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Control of Compositional Disordering of AlAs/GaAs Superlattice by Ar Ion Implantation

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Compositional disordering induced by impurity diffusion is utilized for lateral patterning of AlAs/GaAs superlattice. We propose a new method which can be applied to fine patterning of the superlattice. Ar ion implantation can suppress the disordering of Si-doped AlAs/GaAs superlattice on account of suppression of Si diffusion constant. The Si diffusion constant in GaAs is decreased approximately by two orders of magnitude due to Ar implantation, which is able to suppress the disordering.

I. Introduction

Compositional disordering of AlAs/GaAs superlattice (SL) is greatly enhanced by Zn[1] or Si[2,3] impurities. Basic mechanism of this effect has not been clear yet but this phenomenon is strongly related to the diffusion constant of the impurities.[4,5] In addition to basic physical interest, this phenomenon is attracting attention from view point of device applications. For fine lateral patterning of SL's, selective diffusion of Zn[6] or focused Ga ion beam[7] has been used. The particular regions of SL where Zn is diffused or Ga is implanted are selectively disordered due to impurity diffusion. Another possible method to control the disordering is to suppress the diffusion of the impurities such as Zn or Si. We have shown that Be is the effective atom to decrease the Si diffusion constant in GaAs and suppress the disordering.[4] However, the doping concentration of Be enough to suppress the disordering should be more than that of Si, which means that the SL becomes intrinsic or p type. In this report, a new control method of the disordering of AlAs/GaAs SL doped with Si is demonstrated by Ar implantation.

II. Experimental

AlAs/GaAs SL's were grown by molecular beam epitaxy on Cr-doped semi-insulating <100> GaAs at a substrate temperature of 580 °C. The thickness of both AlAs and GaAs layers was 15 nm, which was estimated from the growth rate of 800 nm/h. Ar ions were implanted into the SL at the energy of 80 keV with doses of $5x10^{13}$ cm^{-2} and $1x10^{14}$ cm^{-2}. In order to investigate the effect of Ar implantation on Si diffusion, a selectively-Si doped GaAs was grown. The annealing condition was face to face contact with another GaAs surface in H_2 atmosphere. To observe the SL disordering we employed sputtering auger spectroscopy. The SL structures were profiled by monitoring Ga auger electron (1070 eV) with Ar sputtering.

III. Results and Discussion

The impurity induced disordering of SL depends strongly on the diffusion constant of the impurity. At first we show the change in diffusion constant of Si in GaAs by Ar implantation. Figure 1 shows the SIMS profiles of Si under various treatment. In the as-grown sample, Si was doped between 60 nm and 120 nm deep from the surface rectangularly as shown in Fig. 1(a). The doping level in this region was $6x10^{18}$ cm^{-3}. After annealing at 800 °C for 1 h, the Si profile gets out of shape due to diffusion as shown in Fig. 1(b). The diffusion constant of Si estimated from this result is $9.5x10^{-15}$ cm^2/s. Figure 1(c) shows the Si profile annealed under the same condition after Ar ion implantation with the dose of $5x10^{13}$ cm^{-2}. The effect of Ar

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implantation is remarkable as shown in the figure. The projected range and the standard deviation of 80 keV Ar in GaAs are 59 nm and 29 nm, respectively. The Si profile at the front end keeps the initial profile better than that at the back end. This is because the position of the front end is in between the heavily damaged region. The diffusion constant estimated from the slope of the front end in Fig. 1(c) is 1.6×10^{-16} cm^2/s, which is less than that of the unimplanted sample by 60 times.

There are two probable explanations for this effect. One is that Ar implantation creates particular defects which trap Si and are not annealed out under this annealing condition. The other is that the Si-Si pairs, which take an important role in Si diffusion, are dissociated by Ar implantation.

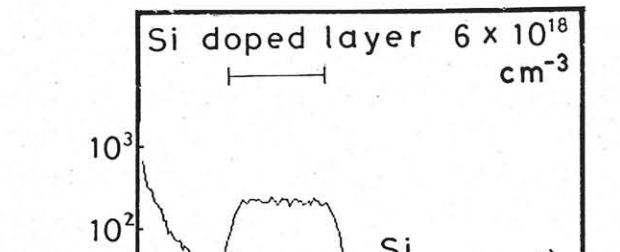

FiG. 1 SIMS profiles of Si, (a) as-grown, (b) annealed at 800 °C, 1 h, (C) annealed at 800 °C, 1 h after Ar implantation.

Figure 2 is the sputtering auger profiles of the SL showing the effect of Ar ion implantation on SL disordering. A SL partially doped with Si was used. The SL consists of 10 periods of 15 nm AlAs and 15 nm GaAs. Two periods of the SL are doped with 7.2×10^{18} Si cm^{-3} as shown in the figure. After annealing at 800 °C for 1 h, 4 periods of the SL centering around the Si doped region are disordered as shown in Fig. 2(a). Cn the other hand, when the SL is implanted with 80 keV Ar, annealing under the same condition does not induce the disordering as shown in Fig. 2(b). This is explained by the suppression of Si diffusion due to Ar implantation. The projected range of 80 keV Ar in $Al_{0.5}Ga_{0.5}As$ are shown in the figure.

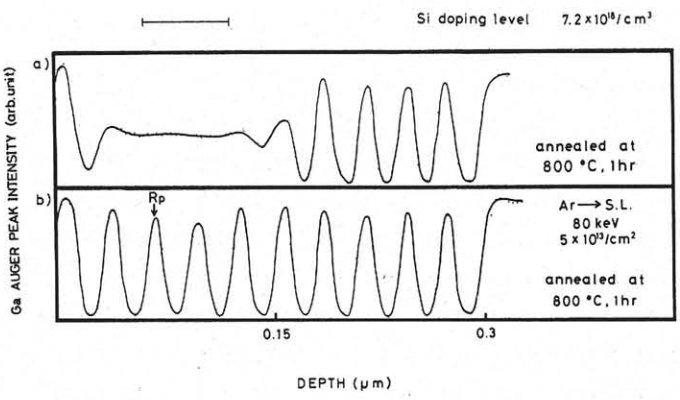

Fig. 2 Auger profiles of SL, (a) annealed at 800 °C, 1 h, (b) annealed at 800 °C, 1 h after Ar implantation.

Figure 3 is the sputtering auger profile of SL's showing the depth definition of the SL. A SL homogeneously doped with 2×10^{19} Si cm^{-3} was grown, which consists of 10 periods of 15 nm AlAs and 15 nm GaAs. Figure 3(a) is the Ga profile for the as-grown sample. After implantation of 1×10^{14} Ar cm^{-2} at 80 keV, the sample was annealed at 750 °C for 1 h. Figure 3(b) shows the Ga profile after this treatment.

The surface three layers of GaAs keep almost the initial profile and the layers deeper than the fifth are disordered completely. There is a transient region between the fourth and the fifth GaAs layers. The thickness of the transient region is about 20 nm to 30 nm, which is located at 90 nm to 120 nm deep from the surface. The

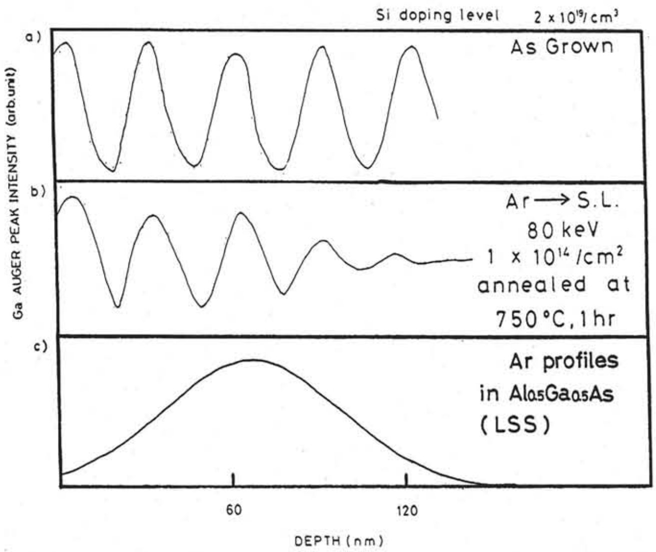

Fig. 3 Auger profiles of SL and implanted Ar profiles in $Al_{0.5}Ga_{0.5}As$, (a) as grown, (b) after Ar implantation and annealing, (c) Ar profile(LSS).

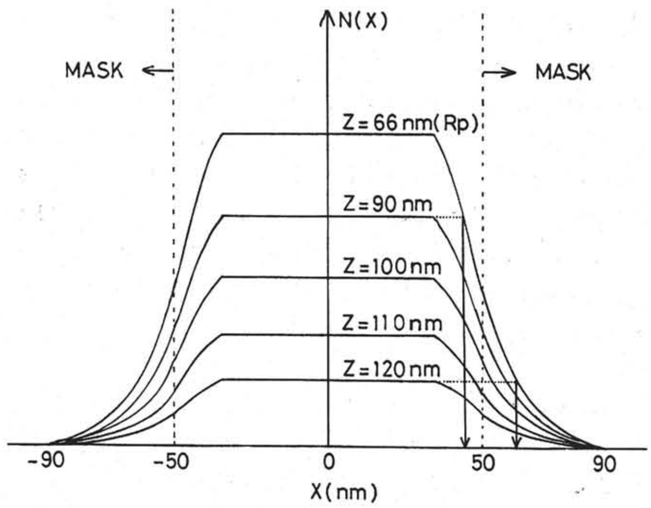

Fig. 4 CalculatedAr. distribution along the lateral direction when implanted into $Al_{0.5}Ga_{0.5}As$ through a mask with a 100 nm slit. Z is depth from the surface.

projected range and the standard deviation of 80 keV Ar in $Al_{0.5}Ga_{0.5}As$ are 66 nm and 31 nm, respectively. Apparently, the undisordered region corresponds to the Ar distribution calculated by LSS theory as shown in Fig. 3(c). However, the undisordered region should have the closer relation with the defect distribution, the maximum of which locates at the depth of about 80 % of Ar peak. Figure. 4 shows the caluculated Ar distribution along the lateral direction when implanted into $Al_{0.5}Ga_{0.5}As$ through a mask with a 100 nm slit.(10) z is depth from the surface . For discussion about the transient region, which is the boundary between the disorderded and undisorderded region in Fig. 3(a), Ar profiles deeper than the projected range(66 nm) are shown. The Ar profiles have exponential tail under the masked area and at the mask edge Ar density decreases to the half value of the unmasked area. Assuming that, beyond the projected range, the cross sectional distribution of the defect, which is directly related to suppression of the disordering, are roughly proportional to those of Ar distribution, we can get rough estimation about the lateral definition of the SL by using the cross sectional distribution of Ar in stead of defect distribution. As mentioned before, there is a transient region between 90 nm and 120 nm in z direction. If we suppose that the Ar density between 90 nm and 120 nm makes the transient region in Fig. 3(b), the lateral transient region may be estimated by finding the same Ar density along the lateral direction. The region between the two arrows in Fig. 4 shows the transient region at the projected range. The width of the region is approximately 15 nm. This value gives the rough estimation of the lateral ambiguity of the SL. The thinner the total thickness of SL for fine patterning, the lateral definition may become sharp.

We did not consider the lateral diffusion of Si. Originally the mechanism of the suppression of the SL's disordering is due to the suppression of Si diffusion, therefore, the Si in the Ar implanted region is hard to move and Si in the outside of the implanted region may not diffuse into the implanted region. This feature is quite different from other patterning methods used so far, which are selective diffusion of Zn through a mask[6] or a focused-ion beam implantation followed by annealing[7]. In these methods, the impurity diffusion is neccessary to induce the SL disordering. Therefore, the lateral ambiguity may be in the order of diffusion length.

IV Conclusion

A new method of controlling the compositional disordering of AlAs/GaAs SL was presented. It was shown that Ar ion implantation suppresses the Si diffusion in heavily Si doped GaAs and that this effect can be applied to controlling the compositional disordering of the Si doped SL. It was suggested that this method is suitable for lateral fine patterning of SL.

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