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Effect of High Operating Temperature on Electrical Quantities of CdTe Radiation Detectors

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***Abstract*—Analysis electrical properties change of a semiconductor radiation detector, based on Cadmium-Telluride material has been carried out. The detector was exposed to temperature 100 °C for time period of 24 hours. Heat stress caused an increase of leakage currents by two orders. New defect energy levels caused difference in detector current transit, typical for the polarization effect. The noise spectral density of the detector after thermal stressing increases with the power of 6.81, which is significantly higher value than 2.70, measured before thermal stressing.**

Keywords*— *CdTe, semiconductor radiation detector, ageing, noise

Due to medical and safety industry requirements, the new generation of semiconductor radiation detectors of a small geometrical dimensions and good spectral resolution are needed. The key parameters of the new materials are: high atom number, high linear attenuation coefficient and ability to operate at the room temperature. All the mentioned requirements meet and as the most promising detector material is considered Cadmium – telluride (CdTe). CdTe has effective atomic number 50 [1], density 5.86 g/cm^3 and wide band gap 1.475eV [2], which allows to operate at the room temperature.

Nevertheless, the process of CdTe crystal growth is still far from perfect. Crystals suffer from inhommogenity [3], Even though many efforts have been made, compensation of unwanted defects is still an unsolved issue [4]. Generally, the problem lies in difficulty with dopants diffusion control [5]. Additionally, CdTe is capable to operate without cooling temperature, but cannot be exposed to temperatures higher than 60°C which cause generation of dislocations in the crystal structure [6]. The goal of this paper is to investigate the changes of electrical properties of CdTe crystal, which was exposed to a heat stress. We analyzed the changes of polarization, Current – voltage (*IV*) characteristics and detector additional noise.

I. Measuring Setup

Figure 1 shows the experimental setup used for our measurements. The samples with a load resistor are placed into the cryostat. The cryostat allows controlling operating temperature in the range from 77 K to 400 K by a heating spiral and liquid nitrogen dosing. The cryostat also acts as undesired electrical field screening. The programmable digital-analog converter Agilent E34401A is used for the IV characteristics measurements. Measuring instruments are interconnected by the data acquisition unit Agilent 34970A with the plug-in module Agilent 34902A, which is used for data conversion and is connected with PC via GPIB / IEEE488 interface. Noise measurements in the dark were carried out at the room temperature. Sample was fed from dry cells, which show negligible noise, compared to measuring electronics. Applied voltage was 50, 66, 90 V. The sample fluctuating voltage was amplified by an ultra-low-noise voltage amplifier FEMTO DLPVA-100-F-S on the load resistor and sampled by an external data acquisition card National Instruments NI USB-6216. The noise voltage was transformed into the corresponding noise spectral density using the Fast Fourier Transformation algorithm. Our set-up allows us to measure the sample current and the noise voltage simultaneously without any effect on the additive noise of measured sample. The measured values were recorded and analyzed in a personal computer.

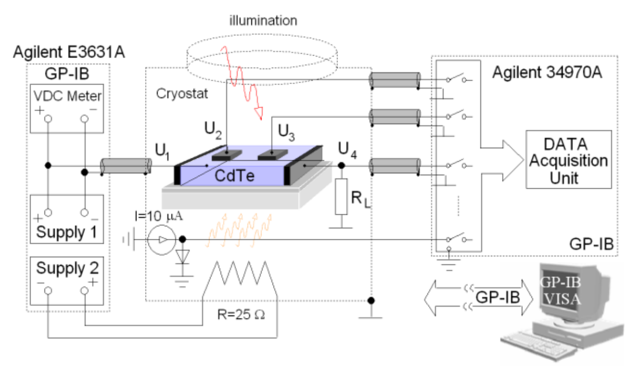

Figure 1. Experimental setup for the transport and the noise characteristics measurements.

II. Results and Discussion

The investigated sample was made from an n-type CdZnTe (Zn = 10%) crystal, grown by the Vertical Gradient Freeze method at the Institute of Physics, Charles University, Prague [7]. The dimensions of the sample are 5 x 5 x 2.5 mm^3. The sample specific resistivity is 10^7 Ωcm. Sides of the detector were mechanically polished by the 0.25 µm grit. Surface chemical treatment was carried out by etching in 1 % Br-methanol solution. Geometrically identical gold electrodes were chemically deposited on the opposite surfaces of the sample from an aqueous solution of $AuCl_3$. Measurements were carried out in the dark and at the room temperature T = 300 K. To simulate the effect of an increased operating on the parameters of the detector, the sample was exposed to temperature 100 °C for time period of 24 hours.

A. *IV characterstics measurements*

Figure 2 shows the IV characteristic of the sample before exposing to high temperatures. As can be seen, the characteristic shows apparent nonlinearity.

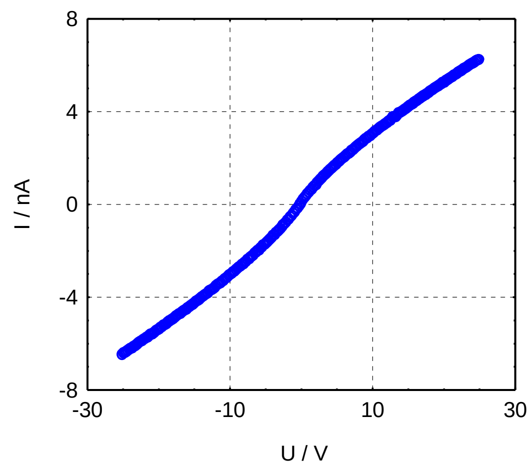

Figure 2. *IV* characteristic of the sample before applying the process of thermal stressing.

For both detector polarities, the slope of *IV* curve changes at bias voltage 7.7 V. The steeper rise of detector current with increasing voltage below above mentioned bias voltage are followed by characteristics that exhibits a linear relationship between the applied voltage and the resulting electric current. The border voltage indicates full depletion of the detector. At voltages high enough for complete depletion, the detector has resistance 3.85 GΩ, which is value that meets the requirements for a good spectroscopic detector.

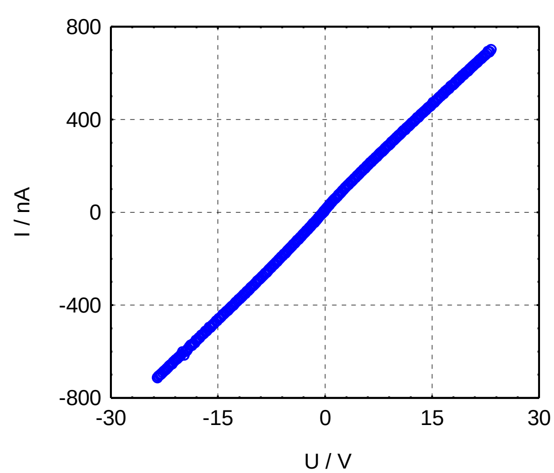

Figure 3. *IV* characteristic of the sample after applying the process of thermal stressing.

The *IV* characteristics of analyzed detector ofter thermal stressing are shown in Fig. 3. Compared with Fig. 2, the leakage current of the sample increased by two orders. The effect of detector full depletition is masked by a higher concentration of charge carriers that originated in thermal induced structural defects of the detector bulk. Higher concentration of carriers causes worsen rectifying effect of the reverse biased Schottky contact. After the thermal degradation caused by heat stressing, the dynamic resistance of the detector decreased to 31.5 MΩ.

To analyze changes of detector polarization, long time current measurements have been carried out. Applied bias voltage was U = 20 V. Current transient, which represents macroscopic effect of polarization, shows an abrupt rise in time at first 2000 seconds after biasing. Even though *IV* characteristics of detector before heat stressing show symmetry for both polarities, difference of current transients appeared.

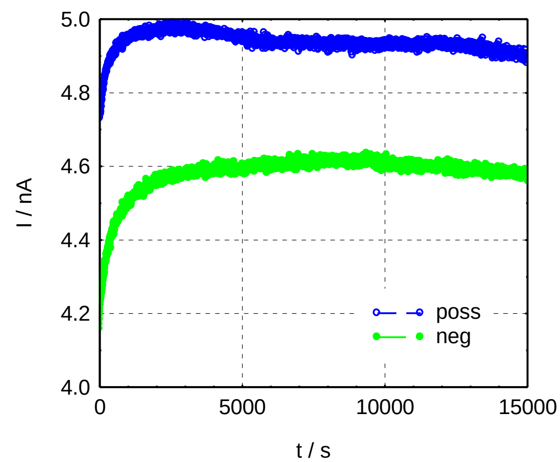

Figure 4. Current transit after detector biasing of the sample before applying the process of thermal stressing.

We can see that the electric field quickly increases with time in the beginning, and reaches saturation after about 2500 seconds. We attribute this behavior to the fast retrapping of the carriers that cause fast change of depletion width L_d and consequently fast increase of the electric field. After about 2500 seconds from application of bias, almost all carriers are re-trapped. We can notice differences of the current transit for each bias polarity in maximal values of leakage currents (5 nA for "poss" polarity, 4.6 nA for "neg" polarity at t = 2500 s). In time > 2500 s after the detector biasing, we can still observe fluctuation of the leakage currents caused by unstable parameters of potential barriers for both polarities. This is due to ongoing carrier trapping-detrapping processes. Fig. 5 shows current transit of the detector after heat stressing. As in case of *IV* characteristics measurement, detector showed approx. two orders higher values of leakage current. After 1000 seconds, when we observed an abrupt rise of the detector current, the detector current was increasing linearly for both polarities. The shape of time evolution of current transit is very similar and the carrier re-trapping processes has not ended in observed time interval. As in the previous case, the detector biased in the “neg” polarity, showed higher values of leakage current. The duration of fast current change was, compared with current transits of undegraded detector, faster. That point to existence of a new defect energy level situated closer to the conductivity band, which effect is faster retrapping. The continuous increase of the detector current is caused by another, deep level, for which is typical long time retrapping.

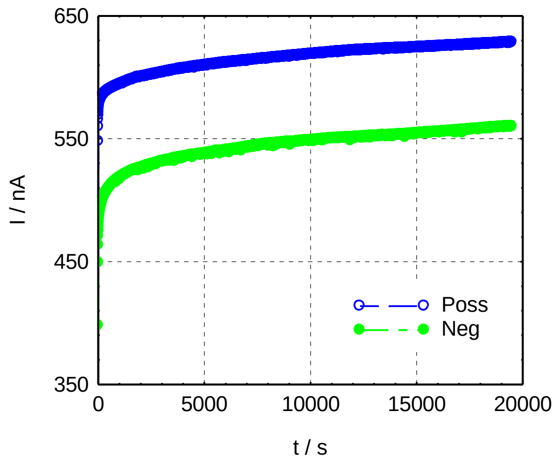

Figure 5. Current transit after detector biasing of the sample after applying the process of thermal stressing.

B. Low frequency noise spectral density analysis

This part of the paper presents analysis of the noise spectral density change after the detector thermal stressing. In our recent work, [8] we found out that contact behavior is masked by the most dominant source of the detector additive noise – surface. Subscription of contacts to the the total noise of the detector can be revealed only, if an extra guard ring electrode that grounds surface current is presented. The used sample was not equipped with this electrode, so the total additive noise of the detector is analyzed. To avoid the influence of the detector polarization effect, all the measurements were carried out 30 000 seconds after detector biasing.

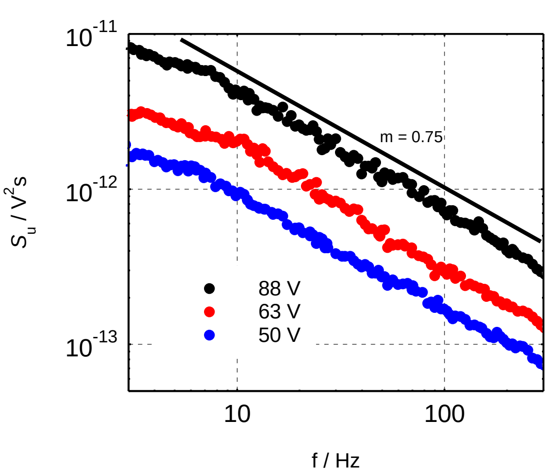

Figure 6. Low frequency noise spectral density of sample before applying the process of thermal stressing.

The observed frequency range was from 1 Hz to 300 Hz. The applied detector bias voltage was U = 50, 65 and 90 V.

Figure 7 shows the low frequency noise spectrum of the detector before heat stressing. The detector exhibits the generic $1/f^{\,m}$ noise, which is typical for enormous number of electric devices [9] and is also found in biological systems [10]. The slope of the $1/f^{\,m}$ noise was m = 0.75, which points out that the magnitude of fluctuating $1/f$ noise increases with exponent - 0.75 with decreasing frequency towards to the DC value of bias voltage, The value of parameter m is constant for the whole analyzed frequency range and for all applied voltages.

The values of the noise spectral densities at f = 10 Hz were measured 1×10^{-12} V^2s for U = 50 V, 2.1×10^{-12} V^2s for U = 63 V and 4.35×10^{-12} V^2s for U = 90 V.

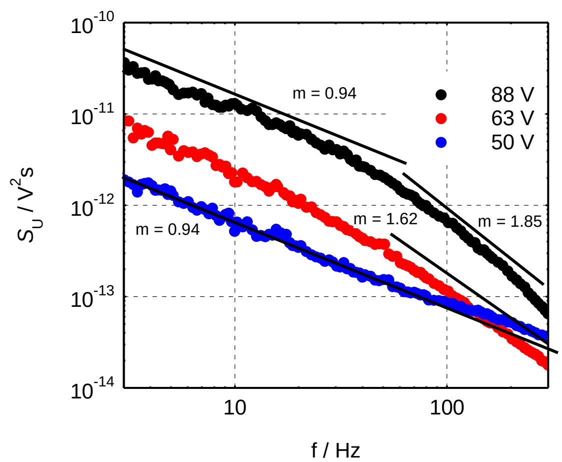

Figure 7. Low frequency noise spectral density of sample after applying the process of thermal stressing.

The noise spectra of the detector after heat stress are shown in Fig. 2. Apparently, the shape of has lost the uniformity of the m parameter at bias voltages U = 66V and U = 90 V.

In case of U = 50 V (whole frequency range) and frequencies below 30 Hz (U = 66 V and U = 90 V) the slope of the spectra was very close to 1. At frequencies above 30 Hz, the value of spectra slope has increased to the value of 1.62 (U = 66 V) and 1.85 (U = 90 V). This is caused by the reinforced effect of the generation – recombination noise, for which is peculiar process of charge carriers trapping, followed by their detrapping. These processes take place between defect energy levels in the band gap [11, 12].

The values of the noise spectral density at f = 10 Hz were measured 6.65×10^{-13} V^2s V^2s for U = 50 V, 2.20×10^{-12} V^2s V^2s for U = 63 V and 1.25 V^2s for U = 90 V.

The most remarkable change of the detector additive noise behavior before and after applying thermal stress is the increase of the noise spectral density with increasing voltage. Voltage noise spectral density is proportional to the power of 2.60 with the applied voltage as it is shown in Fig. 8.

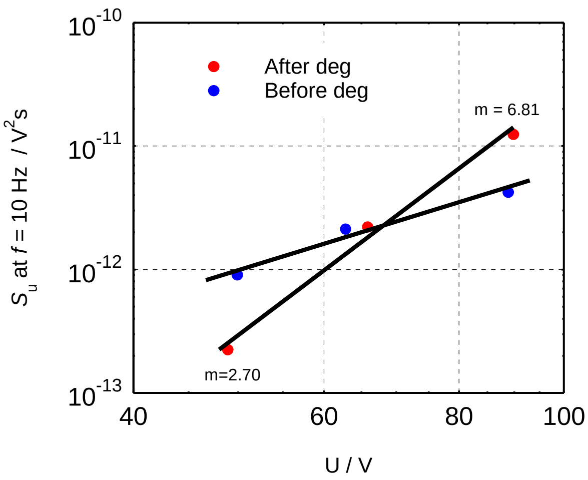

Figure 8. Low frequency noise spectral density vs. applied voltage at f = 10 Hz of the detector.

After heat stressing, we observed a distinct change of this parameter to 6.81. The value of 2.6 is close to the value assumed by Hooge [11]

$$\frac{S_U}{U^2} = \frac{\alpha}{Nf}, \tag{1}$$

where S_U is the noise spectral density of a fluctuating voltage U developed in a material bulk between the terminals of a linear system when a current is injected into it; $\alpha = 10^{-3}$ is the Hooge constant, N is the total number of charge carriers in the system.

This heuristic formula presumes that the value of the noise spectral density is proportional to the square of the applied voltage. Higher value is caused by a fundamental requirement breach – the requirement of a uniform distribution of defects in the material bulk. Imperfections are always present in bulk and, furthermore, just the presence of Schottky barrier is an unexceptionable place of inhomogenous distribution of charge carriers in the detector system. Further deviations from prefect state cause higher increase of the noise spectral density than with the square of the voltage. So, after the detector heat stressing, input parameters for calculation eq. (1) are changed, especially N, which, due to the generation of defects in the crystal structure, increases.

III. Conclusion

Heat stress caused increased carrier concentration in semiconductor bulk. This fact has a multiple effect. Not only conductivity of the detector bulk increased, but higher concentration of charge carriers caused worsen rectifying properties of reverse biased contact by thickening the potential barrier. Current transit of detector before thermal stressing lasted 15 000 seconds whereas the current transit of the detector after exposing to high operating temperature has not ended in the observed time period and the detector leakage current was still increasing. The increase of the power spectral density with applied bias voltage was found as the most obvious indicator of the detector ageing. This quantity evaluation is very easy to implement to the detector system control electronics and can be used as an indicator of the detector lifecycle.

Acknowledgment

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