ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/252380108

Study of PbTe p-type doping with BaF2

Article · January 2010

DOI: 10.1063/1.3295420

CITATIONS
0

READS
28

6 authors, including:

Úrsula Andréia Mengui
National Institute for Space Research, Brazil
48 PUBLICATIONS **113** CITATIONS

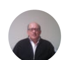
SEE PROFILE

P. H. O. Rappl
National Institute for Space Research, Brazil
115 PUBLICATIONS **622** CITATIONS

SEE PROFILE

Beatriz Moreno
Canadian Light Source Inc. (CLS)
35 PUBLICATIONS **93** CITATIONS

SEE PROFILE



Eduardo Abramof
National Institute for Space Research, Brazil
169 PUBLICATIONS **1,304** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Dynamical diffraction of X-rays in amino acid crystals, phase measurements, hydrogen bonds, radiation damage in biological molecules, simulation of extended crystal truncation rods in epitaxic layers for nanostructured devices. Bragg-surface diffraction with focused beams for studying embedded nanostructures. View project

Estudo das propriedades elétricas de isolantes topológicos baseados em semicondutores de gap estreito View project

All content following this page was uploaded by P. H. O. Rappl on 26 July 2016.

The user has requested enhancement of the downloaded file.

Study of PbTe p-Type Doping With BaF 2

U. A. Mengui, P. H. O. Rappl, B. Díaz, H. Closs, A. Y. Ueta, and E. Abramof

Citation: AIP Conference Proceedings **1199**, 29 (2010); doi: 10.1063/1.3295420
View online: http://dx.doi.org/10.1063/1.3295420
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1199?ver=pdfcov
Published by the AIP Publishing

Articles you may be interested in
Defects responsible for abnormal n-type conductivity in Ag-excess doped PbTe thermoelectrics
J. Appl. Phys. **118**, 015705 (2015); 10.1063/1.4923391

Systematic study of doping dependence on linear magnetoresistance in p-PbTe
Appl. Phys. Lett. **105**, 162108 (2014); 10.1063/1.4900486

Thermoelectric properties of Bi-doped PbTe composites
J. Appl. Phys. **109**, 103709 (2011); 10.1063/1.3586240

Electrical properties of PbTe doped with BaF 2
J. Appl. Phys. **105**, 043709 (2009); 10.1063/1.3082043

Molecular-beam epitaxy growth and nitrogen doping of ZnSe 1−x Te x alloys grown on InP substrates
Appl. Phys. Lett. **75**, 2608 (1999); 10.1063/1.125093

Reuse of AIP Publishing content is subject to the terms at: https://publishing.aip.org/authors/rights-and-permissions IP: 191.96.181.11 On: Tue, 26 Jul 2016 18:29:31

Study of PbTe *p*-Type Doping With BaF_2

U.A. Mengui, P.H.O. Rappl, B. Díaz, H. Closs, A.Y. Ueta, E. Abramof

Laboratório Associado de Sensores e Materiais- LAS, Instituto Nacional de Pesquisas Espaciais - INPE, CP 515, 12245-970, São José dos Campos – SP, Brazil

Abstract. We investigate here the electrical and structural properties of PbTe layers doped with BaF_2. The layers were grown on (111) BaF_2 substrates by molecular beam epitaxy. The nominal doping level, defined as the beam flux ratio between BaF_2 and PbTe, was varied from 0.02 to 1%. The hole concentration increases monotonously from $5x10^{17}$ to $1x10^{19}$ cm^{-3} as the doping level is raised from 0.02 to 0.4%, and saturates at $p \sim 10^{19}$ cm^{-3} for higher doping levels. This result demonstrates that PbTe can be effectively *p*-type doped with BaF_2. Even for the highest doping levels, the PbTe layers remained with a good structural quality, as evidenced by the (222) x-ray rocking curves.

Keywords: lead telluride; barium fluoride; molecular beam epitaxy; *p*-type doping; electrical properties.
PACS: 81.05.Hd; 81.15.Hi; 73.61.-r; 68.37.Hk.

INTRODUCTION

Lead telluride is a narrow gap semiconductor that finds its applications in thermoelectric devices [1,2] and in infrared lasers and detectors [3]. *n*-Type doping of the narrow gap semiconductor PbTe is obtained in a controlled manner up to 10^{20} cm^{-3} using Bi_2Te_3 as a dopant [4]. Contrarily, the *p*-type doping of PbTe at high levels is not easily achieved. For device applications, the control of PbTe *p*-type doping is highly desirable.

In this work, we present results on the investigation of electrical and structural properties of PbTe epitaxial layers doped with BaF_2. For this purpose, PbTe:BaF_2 epilayers were grown by molecular beam epitaxy on (111) BaF_2 substrates. In order to control the doping level, the flux ratio between BaF_2 and PbTe was ranged from 0.02 to 1%. The electrical properties were determined by Hall effect and resistivity measurements at room and liquid nitrogen temperatures. X-ray rocking curves around the (222) Bragg peak was measured to evaluate the structural characteristics.

RESULTS AND DISCUSSION

The PbTe layers were grown on freshly cleaved (111) BaF_2 substrates by molecular beam epitaxy (MBE) in a Riber 32P MBE system equipped with effusion cells cointaining PbTe, Te and BaF_2. The beam equivalent pressure (BEP) of each cell was measured separately in an ion-gauge flux monitor. During this experiment, the PbTe cell temperature was kept at 645 °C, leading to a BEP of $5.8x10^{-7}$ Torr. The layers were deposited at a substrate temperature of 300 °C. In these conditions, the growth rate was 1.1 μm/h.

To determine the electrical properties, Van der Pauw geometry samples were prepared by soldering Au wires with In pellets. Resistivity and Hall effect measurements were performed at 300 and 77 K with a magnetic field of 0.7 Tesla.

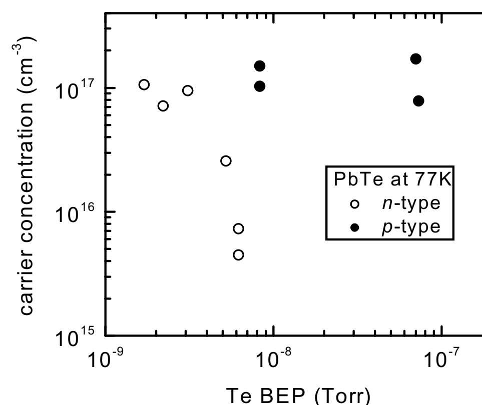


FIGURE 1. Carrier concentration at 77 K of PbTe layers grown by MBE with increasing Te beam equivalent pressure. The transition from *n* to *p*-type occurs at a Te flux of $8x10^{-9}$ Torr.

The electrical characteristics of undoped lead salts are controlled by native defects created by the deviation from stoichiometry, i.e. metal or chalcogen vacancies act as acceptors or donors, respectively.

Reuse of AIP Publishing content is subject to the terms at: https://publishing.aip.org/authors/rights-and-permissions IP: 191.96.181.11 On: Tue, 26 Jul 2016 18:29:31

Before growing the BaF_2 doped PbTe sample series, we first determined the additional Te flux necessary to obtain a *p*-type PbTe layer controlled only by Pb vacancies. Figure 1 shows the carrier concentration at 77 K of PbTe layers grown at different Te fluxes. For this purpose, the Te cell temperature was increased from 259 to 295 °C. In these conditions, the transition from *n* to *p*-type occurred with an additional Te flux of $8.2x10^{-9}$ Torr. The sample with this additional Te flux, which exhibited a hole concentration of $1x10^{17}$ cm^{-3}, was set as the reference to start doping with BaF_2.

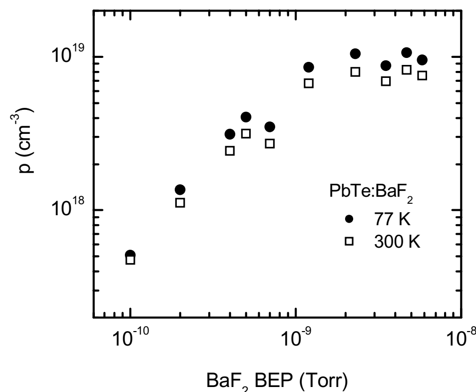


FIGURE 2. Hole concentration of PbTe layers as a function of BaF_2 beam flux. *p*-Type layers with concentration up to 10^{19} cm^{-3} were obtained.

To obtain the PbTe layers with different BaF_2 doping levels, a series of samples were produced with BaF_2 effusion cell temperature varying from 850 to 1040 °C, which gave a BaF_2 beam equivalent pressure ranging from $1.0x10^{-10}$ to $5.8x10^{-9}$ Torr. Consequently, the nominal doping level, defined as the BEP ratio between BaF_2 and PbTe, varied from 0.02 to 1%.

Figure 2 shows the hole concentration at 77 and 300 K of the PbTe layers doped with BaF_2. It increases from $5x10^{17}$ to $1x10^{19}$ cm^{-3} as the BaF_2 beam flux raises from $1x10^{-10}$ to $2x10^{-9}$ Torr (doping levels from 0.02 to 0.4%), and saturates at $p \sim 10^{19}$ cm^{-3} for higher doping levels. This result evidences that PbTe can be effectively *p*-type doped with BaF_2 up to 10^{19} cm^{-3}, and that the doping can be controlled by varying the BaF_2 beam flux in a specific range.

The difference between the carrier concentration at room and liquid nitrogen temperatures is small, as can be seen in Figure 2. This fact indicates that no thermal activation is present in the whole doping range investigated. The result observed here suggests that the impurity levels in the PbTe doped with BaF_2 remain resonant with the valence band.

The Hall mobility at 77 and 300 K of the PbTe:BaF_2 layers is shown if Figure 3 as a function of the BaF_2 beam equivalent pressure. The mobility at 300 K has only a small decrease from 500 to 400 cm^2/V.s, as the doping level is increased. This is an expected behavior, since phonons dominate over other scattering mechanisms at room temperature. In the other hand, at 77 K, it decreases from 10000 to 2000 cm^2/V.s as the doping level increases from 0.02 to 1%, indicating that additional carrier scattering process start to limit the mobility at this intermediate temperature as the hole concentration increases.

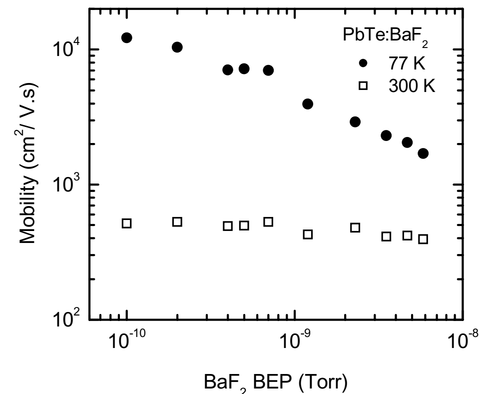


FIGURE 3. Mobility at 77 and 300 K of PbTe layers doped with BaF_2 as a function of BaF_2 beam equivalent pressure.

To determine the structural characteristics of the doped layers, the x-ray rocking curves were measured around the (222) PbTe Bragg peaks in a Philips X´Pert high resolution diffractometer. The full width at half maximum of the PbTe rocking curves varied from 120 to 330" as the BaF_2 doping level is raised. It indicates that PbTe layers remain with a relatively good crystalline quality even for the highest doping level produced here. This fact shows that the pronounced reduction of the mobility at 77 K is mainly due to the substantial increase of the hole concentration.

ACKNOWLEDGMENTS

This work is supported by CNPq and FAPESP funding agencies. U.A. Mengui acknowledges the CNPq Ph.D. scholarship.

REFERENCES

1. T. Koga, T.C. Harman, S.B. Cronin, M.S. Dresselhaus, *Phys. Rev. B* **60**, 14286-14293 (1999).
2. H. Beyer, J. Nurnus, H. Böttner, A. Lambrecht, E. Wagner, G. Bauer, *Physica E* **13**, 965-968 (2002).
3. G. Bauer, M. Kriechbaum, Z. Shi, M. Tacke, *J. Nonlinear Opt. Phys.& Mater.* **4**, 283-312 (1995)
4. A.M.P. dos Anjos, E. Abramof, P.H.O. Rappl, A.Y. Ueta, H. Closs, *Braz. J. Phys.* **34**, 653-655 (2004).

View publication stats
Reuse of AIP Publishing content is subject to the terms at: https://publishing.aip.org/authors/rights-and-permissions IP: 191.96.181.11 On: Tue, 26 Jul 2016 18:29:31