Comparison Between Epitaxial Layers grown by Hot Wall Epitaxy and Flash Evaporation

Sonia Guimarães[1]; Sabrina de C.F. da Silva[2] and João M.K. de Assis[1,2]
[1] *Divisão de Materiais-AMR, Instituto de Aeronáutica e Espaço-IAE, Centro Técnico Aeroespacial-CTA,*
Pr. Mal. Do Ar Eduardo Gomes, 50 – CEP.12228-904, São José dos Campos – SP - Brazil
[2] *Faculdade de Engenharia Química de Lorena – Faenquil – Lorena – SP – Brazil.*

Abstract

Images generated by Scanning Electronic Microscopy (SEM) were used in order to compare epitaxial layers of lead telluride (PbTe), grown by Hot Wall Epitaxial technique (HWE) and Flash Evaporation (FE), directly over single crystal silicon (Si) wafers, p-type. These heterojunctions are used as thermal infrared detectors, which work at room temperature. Infrared detectors are radiant energy transducers, which convert this energy in electric energy, and usually have to be cooled and kept at 77 K to work properly (1).

Keywords: epitaxial growth, lead telluride, Si, flash evaporation.

Introduction

Narrow gap semiconductors are among the most suitable materials for infrared detectors due to their high quantum efficiency, low noise level at given operating temperatures and their band gap that can be tailored to achieve the desired cut off wavelengths.

Scott et al. (2) predicted the heterojunction n-PbTe/p-Si as an ideal detector similar to a Schottky diode, because the n-type doping of PbTe is sufficient for any band bending to be negligible. The photo response threshold is the energy difference between the valence band maximum of the Si and conduction band minimum of PbTe. This structure will minimize the inelastic processes. The band gap of PbTe is less than the threshold, which can maximize absorption in the over layer. In the absorption step, the narrow gap semiconductor will produce more detectable carriers than a metal or silicide. Consequently the density of states will make the absorption length in a semiconductor larger than that in a metal, therefore a thicker PbTe layer can be used to absorb more photons. In the transport step, there are few holes near the valence band maximum on n-PbTe, so hole-hole scattering can be neglected. In the transmission step the $K_\perp$ matching is better than for a Schottky barrier, reducing reflections near the threshold. The above factors can result in a substantial increase in quantum efficiency of a n-PbTe/p-Si heterostructure over other Si-based infrared detectors.

The HWE method combines two characteristics, growth under near-equilibrium conditions and versatility. The first serves to provide crystals with the required crystalline perfection; the second is necessary for the preparation of different types of materials with different characteristics and for the production of modem solid-state devices. Flash evaporation used in this work consisted of a modified vacuum equipment with three basic steps: a) solid phase source transition to gas phase, using the heat of a resistor, which contains the material to be evaporated; b) vapor transportation to the substrate surface, c) vapor condensation on. the substrate surface. The modification performed in the evaporator was to provide a sample heater system, which enable us to heat, and control the Si substrates temperature till about 230°C.

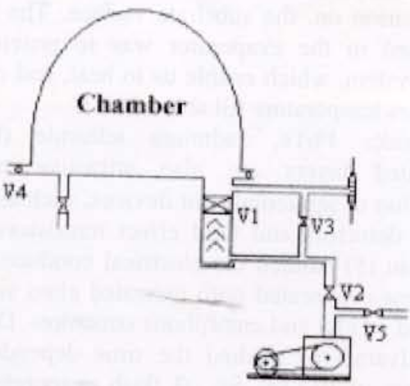
Besides PbTe, cadmium telluride (CdTe) flash evaporated layers are also attractive materials for fabrication of semiconductor devices, such as solar cells, γ and IR detectors and field effect transistors (3-5). Rusu and Rusu (5) studied the electrical conductivity of CdTe thin films evaporated onto unheated glass substrates, and obtained <111> and amorphous structures. Domadara Das and Selvaraj (6) studied the time dependent electrical resistance of $Bi_2(Te_{0.4}Se_{0.6})3$ flash evaporated thin films, related with the effects of oxygen adsorption. These thin films find many applications. such as in small thermoelectric power generators, thermoelectric refrigerators, thermopile detectors, etc. Boustani et al. (7) studied the influence of the substrate temperature during $CuInTe_2$ flash evaporation thin films, on its properties. These films have been extensively studied because of the potential applications in multijunction thin-film solar cells (8).

Materials and Methods

Si wafers <100> crystal oriented, 1 - 10 Ω.cm as resistivity, chemically and thermally treated before the epilayers growth, were used, in order to define the best conditions to obtain the higher specific detectivity values (D*). High purity (99,9999%) tellurium and lead, Pb_xTe_{x-1} ($x = 0.502$), was used. The evaporation was performed on modified JEOL vacuum equipment, model JEE4B (Fig. 1), working with vacuum pressure around 10^{-4} torr, using diffusion pump. HWE system is self-built equipment (Figs. 2 and 3), consisting of a high-vacuum chamber (10^{-7} torr), where two HWE reactors, each one consisting of a main zone for the PbTe salt and a second zone for tellurium, were used. It is described by Boschetti et al.(9).

Thickness was measured with an Alfa Step 500 Surface Profiler. X-ray diffraction spectrum of the samples was taken, with a High Resolution X-Ray Diffraction Spectrometer Philips X'Pert (PW3 710), equipped with Copper anodic tube, Nickel filter, 40kV as voltage value, and 20 mA as current, $2\theta = 0.02°$ step, each step taking 1 sec. Powder Diffraction Files had identified the diffraction lines, from International Center for Diffraction Data (ICDD). The SEM used to analyze the thin films surfaces under low vacuum pressure (10^{-5} torr) was a LEO 435 Vpi type; no coating was used over the samples.

Fig. 1



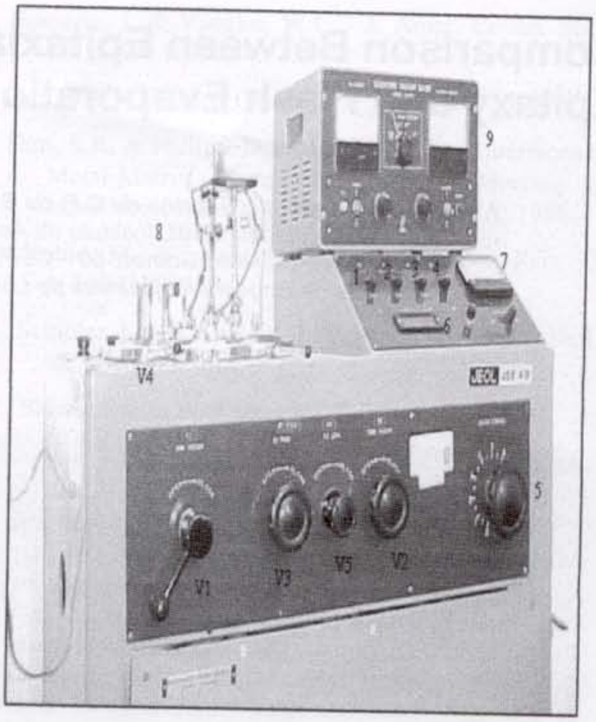


Fig. 1 - Flash Evaporation System: V_1 – high vacuum valve, V_2 – fore vacuum valve, V_3 – by pass valve, V_4 – chamber valve, V_5 – ***R.P.*** leak valve.

Fig. 2

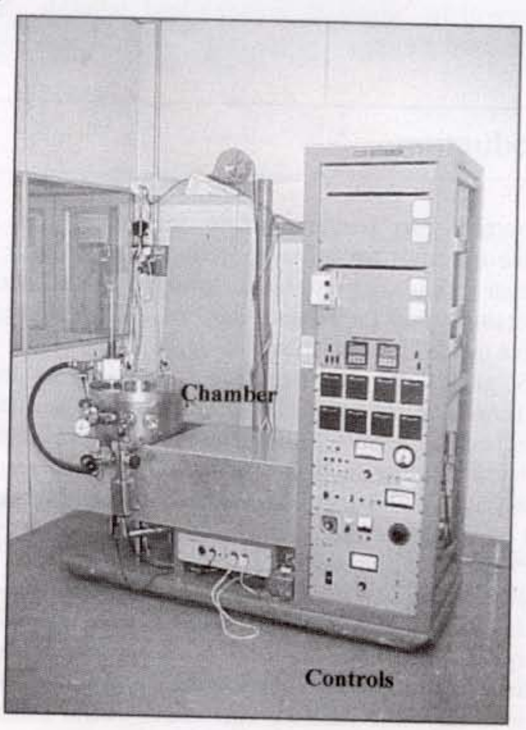


Fig. 2 – Hot Wall Epitaxy System.

Fig. 3

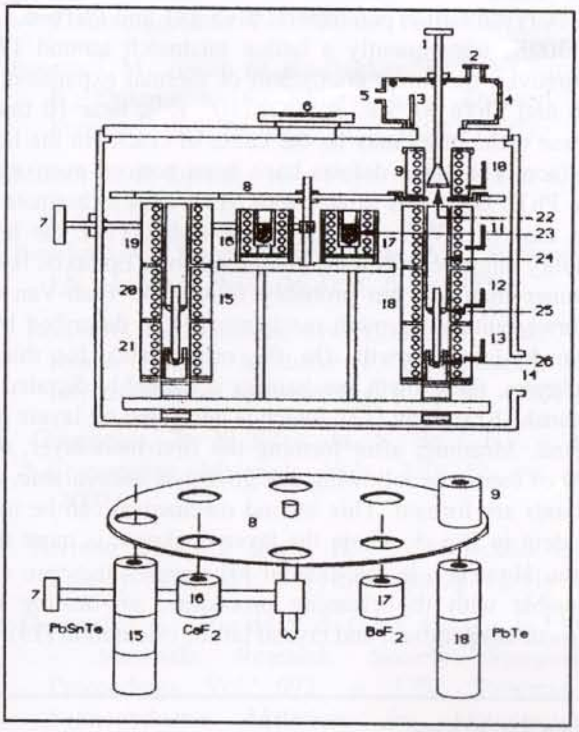


Fig. 3 – Hot Wall Epitaxy Chamber: 8 – substrate disc, 9 – substrate oven, 18 – PbTe oven, 22 – substrate holder, 24 – quartz tube, 25 – PbTe source, 26 – Te compensation.

The PbTe/p-Si heterostructures were electrically analyzed by making electrical contacts between PbTe layers and Si substrate, in order to make the current (I) *versus* voltage (V) measurements, and obtain the junction characterization, IxV plot. The junctions that presented better electrical characterization had their detectivity signal measured by irradiating infrared beams at the back of the Si substrate. This IR radiation coming from a black body at 700K (λmax = 4.3 μm), 908 Hz as modulator frequency (Lock-in) PAR 124A, and pre-amplification bandwidth frequency Δf = 14Hz.

Results

Table 1 summarizes the results. Analyze made with X. Ray Diffraction Spectrometry confirmed that the epilayers obtained with both techniques are all single crystal as can be seen in Fig. 4, which represents the X Ray results of both methods. The SEM images of them showed some surface defects, like cracks as can be seen in Figs 5, 6 and 8, and, in some cases, they are not very flat, Fig. 5. However, sample FE15, HWEI170 and 172, did not show majors defects, as shown in Fig 6.

Samples	ρ (Ω.cm)	d (μm)	D*.10^{-5} (cm.Hz$^{1/2}$.W^{-1})
FE05	3-8	4.9	4.7
FE12	1-10	0.9	4.8
FE04	3-8	1.2	2.2
FE15	1-10	0.6	1.8
HWE172	1-10	0.5	4.8
HWE170	3-8	0.2	3.2
HWE142	1-10	0.9	3.2
HWE153	1-10	1.0	2.8

Table 1 – Epilayer thickness and optoelectrical characteristics of the studied samples: ρ - substrate resistivity, **d** – epilayer thickness, **D*** - specific detectivity.

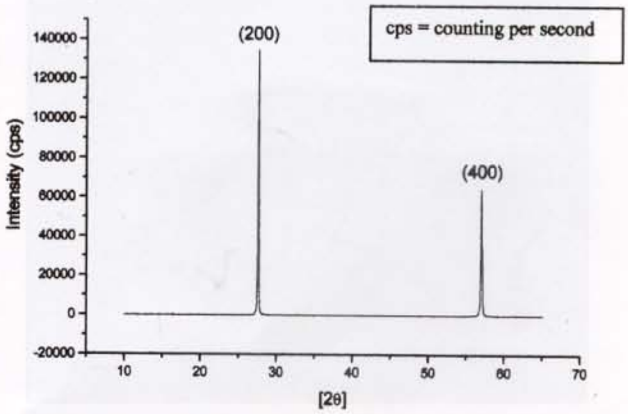


Fig. 4 – X-ray diffraction spectrum of sample FE05.

Fig.5

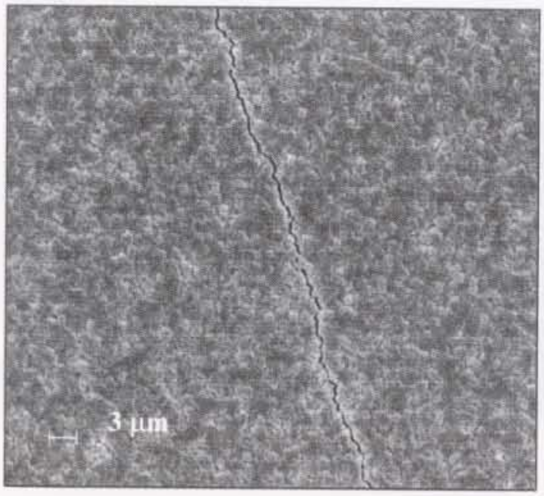


Fig. 5 – SEM micrograph of sample FE05

Fig. 6

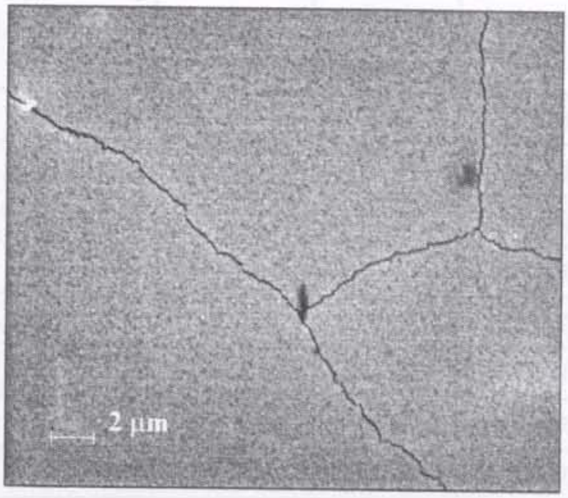


Fig. 6 – SEM micrograph of sample FE12.

Fig. 7

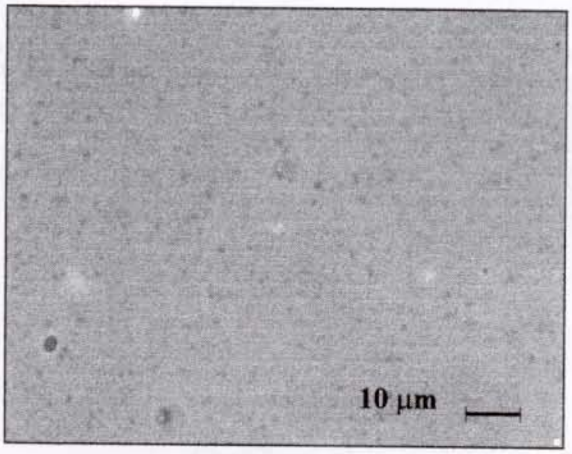


Fig.7 – SEM micrograph of sample HWE170.

Fig. 8

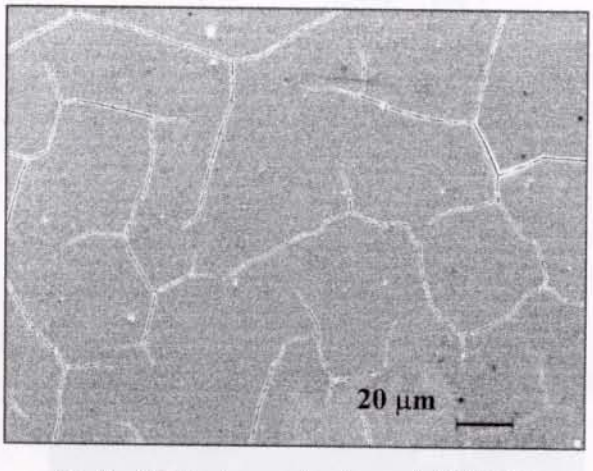


Fig. 8 – SEM micrograph of sample HWE153.

Discussions

Crystal lattice parameters: Si=5,431 and PbTe=6,459, at 300K, consequently a lattice mismatch around 17%. Moreover, the linear coefficient of thermal expansion: Si 2,6 and PbTe =1 9,8, at 30OK(10^{-6} K^{-1}), near 10 times. These differences may be the cause of cracks in the layer surface. The same defects have been noticed even when the PbTe layer was grown with MBE (10) techniques. In the case of HWE samples and published (11), the layer quality improves when the layer is thinner. Epitaxial layers thinner than 0.9 gm probably follow the Fran-Van der Merwe epitaxial growth mechanism [12], described by a layer-by-layer growth. On the other hand, for thicker epilayers, the growth mechanism is probably dictated by Stranski-Krastanov [12], which is described by layers plus island. Meaning, after forming the first monolayer, or a few of them, the following one growth is unfavorable, and islands are formed. This second mechanism can be more evident in Fig. 5, where the layer thickness is more than 4µm. However, in the case of FE samples they are very sensible with the cleaning procedure, pre-heating and growth temperature, and crystal lattice orientation (13).

Conclusions

The crystal layer quality seems not interfere in the device detectivity, as can be seen for samples FE05 and HWE 153.

Despite the epilayers have been grown for so different equipments (HWE sophisticated, FE low cost) the results are not different, even the surface defects are very similar, as well as the detectivity values of the devices.

Acknowledgments

The authors would like to thank Prof. Dr. Ivan Zassavitskii for the flash evaporator modification, and discussions on entire procedure. Research partially supported by the São Paulo State Research Foundation, (FAPESP - Fundação de Amparo à Pesquisa do Estado de São Paulo).

References

1. Guimarães, S.; Zassavitskii, I. & Bandeira, I.N. - Brazilian Journal of Vacuum Applications, Vol. 19, no. 1, p. 15, (2.000);

2. Scott, G.; Mercer, D.E. & Helms C.R. – J. Vac. Sci. Technol. B 9 (3), p. 1781, (1991);

3. Rusu, M.; Nicolaeseu, I.I. & Rusu, G.G. - Appl. Phys. A 70: p. 565, (2000);

4. Bangava, R. (Ed.) - Properties of Wide Bandgap II-VI Semiconductors, INSPEC, IEE, Herts, W (1996);

5. Rusu, G.G. & Rusu, M. - Solid State Communications 116, p. 363, (2000);

6. Damodara Das, V. & Selvaraj, S. - Solid State Communications, Vol. 108, no. 11, p. 873, (1998);

7. Boustani, M.; Assali El, K.; Bekkay, T.; Ech-Chamikh, E.; Outzourhit, A.; Khiara, A. & Dreesen L. - Semicond. Sci. Technol., 12, p. 1658, (1997);

8. Massé, G. & Djessas; K. - Phys. Status Solidi a, 139 W5, (1993);

9. Boschetti, C.; Rappl, P.H.O.; Ueta, A.Y. & Bandeira I.N. - Infrared Phys., 34(3): p. 281, (1993);

10. Boschetti, C.; Bandeira, I.N.; Closs, H.; Ueta, A.Y.; Rappl, P.H.O.; Motisuke P. & Abramof, E. - Infrared Physics & Technology 42, p. 91, (2001);

11. Guimarães, S. & Silva da, S. de C.F.F. - Key Engineering Materials Vols. 230-232, pp. 607, (2002);

12. Herman, M.A. & Sitter, H. - "Molecular Beam Epitaxy, New York, N.Y, (Springer), p. 12, (1996);

13. Guimarães, S.; Silva da, S. de C.F.F & Assis de J.M.K. – Materials Research Society Symposium Proceedings Vol. 692, p. 175, "Progress in Semiconductor Materials for Optoelectronic Applications".