ELECTRICAL PROPERTIES TIME STABILITY OF CADMIUM-TELLURIDE BASED RADIATION DETECTORS

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Abstract: The aim of this paper is to analyze electric charge transport properties on two low-ohmic and high-ohmic sample of radiation detectors based on Cadmium-Telluride semiconductor material. The samples were prepared by Department of Physics at the Charles University Prague. Time stability of bulk resistivity was observed. Decrease of samples bulk resistivity showed exponential drop down. The resulting characteristics were fitted and the relaxation time constants were evaluated. Noise spectral density measured shortly after biasing showed different ageing from power spectral density measured 600 seconds and more after applying voltage.

Keywords: Cadmium-telluride, time stability, 1/*f* noise, power spectral density.

1. INTRODUCTION

Cadmium-Telluride (CdTe) is a very promising material for sensitive detectors of high energy radiation. X-rays & gamma rays interact with CdTe atoms to create an average of one electron/hole pair for every 4,43 eV of energy lost in the CdTe [1]. Depending on the energy of the incoming radiation, this energy loss is dominated by either the photoelectric effect or Compton scattering. CdTe based sensors can operate at room temperatures. CdTe detectors can be used in safety systems in the nuclear power industry and in radio diagnostic devices, such as tomographs.

The main problems of nowadays sensor manufacturing technology are poor carrier mobility of holes, presence of heavy ions in substrate and contacting technology. These manufacturing process imperfections result in detectors time insatiability of electric properties and long transients between stable states. No uniform distribution of structural defects causes disunited charge transport and electric field distribution. One of the most important qualities, describing time behavior of detectors is the bulk resistance that indicates changes of free charge carriers and its mobility fluctuations. During this long-time measurement, the progress noise spectral density was observed.

Long-time measurements are carried out on fully automated measuring apparatus shown in Fig. 1. Analyzed sample is placed into cryostat. Operating temperature of sensor is controlled by the Proportial-Integral-Derivative controller. Cryostat also acts as a parasite magnetic field shielding.

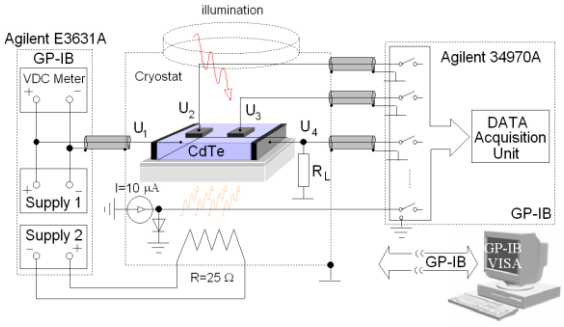

Figure 1: Measuring setup

Power sources (one for heating, one for biasing) are controlled from PC. Measured data are collected by Data Acquisition Unit and sent via GPIB communication interface to PC for postprocessing.

2. MEASURING RESULTS

Measurements were carried out under constant temperature and constant applied voltage. Mobility of charge carriers varies only with temperature. Thermal conditions were stable among the whole measurements, so changes of detector resistivity are caused only by variation of charge carriers number in crystal bulk.

2.1. LONG TIME RESISTIVITY MEASUREMENTS

From our measurement results shown in Fig.2 it's apparent that the resistivity of detector decays with time. It is a very slow process that lasts for thousands seconds and has similar time behavior as transient of RC element with time constant τ . So, the time progress of resistance decrease of detector has exponential nature and can be fitted by exponential function. Nevertheless, the energy levels of impurities, which are situated in gap, cause additional transients. As a result, the final fitting equation is superposition of certain number of exponential function described by equation [2]:

$$R_{\text{bulk}} = \sum_{i=1}^{n} a_i \exp(-t/\tau_i) + c\,. \qquad (1)$$

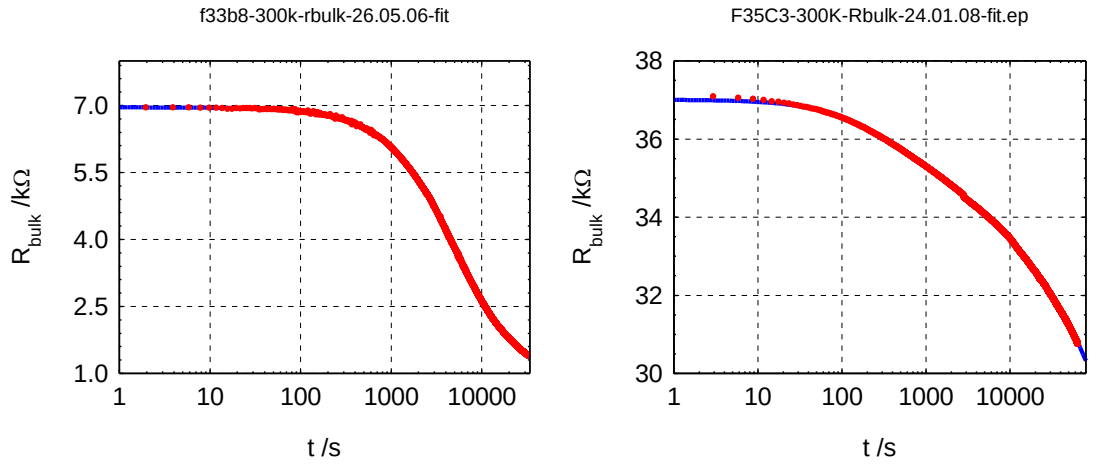

Figure 2: Time progress of low ohmic samples F33B8 and F35C3 at room temperature

The same measurement was carried out again with higher operating temperature. The effect of higher operating temperatures is thermal generation of free charge carriers that results in lower ohmic bulk resistance of detector. Furthermore, the electrons located in defect energy states relocate to conductive band. Instead of lower initial bulk resistance of samples shown in Fig. 3, higher temperature also caused faster relaxation process for both investigated samples. The first time constant τ_1 (see Tab. 1) describes most influentious relaxation process in sample bulk. After thermal stabilisation of analysed samples the sarting resistivity of sample F33B8 dropped by 63 percent and 82 percent for sample F35C3. One thousand seconds after samples biasing, the resistance of sample F33B8 droped to 17 percent of its initial value. After approx. 10 000 seconds resistance started to be stable. Another analysed sample F33C3 showed less remarkable change of resistivity after biasing. The resistance drop was only 22 percent. On the other hand, the relaxation process didn't end up. From Fig. 3 right we can obsreve rise of sample bulk resistivity. It can be caused by exhaustion of space charge in bulk or sigmifficant trapping of carriers without it's consequent retrapping.

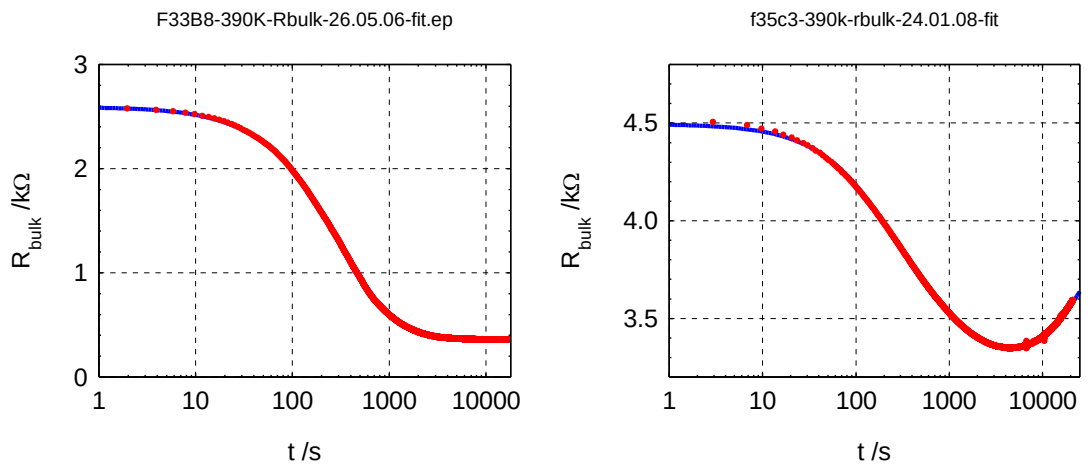

Figure 3: Time progress of low ohmic samples F33B8 and F35C3 at temperature 390K

For approximation of decay of sample resistance, time constants of each relaxation processes, shown on Tab. 1 were found. We can estimate that at least four important trap energy levels are presented in investigated samples. These electron traps are activated with increasing temperature. The process of trapping is not direct. Each carrier can be retrapped. So, electron can reach conductive band at wide range of time and that is the cause of long relaxation of Cadmium-Telluride material. Another negative result is fluctuation of free charge carriers number that adds noise and deteoriates signal-to-noise ratio.

SAMPLE	Temperatue [K]	Time constants of relaxation processes			
		τ_1 [s]	τ_2 [s]	τ_3 [s]	τ_4 [s]
F33B8 type p	300	4378	19450	-	-
	390	59	286	911	3330
F35C3 type n	300	187	1321	11590	191700
	390	160	756	5594	-

Table 1: Time relaxation constants for samples F33B8 and F35C3

2.2. LONG TIME SAMPLE VS. NOISE MEASUREMENTS

Our latest work aim is to estimate influence change of resistivity in time on Cadmium-Telluride based detectors noise characteristics. We assume not only influence of trapping effect, but also ion diffusion in depletion layer. The diffusion takes part on noise properties right after sample biasing. Time regions in which was sampling applied are shown in Fig. 4. For this purposes, the high-ohmic sample E29D1G was chosen.

The most remarkable part of Cadmium-Telluride based sensor noise signal spectrum is the low frequency region that dramatically affects the overall signal-to-noise ratio of detector system. In this frequency area, the 1/*f* noise dominates. The theoretical basis of the 1/*f* noise was given by Hooge. He found that the noise intensity is inversely proportional to the total number of carriers in the sample (*N*). This finding describes formula [3]

$$S_U = \frac{V^2 \alpha_h}{Nf}, . \qquad (2)$$

where S_U is the noise spectral density of a fluctuating voltage developed across the terminals of a linear resistor when a current is injected into it. α_h is Hooge constant, which insignificantly depends on temperature and its value. In other words α_h gives us information about noise subscription of a single charge carrier in the system.

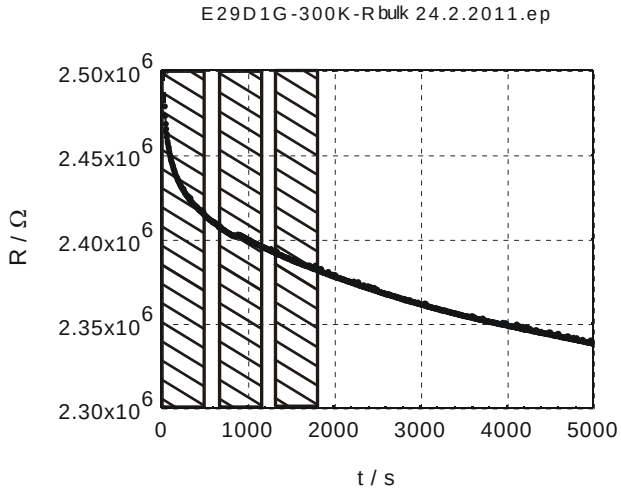

Figure 4: Resistivity time progress of high ohmic sample E39D1G and sampled time areas

As shown in Fig. 4, noise spectral densities were taken from 4 time regions.. Each sampled realization is 437 seconds long. The sampling frequency is 80 kHz. For power spectral density evaluation with constant frequency resolution, the amplified output signal from detector (gain 70 dB) was sampled and processed by the sub-band coding. This was realized by the quadrature mirror filter bank known from the Redundant Dyadic Wavelet transformation. The level of decomposition was set to 4 (signal on filter bank input was divided to sixteen bands). Afterwards, the power spectral density is evaluated for each band by the well-known Welch method. The resulting spectrum is sum of all fractional spectra. Because of sample redundancy of each spectrum, the continuity between fractional spectra is very smooth.

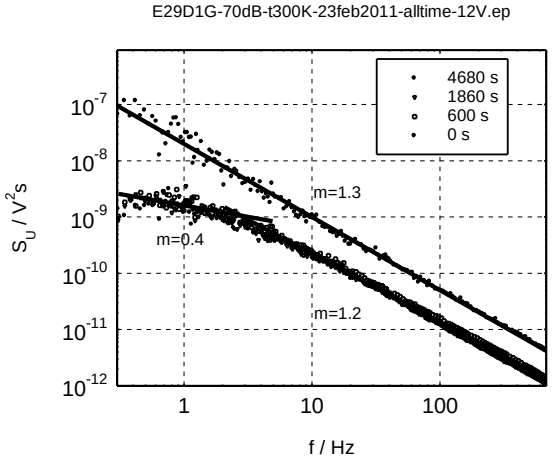

Figure 5: Noise spectral densities of sample E29D1G measured at various times after biasing

The resulting voltage power spectral density diagram is shown in Fig. 5. The most interesting area is the area with abrupt drop of resistivity, which is held shortly after sample biasing. In this time area, The $1/f^{\,m}$ noise spectra has constant slope among whole observed spectrum m = 1.3. In remaining areas with less rapid resistance decay, the m paramater has value 1.2. We can notice that at very low frequencies thermal noise dominates. Typical feature of thermal noise is constant spectral density, that means m = 0.

3. CONCLUSION

Compared with other convential semicounductors, such as silicone, the relaxation times at Cadmium Telluride detectors showed very high values, ranging from hundreds to thousands seconds. This fact reduces utilisability of detectors in practice. The main casuse of long Cadmium-Telluride based detectors relaxation time is repeated trapping of charge carriers, which leads into incomplete charge collection on detector anode. To supress negative trapping effects, it is necessary to improve manufacturing technology or apply trapping compensation methods. Our measurements showed higher thermal dependence of detector with higher ohmic resistance. From long time measurements, we are able to estimate number of trap energy levels in bulk.

The time progress of powers spectral density points at a single process that occurs in the first moments after sample biasing. The initial sudden drop of resistivity and domination of 1/*f* noise at whole spectrum can be result of ion diffusion to depletition layer at the sample area. The parameter *m* has values 1.3 and 1.2. The ideal case, $m = 1$ wasn't received, because this state presumes constant current density among whole sample. This condition cannot be met because of impurities (such as Tellur clusters or presence of unwanted oxygen ions) are distributed nonuniformly among the whole crystal bulk.

From reported reuslts [3], the 1/*f* noise is supposed to be a result of some kind of defect motion. This attitude strengtens the idea about ion diffusion in crystal. General idea about natural presence of 1/*f* noise in all systems was discormfirmed, because 1/*f* noise was not detected in measurements under perfect conditions (clean-gas bubble-free electrolyte) [4].

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