

Review of the doctoral thesis of Mgr. Artem Musiienko:

Photo-Hall effect spectroscopy and laser-induced transient currents in CdTe-based semiconductor radiation detectors

Study program: Physics

Specialization: Quantum Optics and Optoelectronics

Submitted dissertation of Mr. Artem Musiienko is devoted to the study of high resistivity II-VI compound semiconductors CdTe (CT), CdZnTe (CZT) and CdMnTe (CMT) and radiation detectors fabricated from them. The key characterization method used presents Photo-Hall effect spectroscopy (PHES) and transient current technique (TCT) which are completed by the photoconductivity (PC) and photoluminescence (PL) measurements. Fabricated detector structures are analysed by introduced laser-induced transient currents technique (L-TCT). The work has experimental character with included corresponding theoretical background.

The investigated CdTe-based II-VI materials follow very actual trends in their research and development. The main application goals of these materials include an improvement of radiation detection in security, medical, material defectoscopy, etc., considering a high energy X- and gamma-rays, exceeding about 50 keV, due to their high density, i.e. high detection efficiency. Main part of these materials used for application is fabricated in a high-resistivity stage reached by overcompensation of shallow residual impurities by deep-level (DL) states created near the band gap by crystallographic DL impurities or various complex defects. High base material resistivity allows fabrication of detectors with enough low dark current using simple blocking or quasi-ohmic contacts leading to almost homogenous distribution of the electric field within the active detector volume. So, the study of DL states, their detection and evaluation in CdTe-based materials is very important from the point of view of following improvement of material and device technology. Hence, the concentration of the doctoral thesis to the investigation of DLs in CdTe-based materials using PHES and L-TCT in fabricated structures seems to me very interesting, actual and progressive.

Doctoral thesis presents 89 pgs including 12 pgs of cited papers (127 references) and 2 pages of content. Attached are: list of Tables, list of abbreviations, list of symbols and summary table of detected DLs, total 7 pgs. Within the work are presented 36 figures and 8 tables. The work is written in a good level English.

Contents of the dissertation is demonstrated in 7 chapters including introduction and conclusion. The key parts present Experimental (3), Photo-Hall effect spectroscopy in n-type (4) and p-type (5) samples, and Characterization of polarizing semiconductor radiation detector by laser-induced transient currents (6). Motivation and goals of the work are described in part 1.5. (pg 10) which include: (i) upgrading of a classic Hall effect measurement under illumination at different photon energies (denoted as PHES), (ii) study of selected CdTe-based materials by the PHES technique, (iii) development and application of laser-induced transient technique (L-TCT) in detectors exhibiting polarization.

In the study are demonstrated five groups including 9 samples of different materials: n-CZT (1: I, 2-3: II), n-CT (4,5: III), p-CT (6-7: IV, 8:V) and p-CMT (9:V). Problem with very low hole detection sensitivity using PHES in n-type materials was overcome using dual wavelength illumination. The proposed L-TCT technique at a high level illumination allowed detection and identification of an unknown DL at $E_C-0.75$ eV responsible for sample polarization (sample No. 4). Complete list of the detected DLs by used methods (PHES, PL, L-TCT and DWPHES) is presented in the attached Table A (pg. 95).

Remarks, comments and questions to the work:

A. Formal comments and remarks

- Within the thesis are observable some formal drawbacks, e.g. missing gaps between words mainly number and responsible symbol (e.g. pgs. 7, 8, 28,...); incorrect multiplication sign (dot or „x“, e.g. pgs. 13, eq. (2.11),...); identical formatting of the text (e.g. pgs 3, 4, 5, 11, 15, 36,...); some formulation are not precisely used through the work, e.g. Hall-effect parameters under illumination is better to note as Photo-Hall-effect, -mobility,... (e.g. also axis description, in Figs. 4.6., 4.7., 4.9.,...).
- In the figure 2.3. (d) is E_C labelled incorrectly.
- Description within the figures 3.2. and 3.3. is not enough visible, there are used black description symbols on dark color background. This should be presented in a readable form.
- The reading or study of the thesis is complicated by not systematic description of the used symbols and abbreviations, the main problem is due to their lists in attachments which are not written in the alphabet order. Some symbols are missing (e.g. ε but in the list is introduced ε_0 and ε_r) or even written in the list double (e.g. $\mu\tau$).

B. Expert comments, remarks and questions

- There is missing information on the number of fabricated and evaluated samples in each investigated group. Please, specify. How reproducibility was observed in the case of different samples in the particular group?
- I did not find the geometry of the fabricated detector structure used in the L-TCT experiments? What about homogeneity of the illumination through the sample contact (mentioned area of the used laser beam $\sim 3 \text{ mm}^2$)?
- Within the work no I - V characteristics of the investigated detector structures are presented, while they could give a useful completion information to the study. Were measured these characteristics? If Y, they behave as diodes or rather have ohmic characteristics?
- Remark: I note also another useful complementary information (it was not included in the thesis goals) - chemical content of impurities in the investigated materials obtainable by various high resolution techniques such as e.g. SIMS, PES, etc. Are such results available?

Summary evaluation:

Thesis submitted by graduate Mr. Artem Musiienko presents interesting work with goals corresponding to the actual research target related to improvement of CdTe-based compound semiconductors toward detector-grade level. Graduate observed very interesting results which were, in some range, already accepted for publication in CC journals. Remarks and comments do not decrease the thesis quality considerably, but indicate necessity of an improvement of formal aspects of future graduate works.

I conclude that within the doctoral thesis Mr. A. Musiienko reached given goals in full range. He presented valuable results which contribute to development of physics particularly in detection and characterization of deep-level defects in CdTe-based semiconductor compounds and radiation detectors fabricated from such materials. I recommend to accept the submitted doctoral thesis and after successful advocacy to award Mgr. Artem Musiienko by PhD degree.

September 12, 2018.

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