ANALYSIS OF CONTACT QUALITY IN CDTE DETECTORS

Ing. Alexey ANDREEV, Doctoral Degree Programme (1)
Dept. of Physics, FEEC, BUT
E-mail: xandre00@stud.feec.vutbr.cz

Ing. Jiří ZAJAČEK, Doctoral Degree Programme (2)
Dept. of Physics, FEEC, BUT
E-mail: xzajac00@stud.feec.vutbr.cz

Supervised by: Dr. Lubomir Grmela

ABSTRACT

Contact metal - semiconductor is an obligatory element of all semiconductor devices.

Energy band diagrams of the CdTe-metal interface have been modeled on the basis of the semiconductor parameters. Energy band diagram shows position of the Fermi level in metal and bottom of conductivity band Ec, valence band ceiling Ev, Fermi level, and impurity activation energy in the semiconductor.

In the area of CdTe-metal interface arises a contact field. It causes bending of the energy bands in the depleted zone of the semiconductor.

A series of measurements of VA characteristics at various temperatures was carried out in the dark and the changes of the current function with temperature were determined.

1 INTRODUCTION

The cadmium telluride (CdTe) is a II–VI semiconductor material useful for the detection of high energy radiations, such as X-rays and gamma rays.

When radiation (e.g., a photon) strikes it, electrons are freed from their electronic states in the atoms of CdTe. The electrons leave behind "holes," i.e., empty electronic states. If an electric field is applied, the electrons will move towards the positive electrode; it turns out that the "holes" behave like positive charges and move towards the negative voltage.

The main application of CdTe consists in high-resolution detection of radiation. A fairly wide energy gap Eg = 1.5 eV makes room temperature operation of these detectors possible; the detector therefore needs not to be cooled. High atomic number and high absorbing coefficient are the main advantage of such a radiation detector.

Generally, the application of strong electric fields to semiconductors with deep centres yields stimulation of ionisation or capture processes due to: Poole-Frenkel effect, the phonon-assisted tunnelling, and the direct tunnelling. All this effects appear in high ohmic samples.

We have performed analysis of contact metal-semiconductor of CdTe detectors [1], prepared by Physical Institute of Charles University in Prague. Temperature dependencies of the electrical conductivity and Hall coefficient were measured by a classical six-probe method. Gold electrical contacts were prepared by electrodes deposition from aqueous solution of $AuCl_3$.

2 CONTACT METAL – SEMICONDUCTOR

Two various types of contacts are used at preparing semi-conductor devices and electronic circuits: Ohmic and rectifying contacts. Ohmic contacts are intended for passive connection of the semiconductor to an external circuit, therefore they should have constant and extremely low resistance.

Other type of contact is formed, if surface area of the semiconductor is depleted by the basic carriers. In this case in the contact area from the semiconductor side the area of a space charge ionized donors or acceptors is formed and realized blocking contact, or Schottky barrier. It has nonlinear VA characteristic.

The current density of thermionic emission from the surface is defined by Richardson's equation: [2]

$$J_T = AT^2 \exp(-\frac{\Phi}{kT}), \quad (1)$$

where J_T is current density, A is area cross section, T is absolute temperature, Φ is work function and k is Boltzmann constant. We can see from the equation that by increasing the material work function, the current of thermionic emission from a solid state material surface decreases. Work function of a semiconductor material is defined by the Fermi level position. Work function of the gold contact Φ_{Au} = 5.37 eV. CdTe sensor parameters: afinity χ = 4.5 eV; gap zone width Eg = 1.47 eV; acceptor impurity concentration $N_A = 10^{17}$ cm^{-3}; acceptor impurity activation energy ΔE_t = 0.3 eV.

$$E_F = \frac{E_V}{2} + \frac{E_A}{2} - \frac{kT}{2e}\ln(\frac{N_V}{N_A}), \quad (2)$$

where E_V is the valence band ceiling; N_V is the effective density of conditions in the valence band, defined by the following ratio:

$$N_V = 2\left(\frac{2\pi m^* kT}{h^2}\right)^{3/2}, \quad (3)$$

where m* is the effective hole weight.

We can find the valence band ceiling from the following expression

$$E_V = \chi + E_g. \quad (4)$$

The thermodynamic work function of the semiconductor Φ_{CdTe} for Au - CdTe p-type contact is greater than the thermodynamic work function of the metal Φ_{Au} ($\Phi_{CdTe} = 5.79$ eV, $\Phi_{Au} = 5.37$ eV). In this case, according to the equation (1), the thermionic emission current density J_S from a semiconductor surface is less than the thermionic emission current density J_{Au} from a metal surface

$$\Phi_{CdTe} > \Phi_{Au}, J_{CdTe} < J_{Au}. \quad (5)$$

The energy diagrams of the metal and the semiconductor before the formation of contact are shown in figure 1.

$E_{F\,(S)}$ = 5.79 eV; E_C = 4.5 eV; E_V = 5.97 eV; E_t = 5.67 eV

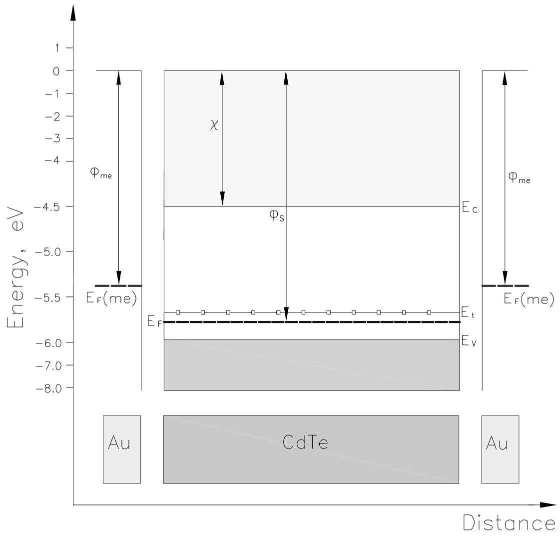

Fig. 1: *Energy diagram Au and CdTe before formation of contact*

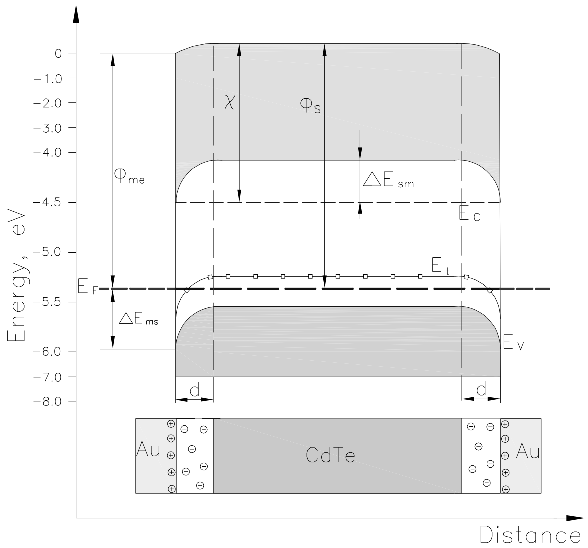

Fig. 2: *Energy diagram of Au - CdTe contact*

After connecting these materials, the current flowing from the metal into the semiconductor will exceed the return current from the semiconductor into the metal. The positive charges will collect in the metal and the negative charges will collect in the semiconductor in the surface areas of both the semiconductor and the metal. The energy bands will bend due to the electric field generated in the contact area. As a result of the field effect, the thermodynamic work function will decrease on the surfaces of the semiconductor. This process will continue until the contact field stops equalizing thermionic emission currents. The thermodynamic work function values will equalize on the surfaces too [3,4]. There is a potential barrier whose height equals to a difference of thermodynamic work functions

$$E_{\mathrm{sm}} = \Phi_{\mathrm{CdTe}} - \Phi_{\mathrm{Au}}\,. \qquad (6)$$

Depleted layer width in the semiconductor is considerably greater then the depleted layer width *d* of the contact of two metals. It is defined by the following ratio

$$d = \sqrt{2\varepsilon\varepsilon_0 \left(\frac{E_F - \Phi_{Au} \pm eV}{e^2 N_A} \right)}\,. \qquad (7)$$

According to calculations, *d* = 57.8 µm. Concentration of holes in the semiconductor is some orders of magnitude less than the concentration of electrons in metals, and the transition of holes from approximately thousand atomic semiconductor layers is necessary for the alignment of Fermi levels in metal. As a result, a high resistance surface layer with almost constant negative charge density (the blocking layer or Schottky barrier) appears in the semiconductor.

$$E_{\mathrm{ms}} = (\chi + E_{\mathrm{g}}) - \Phi_{\mathrm{Au}}\,. \qquad (8)$$

Calculations have shown, that the barrier for electrons moving from metal into semiconductor is E_{ms} = 0.6 eV, and from the semiconductor into metal is E_{sm} = 0.42 eV.

3 VA CHARACTERISTICS

VA measurements in the dark were carried out depending on temperature. The standard measuring set up is in Fig. 3.

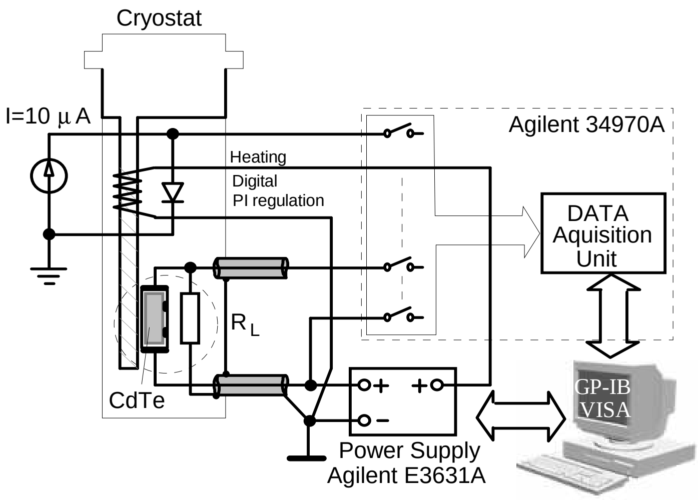

Fig. 3: *VA characteristic measuring set up*

VA characteristics of the sample were measured twice. Result of the first set of measurements for the used CdTe sample is in Fig. 4. VA characteristic is non-linear and resistance of the sample increases with decreasing temperature.

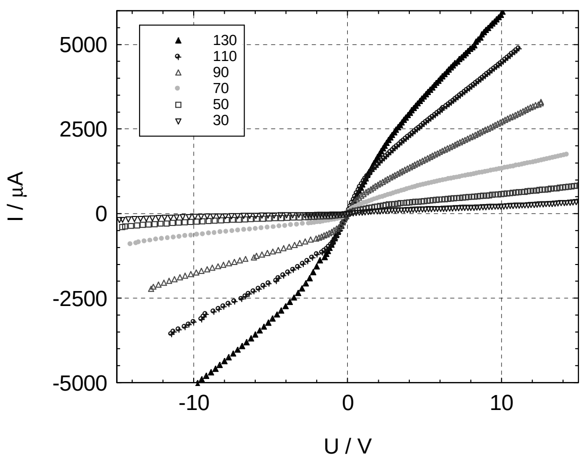

Fig. 4: *VA characteristics dependent on temperature. First measurements*

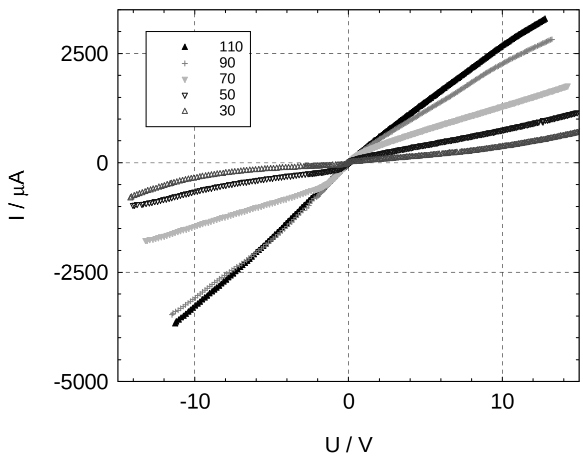

Fig. 5: *VA characteristics dependent on temperature. Second measurements*

Result of the second set of VA measurements is in Fig. 5. Resistance of the sample increases with the decrease of temperature in both measurements, but the VA characteristics are different in each set of measurements. Resistances of the sample measured at temperatures below 60 °C are the same for both sets of measurements. At temperatures above 60 °C, the resistance of the sample at first measuring decreases more rapidly than the resistance at second measuring.

Under the applied external voltage V>> kT/e in a direct direction, the depleted layer *d* disappears and the current strength is limited by the bulk resistance of the semiconductor and metal. Under the external voltage applied in the opposite direction, the thickness of the depleted layer increases according to equation (7). Accordingly, the resistance of the semiconductor increases too. The semiconductor has both contacts to which is the external voltage applied made from metal. The first contact is the positive electrode, the second one is the negative electrode. Therefore VA characteristics should be symmetric for direct and opposite directions as seen from Fig. 4 and Fig. 5. Thickness of the depleted layer increases with the voltage according to equation (7).

4 CONCLUSION

The following results were calculated from the known values of the Au work function Φ_{Au}, CdTe afinity χ, forbidden zone width Eg, and the acceptor concentrations. The measurements were carried out with both the absence of external voltage and the applied external voltage V_E:

ΔE_{sm} = 0.42 eV – from the semiconductor into metal; ΔE_{ms} = 0.6 eV – potential barrier from the metal into the semiconductor; E_F (S) = 5.79 eV – the Fermi level position; E_t = 5.67 eV – the acceptor level position; d = 57.8 8 μm – the depleted zone width.

Two sets of the VA characteristics of the sample were measured, each set consists of measurements at various temperatures. The VA characteristics have changed after the first set of measurements. The resistance of the sample decreases more rapidly with the increasing temperature at the first measurement set than at the second measurement set.

Quality of contact technology preparation for P type semiconductor is very difficult. It's impossible to prepare ohmic contacts for samples of CdTe at present. But VA characteristics are symmetric as for ohmic contacts.

ACKNOWLEDGMENTS

This research has been supported by GACR No.102/05/2095 and by the Czech Ministry of Education in the frame of MSM 0021630503 Research Intention MIKROSYN "New Trends in Microelectronic System and Nanotechnologies".

REFERENCES/LITERATURA

[1] Schauer, P., Šikula, J., Moravec, P.: Transport and Noise Properties of CdTe(Cl) Crystals, Microelectronics Reliability 2001, p431, 41.

[2] Gurtov, V., A.: Solid state electronics, Petrozavodsk 2004, 37-39

[3] Gurtov, V., A.: Physics of metal – semiconductor structure, Petrozavodsk 1983

[4] Parsin , A., S.: Electrons in solid materials 1998

[5] Fedosov, J., L.: Physics of semiconductor devices, Moscow 1969

[6] Sze, S., M.: Physics of Semiconductor Devices, J.Wiley & Sons New York 1981