Rapid thermal annealing effects on the optical properties in strained CdTe (100)/GaAs (100) heterostructures

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The growth of CdTe thin films has attracted much interest because of their potential applications in the areas of solar energy conversion, gamma-ray detection, and electro-optic modulation due to their low thermal noise and large absorption coefficient [1–5]. CdTe epitaxial layers have been extensively grown because CdTe thin films can be useful buffer layers for the growth of $Hg_{1-x}Cd_xTe$ epilayers [6–9]. However, since the growth of high-quality CdTe/GaAs heterostructures has inherent problems due to the large lattice mismatch ($\Delta a/a = 14.6\%$ at 25 °C), studies of the structural and optical properties of CdTe/GaAs heterostructures are very important for achieving high-quality optoelectronic devices that can operate in the blue-green region of the spectrum [10]. In addition, studies of the effects of thermal annealing on the optical properties play a very important role in enhancing device efficiency, and systematic studies concerning rapid thermal annealing effects on the optical properties of the CdTe/GaAs heterostructures are still necessary if high-quality heterostructures are to be obtained after thermal annealing [11].

This letter reports the dependence of the optical properties on the annealing treatment for CdTe thin films grown on GaAs (100) substrates by using molecular beam epitaxy. Photoluminescence (PL) measurements were carried out to investigate the optical properties and to determine the activation energy of the confined electrons existing at the donor state in the as-grown CdTe/GaAs heterostructures.

Elemental Cd and Te with purities of 99.9999% were used as the source materials and were precleaned by repeated sublimation. Cr-doped and semi-insulating (100) GaAs substrates were degreased in warm trichloroethylene (TCE), rinsed thoroughly in deionized water, etched in a HF solution, and rinsed in TCE again. As soon as the chemical cleaning process was finished, the GaAs substrates were mounted onto a molybdenum susceptor. Prior to CdTe thin-film growth, the GaAs substrates were thermally cleaned at 600 °C for 5 min *in situ* in the growth chamber at a pressure of 10^{-10} Torr. The depositions of the CdTe epilayers were done on GaAs substrates by using the MBE technique at substrate temperatures between 300 and 340 °C, and at a system pressure of 10^{-9} Torr. The source temperatures of the Cd and the Zn sources for the CdTe epilayers were 195 and 300 °C respectively, and the typical growth rate was approximately 1.38 Å/s. After the CdTe thin films were grown, the samples were annealed at 500 °C for 5 min to stabilize the layer. The typical thickness of the CdTe film was approximately 1 μm. The PL measurements were carried out using a 75 cm monochromator equipped with an RCA 310034 photomultiplier tube. The excitation source was the 4880 Å line of an Ar-ion laser, and the sample temperature was controlled between 20 and 120 K by using a He displex system.

The as-grown CdTe thin films obtained by using MBE had mirror-like surfaces without any indication of pin holes, which was confirmed by Normarski optical microscopy and scanning electron microscopy. The XRD patterns for the CdTe/GaAs heterostructures grown at various temperatures clearly show the (400) $K_{\alpha 1}$ diffraction peak of CdTe (100), together with that of GaAs (100). The lattice constant of the CdTe film grown on the GaAs substrate, as determined from the XRD peak, is a little larger than the bulk value of CdTe (100) due to the tensile effect [12]. The full width at half-maximum (FWHM) value of the ZnTe (400) $K_{\alpha 1}$ peak slightly decreases with increasing growth temperature. These results indicate that high-quality CdTe (100) epilayers can be grown on GaAs (100) substrates by using MBE.

Fig 1 shows the PL spectra measured at several temperatures for (a) as-grown and (b) annealed CdTe/GaAs heterostructures. Although the growth of the CdTe films were performed in the temperature range between 300 and 340 °C, only the optical properties of the film grown at 340 °C are described in this letter because it had the best surface morphology among the several samples grown at various growth temperatures. The dominant peaks around 1.58 eV in the energy range from 1.55 to 1.61 eV in the PL spectra for as-grown CdTe/GaAs heterostructures are considered to be from excitons bound to neutral donors (D°, X) caused by impurities [13, 14]. Temperature dependence of the (D°, X) peak position

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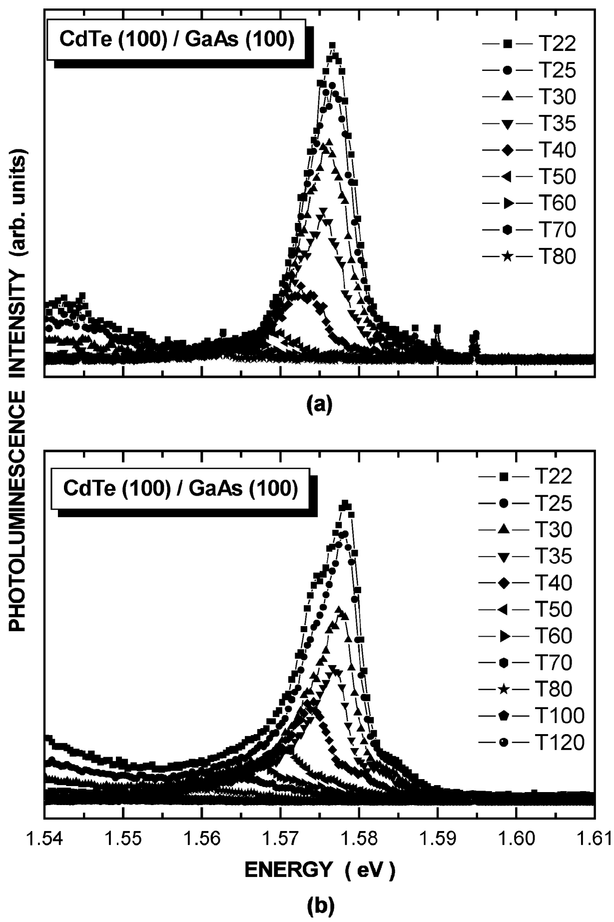

Figure 1 Photoluminescence spectra at several temperatures for (a) as-grown and (b) annealed CdTe/GaAs heterostructures.

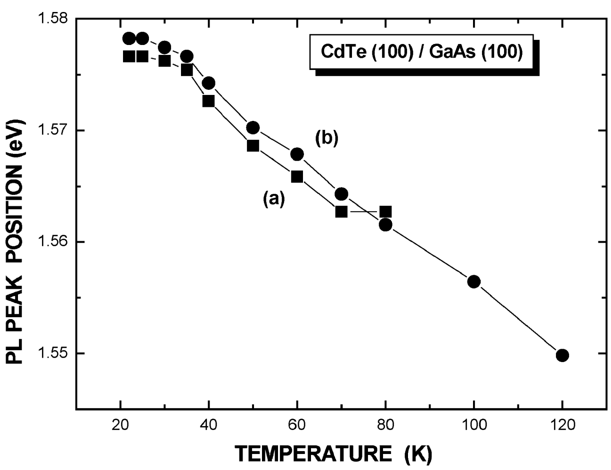

Figure 2 Temperature dependences of the (D°, X) peak position for (a) as-grown and (b) annealed CdTe/GaAs heterostructures.

for the (a) as-grown and the (b) annealed CdTe/GaAs heterostructures are shown in Fig. 2. As the values for the energy gaps of the CdTe thin film decrease with increasing temperature, the PL peaks corresponding to the (D°, X) peak shift to the low-energy side with increasing temperature. The variation in the peak position with changing temperature can be attributed to the effects of lattice dilation and electron-lattice interactions. Fig. 3 shows the temperature dependence of the FWHM of the (D°, X) peak for the (a) as-grown and the (b) annealed CdTe/GaAs heterostructures. While the values of the FWHMs of the (D°, X) peak are almost constant

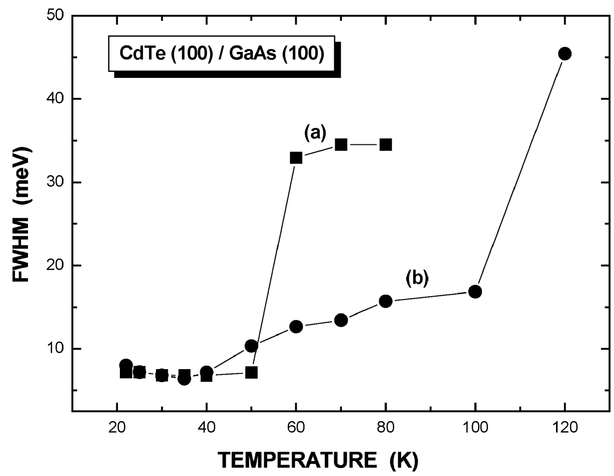

Figure 3 Temperature dependences of the FWHM of the (D°, X) peak for (a) as-grown and (b) annealed CdTe/GaAs heterostructures.

in the temperature range from 22 to 50 K, they dramatically increase above 60 K. When the temperature is high, since the effect of electron-photon scattering becomes dominant, the PL linewidth starts to increase with increasing temperature.

The activation energies of the confined electrons existing at the donor state in the as-grown and the annealed CdTe/GaAs heterostructures are determined from the temperature-dependent PL measurements. The quenching is attributed to the thermal release of trapped electrons from a donor state. The activation energies of the electrons existing at the donor state can be determined from the temperature dependence of the integrated PL intensity and the following equation [15]:

$$I = I_0/[1 + C\exp(-\Delta E_A/k_B T)], \tag{1}$$

where I_0 is the integrated PL intensity at 0 K, C is the ratio of the thermal escape rate to the radiation recombination rate, ΔE_A is the activation energy, and k_B is the Boltzmann constant. With Equation1, the activation energies, ΔE_A, of the donor in the as-grown and the annealed CdTe/GaAs heterostructures, as determined

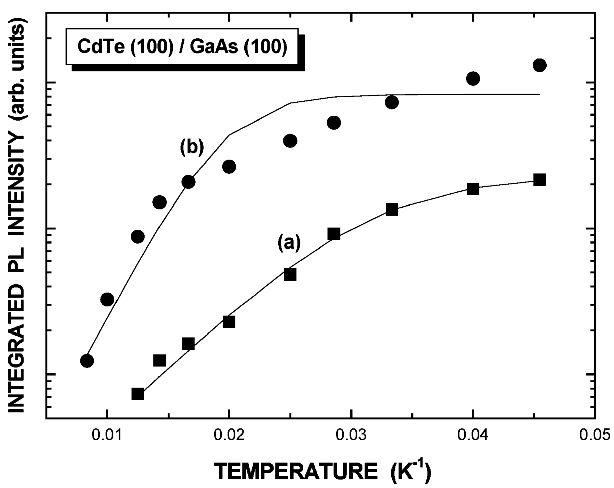

Figure 4 Temperature dependences of the integrated intensity of the (D°, X) peak for (a) as-grown and (b) annealed CdTe/GaAs heterostructures.

from the solid lines of Fig. 4, are 18 and 36 meV, respectively. The enhancement of the activation energy of the electron existing at the donor state due to thermal energy originates from an increase in the thermal emission of the electrons in the impurity donor bound excitons resulting from deeper movement of the donor site.

In summary, the results of the PL measurements showed that the crystallinity of the CdTe/GaAs heterostructure was improved by thermal treatment. The activation energies of the electrons existing at the donor state in the as-grown and the annealed CdTe/GaAs heterostructures were 18 and 36 meV, respectively. These results indicate that the crystallinity of the CdTe/GaAs heterostructure is improved by the thermal annealing, and the annealed CdTe epilayers grown on GaAs substrates can be used for applications as buffer layers for the growth of $Hg_xCd_{1-x}Te$.

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