ISSN 1063-7826, Semiconductors, 2009, Vol. 43, No. 3, pp. 379–381. © Pleiades Publishing, Ltd., 2009.
Original Russian Text © N.J. Ismailov, 2009, published in Fizika i Tekhnika Poluprovodnikov, 2009, Vol. 43, No. 3, pp. 396–398.

PHYSICS OF SEMICONDUCTOR DEVICES

$Cd_xHg_{1-x}Te$-Based Photodetector with the Spectral Characteristic Controlled by the Voltage

N. J. Ismailov^

Institute of Physics, Azerbaijan National Academy of Sciences, pr. G. Dzhavida 33, Baku, AZ-1143 Azerbaijan

^e-mail: ismailov namik@yahoo.com

Submitted December 24, 2007; accepted for publication May 15, 2008

Abstract—A photodetector with a spectral characteristic of the photoresponse controlled by the bias voltage is realized on the basis of the Al–n-$Cd_xHg_{1-x}Te$ heterostructure with a narrow insulator gap. The features of the spectral characteristic of the photocurrent are accounted for by the variation in the ratio between the surface and bulk components of the photocurrent upon varying the bias voltage. The possibility of simultaneous detection and control over the spectral characteristic of photosensitivity at the fundamental adsorption edge and in the short-wavelength spectral region is shown.

PACS numbers: 73.50.Pz, 73.50.Cr, 73.61.Ga, 73.40.Gv

DOI: 10.1134/S1063782609030221

1. INTRODUCTION

The spectral characteristic of photosensitivity is an important characteristic of photodetectors. It is known that the spectral characteristic of photosensitivity of photoresistors with a thickness on the order of the diffusion length of minority carriers depends on both bulk parameters of the semiconductor and on the state of the surface. For the $Cd_xHg_{1-x}Te$ alloys, which are the base materials for the fabrication of detectors of IR radiation, the state of the surface substantially affects its photoelectric properties. By depositing thin layers of various metals on the $Cd_xHg_{1-x}Te$ surface, one can control the spectral characteristic of photosensitivity in the fundamental absorption region [1, 2]. However, this method is of irreversible character since, after deposition of metal, the spectral characteristic remains the same. In certain optoelectronic applications, for the spectral analysis of the incident radiation, the necessity appears in photodetectors, in which the spectral characteristic of photosensitivity can be varied by applying the variable external voltage [3]. Such types of photodetectors involve the MIS photoresistors, in which an increase in conductivity of the near-surface layers of the semiconductor with the corresponding gate potential is used [4]. In this case, an increase in the spectral characteristic of photosensitivity is attained in the short-wavelength spectral region without varying the boundary of long-wavelength photosensitivity, which is determined by the fundamental absorption edge. However, for the structures with the Schottky barrier with the operational mechanism of intraemission, by varying the external bias voltage, it is possible to shift only the long-wavelength boundary of its photosensitivity spectrum [5]. In this article, we describe the $Cd_xHg_{1-x}Te$-based ($x = 0.28$) experimentally fabricated photodetector with a semitransparent aluminum layer deposited on the surfaces, the spectral characteristic of photosensitivity of which can be controlled by the applied voltage both in the short-wavelength region and in the region of the long-wavelength boundary.

2. EXPERIMENTAL

For the fabrication of experimental samples, we used the compensated n-$Cd_xHg_{1-x}Te$ single crystals with $N_D - N_A = (1–4) \times 10^{14}$ cm^{-3} and $\mu_n = (6–8) \times 10^4$ cm^2/(V s) at 77 K. The wafers were rectangular with the sizes $2 \times 5 \times 0.07$ mm. The ohmic contacts were formed by electrochemical deposition of In. The field's semitransparent electrode was fabricated by vacuum–thermal evaporation of Al through a mask to provide an intermediate gap of 0.1 mm between the electrode and ohmic contacts. The insulator gap between Al and narrow-gap $Cd_xHg_{1-x}Te$ was tunneling–impenetrable for charge carriers and was similar to the MIS structure with an ultrathin (5–6 nm) insulator layer. We reported the features of photoconductivity of narrow-gap $Cd_xHg_{1-x}Te$ with the Al coating in [6], where the measurement procedure was also reported. To detect the signal, we used an amplifier with a phase detector. In this structure, although all dc bias voltage U_0 applied to the gate dropped on the insulator gap, at a frequency of radiation modulation $f \approx 1$ kHz, because of the large capacitance of insulator C_d, the voltage drop of the signal across the structure of the surface–barrier was considerably smaller than across the load resistor R_L ($1/\omega C_d < R_L$).

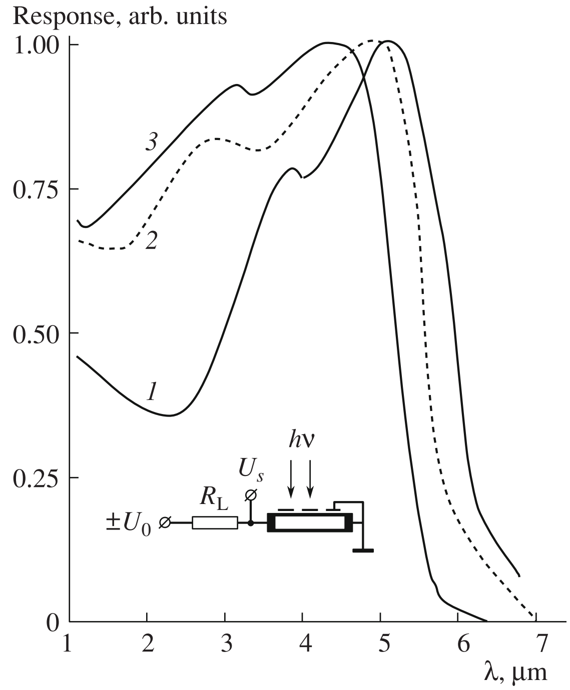

Fig. 1. Spectral distribution of photoconductivity of n-$Cd_xHg_{1-x}Te$ (*1*) prior to and (*2*) after coating with a semitransparent Al layer and (*3*) distribution of the photocurrent of the Al–n-$Cd_xHg_{1-x}Te$ surface–barrier's structure at an applied voltage of +1.5 V. Schematics of connections of electrodes of the structure is shown in the inset.

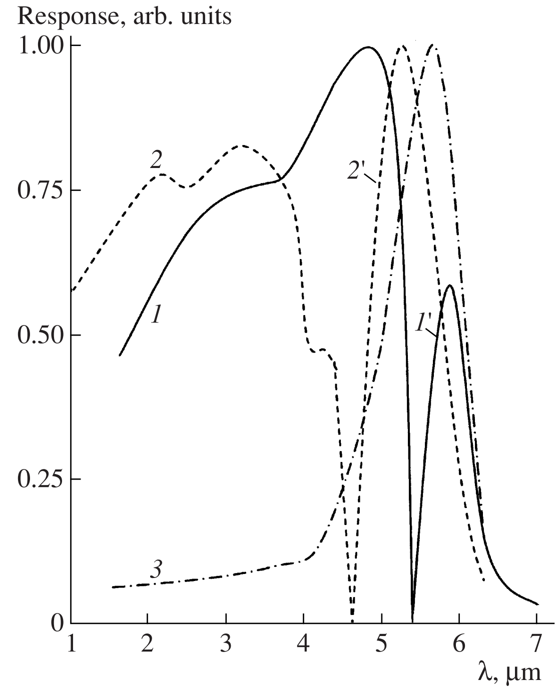

Fig. 2. Spectral distribution of the photoconductivity photocurrent for n-$Cd_xHg_{1-x}Te$ coated with a semitransparent Al layer at negative voltages: (*1*, *1'*) 0.05, (*2*, *2'*) 0.1, and (*3*, *3'*) 1.5 V. Curves (*1*), (*2*), (*3*) and (*1'*), (*2'*) correspond to photocurrents occurring in the antiphase.

3. RESULTS AND DISCUSSION

Figures 1 and 2 represent the spectral characteristics of the photoresponse of the considered photodetector at various bias voltages and $T = 80$ K. As evident from Fig. 1, at the positive polarity of the applied voltage for the mentioned circuit of connection of electrodes, a substantial increase in photosensitivity in the short-wavelength spectral region is observed compared with the photoresistor without the coating. For comparison, Fig. 1 also represents the spectral characteristic of the photoresponse at the zero bias, which coincides with the characteristic of the surface-barrier photoresponse of the Al–n-$Cd_xHg_{1-x}Te$ structure. In contrast, at negative bias voltages $|U_0| \geq 0.5$ V, a photosensitivity drop is observed in the short-wavelength region, and its peak falls on the fundamental absorption edge. At low negative voltages $|U_0| \leq 0.5$ V, the spectral characteristic consists of two regions with different signs of the value of the photosignal, namely, the long-wavelength portion with the sensitivity maximum at the fundamental absorption edge λ_1 and short-wavelength portion peaked at a certain $\lambda_2 < \lambda_1$. The wavelength value λ_3, at which the photosignal's sign changes, varies with the bias voltage.

In the structure under consideration, the photocurrent forming under illumination consists of the bulk component, which emerges in a quasi-neutral semiconductor region, and of the surface component of the photocurrent, which emerges in the near-surface region of the space charge. At a zero bias voltage, the signal on the series-connected load resistor R emerges due to the surface–barrier's photocurrent (Fig. 1). As the bias voltage is supplied, the bulk's photocurrent due to the photoconductivity also emerges. Depending on the polarity of the applied voltage, this photocurrent is added to the surface's photocurrent or is subtracted from it. Since the spectral characteristic of each component of the photocurrent varies differently depending on the radiation's wavelength, then, varying their ratio by varying the applied bias voltage, we can control the spectral characteristic of photosensitivity of the photodetector.

For the quantitative description of the observed features of the photocurrent, we can use the relations for the spectral dependence of the bipolar photoconductivity taking into account the conductivity of the quasi-neutral volume and surface region of the spatial charge [7]. For the photocurrent, under the positive bias, we can write the simplified expression:

$$U_s(\lambda) = eP_\lambda R_L \frac{\eta\lambda}{hc}\left\{\frac{U_0}{l^2}(\mu_n + \mu_p)(1 - e^{-kd})\right.$$

$$\left.\times\left[\tau_{ef}\left(1 - \frac{e^{-kw}}{1 + kL}\right) + \tau_v \frac{e^{-kw}}{1 + kL}\right] + I_s(U_0)\left(1 - \frac{e^{-kw}}{1 + kL}\right)\right\}.$$

Here, P_λ, λ, and k are the incident's power, wavelength, and absorption coefficient of radiation; η is the quantum efficiency; h is Planck's constant; e is the elementary charge; μ_n and μ_p are the electron and hole mobilities; l and d are the sample's length and thickness; w is the width of the space charge region; L is the diffusion length of minority carriers; τ_{ef} and τ_v are the effective and volume lifetimes of minority carriers; and $I_s(U_0)$ is the dependence of the surface–barrier's photocurrent on the applied voltage in relative units.

It is evident from the relation that the spectral dependence has an increase in the short-wavelength spectral region both due to the contribution of photoconductivity of the near-surface space charge region at $\tau_{ef} > \tau_v > l^2/U_0(\mu_n + \mu_p)$ and due to the contribution of the surface–barrier's photocurrent at $\tau_{ef}, \tau_v < l^2/U_0(\mu_n + \mu_p)$.

For the negative bias, the surface's photocurrent is directed oppositely to the bulk's photocurrent, and we can write the simplified relation for the photosignal

$$U_s(\lambda) = eP_\lambda R_L \frac{\eta\lambda}{hc}\left\{\frac{U_0}{l^2}(\mu_n + \mu_p)(1 - e^{-kd})\right.$$

$$\left.\times\left(\tau_v \frac{e^{-kw}}{1 + kL}\right) - I_s(U_0)\left(1 - \frac{e^{-kw}}{1 + kL}\right)\right\}.$$

At small negative values of the applied voltage, where these components are comparable and directed oppositely, the bulk component is dominant in the absorption edge region, and in the short-wavelength region, in the antiphase, the surface component is dominant. As the bias voltage increases, the surface bending of the bands decreases, and the effective rate of the surface recombination increases, which leads to a decrease in the surface–barrier's photocurrent, while the bulk component of the photocurrent increases proportionally to the applied voltage. As a result, the wavelength λ_3, at which the change in the signal's sign is observed, and the long-wavelength boundaries of the surface and bulk components of the photocurrent are shifted to the short-wavelength region. At the applied bias voltages $|U_0| >$ 0.5 V, where the surface bands are almost flat and we can disregard the surface's photocurrent, the purely bulk component of the photocurrent prevails, which is observed experimentally.

The calculated values of spectral dependences by these relations agree well with the experimental ones with the use of actual absorption factors, which appreciably differ from the theoretical ones for the compensated samples at the fundamental absorption edge. This is explained by the presence of different microinhomogeneities in the compensated sample and by the existence of the vacancy band [8]. The dependence $I_s(U_0)$ used in the formula was also obtained from the measurements and was similar to that presented in [6], which is more gently sloped compared with the ideal calculated curve because of the effect of the surface states.

If the amplifier with the phase detector is used for the detection of radiation, we can simultaneously use both portions of the spectral characteristic varying them by changing the sign and the value of the applied bias voltage. This feature makes this photodetector attractive for the application, for example, in analyzers of the spectrum of the detected radiation or as the two-band photodetector for actual ranges of the infrared spectral region, which correspond to the atmospheric transparency windows.

Therefore, by the example of the structure Al–*n*-$Cd_xHg_{1-x}Te$, it is shown that based on the uniform semiconductor with a constant band gap, it is possible to realize the photodetector, the spectral characteristic of which can be controlled by the applied bias voltage both at the edge and in the region of fundamental absorption.

REFERENCES

1. E. P. Matsass, A. I. Vlasenko, E. A. Sal'kov, O. V. Snitko, and A. V. Lyubchenko, Ukr. Fiz. Zh. **26**, 670 (1981).
2. N. J. Ismailov and E. K. Guseinov, Tr. J. Phys. **18** (4), 669 (1994).
3. V. L. Bakumenko and A. N. Sviridov, Prikl. Fiz., No. 2, 34 (1999).
4. V. A. Zuev and V. G. Popov, *Photoelectrical MIS-Devices* (Radio i Svyaz', Moscow, 1983) [in Russian].
5. L. Pahun, Y. Campidelli, F. Arnaud d'Advitava, and P. A. Bodoz, Appl. Phys. Lett. **10**, 1166 (1992).
6. É. Yu. Salaev, É. K. Guseinov, A. Tezer, and N. D. Ismailov, Fiz. Tekh. Poluprovodn. **31**, 740 (1997) [Semiconductors **31**, 635 (1997)].
7. V. A. Zuev, V. G. Litovchenko, V. G. Popov, and G. A. Sukach, Poluprovodn. Tekhn. Mikroelektron., No. 12, 32 (1973).
8. L. A. Bovina and V. I. Stafeev, in *Physics of II–VI Compounds*, Ed. by A. N. Georgobiani and M. K. Sheinkman (Nauka, Moscow, 1986), ch. 8, p. 276 [in Russian].

Translated by N. Korovin