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Disordering of CdZnSe/ZnSe Strained Layer Superlattices by Si Ion-Implantation and Low-Temperature Annealing

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We report the first confirmation of disordering of CdZnSe/ZnSe strained layer superlattices (SLSs) by ion-implantation and low-temperature anealing. Both the as-grown sample and the sample annealed without Si-implantation showed several orders of well-resolved double crystal X-ray satellite peaks due to SLS periodic structure. However, the satellite peaks completely disappeared in the Si implanted and annealed (300 °C) sample, indicating that the SLS structure was disordered by the Si-implantation and not caused by the annealing process.

1. INTRODUCTION

Wide bandgap II-VI materials such as ZnSe and CdZnSe have drawn much attention because of their application for blue laser diodes. The first blue/green laser diodes were reported by Haase et al. and Jeon et al. using a CdZnSe quantum well active layer.[1,2] Impurity-induced disordering of semiconductor superlattices (SLs) has proven to be a useful technique for patterning the refractive index and bandgap in the plane of the SL layers.[3,4,5] This technology is now routinely used in GaAs/AlGaAs system. The disordering of ZnSe/ZnS SLs has previously been demonstrated by Yokogawa et al. using N^+ or Li^+ ion implantation.[6] However, so far there are no reports on the similar disordering in CdZnSe/ZnSe heterostructures by ion-implantation. In this paper we report the first observation of disordering of CdZnSe/ZnSe SLs by ion-implantation.

2. EXPERIMENT

CdZnSe/ZnSe strained layer superlattices (SLSs) were grown by molecular beam epitaxy with elemental sources of Zn, Cd, and Se. The growth temperature was 250 °C. The composition x of the

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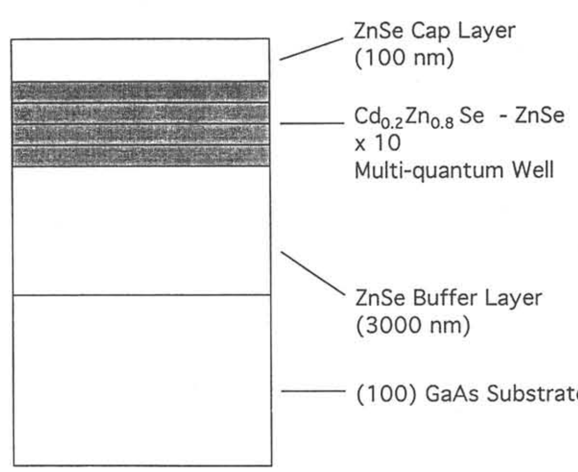

Fig.1 The structure used for the disordering experiments. The sample consisted of the following sequence of layers grown on a (100) GaAs substrate: (1) a ZnSe buffer layer (3 μm), (2) a ten period superlattice of alternating 20 nm - $Cd_xZn_{1-x}Se$ (x=0.2) and 10 nm - ZnSe layers, and (3) a ZnSe cap layer (0.1 μm) to prevent degradation of the crystalline quality of the SLS during ion-implantation and annealing.

$Cd_xZn_{1-x}Se$ alloy was determined by assuming a linear variation of the lattice constant with x (Vegard's law), and also confirmed by energy-dispersive x-ray fluorescence analysis. Details of the crystal growth were reported elsewhere.[7] The structure used for the disordering experiments, shown in Figure 1, was grown on a (100) GaAs substrate and consisted of a ZnSe buffer layer (3 μm), a ten period superlattice of alternating 20 nm - $Cd_xZn_{1-x}Se$ (x=0.2) and 10 nm - ZnSe layers, and a ZnSe cap layer (0.1 μm) to prevent the degradation of crystalline quality of the SLS during ion-implantation and annealing. Ne or Si was used for ion species. Ne-implantations were carried out at temperatures of 400 and 500 °C for 15 min. in a vaccum. Ne ions were implanted at an energy of 200 keV and an incident angle of 7° with respect to the sample surface normal. Penetration depths of Rp=2900 Å, ΔRp=1500 Å are projected from the Ne implantation. Implantation dose of $5\times10^{15}/cm^2$ were used. Si-implantations were also carried out at room temperature. Si ions were implanted at an energy of 300 keV and an incident angle of 7° with respect to the sample surface normal. Penetration depths of Rp=4100 Å, ΔRp=1500 Å are projected from the Si implantation. Implantation dose of $5\times10^{13}/cm^2$ were used. The annealing for Si-implanted samples was carried out at 300 °C for 4.5 h in a Se ambient.

3. RESULTS AND DISCUSSION

3-1. Ne-IMPLANTATION

$Cd_xZn_{1-x}Se/ZnSe$ interdiffusion was investigated by double crystal X-ray diffractometry. The rocking curves were obtained for symmetric (400) reflections using a Cu Kα1 line (λ=0.15405 nm). Figure 2 shows the rocking curves (a) for the as-grown $Cd_xZn_{1-x}Se/ZnSe$ SLS (not annealed); (b) for the as-grown $Cd_xZn_{1-x}Se/ZnSe$ SLS (annealed at 400 °C); (c) for the Ne-implanted SLS at 400 °C; and (d) for the Ne-implanted SLS at 500 °C. Several orders of well-resolved satellite peaks are clearly observed in Figure 2 (a,b) due to the periodic structure of the SLS. The angular separation of adjacent diffraction satellites, calculated for the 30 nm-thick period of the SLS[8], is 631.6 arcsec, which is in good agreement with the experimental result in Figure 2 (a,b). However, the satellite peaks completely disappeared in the Ne-implanted SLS, as shown in Figure 2 (c, d). This indicates that the SLS structure was disordered by the Ne-implantation.

Photoluminescence (PL) measurements were

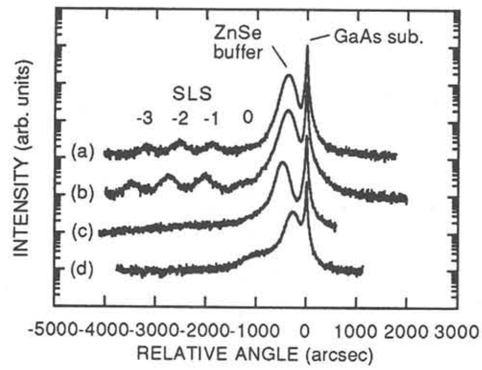

Fig.2 X-ray diffraction profile (a) for the as-grown $Cd_xZn_{1-x}Se/ZnSe$ SLS; (b) for the annealed SLS without the Ne-implantation (400 °C, 4.5 hours); (c) for the Ne-implanted SLS at 400 °C; and (d) for the Ne-implanted SLS at 500 °C.

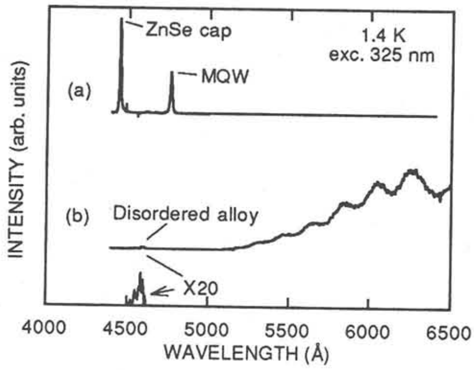

Fig.3 PL spectra (a) for the as-grown $Cd_xZn_{1-x}Se/ZnSe$ SLS; and (b) for the Ne-implanted (400 °C) SLS after the ZnSe cap layer was removed by etching in HCl.

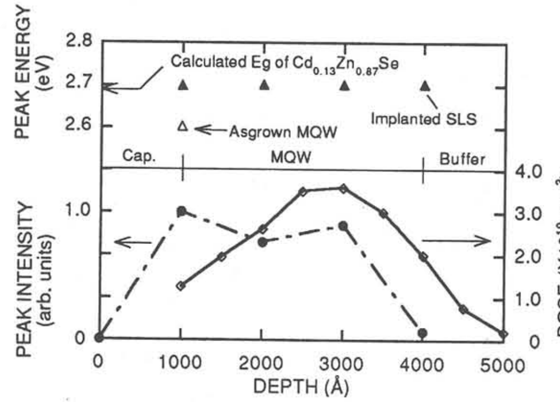

Fig.4 Depth profile of the peak intensity and peak energy of the 458.6 nm emission.

carried out in order to investigate the change of the effective energy gap with disordering. A He-Cd laser (325 nm) with an intensity of 5 mW was used as the excitation source. The PL was measured at 1.4 K. Figure 3 shows PL spectra (a) from the as-grown $Cd_xZn_{1-x}Se$/ZnSe SLS; and (b) from the Ne-implanted SLS. The ZnSe cap layer in Ne-implanted sample was removed by a HCl etchant before PL measurements. PL measurements of the as-grown show intense, sharp excitonic emission from SLS at the wavelength of 476.5 nm. However, after the Ne-implantation, the excitonic emission was observed at 458.6 nm.

The depth dependence of the PL spectra in Ne-implanted CdZnSe/ZnSe SLS was investigated by wet etching technique. Figure 4 shows the depth profile of the peak intensity and peak energy of the 458.6 nm emission. The total emission intensity increased significantly by etching the top ZnSe cap layer. The excitonic peak was located at 2.703 eV (458.6 nm), which is fairly good agreement with the band gap (2.688 eV) estimated in the completely disordered $Cd_xZn_{1-x}Se$ alloy with composition $x = 0.133$. It is therefore thought that the excitonic line of 2.703 eV is related to the band edge of the disordered $Cd_xZn_{1-x}Se$ alloy. These results therefore indicate that the observed large blue shift between the as-grown SLS and the Ne-implanted SLS is a result of layer disordering of the SLS.

3-2. Si-IMPLANTATION

$Cd_xZn_{1-x}Se$/ZnSe interdiffusion was also studied using Si-implantation. Figure 5 shows the rocking curves (a) for the as-grown $Cd_xZn_{1-x}Se$/ZnSe SLS (not annealed); (b) for the as-grown $Cd_xZn_{1-x}Se$/ZnSe SLS (annealed at 400 °C); (c) for the Si-implanted and annealed (300 °C) SLS. In Fig. 5 (a,b), both the as-grown sample and the sample annealed without Si-implantation showed several orders of well-resolved satellite peaks due to the periodic structure of the SLS. However, the satellite peaks completely disappeared in the Si-implanted SLS, as shown in Figure 5 (c), indicating that the SLS structure was disordered by the Si-implantation and annealing at 300 °C. This low-temperature disordering process will be very useful for the fabrication of blue laser diodes.

4. CONCLUSION

In conclusion, we have demonstrated, for the first time, disordering of CdZnSe/ZnSe strained layer superlattices (SLSs) by ion-implantation. As-grown samples showed several orders of well-resolved satellite peaks due to the SLS periodic structure. However, the satellite peaks completely disappeared in ion-implanted samples, indicating that the SLS structure became disordered by the ion-implantation.

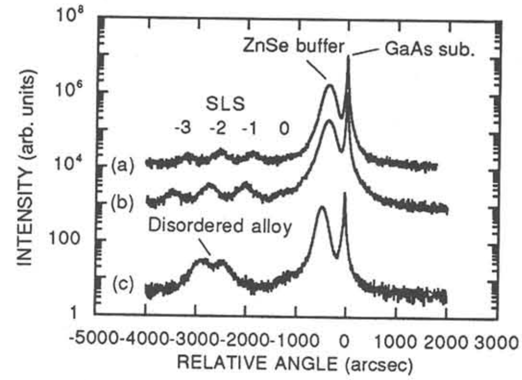

Fig.5 X-ray diffraction profile (a) for the as-grown CdZnSe/ZnSe SLS; (b) for the SLS annealed at 400 °C without the Si ion-implantation; and (c) for the Si implanted and annealed SLS (300 °C).

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