

# Properties of Infrared Detector and Growth for HgCdTe Epilayers

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## Abstract

Hg<sub>1-x</sub>Cd<sub>x</sub>Te (MCT) was grown by hot wall epitaxy method. 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 temperature *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<sub>1-x</sub>Cd<sub>x</sub>Te; Hot wall epitaxy; CdTe buffer layer; Photocurrent; Photoconductor

## 1. Introduction

Hg<sub>1-x</sub>Cd<sub>x</sub>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 a 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 to efficient the 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].

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.

## 2. Experimental procedure

A homemade HWE apparatus was used for growing the MCT epilayers on the GaAs substrates. This HWE apparatus consist of the two electric furnaces, which make of 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. Prior to growth, the semi-insulation GaAs (100) substrate was cleaned

ultrasonically for 1 min in successive baths of trichloroethylene, acetone, 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 M). After the substrate was dried off, the substrate was immediately loaded onto the substrate holder in the HWE. The GaAs substrate was annealed as a preheating process to remove the oxide of substrate surface.

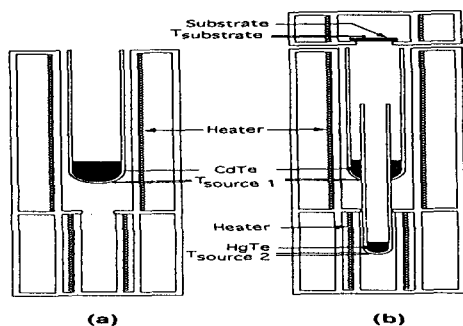


Fig. 1. Schematic diagram of a HWE apparatus used for growing MCT.

Fourie *et al.* [10] reported that the grown CdTe showed (100) and (111) planes depending on the preheating 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, source1, was set at 460 C, respectively. The grown CdTe buffer layers with a thickness of 3  $\mu$ m were examined by using the x-ray diffraction of 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.

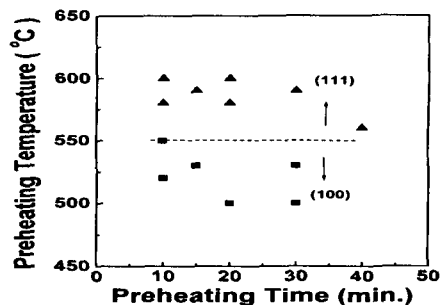


Fig. 2. The growth orientation of the CdTe epilayers with the preheating condition of substrate

The HgCdTe/CdTe/GaAs epilayers 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, 6N), 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  $\alpha$ -step profilometer (Tencor,  $\alpha$ -step 200).

### 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  $\mu$ m and 12  $\mu$ m were grown at 280 C to find the optimum buffer layer, prior to the MCT growth.

Figure 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 m 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.

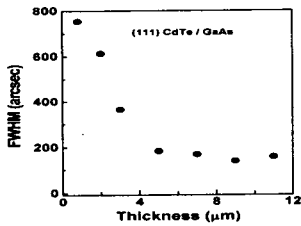


Fig. 3. The dependence of FWHM with the thickness of the CdTe epilayers.

At this time, the thickness of the CdTe (111) epilayer was 9 m and a minimum FWHM value was 139 arcsec, respectively. This thickness was comparable to the reported thickness, 10 m, 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 m/h and 0.8 m/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-mean-square values,  $R_{ms}$ , for the surface roughness of the MCT-1 and 2 samples were obtained to be 7 and 9 nm, respectively.

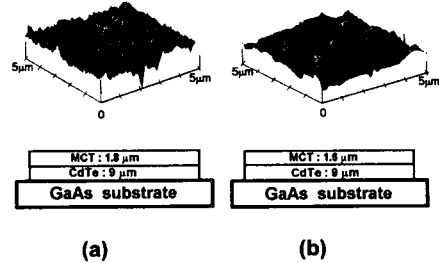


Fig. 4. AFM images and schematic diagram of cross section for the epitaxial growth of MCT: (a) the MCT-1 epilayer, (b) the MCT-2 epilayer.

### 3.2 Photocurrent measurement

The semiconductors of single crystal have two basic 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, the intrinsic photoconductor like a MCT semiconductor 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. Figure 5 shows the PC spectra for the MCT-1 epilayer with the dark resistance of 45 Ω at 77 K. The spectrum 1 was measured without filter in the front of halogen lamp. The PC peaks at 0.784 m (1.5815 eV) and 0.842 m (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 m and 1.6 m 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.

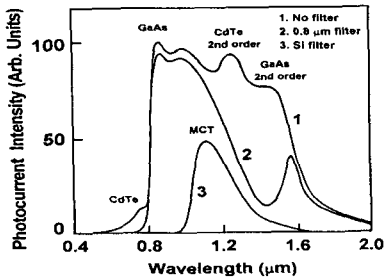


Fig. 5. The PC spectra for the MCT-1 epilayer measured at 77 K.

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 m (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 m filter placed in the front of light source. Because of cutting the wavelength having less than 0.8 m, the CdTe peak corresponding to the band gap and its 2<sup>nd</sup> order were disappeared, as is shown in the spectrum 2 of Fig. 5. But the GaAs peaks were not disappeared yet. Thus, as disappearing the CdTe peak of 2<sup>nd</sup> order, the GaAs peak of 2<sup>nd</sup> order was clearly observed. When the Si-filter was put in the front of light source, other peaks except the MCT peak were disappeared, as is shown in the spectrum 3 of Fig. 5. The PC spectrum for MCT were observed to be the range from 1.0 m to 1.6 m and the spectral peak wavelength,  $\lambda_p$ , was 1.1059 m (1.1220 eV). This peak due to intrinsic transition 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:

$$E_g = [-304 + 0.63T^2(1 - 2x)/(11 + T) + 1858x$$

$$+ 54x^2] \text{ meV, } \text{----(1)}$$

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  $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ . From the eq. (1), the  $x$  value of  $\lambda_p$  for MCT at 77 K is estimated to be 0.762. And the cut-off wavelength,  $\lambda_c$ , is 1.2632 m (0.9815 eV), which means the band width wavelength of the half intensity for maximum intensity of  $\lambda_p$ .

#### 4. Conclusion

$\text{Hg}_{1-x}\text{Cd}_x\text{Te}$  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 the high quality crystal and the very smooth surface by using DCRC and AFM measurement. From the PC measurement, MCT-1 showed the spectrum range from 1.0 m to 1.6 m and the spectral peak wavelength located at 1.1059 m (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 m to 5.5 m and its spectral peak was located at 4.0750 m (0.3043 eV). The  $x$  values of composition rate for the MCT-1 and 2 epilayers at 77 K were turned out to be 0.762 and 0.317 respectively. Also, the comparatively steep slopes to the right region of 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.

#### References

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