Optoelectrical Properties of HgCdTe Epilayers Grown by Hot Wall Epitaxy

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Abstract

Hg$_{1-x}$Cd$_x$Te (MCT) was grown by hot wall epitaxy. Prior to the MCT growth, the CdTe (111) buffer layer was grown on the GaAs substrate at the temperature of 590°C for 15 min. When the thickness of the CdTe buffer layer was 5 μm or thicker, the full width at half maximum values obtained from the x-ray rocking curves were found to significantly decrease. After a good quality CdTe buffer layer was grown, the MCT epilayers were grown on the CdTe (111)/GaAs substrate at various temperatures *in situ*. The crystal quality for those epilayers was investigated by means of the x-ray rocking curves and the photocurrent experiment. The photoconductor characterization for the epilayers was also measured. The energy band gap of MCT was determined from the photocurrent measurement and the x composition rates from the temperature dependence of the energy band gap were turned out.

Key Words : Hg$_{1-x}$Cd$_x$Te, hot wall epitaxy, CdTe buffer layer, photocurrent, photoconductor

1. Introduction

Hg$_{1-x}$Cd$_x$Te (MCT) is an important electro-optical band gap semiconductor for infrared region (IR) detector technology due to the ease of wavelength tunability[1]. However, the detection wavelength is very sensitive to the alloy composition, x. Currently, IR sensor and imaging array development has focused on the detection of a single band of IR radiation typically in one of the following three atmospheric transmission windows such as 1 − 2.5, 3 − 5, and 8 − 12 μm. However, although the MCT epilayers on a bulk CdTe could be grown by various epitaxial methods, the current lack of availability of high-quality and large-area CdTe substrates is generally recognized as a main limitation for efficient MCT detector technology. Recently, epitaxial MCT layers have been grown on lattice matched CdZnTe substrates by liquid phase epitaxy (LPE), metalorganic chemical vapor deposition (MOCVD), and molecular beam epitaxy (MBE) techniques[2-5]. Thus, MOCVD and MBE has recently improved the CdTe epitaxial films. These CdTe films were epitaxially grown on foreign substrates

like sapphire, GaAs, and Si[6-9]. These substrates are available at low cost, in large area, with good structural quality and CdTe is an ideal buffer material for the subsequent growth of epitaxial MCT. Moreover, GaAs and Si are the basic materials for the fabrication of electronic circuits, so that the IR detector and the signal processing circuit on a single chip could be integrated on the MCT layer deposited on such a substrate. However, up to now the cost of device-quality MCT/Si and MCT/GaAs substrates, grown by MOCVD and MBE, is too high for commercial applications. Compared with these methods, the hot wall epitaxy (HWE) technique has the advantages of low cost, simplicity, convenience and relatively large growth rate under the thermodynamic equilibrium growth.

In this paper, MCT on the CdTe buffer layer was grown by using a HWE method. Here, the CdTe buffer layers were grown under various growth conditions on the semi-insulating GaAs (100). The crystal quality of the grown MCTs was estimated by means of the powder and the double crystal x-ray diffraction technique. Also, the photoconductor characterization for these epilayers is examined through a photocurrent (PC) measurement.

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2. Experimental Procedure

A homemade HWE apparatus was used for growing the MCT epilayers on the GaAs substrates. This HWE

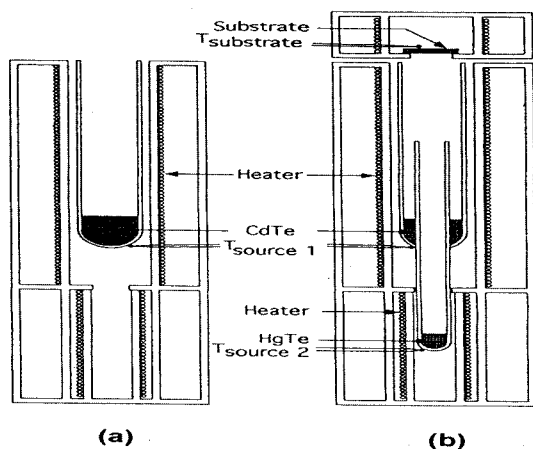**(a)**   **(b)**

Fig. 1. Schematic diagram of a HWE apparatus on the growth furnaces: (a) the first furnace shown in Fig. 1(a) was used to grow the CdTe buffer layer without influencing the HgTe power and (b) after the CdTe buffer layer growth, the second furnace shown in Fig. 1(b) was used to grow the MCT epilayer on the CdTe buffer layer.

Fig. 2. The growth orientation of the CdTe epilayers determined by the preheating condition of the substrate.

apparatus consist of the two electric furnaces, made of a quartz tube with kanthal wire. And, a substrate holder is placed on the top of the furnace and easily switched on the top of the two furnaces as shown in Fig. 1. Here, the first furnace shown in Fig. 1(a) is necessary to grow the CdTe buffer layer without influencing the HgTe powder. If the second furnace shown in Fig. 1(b) is used to grow the CdTe buffer layer, the the HgTe powder in the furnace located below the CdTe furnace is simultaneously evaporated during the CdTe buffer growth because the evaporation temperature of the HgTe powder is very low. Therefore, HWE apparatus was used to the separated furnaces for the CdTe buffer growth of Fig. 1(a) and the MCT growth of Fig. 1(b).

Prior to growth, the semi-insulating GaAs (100) substrate was cleaned ultrasonically for 1 min in successive baths of trichloroethylene, aceton, methanol, and 2-propanol and etched for 1 min in a solution of H_2SO_4 : H_2O_2 : H_2O (5:1:1). The substrate was degreased in organic solvents, and rinsed with deionized water (18.2 MΩ). After the substrate was dried off, the substrate was immediately loaded onto the substrate holder in the HWE. The GaAs substrate was annealed in a preheating process to remove the oxide of the substrate surface. Fourie et al.[10] reported that the grown CdTe showed (100) and (111) planes depending on the pre-
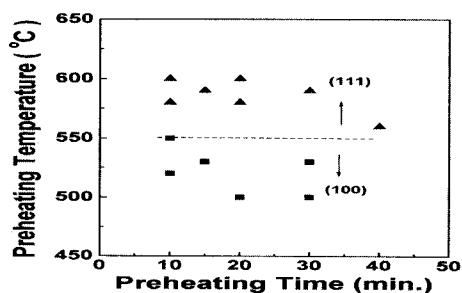
heating temperature. In this experiment, after the GaAs substrates were annealed at the temperature of 550°C and above or below as a preheating process, the CdTe buffer layers on the preheated substrates were grown by using the (a) furnace as shown in Fig. 1. The CdTe buffer layers were grown while the temperature of the substrate was set at 280°C and the source temperature, source 1, was set at 460°C, respectively. The grown CdTe buffer layers with a thickness of 3 μm were examined by using the x-ray diffraction powder method. From these results, we confirmed that the samples preheated below 550°C were (100) plane and the samples preheated above 550°C were the (111) plane, respectively, as is shown in Fig. 2. Also, the full width at half maximum (FWHM) values of these samples were measured by using the double crystal rocking curve (DCRC) experiment. The preheated sample for 15 min at 590°C showed a minimum FWHM value. And the grown CdTe on these substrates was revealed to be the (111) plane. The HgCdTe/CdTe/GaAs epilayes were grown with HWE, while the substrate was switched successively on the top of the (a) and (b) furnace as shown in Fig. 1. The source materials 1 and 2 as shown in Fig. 1 were CdTe and HgTe powder (Rare Metallic, 6 N), respectively. After the CdTe buffer epilayer on the GaAs was grown in the (a) furnace, the CdTe/GaAs epilayer was immediately moved to the (b) furnace. Then, the HgCdTe/CdTe/GaAs epilayer was grown by using the heating source 1 and 2, simultaneously. The grown epilayers were analyzed by DCRC to obtain the optimum growth condition. The thickness of the grown samples was measured by a α-step profilometer (Tencor, α-step 200). Also, to measure the PC spectra, the electrodes were made on the both ends of the sample and connected to a gold wire. The electrode space was

100 μm. After this the sample was mounted on the holder in the low temperature cryostat equipment, the PC spectrum measurement was made while the mono-chromatic light emitted from light source passed through a chopper was illustrated on the sample. This experiment was carried out at the temperature of 77 K by using the light emitted from a halogen lamp and a 600°C black body radiation.

3. Results and Discussion

3.1. Growth of the MCT Epilayers

In general, the quality of the MCT epilayers has been known to be strongly dependent on that of the CdTe buffer layer. The quality of CdTe epilayer was influenced by both the Ga outdiffused from the GaAs substrate and the defects generated at the interface due to the misfit layers. To reduce the Ga outdiffusion and the defect generation, the proper thickness of the CdTe buffer layer must be chosen to grow a high quality the MCT epilayers on the CdTe/GaAs substrate. Therefore, the CdTe buffer layers in the thickness ranging between 0.8 μm and 12 μm were grown at 280°C to find the optimum buffer layer, prior to the MCT growth.

Fig. 3 shows FWHM values as a function of the thickness of the CdTe epilayers grown on the GaAs (100) substrates. The FWHM values remarkably decreased when the thickness of the CdTe layer was 5 μm or thicker. These results indicate that the biaxial compressive stress of the CdTe epilayers on GaAs is significantly relaxed with increasing the CdTe thickness. As is listed in Table 1, the optimum growth temperatures of the substrate and the source 1 for the CdTe (111) epilayers were found to be 280°C and 460°C, respectively. At this time, the thickness of the CdTe (111) epilayer was 9 μm and
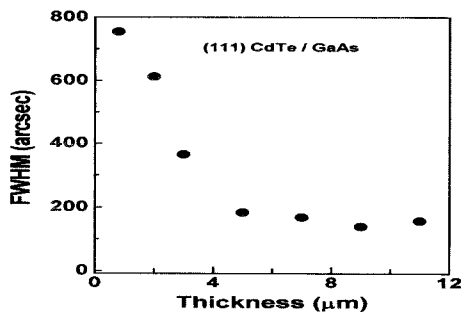
Table 1. Optimum growth conditions for the MCT epilayers

	CdTe	MCT-1	MCT-2
Substrate Tem.	280°C	170°C	170°C
Source 1 Tem.	460°C	380°C	360°C
Source 2 Tem.		185°C	190°C
Composition x		0.762	0.317

a minimum FWHM value was 139 arcsec, respectively. This thickness was comparable to the reported thickness, 10 μm, of high quality CdTe grown by HWE[11]. Then, the MCT epilayers were grown in situ on the CdTe(111)/GaAs(100) substrate with the apparatus as shown in Fig. 1(a) and 1(b). As is listed in Table 1, the heating temperatures of the source 1 and the source 2 for the MCT-1 sample were set at 380°C and 185°C, respectively. Also, the heating temperatures of the source 1 and the source 2 for the MCT-2 sample were kept at 360°C and 190°C, respectively. The substrate temperature was maintained at 170°C, while the MCT samples were growing. The growth rates of the MCT 1 and 2 samples were 0.9 μm/h and 0.8 μm/h, respectively. Also, the FWHM values obtained from DCRC analysis for the MCT 1 and 2 samples were determined to be 125 arcsec and 120 arcsec, respectively. These values are comparable with other MCT samples grown by MBE[12] and MOCVD[13]. It should be noted that the crystalline quality of the MCT epilayers is better than that of the CdTe/GaAs substrate epilayers. The surface morphologies observed by atomic force microscopy (AFM) and the schematic cross section of the epitaxial grown MCT samples were shown in Fig. 4. The root-meansquare values, R_{ms}, for the surface roughness of the MCT-1 and 2 samples were obtained to be 7 and 9 nm, respectively.
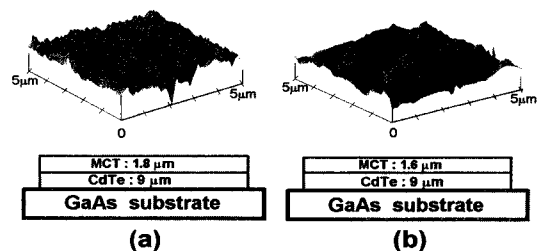

Fig. 3. The dependence of FWHM of the XRD rocking curves on the thickness of the CdTe epilayers.

Fig. 4. AFM images and schematic diagram of the cross section for epitaxial MCT: (a) the MCT-1 epilayer and (b) the MCT-2 epilayer.

3.2. Photocurrent Measurement

Single crystal semiconductors of have two types of photoconduction, extrinsic and intrinsic. In the extrinsic case, a free electron in an n-type photoconductor, or a free hole in a p-type photoconductor is created through the impurity levels when the light illuminates the semiconductor. However, on intrinsic photoconductor like MCT depends upon the band-to-band transition and a free electron and hole generated simultaneously by the illuminated light. Also, the cut off wavelength is determined by the band gap energy of the intrinsic photoconductor. Therefore, to characterize the photoconductor for the grown MCT epilayers, the PC spectra were measured at 77 K. Fig. 5 shows the PC spectra for the MCT-1 epilayer with the dark resistance of 45 at 77 K. The spectrum 1 was measured without filter in the front of halogen lamp. The PC peaks at 0.784 μm (1.5815 eV) and 0.842 μm (1.4735 eV) in the spectrum 1 correspond to the energy band gap of CdTe and GaAs, respectively. And, the shown peaks between 1.2 μm and 1.6 μm to the right of the energy band gap are associated with the second order of CdTe and GaAs. Here, electrons in valence band are excited by the absorbed light and the excited electrons transit from the valence band to the conduction band. The transited electrons are immediately guided to both sides of electrodes. Therefore, the PC peaks corresponding to the band gap are guided to the electrodes. This is called intrinsic transition[14,15]. The photocurrent in the short wavelength region except the peak corresponding to the band gap is reduced. The reason is that incident light is absorbed mostly at the surface and the electrons and holes produced by the incident light are mutually recombined[16]. Also, the peak associated with MCT at 0.990 μm (1.2524 eV) was overlapped with the CdTe and the

GaAs peaks. Therefore, we must confirm whether it is the MCT peak or not, through the 0.8 μm filter placed in the front of light source. By cutting the wavelength having less than 0.8 μm, the CdTe peak corresponding to the band gap and its 2nd order peak disappeared, as is shown in the spectrum 2 of Fig. 5. But the GaAs peaks did not disappear yet. Thus, by the disappearing of the CdTe peak of 2nd order, the GaAs peak of 2nd order was clearly observed. When the Si-filter was put in the front of light source, other peaks except the MCT peak disappeared, as is shown in the spectrum 3 of Fig. 5. The PC spectrum for MCT was observed to be in the range from 1.0 μm to 1.6 μm and the spectral peak wavelength, λ_p, was 1.1059 μm (1.1220 eV). This peak is due to intrinsic transition which corresponds to the band gap of the MCT epilayer. Therefore, the equation[17] for the composition and temperature dependence of the energy band gap of the MCT epilayer was given:

$$E_g = [-304 + 0.63T^2(1 - 2x)/(11 + T) + 1858x + 54x^2] \text{ meV}, \qquad (1)$$

where E_g and T were the energy band gap and the absolute temperature, respectively. This equation was used to calculate the composition rate for the x value of $Hg_{1-x}Cd_xTe$. From the eq. (1), the x value of λ_p for MCT at 77 K is estimated to be 0.762. And the cut-off wavelength, λ_c, is 1.2632 μm (0.9815 eV), which means the band width wavelength of the half intensity for maximum intensity of λ_p.

Fig. 6 shows the PC spectrum of the MCT-2 epilayer measured at 77 K using a 600°C blank body source and the dark resistance of this sample at the same temperature was measured of 60 Ω. As is shown in Fig. 6, the PC spectrum of MCT appeared in the wavelength range from 3.5 μm to 5.5 μm. Thus, λ_p, which corresponds to
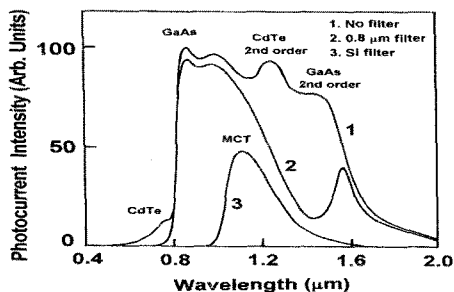

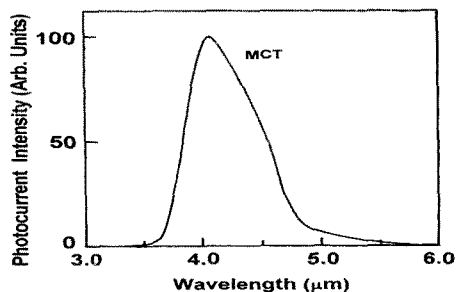Fig. 5. The PC spectra for the MCT-1 epilayer measured at 77 K.

Fig. 6. The PC spectrum for the MCT-2 epilayer measured at 77 K.

the intrinsic transition and λ_c were 4.0750 µm (0.3043 eV) and 4.5600 µm (0.2719 eV), respectively. From the eq. (1), the x value of λ_p for the MCT-2 epilayer at 77 K turned out to be 0.317. Also, the comparatively steep slope to the long wavelength region of the spectra shown in Fig. 5 and 6 was thought to be an evidence of homogeneity of the composition in the surface epilayer.

4. Conclusion

$Hg_{1-x}Cd_xTe$ was grown by hot wall epitaxy method. The (111) CdTe buffer epilayer was grown on the GaAs substrate at 590°C for 15 min. Then, MCT epilayers were grown on the grown CdTe buffer epilayer. The grown MCT epilayers were confirmed to be of high quality crystal and the very smooth surface was proven by using DCRC and AFM measurement. From the PC measurement, MCT-1 showed the spectrum range from 1.0 µm to 1.6 µm and the spectral peak wavelength located at 1.1059 µm (1.1220 eV) corresponds to the band gap of the MCT epilayer. The spectrum of MCT-2 was observed within the wavelength range from 3.5 µm to 5.5 µm and its spectral peak was located at 4.0750 µm (0.3043 eV). The x values of composition rate for the MCT-1 and 2 epilayers at 77 K turned out to be 0.762 and 0.317 respectively. Also, the comparatively steep slopes to the right region of the spectral peaks wavelength as shown in Fig. 5 and 6 were thought to be an evidence of the homogeneity of the composition in the surface epilayers. Therefore, these results mean that the grown MCT epilayers can be applied as a photoconductor for infrared region detector.

Acknowledgement

References

[1] R. Korenstein, P. Hallock, and B. MacLeod, *J. Vac. Sci. Technol.*, vol. B9, pp. 630, 1991.

[2] B. Pelliciari, *J. Crystal Growth*, vol. 86, pp. 146, 1988.

[3] I. Bath, *J. Crystal Growth*, vol. 117, pp. 1, 1992.

[4] J. M. Arias, S. H. Shin, J. G. Pasko, R. E. DeWames, and E. R. Gertner, *J. Appl. Phys.*, vol. 65, pp. 1747, 1989.

[5] P. S. Wijewarnasuriya, M. Boukerche, and J. P. Faurie, *J. Appl. Phys.*, vol. 67, pp. 859, 1990.

[6] M. Kasuga, D. Kodama, H. H. Agiwara, and K. Kagami, *J. Jpn. Assoc. Crystal Growth*, vol. 21, pp. 5377, 1994.

[7] K. Shigenaka, L. Sugiura, F. Nakata, and K. Hirahara, *J. Crystal Growth*, vol. 145, pp. 145, 1994.

[8] S. H. Shin, J. M. Arias, D. D. Edwall, M. Zandian, J. G. Pasko, and R. E. DeWames, *J. Vac. Sci. Technol.*, vol. B10, pp. 1492, 1992.

[9] R. Sporken, Y. P. Chen, S. Sivananthan, M. D. Lange, and J. P. Faurie, *J. Vac. Sci. Technol.*, vol. B10, pp. 1405, 1992.

[10] J. P. Fourie, C. Hsu, S. Sivananthan, and X. Chu, *Surf. Sci.*, vol. 168, pp. 473, 1986.

[11] J. F. Wang, K. Kikuchi, B. H. Koo, Y. Ishikawa, W. Uchida, and M. Isshiki, *J. Crystal Growth*, vol. 187, pp. 373, 1998.

[12] S. D. Chen, L. Lin, X. Z. He, M. J. Ying, and R. Q. Wu, *J. Crystal Growth*, vol. 152, pp. 261, 1995.

[13] D. D. Edwall, J. Bajai, and E. R. Gertner, *J. Vac. Sci. Technol.*, vol. A8, pp. 1045, 1990.

[14] C. C. Klick, *Phys. Rev.*, vol. 89, pp. 274, 1953.

[15] R. H. Bube, *Phys. Rev.*, vol. 101, pp. 1668, 1956.

[16] R. H. Bube, Photoconductivity of Solids (Wiley, New York, 1969) p. 391.

[17] M. H. Weiler, In: Semiconductors and Semimetals, Eds. R. K. Willardson and A. C. Beer (Academic, New York, 1981) vol. 16, p. 180.

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