Influence of a ZnTe buffer layer on the structural quality of CdTe epilayers grown on (100)GaAs by metalorganic vapor phase epitaxy

G. Leo, M. Longo, N. Lovergine, A. M. Mancini, L. Vasanelli et al.

Related Articles

Size dependent enhancement of photoelectron emission quantum efficiencies from magnesium dots
J. Vac. Sci. Technol. B 30, 06F605 (2012)

Transparent conductive indium zinc oxide films prepared by pulsed plasma deposition
J. Vac. Sci. Technol. A 30, 061508 (2012)

Study of surface cleaning methods and pyrolysis temperatures on nanostructured carbon films using x-ray photoelectron spectroscopy
J. Vac. Sci. Technol. A 30, 061407 (2012)

Optimization of the visibility of graphene on poly-Si film by thin-film optics engineering
J. Vac. Sci. Technol. B 30, 06FJ01 (2012)

Direct observation of hopping and merging of single Au adatoms to form dimers on Si(111)-(7×7)
J. Vac. Sci. Technol. A 30, 061406 (2012)

Additional information on J. Vac. Sci. Technol. B

Influence of a ZnTe buffer layer on the structural quality of CdTe epilayers grown on (100)GaAs by metalorganic vapor phase epitaxy

G. Leo
Istituto per lo Studio di Nuovi Materiali per l'Elettronica (IME)-C.N.R., Via Arnesano, 73100 Lecce, Italy

M. Longo, N. Lovergine, A. M. Mancini, and L. Vasanelli
Istituto Nazionale di Fisica della Materia, Dipartimento di Scienza dei Materiali, Università di Lecce, Via Arnesano, 73100 Lecce, Italy

A. V. Drigo and F. Romanato
Istituto Nazionale di Fisica della Materia, Dipartimento di Fisica "G. Galilei," Università di Padova, Via Marzolo 8, 35131 Padova, Italy

T. Peluso and L. Tapfer
PASTIS-CNRSM, S.S. 7 per Mesagne, Km 7/300, 72100 Brindisi e Istituto Nazionale di Fisica della Materia, Dipartimento di Scienza dei Materiali, Università di Lecce, Via Arnesano, 73100 Lecce, Italy

The influence of a ZnTe buffer layer on the structural quality of CdTe epilayers grown on (100)GaAs substrates by metalorganic vapor phase epitaxy has been investigated by both x-ray diffraction and ion channeling Rutherford backscattering spectrometry measurements. Single-crystal (100) oriented CdTe epilayers of good structural quality have been obtained after inserting a ZnTe buffer layer of a thickness ranging between 300 and 500 nm. The influence of the buffer layer thickness on the crystalline quality and the morphology of the CdTe epilayer has been related to the defect distribution and the surface roughness of the ZnTe buffer layer. The crystalline quality and the surface strain have been thus studied as a function of the CdTe thickness on samples having optimal ZnTe layer thickness. The initial compressive mismatch between CdTe and ZnTe, $f = -5.8\%$, appears to be almost fully relaxed for a CdTe thickness around 200 nm. A residual compressive in-plane strain (about -0.02%), independent of the CdTe epilayer thickness, has been found above 300 nm which can be ascribed to thermal strain and indicates a complete relaxation of the lattice misfit at the growth temperature. © *1996 American Vacuum Society.*

I. INTRODUCTION

Cadmium telluride is a direct gap ($E_g = 1.5$ eV) semiconductor material of considerable technological interest. Because of its high average atomic number, it is one of the most promising candidates for nuclear detectors and high efficiency solar cell fabrication.[1-3] Moreover, as CdTe and HgCdTe are both II–VI compounds with the same crystalline structure, very close lattice matching and chemical compatibility, CdTe is considered the ideal substrate for the growth of high quality epitaxial HgCdTe based structures for infrared detector applications. However, bulk CdTe single crystals of sufficiently good crystalline quality and large dimensions are costly and difficult to grow. Hence, the growth of high quality and low cost CdTe/GaAs and CdTe/Si hybrid substrates is desirable as an alternative to bulk CdTe substrates for the HgCdTe epitaxy.

Despite the high lattice mismatches between CdTe and GaAs or Si, that equals to 14.6% for (100)CdTe//(100)GaAs and 19.3% for (100)CdTe//(100)Si, the growth of fairly high quality CdTe epilayers on GaAs and Si by both molecular beam epitaxy (MBE) and metalorganic vapor phase epitaxy (MOVPE) has been demonstrated.[4-7] As a matter of fact, it has been found that the growth of CdTe epilayers on (100)-oriented GaAs substrates can proceed according to two different epitaxial relationships, namely (100)CdTe//(100) sub-strate or (111)CdTe//(100) substrate, although this double epitaxy can not be entirely attributed to the reduction in the lattice mismatch occurring when (111) oriented CdTe is grown on (100)GaAs. In fact, several studies have shown that both surface reconstruction and stoichiometry of the GaAs substrate strongly influence the initial stages of the CdTe growth and, therefore, the subsequent orientation of the epilayer. (100) or (111) oriented CdTe films were obtained reproducibly depending on the degree of Te coverage of the GaAs substrate surface.[8-10] Moreover, it has been reported that the CdTe orientation also depends on the substrate annealing temperature which can change the (100)GaAs surface reconstruction.[11] Recently, a thin Ga_xTe_y intralayer has also been observed at the CdTe/GaAs interface due to Ga diffusion from the substrate that seems to facilitate the (111) growth.[12]

Worth noting are the differences in the type and distribution of defects were revealed by transmission electron microscopy (TEM) observations in (111) and (100) oriented CdTe.[10] In contrast to (100)CdTe/GaAs, where misfit dislocations were mainly observed, a distribution of rotational twins, gradually accommodating the residual strain at the interface, are generated in (111) oriented epilayers.

In order to intentionally nucleate the CdTe layer along the (100) direction as well as to reduce the large CdTe/GaAs mismatch the insertion of a ZnTe buffer layer has been some-

times reported in literature.[12,13] However, to our knowledge, no detailed study of the CdTe structural quality grown on a ZnTe buffer layer has yet been published in the literature.

In this article, we report on the structural characterization of CdTe epilayers grown by MOVPE on (100)GaAs substrates. In order to improve the structural quality of these films, a ZnTe buffer layer has been inserted and the structural quality of the overgrown CdTe has been studied as a function of the buffer thickness by both x-ray diffraction (XRD) and Rutherford backscattering spectrometry (RBS)-channeling technique. From the analysis of the present data, we are able to correlate the CdTe epilayer crystalline quality to the structural and morphological properties of the ZnTe buffer layer. This allows us to determine the best ZnTe buffer thickness for the growth of high quality (100)CdTe epilayers. Finally, structural quality and surface strain of samples grown on optimized ZnTe buffer layers have also been studied as a function of the CdTe thickness.

II. EXPERIMENT

CdTe epilayers were grown on (100)GaAs substrates by atmospheric pressure MOVPE in a horizontal chamber reactor of the vent-run type. For most samples, a ZnTe buffer layer was grown on GaAs before depositing CdTe. To this purpose, electronic grade dimethyl–cadmium (Me_2Cd), diisopropyltelluride [$(i\text{-}Pr)_2Te$] and dimethyl–zinc (Me_2Zn), supplied by Epichem Ltd., were used as Cd, Te, and Zn precursors, respectively.

GaAs substrates cut from liquid encopsulated Czochmalski (LEC)-grown semi-insulating (resistivity $>10^7$ Ω cm) (100) $\pm0.25°$ oriented 2 in. wafers, were supplied by Nippon Mining Ltd. Before being loaded into the reactor, the substrates were degreased in isopropanol vapor and then etched for 8 min at 40 °C in a H_2SO_4:H_2O_2:H_2O (4:1:2) solution, rinsed in 18.2 MΩ deionized water and finally dried under pure N_2 flow. In order to get an oxide-free surface, an *in situ* thermal treatment was routinely performed on the GaAs substrates at 460 °C for 20 min under 1.0 SLM total H_2 flow immediately before the growth. For all samples the growth temperature was kept fixed at 350 °C, whereas the molar flows of Me_2Cd, $(i\text{-}Pr)_2Te$ and Me_2Zn through the reactor chamber were fixed at about 55 μmol/min, determining a precursors concentration of about 1.2×10^{-8} mol/cm^3 in the vapor phase for a total H_2 dilution flow of about 4.5 SLM. These conditions gave us growth rates of about 2.1 μm/h for ZnTe and 2.5 μm/h for CdTe. Furthermore, in order to have sharp CdTe/ZnTe interfaces a 60 s growth interruption time was adopted between the growth of ZnTe and CdTe. Several CdTe epilayers were grown for the present study, their thicknesses ranging from 200 to 1100 nm while the ZnTe buffer layer thickness ranged from 0 to 1300 nm.

A quantitative evaluation of the CdTe surface roughness was obtained by using a Tencor Instruments Model 200 α-step surface profiler, having a maximum vertical resolution of 0.5 nm and a lateral resolution of about 40 nm. Several 40 μm surface scans (sampling rate of 25 point/μm) were per-
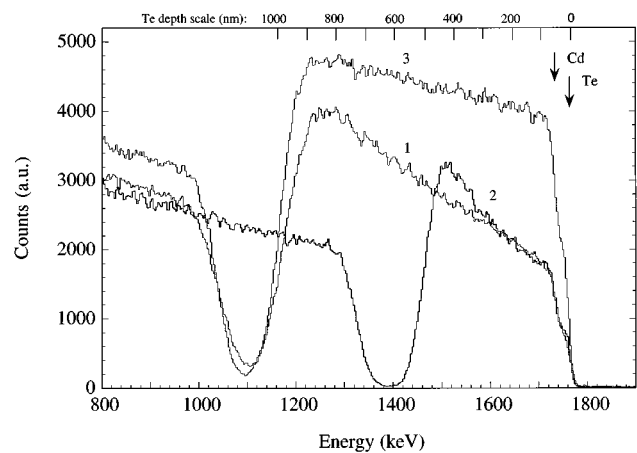

FIG. 1. 2.0 MeV [100] aligned $^4He^+$ RBS spectra of CdTe/GaAs epilayers: (1) 952 nm; (2) 486 nm. The random spectrum recorded for the 952 nm thick CdTe epilayer is also reported for comparison (3).

formed for each sample, allowing us to calculate the value of the surface average roughness R_a, i.e., the arithmetic average of the absolute surface height deviations from the mean surface height along the scan line.[14] As for the CdTe/ZnTe interface roughness, we used the data measured by the same technique on the ZnTe surface in a former study.[15]

In order to measure the epilayer thickness and to roughly estimate their crystalline quality, RBS measurements in both random and [100] aligned geometry (ion channeling) were performed at the Laboratori Nazionali di Legnaro (Italy) on both CdTe/GaAs and CdTe/ZnTe/GaAs heterostructures by using $^4He^+$ beams of 2 or 3.5 MeV energy, following the thickness of the structure. A measure of the lattice tetragonal distortion was also performed by ion-channeling recording the angular yield curves for a surface region for several lattice directions inclined to the surface normal. To this purpose, a goniometer sample holder with an overall precision of 0.01° was used for the ion channeling measurements.[16]

The CdTe/GaAs and CdTe/ZnTe/GaAs epitaxial relationships were assessed by x-ray diffraction (SA-XRD) measurements routinely performed by means of a single-crystal diffractometer (Philips PW 1880). A Cu-target x-ray tube as x-ray source and a proportional counter as detector were used. A flat graphite monochromator placed before the detector was used in order to reduce the K_β diffraction peak. Finally, the crystalline quality of selected epilayers was investigated by using a high resolution x-ray diffractometer (Philips MRD) composed of a four-reflection Ge(220) monochromator (DA-XRD). The source was a Cu K_α radiation emitting x-ray tube and the detector a proportional counter.

III. RESULTS

[100] aligned RBS spectra of CdTe/GaAs heterostructures having epilayer thicknesses of 486 and 952 nm are reported in Fig. 1 together with the random spectrum of the thickest sample. The epilayer thicknesses were determined by computer simulation of the random spectra with a possible systematic error lower than 10% due to uncertainties in the stopping powers of the target material.[17] The [100]-aligned
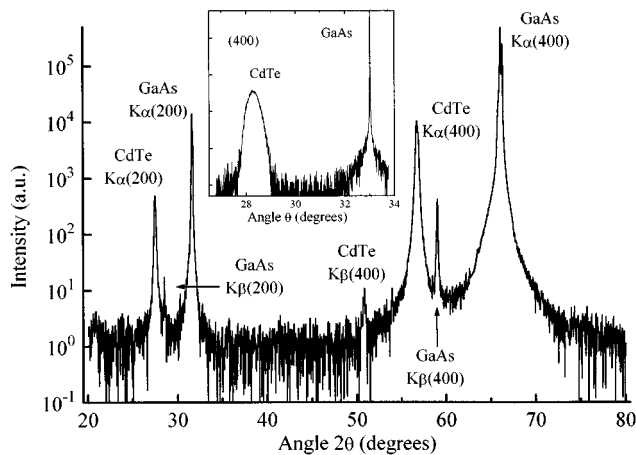
FIG. 2. SA-XRD rocking curve of a CdTe/GaAs sample, the CdTe thickness being 486 nm. The DA-XRD rocking curve in the vicinity of the (400) reflections for the same sample is shown in the inset for one of the four azimuthal angles measured.
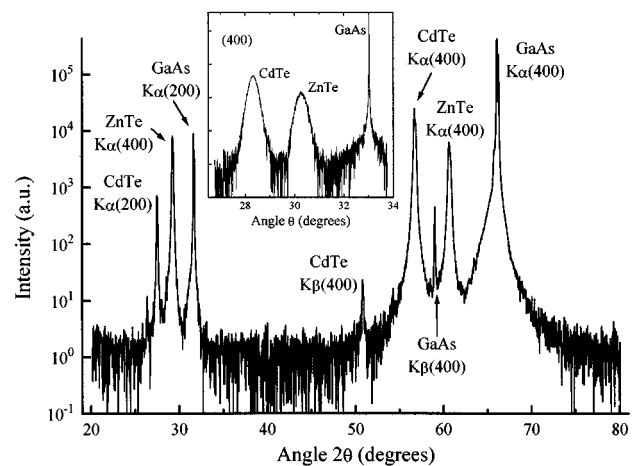

FIG. 3. SA-XRD rocking curve of a CdTe/ZnTe/GaAs sample, the CdTe thickness being 435 nm and the ZnTe buffer layer 218 nm thick. The DA-XRD rocking curve recorded in the vicinity of the (400) reflections for the same sample is shown in the inset for one of the four azimuthal angles measured.

spectra show a very high dechanneling rate due to defects by increasing the penetration depth from the surface down to the interface. Also, the channeling surface yield normalized to the random yield, χ_{min}, that gives an estimate of the crystalline quality of the sample, turned out to be ~50% independently of the CdTe thickness. Due to the limit in the mass resolution between Te and Cd signals, the χ_{min} values have been evaluated just behind the Cd surface peak, hence about 130 nm below the epilayer surface for 2.0 MeV ^{4}He$^+$ beam. As a consequence of this all the χ_{min} values reported in this work are overestimated. Nevertheless χ_{min} values around 50% are one order of magnitude larger than the theoretical value expected for a perfect CdTe crystal[18] pointing out the poor crystalline coherency of the CdTe epilayers grown directly on GaAs.

In order to assess the crystalline quality of the CdTe epilayers and to exclude any chance of pseudoepitaxy, XRD measurements have been performed on several CdTe/GaAs heterostructures. A typical θ–2θ angular scan is reported in Fig. 2 for the 486 nm thick CdTe epilayer. Only the (100)-related CdTe reflections in addition to the GaAs substrate peaks can be observed in the XRD rocking curve showing that the unique (100)CdTe//(100)GaAs epitaxial relationship holds for these samples. The inset of Fig. 2 shows the double axis XRD (DA-XRD) spectrum recorded in vicinity of the CdTe and GaAs(400) reflections for the same sample. It appears that the CdTe reflection peak is much broader then expected for an ideal CdTe epilayer of the same thickness, its full width at half-maximum (FWHM) value being 1574 arcsec. This fact can be related to the occurrence of a high defect density in the epilayer due to plastic relaxation of the CdTe/GaAs high lattice misfit. Moreover (400) symmetric reflections, recorded at four different azimuthal angles, have shown FWHM values as large as 1940 arcsec and a certain asymmetry in the CdTe peak shape when the sample is rotated by 90°.

In the attempt to improve the CdTe structural quality, a

ZnTe buffer layer has been inserted. XRD measurements of the CdTe/ZnTe/GaAs heterostructures indicate that fully (100)-oriented CdTe epilayers are still obtained (Fig. 3) but their crystallographic quality is now strongly improved. In fact, the DA-XRD spectrum of a 435 nm thick CdTe epilayer grown on a 240 nm thick ZnTe buffer layer, shows a FWHM of 1088 arcsec for the (400) reflection (inset of Fig. 3). Still, different FWHM values and asymmetry in the (400)CdTe peak shape have been observed also for these samples, independently of the buffer layer thickness, when the sample is rotated of 90°.

RBS-channeling measurements have been systematically performed on CdTe/ZnTe/GaAs heterostructures as a function of both the ZnTe buffer layer and the CdTe thicknesses. Typical ^{4}He$^+$ RBS spectra of a CdTe/ZnTe/GaAs heterostructure in both random and [100] channeling condition are reported in Fig. 4 together with the random computer simulation. The CdTe thickness turns out to be 435 nm hence very close to the one of the CdTe/GaAs sample shown above.

The channeling spectrum shows a strong increase in the dechanneling rate by increasing the beam penetration depth, indicating the occurrence of a high defect density in a region about 400 nm thick close to the CdTe/ZnTe interface, as already observed for the CdTe/GaAs heterostructure. However, in agreement with XRD results, the surface crystalline quality of the buffered heterostructure appears to be strongly improved, its χ_{min} value being about 17%. The χ_{min} values of a 435 nm thick CdTe epilayer as a function of the ZnTe buffer layer thickness are reported in Fig. 5. It appears that the χ_{min} value monotonically decreases from 50% for no buffer down to a minimum value of about 12% by increasing the ZnTe thickness up to 300–500 nm, pointing out an important improvement in the crystalline quality of the CdTe epilayers. Moreover, as a striking feature, the strongest decrease in the χ_{min} value is observed for ZnTe buffer layer thickness up to 10 nm and then only a fairly smooth decrease
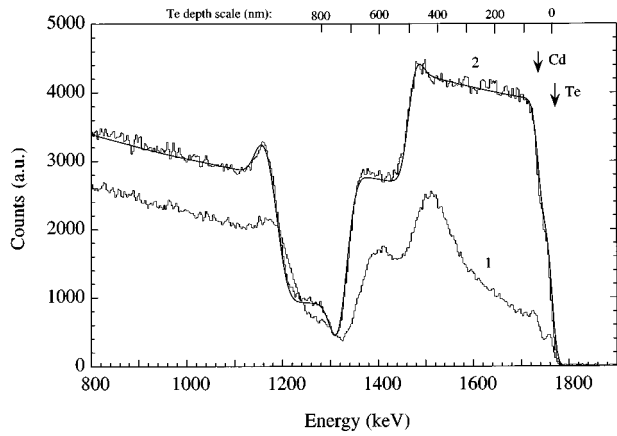
FIG. 4. 2.0 MeV ^{4}He$^+$ RBS spectra of a 435 nm thick CdTe epilayers grown on (100)GaAs after inserting a 218 nm thick ZnTe buffer layer: (1) [100] aligned; (2) random geometry. The solid line superposed to the random spectrum is the corresponding RBS simulation.

FIG. 6. Average surface roughness values R_a of ZnTe epilayers (filled circle) and of a 435 nm overgrown CdTe layer (open circle), as a function of the ZnTe thickness.

in the CdTe χ_{min} is observed up to about 400 nm. Finally a further increase of the buffer layer thickness above 500 nm causes a slight increase of χ_{min}, that reaches the value of 16% for a 1330 nm thick ZnTe buffer layer, as can be observed in the inset of the figure. Thus, the optimal buffer layer thickness has been determined to vary between 300 and 500 nm.

Computer simulations of the random spectra have been performed in order to obtain a measure of the epilayer thickness and to estimate the sharpness of the interface. The simulations show that a fairly good agreement with the corresponding experimental spectra can be achieved only by introducing an interfacial linearly graded composition profile between CdTe and ZnTe over a thickness Δt whose average value is 74±6 nm independently of the buffer layer thickness. As a matter of fact the RBS technique cannot distinguish between surface and interface roughness and interface interdiffusion, hence the surface roughness, R_a, of the ZnTe buffer was systematically measured by surface profilometry.
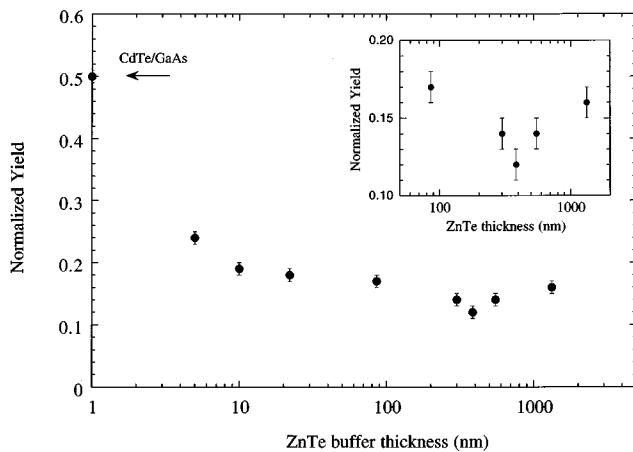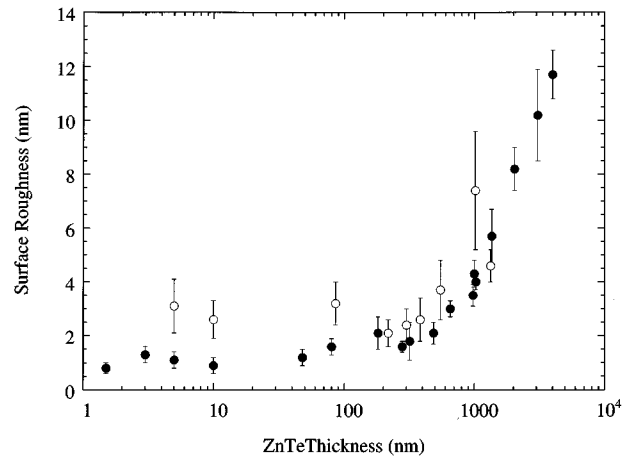
The results are reported in Fig. 6 as a function of the ZnTe thickness. In the same figure, the R_a values of a 435 nm thick CdTe film grown on top of different thickness ZnTe buffer layers are also reported for comparison. The ZnTe roughness is almost constant at a value of 1.6±0.5 nm up to a thickness of about 300 nm and above 500 nm shows a dramatic increase. The CdTe roughness is likely higher than that of the ZnTe buffer and mimic the ZnTe behavior. In fact, it is nearly constant at a value of 2.8±0.5 nm for ZnTe thicknesses below 300 nm and then sharply increases. These data, together with the RBS Δt data, allow us to conclude that Cd and Zn interdiffusion takes place at the interface, its extension being of the order of 50 nm.

(100)CdTe epilayers with different thicknesses have been grown on 307±7.5 nm thick ZnTe buffer layers. The normalized channeling yield, χ_{min}, as a function of the CdTe epilayer thickness is reported in Fig. 7. A sharp decrease in the

FIG. 5. Values of the [100]-channeling surface yield normalized to the random yield, χ_{min}, as a function of the ZnTe buffer layer thickness for 435 nm thick CdTe epilayers.
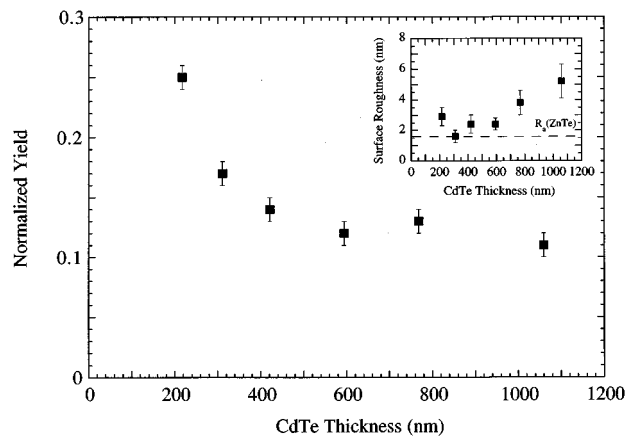

FIG. 7. Values of the [100]-aligned RBS minimum yield χ_{min} as a function of the CdTe epilayer thickness, the ZnTe buffer layer thickness being 307 nm. In the inset the CdTe surface roughness is also reported as a function of the epilayer thickness. The dashed line indicates the surface average roughness value of the ZnTe buffer layer.

TABLE I. Tetragonal distortion and parallel strain values determined by ion-channeling measurements for several CdTe/ZnTe/GaAs samples having around 300 nm thick ZnTe buffer layer.

Sample	h_{CdTe} (nm)	ϵ_T (%)	$\epsilon_\parallel$ (%)
ZCT12	217	$+0.21\pm0.06$	-0.09 ± 0.02
ZCT21	311	$+0.06\pm0.02$	-0.02 ± 0.01
ZCT11	421	$+0.06\pm0.03$	-0.02 ± 0.01
ZCT15	1059	$+0.06\pm0.03$	-0.02 ± 0.01

χ_{min} value from 25% down to an average value of 12% is observed by increasing the CdTe thickness from 200 to 500 nm, pointing out a fairly good improvement in the CdTe epilayer crystalline quality when its thickness is larger than 500 nm. The surface average roughness, R_a, of the CdTe epilayers is reported in the inset of Fig. 6 as a function of their thickness.

Finally, surface strain measurements as a function of the CdTe thickness have been performed by ion channeling on CdTe/ZnTe/GaAs samples having optimal buffer layer thickness around 300 nm. For such ZnTe thickness, the lattice mismatch between the ZnTe buffer layer and the GaAs substrate is totally relaxed, as reported in a previous paper.[19] Values of the tetragonal distortion, $\epsilon_T = a_\perp/a_\parallel + 1$, where $a_\perp$ and $a_\parallel$ are the CdTe lattice parameters normal and parallel to the CdTe/ZnTe interface, respectively, have been obtained by measuring the angular deviations of lattice directions inclined to the surface normal with respect to the corresponding directions in the unstrained lattice.[16] By assuming a tetragonal distortion approximation for the CdTe unit cell, the in-plane strain values, $\epsilon_\parallel$, have been obtained by the relationship: $\epsilon_\parallel = -\epsilon_T/(1+\alpha)$, where $\alpha = 2C_{12}/C_{11}$ is 1.37 for CdTe. In Table I $\epsilon_\parallel$ and ϵ_T values are reported for different CdTe epilayer thickness. The table shows that the initial compressive strain induced by the lattice mismatch between CdTe and ZnTe ($f = -5.8\%$) is almost totally relaxed for a CdTe thickness of 217 nm. A further slight relaxation takes place by increasing the CdTe thickness up to 311 nm. In fact, $\epsilon_\parallel$ increases from -0.09% at 217 nm up to -0.02% at 311 nm whereas no further increase is observed up to 1060 nm.

IV. DISCUSSION

In the previous section the structural quality of CdTe epilayers has been evaluated for ZnTe buffer layer thicknesses varying from 0 to 1330 nm. It is evident from both ion-channeling and DA-XRD measurements that the insertion of the ZnTe buffer layer causes a noteworthy improvement in the structural quality of the CdTe epilayers. Single-crystal CdTe epilayers of fairly good crystalline quality ($\chi_{min} = 12\%$) have been obtained for ZnTe buffer layer thicknesses in the range from 300 to 500 nm.

The CdTe crystalline quality evolution as a function of the ZnTe buffer layer thickness can be related to previous RBS and TEM results about the ZnTe/GaAs heterostructures.[19,20] In fact, RBS-channeling damage profile pointed out the high lattice deformation, induced by the high density of misfit dislocation generated at the interface and extended defects

which occur in the first 60 nm, from the interface. In addition, beyond this region further defects occurs into the epilayers, with a slowly decreasing density by increasing the distance from the interface. These results were also confirmed by TEM observations showing, in addition to 60° misfit dislocations along the interface, an inhomogeneous distribution of defects extending into the ZnTe epilayer. The density of these defects was found to vary within the epilayer thickness in agreement with the observed residual strain gradient.[20]

Taking into account this defect distribution for the ZnTe buffer layer, it is possible to explain the two regions evidenced by the χ_{min} curve of the CdTe as a function of the ZnTe thickness. In fact, for ZnTe ranging from 0 to 10 nm the CdTe crystalline quality sharply increases as a consequence of both the reduction in the CdTe/GaAs lattice misfit induced by the ZnTe buffer layer insertion and of the rapid decrease of the defect density in the ZnTe buffer. Above 10 nm the slower increase in the CdTe structural quality can be accounted for by the slow decrease in the buffer density of threading dislocations which propagate into the overgrown CdTe epilayer deteriorating its surface crystalline quality. The fairly good structural quality of CdTe films grown on ZnTe buffers with thicknesses ranging from 300 to 500 nm ($\chi_{min} = 12\%$) are thus explained by the stabilization of the buffer surface crystalline quality for ZnTe thickness above 300 nm.[19] Finally, the slight worsening of the CdTe quality observed when increasing the ZnTe thickness above 500 nm can be related to the rapid increase of the ZnTe surface roughness that favors the generation of defects threading to the surface. In fact, a strong dependence between the structural quality of epilayers and the morphology and surface roughness of the substrate has been recently reported.[21]

As a consequence of these results the most favorable ZnTe buffer layer thickness has been determined to be 300 nm. The ion-channeling measurements shown in the previous section have pointed out that the surface crystalline quality of a CdTe epilayer, grown on ZnTe buffers of optimal thickness, is relatively high for CdTe thicknesses above 400 nm (χ_{min} around 12%). Even though this χ_{min} value is overestimated as a consequence of the limited RBS mass resolution for Cd and Te (see Sec. III), it is nearly twice the theoretical value for a perfect crystal. Thus, the crystalline quality of the CdTe epilayers is not perfect, nevertheless it is much better than that of a CdTe epilayer directly grown on the GaAs substrate.

Concerning the surface morphology, it appears to be quite good for layer thicknesses lower than 600 nm, as the surface roughness is of the order of 2.8 nm. At present, we do not have any explanation for the rapid increase of the surface roughness at higher thicknesses. However, we observe that this behavior is quite similar to that of ZnTe which is unexplained as well.

Furthermore, no direct correlation appears between the surface roughness and the surface crystalline quality of the CdTe epilayers grown on a ZnTe buffer layer of optimized thickness. In fact, in contrast to the constant trend of R_a, both the χ_{min} and XRD—FWHM values show a worsening

of the CdTe structural quality for epilayers thinner than 400 nm. This behavior can be ascribed to the occurrence of extended defects generated as a consequence of the plastic relaxation of the initial lattice misfit between CdTe and ZnTe. As it can be inferred by the high dechanneling rate observed in this region in the aligned RBS spectra, these defects should extend in an almost 400 nm thick region close to the CdTe/ZnTe interface. This interpretation is in good agreement with high resolution (HR)-TEM observation of both CdTe/GaAs and CdTe/ZnTe/GaAs heterostructures[10,13,22] showing that the relaxation of these large lattice mismatches takes place only partially through a network of 60° misfit dislocations at the interface. In fact, in addition to this network, threading dislocations and, in some cases, also stacking faults were observed in the epilayers.[13,22] The different FWHM values of the (400) reflection shown by the DA-XRD measurements, at different azimuthal angle in both CdTe/GaAs and CdTe/ZnTe/GaAs samples suggest that defects with different density are generated along the two orthogonal [011] and [0–11] directions. Hence, a certain anisotropy in the strain relaxation is expected in both CdTe/GaAs and CdTe/ZnTe heterostructures. As a consequence of the defect concentration gradient, a strain gradient is also expected to occur in the layer.

The surface residual strain measured as a function of the CdTe thickness on samples having optimized ZnTe buffers, show that the high lattice misfit between CdTe and ZnTe is, almost totally relaxed for a 200 nm thick CdTe epilayer while a small and constant residual compressive strain, $\epsilon_\parallel=(-0.02\pm0.01)\%$, was measured for CdTe epilayers thicker than 300 nm. This residual strain can be attributed to a small, not-relaxed, thermal strain induced in the relaxed CdTe/ZnTe/GaAs heterostructure during the cooling down from the growth temperature to room temperature. On the basis of the currently available ZnTe and CdTe linear expansion coefficient data,[23–26] the thermal strain has been calculated to be -0.008% with a relative error of about 10%, in perfect agreement with our measurements within the experimental error.

V. CONCLUSIONS

We have reported the structural characterization of CdTe epilayers grown by MOVPE technique on (100)GaAs. The effect of the insertion of a ZnTe buffer layer on the CdTe quality has been studied as a function of the ZnTe thickness. DA-XRD and ion-channeling measurements show that high crystalline quality CdTe epilayers can be obtained by growing on buffer layers with a thickness ranging between 300 and 500 nm. This result is in good agreement with the ZnTe defect distribution determined in a former TEM study of the ZnTe/GaAs heterostructure, whereas the worsening of the CdTe structural quality by increasing the buffer layer thickness above 600 nm can be fully ascribed to the rapid increase in the ZnTe surface roughness.

Systematic ion-channeling measurements of the surface structural quality and the built-in lattice strain have been performed as a function of the CdTe thickness for samples grown on 300 nm thick ZnTe buffer layers. The relaxation of the initial CdTe/ZnTe high lattice misfit seems to occur through the generation of extended defects extending in the epilayer for about 400 nm from the interface. Thus high quality CdTe epilayers can be obtained for thicknesses above 400 nm. The lattice misfit appears to be already fully relaxed in a 300 nm thick CdTe film and the small residual strain revealed at the sample surface can be ascribed to the thermal strain induced in the CdTe/ZnTe/GaAs heterostructure during the cooling down from the growth temperature.

[1] C. Scheiber and J. Chambran, Nucl. Instrum. Methods Phys. Res. A **322**, 604 (1994).
[2] J. Britt and C. Ferekides, Appl. Phys. Lett. **62**, 2851 (1993).
[3] R. K. Ahrenkil, B. M. Keyes, D. L. Levi, K. Emery, T. L. Chu, and S. Chu, Appl. Phys. Lett. **64**, 2879 (1994).
[4] R. F. C. Farrow, J. Vac. Sci. Technol. A **3**, 60 (1985).
[5] P. L. Anderson, J. Vac. Sci. Technol. A **4**, 2162 (1986).
[6] R. Sporken, S. Sivananthan, K. K. Mahavadi, G. Monfroy, M. Boukerche, and J. P. Faurie, Appl. Phys. Lett. **55**, 1879 (1989).
[7] I. Bhat and W.-S. Wang, Appl. Phys. Lett. **64**, 566 (1994).
[8] S. Sone, M. Ekawa, K. Yasuda, Y. Sugiura, M. Saji, and A. Tanaka, Appl. Phys. Lett. **56**, 539 (1990).
[9] A. Bourret, P. Fuoss, G. Feuillet, and S. Taterenko, Phys. Rev. Lett. **70**, 311 (1993).
[10] G. Bratina, L. Sorba, A. Antonini, G. Ceccone, R. Nicolini, G. Biasiol, A. Franciosi, J. E. Angelo, and W. W. Gerberich, Phys. Rev. B **48**, 8899 (1993), and references therein.
[11] T. T. Cheng, M. Aindow, I. P. Lones, J. E. Hails, D. J. Williams, and M. G. Astels, J. Cryst. Growth **135**, 409 (1994).
[12] J. W. Cairns, D. A. Woolf, M. R. Bennett, R. H. Williams, and R. A. Ballingall, J. Vac. Sci. Technol. B **12**, 2587 (1994).
[13] G. Patriarche, R. Triboulet, Y. Marfaing, and J. Castaing, J. Cryst. Growth **129**, 375 (1993).
[14] ANSI Specifications No. B **46**, I-1978.
[15] M. Longo, Tesi di Laurea, University of Lecce, 1992.
[16] A. Carnera and A. V. Drigo, Nucl. Instrum. Methods B **44**, 357 (1990).
[17] J. Ziegler, *Stopping and Ranges of Ions in Matter* (Pergamon, New York, 1977), Vol. 4.
[18] D. S. Gemmel and R. C. Mikkelson, Phys. Rev. B **6**, 1613 (1972).
[19] N. Lovergine, R. Cingolani, G. Leo, A. M. Mancini, L. Vasanelli, F. Romanato, A. V. Drigo, and M. Mazzer, Appl. Phys. Lett. **63**, 3454 (1993).
[20] N. Lovergine, F. Liaci, J.-D. Ganière, G. Leo, A. V. Drigo, F. Romanato, A. M. Mancini, and L. Vasanelli, J. Appl. Phys. **78**, 229 (1995).
[21] Wu. Xuehua, A. A. Tikhonova, D. E. Skolovsky, N. A. Kiselev, and Wu Ziqin, Philos. Mag. A **70**, 277 (1994).
[22] J. Petruzzello, D. Olego, S. K. Ghandhi, N. R. Taskar, and I. Bhat, Appl. Phys. Lett. **50**, 1423 (1987).
[23] S. I. Novikova and N. Kh. Abrikosov, Fiz. Tverd. Tela **5**, 2138 (1963) [Sov. Phys. Solid State **5**, 1558 (1964)].
[24] H. J. Holland and K. Beck, J. Appl. Phys. **39**, 3498 (1968).
[25] S. I. Novikova, Fiz. Tverd. Tela **2**, 2341 (1960) [Sov. Phys. Sol. State **2**, 2087 (1960)].
[26] M. G. Williams, R. D. Tomlinson, and M. J. Hampshire, Solid State Commun. **7**, 1831 (1969).