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Contactless resistivity and photoconductivity correlation to surface preparation of CdZnTe

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ABSTRACT

We investigated the influence of lapping, polishing and chemical etching of semi-insulating CdZnTe by the contactless resistivity and photoconductivity method. This method can determine the sample parameters independent of the type and quality of the metallization. We observed that the evaluated sample resistivity varies with the surface preparation method up to a factor of two. The photoconductivity anti-correlates with resistivity and it changes strongly within one order of magnitude. We determined a correlation between surface roughness, oxide layer thickness and material resistivity. Deviation of the trends is visible with surface preparation by chemical etching. We propose an optimal surface treatment to maximize the resistivity and thus to decrease the dark current.

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1. Introduction

CdTe/CdZnTe is a material of choice for high-energy X-ray and gamma-ray detectors due to its high absorption coefficient caused by large average atomic number, a relatively large bandgap at room-temperature (∼1.5 eV), and the possibility to achieve resistivity up to $\sim 10^{10}\,\Omega\,\text{cm}$ by compensation of shallow defects. This way a good signal/noise ratio can be achieved. However, surface leakage currents often deteriorate detector performance. Recent research shows that the surface leakage current as an indicator for the detector performance is very dependent on the surface treatment prior to contacts deposition [1]. Procedures commonly used during fabrication of detectors are surface polishing with different size abrasives and chemical etching in different solutions, mostly Br–methanol [2,3]. A number of publications indicates an increased surface leakage current after chemical treatment than after the mechanical one [4,5]. All of the published investigations of the plane surface treatments on the material and detector performance have been measured using current–voltage characteristics and X-ray spatial mapping with a gold strip or plane contacts [6–10]. Little attention has been paid to investigation of the surface without gold contact. Bensouici et al. [11] investigated the plane surface roughness after lapping and polishing using AFM and contactless resistivity measurement. With a greater focus on surface morphology they observed a change of resistivity during chemical etching, but the results were only briefly mentioned in the paper. In our current contribution we concentrate on a contactless complex study of resistivity and photoconductivity and their mutual correlation in dependence on the type of surface treatment. This enables the research of the material parameters independent of metallization, which can be useful to understand the variations in detector performance. In this research we used a contactless resistivity measurement to study the sample resistivity and transport properties. No metal contacts are needed for the determination of the resistivity and photoconductivity [12]. Changes in the resistivity and photoconductivity without contacts in the dependence of the achieved surface roughness and oxide layer thickness were studied.

2. Experimental

2.1. Samples

We used a semi-insulating CdZnTe crystal with an average Zn concentration of 3.5%, grown in the Crystal growth laboratory of the Institute of Physics of Charles University. The single-crystalline sample was cut from an ingot grown by the vertical-gradient-freeze method. The sample dimensions were $8 \times 5 \times 2\,\text{mm}^3$. The first cut was done using a diamond saw. Both of the large $8 \times 5\,\text{mm}^2$ plane

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Table 1
Used surface preparation methods and parameters.

Method	Al_2O_3 abrasive size	Abbreviation	RMS roughness [nm]	Oxide thickness [nm]
Lapping	9 μm	LAP9	–	–
Lapping	4 μm	LAP4	–	–
Polishing	3 μm	POL3	11.616	10.75
Polishing	1 μm	POL1	4.989	–
Polishing	0.3 μm	POL0.3	2.063	4.52
Polishing	0.05 μm	POL0.05	2.267	–
Etching	0.5% Br–methanol for 45 s	CHE1	3.855	0.78
Etching	1% Br–methanol for 180 s	CHE2	–	0.69

surfaces of the sample (usually contact surfaces) were then prepared using different treatments. Lapping with Al_2O_3 with grain size 9 μm and 4 μm (LAP9 and LAP4), polishing using Al_2O_3 with grain size 3 μm, 1 μm, 0.3 μm, and 0.05 μm (POL3, POL1, POL0.3, and POL0.05, respectively) were used. As a final step, the sample was immersed into a chemical 0.5% Br–methanol solution for 45 s (CHE1) and after that it was immersed into a 1% Br–methanol solution for 180 s (CHE2). The summary of used surface preparation treatments is shown in Table 1. The resistivity of the sample was mapped after each surface preparation process. Photoconductivity of the sample after different surface preparations was measured on the polished and chemically etched surfaces. The lateral sides were protected during the surface preparation and did not change during the measurements. No passivation was used for the plane surfaces.

2.2. Experimental setup

The applied contactless method is based on measurement and evaluation of dielectric properties of the material. The sample is put between two electrodes. One of them is a metal plate on which the sample is set. The other one is a measuring electrode with a charge sensitive amplifier moving in the z-direction. There is a small air gap between the sample and the measuring electrode. The setup of the experiment is shown in Fig. 1 and is described in detail in Ref. [12]. After biasing the electrodes the material acts as a medium in a capacitor and is charged. The time evolution of charging of the sample is detected and resistivity can be evaluated from initial charge Q_0, steady-state charge Q_{inf} and relaxation parameter τ using Eq. (1)

$$\rho = \frac{Q_0 \cdot \tau}{\varepsilon_0 \cdot \varepsilon_r \cdot Q_{inf}} \quad (1)$$

where ε_0 and ε_r are vacuum permittivity and permittivity of CdTe, respectively. Mounting one of the electrodes with an x–y feed can be used to get a plane map of the resistivity distribution. We used a commercial COREMA device from Semimap Scientific Instruments (Freiburg, Germany). For the photoconductivity measurement, the gold bottom electrode of the COREMA setup was replaced with a conductive indium tin oxide layer on a silicon glass, so that the electrode is transparent to visible and near infrared light. We used either a He–Ne laser or laser diodes with various wavelengths as the light sources for photoconductivity measurements. Focused light is brought to the sample by an optical fiber positioned near the transparent back electrode. The scheme of the modified setup is shown in Fig. 1.

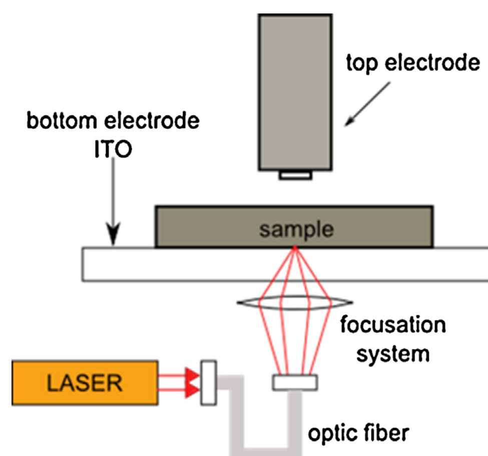

Fig. 1. Illustrative scheme of the contactless resistivity measurement setup.

The light source used for all photoconductivity measurements was a commercial L785P090 laser diode with peak wavelength at 785 nm (≈1.58 eV) with FWHM wavelength 20 nm and output power 90 mW at 120 mA operating current. We have chosen the type of the diode with a maximum wavelength of the light close to the maximum of spectral dependence of photoconductivity. In this case the light penetrates to such a depth below the surface where the surface recombination is still negligible, but the electron–hole pairs are generated only several μm below the contact. A calibration of the optical setup was made to determine how much of the light set outside the apparatus is focused on the measured point on the detector. Counting the light/fiber coupling and the transmittance of the ITO electrode the effective output power was determined as ≈70% of the set optical power on the light source. Photoconductivity was evaluated simply as the difference between the reciprocal values of resistivity with and without illumination.

$$g = \frac{1}{\rho_{light}} - \frac{1}{\rho_{dark}} \quad (2)$$

3. Results and discussions

The surface roughness of treated surfaces was measured by a noncontact three-dimensional surface profiler (Zygo, USA), which uses noncontact scanning white-light interferometry to acquire ultrahigh-z-resolution images. With this method only good reflective surface can be measured. We therefore evaluated the surface roughness by this method on all types of surfaces except of LAP9, LAP4 and CHE2 (Table 1). The values of the root-mean-square (RMS) surface roughness are also shown in the Table 1.

Two selected morphology representations of the detector sample after lapping with 0.3 μm Al_2O_3 (LAP0.3) and after etching in a 0.5% Br–methanol solution for 45 s (CHE1) are presented in Figs. 2 and 3. We can see that in contrast to mechanical lapping after the CHE1 procedure lots of thin and very high peaks are visible. This is due to the different etching velocity of these spots caused by stoichiometry deviation and/or structural defects of the crystal. Directly after each surface preparation procedure a resistivity map of the sample was measured. An area of 10 × 10 mm^2 with the resolution of 64 × 64 pixels was mapped. Fig. 4 shows a resistivity map of the sample after polishing the surfaces with a 0.3 μm alumina abrasive (POL0.3).

We can observe that the sample has a high resistivity and that the maximum and minimum values of the resistivity distribution

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