STUDY OF POLARIZATION EFFECT IN CDTE RADIATION DETECTORS

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Abstract: Relaxation times of CdTe radiation detectors with ohmic and Schottky contacts are compared. Presence of Schottky barrier elongates relaxation time of the detector. Sample with Au schottky (blocking) contacts underwent degeneration process, effectuated by storing detector at temperature 120°C for 48 hours. The result of degradation process was creation of conductive surface layer, causing three orders higher resistance of the detector. Material ageing caused significant change of current evolution during the polarization process: Undegraded sample showed decrease of sample current in time. After applying degradation procedure, we observed sample current increase in time. Plotted current evolutions in time were fitted by superposition of exponential functions, indicating traps energies, causing polarization. Simultaneously with analysis of current, the low frequency noise spectral density was progress investigated.

Keywords: CdTe, polarization, noise, reliability, ageing

1. INTRODUCTION

Because direct band gap and high atom number, Cadmium Telluride based detectors are promising for the next generation of high energy radiation detector devices. Nowadays manufacturing technology of CdTe radiation detectors does not satisfactory solves compensation of deep levels [1]. Presence of deep levels leads to charge trapping in detectors bulk. The effect of charge trapping is inferior charge collection in contacts area and deteriorated spectral resolution of detector. This polarization phenomenon has been studied since early seventies [2]. To explain polarization effects, many methods were determine electric field, traps concentrations and energies, were applied by means of ion beam induced current [3], direct mapping of electric field by Pockels Effect measurement [4], Time-of-Flight drift mobiliy measurements [5], etc. The studies reported major changes of electric field intensity in anode contact areas, where are major carriers blocked. Space charge formation in detector bulk, screening the bias is caused by the mid-gap region traps with energies around 0.8eV. Existence of Deep acceptor level at 0.64eV (vacancy V_{Cd}) [6, 7] is the most often discussed cause of polarization. Studies of detectors polarization and important operational parameter – noise changes, as a result of detector heat stressing, are almost absent. To describe this, the analysis of detector relaxation time, hand in hand with noise spectral density evaluation, is used in this paper.

2. POLARISATION CURRENT ANALYSIS

From our measurement results, shown in Fig. 1 and Fig.2, it's apparent that the resistence 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. More energy levels of impurities are situated in gap.

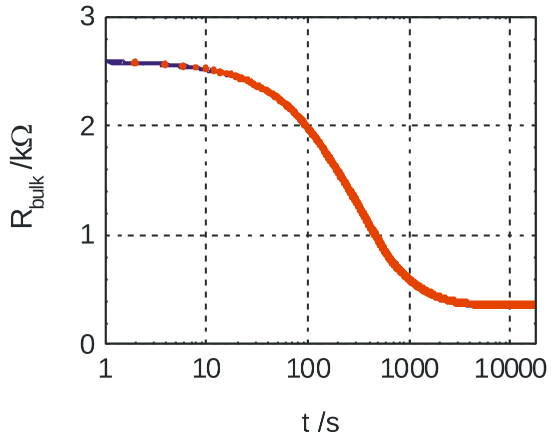

Figure 1: Low-ohmic CdTe detector resistance decay

Because of presence of more trap energies [1] and indirect relocation of detrapped electron, We are is unable to evaluate each trap energies by means of macroscopic quantities measurement. Fig. 1 shows polarization current evolution of pp+m structure CdTe detector with ohmic contacts. Applied voltage was U =25 V. We observed exponential-like decay of sample resistance. Polarization effect duration was approx. 2000 seconds. After this time, detector started to have stable electrical parameters.

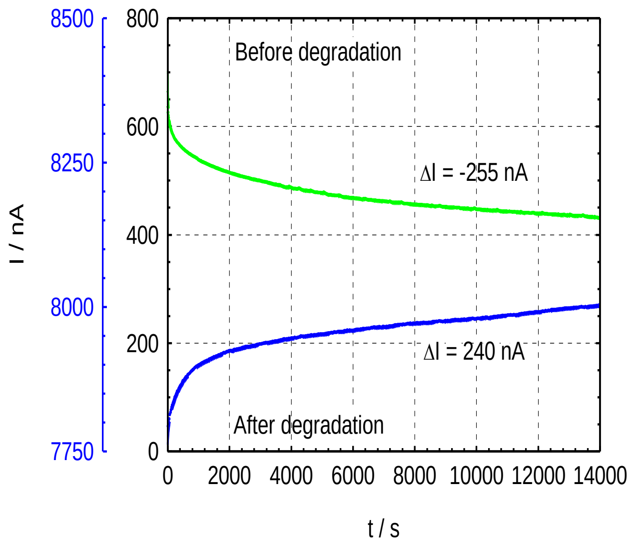

Figure 2: Polarization current of semi-insulating Schottky CdTe detector before and after degradation

Another analyzed sample, symmetrical analyzed sample, symmetrical MSM detector with semi-insulating (~10^8 Ωcm) [8] CdTe:Cl single crystal with golden Schottky contacts, manufactured at Institute of Physics, Charles University, Prague, was studied.

Comparing polarisation prophiles from Fig. 1 and Fig. 2, we can see that polarization of CdTe detector is significantly influenced by contact manufacturing technology. Low resistivity ohmic contacts suppress polarization phenomena by absence of depleted layer of negatively biased layer. This is achieved by increased dopants concentration in metal- semiconductor interface structure. The semi-insulating sample before process of degradation showed leakage current decrease during its polarization. Leakage current decreased from initial 700 nA to 429 nA at time 14 000 seconds after biasing.

Next, we investigated change of detector polarization nature after ageing, carried out by storing sample at temperature 400K for 48 hours. After ageing process, the initial current was 7761 nA. At time 14 000 seconds, current increased to 8000 nA. The absolute values of polarization currents changes during observed time interval for ungenerated / degenerated sample were for both cases very close: 255 / 240 nA.

The most remarkable difference in detector leakage current evolution is that after applying ageing process, we observe detector leakage current increase with time, which is in contrast with recorded detector leakage current fall during polarization effect in case of undegenerated detector. Degradation process caused changes of space charge evolution during polarization.

Beside the undegenerated sample, the degenerated detector shows electric intensity increase at anode area in time, which is connected with space charge decrease that is caused by detrapping of deep of holes in deep acceptors [9]. Also, we observed leakage current increase by more than tree orders. Degradation procedure caused creation of shallow layer of conductive degenerated CdTe substrate, significantly deteriorating detector electrical properties because of increased leakage current.

3. NOISE INVESTIGATION

The most important 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 $1/f^{\,m}$ noise type predominates. The theoretical basis of the $1/f^{\,m}$ noise was given by Hooge [10]. He found that the noise intensity is inversely proportional to the total number of carriers in the sample (N). This finding describes formula

$$S_U = \frac{V^2 \alpha_{\mathrm{h}}}{Nf} \approx S_I = \frac{I^2 \alpha_{\mathrm{h}}}{Nf} \qquad (1)$$

where S_U (S_I) is the voltage (current) noise spectral density of a fluctuating voltage (current) 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, this value gives us information about noise subscription of a single charge carrier in the system. Fig. 3. Low frequency spectrum evolution of semi-insulating sample before degradation.

During the polarization process, the low frequency noise spectra were analyzed. For both cases, we found two stages of noise behavior during the polarization process. The first stage plotted as line (1) in Fig 2 and Fig 3 is related to the fast processes involving free carrier injection into detector system or its depletition. This stage is remarkable by temporally increased magnitude of noise spectrum at very low frequencies. After this stage, the ongoing trapping or de-trapping does not

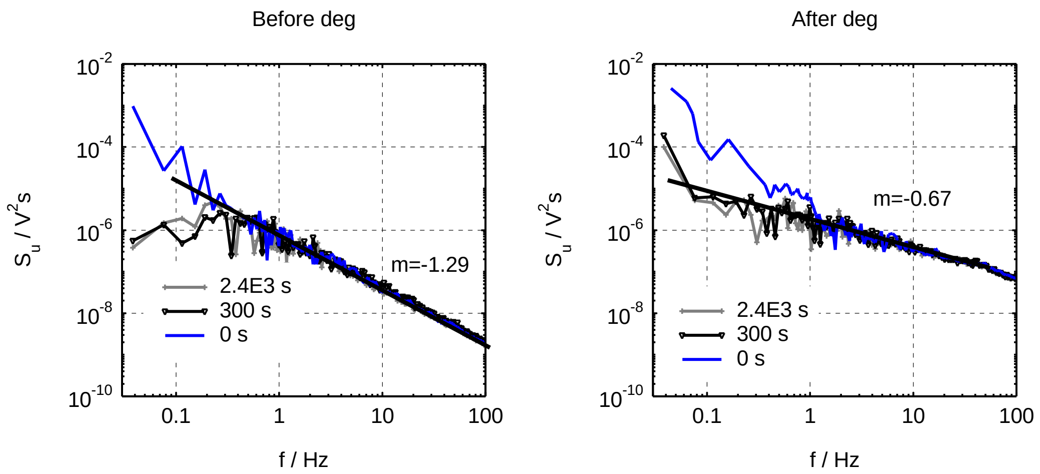

Figure 3: Low frequency spectrum evolution of semi-insulating sample before degradation.

affect magnitude and shape of noise spectra (1-9), even though we still observe increase / decrease of sample current. This is in contrary with the Hooge formula, which counts noise spectral density magnitude proportional to the square of detector current / voltage.

Heat stress caused formation of new structural defects in crystal bulk. Noise spectral density, as an indicator of defective charge transport, shows approx. one order higher magnitude in case of the degenerated sample. Degradation of the sample caused change of the $1/f^{\,m}$ low frequency noise type spectrum slope m. The value changed from -1.29 to -0.67. Lowering of slope m indicates generation - recombination process of carriers with shallow layer of degraded CdTe substrate.

From Hall measurements, carried out at Institute of Physics, Carles University, carrier concentration of sample is $n = 3.2 \cdot 10^7$ cm^{-3}, sample volume is 6.95·5.2·2.0 mm^3. The total number of charge carriers in detector system is 2.414·10^6. Theoretical noise spectral density value at $f = 1$ Hz, $U = 25$ V, given by Eq. 2, is 5.187·10^{-7} V^{2}s. Measured value was S_U = 5.2410^{-7} V^{2}s, which corresponds to the theoretical value. In case of degenerated sample, measured value was 1.32 10^{-6} V^{2}s. This value is higher than theoretical. The increase is caused by creation of structural defects as a result of heat stress of detector.

4. CONCLUSION

Long relaxation times at Cadmium Telluride based detectors showed very high values. This fact reduces utilisability of detectors in practice. Also, re-biasing causes increase of additional noise in detector system. Thermal degradation causes creation of conductive layer at detector surface. Thin surface layer of degraded CdTe causes increased reverse current of detector, but does not affect length of polarization. The nature of resistance change during polarization takes place at depletition layer of Schottky contact. By the noise spectral density analysis, significant stage of polarization was found: Time region after detector biasing, in which fast processes involving free carrier injection into detector system or its depletition prevails. The change of the $1/f^{\,m}$ spectrum slope m from -1.29 to -0.67 is related to the surface generation – recombination noise. Furthermore, this spectrum shape indicates exponential decrease of traps (from detector surface to its bulk).

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