AIP | Applied Physics Letters

The effect of a ZnTe buffer layer on the structural and optical properties of the CdTe/ZnTe/GaAs strained heterostructures grown by temperature gradient vaportransport deposition

T. W. Kim, H. L. Park, and J. Y. Lee

Citation: Appl. Phys. Lett. **67**, 2388 (1995); doi: 10.1063/1.114556
View online: http://dx.doi.org/10.1063/1.114556
View Table of Contents: http://apl.aip.org/resource/1/APPLAB/v67/i16
Published by the American Institute of Physics.

The effect of a ZnTe buffer layer on the structural and optical properties of the CdTe/ZnTe/GaAs strained heterostructures grown by temperature-gradient vapor-transport deposition

T. W. Kim
Department of Physics, Kwangwoon University, 447-1 Wolgye-dong, Nowon-ku, Seoul 139-701, Korea

H. L. Park
Department of Physics, Yonsei University, Seoul 120-749, Korea

J. Y. Lee
Department of Electronic Materials Engineering, Korea Advanced Institute of Science and Technology, Taejon 305-701, Korea

(Received 7 June 1995; accepted for publication 6 August 1995)

Lattice-mismatched CdTe epilayers on GaAs (100) substrates with and without ZnTe buffer layers were grown by the simple method of double-well temperature gradient vapor-transport deposition. X-ray diffraction measurements were performed to investigate the structural properties of the epitaxial layers. Photoluminescence and transmission electron microscopy measurements showed that the crystallinity of the CdTe epilayers grown on the GaAs substrates was remarkably improved using the ZnTe buffer. The strain of the CdTe layer was determined from photoreflectance measurements. These results indicated that the CdTe epitaxial films grown on GaAs substrates with the ZnTe buffer can be used for applications as buffer layers for the growth of $Hg_xCd_{1-x}Te$ and $Cd_xZn_{1-x}Te$. © *1995 American Institute of Physics.*

Recently, with rapid advancements in epitaxial growth techniques, the fabrication of new types of strained heterostructures has attracted much attention for both scientific and technological reasons.[1–3] Potential applications of II-VI compound semiconductors in optoelectronic devices have driven an extensive and successful effort to grow CdTe epilayers on various substrates.[4–8] However, since there are inherent problems due to possible cross-doping effects resulting from interdiffusion[8] or due to strain effects as a consequence of the lattice mismatch,[9] relatively little work has been performed on II-VI/III-V mixed heterostructures. Among these mixed heterostructures, even though CdTe/GaAs heterostructures have inherent difficulties due to the large lattice mismatch ($\Delta a/a \cong 14.6\%$ at 25 °C), the CdTe epitaxial layer grown on GaAs is particularly interesting because of its important advantages for optoelectronic devices such as solar cells and gamma-ray detectors.[10] Although some works concerning CdTe/GaAs heterostructures have been reported,[10–12] to the best of our knowledge, all of the CdTe epitaxial layers were grown directly on the GaAs substrate.[10–12]

This letter presents data for CdTe thin films grown on GaAs substrates with and without ZnTe buffer layers by the simple technique of double-well temperature-gradient vapor-transport deposition (DWTGVTD). X-ray diffraction (XRD) measurements were carried out to demonstrate the heteroepitaxy of the CdTe films. Photoluminescence (PL) and transmission electron microscopy (TEM) measurements were performed to characterize the CdTe film's quality. The magnitude of the strain in the CdTe epilayers was determined from the photoreflectance measurements.

Polycrystalline stoichiometric CdTe and ZnTe with purities of 99.9999% grown by the Bridgman method were used as source materials and were precleaned by repeated sublimation. Cr-doped semi-insulating GaAs was degreased in warm trichloroethylene (TCE), rinsed in de-ionized water thoroughly, etched in a HF solution, and rinsed in TCE again. As soon as the chemical cleaning process was finished, the wafers were mounted onto a molybdenum susceptor. Before CdTe and ZnTe growth, the GaAs substrates were thermally cleaned at 600 °C for 10 min *in situ* in a growth chamber at a pressure of 10^{-8} Torr. The depositions were done at substrate temperatures of 290 and 310 °C for the CdTe and the ZnTe layers, respectively, and at a system pressure of 5×10^{-7} Torr. Source temperatures for athe CdTe and ZnTe were 470 and 540 °C, respectively, and the growth rates were 0.36 and 1.2 μm/h, respectively. A detailed schematic diagram of the single-well TGVTD was reported previously,[6] and the DWTGVTD system is a modified version of the one based on the TGVTD with two effusion cells.

The PL measurements were carried out using a 75 cm monochromator equipped with an RCA 31034 photomultiplier tube. The excitation source was the 4880 Å line of an Ar-ion laser. The PR measurements were performed using a 75 cm monochromator equipped with a 250 W Xe lamp as a probe source and the 4880 Å line of an Ar-ion laser as a modulation source. The samples were mounted on a cold finger in a cryostat and kept either at room temperature or 20 K throughout the experiment. The TEM observations were performed in a JEOL 200CX transmission electron microscope operating at 400 kV. The samples for TEM measurements were prepared by cutting and polishing to an approximately 30 μm thickness using a diamond paper, and then argon-ion milling at liquid-nitrogen temperature to electron transparency.

The CdTe films as grown by DWTGVTD had mirrorlike surfaces without any indication of pinholes, which was confirmed by Normarski optical microscopy and scanning elec-

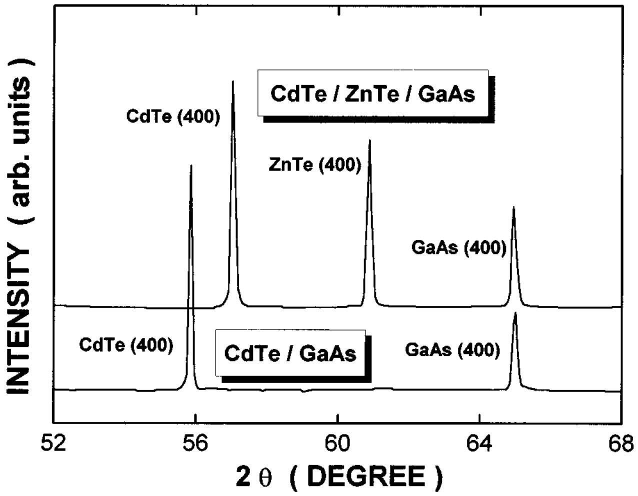

FIG. 1. X-ray diffraction curves of the CdTe/GaAs and the CdTe/ZnTe/GaAs heterostructures.

tron microscopy. The x-ray diffraction pattern for the CdTe epilayer on a GaAs (100) substrate shows the (400) $K\alpha_1$ diffraction peaks corresponding to the CdTe (100) epilayer on the GaAs (100) substrate (see Fig. 1). The diffraction pattern for the CdTe epilayer on a GaAs (100) substrate with a ZnTe buffer shows the (400) $K\alpha_1$ diffraction peaks corresponding to the CdTe (100) epilayer, the ZnTe (100) buffer, and the GaAs (100) substrate Although the growth of the CdTe films was performed in the thickness range between 0.5 and 10 μm, only the physical properties of the CdTe films with a 1 μm thickness are described for convenience. These results indicate that a CdTe (100) epilayer with and without a ZnTe buffer layer can be grown on a GaAs (100) substrate using the simple DWTGVTD technique. The lattice constants of the CdTe films with and without the ZnTe buffer layer as determined from their XRD peaks were 6.4861 and 6.4961 Å, respectively. Even though the lattice constant of the CdTe film grown on the ZnTe buffer layer is a little larger than the bulk value of CdTe (100) due to the tensile effect,[12] it is much smaller than the value of the CdTe epilayer directly grown on the GaAs substrate.

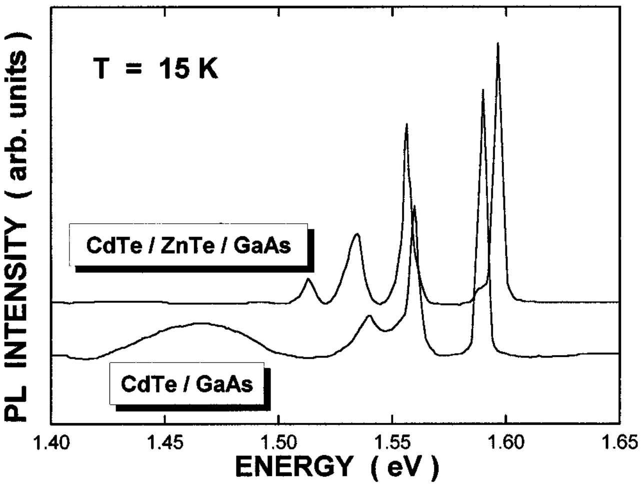

FIG. 2. Photoluminescence spectra of the CdTe/GaAs and the CdTe/ZnTe/GaAs heterostructures.

The results of the PL measurements for the CdTe/GaAs and CdTe/ZnTe/GaAs heterostructures are shown in Fig. 2. The peaks at 1.591 eV for the CdTe/GaAs and 1.596 eV for the CeTe/ZnTe/GaAs are considered to be from excitons bound to neutral donors caused by impurities.[13] The peaks at 1.561 eV for the CdTe/GaAs and at 1.556 eV for the CdTe/ZnTe/GaAs are attributed to donor-acceptor pair transitions, and the peaks at 1.539 eV for the CdTe/GaAs and at 1.535 eV for the CdTe/ZnTe/GaAs are related to longitudinal optical (LO) phonon replicas.[14] While the 1.514 eV peak for the CdTe/ZnTe/GaAs heterostructure is also considered to be a LO phonon replica, the corresponding replica does not appear for the CdTe/GaAs heterostructure. Furthermore, the peak intensity of the defect-related emission in the range between 1.40 to 1.50 eV for the CdTe/ZnTe/GaAs heterostructure is much smaller than that for the CdTe/GaAs heterostructure.

The selected-area electron-diffraction patterns from TEM of the CdTe/GaAs and the CdTe/ZnTe/GaAs heterostructures are shown in Fig. 3. Figure 3 shows misfit dislo-

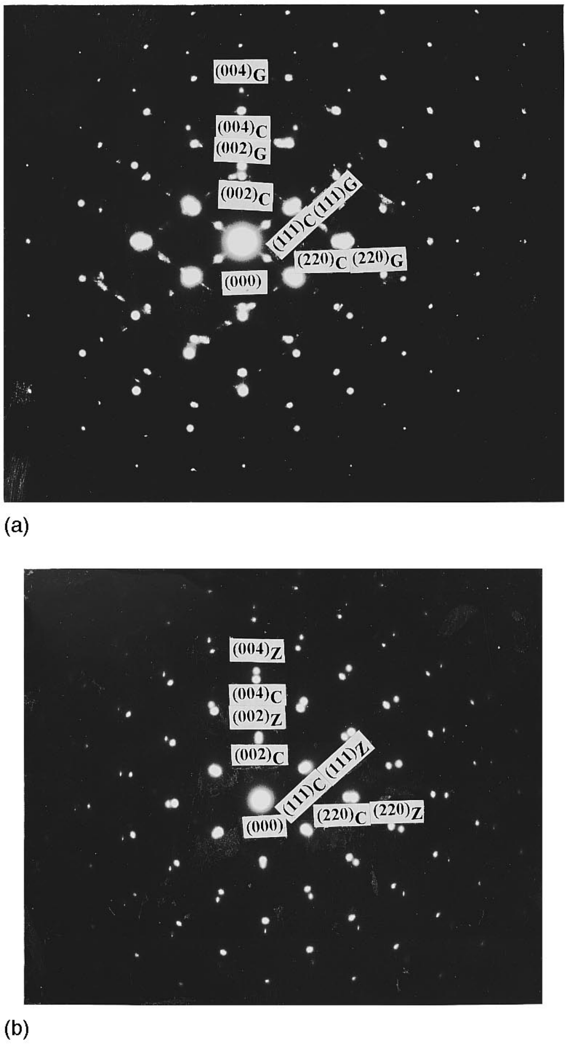

FIG. 3. Selected-area electron-diffraction patterns from transmission electron microscopy of the CdTe/GaAs and the CdTe/ZnTe/GaAs heterostructures, $(hkl)_C$, $(hkl)_Z$, and $(hkl)_G$ corresponding to the CdTe, ZnTe, and GaAs indices, respectively. These images are plane-view transmission electron diffraction patterns.

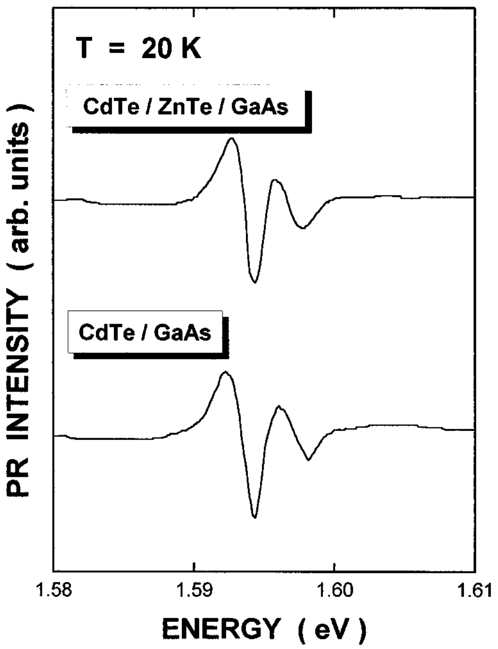

FIG. 4. Photoreflectance spectra of the CdTe/GaAs and the CdTe/ZnTe/GaAs heterostructures.

cations in both heterostructures due to the lattice mismatch. Figure 3(a) shows that the diffraction spots occur in pairs, with the inside spot and the smaller outside spot corresponding to the CdTe and the GaAs, respectively. Figure 3(b) shows similar diffraction spots occurring in pairs, corresponding to the CdTe and ZnTe. The diffraction patterns indicate that an epitaxial orientation relationship was formed between the CdTe and the GaAs in the CdTe/GaAs heterostructure and between the CdTe and the ZnTe in the CdTe/ZnTe/GaAs heterostructures. All of the CdTe (hkl) are parallel to the GaAs (*hkl*) and the ZnTe (hkl). However, the distance between the CdTe (hkl) and the ZnTe (hkl) is much smaller than that between the CdTe (hkl) and the GaAs (hkl) resulting from the different lattice constants among CdTe, ZnTe, and GaAs. Furthermore, there are slight lines between the (hkl) indices in the CdTe/GaAs heterostructures due to the dislocations or the stacking faults. High-resolution TEM images of cross-sectional samples of the CdTe/GaAs and the CdTe/ZnTe/GaAs structures show that both the CdTe/GaAs and the CdTe/ZnTe heterointerfaces exhibit sawtoothed structures. While the CdTe epilayer grown directly on the GaAs substrate has dislocations and stacking faults, the CdTe epilayer grown on the GaAs substrate with the ZnTe buffer layer has no stacking faults.

PR measurements were performed to determine the strain in the CdTe epilayers. The results of the PR spectra are shown in Fig. 4. The strain (ϵ) of the CdTe epilayer can be determined using the following equation:[15,16]

$$\epsilon = -\frac{C_{11}(E_{\mathrm{hh}}-E_{\mathrm{lh}})}{2b(C_{11}+2C_{12})}, \qquad (1)$$

where C_{ij} is the stiffness coefficient, b is the shear deformation potential, and E_{hh} and E_{lh} are the energies corresponding to the heavy-hole and light-hole bands. Using Eq. (1), the strains of the CdTe epilayers determined for the CdTe/GaAs and the CdTe/ZnTe/GaAs heterostructures were -5.32×10^{-4} and -1.58×10^{-3},[15,16] respectively. Thus, the strain induced in the CdTe epilayer can be reduced using the ZnTe buffer layer. Furthermore, the value of the strain in the CdTe epilayer obtained from the CdTe/ZnTe/GaAs heterostructures is much smaller than that from the CdTe/GaAs heterostructure grown by molecular beam epitaxy;[10] this result is also confirmed by the results of the XRD measurements.

In summary, the results of XRD, PL, and TEM measurements showed that high-quality CdTe epilayers can be grown on GaAs substrates with ZnTe buffer layers. XRD and TEM measurements clearly confirm the lattice mismatch among the CdTe, ZnTe, and GaAs. These results indicate that the ZnTe buffer layer on GaAs (100) improves the crystallinity of the CdTe epilayer. The strain of the CdTe epilayers determined for the CdTe/ZnTe/GaAs heterostructure was as small as -5.32×10^{-4}. Although some details of the electrical properties remain to be clarified, these results indicate that the CdTe epitaxial films grown on a ZnTe buffer layer by DWTGVTD have high quality. Furthermore, such high-quality films hold promise for applications as buffer layers for the growth of $Hg_xCd_{1-x}Te$ and $Cd_xZn_{1-x}Te$.

This work was supported by the Faculty Research Grant of the Yonsei University in 1995.

[1] F. Capasso, *Physics of Quantum Electron Devices* (Springer, Berlin, 1990).
[2] C. Weisbuch and B. Vinter, *Quantum Semiconductor Structures* (Academic, Boston, 1991).
[3] D. K. Ferry and C. Jacononi, *Quantum Transport in Semiconductors* (Plenum, New York, 1992).
[4] R. F. C. Farrow, G. R. Jones, G. H. Williams, and I. M. Young, Appl. Phys. Lett. **39**, 954 (1981).
[5] T. W. Kim, Y. H. Chang, Y. D. Zheng, A. A. Reader, B. D. McCombe, R. F. C. Farrow, T. Temofonte, F. A. Shirland, A. Noreika, J. Vac. Sci. Technol. B **5**, 980 (1987).
[6] T. W. Kim, B. J. Koo, M. Jung, S. B. Kim, H. L. Park, H. Lim, J. I. Lee, and K. N. Kang, J. Appl. Phys. **71**, 1049 (1992).
[7] T. W. Kim, M. Jung, H. L. Park, H. K. Na, and J. S. Kim , Appl. Phys. Lett. **61**, 1101 (1992).
[8] T. W. Kim, H. L. Park, J. Y. Lee, and H. J. Lee, Appl. Phys. Lett. **65**, 2597 (1994).
[9] J. H. Lee, S. B. Kim, B. J. Koo, I. H. Chang, M. Jung, H. L. Park, and T. W. Kim, Solid State Commun. **84**, 901 (1992).
[10] G. Bratina, L. Sorba, A. Antonini, G. Ceccone, R. Nicolini, G. Biasiol, A. Franciosi, J. E. Angelo, and W. W. Gerberich, Phys. Rev. B **48**, 8899 (1993).
[11] A. Bourret, P. Fuoss, G. Feuillet, and S. Tatarenko, Phys. Rev. Lett. **70**, 311 (1993).
[12] M. Ekawa and T. Taguchi, Jpn. J. Appl. Phys. **28**, L1341 (1989).
[13] C. E. Barnes and K. Zanio, J. Appl. Phys. **46**, 3959 (1975).
[14] K. Sugiyama, Thin Solid Films **115**, 97 (1984).
[15] D. E. Aspnes, Surf. Sci. **37**, 418 (1973).
[16] T. P. Pearsal, F. H. Pollak, J. C. Bean, and R. Hull, Phys. Rev. B **33**, 6821 (1986).