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Dielectric properties and quality of $Cd_{1-X}Zn_XTe$ crystals for gamma radiation detectors

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ABSTRACT

The real and imaginary parts of dielectric permittivity of semi-insulating $Cd_{1-x}Zn_xTe$ (x = 0.05–0.15) crystals had been measured. Also we studied energy resolution of radiation detectors made from these crystals under ^{137}Cs radiation. These studies have been carried out on specimens from different crystal ingot regions and taking it into account. It is ascertained that investigated permittivity values correlate with energy resolution of detectors. Such correlation is explained with presence of electrically active defects in the crystal volume which have been generated during the growth.

1. Introduction

It is well-known that semiconductors of any composition contain intrinsic structural defects. But in binary and ternary semiconductors and solid solutions on their basis there is a greater variety of such defects, than in elementary semiconductors. It is important, that formation of intrinsic defects depends not only from composition, but also from semiconductor obtaining technique. These defects generally have an appreciable influence on electrical properties of semiconductors and on technical characteristics of electronic devices for different purposes made on their basis.

$Cd_{1-x}Zn_xTe$ (x = 0.05–0.15) crystals are widely used in the uncooled gamma radiation detectors and are often grown by Bridgeman technique [1]. Large values of electrical resistivity as well as non-equilibrium carriers mobility-lifetime product ($\mu\tau$) in crystals have primary importance [2]. In almost all works devoted to the control of electrical properties of mentioned semiconductors, an impact on intrinsic defects has been used, as example with annealing [3,4]. Besides these defects as well as residual impurities are inhomogeneously distributed within crystalline ingot grown by Bridgeman technique [5,6]. The result is a non-uniform distribution of the low-frequency complex dielectric permittivity ε^* in the ingot volume [7]. So the purpose of our work is to study connection between heterogeneity of dielectric properties of $Cd_{1-x}Zn_xTe$ (CZT) crystal ingots grown with mentioned technique and energy resolution (FWHM) of gamma radiation detectors made from their fragments.

2. Specimens and method of experiment

In our experiment we used crystal ingots grown by Bridgeman technique from melt under high pressure of argon [8]. The pressure was about 100 atm. Charge was loaded into a graphite crucible with reinforcing pyrocarbon coating. Charge consisted of CdTe and ZnTe crystals. Mass ratio of these crystals was selected to form $Cd_{1-x}Zn_xTe$ solid solution with nominal zinc content x = 0.10 for the most part of the ingot. Real zinc content in crystals is in the range 0.05–0.15 and it was estimated by energy dispersive method. The sequence of cutting crystalline ingot by making specimens for study of dielectric properties and next, gamma radiation detectors, is shown in Fig. 1. Notice that we used central part of the wafer oriented with its plane parallel to the axis of crystal ingot (axis Z on Fig. 1). We seem important that under investigation how different types of structure defects and inhomogeneities influence on electrical properties of CZT-type crystals specimens had been grown at identical conditions and had the same composition. Having regard to Zn segregation at crystal growth from the melt (see e.g. [9,10]),

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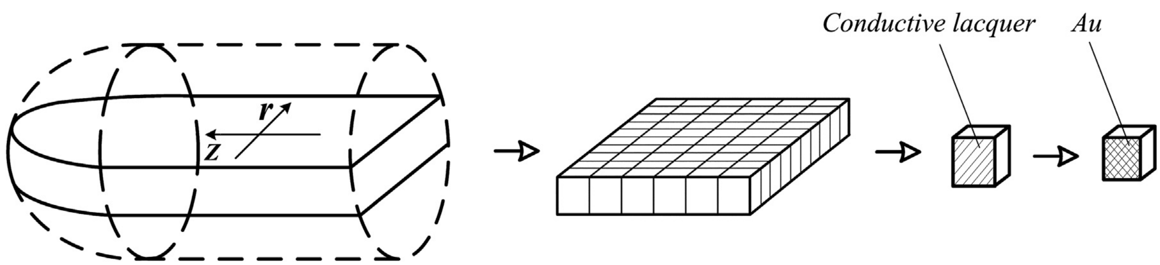

Fig. 1. Scheme of crystal ingot cutting and making specimens and radiation detectors.

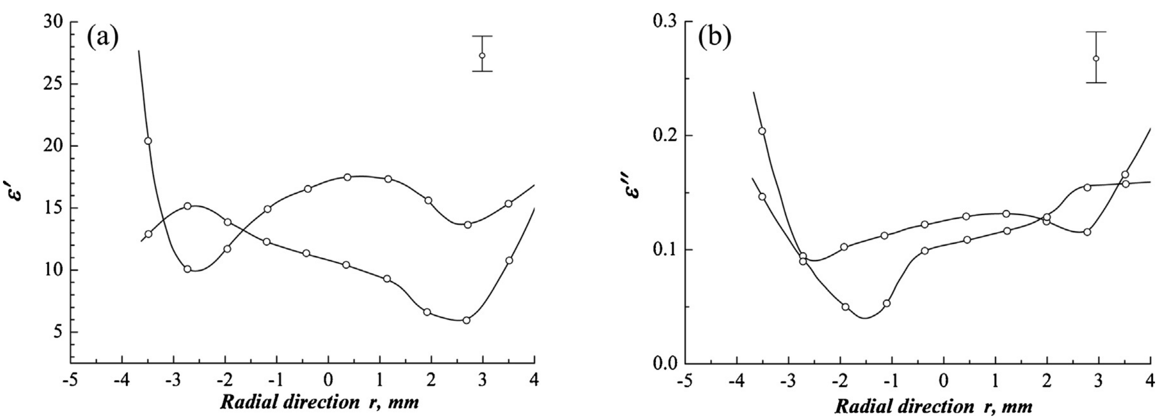

Fig. 2. Radial distribution for real (a) and imaginary (b) parts of crystals dielectric permittivity.

specimens situated at equal distances from the beginning of crystal ingot along Z axis satisfy these requirements.

Electrodes were made on specimens surfaces parallel to the axis of crystal ingot. Before electrodes applying all facets of specimens were sequentially mechanically grinded, polished and chemically etched. Etching ensured removal of affected subsurface layer. Specimens had right-angled form and dimensions $6 \times 6 \times 5$ mm. Contacts for specimens were produced by coating with conducting lacquer. Parts of ε^* were measured in a low-frequency region with condenser-type method using immittance meter LCR-819 by Instek (Taiwan) with original measuring cell. Detectors were made of the same specimens keeping their shape and surface orientation. Besides surfaces iteratively were subjected to listed processing. Dimensions of detectors were $5 \times 5 \times 3$ mm. Chemical deposition of gold from aqueous solution $HAuCl_4 \times 4H_2O$ was used for making electrodes [11]. Computerized setup on basis of universal radiation spectrum analyzer URSA-II by eV Products (USA) was used for measuring energy resolution of detectors.

3. Results and discussion

Typical radial distributions for real and imaginary parts of ε^* i.e. ε'(r) and ε'(r) at investigated specimens are shown in Fig. 2. As you can see, these dependencies are individual for groups of specimens with different situation along Z. At that for specimens situated farther from ingot axis (r = 0) greater magnitudes of investigated values are characteristic. Notice that ε' value is close to known ($\varepsilon' = 11.5$) from literature sources [12] only for specimens made from ingot parts closest to the axis. Literature data about ε' of CZT crystals in low-frequency region is absent. It is notable that if ε' value is greater than specified – it increases with decreasing of electric field frequency (Fig. 3). The same is characteristic for the other ε^* component.

Dependency for energy resolution of detectors that were made of CZT specimens from ε' is given on Fig. 4. Specimens are equidistant from the beginning of crystal ingot. As we can see, specimens

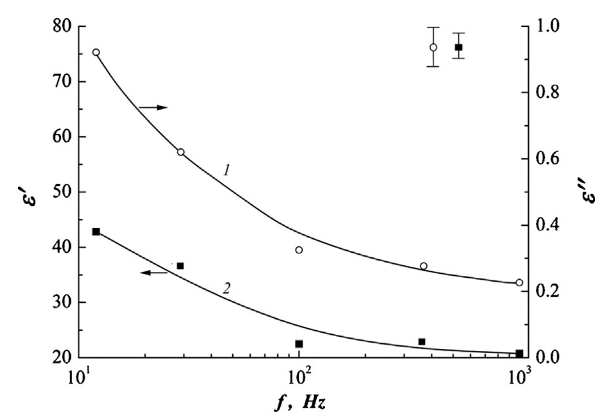

Fig. 3. Frequency dependence distribution for real and imaginary parts of crystals dielectric permittivity.

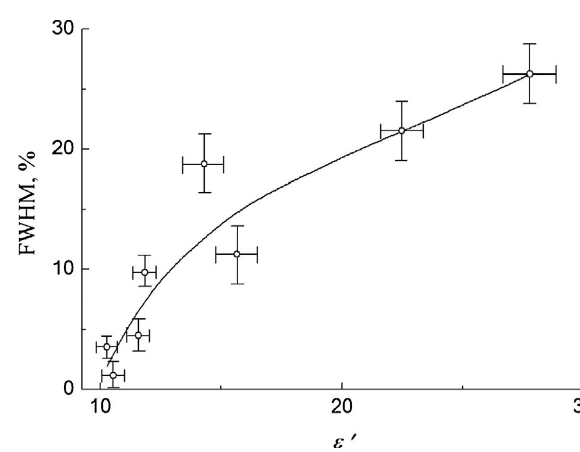

Fig. 4. Dependency for energy resolution of gamma radiation detectors from real part of crystals dielectric permittivity.