SCHOTTKY DIODES METAL-CdTe*

By J. M. Pawlikowski and J. Żyliński

Institute of Physics, Wrocław Technical University**

(*Received October 27, 1977*)

Contacts on weakly-doped p-type CdTe samples were obtained by vacuum evaporation of Au and In. The current-voltage (CV) and photo-voltage (PV) characteristics were measured for the temperature range 77–300 K. The barrier height has been estimated and the Schottky model for contacts at 300 K presented.

1. *Introduction*

The choice of metal contacts with appropriate properties is an essential problem in the production of semiconductor elements as well as in investigating transport phenomena in semiconductor materials. The knowledge of the electrical properties of contacts used for a wide-gap, weakly-doped semiconductor is of a particular importance because of the relatively greater difficulty encountered in the production of an ohmic contact.

Increasing interest in the properties of the rectifying metal-semiconductor contacts (commonly called s.o. Schottky diodes) has taken place in recent years, as manifested by the numerous papers published yearly [1]. Special interest was shown in Schottky diodes used as e.g. nonlinear electronic elements and photovoltaic detectors or solar cells [2, 3]. Metal-CdTe contact is very suited to this application [4], its properties have been widely discussed in [5]. Technology, properties and applications of the metal n-type CdTe contacts were also investigated in [6–9]; the discussion of the results are included in Part III of this work.

Our research on electrical transport properties of contacts with Te compounds was directed to the metal contacts with CdTe-HgTe mixed crystals, with small fractions of CdTe [10–14]. In this work we describe the experiments performed on metalic contacts to weakly-doped p-type ($10^{19}-10^{20}$ m^{-3}) CdTe samples which are used by us in both epitaxial $Cd_xHg_{1-x}Te$ layers and solar-cell technology.

---

* Work sponsored by the Wrocław Technical University under contract 7/77 (IM-116).

** Address: Instytut Fizyki, Politechnika Wrocławska, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland.

2. *Experimental part*

The semiconductor surfaces were first ground and polished mechanically and next etched for 2 min. in a 5% solution of Br in methyl alcohol. The metallic contacts were prepared by vacuum ($p \cong 10^{-5}$ Torr) thermal evaporation. The CdTe sample area was 8×3 mm^2, the contact surfaces were 1.61 mm^2 (In) and 2.17 mm^2 and 2.02 mm^2 (Au). The contact configurations were similar to those in [10]. The current and voltage electrodes were connected by indium soldering a Au wire 0.1 mm in diameter.

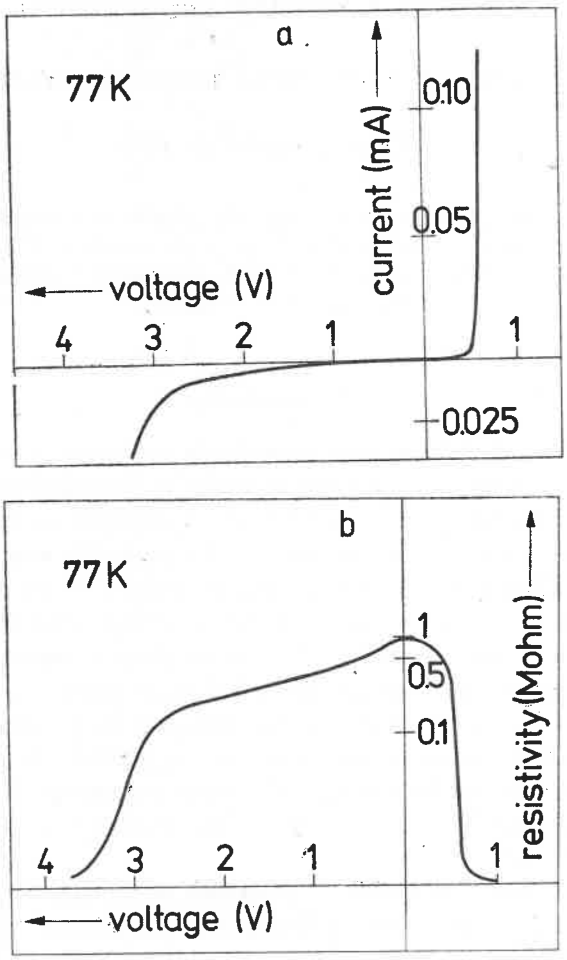

Fig. 1. CV (a) and $(dI/dV)^{-1}$ (b) characteristics for In-CdTe contact at 77 K

The measurements of CV characteristics were made by the d.c. intermediate method just as in our former papers [10, 11] using a DC Microvoltmeter V 623 Meratronic and Keithly 150 B Micrometer and recording the results with a Rikken-Denshi AT-5B $X-Y$ recorder. Using the additional electronic equipment we simultaneously recorded the differential resistivity plots $(dI/dV)^{-1}$ and lg I vs V dependences. Typical[1] CV characteristics of an In-CdTe contact at 77 K and 300 K are presented in Figs. 1a and 2a, respectively. The $(dI/dV)^{-1}$ plots are shown in Fig. 1b and 2b, respectively.

Spectral measurements were performed for the wavelenght range 0.35 μm—1.3 μm using the experimental arrangement described in detail in [15]. The arrangement used allows one to obtained directly the ratios of photoresponses of contacts investigated

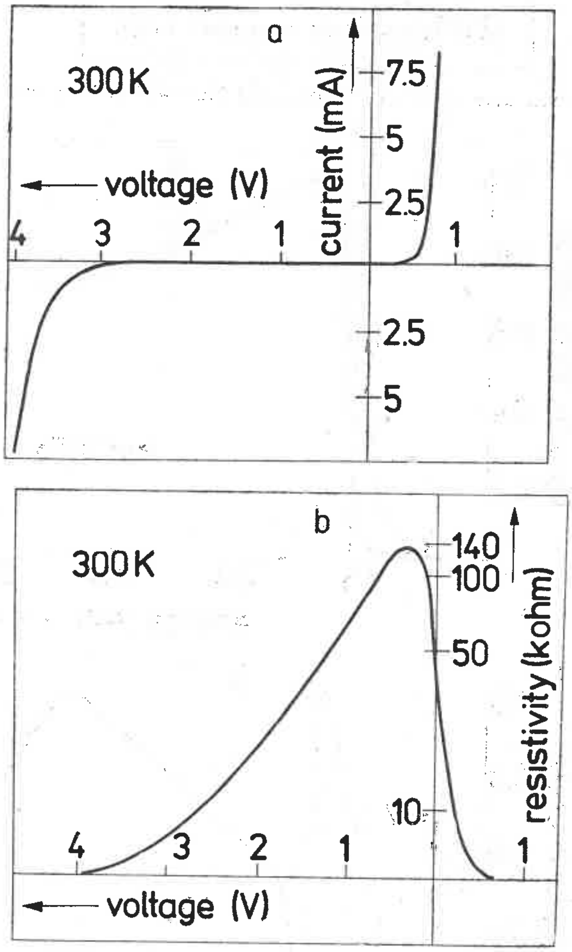

Fig. 2. CV (a) and $(dI/dV)^{-1}$ (b) characteristics for In-CdTe contact at 300 K

to the photoresponse of a standard detector. The schematic set-up of the open-circuit photovoltage measurements has been described in [15] and the contact configuration is shown in Fig. 3. The monochromatic radiation was incident both on the semitrans-

[1] Sixteen contacts were measured and the other current-voltage plots are very close to this one; only quantitative differences (see discussion of results) were observed.

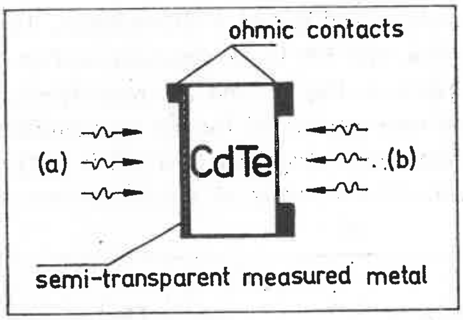

Fig. 3. Contact configuration used in PV experiments and front-wall (a) and back wall (b) illuminations

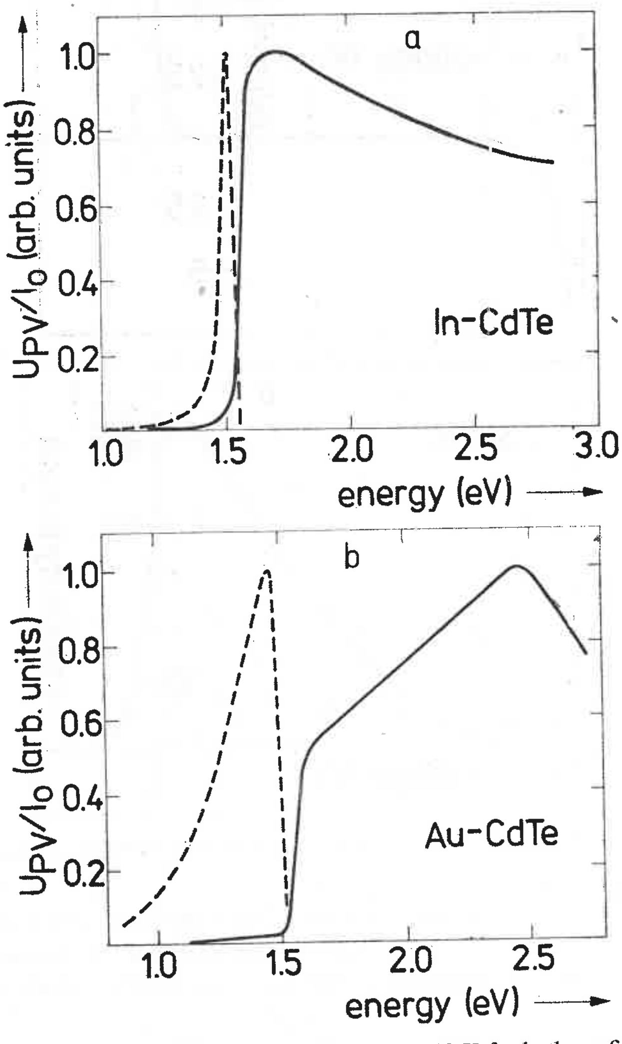

Fig. 4. PV spectra of In-CdTe (a) and Au-CdTe (b) contacts at 300 K for both configurations: front-wall lighting (solid line) and back-wall lighting (broken line)

parent metal layers (of thickness $d_m \leqslant 15$ nm, according to [16]) and on the semiconductor surface. The obtained results in the form of the photovoltage spectra of U_{PV}/I_0 where U_{PV} is the open-circuit photovoltage and I_0 is the photon flux density, are shown in Figs. 4a and 4b for In-CdTe and Au-CdTe contacts, respectively.

3. *Discussion of results*

The measurements of CV characteristics (schown in Figs 1 and 2) allow one to obtain the lg I vs V plots presented, for example, in Fig. 5 for In-CdTe contact under foıward bias at 300 K. Using the current density versus voltage relationship for a Schottky barrier (the thermoemission-diffusion theory by Crowell and Sze [17])

$$j = j_s \exp\left(\frac{qV_c}{nkT}\right)\left[1-\exp\left(-\frac{qV_c}{kT}\right)\right], \tag{1}$$

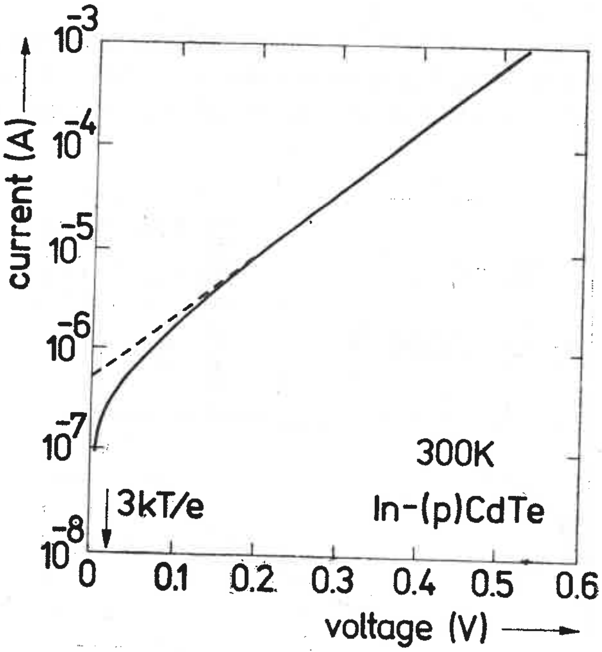

Fig. 5. lg I versus V of In-CdTe contact at 300 K

where the contact voltage V_c is related to the applied voltage V_a by

$$V_c = V_a - IR_s, \tag{2}$$

where R_s is the series resistance of contacts, I is the contact current and

$$n \equiv \frac{q}{kT}\frac{d(V_c)}{d(\ln I)} = \left[1-\frac{d(\Phi_B)}{d(V_c)}\right]^{-1}. \tag{3}$$

when $V_c \gg kT/e$ and Φ_B is a Schottky barrier height when $V_c = 0$, we can obtain the values of Φ_B. The saturation current density j_s is given by

$$j_s = A^{**}T^2 \exp\left(-\frac{\Phi_B}{kT}\right), \tag{4}$$

where A^{**} is the modified Richardson constant (being a function of the appropriate Richardson constant A^* and probabilities of the overbarrier carrier emission and tunneling as well as a function of the ratio of the recombination and diffusion velocity). We have assumed $A^{**} = A^*$ and $A^*/A = m_h^*/m_0$ as for a semiconductor with the isotropic effective mass of carriers m_h^* where $A = 1.2 \times 10^6$ $Am^{-2}K^{-2}$ is the Richardson constant for a free electron with mass m_0. The effective mass m_h^* of heavy hole in CdTe we have taken at different temperatures from the ones of Ref. [18]. Thus, if n is experimentally obtained from Eq. (3), Eqs. (1) and (4) can be solved and the value of the Schottky barrier height obtained.

The Φ_B-value obtained from CV characteristics of In-CdTe contacts at 300 K varies between 0.58 eV and 0.67 eV having a mean value of 0.60 eV whereas for Au-CdTe contacts at 300 K it varies between 0.51 eV and 0.55 eV with the mean value of 0.52 eV.

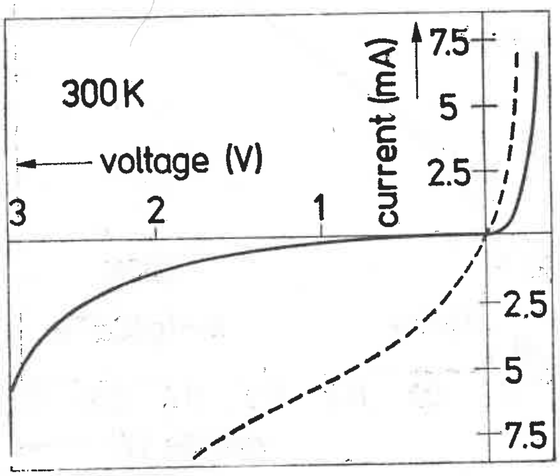

Fig. 6. CV characteristics of Au-CdTe contact at 300 K soon after evaporation (solid line) and 800 HR after (broken line)

It has been noted that the CV characteristics of Au-CdTe contacts change their plots with time as shown in Fig. 6. The origin of this phenomenon is still unknown, this problem requires further investigation.

The results of PV measurements (Figs. 4a, b) allow one to obtain the $(U_{PV} \times h\nu/I_0)^{1/2}$ vs photon energy plots presented in Figs. 7a, b for both configurations of contact lighting shown in Fig. 3.

With Fowler's carrier distribution [19] and the relation[2]

$$\left(\frac{U_{PV}}{I_0}h\nu\right)^{1/2} \sim (h\nu - \Phi_B), \tag{5}$$

we obtained the Φ_B values at 300 K as a cut-off of PV-plots from long waverange (in Figs. 7). For In-CdTe contacts Φ_B varies between 0.90 eV and 1.02 eV having the mean

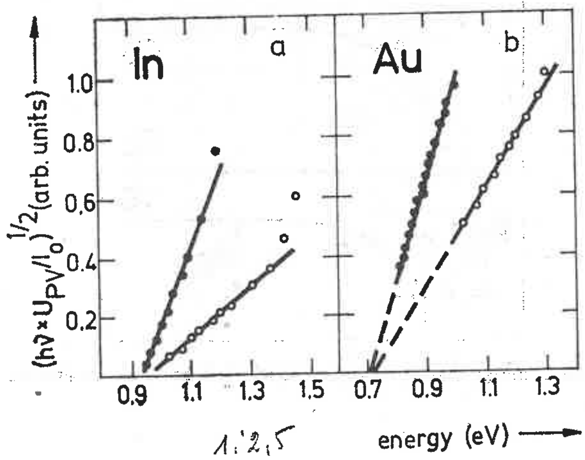

Fig. 7. $\left(\frac{U_{PV}}{I_0}h\nu\right)^{1/2}$ vs $h\nu$ for the In (a) and Au (b) contact at 300 K. Open and closed circles denote the front-wall and back-wall lighting, respectively

value of 0.95 eV whereas for Au-CdTe contacts $\Phi_B = 0.66\text{ eV} - 0.95\text{ eV}$ and the mean value of Φ_B is 0.84 eV.

A comparison between the values obtained from CV and PV measurements as well as between In-CdTe and Au-CdTe contacts allows one to draw the schematic energy band diagram (SEBD) of the contacts investigated, shown in Fig. 8. In the SEBD presented $E_F = 0.32$ eV is the Fermi level (above the valence band) acc. to holes concentration $p \cong 5 \times 10^{19}\ \text{m}^{-3}$ [20], and (a) and (b) are the two mechanisms of photoresponse generation which denote the emission of photoexcited holes from the Fermi level of metal to the valence band of the semiconductor (for $h\nu \geqslant \Phi_{B1}$) and band-to-band excitation of hole--electron pairs in the depleted region of the semiconductor (for $h\nu \geqslant E_g$), respectively. Φ_{B1} and Φ_{B2} represent, on one hand, the potential barrier for the electrons moving from the metal- and semiconductor-side, respectively. On the other hand, if by Φ_{B1} and Φ_{B2} we denote the barrier height obtained experimentally, from PV and CV measurements, respectively, then distinct differences between Φ_{B1} and Φ_{B2} should be expected. More precisely,

$$\Phi_{B1} - \Phi_{B2} = E_F, \tag{6a}$$

[2] Always for $h\nu \geqslant \Phi_B - 5kT$, see e. g. [15].

if the effect of surface states is neglected, and with the experimental (mean) results (see above) we have obtained

$$\Phi_{B1}-\Phi_{B2} = 0.95\ \mathrm{eV}-0.60\ \mathrm{eV} = 0.35\ \mathrm{eV} \quad (6b)$$

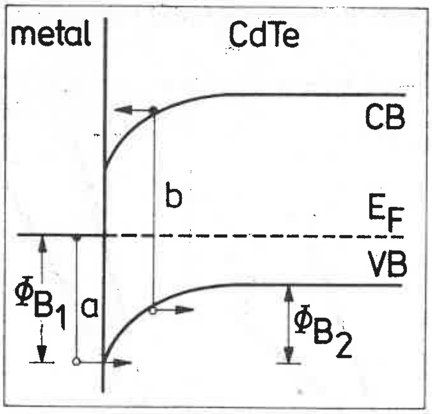

Fig. 8. Schematic energy band diagram (SEBD) of contacts measured, at 300 K

for In contacts and

$$\Phi_{B1}-\Phi_{B2} = 0.84\ \mathrm{eV}-0.52\ \mathrm{eV} = 0.32\ \mathrm{eV} \quad (6c)$$

for Au contacts, at 300 K. These results are in good agreement with the value of the Fermi-level energy, 0.32 eV, calculated from the semiconductor properties, taking also into account the experimental and computational errors.

It has been noted that often discussed equality between Φ_{B1} and Φ_{B2} (see e.g. [8] for metal-CdTe contacts) probably does not always exist for a Schottky contact with non-degenerate semiconductors, as has been shown in this paper.

The authors are deeply indebted to Dr. P. Becla and G. Wójcik, M.Sc., for their help in the measurements.

REFERENCES

[1] See, for example, *Metal-Semiconductor Contacts*, Inst. Phys. London, Conf. Ser. No 22, London 1974.
[2] A. van der Ziel, *J. Appl. Phys.* **47**, 2059 (1976).
[3] M. Lavagna, J. P. Pique, Y. Marfaing, *Solid-State Electron.* **20**, 235 (1977).
[4] M. Rodot, M. Barbe, J. Dixmier, *Rev. Phys. Appl.* **12**, 1223 (1977).
[5] Proc. of 2nd Internat. Symp. on CdTe, Strasbourg (France) 1976; *Rev. Phys. Appl.* **12**, No 2 (1977).
[6] J. Touškova, R. Kužel, *Phys. Status Solidi* (a) **10**, 91 (1972).
[7] J. Touškova, R. Kužel, *Phys. Status Solidi* (a) **15**, 257 (1973).
[8] J. Touškova, R. Kužel, *Phys. Status Solidi* (a) **36**, 747 (1976).
[9] Y. Marfaing, J. Lascary, R. Triboulet, in Ref. [1], p. 201.
[10] J. M. Pawlikowski, *Acta Phys. Pol.* **A49**, 139 (1976).

[11] J. M. Pawlikowski, P. Becla, K. Lubowski, K. Roszkiewicz, *Acta Phys. Pol.* **A49**, 563 (1976).
[12] J. M. Pawlikowski, *Acta Phys. Pol.* **A51**, 95 (1977).
[13] J. M. Pawlikowski, *Phys. Status Solidi* (a) **37**, K183 (1976).
[14] J. M. Pawlikowski, *Phys. Status Solidi* (a) **40**, 613 (1977).
[15] J. M. Pawlikowski, J. Żyliński, *Optica Applicata* **7**, 127 (1977).
[16] E. Ahlstrom, W. W. Gartner, *J. Appl. Phys.* **33**, 2601 (1962).
[17] C. R. Crowell, S. M. Sze, *Solid-State Electron.* **9**, 1035 (1966).
[18] K. Sierański, J. Szatkowski, E. Majchrowska, *Phys. Status Solidi* (b) **77**, K91 (1976).
[19] R. H. Fowler, *Phys. Rev.* **38**, 45 (1931).
[20] Our calculations, unpublished.