Cryst. Res. Technol. **39**, No. 10, 881 – 885 (2004) / **DOI** 10.1002/crat.200410271

Properties of $Hg_{1-x}Cd_xTe$ epitaxial films grown on (211)CdTe and (211)CdZnTe

M. C. Di Stefano[1], E. Heredia[2,3], U. Gilabert[1], and A. B. Trigubó*[1,3]

[1] Facultad Regional Buenos Aires – Universidad Tecnológica Nacional (FRBA-UTN)
[2] Instituto de Investigaciones Científicas y Técnicas de las Fuerzas Armadas (CITEFA)
[3] Centro de Investigaciones en Sólidos (CINSO) – Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) – CITEFA: Juan Bautista de La Salle 4397, B1603ALO Villa Martelli, Pcia de Buenos Aires, Argentina

Received 24 February 2004, accepted 20 April 2004
Published online 1 September 2004

Key words $Hg_{1-x}Cd_xTe$, MCT, ISOVPE, epitaxial films.
PACS 68.55.-a

$Hg_{1-x}Cd_xTe$ (MCT) epitaxial films have been grown employing single crystalline substrates of CdTe and $Cd_{0.96}Zn_{0.04}Te$ with (211)Cd and (211)Te crystalline orientations. The Isothermal Vapor Phase Epitaxy (ISOVPE) technique without Hg overpressure has been used for the epitaxial growth. Substrates and films were characterized by optical microscopy, chemical etching and x ray diffraction (Laue technique). The electrical properties were determined by Hall effect measurements. The characterization results allowed to evaluate the crystalline quality of MCT films.

© 2004 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

1 Introduction

Among the semiconductors alloys that are used in infrared detectors for the second atmospheric transmission window, the $Hg_{1-x}Cd_xTe$ (MCT) is preferred by its high optical absorption coefficient, high electronic mobility, small thermal generation rate of carriers and the possibility of adjustment of the "bandgap" by means of the chemical composition (x) change [1]. The employed chemical concentration was $x \approx 0.2$.

It is a hard process to grow large MCT single crystals with homogeneous composition. This fact determined the development of different epitaxial growth techniques (VPE, LPE, MBE, MOCVD). It has been experimentally found that CdZnTe substrates allows to get a better result. The smaller density of dislocations in the ternary substrates than in the pure CdTe, determine a smaller density of threading dislocations. Likewise, the lattice parameter similarity of $Cd_{0.96}Zn_{0.04}Te$ to the MCT ($x = 0.2$) diminish the generation of misfit dislocations. Table 1 shows the lattice parameters of the substrates and MCT ($x = 0.2$) and it can be observed the improvement of the ternary substrate with regard to the binary substrate when these values are compared to MCT ($x = 0.2$).

The quality and reliability of MCT devices depend on the distribution and density of dislocations, since these lineal defects are electrically charged and determine the decrease of the average life time of the carriers due to recombination [2]. As a consequence, device detectivity manufactured with this material diminishes.

It has been reported that when the growth is carried out by MBE on (211)Te substrates the propagation of twins during nucleation and growth is not stable, and consequently, twin free, very smooth and free of hillocks MCT epitaxial layers can be obtained [3,4]. Recently Krishnamurthy et al [5] have used Green's function

* Corresponding author: e-mail: atrigubo@citefa.gov.ar

© 2004 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

method to calculate the excess pair energies. These calculations suggested the growth in (211)Cd and (211)Te directions will be considerably better than that on (100), (111) or (110) surfaces. In consequence, it is of great interest to study MCT growth on (211)Cd and (211)Te substrates by ISOVPE, the most suitable MCT growth technology for small industries.

This work is part of a systematic determination of properties in single crystalline epitaxial films of MCT ($x \approx 0.2$) grown in different crystalline orientations and on pure CdTe or CdZnTe substrates [6-9].

Table 1 MCT (x = 0.2) and substrates lattice parameter.

Semiconductor material	CdTe	$Cd_{0.96}Zn_{0.04}Te$	$Hg_{0.8}Cd_{0.2}Te$
Lattice parameter (Å)	6.4823	6.4656	6.4637

2 Experimental

Single crystalline substrates of CdTe and $Cd_{0.96}Zn_{0.04}Te$, with crystallographic orientation (211)Cd and (211)Te, were employed to grow MCT epilayers. Substrates were provided by II-VI Inc and their crystalline orientation was checked by x-ray diffraction (Laue technique).

Table 2 Dislocation density and misorientation angle between adjacent subgrains on substrates and MCT epitaxial films grown over them.

Substrates					Epitaxies		
Semiconductor Material	Crystalline Orientation	Dislocation Density (cm^{-2})	Misorientation (“)	Figure Nº	Dislocation Density (cm^{-2})	Misorientation (“)	Figure Nº
CdTe	(211)Cd	$1.8\ 10^5$	11	1a	$1.0\ 10^6$	19	1b
CdTe	(211)Te	$9.4\ 10^4$	5	2a	$2.5\ 10^6$	49	2b
$Cd_{0.96}Zn_{0.04}Te$	(211)Cd	$4.8\ 10^4$	13	3a	$2.9\ 10^5$	31	3b
$Cd_{0.96}Zn_{0.04}Te$	(211)Te	$2.7\ 10^4$	11	4a	$6.9\ 10^5$	17	4b

Table 3 Average surface composition, thickness and electrical properties of the MCT films.

Substrates	Crystalline Orientation	<x>	Thickness (μm)	Hall effect Measurements 77 K		
				p (cm^{-3})	μ ($cm^2V^{-1}s^{-1}$)	ρ (Ωcm)
CdTe	(211)Cd	0.171	29	$2.0\ 10^{17}$	192	0.016
CdTe	(211)Te	0.203	28	$7.5\ 10^{17}$	527	0.016
$Cd_{0.96}Zn_{0.04}Te$	(211)Cd	0.176	21	$8.9\ 10^{17}$	102	0.069
$Cd_{0.96}Zn_{0.04}Te$	(211)Te	0.172	20	$9.7\ 10^{17}$	954	0.068

The substrates were chemo-mechanically polished with Br_2 (1%) in ethylenglicol solution to get mirror like surfaces previous to MCT films crystal growth.

The epilayer growth was carried out employing the Isothermal Vapor Phase Epitaxy technique (ISOVPE) without Hg overpressure. The temperature of the HgTe source and substrate was (610 ± 1)°C. The growth time was 3.25 hours.

The structural, chemical and electrical properties of substrates and films were determined employing different techniques:

- The structural properties were determined by x-ray diffraction (Laue technique), preferential chemical etching and optical microscopy. The dislocation density and the adjacent subgrain misorientation were measured on optical micrographs obtained from the surfaces of the chemical etched substrates (Figures 1a, 2a, 3a, 4a). Then, the Shockley-Read approximation was used to calculate the misorientation. The Everson et al. [10] reagent was employed to etch the Te face on the binary and ternary substrates, since it is the only

© 2004 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

surface where the solution is effective producing pits. For the MCT films Hähnert et al [11] reagent was used (Figures 1b, 2b, 3b, 4b). The obtained values are shown in Table 2.

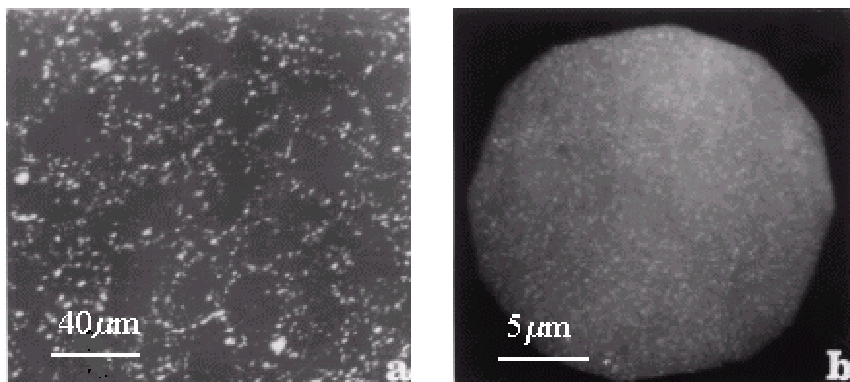

Fig. 1 a) CdTe (211)Te chemically etched by Everson et al reagent [10]. b) MCT epitaxy grown on the polished surface of the opposite side of the substrate crystalline face shown in Figure 1a and chemically etched by Hähnert et al reagent [11].

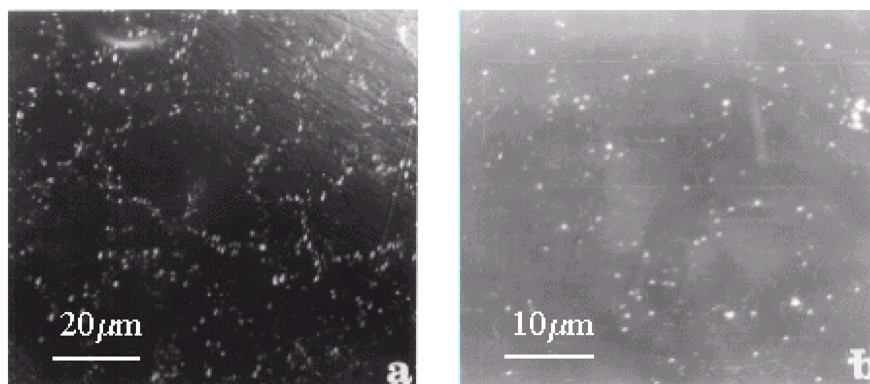

Fig. 2 a) CdTe (211)Te chemically etched by Everson et al reagent [10]. b) MCT epitaxy grown on the polished surface of the same substrate crystalline face shown in the Figure 2a and chemically etched by Hähnert et al reagent [11].

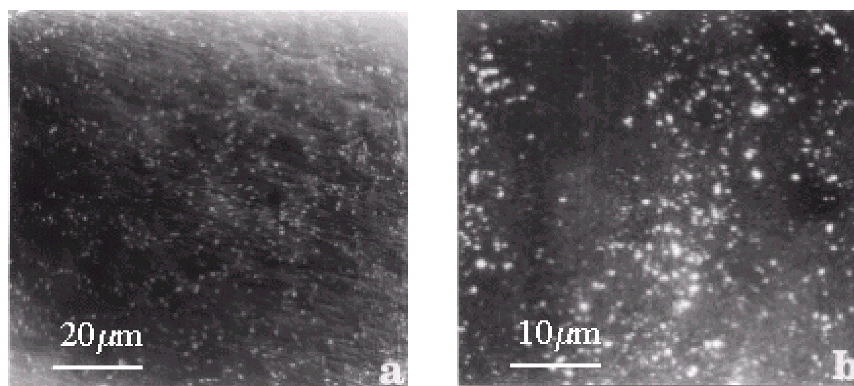

Fig. 3 a) CdZnTe (211)Te chemically etched by Everson et al reagent [10]. b) MCT epitaxy grown on the polished surface of the opposite side of the substrate crystalline face shown in Figure 3a and chemically etched by Hähnert et al reagent [11].

© 2004 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

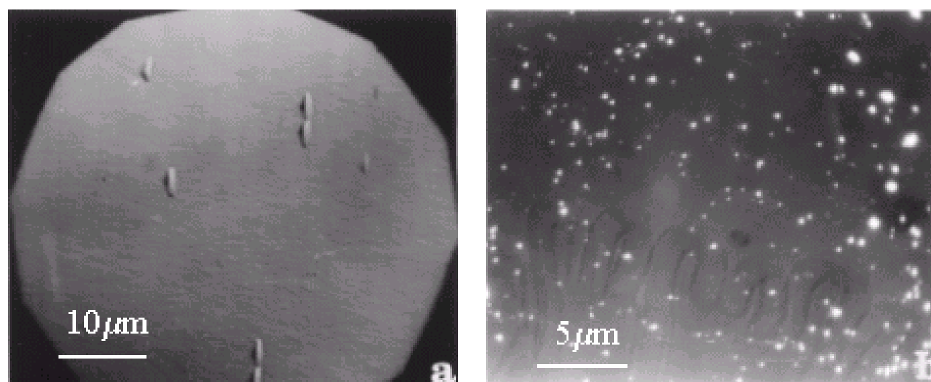

Fig. 4 a) CdZnTe (211)Te chemically etched by Everson et al reagent [10]. b) MCT epitaxy grown on the polished surface of the same substrate crystalline face shown in the Figure 4a and chemically etched by Hähnert et al. reagent [11].

- The chemical composition (Table 2) was obtained employing the electronic microprobe (CAMECA) in the wavelength dispersive mode, using the elements Cd, Zn and Te as standards. Mercury (Hg) was determined by difference. No significant levels of Zn was detected on the surface of the epilayers grown over the ternary substrates.
- The electrical properties were determined by Hall effect measurements at 77 K (Table 3).

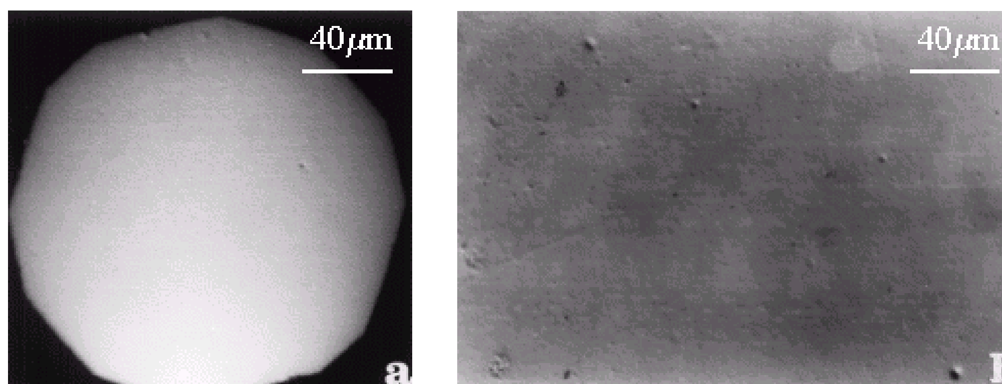

Fig. 5 a) Surface morphology of a (211)Te MCT epitaxy. b) Surface morphology of a (211)Cd MCT epitaxy.

3 Results and Discussion

The sensitivity of a detector depends on the quality of the material that was used in its manufacture. The material growth process is decisive on device properties. Properties as density and distribution of dislocations, composition homogeneity, concentration of point defects and surface morphology (Figure 5) constitute the bases for a systematic knowledge of this alloy [12].

The structural characteristics of substrates and films are shown in Table 2. The following considerations can be made:

- The epilayer dislocation density is larger than the substrate dislocation density .
- The dislocation density of the epitaxies grown on ternary substrates is smaller than the corresponding values of the films grown on pure CdTe [6-9].

© 2004 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

- The fluctuations in the ratio [epitaxy dislocation density / substrate dislocation density], as much for pure substrates as for those alloyed, is probably due to that some reagents used in the determinations are reliable, like Hähnert et al [11] for the epitaxies, meanwhile Everson et al [10] for the (211)Te substrates are not reliable.

All these facts were already observed in the other crystalline orientations studied [6-9].

The average surface composition, thickness and electrical properties of the epitaxies are shown in Table 3. With regard to these values we can consider that:

- The composition homogeneity on the films fulfill the necessary requirements to make them capable to detect in the infrared wavelength range.
- The charge carriers concentration is of the order of 10^{17} cm^{-3}. In the grown material with Hg overpressure the corresponding value is of the order of 10^{16} cm^{-3} [12]. When the growth condition is without Hg overpressure, the Hg vacancies concentration is larger, which determines that holes concentration is also larger [13].
- The charge carriers mobility is similar, in general, to the literature references and to those values obtained by the authors of this work in other crystalline orientations [1, 6-9].

4 Conclusions

The surface morphology and electrical properties of MCT epitaxial films in the (211)Cd and (211)Te crystallographic orientations are similar to each other and are not determined if pure or alloyed CdTe have been employed as substrates.

The epitaxies obtained on alloyed substrates have smaller density of dislocations. This determines a larger carriers average time life and in consequence an improvement of the electrical properties of the devices that can be manufactured with these films.

References

[1] P. Capper (ed.), Narrow-Gap Base Compounds, EMIS Datareviews Series Nº 10, INSPEC, 1994.
[2] T. H. Moore and H. F Schaake, J. Vac. Sci. Technol A1 **1**, 1666 (1983).
[3] M. Kawano et al., J. Cryst. Growth **117**, 171 (1992).
[4] J. M. Arias et al., Appl. Phys. Lett. **62**, 976 (1993).
[5] S. Krishnamurthy, A. B. Chen, and A. Sher, J. Electron. Mat. **25**, 1254 (1996).
[6] U. Gilabert, O. Serravalle, E. Heredia, H. Cánepa, A. B. Trigubó, and N. E. Walsöe de Reca, Anales de la Asoc. Quím Arg. **83**, 65 (1995).
[7] U. Gilabert, A. B. Trigubó, O. Serravalle, E. Heredia, R. González, and N. E. Walsöe de Reca, Anales Asoc. Quím. Arg. **84**, 49 (1996).
[8] U. Gilabert, A. B. Trigubó, E. Heredia, and N. E. Walsöe de Reca, Revista Mexicana de Física **44**, 89 (1998).
[9] U. Gilabert, A. B. Trigubó, E. Heredia, and N. E. Walsöe de Reca, Superficies y Vacío **13**, 20 (2001).
[10] W. J. Everson, C. K. Ard, J. L. Sepich, B. E. Dean, G. T. Neugebauer, and H. F. Shaake, J. Electron Mat. **2**, 505 (1995).
[11] I. Hähnert and M. J. Schenk, J. Cryst. Growth **101**, 251 (1990).
[12] G. Cinader, A. Raizman, and A. Sher, J. Vac. Sci. Technol. B **9**, 1634 (1991).
[13] A. B. Trigubó and N. E. Walsöe de Reca, Mat. Sci. Eng B. **27**, 87 (1994).
[14] H. R. Vydyanath, J. Vac. Sci Technol. B **9**, 1716 (1991).

© 2004 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim