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Compositional disordering of AlGaAs/GaAs superlattices by using the low-temperature grown GaAs

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The use of low-temperature (~200 °C) grown GaAs by molecular beam epitaxy to induce compositional disordering of AlGaAs/GaAs superlattices has been studied. After furnace annealing between 700 and 850 °C for 30 min, an obvious blue shift in the peak wavelength of the superlattice emission is observed by the 77 K photoluminescence (PL), indicating that the emission has been changed from that of the GaAs quantum wells to that of the intermixed AlGaAs. The PL shift and the depth profile of Al concentration measured by secondary ion mass spectrometry indicate that the superlattice is nearly totally disordered after 850 °C annealing. © *1995 American Vacuum Society.*

I. INTRODUCTION

Compositional disordering of III–V superlattices has been extensively studied. The disordering techniques reported include the Zn-diffusion-induced layer disordering,[1] Si-implantation-induced layer disordering,[2] Si-diffusion-induced layer disordering,[3] and vacancy-diffusion-induced layer disordering.[4] All of these methods need impurities or defects to induce the disordering process under thermal treatment. The GaAs epilayers grown by molecular beam epitaxy (MBE) at low substrate temperatures (~200 °C) have been found to be semi-insulating and are useful for many device applications. The high resistivity stems from existence of a large number of defects, such as interstitial arsenic (As_i), arsenic antisites (As_{Ga}), Ga vacancies (V_{Ga}), and complexes.[5,6] Among these defects, the Ga vacancy has a large diffusion coefficient ($\sim 5\times 10^{-13}$ cm^2/s at 850 °C)[7] and has been found to be the diffusive mediator of the intrinsic diffusion and the SiO_2 capped enhanced diffusion for the AlGaAs/GaAs material system.[4,8] In this study, we have studied and demonstrated the use of low-temperature (LT) GaAs as the defect source to induce the disordering of the AlGaAs/GaAs superlattices. The disordering has been verified by 77 K photoluminescence (PL) spectra and secondary ion mass spectrometry (SIMS) measurement.

II. EXPERIMENT

The superlattice structure used in this study is shown in Fig. 1. It was grown by a Varian GEN II MBE system on a semi-insulating GaAs substrate. It consists of a 0.5 μm GaAs buffer layer and a 4.5 pairs of 65 Å $Al_{0.45}Ga_{0.55}As$/40 Å GaAs superlattice sandwiched between two GaAs layers. All of the layers were grown at 580 °C, except for the two GaAs confining layers. Two samples with the confining GaAs layers grown at 580 and 200 °C were compared. The thicknesses of the bottom and top confining layers were chosen to be 0.5 and 0.1 μm, respectively. The V/III beam equivalent pressure ratio was around 15 and the growth rate was 1 μm/h. Growth interruption was used before and after the growth of the AlGaAs/GaAs superlattices for both samples. After growth, the samples were furnace annealed in forming gas between 700 and 850 °C for 30 min. During annealing, the samples were placed in between two semi-insulating GaAs wafers to avoid arsenic loss. The samples were then characterized by 77 K PL and SIMS. The PL was excited with the 514.5 nm line of an Ar laser. The power density was about 1 W/cm^2. The depth profiles of the Al composition were measured by a Cameca IMS-5F SIMS spectrometer.

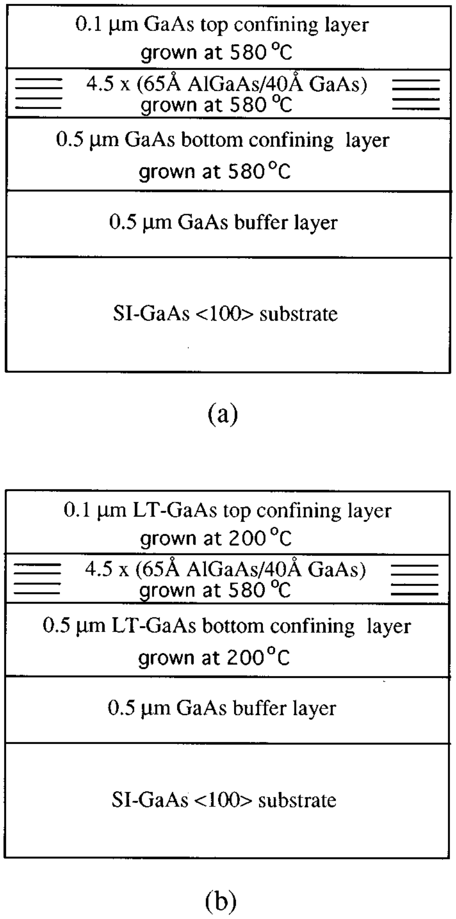

FIG. 1. Layer structure used in this study. The top and bottom confining layers are 0.1 and 0.5 μm thick, respectively. Two samples with the GaAs confining layers grown at 580 and 200 °C were compared.

III. RESULTS AND DISCUSSION

Figure 2 shows the PL spectra of the samples before and after thermal treatment. Only the emission peaks from the superlattice region are shown. From Fig. 2(a), the PL spectra of the sample with normal-temperature (580 °C) grown GaAs confining layers before and after annealing did not show any obvious difference with annealing temperatures up to 800 °C. A shift in the peak wavelength (from 7429 to 7312 Å) occurs only after the sample was annealed at 850 °C. This energy shift is due to the intrinsic self-interdiffusion of the AlGaAs/GaAs layers within the superlattice. The intrinsic interdiffusion coefficient of GaAs and AlGaAs is around 5×10^{-19} cm^2/s at 850 °C.[9,10] The PL spectra, shown in Fig. 2(b), of the sample with low-temperature-grown GaAs confining layers, however, are very different before and after annealing. Obvious blue shift in the peak wavelength of the superlattice emission is observed even after 700 °C annealing. This phenomenon indicates that the presence of the low-temperature-grown GaAs enhances the intermixing of GaAs and AlGaAs. After 850 °C annealing, the peak wavelength shifts to 6731 Å, which corresponds to the emission peak of bulk $Al_{0.23}Ga_{0.77}As$, indicating that the superlattice is nearly totally disordered (a totally disordered layer should have an Al content of 28% in our structure). The full width at half maximum (FWHM) of the PL spectra for both of the samples before and after annealing is shown in Fig. 3. The FWHM of the sample with normal-temperature-grown GaAs did not show any obvious difference with annealing temperature up to 800 °C. The FWHM of the sample with the low-temperature-grown GaAs obviously increased with the increase of the annealing temperature. After the sample was annealed at 850 °C for 30 min, the FWHM of the sample with the LT-GaAs layer increased from 12 to 31 meV. The increase in FWHM after thermal treatment indicated the intermixing between GaAs and AlGaAs. The broadening in the emission peak is due to the variation of the quantum well width and the reduction of the quantum confinement as the interdiffusion takes place. We have also noticed that the PL intensity of the sample with LT-GaAs first increased with annealing temperature up to 750 °C, then decreased at higher temperatures. The enhancement in PL intensity after thermal treatment is probably due to the reduction of the nonradiative defects in the GaAs quantum well and the improvement of the optical property of the LT-GaAs cap layer. But, at very high temperatures, the intensity decreases due to the reduction of the quantum confinement and the increase of the Al composition in the quantum well.

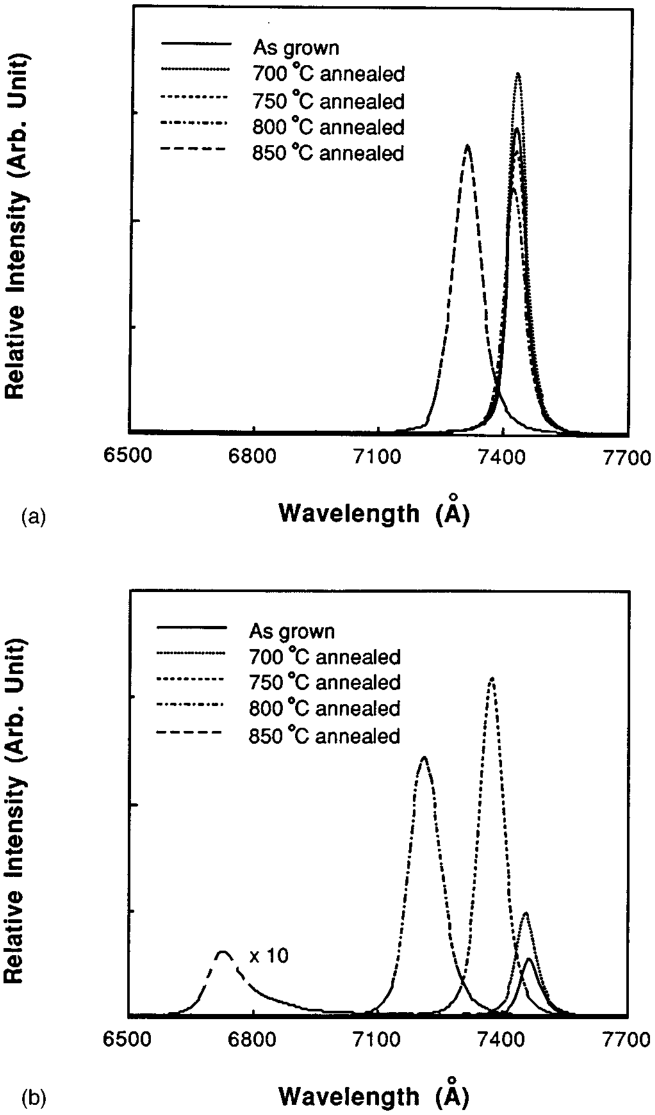

FIG. 2. The 77 K PL spectra of the samples. (a) The spectra of the sample with normal-temperature-grown GaAs confining layers before and after furnace annealing. (b) The spectra of the sample with LT-GaAs confining layers before and after furnace annealing. The annealing temperatures were 700, 750, 800, and 850 °C. The annealing time was 30 min.

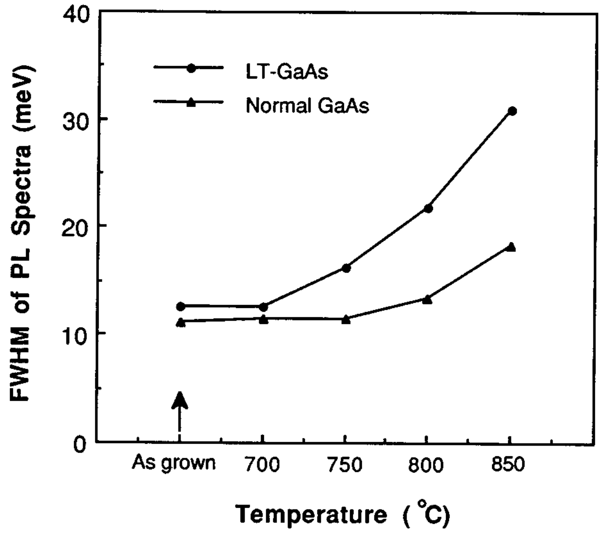

FIG. 3. The FWHM of the PL spectra for samples before and after annealing at various annealing temperatures.

The disordering of GaAs/AlGaAs because of low temperature grown GaAs has also been verified by SIMS. Figure 4 shows the Al composition profiles of the superlattice sandwiched between two normal-temperature-grown GaAs layers or two low-temperature-grown GaAs layers before and after annealing at 850 °C for 30 min. For the sample with normal-temperature-grown GaAs confining layers [see Fig. 4(a)], the Al composition profile did not show any obvious change

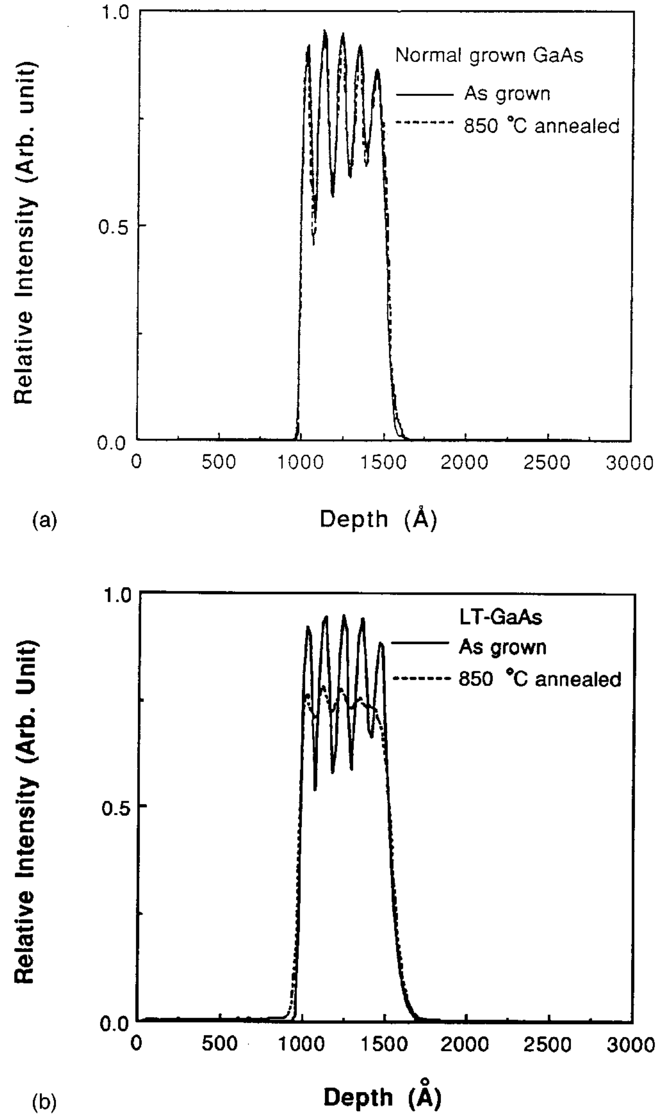

FIG. 4. The Al compositional profile of the samples. (a) The Al compositional profile of the sample with normal-temperature-grown GaAs confining layers before and after annealing. (b) The Al compositional profile of the sample with LT-GaAs confining layers before and after annealing. The intermixing of GaAs and AlGaAs is clearly observed in (b).

after annealing. For the sample with LT-GaAs confining layers, however, the Al profile, shown in Fig. 4(b), had a drastic change after annealing, clearly indicating that the superlattice was disordered after annealing. The disordered layer has a nearly average Al composition of the AlGaAs/GaAs superlattice. These SIMS observations are in good agreement with the PL results presented earlier.

The enhanced disordering of AlGaAs/GaAs superlattices due to the presence of LT-GaAs can be explained by the defect induced interdiffusion between GaAs and AlGaAs. The two major defects in LT-GaAs are As_{Ga} antisite defects and V_{Ga} vacancies. Since the Ga vacancy has a much larger diffusion coefficient than the arsenic antisite defect, the Ga vacancy in the LT-GaAs layer is the dominant defect to cause the intermixing in the AlGaAs/GaAs superlattice. The diffusion mechanism is similar to that of the SiO_2 capped layer enhanced interdiffusion,[4,11] which is also caused by the Ga vacancy diffusion. We have simulated the diffusion process numerically. It was found that the activation energy for the interdiffusion of AlGaAs/GaAs due to Ga vacancies from LT-GaAs is 4.08 eV, which is much smaller than that of the interdiffusion of normal temperature grown GaAs/AlGaAs heterostructures.[10] The details of the theoretical simulation for the LT-GaAs layer enhanced interdiffusion will be published elsewhere.[12]

IV. CONCLUSIONS

The low-temperature MBE grown GaAs used as the defects source to induce compositional disordering of AlGaAs/GaAs superlattices has been studied. After furnace annealing between 700 and 850 °C for 30 min, obvious blue shift in the peak wavelength of the superlattice emission is observed by the 77 K PL, indicating that the emission has been changed from that of the GaAs quantum wells to that of the intermixed AlGaAs. The presence of the low-temperature-grown GaAs enhances the intermixing of GaAs and AlGaAs even after 700 °C annealing. For the sample with LT-GaAs layers after 850 °C annealing, the peak wavelength shifts to 6731 Å, which corresponds to the emission peak of $Al_{0.23}Ga_{0.77}As$, indicating the superlattice is nearly totally disordered. The Al composition profile measured by SIMS also shows the superlattice disordering taking place and resulting in the formation of a disordered layer with a nearly average Al composition of the superlattice. Because the low-temperature-grown GaAs can be easily incorporated in various multilayer heterostructures, the use of such material for superlattice disordering should find applications for many devices.

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