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High-Quality ZnSe/GaAs Superlattice Grown by Migration-Enhanced Epitaxy

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The difficulty of ZnSe/GaAs superlattice growth is primarily due to the large difference in optimal growth temperatures between ZnSe and GaAs, and low sticking coefficient of As_4 on ZnSe surface. By using the migration-enhanced epitaxy and room temperature As_4 deposition onto ZnSe surface, these difficulties have been solved, and the superlattice structure has been successfully grown. We report the characterization of ZnSe/GaAs superlattice using X-ray diffraction, and transmission electron microscopy. The sharp satellite peaks observed in the double-crystal X-ray diffraction rocking curve confirm the high crystalline and interfacial quality of the superlattice. Transmission electron microscopy indicates abrupt interface at ZnSe-on-GaAs as well as GaAs-on-ZnSe.

ZnSe/GaAs superlattice is attractive because of the small lattice mismatch (0.27%), and the wide band-gap and small dielectric constant of ZnSe. However, while a large number of studies have been reported on ZnSe-on-GaAs heterostructures[1,2], it is difficult to form the GaAs-on-ZnSe heterostructure by conventional molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD). This difficulty is mainly due to the large difference in optimal growth temperatures (~300°C for ZnSe and 550°C for GaAs) and low sticking coefficient of As_4 molecules on ZnSe surface.

Migration-enhanced epitaxy (MEE) has been developed to grow high-quality GaAs layers at substrate temperatures as low as 300°C[3]. This method utilizes the rapid migration of Ga atoms in an As-free atmosphere and is based on an alternate deposition of Ga and As_4 to the growing surface. MEE is also effective in the growth of ZnSe-on-GaAs. A flat and abrupt ZnSe/GaAs heterojunction with good interface quality has been obtained at the substrate temperature of 250°C[4].

Recently, the problem of low sticking coefficient of As_4 has been solved by room temperature As_4 deposition on ZnSe surface. By combining MEE and room temperature As_4 deposition, ZnSe/GaAs superlattice structure has been successfully grown[5].

In this paper, we report the characterization of ZnSe/GaAs superlattice using X-ray diffraction and transmission electron microscopy. These results indicate high-quality ZnSe /GaAs superlattice can be grown by MEE.

A conventional MBE apparatus equipped with a reflection high-energy electron diffraction (RHEED) gun having an acceleration voltage of 10 kV was used for the MEE growth. Both GaAs and ZnSe layers were grown in the same MBE chamber. ZnSe/GaAs superlattice was grown on (001) oriented GaAs substrate. For the MEE growth of GaAs, the beam flux intensity of Ga (f_{Ga}) was 1.5×10^{-7} Torr, and the deposition duration was 1.6s. The beam flux intensity of As_4 (f_{As}) was 1.2×10^{-6} Torr, and the deposition duration was 8.4s. For the MEE growth of ZnSe, beam flux intensities were 1.5×10^{-7} Torr for Zn and 1.7×10^{-7} Torr for Se. The deposition duration was 10s each. For the growth of ZnSe-on-GaAs, ZnSe layer can be grown just after the GaAs MEE growth at 250°C without deterioration of the heterointerface. This was confirmed by the conservation of both streaky patterns and specular beam intensity oscillations in RHEED during the ZnSe-on-GaAs heterostructure growth. On the other hand, for the growth of GaAs-on-ZnSe, when GaAs layer is grown on ZnSe just after the ZnSe MEE growth at 250°C, RHEED specular beam intensity weakens rapidly, indicating that the growing surface of GaAs becomes rough due to the extremely low As_4 sticking coefficient on ZnSe surface. This phenomenon was observed independently of the growth initiations such as Ga deposition on either Zn or Se atomic surface and As_4 deposition on either Zn or Se atomic surface. As described before, this problem can be solved by the room temperature As_4 deposition on ZnSe surface. Figure 1 shows the RHEED specular beam intensity trace in the [100] azimuth, during ZnSe/GaAs superlattice growth using As_4 deposition at room temperature. After As_4 deposition, two atomic layers of Ga were deposited at room temperature and then annealed at 250°C. RHEED specular beam intensity decreased after the As_4 deposition at room temperature. Since such RHEED intensity decrease was not observed at substrate temperatures above 100°C, this phenomenon indicates the adsorption of As_4 on ZnSe surface. When two atomic layers of Ga were deposited at room temperature, the halo-RHEED pattern was observed, and it did not show any streak lines. However, increasing the substrate temperature from room temperature to 250°C and then annealing at 250°C for a few minutes resulted in a streaky RHEED pattern, indicating that a thin GaAs layer was grown on ZnSe surface. As a result, subsequent MEE growth of GaAs could be performed without degradation of the growing surface. This was confirmed by the streaky RHEED pattern and persistent RHEED intensity oscillation.

The interface and the crystalline quality of the superlattice as well as the period thickness were determined using double-crystal X-ray diffraction and transmission electron microscopy (TEM). Figure 2 shows a X-ray diffraction rocking curve profile obtained from a 21-period ZnSe/GaAs superlattice in the vicinity of the (004) GaAs Bragg angle. The wavelength of X-ray was 1.5406Å. The sharpness of the diffraction satellite peaks, with full-width at half-maximum of 100 arcseconds, indicates the high crystalline and interfacial quality of the superlattice. The period thickness of this superlattice, calculated from the angular spacing of the superlattice satellite peaks is 40.8nm which is in agreement with the average period thickness obtained from TEM observation.

Cross-section bright-field TEM image (Fig.3) shows that flat heterointerfaces were realized at both the ZnSe-on-GaAs and GaAs-on-ZnSe heterointerfaces. The thickness of the GaAs layers of the superlattice obtained from the TEM micrograph is as expected from a MEE-growth rate of about one monolayer/cycle. However, the thickness of the ZnSe layers of the superlattice obtained from TEM micrograph yields a MEE-growth rate of less than 0.67 monolayer/cycle for ZnSe growth at 250°C. It appears that in our study of ZnSe growth at 250°C, the RHEED-oscillation amplitude saturation and the alternate observation of the c(2x2) and (1x2) RHEED patterns do not guarantee the complete monolayer coverage.

In this study, we have demonstrated the high-quality ZnSe/GaAs superlattice grown by MEE. Double-crystal X-ray rocking curve profile and TEM images confirm the excellent interfacial and crystalline quality of the superlattice.

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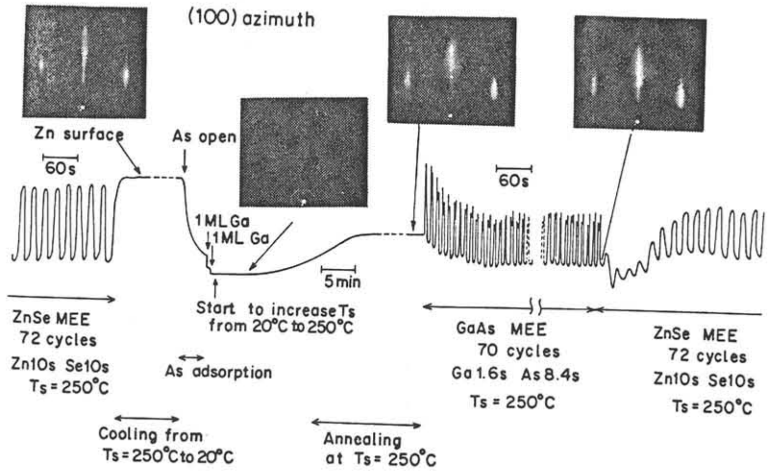

Fig.1 RHEED specular beam intensity trace in [100] azimuth, during ZnSe/GaAs superlattice MEE growth using As_4 adsorption at room temperature.

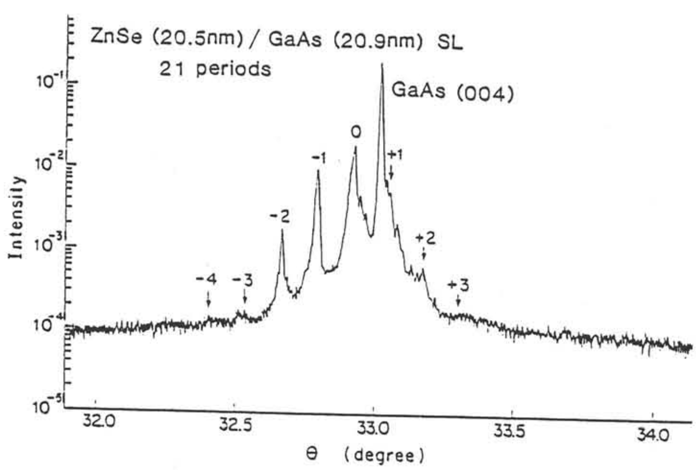

Fig.2 Double-crystal X-ray rocking-curve of a 21-period ZnSe/GaAs SL obtained in the vicinity of the (004) GaAs Bragg reflection.

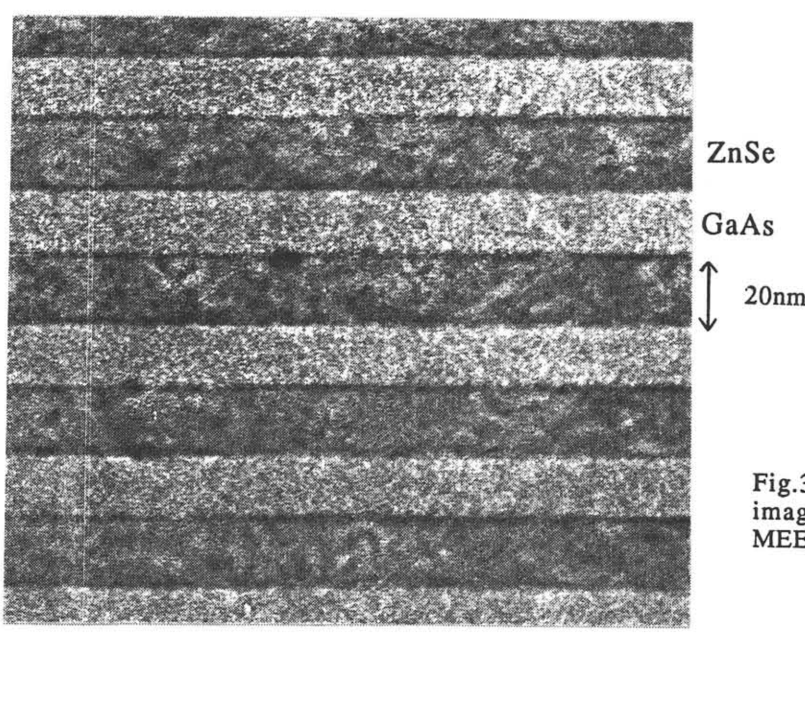

Fig.3 Cross-section TEM bright-field image of a ZnSe/GaAs SL grown by MEE.