Optica Applicata, Vol. X, No. 1, 1980

Photo–effect on metal–$Cd_xHg_{1-x}Te$ ($x = 0.175$ and $x = 1$) contacts*

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Contacts on weakly-doped *p*-type CdTe samples and on moderate-doped *n*-type $Cd_{0.175}Hg_{0.825}Te$ ones were obtained by vacuum evaporation of Au and In. The photovoltage spectral characteristic were measured at the 77-300 K temperature range and the barrier height estimated.

Introduction

The choice of metal contacts with appropriate properties is an essential problem in the production of semiconductor elements as well as in the investigations of transport phenomena in semiconductor materials. The knowledge of the electrical properties of contacts to both wide-gap weakly-doped and small-gap semiconductors is of a particular importance because of relatively greater difficulty encountered in production of the ohmic contact and interesting phenomena.

An increasing interest in the properties of the rectifying metal-semiconductor contacts (commonly called s.o. Schottky diodes) observed in the recent years has been manifested by the numerous papers published yearly [1]. Special interest was, amang others, focused on the application of the Schottky diodes as e.g. nonlinear electronic elements and photovoltaic detectors or solar cells [2, 3]. Metal-CdTe contact is very suitable to this operation [4]; its properties and applications have been widely discussed in [5]. Technology, properties and applications of the metal-*n*-type CdTe contacts were investigated also in [6-10].

Our research on electrical transport properties of contacts with Te compounds was confined to the metal contacts with CdTe-HgTe mixed crystals, with small CdTe fractions [11-15]. In this work we describe the photovoltage experiments performed on contacts to weakly-doped *p*-type CdTe samples and moderate-doped *n*-type $Cd_{0.175}Hg_{0.825}Te$ ones, used by us in the solar-cells as well as the epitaxial $Cd_xHg_{1-x}Te$ layers technology.

Experimental

The semiconductor (111) surfaces were first ground and polished mechanically and next etched for about 2 min. in a 5% solution of Br in the methyl alcohol. The metalic contacts were prepared by vacuum ($p \cong 10^{-5}$ Torr) ($\cong 0.00133416$ Pa) thermal evaporation. The effective area of the samples was $8 \times 3\ mm^2$, the thickness equal to 70-400 μm, the contact surface being $1.64\ mm^2$. The contact configurations were similar as in [10]. The voltage electrodes were connected by indium soldering the Au wire of 0.1 mm diameter.

* Work sponsored under contract 7/78 (IM-116).

The carrier concentrations obtained from conductivity and Hall-voltage measurement were $p \cong 10^{19}-10^{20}$ m^{-3} at 300 K for CdTe and $n = 4\times10^{22}$ m^{-3} at 77 K, and $n = 3\times10^{23}$ m^{-3} at 300 K for $Cd_{0.175}Hg_{0.825}Te$.

The spectral measurements were performed in the wavelength range 0.35-μm 1.3 μm for CdTe contacts and 0.8-5.0 μm for $Cd_{0.175}Hg_{0.825}Te$ ones using the experimental arrangement, described in detail in [16]. The arrangement used allows to obtained directly the ratio of photoresponses of contacts investigated and standard detector. The schematic set-up of open-circuit photovoltage measurements has been described in [16] and contact configuration is shown in fig. 1. The monochromatic radiation

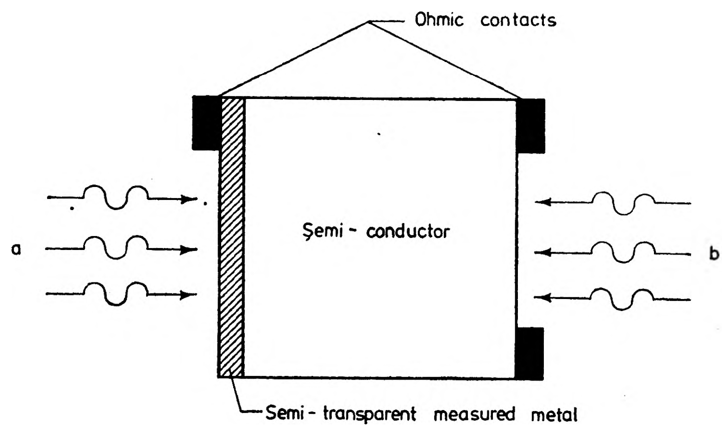


Fig. 1. Contact configuration used in photo-voltage experiments with front-wall (a) and back-wall (b) illuminations

were incident both upon the metal semi-transparent layers (with thickness $d_m \lesssim 15$nm) and the semiconductor surface (for CdTe-contacts only). The results obtained as the photovoltage spectra U_{PV}/I_0 (where U_{PV} is the open-circuit photovoltage and I_0 is the photon flux density) 1, 2 are exemplarily shown for In-$Cd_{0.175}Hg_{0.825}Te$ in figs. 2a and 2b, for Au-$Cd_{0.175}Hg_{0.825}Te$ — in figs. 3a and 3b, for In-CdTe — in figs. 4a and 4b, for Au-CdTe contacts — in figs. 5a and 5b, respectively, at 300 K and 77 K.

Discussion of results

The distinct difference has been observed between photovoltage plots of metal-$Cd_{0.175}Hg_{0.825}Te$ and metal-CdTe contacts. Main dissimilarity is lack of long-wave tails in photovoltage response for metal-$Cd_{0.175}Hg_{0.825}Te$ contacts. It is due to the difference in barrier height; in metal-CdTe contacts the relation $\Phi_B < E_g$ takes place, whereas in metal-$Cd_{0.175}Hg_{0.825}Te$ ones the relation $\Phi_B \gtrsim E_g$ arises [15]. It has also been noted that at 77 K the distinct minimum in photovoltage plots of metal-$Cd_{0.175}Hg_{0.825}Te$ contacts takes place for about 0.52 eV and about 0.45eV of In- and Au-contacts, respectively.

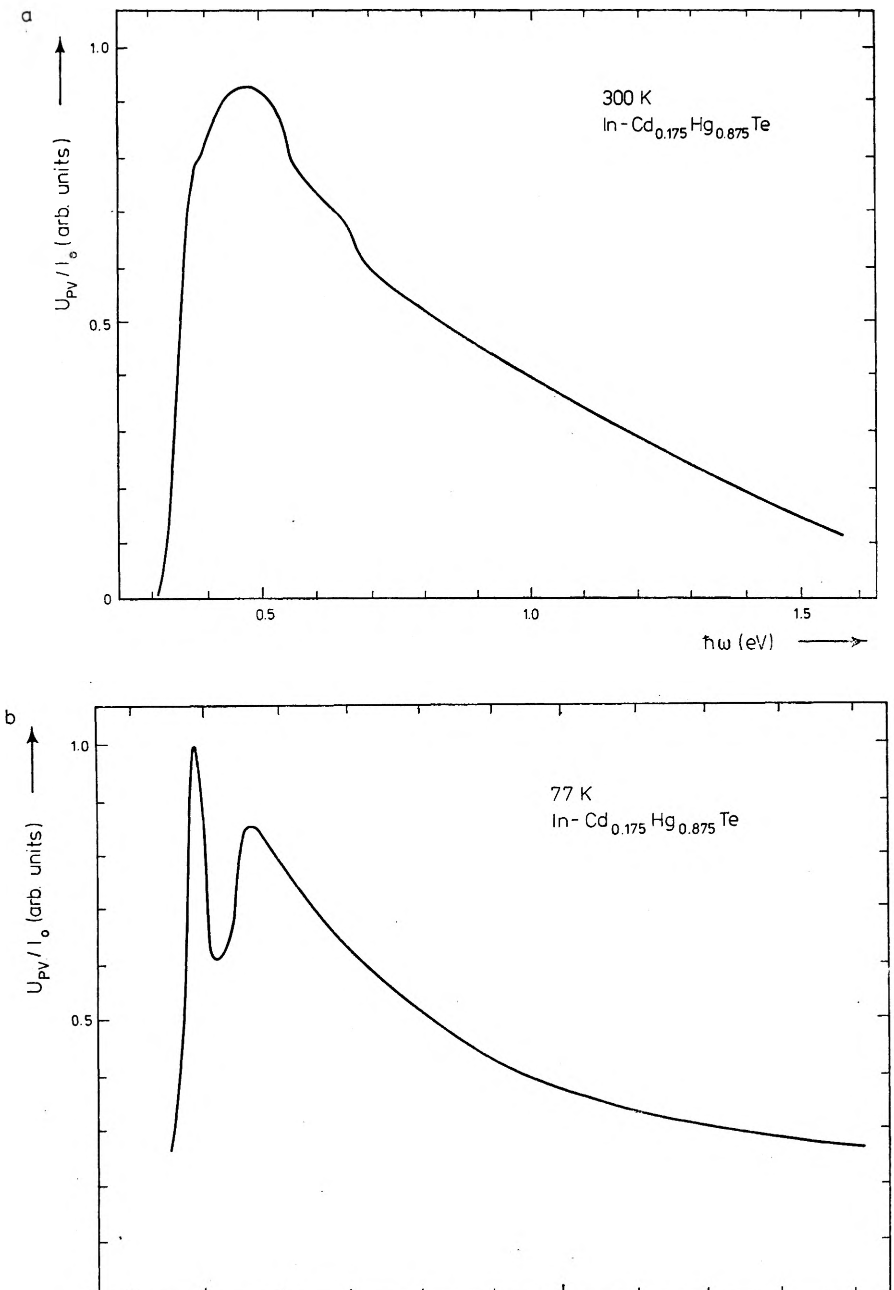
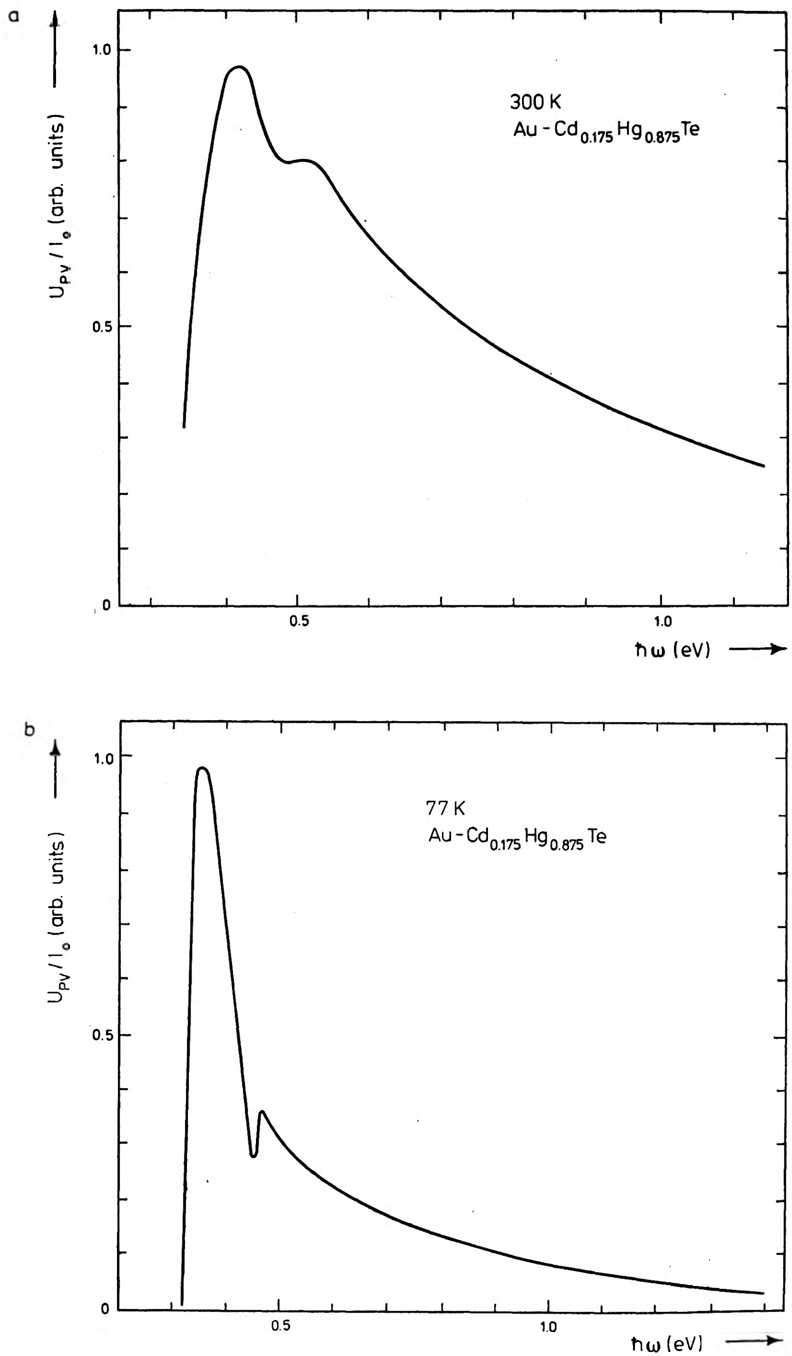


Fig. 2. Photovoltage spectra of In-$Cd_{0.175}Hg_{0.825}Te$ contact at 300 K (a) and 77 K (b)



Rys. 3. Photovoltage spectra of Au-$Cd_{0.175}Hg_{0.825}Te$ contact at 300 K (a) and 77 K (b)

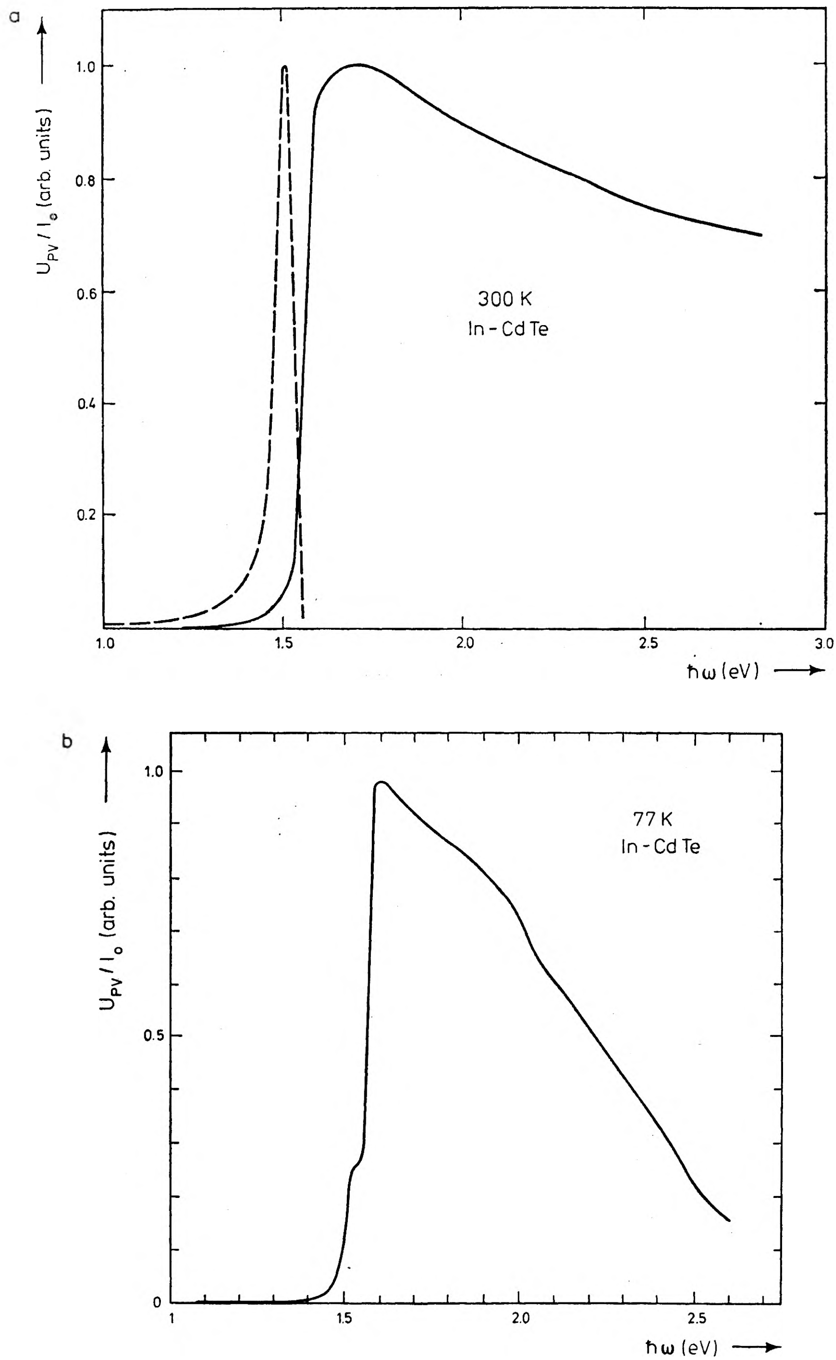


Fig. 4. Photovoltage spectra of In-CdTe contact at 300 K (a) and 77 K (b) for both configuration (at 300 K): front-wall lighting (solid line) and back-wall lighting (broken line)

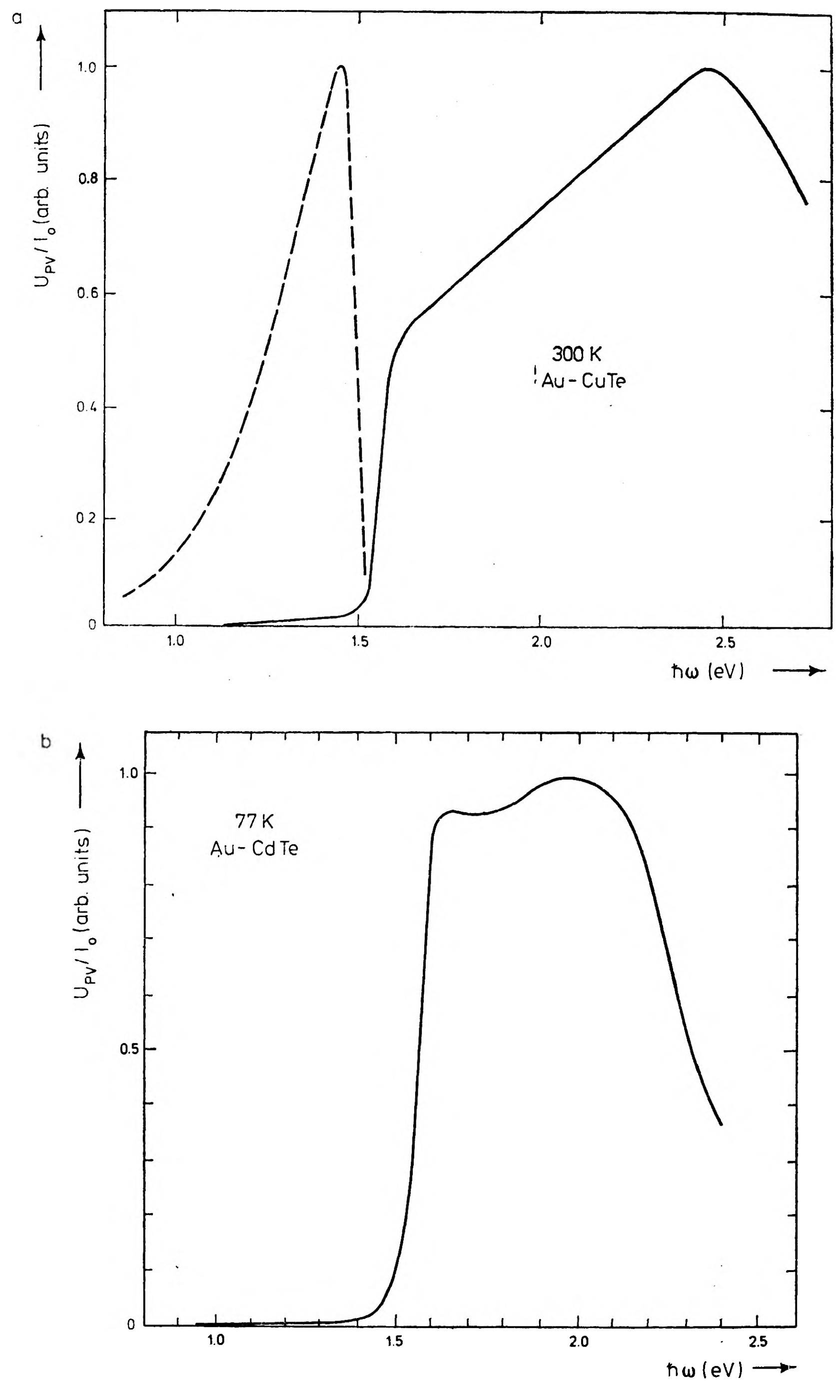


Fig. 5. Photovoltage spectra of Au-CdTe contact at 300 K (a) and 77 K (b) for both configurations (at 300 K): front-wall lighting (solid line) and back-wall lighting (broken line)

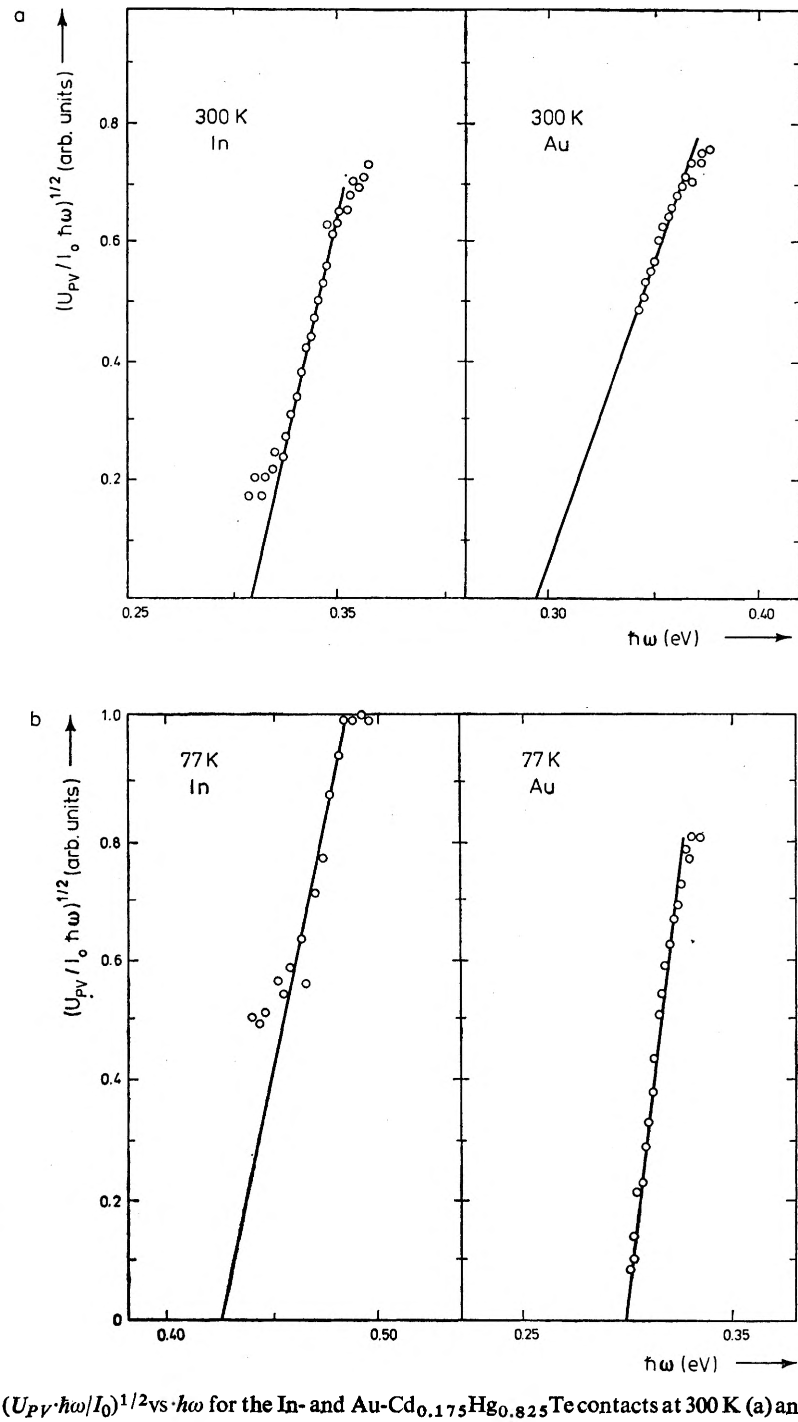


Fig. 6. $(U_{PV}\cdot\hbar\omega/I_0)^{1/2}$ vs $\cdot\hbar\omega$ for the In- and Au-$Cd_{0.175}Hg_{0.825}Te$ contacts at 300 K (a) and 77 K (b)

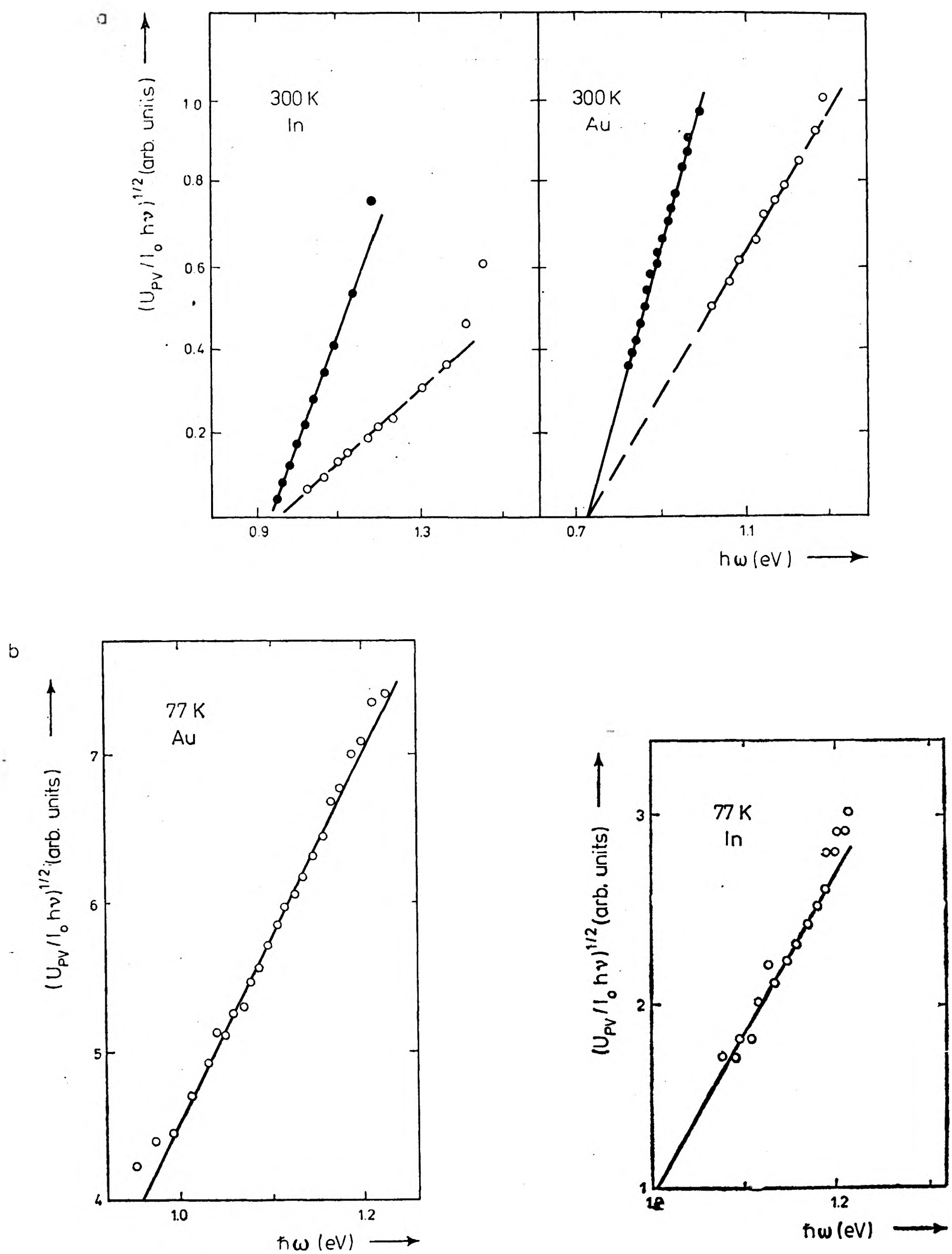


Fig. 7. $(U_{PV}\cdot\hbar\omega/I_0)^{1/2}$vs.$\hbar\omega$ **for the In- and Au-CdTe contacts at 300 K (a) and 77 K (b). Open and closed circles denote the front-wall and back-wall lighting, respectively**

The plots in figs. 4a and 4b show the fundamental dissimilarities between front--surface and back-surface illumination of contacts to CdTe. For back-wall lighting the observed sharp drop for $\hbar\omega \gtrsim E_g$ is due to fundamental absorption in semiconductor.

The results of PV measurements (figs. 2-5) allow to obtain the $(U_{PV}\cdot\hbar\omega/I_0)^{1/2}$ vs. photon energy plots, presented in figs. 6a, b and 7a, b for metal-$Cd_{0.175}Hg_{0.825}Te$ and metal-CdTe contacts, respectively.

Basing on FOWLER's carrier distribution [17] and using the relation*

$$\left(\frac{U_{PV}}{I_0}\hbar\omega\right)^{1/2} \sim [\hbar\omega - \Phi_B] \qquad (1)$$

we have obtained the Φ_B values as the values of cut-off of *PV*-plots from long wavelength.

Barrier height on metal-$Cd_{0.175}Hg_{0.825}Te$ contacts

Plots (1) for these contacts obtained from spectral characteristics presented in figs. 2, 3 are shown in figs. 6a and 6b (at 77 K).

The analyses of the obtained results allow to formulate the following conclusions:

a. Contacts measured are not Schottky-type (see also [15]). Overlooking the lack of precise data on work-function value of $Cd_{0.175}Hg_{0.825}Te$ and electron affinity of metal used, it is easy to state that $E_g \lesssim \Phi_B$ and that (what was stated early [11]) *n*-type $Cd_xHg_{1-x}Te$ with small x generally made ohmic contact to the metal used.

b. The obtained barrier height (mean values are presented in table 1) is probably due to the existence of high-density surface states on specimens used. In some contacts measured the photovoltage responses were weak (on the noise level), and relatively high dispersion in barrier-high values ($\Delta\Phi_B$) were observed. Additionally, no correlations (dependence on surface preparation, time of surface exposure on atmospheric conditions, etc.) were observed.

c. In general, Φ_B of In contacts is higher than of Au ones, being also higher rather at 77 K than at 300 K. A precise analysis cannot, however, be made at present.

Table 1

Mean values of barrier height Φ_B (in eV) of metal–$Cd_{0.175}Hg_{0.825}$ Te contacts ($\Delta\Phi_B = \pm 0.05$ eV)

	In	Au
77 K	0.42	0.31
300 K	0.29	0.29

Barrier height on metal-CdTe contacts

Plots (1) for these contacts obtained from spectral characteristics presented in figs. 4,5 are shown in figs. 7a (at 300 K) and 7b (at 77 K).

* Always for $\hbar\omega > \Phi_B + 5kT$, see e.g. [16].

The analysis of the obtained results allow to formulate the following conclusions:

a. The obtained Φ -values (mean values are presented in table 2) give the following relations between the barrier height and metal work-functions Φ_m:

$$\Phi_B = -0.14\ \Phi_m + 1.47\ \text{[in eV] at } 300\,\text{K},$$

and (2)

$$\Phi_B = -0.19\ \Phi_m + 1.56\ \text{[in eV] at } 77\,\text{K}.$$

Small values of slop coefficient γ in $\Phi_B = f(\Phi_M)$ indicate a relatively great influence of surface states on Φ_B-value.

Table 2

Mean values of barrier height Φ_B (in eV) of metal—CdTe contacts ($\Delta\Phi_B = \pm 0.1$ eV)

	In	Au
77 K	0.85	0.70
300 K	0.95	0.84

b. The surface-state density D_s may be estimated from the relation [18]:

$$D_s = \frac{1-\gamma}{e\gamma\delta}\,\varepsilon_i, \tag{3}$$

where the assumed dielectric constant of near-contact regions is $\varepsilon_i = 4\varepsilon_0$, and the thickness of depletion region near contact $\delta = 5.0$ nm. The D_s-values are equal to about 2.7×10^{17} eV^{-1} m^{-1} at 300 K and to about 1.9×10^{17} eV^{-1} m^{-1} at 77 K. A great influence of surface states on metal-CdTe contact properties was also observed in [19-22], however, was dissimilarly interpreted (including effects of excess-concentration of Cd or O_2 on the surface as well as effect of methods of surface preparations). In our opinion, all the above mentioned reasons and the influence of Br (from etching solution) are probable.

c. The temperature dependences of Φ_B both for In and Au contacts are in opposition to the simple Schottky model. The temperature coefficients $d\Phi_B/dT$ for In- and Au-contacts are positive and equal to 4.5×10^{-4} eV/K and 6.4×10^{-4} eV/K, respectively, being in opposition to dE_g/dT for CdTe which is negative and equals to -3.3×10^{-4} eV/K. So far these discrepancies have not been explained at present.

Acknowledgments — We express our best thanks to Mr. R. Polewski for his helpful technical assistance.

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Received, December 28, 1978

Фотовольтаический эффект на контактах металл-$Cd_xHg_{1-x}Te$ ($x = 0{,}175$, а также $x = 1$)

Были получены контакты Au и In к слабопримесному CdTe и среднепримесному $Cd_{0.175}Hg_{0.825}Te$ методом вакуумного испарения. Измерены спектральные характеристики фотоответа при температурах 77 и 300 K, а также оценена высота потенциального барьера.