1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

Project title:

Growth and characterization of II-VI crystals based on CdTe for the detection of ionizing radiation

1.1 Project goals

The project aims to investigate lattice disorder effects and defects in CdTe-based solid solution with some admixture of Zn, Mn, Se, Mg and Be atoms for different compositions with numerous experimental methods. The efficiency and sensitivity of the potential detector strongly depend on the quality of the used crystal. Therefore, it is essential to define its lattice disorder, defects, and radial and axial homogeneity. The substitution of the native element with a foreign atom within the crystal always leads to undesired effects like disordered structure, defects generation, etc. However, the nature of these phenomena is sometimes not precise. Complex characterization of the materials will help explain the mechanism of the defect generation and how the host crystal structure reacts for the foreign atom substitution. Therefore, one goal is to find the best substituting atoms with optimal composition in the matrix of CdTe crystal.

Several series of the crystals will be grown and then tested by various experimental techniques to determine their physical properties like accurate composition, nature of the atom substitution (random or due to clustering or anticlustering), segregation coefficients, structural (XRD), thermal, optical (energy gap, energy structure), electrical (resistivity), transport (scattering mechanism), defects (with positron annihilation technique and photoluminescence) properties. The response of the crystals to x-ray radiation will be checked as well.

1.2 Outline

The subject of the project is to grow several II-VI compounds based on cadmium telluride binary crystal with Zn, Mn, Se, Mg and Be atoms incorporated into the matrix of CdTe crystal and verify their capability as materials for ionizing radiation detectors. CdTe-based compounds in bulk crystal form have a fairly long history. They are used in a variety of applications as X-ray and gamma-ray sensors [1], in electro-optic and photorefractive devices [2], and as substrates for epitaxy [3].

The production of large and homogenous crystals is still problematic due non-unity segregation coefficient of zinc in the CdTe matrix (1.35 [4]). This is why $Cd_{1-x}Mn_xTe$, $Cd_{1-x}Mg_xTe$, $CdTe_{1-x}Se_x$, and also quaternary $Cd_{1-x}Zn_xTe_{1-y}Se_y$ [5] compounds are also being considered as promising materials for gamma radiation detection. The authors in [5] have reported better quality and efficiency of potential detector once they add selenium to the $Cd_{1-x}Zn_xTe$ alloy. However, they did not provide any physical explanation of this phenomenon or detailed characterization of the given material. There is no simple mechanism of the defect generation or disordering of the crystal structure in quaternary compounds. Therefore more complex characterization is needed here. We want to verify if similar “stabilizing” effects can be found in the crystals planned to be grown within the project.

Investigated crystals will be grown in Torun, Poland, at the Institute of Physics NCU with high pressure (HP), high-temperature Bridgman method under argon atmosphere. It is planned to grow several series of ternary and quaternary mixed crystals for a different composition. HP Bridgman technique is very suitable for the growth of high-resistivity crystals and is commonly used to grow them for *X*-ray or gamma-ray detectors.

1.3 Work plan

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

1. Growth, structure (national cooperation), and composition of mixed crystals.
2. Optical transmission and photoluminescence investigation.
3. Thermal and electrical resistivity parameters determination.
4. Investigation of *X*-ray radiation response of the crystals (national cooperation).
5. Characterization of defects by positron annihilation technique (national cooperation).
6. Raman scattering investigations (in cooperation with France).

1.4 Literature

1. T.E. Schlesinger, J.E. Toney, H. Yoon, E.Y. Lee, B. A. Brunett, L. Franks, R. B. James, Cadmium zinc telluride and its use as a nuclear radiation detector material, *Mater. Sci. Eng. R* 32, 103 (2001).
2. H. Choi, Growth and Fabrication Method of CdTe and Its Performance As a Radiation Detector, *J. Korean Phys. Soc.* 66, 27 (2015).
3. C. Szeles, S. E. Cameron, J. O. Ndap, W. Chalmers, Advances in the High-pressure Crystal Growth Technology of Semi-insulating CdZnTe for Radiation Detector Applications, *IEEE Trans. Nucl. Sci.* 49, 2535 (2002).
4. S. Del Sordo, L. Abbene, E. Caroli, A. M. Mancini, A. Zappettini, P. Ubertini, Progress in the Development of CdTe and CdZnTe Semiconductor Radiation Detectors for Astrophysical and Medical Applications, *Sensors* 9, 3491 (2009).
5. Utpal N. Roy, G.S. Camarda, Y. Cui, R. Gul, GeYang, J. Zazvorka, V. Dedic, J. Franc, R.B. James, Evaluation of CdZnTeSe as a highquality gamma-ray spectroscopic material with better compositional homogeneity and reduced defects, *Sci. Rep.* 9, 7303 (2019).

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 the field of crystal growth and sample preparation
- programming in LabView
- experience in experimental physics
- basic knowledge about solid-state physics

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

- experience in the crystal growth (Bridgman technique) and sample preparation (cutting, polishing, etching, etc.)
- skills of the characterization of the material with different experimental methods (Photopyroelectric calorimetry – thermal parameters, photoluminescence, transmission, and photopyroelectric spectroscopy – optical properties)
- theoretical basics of applied practical methods
- 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.