared with sample (c) result obtained at the same growth temperature. The FWHM of spectra grown with interruption were wider than those without interruption, which indicate that quantum well quality and the photoluminescence performance were not improved. Kinetic process of atom diffusion in the SL growth process with interruption can be significantly different with the growth process without interruption. In the growth process with interruption, the surface atom was relatively stable due to atom with enough long diffusion time. When the following layer was grown, the interdiffusion can be incomplete between the stable GaAs (AlGaAs) layer and surface AlGaAs (GaAs) layer. In the growth process with-
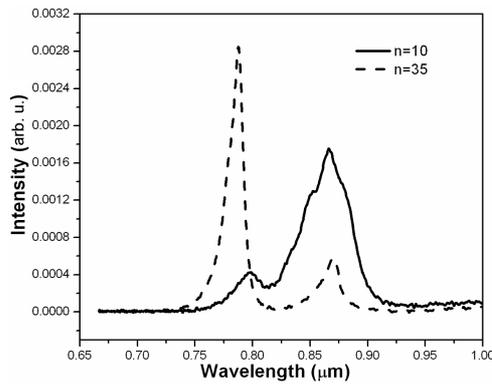
Fig. 4. The PL spectra of the SL samples with the different period, (e) 10, (c) 35, respectively.

by the period of superlattice in the process of obtaining high quality film material with low composition is investigated in detail. Effect of the growth interrupt in the growth process of superlattice on film optical quality is also discussed.

out interruption, atom was unstable or metastable, the interdiffusion can take place easily between the unstable or metastable layers. The activation energy of the interdiffusion in the *in situ* growing process of SL, especially in unstable or metastable growth process (for example, continuous growth process) is smaller than that of stable growth process (for example, growth with interruption and *ex situ* postgrowth rapid annealing).

The room temperature of PL spectra for the samples grown for 10 and 35 periods are shown by dash line (sample (e)) and black line (sample (c)) in Fig. 4, respectively. The thickness of SL in sample (e) is the same to that in sample (c), equal to 7 nm. The thickness of each GaAs and AlGaAs in SL decreases with the period increase. The diffusion length is shortened, giving rise to Al composition uniform distributions easily. It is to note that the PL peaks of the two samples have slightly different. The slight variation of the quantum well layer width could also result in the energy shift of the PL line during the two different growth processes. The specific influencing factors can need further investigation in the future.

4. Conclusions

In conclusion, we have studied the composition modulated via diffusion process in superlattice experimentally. This study may be applied to the fabrication of other group elements film materials with low composition. Results show Al composition can be modulated under some growth temperature or period. Especially, the role played

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