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LETTER TO THE EDITOR

SOME ELECTRICAL PROPERTIES OF AN *n*-InSe/*p*-CdTe HETEROJUNCTION

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Some electrical properties of a new anisotype heterojunction between indium monoselenide, InSe, and cadmium telluride, CdTe, has been studied in the present paper. To the authors' best knowledge, the electrical behaviour of this heterojunction has not been investigated previously. Interesting photoelectric behaviour found by the present authors will be described elsewhere.

Single crystals of undoped InSe, prepared in exact stoichiometric proportions of In and Se and showing *n*-type conductivity, have been used as substrates, on which thin films of CdTe have been deposited by vacuum thermal evaporation. During the deposition a slight deviation from stoichiometry in the CdTe thin films takes place (i. e. an excess of Te) due to a higher vapour pressure of Cd with respect to Te, this favouring *p*-type conductivity.

The InSe has been prepared by direct synthesis of high purity indium (purity 6*N*) and selenium (purity 5*N*8) in an evacuated and sealed silica tube at 960 K (melting point is 930 K). During the preparation molten InSe was cooled in a furnace at a temperature gradient of 0.3 °C/cm. The sample obtained has had hexagonal crystal lattice with the space group $P6_3/mmc$, and the unit-cell parameters $a = 0.4005$ nm, $c = 1.6640$ nm[1], consisting of large single-crystal regions with good cleavage property parallel to the (001) crystal planes. Freshly cleaved platelets with 100 to 200 μm in thickness, exhibiting *n*-type conductivity and the electrical resistivity of about 3 Ωm in the direction parallel to the *c*-axis [normally to the (001) planes], have been used as substrates for the deposition of the thin films of CdTe by thermal evaporation from the tantalum boat at a pressure of

1.33×10^{-4} Pa and the substrate temperature of 720 K. The area of the junction has been of the order of 5 mm^2. The films have shown *p*-type conductivity with the electrical resistivity of $\approx 2 \times 10^2\ \Omega m$ at room temperature. X-ray diffraction analysis (counter diffractometer) of the thin films of CdTe has revealed that they have been polycrystalline. The diffraction patterns have been interpreted in terms of a cubic, sphalerite-type, structure with the unit-cell parameter $a =$ $= 0.6481$ nm (at 298 K). The crystallites of CdTe have exhibited a very strong preferred orientation with their (111) crystal lattice planes parallel to the substrate. The thicknesses of the films have been of the order of 0.5 μm. Soldered indium has been applied as an ohmic contact to InSe[9]. Silver colloidal paste (Acheson Colloiden B. V., Scheemde, Holland) proved to be a good ohmic contact to CdTe. The energy gap of InSe at room temperature is close to 1.2 eV[9]. The energy gap of CdTe is 1.44 eV at 300 K[3].

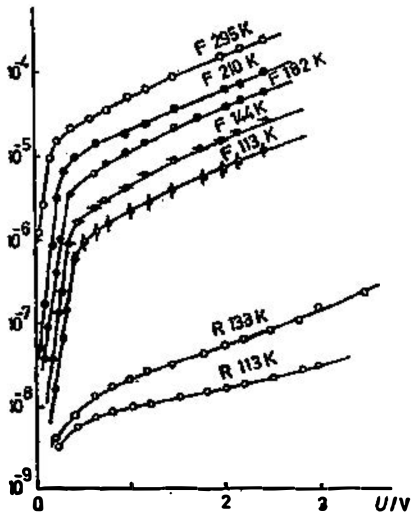

Fig. 1. Current-voltage (I — U) characteristics measured in the dark at different temperatures.

Figure 1 shows representative current-voltage characteristics (log I vs. U) for an *n*-InSe/*p*-CdTe heterojunction measured in the dark at different temperatures. The forward bias characteristics can be divided into two regions, a low-voltage and a high-voltage region. The transition voltage U_T between these two regions decreases with increasing temperature. In the low-voltage region (i. e. for voltages of less than 0.22 V at room temperature) the measured curves can be fitted to an expression of the form:

$$I_F \sim \exp\left(\frac{e\,U_F}{nkT}\right), \tag{1}$$

where e is the electronic charge, k the Boltzmann constant, T the absolute temperature and n a parameter which in this case has the value $n = 2.6$ at room temperature.

In the high-voltage region (i. e. for voltages higher than 0.22 V at room temperature) the curves can be expressed by a relation of the type

$$I_F \sim \exp(A\, U_F), \qquad (2)$$

where A is a constant independent of temperature in the temperature region between about 100 and 300 K and is equal to 0.66 V^{-1}.

Figure 2 shows semilogarithmic plot of the forward current (log I_F) against $10^3/T$. At low voltages log I_F is proportional to $-1/T$. Therefore the voltage and temperature dependence of the forward current in the low-voltage region ($U < U_T$) can be written as

$$I_F \sim \exp\left(-\frac{B}{T}\right) \exp\left(\frac{e\, U_F}{nkT}\right), \qquad (3)$$

where B is a constant.

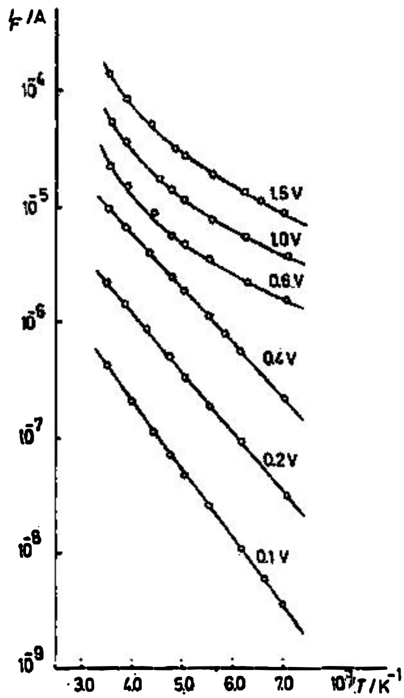

Fig. 2. Forward current vs. $10^3/T$ curves at various voltages.

Figure 3 shows the plots of the forward current (log I_F) against the temperature for various voltages. It can be seen that for higher voltages log I_F varies approximately linearly with T. Therefore in the high-voltage region ($U > U_T$) the voltage and temperature dependence of the forward current obeys the relation:

$$I_F \sim \exp(CT) \exp(AU_F), \tag{4}$$

where C is a constant.

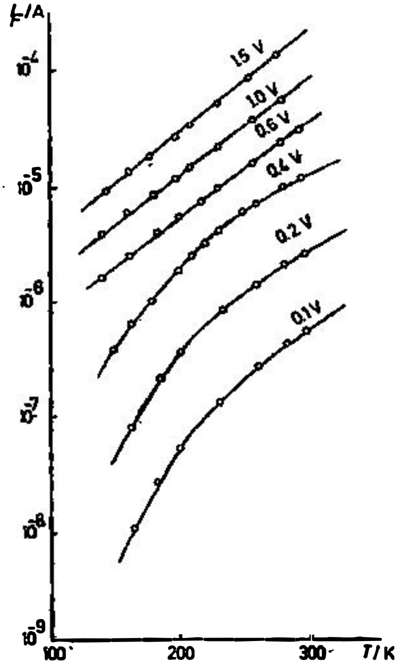

Fig. 3. Forward current vs. T curves at various voltages.

The forward characteristics found for the n-InSe/p-CdTe heterojunction, which are described by equation (3) for the low-voltage region and by equation (4) for the high-voltage region could be interpreted in terms of the recombination--tunnelling mechanism of the current transport proposed by Donnelly and Milnes[2].

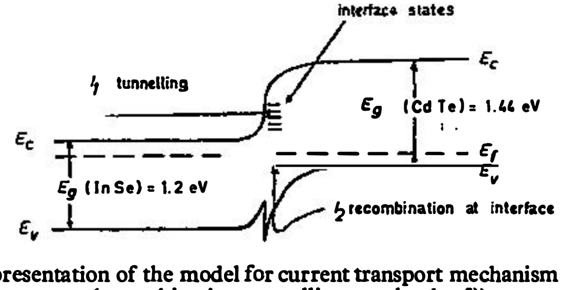

Fig. 4. Shematic presentation of the model for current transport mechanism in n-p heterojunction (recombination-tunnelling mechanism[2]).

A model for such a transport process is shown in Figure 4. The thermal-emission or diffusion current, which recombines at the interface, flows in the wide-gap material, while the tunnelling current flows through the narrow-gap material barrier. These two currents flow in series and are related by the interface parameters. The total current may be therefore limited by any of the two currents and may exhibit either thermal- or tunnelling-current characteristics. Since the recombination current increases with voltage more rapidly than the tunnelling current, a transition from the recombination-limited to the tunnelling-limited current with increasing forward bias is possible. The low-voltage region for $U < U_T$ where equation (3) is valid, would correspond to the recombination limited current, while the high-voltage region with $U > U_T$, where equation (4) is obeyed, would correspond to the tunnelling limited current. The model shown in Figure 4 was the appropriate one also for the *p*-Ge/*n*-GaAs, *n*-Ge/*p*-Si, and *p*-Ge/*n*-Si heterojunctions studied in the work of Donnelly and Milnes[2].

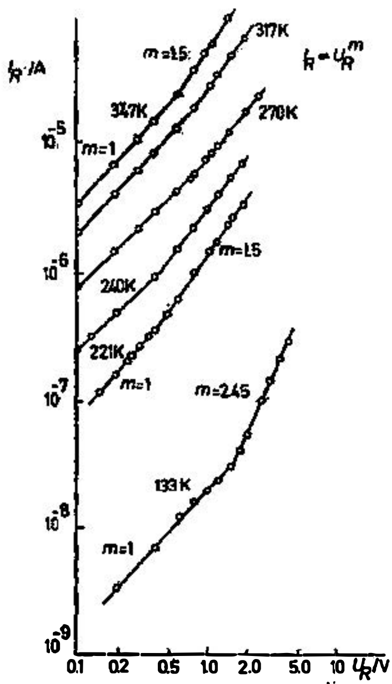

Fig. 5. Reverse current-voltage (I_R vs. U_R) characteristics measured in the dark at different temperatures.

The reverse current-voltage characteristics measured in the dark at different temperatures are presented in Figure 5 ($\log I_R$ vs. $\log U_R$). One can see that in the measured temperature range between 130 and 350 K there exists a linear variation of I_R with U_R at low reverse voltages, while a power-law variation $I_R \sim U_R^m \sim$ with $m > 1$ holds for high voltages. This is in agreement with observations on different types of heterojunctions such as *p*-Ge/*n*-GaAs[3], *p*-Ge/*n*-Si[4], and *p*-GaAs/*n*-ZnSe[5] heterojunction. Riben and Feucht[6,7] have explained this type of characteristics by a Zener-type tunnelling model in which the behaviour of the reverse current as a function of reverse voltage and temperature is of the form:

(5)

where U_D is the diffusion potential and E is the constant independent of temperature. Our experimental data on reverse bias current-voltage characteristics measured in the dark at different temperatures can be described well by equation (5) with E independent of T and equal to 5.98 $V^{1/2}$; in this case the diffusion potential U_D of the heterojunction has been estimated by extrapolation of the linear forward characteristic to the point where the current equals zero[8] and has been found to be 0.6 V. This behaviour of reverse currents as a function of U_R and T is indicative of tunnel current. However, more experimental data are needed for a detailed analysis of this heterojunction.

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NEKA ELEKTRIČNA SVOJSTVA HETEROSPOJA *n*-InSe/*p*-CdTe

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Izmjerene su istosmjerne strujno-naponske karakteristike heterospoja *n*-InSe/*p*-CdTe u mraku na različitim temperaturama. Eksperimentalni podaci se mogu interpretirati pomoću rekombinaciono-tunelirajućeg mehanizma transporta struje.