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LATTICE PARAMETER RELAXATION DURING MBE OF $ZnTe/Cd_{1-x}Zn_xTe/Cd_{0.5}Mn_{0.5}Te$ BUFFER LAYERS BY RHEED AND HRTEM

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The dynamics of the lattice relaxation processes were investigated using a reflection of a high energy electron diffraction analysis system during growth by molecular beam epitaxy of $ZnTe/Cd_{1-x}Zn_xTe/Cd_{0.5}Mn_{0.5}Te$ buffers on GaAs substrates. The variation of the lattice parameter recorded by the high energy electron diffraction during the growth was later confirmed by an analysis of high resolution transmission electron microscopy images. We report also on an observation of oscillations of the lattice parameter during the deposition of several first layers of ZnTe on CdTe.

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This paper is devoted to an observation of the lattice parameter variations during molecular beam epitaxy (MBE) growth of various II–VI semiconductor buffer layers deposited on (001)GaAs substrate 2°-misoriented toward (110). After the thermal desorption of oxide layer, the growth of a ZnTe layer was initiated at about 300°C at a slight Te overpressure. After 50 s of growth (corresponding to 75 Å of the layer's thickness) the deposition was followed by various other buffers as shown by differently shaded stripes in Fig. 1.

During the growth the reflection of a high energy electron diffraction (RHEED) pattern was recorded using the system that consisted of 10 kV electron gun, CCD camera collecting the image formed on a fluorescent screen, and an S-VHS video tape recorder. The recording took place while the substrate was stationary with the electron beam (at 1° to the surface) directed along (110) crystallographic direction. We made sure that the RHEED streaks were parallel to the columns of the pixels observed on the computer-grabbed image given by the CCD camera. The recorded RHEED images were, at a later time, analyzed using a specially developed dedicated software running on 486 computer equipped with a

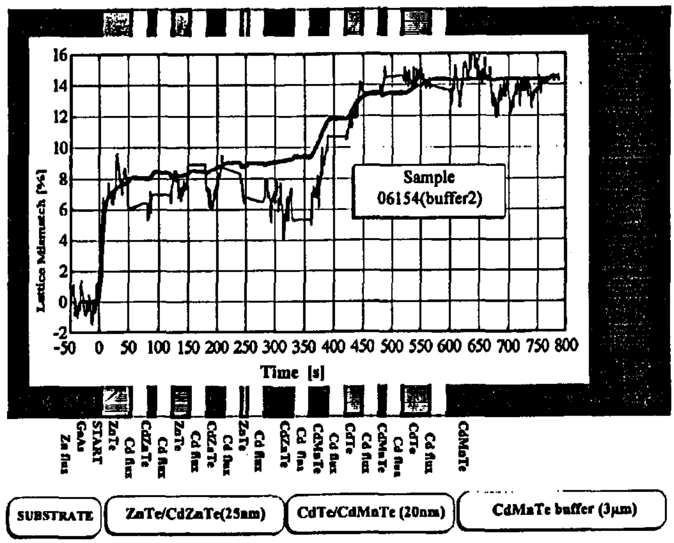

Fig. 1. Variation of the lattice parameter (a thick solid line) as determined from RHEED images recorded during the growth of buffer layers shown schematically by variously shaded stripes. Note that during the growth interruptions (when the surface of the multilayer structure was exposed to Cd flux only) the lattice parameter seen by RHEED changes slowly. A thin, noisy curve shows the lattice parameter variation as determined from an analysis of the distances between the atomic planes seen in HRTEM image of the same buffer structure. The 30 seconds stops made during the growth were added artificially to the HRTEM-derived curve in the form of horizontal portions joining the parts corresponding to various layers.

frame grabber. The software, first, determined a spatial position of a given streak at a fixed moment of time by finding a maximum of its intensity after averaging it along the length of the streak. Then, the distance between the positions of the streaks was calculated and, from that, the "lattice parameter" was determined. The procedure was repeated for images recorded every 1/3 of a second of the growth. The variation of the lattice parameter is shown in Fig. 1 as a function of the growth time by the thick solid line. The steep, initial part of the curve in Fig. 1 shows that the deposition of ZnTe on GaAs is associated with a rapid change of the lattice parameter of the growing film. The magnitude of the variation of the lattice parameter observed is consistent with the difference between lattice parameters of GaAs and ZnTe taken from the literature. By inspecting the high resolution transmission electron microscopy (HRTEM) images made of specimens prepared from the same buffers structure we found that at the GaAs/ZnTe interface there is a dense network consisting mostly of 60° and Lomer–Cottrell dislocations. Several growth interruptions (each lasting 30 seconds) were made during the process when only the Cd cell remained open. During the growth of ZnTe/CdZnTe buffer, which lasted for total 300 seconds, five such stops were made. In the RHEED curve they are distinguishable as portions that are slightly flatter than the parts obtained during the actual growth. A small slope of $\delta a/a$ curve seen in Fig. 1 at the later stages of the ZnTe/CdZnTe buffer growth is, most probably, related to serial stacking faults seen also in the HRTEM images.

After the deposition of the ZnTe/CdZnTe structure for 350 seconds, a CdTe/CdMnTe buffer was grown for 250 seconds followed by the growth of a thick $Cd_{0.5}Mn_{0.5}Te$ layer. The gradual lattice parameter change observed during the growth of CdTe/CdMnTe structure is caused by a plastic deformation of the lattice. The deformation is realized by a series of nonlocalized misfit dislocations relieving the strain. The appearance of dislocations in this part of the structure is evidenced in the HRTEM images.

To check the accuracy of the determination of $\delta a/a$ we used also direct information concerning the interplane distances visible on the high resolution electron micrographs (HRTEM) of the same structure. The cross sectional specimens were prepared by conventional mechanical polishing followed by Ar-ion milling with a LN_2 cooling system. High resolution images were obtained using a Philips CM-20 UT 200 keV transmission electron microscope with a point resolution 1.9 Å. Image processing based on the Fourier–Bragg filtering technique [1] was used to determine the $\delta a/a$ profile from the images. As a result of the original image processing we obtain a secondary image containing only the [111] atomic plane fringes. The result is shown in Fig. 1 by a noisy curve. The noise has its origin in the regions with a high density of defects which are not averaged out due to a relatively small area (900 Å× 600 Å) examined by HRTEM (as compared to 0.5 mm^2 sampled by electrons in the RHEED experiment).

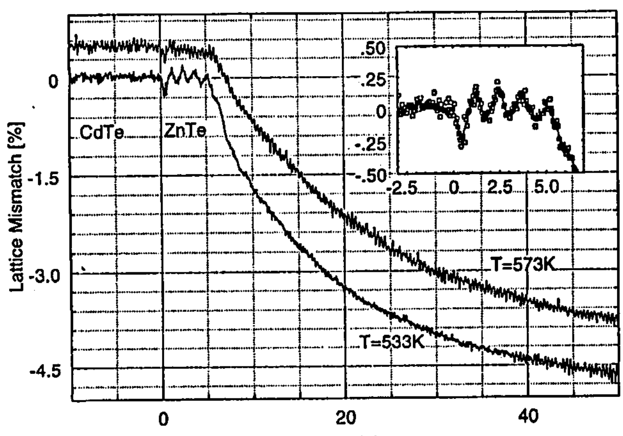

Fig. 2. Variation of the lattice constant during deposition of ZnTe layer on CdTe buffer as a function of the deposition time. The oscillations observed in the initial stages of the growth are showed in detail in the inset. The oscillations were observed only at the lower temperature of the substrate while at the growth temperature elevated by 40°C only one undulation can be resolved.

With such corroboration of the values of $\delta a/a$ obtained from the RHEED method we can attach a greater level of confidence to oscillations observed during an experiment of the second type when a different ZnTe layer on CdTe buffer was grown, see Fig. 2. The growth conditions were the same as previously described. A streaky RHEED pattern of a reconstructed surface characteristic for Te-rich growth conditions was observed. We notice that at the beginning of the ZnTe deposition there is a number of undulations of $\delta a/a$ as a function of the deposition time (i.e., of the deposited layer thickness). The oscillations of $\delta a/a$ are in phase with the oscillations of the integrated intensity of the first order RHEED streaks. The oscillations ceased after 4–5 monolayers of ZnTe were deposited. Then, after exceeding the critical thickness, the lattice parameter decreases monotonically. The number of images analyzed in this case was 20 per second (with the growth rate being 1.4 monolayer per second). The oscillations are observable only at a low growth temperature. At the substrate temperature increased by 40° only one undulation on the $\delta a/a$ curve remains.

Similar oscillations were observed in the case of the MBE growth of InGaAs on GaAs [2] and, recently, of ZnTe on CdTe [3]. These authors relate the oscillations to periodic modifications of the distortion of the lattice driven by the lattice-mismatch induced strain. The strain is clearly not the only factor causing the oscillations since no such behavior was observable during the growth of CdTe on ZnTe.

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