Attainment crystalline films for manufacturing thermal infrared optoelectronic detectors

Obtenção de filmes cristalinos para produção de detectores optoeletrônicos de infravermelho termal

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Abstract

The project has as objective to make the system of epitaxial growth Hot Wall Beam Epitaxy (HWBE) enter in operation for the attainment of compound semiconductors IV-VI family single crystalline films, over barium fluoride (BaF_2) substrates. This called epitaxial system (HWBE) is the technique that involves physical transport and works next to the thermodynamics equilibrium. Its main function is the growth of single crystalline films, which by the choice of the compounds they behave as photonic crystals. The advantage in the use of BaF_2 as substrate is its good match of the crystallographic arrangement and thermal expansion coefficient with the compound film used, that are: lead telluride (PbTe), chosen because they possess optic properties, high quantum efficiency and mainly the energy of the forbidden band - band gap (Eg) is direct and narrow (Eg < 270meV). It can thus be used as P-N junctions, which are the infrared detectors that work with the wavelength (λ) range - 5 μm.

Keywords

Epitaxial growth. Semiconductors compounds. Lead telluride. Infrared radiation.

Resumo

Este projeto de tem como objetivo a operacionalização do sistema de crescimento epitaxial: Hot Wall Beam Epitaxy (HWBE) usado na obtenção de filmes cristalinos de compostos semicondutores das famílias IV e VI, crescidos sobre substratos de fluoreto de bário (BaF_2). Nesse sistema chamado de HWBE envolve o transporte físico no equilíbrio termodinâmico. Os filmes obtidos, devido à escolha do composto, comportam-se como cristais fotônicos. A vantagem na utilização do substrato de BaF_2 deve-se ao bom casamento do arranjo cristalográfico e do coeficiente de expansão térmica com a do composto semicondutor utilizado, que é o telureto de chumbo (PbTe), escolhido por possuir propriedades ópticas, alta eficiência quântica e principalmente de ser dono de uma banda de energia do gap (Eg) direta e estreita (Eg < 270meV). Podendo-se assim utilizar junções P-N, obtidas a partir desses filmes, em detectores de radiação com comprimento de onda na faixa do infravermelho termal 5 μm.

Palavras Chave

Crescimento epitaxial. Compostos semicondutores. Telureto de chumbo. Radiação infravermelha.

Introduction

Despite Lead Telluride (PbTe) was studied some time ago, this still possess important technological applications that if extend since the use as Quantum Dots, as in the work of Jacobs G. J. (2003), until aeronautical systems, which use heterojunction of this composition in Infrared Radiation Detectors, as described in the C. Boschetti (1993) publication.

The PbTe is an important compound semiconductor, that crystallizes as a cubical centered face structure (FCC), and it is formed from binaries cells of lead and tellurium, of the families IV e VI, respectively, as described in the C. Boschetti (1983) work. It possesses among others characteristics, high quantum efficiency, with fast time reply, and gap energy narrow and direct (88mev < Eg < 270mev). Besides, it possesses equal peaks of the conduction and valence bands, and they are inverted in the Brillouim zone, it provides to this semiconductor similar mobility of the charge carriers, as observed in the work of P. H. Rappl (1998).

In order to obtain P-N junctions of PbTe compound, the type of the carriers are not defined by doping, but by stoichiometric equilibrium in the crystalline structure, this characteristic is presented in the work of Bandeira, I. N (1994). The layers grown with atomic imperfections for interstitial metal (Frankel type) produce donors levels (N type), those associates to the excess of the calcogen (Schottky type) produce acceptors levels (P type) or combination of both; the concentration of the carriers is argued by Kovalchik (1957), Borisova (1979) and Rustamov (1972).

Materials and Methods

With the development of science and the technology many techniques to obtain crystalline films of PbTe had been developed: Flash Evaporation (FE), as presented in work for S. Guimarães (2003), Molecular Beam Epitaxy (MBE), as described in M. A. Herman (1996) work, Liquid Phase Epitaxy (LPE), with results argued by A. Belenchuk (2000), among others, improving each time more the quality of the samples. In our work the process of Hot Wall Beam Epitaxy (HWBE) obtains the films. That it consists of a high vacuum chamber cylindrical, inside of it exist two epitaxiais reactors (oven), each one with three zones with independent control of temperature, above of the reactors exists one fourth zone fixed in a revolving disc, that can dislocate the substrate between the two reactors, assisting in the process of attainment of P-N junction, described in the work of Bandeira, I. N (1994), shown in the figure Fig.1 and Fig. 2. A characteristic of this equipment is to exist a discrepancy in the temperature, decurrent of physical limitations and thermal distribution, the approximately order 5,24; 7,39; 8,41 and 12,54 %, in the compensation, source, wall and substrate zones, respectively.

Differently of the works carried through for V. F. Chishko (2000), where it uses as substrate silicon polycrystalline and silicon oxide (SiO_2), and A. Belenchuk (2000), that uses buffer of Barium Fluoride (BaF_2) on the crystalline Si substrate. We grew PbTe films directly over BaF_2. The advantages of using this substrate is its no interaction with the detected radiation, nearest-neighbor distance (PbTe: 6,462 and BaF2: 6,200 Å) of the crystallographic arrangement and the thermal expansion coefficient (PbTe: 19.8 and BaF2: $18.2 \times 10^{-6} K^{-1}$), data presented for R. A. Dalven (1969) and C. Kittel (1978).

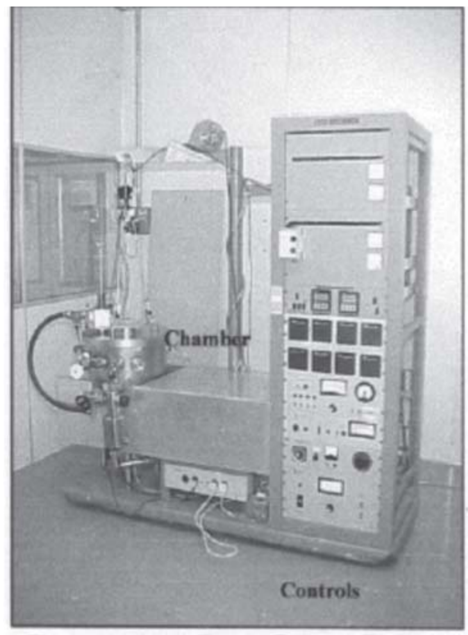

Figure 1 - Hot wall beam epitaxy system

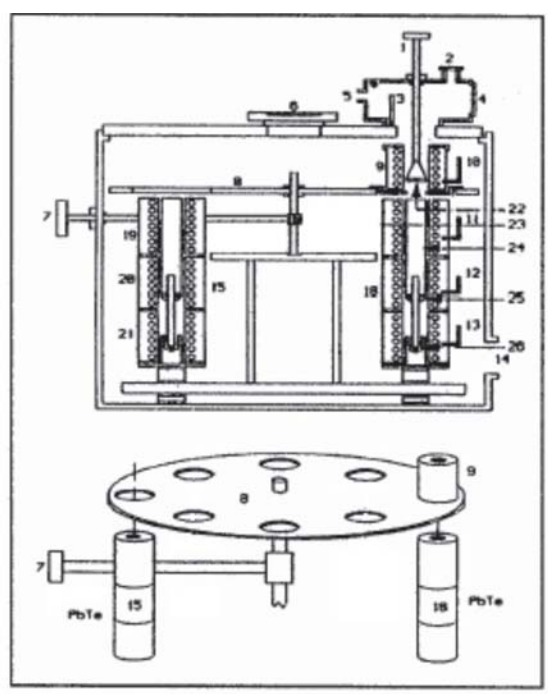

Figure 2 - HWBE chamber: 8 - substrate disc; 9 - substrate oven; 18 - PbTe oven; 22 - substrate holder; 24 - quartz tube; 25 - PbTe source; 26 - Te compensation.

Results

Table 1 presents a summary of the results obtained; we can observe the different thickness gotten in three films grown, despite the growth time relatively equal.

X - Ray Diffraction, is show in Fig. 3, confirms that film T1 has monocrystallines characteristics, following the same BaF_2 (111) substrate crystalline orientation, as it shows the peaks of the cited figure, with orientation (222).

Figure 4 presents its 300k Transmission Spectrum on the film T1, showing to the end transmission the 2760 cm^{-1}.

The Figures 5, 6, and 7 shows the Scanning Electronic Microscopy (SEM) images or the T1, T2 and T3 films, respectively, images generated salient that T2 and T3 are not homogeneous as T1.

The table 2 summarizes the Effect Hall results as concentration, mobility and type of majority carriers, measured at the temperature of 300K and 77K of the films T1.

Table 1 – Summary of the films obtained: T – Thickness, C – Crystallography and Gt - Growth time

Film	T1	T2	T3
T	5,5 μm	0,2 μm	3,3 μm
C	Single	Polycrystal.	Policristal.
Gt	2h 5min	2h	1h 58min

Table 2 – Analysis results for Effect Hall in Film T1: Tp – Temperature, Cc – Carrier Concentration, Cm – Carrier Mobility and E – Error

Tp	300 K	77 K
Cc	-1,19E+20	-7,08E+19
Cm	5,24E+05	1,99E+06
E	0,5 %	0,31 %

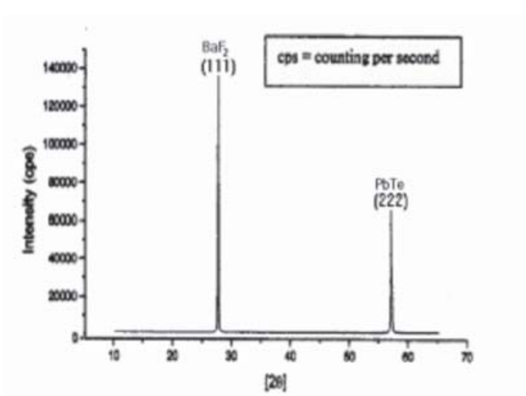

Figure 3 - X-ray diffraction spectrum of film T1

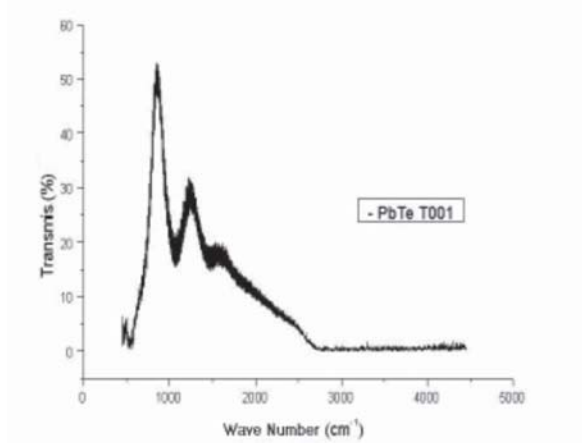

Figure 4 - Transmission spectrum of film T1

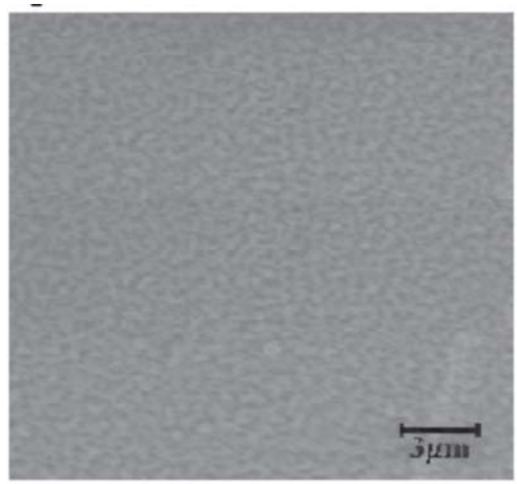

Figure 5 - SEM micrograph of the film T1

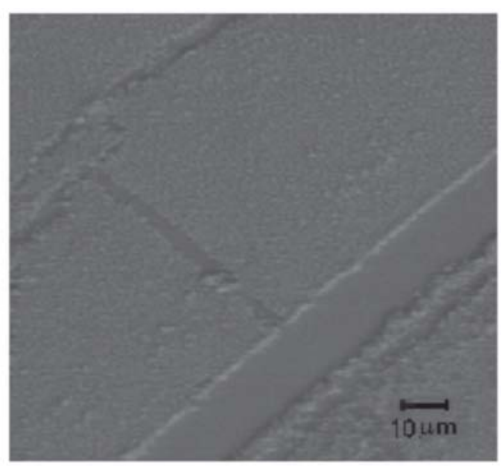

Figure 6 - SEM micrograph of the film T2

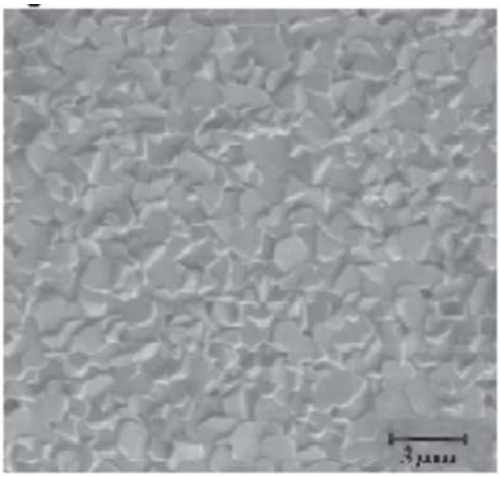

Figure 7 - SEM micrograph of the film T3

DISCUSSIONS

The characterization of system HWBE is of extreme importance, therefore the unfamiliarity of the profile of behavior of the equipment influences in the quality of the gotten films. Had to this, getting the profile of temperature and the stability of the pressure of in the chamber during the growth process, a discrepancy in the observed values of temperature in the pyrometers in relation to the real values is noticed, that is had to the fact of the thermocouples to be situated in the laterals of the reactor epitaxy; in table 3 to observe the influences it of the temperature and vacuum pressure in the growth speed.

Under circumstances optimal, the fine film of PbTe gotten in sample T1 shows to one crystallinity good and a composition stoichiometric with carriers N Type. In the X - Ray Diffraction Spectrometry presents identical orientation to the one of substrate used. The reduced thickness of the T2 film can be explained by low the temperature in the zone wall.

Exactly thus although similar temperatures in the films growth T1 and T3, I finish it presents characteristics polycrystalline, this must it the fact of the contamination of the substratum in the chamber due the fall in the vacuum pressure in the epitaxial deposition.

CONCLUSIONS

The involved conditions in the process of deposition of PbTe in a system HWBE had been studied. The criteria that involve growth speed and the quality of film are conditional essentially to the balance between the temperatures and the pressure of vacuum in the instant of epitaxy. We establish three types of conditions for deposition depending on the scale of temperature,

Table 3 – Profile of temperature in the growth: Zone 1 – Substrate, Zone 2 – Wall, Zone 3 – Source and Zone 4 – Compensation; Temperature discrepancy line in the epitaxy reactor: R – Real in the reactor zones and the A – Applied in pyrometer

Film		T1	T2	T3
Zone 1 (°C)	R	422	428	422
	A	375	380	375
Zone 2 (°C)	R	596	287	596
	A	550	265	550
Zone 3 (°C)	R	516	516	516
	A	480	480	480
Zone 4 (°C)	R	284	295	295
	A	270	280	280
Growth Speed (molecular layer / second)		4,09	0,15	2,60
Vacuum pressure (Torr)		1,6E-6	2,0E-6	3,9E-6

similar of if to get films N type in the considered system we determine experimental the conditions optimal to get films PbTe single crystalline arrangement. Of this form the samples grown with crystallinity good will only be possible to produce optoeletronics detectors that they work in the PbTe band gap.

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