PHD PROJECT DESCRIPTION

(4000 characters max., including the aims and work plan to de published online)

Project title: Thermal, Elastic and Optical Characterization of New II-VI Ternary And Quaternary Mixed Crystals Based On CdTe for Applications in Optoelectronic Devices

1.1. Project goals

The project aims to obtain and characterize new materials based on CdTe crystals. It is planned to make their comprehensive characterization using thermal, elastic, and optical methods available in the Applied Physics Group and in cooperation with other laboratories at the Institute of Physics, in Poland and abroad. The compounds that will be tested are ternary CdSeTe, CdMgTe, and quaternary CdZnSeTe, CdBeSeTe, CdBeMgTe.
The piezoelectric, photoacoustic, and pyroelectric photothermal methods are planned to be used first to obtain energy gap values, thermal diffusivity, and surface quality. In collaboration with a group from Koszalin, photothermal radiometry spectra will be used to determine thermal conductivity. The images of the surfaces at various preparation stages will be examined using AFM in Toruń. In collaboration with a laboratory in Le Mans, France, elastic properties will be determined.
The aim of the project is also the development of interpretation models - the layered one will be constructed, including all the physical phenomena responsible for the generation of the photothermal signal (thermal, plasma waves, thermalization of carriers, and nonradiative surface recombination).
The samples, after growth, are subjected to various surface treatment procedures: mechanical, chemical, and thermal. The proper surface treatment method is essential for device quality, and photothermal methods allow selecting and evaluating the appropriate one.

1.2. Outline

Cadmium telluride II–VI based mixed crystals are industrially used for fabrication of variety of optoelectronic components: high-energy radiation detectors, photorefractive devices, electro-optic modulators, laser windows, solar cells, substrates for epitaxial growth of IR imaging systems. Their physical properties can be altered to a considerable extent by choosing the appropriate dopant and doping level.
The proper method of surface processing for samples is essential for the quality of the manufactured element. Surface quality and surface recombination velocity have a significant influence on the device's performance. A known approach to control it consists of reducing the surface recombination velocity through surface treatments. It influences the results of measurements of several experimental parameters. For a pure CdTe crystal, the proper etching allows surface smoothening, cleaning it from oxides and other contaminations. At the same time, wet-chemical etching creates a Te-rich surface layer on CdTe, effectively forming a p+-doped zone that produces a back surface field. The goal of the project will also be to determine the optimal etching procedure for the new CdTe-based solid solutions.
Investigations of carrier lifetimes in these compounds are crucial to the performance and applications of CdTe-based detectors. The first measurements have already been done; minority-carrier lifetimes in a single-crystal CdTe sample have been simultaneously measured using three transient decay techniques.
The investigated crystals will be grown in Torun, Poland, at the Institute of Physics NCU using the high-pressure (HP), high-temperature Bridgman method under an argon atmosphere. It is planned to grow several series of ternary and quaternary mixed crystals with different compositions.

1.3. Work plan

The work plan of the proposal can be summed up in several main points:

1. The growth of the mixed crystals
2. The choice and preparation of the mechanical, chemical, and thermal treatments of the obtained samples
3. Measurements of:
   a) Piezoelectric and pyroelectric photothermal spectra.
   b) Photothermal radiometry spectra
   c) AFM images
   d) Elastic parameters
4. Preparation and application of the theoretical layer model for the interpretation
5. Thermal and optical parameters determination.
6. Characterization of surface defects due to the prepared model.

1.4. Literature (max. 7 listed as a suggestion for a PhD candidate preliminary study)

1. M. D. Dramicanin, Z. D. Ristovski, P. M. Nikolic, D. G. Vasiljevic and D. M. Todorovic" Photoacoustic investigation of transport in semiconductors: Theoretical and experimental study of a Ge single crystal" Physical review. B, Condensed matter 51(20):14226-14232, 1995
2. V. Blonskij, V.A.Tkhoryk, and M. L. Shendeleva, "Thermal Diffusivity of Solids Determination By Photoacoustic Piezoelectric Technique" J. Appl. Phys.79 (7), 1 1996
3. M. Maliński, J. Zakrzewski, K. Strzałkowski "Numerical Analysis of Piezoelectric Spectra of Zn1−x−yBexMnySe Mixed Crystals" , International Journal of Thermophysics, Vol. 28, No. 1, February 2007
4. N. Chigarev, K. Strzalkowski, V. Gusev, P. Sedzicki, J. Alcaraz, S. Raetz, J. Zakrzewski " Evaluation of the sound velocities of cadmium zinc telluride crystals by time domain Brillouin scattering technique", Applied Physics A-Materials Science & Processing, 2024
5. J. Zakrzewski,M. Maliński, M. Boumhamdi, J. Strzelecki, K. Strzałkowski, „The new interpretation of the photothermal spectra of CdTe samples after different surface treatments", Crystals, 2024, vol. 14, nr 12, s.1-18 DOI:10.3390/cryst14121019
6. L Bychto, M Maliński, Ł Chrobak, J Zakrzewski, M Boumhamdi "Photoacoustic investigations of the quality of the surface preparation of Cd1-xBexTe samples" Opto-Electronics Review 33 (2025) e155877
7. M. Boumhamdi, J. Zakrzewski, M. Maliński, A. A. Belghiti, A. Abouais, K. Strzałkowski, A. Marasek, G. Trykowski, S. Laasri, "Thermal and optical properties of CdSxTe1-x mixed crystals grown by the vertical Bridgman technique" Materials Science & Engineering B 323 (2026) 118678

1.5. Required initial knowledge and skills of the PhD candidate

Some experience, according to the following points, will be appreciated (but not necessary):

- experience in experimental physics
- basic knowledge about solid-state physics
- programming in Mathcad or a similar application

1.6. Expected development of the PhD candidate's knowledge and skills

- skills of the characterization of the material with different photothermal experimental methods (piezoelectric spectroscopy, photoacoustic spectroscopy, photopyroelectric calorimetry, photothermal radiometry – thermal and optical parameters, optical properties)
- theoretical basics of applied practical methods
- programming in Mathcad
- skills in collecting, analyzing, and presenting the data
- writing of scientific papers and delivering the results at the conferences
- understanding and description of the observed phenomena.