Dependence of the structural and the electrical properties on the Hg/Te flux-rate ratios for $Hg_{0.7}Cd_{0.3}Te$ epilayers grown on CdTe buffer layers

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Potential applications of $Hg_{1-x}Cd_xTe$ thin films in optoelectronic devices in the area of the infrared detectors have driven an extensive and successful effort to grow the films on various semiconductor substrates [1–3]. The growth of *n*-type and *p*-type $Hg_{1-x}Cd_xTe$ epitaxial films with interfacial abruptnesses on the scale of a few lattice constants has been particularly attractive because of many promising applications for infrared focal-plane array technologies [4, 5]. Even though liquid-phase epitaxy method have been used to grow extensively $Hg_{1-x}Cd_xTe$ epitaxial films, the samples grown by those methods have intermixing problems at heterointerfaces. Since a molecular-beam epitaxy (MBE) growth method has overcome the inherent problems, high-quality $Hg_{1-x}Cd_xTe$ epitaxial films can grown by using the MBE method [6, 7]. There has been considerable interest in the growth of CdTe buffer layers on GaAs substrates prior to the growth of $Hg_{1-x}Cd_xTe$ epitaxial films since the $Hg_{1-x}Cd_xTe$/GaAs heterostructures have inherent problems for obtaining high-quality epitaxial layers due to their large lattice mismatch ($\Delta a/a = 14.6$) [8]. Since the physical properties of the $Hg_{1-x}Cd_xTe$ films significantly affect the fabrication of high-efficiency optoelectronic devices, studies of the structural and the electrical properties of the films are necessary for achieving high-performance devices.

This letter reports the dependence of the structural and the electrical properties on the Hg/Te flux-rate ratios for $Hg_{1-x}Cd_xTe$ thin films grown on CdTe buffer layers by using MBE. Scanning electron microscopy (SEM) measurements were taken to characterize the surface qualities of the $Hg_{1-x}Cd_xTe$ layers, and double crystal X-ray rocking curve (DCRC) measurements were performed to investigate their structural qualities. Hall-effect measurements were carried out to determine the carrier concentrations and the mobilities of the $Hg_{1-x}Cd_xTe$ epilayers.

The samples used in this study were grown on semi-insulating GaAs (211) B substrates. The GaAs substrates were degreased in warm trichloroethylene (TCE), rinsed in deionized water thoroughly, etched in a mixture of H_2SO_4, H_2O_2, and H_2O (5:1:1) at 40 °C for 60 s, and rinsed in TCE again. After the wafers were dried by a N_2 gas, they were mounted onto a molybdenum susceptor. After the GaAs substrates were thermally cleaned at 300 °C for 3 h in the introduction chamber, they were transferred into the growth chamber. Before $Hg_{1-x}Cd_xTe$ growth, the GaAs substrates were thermally cleaned at 580 °C for 15 min in a Te_2 atmosphere to remove the oxide layers existing on the substrates. The deposition of the CdTe buffer layer was performed at a substrate temperature of 310 °C by using CdTe and Te effusion cells, the typical growth rate was approximately 0.6 μm/h. The typical thickness of the CdTe buffer layer was approximately 7 μm, and the CdTe buffer layer was employed to reduce the strain effect in the $Hg_{1-x}Cd_xTe$ layer due to the lattice mismatch between the $Hg_{1-x}Cd_xTe$ layer and the GaAs substrate. The $Hg_{1-x}Cd_xTe$ epilayers were grown on the CdTe buffer layer at 195 °C by using CdTe, Te, and Hg cells. The growth rate of the $Hg_{1-x}Cd_xTe$ thin film was approximately 3 μm/h, and the typical thickness of the film was about 12 μm. The flux-rate ratios of Hg/Te were 80, 85, 90, 95, 100, 120, and 150. Hall-effect measurements were performed in the temperature of 77 K in a magnetic field of 3200 G in a magnet system using a Keithley 181 nanovoltmeter.

Fig. 1 shows SEM images of the $Hg_{0.7}Cd_{0.3}Te$ epilayers grown on CdTe buffer layers at Hg/Te flux-rate ratios of (a) 80, (b) 85, (c) 90, (d) 100, (e) 120, and (f) 150. When the Hg/Te flux-rate ratio is 80, the high-density defects with a size of about 30 μm appear in the $Hg_{0.7}Cd_{0.3}Te$ epilayers, as shown in Fig. 1a. When the Hg/Te flux-rate ratio is 85, the larger sizes of void defects similar to the Fig. 1a appear in the surface of the $Hg_{0.7}Cd_{0.3}Te$ epilayer, as shown in Fig. 1b, and the existence of the defects is caused by the Hg deficiencies [9, 10]. When the Hg/Te flux-rate ratio is 90, another type of the defect different from the void defect appears in the surface of the $Hg_{0.7}Cd_{0.3}Te$ epilayer. When the Hg/Te flux-rate ratio is 100, the surface of the $Hg_{0.7}Cd_{0.3}Te$ (211) B epilayer is mirrorlike without any indication of microcracks and defects, as shown in Fig. 1d. When the Hg/Te flux-rate ratios are 120 and 150, the honeycomb patterns appear at the surface of the $Hg_{1-x}Cd_xTe$ epilayer due to the Hg oversupply, as

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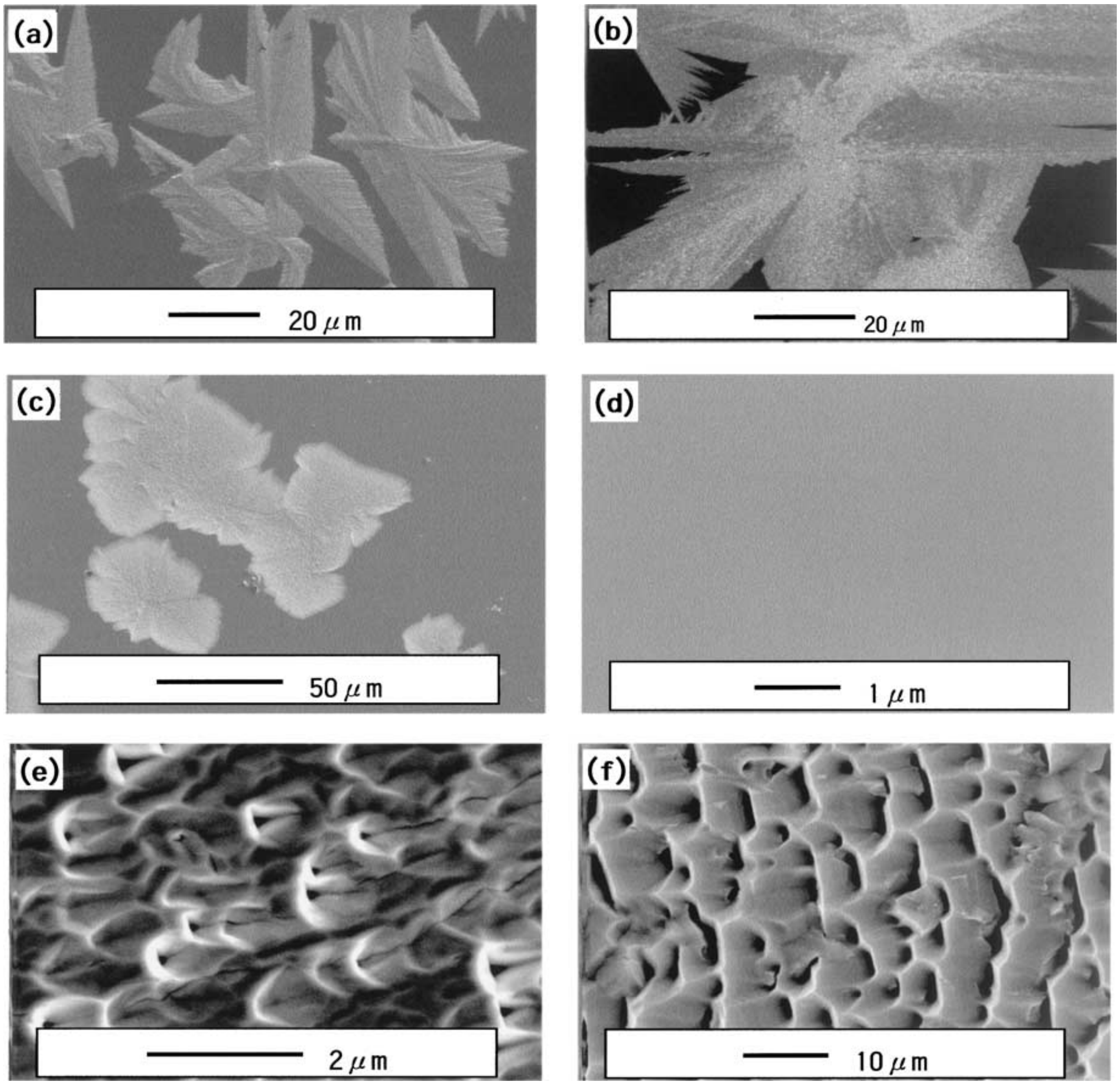

Figure 1 Scanning electron microscopy images of the $Hg_{0.7}Cd_{0.3}Te$ epilayers grown on CdTe buffer layers at Hg/Te flux-rate ratios of (a) 80, (b) 85, (c) 90, (d) 100, (e) 120, and (f) 150.

shown in Fig. 1e and f. Since the $Hg_{0.7}Cd_{0.3}Te$ epitaxial film grown at an Hg/Te flux-rate ratio of 100 has the best surface morphology among the several samples grown at various Hg/Te flux-rate ratios, and the optimum amount of the Hg/Te flux-rate ratio for the growth of the high-quality $Hg_{1-x}Cd_xTe$ thin film is 100.

Fig. 2 shows the full width at half maximum (FWHM) as a function of the Hg/Te flux-rate ratio of the $Hg_{0.7}Cd_{0.3}Te$ epilayers obtained from the DCRC measurements. The FWHM of the $Hg_{0.7}Cd_{0.3}Te$ epilayers decreases with increasing the Hg/Te flux-rate ratio. When the Hg/Te flux-rate ratio is 100, the minimum value of the FWHM of the $Hg_{0.7}Cd_{0.3}Te$ epilayers is as small as 160 arcsec, as shown in Fig. 2. When the Hg/Te flux-rate ratio is above 100, the values of the FWHM of the $Hg_{0.7}Cd_{0.3}Te$ epilayers increases due to the deterioration of the quality of the $Hg_{0.7}Cd_{0.3}Te$ epilayer resulting from the Hg oversupply.

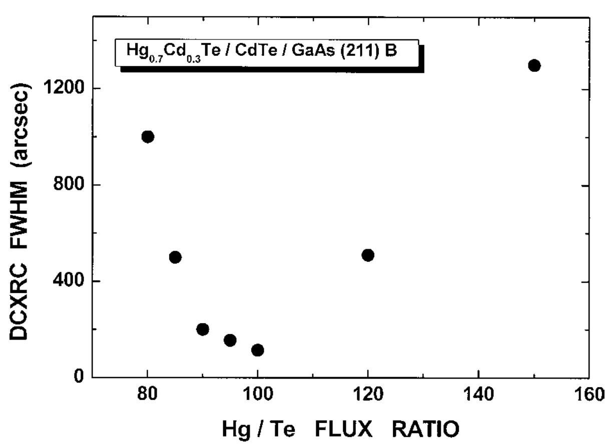

Figure 2 Full width at half maxima as a function of the Hg/Te flux-rate ratio of the $Hg_{0.7}Cd_{0.3}Te$ epilayers determined from the double crystal X-ray rocking curve measurements.

Fig. 3 shows carrier concentrations as a function of the Hg/Te flux—rate ratio of the $Hg_{0.7}Cd_{0.3}Te$ epilayers determined from the Hall effect measurements at 77 K, and mobilities as a function of the Hg/Te flux—rate ratio of the $Hg_{0.7}Cd_{0.3}Te$ epilayers are shown in Fig. 4. When the Hg/Te flux-rate ratio is 100, the values of the carrier concentration and the mobility of the $Hg_{0.7}Cd_{0.3}Te$ epilayer are minimum and maximum,

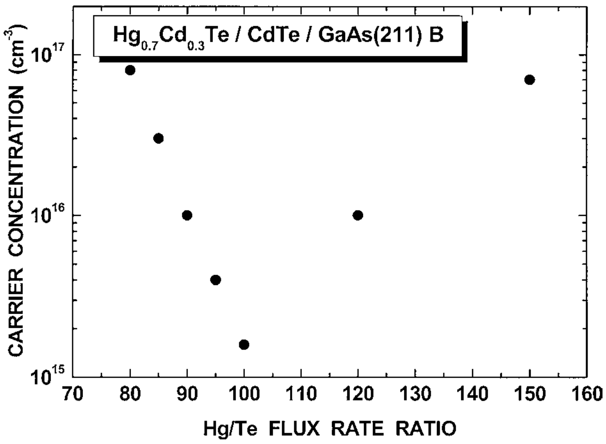

Figure 3 Carrier concentrations as a function of the Hg/Te flux-rate ratio of the $Hg_{0.7}Cd_{0.3}Te$ epilayers determined from the Hall effect measurements at 77 K.

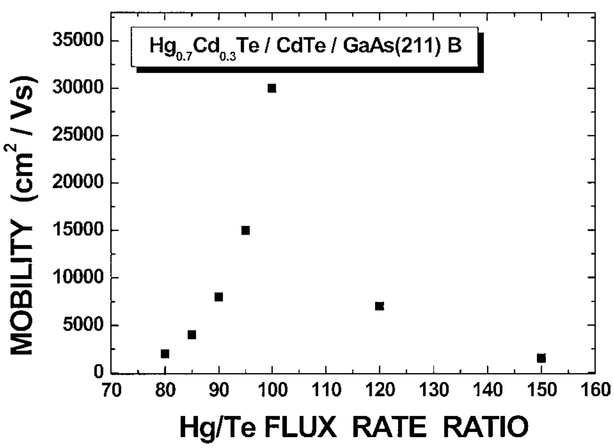

Figure 4 Mobilities as a function of the Hg/Te flux-rate ratio of the $Hg_{0.7}Cd_{0.3}Te$ epilayers determined from the Hall effect measurements at 77 K.

respectively. When the Hg/Te flux-rate ratio is 100, the value of the carrier concentration is 2×10^{15} cm^{-3}, and the corresponding mobility is 30 000 cm^2/Vs. These results are in reasonable agreement with the surface and the structural properties obtained by the SEM and DCRC measurements. Therefore, the optimum condition of the Hg/Te flux-rate ratio for the surface, structural, and electrical properties of the $Hg_{0.7}Cd_{0.3}Te$ epilayers is 100.

In summary, the results of SEM and DCRC measurements showed that the surface and structural properties of the $Hg_{0.7}Cd_{0.3}Te$ epilayers grown on the CdTe buffer layers at a Hg/Te flux-rate ratio of 100 had the best quality. When the Hg/Te flux-rate ratio is 100, the values of the carrier concentration and the mobility of the $Hg_{0.7}Cd_{0.3}Te$ epilayer are minimum and maximum, respectively. These results indicate that the $Hg_{0.7}Cd_{0.3}Te$ epilayers grown on the CdTe buffers at a Hg/Te flux-rate ratio of 100 hold promise for application in optoelectronic devices.

Acknowledgments

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