ANALYSIS OF FERMI LEVEL POSITION IN THE CDTE SINGLE CRYSTAL

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ABSTRACT

The CdTe single crystal radiation detector resistance was measured during long time interval with applied voltage U=1V. Effect of temperature changes on the hole concentration, the hole mobility and the Fermi level position was studied this way.

The hole concentration, the hole mobility and the Fermi level position as a functions of time were calculated. Analysis of the resistance show that the hole concentration is almost constant with temperature changing. It begins to change appreciably just after the temperature became constant. The resistance changing is influenced mainly by the hole mobility changing. As temperature is constant, the resistance changing is influenced only by the hole concentration changing.

1. INTRODUCTION

Cadmium Telluride (CdTe) single crystals had become useful in the last few years as radiation detectors operating at room temperature [1]. A high intrinsic mobility-lifetime product $\mu\tau$ is one of the key conditions for the realization of good spectral resolution and high counting efficiency in radiation detectors. Wide gap zone Eg≈1.5 eV allows working at room temperature.

We have carried out transport measurements of a CdTe detector, prepared by Institute of Physics, Charles University in Prague. The sample F33B8 has *p*-type conductivity and has the following features:

Maximum value of the acceptor concentration $N_A = 10^{16}$ cm^{-1}. The acceptor activation energy $E_A = 0.3$eV. Specific resistance $\rho = 70$ Ωcm. Cross section is 1.7x2.7 mm^2, length is 11.4 mm.

2. MEASUREMENTS

The measuring equipment is in Fig.1. The CdTe sample has voltage and current $AuCl_3$ contacts for four-dot measurements method. This method can be used for research of contacts effect on VA characteristics. The sample with a load resistor are placed into a cryostat. The cryostat allows to control surround work temperature in the range from 77K to 400K by a heating spiral. At the same time cryostat is intend for undesired electrical fields screening.

Programming D/A converter Agilent E3631A is used for VA characteristics and current versus time measurements. D/A converter is also used for automated temperature control into the cryostat. Separated measuring dots are connected to a multiplexer Agilent 34970A with plug-in module Agilent 34902A, which used for measured data A/D converting and connecting to a PC by GPIB.

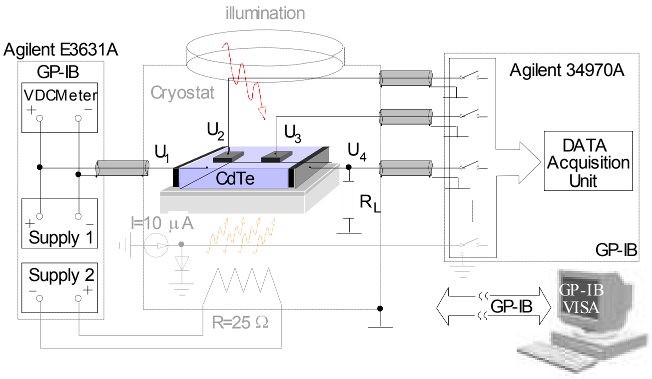

Fig.1. Measuring equipment

The CdTe resistance was measured during 17.5 hours time interval (Fig.2). Applied voltage U=1V. The measurements started with temperature T=309 K and this temperature was constant during 110 minutes. The resistance decreased during this time interval. As we increased temperature up to T=393 K the resistance increased simultaneously until T is 373K. As temperature reached this value, the resistance became to decrease and decreased during the all constant temperature interval.

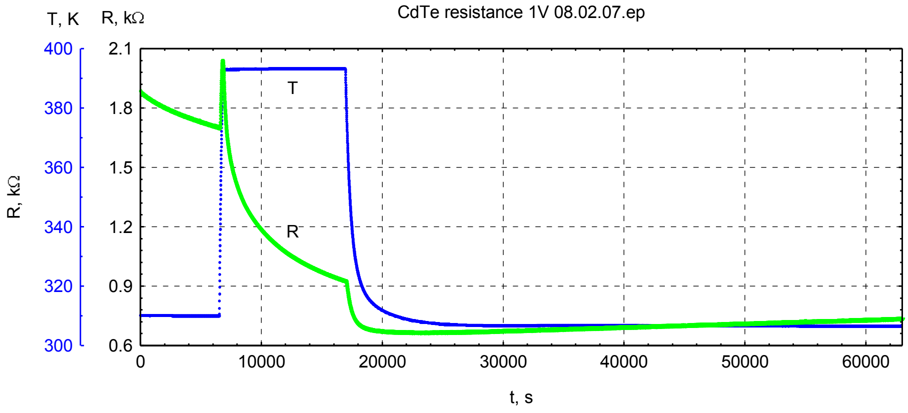

Fig.2. The CdTe resistance and temperature as a function of time

As we cooled the sample down to 309 K the resistance decreased much swiftly then on the constant temperature time interval. At first the resistance decreased simultaneously with temperature decreasing, but then it became to increase and slowly increased during constant temperature interval. At the beginning of the measurements the resistance was R_1=1.9 kΩ and at the end of the measurements R_2=0.26 kΩ. Heating process with following cooling doesn't cause irreversible changes of the sample properties. It takes approximately 3 days to come to the initial state. After this time the sample completely restores its initial properties.

At first the CdTe sample shows metal behavior with every temperature changes. Its resistance increases with the temperature increasing and decreases with the temperature decreasing. Semiconductor properties of the sample begin to dominate just after some period of time.

3. THE HOLE CONCENTRATION AND THE HOLE MOBILITY

A low electric field the drift velocity υ_d is proportional to the electric field strength E, and the proportionality constant is defined as the mobility μ in cm^{2}V^{-1}s^{-1} [2], or

$$\upsilon_d = \mu E \tag{1}$$

The hole mobility in the CdTe was measured the Institute of Physics, Charles University in Prague [3]. From the experiment the hole mobility is fitted well by

$$\mu = 57[\exp(252/T) - \quad], \; [\mathrm{cm^2V^{-1}s^{-1}}] \tag{2}$$

This result is well conformed with [4]. The hole mobility also is

$$\mu = \frac{\sigma}{ep} \tag{3}$$

where σ is the electric conductivity, given by:

$$\sigma = \frac{l}{RS} \tag{4}$$

The CdTe dimensions l = 11,4mm and S=4,59mm^2 From these formulas we can calculate the hole concentration:

$$p = \frac{\sigma}{e\mu} = \frac{24.837}{e\mu}, \; [S/cm] \tag{5}$$

The hole concentration didn’t change instantly with temperature changing. It taken much time to became constant. The hole concentration became to change with temperature changing and kept changing during long time after temperature became constant.

4. CALCULATION OF THE FERMI LEVEL POSITION

The Fermi level for the intrinsic semiconductor lies very close to the middle of the band gap. When impurity atoms are included, the Fermi level must adjust itself to preserve charge neutrality. To preserve electrical neutrality the total negative charges (electrons and ionized acceptors) must equal the total positive charges (holes and ionized donors). For the present case the electron density in the conduction band is neglible little and doesn’t effect the Fermi level position

$$N_A^- = p \tag{6}$$

where p is the hole density in the valence band, N_A^- the number of ionized acceptors, given by

$$N_A^- = \frac{N_A}{1 + 4 \cdot \exp\left(\frac{E_A - E_F}{kT}\right)} \tag{7}$$

From these equations,

$$E_F = E_A - kT\ln\left(\frac{N_A^- - p}{p}\right) \tag{8}$$

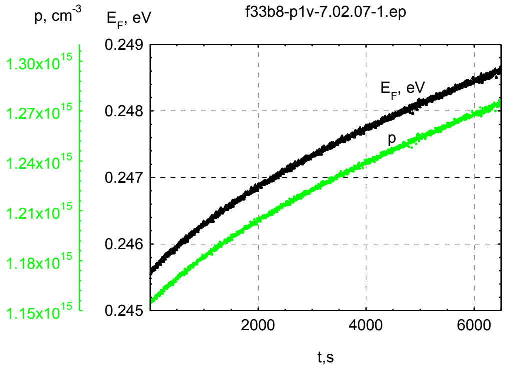

Fig.3. The hole concentration and the Fermi level as a function of time before heating. T=309K, μ=71 cm^{2}V^{-1}s^{-1}

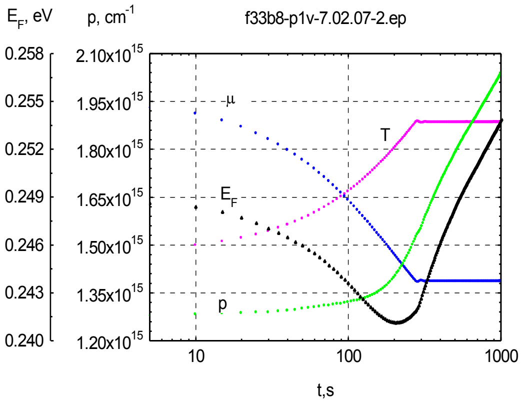

Fig.4. The hole concentration and the Fermi level as a function of time. T changes from 309K up to 393K, μ decreases from 71 cm^{2}V^{-1}s^{-1} down to 51 cm^{2}V^{-1}s^{-1}

For the present case the resistance decreasing at the first time interval with constant temperature T=309K. It caused by the hole concentration increasing according to Eq.2. The hole mobility μ = 71 cm^{2}V^{-1}s^{-1} is constant and therefore the hole concentration is in inverse proportion to the resistance. (Fig. 3). The Fermi level increases from 0.245eV up to 0.248 eV and increasing in the hole concentration is 10.5%.

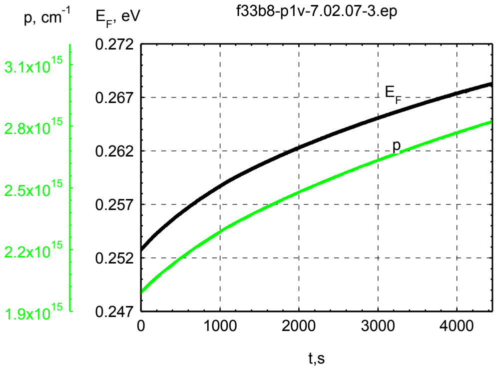

Fig.5. The hole concentration and the Fermi level as a function of time. T=393K, μ=51 cm^{2}V^{-1}s^{-1}

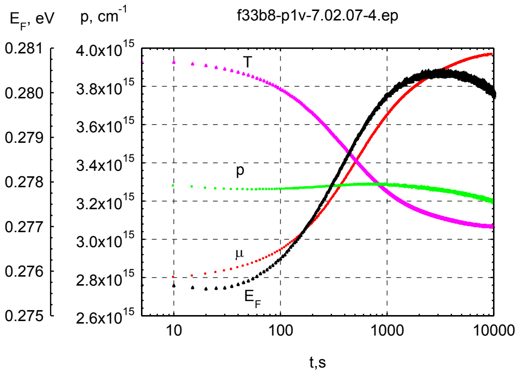

Fig.6. The hole concentration and the Fermi level as a function of time. T changes from 393K down to 309K,μ increases from 51 cm^{2}V^{-1}s^{-1} up to 71cm^{2}V^{-1}s^{-1}

As we increased temperature from 309K up to 393 K the resistance increased simultaneously. The hole mobility decreased down to μ = 51 cm^{2}V^{-1}s^{-1}. The change of the hole concentration is just 21%. The resistance changes due to the hole mobility decreasing. But after the moment the temperature is constant T=393 K the resistance changes only due to the hole concentration increasing in 83% at the all temperature constant interval. The Fermi level influenced mainly by the hole mobility changing at first (E_F decreased down to 0.241 eV). Then influence of the hole concentration increasing become constitutive and E_F became increase up to E_F=0.268eV by the end of the constant temperature time interval (Fig.4, Fig.5).

As we decreased temperature down to 309K the resistance of the CdTe decreased simultaneously. The hole mobility increases up to $\mu = 71\ cm^2V^{-1}s^{-1}$ according to Eq. The hole concentration remains nearly constant (Eq.5). At first the Fermi level rose with the hole mobility rising up to 0.28eV, but then decreasing of the hole concentration influenced mainly the Fermi level position (Fig. 6).

After cooling of the sample we observed the slow linear resistance increasing. The resistance increased approximately during 3 days to the initial value. With constant temperature T=309K the hole mobility is constant according to Eq.2. The hole concentration decreasing causes the Fermi level position decreasing. In 10 hours after cooling the Fermi level E_F= 0.276 eV.

5. CONCLUSION

The CdTe sample shows metal behavior with every temperature changes. Its resistance increases with the temperature increasing and decreases with the temperature decreasing. Semiconductor properties of the sample begin to dominate just after some period of time. As we can see from the measurements, the hole concentration is almost constant with temperature changing. It begins to change appreciably just after the temperature became constant. The resistance changing is influenced mainly by the hole mobility. According to Eq. the hole mobility decreases with temperature increasing and increases with the temperature decreasing. It explains the CdTe metal behavior with temperature changes.

The hole concentration changing is relatively slow process. It doesn't change simultaneously with temperature changing. At the beginning of the measurements the resistance is R_1=1.9 kΩ and at the end of the measurements is R_2=0.26 kΩ. Heating process with following cooling doesn't cause irreversible changes of the sample properties. It takes much time to come to the initial state, about tree days. After this time the sample completely restores its initial properties.

The Fermi level influenced both by the hole mobility and the hole concentration. The Fermi level position varied between E_F=0.241 eV and E_F=0.280 eV during the measurements.

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