Substrate effect on CdTe layers grown by metalorganic vapor phase epitaxy

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CdTe layers were grown by metalorganic vapor phase epitaxy (MOVPE) on different substrates like sapphire, GaAs, and CdTe wafers. The growth was carried out at the temperature 340 °C and time in the range of 2–4 h using dimethyl-cadmium and diisopropil-tellurium as precursors. The layers were studied by scanning electron microscopy, Rutherford backscattering spectroscopy, and high resolution low-temperature photoluminescence spectroscopy. The surface morphology and RBS and PL spectra of CdTe MOVPE layers are reported and the substrate effect on the layer properties is demonstrated. [S0003-6951(97)00710-9]

Stimulated by numerous applications, there has been essential progress in growing CdTe layers on different heterosubstrates like Si, GaAs, or sapphire by metalorganic vapor phase epitaxy (MOVPE).[1] Several characterization techniques have been used to study the structural properties of the layers, such as scanning electron microscopy (SEM), x-ray topography (XRT), and high resolution diffractometry (HRXRD), Rutherford backscattering spectroscopy (RBS), low-temperature photoluminescence spectroscopy (PL), etc. (as recent examples, see Refs. 2–5). These results have shown that the crystalline quality of CdTe MOVPE layers are inferior to that of CdTe bulk crystals.[1–5]

It has been assumed that the poor quality of the layers is because their structure is strongly affected by a strain arising from the large (>10%) lattice mismatch between CdTe and the substrates. Besides the lattice mismatch, it has been demonstrated that the layer quality depends significantly on the particular conditions of the MOVPE process such as the type of MOVPE reactor, precursors, growth temperature and rate, etc. This makes it difficult to compare properly the results reported by several authors who have grown CdTe MOVPE layers on different substrates at various conditions,[1] and it is still unclear to what extent the layer properties can be affected by the substrates.

Following the work carried out before,[2–4] in this letter we present experimental results on the combined SEM, RBS, and PL investigations of CdTe layers grown on different substrates like sapphire, GaAs, and CdTe wafers at identical MOVPE conditions and demonstrate the substrate effect on the layer morphology and RBS and PL spectra.

CdTe single-crystalline layers were grown in a low-pressure horizontal MOVPE reactor with the optimal growth conditions determined previously.[3,4] Dimethyl-cadmium and di-isopropil-tellurium were used as precursors, the growth temperature was 340 °C, and the growth time was in the range of 2–4 h. Three types of conventional commercial substrates were used, such as wafers of sapphire with a misorientation 3° off (0001) plane, GaAs (100), and CdTe (111). They provided the (111), (100), and (111) orientation of CdTe layers, respectively. The thickness of the layers studied in this work was in the range of 5–7 μm.

The layer surface morphology was characterized by SEM (Hitachi S-4100). RBS/channeling spectra were recorded with the 2 MeV $^4He^+$ beam aligned with the main crystallographic axes of the layers and in a random direction. Details on the RBS experimental setup have been reported elsewhere.[6] High-resolution PL spectra were recorded from the layers immersed in liquid helium at 4.2 K. The exciting light was supplied by an Ar^+-ion laser beam and the luminescence was analyzed by a Spex 1404 double-grating monocromator and detected by a Jobin–Yvon Spectraview-2D charge coupled device (CCD) detector.

Figure 1 shows the surface morphology of CdTe MOVPE layers grown on (a) sapphire, (b) GaAs, and (c) CdTe. Although the MOVPE conditions were identical in every growth experiment, each of the layers exhibits a particular microrelief depending on the substrate. The CdTe layer grown on sapphire has a rough microrelief with the height 1.5–2 μm. Due to reduced lattice mismatch, the CdTe/GaAs layer exhibits a surface roughness decreased to 0.5–1 μm. Interestingly, the CdTe layer grown homoepitaxially on CdTe substrate (i.e., with no lattice mismatch) also shows a rough surface with a microrelief even somewhat higher than that of the CdTe/GaAs layer. The most likely explanation for this unexpected finding seems to be thermal

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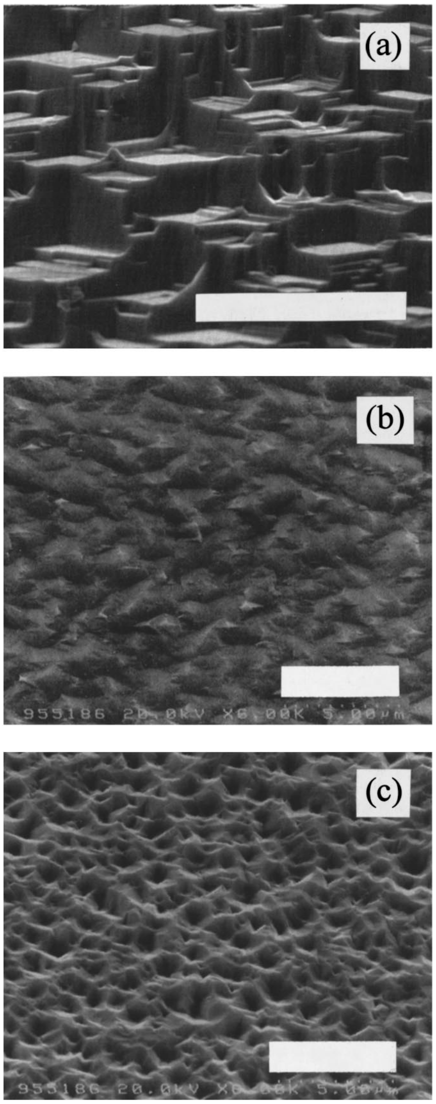

FIG. 1. Surface morphology of CdTe MOVPE layers grown on (a) sapphire, (b) GaAs, and (c) CdTe. Markers correspond to (a) 15 μm and (b) and (c) 5 μm.

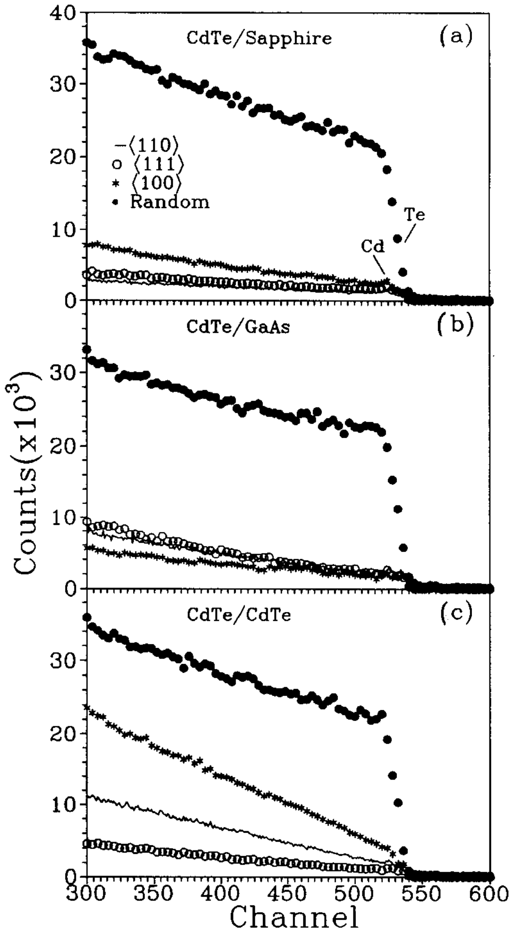

FIG. 2. RBS/channeling spectra recorded with the 2 meV $^4He^+$ beam aligned with the main crystallographic axes of CdTe MOVPE layers grown on (a) sapphire, (b) GaAs, and (c) CdTe and in a random direction.

strains within the CdTe substrate area. These strains may arise from several reasons like a low thermal conductivity of CdTe, uncontrolled inhomogeneities of temperature field in MOVPE reactor, and Te precipitates which have been detected inside CdTe wafers by a number of direct methods such as, for example, infrared microscopy,[7] cathodoluminescence in SEM, and Raman spectroscopy.[8,9]

Figure 2 presents the aligned and random RBS/channeling spectra recorded from CdTe MOVPE layers. The spectra demonstrate that all the layers have a single-crystal nature and their crystalline quality depends strongly on the substrate type. Surprisingly, the lowest dechanneling rates are seen in the CdTe layer grown on sapphire while the lattice difference in CdTe/sapphire heterostructure is the highest. At the same time, the CdTe/CdTe layer exhibits the highest dechanneling rates along the ⟨100⟩ and ⟨110⟩ axes. Considering the similarity with rough surface morphology, we attribute this fact to the effect of thermal strains within the CdTe substrate area. The spectra of the CdTe layer grown on GaAs are similar to those of the CdTe/sapphire layer but show somewhat higher dechanneling rates along the ⟨110⟩ and ⟨111⟩ axes. The latter could be related with an interdiffusion of components at the CdTe/GaAs interface during the MOVPE growth.

To specify quantitatively the structural inequality of the main crystallographic axes of the layers, Table I gives the values of the minimum yield (χ_{min}).[6,10] Typical values of χ_{min} for CdTe wafers which were used as substrates in several MOVPE growth experiments are also presented in Table I to enable a comparison between the layers and CdTe bulk crystals. Details on the CdTe crystal growth and substrate preparation can be found elsewhere.[11]

Figure 3 reports the low temperature (4.2 K) PL spectra of CdTe MOVPE layers. It was found that all spectra are

TABLE I. The minimum yield values for the main crystallographic axes of CdTe MOVPE layers (determined from the spectra of Fig. 1) and CdTe (111) wafer. The experimental error associated with these values is about 1%.

Sample	$\chi_{min}^{\langle 110\rangle}$ (%)	$\chi_{min}^{\langle 111\rangle}$ (%)	$\chi_{min}^{\langle 100\rangle}$ (%)
CdTe/sapphire	6.6	7.8	10.5
CdTe/GaAs	10.0	10.7	9.4
CdTe/CdTe	13.3	8.4	22.1
CdTe bulk	6.2	7.0	10.0

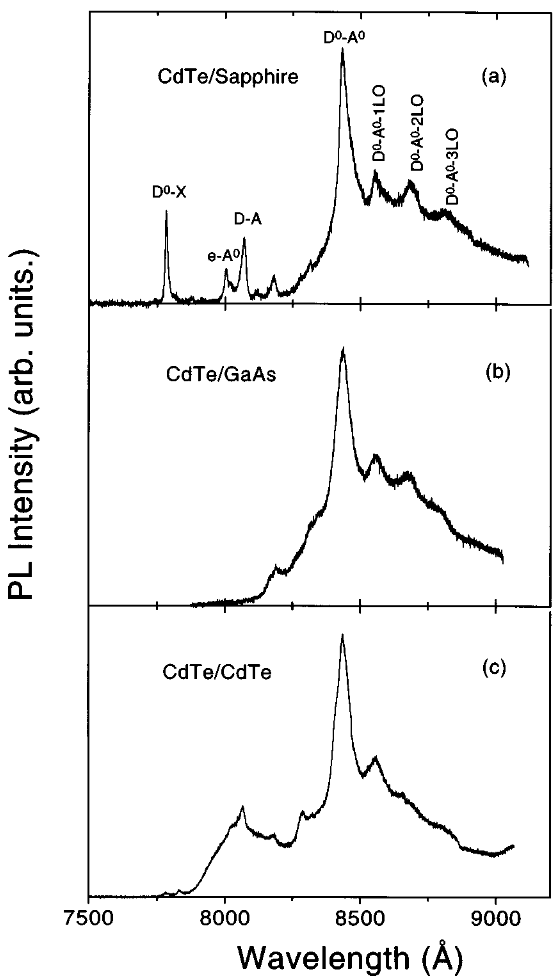

FIG. 3. PL spectra recorded at 4.2 K from CdTe MOVPE layers grown on (a) sapphire, (b) GaAs, and (c) CdTe.

dominated in the low energy range by an emission band with the zero phonon peak ($D°-A°$) at 8430 Å and its three well resolved phonon replicas with a LO-phonon energy of ≈21 meV. This band originates from the recombination of donor-acceptor pairs, like the group I residual impurities and their complexes with vacancies of cadmium, and it is common for CdTe bulk crystals and epitaxial layers.[5,11–14] The comparable intensity of the $D°-A°$ peak in three layers indicates that in spite of the different surface morphology, the identical MOVPE growth conditions provide the layers with similar emission efficiency.

At high energy, the PL spectra of the layers are substantially different. The spectrum of the CdTe layer grown on sapphire [Fig. 3(a)] has a number of sharp peaks which are a donor bound exciton ($D°-X$) line at 7782 Å, a line at 8003 Å attributed to a free electron-acceptor ($e-A°$) recombination, and an edge donor-acceptor ($D-A$) band at 8075 Å and its phonon replicas.[5,11–14] On the contrary, these peaks are suppressed in the PL spectrum of the CdTe/GaAs layer [Fig. 3(b)]. In the PL spectrum of the CdTe/CdTe layer [Fig. 3(c)], the $e-A°$ and $D-A$ emissions are also observed at the same energies as those in the PL spectrum of the CdTe/sapphire layer. Nevertheless, the larger broadening of the $e-A°$ and $D-A$ peaks and the very small intensity of the $D°-X$ line evidence an increase of acceptor concentration in the CdTe/CdTe layer according to previously published data.[11,12] Thus, making a comparison of the PL spectra of Figs. 3(a) and 3(b) and taking into account that the $D°-X$ line has earlier been registrated exclusively in the best CdTe crystals with low ($<10^{15}$ cm^{-3}) concentration of cadmium vacancies,[5,11] one can recognize that the PL spectra correlate well with the RBS data of Fig. 2 and Table I.

In summary, we have reported the surface morphology and RBS and PL spectra of CdTe layers grown on different substrates like sapphire, GaAs, and CdTe wafers by MOVPE at identical conditions. The properties of the layers have been demonstrated to depend significantly on the substrate nature. The set of SEM, RBS, and PL characterizations has determined the superior crystal quality of CdTe layers grown on sapphire. Our results also suggest that factors like thermal strains within the substrate area or/and an interdiffusion at the interface may make an even greater unfavorable impact on the properties of CdTe MOVPE layers than a large layer/substrate lattice mismatch.

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