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HELIOTECHNICAL MATERIALS SCIENCE

Study of Properties of Tellurium-Doped Indium Phosphide as Photoconversion Material

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Abstract—The results of the studies of n-InP⟨Te⟩ with simple ohmic contacts in the temperature range of 30–250°C have been given because this material is promising for the photoconverters due to its wide band-gap and radiation resistance. It has been determined that, at a temperature of $T > 50$°C, this structure generates current (up to 0.15 μA) and voltage (up to 11 mV); this is caused by the thermally stimulated formation of vacancies.

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Despite that, until recently, silicon has remained the main material for manufacturing photoconverters, in recent decades, much attention has been devoted to the search of new materials, which are able to compete with silicon. Here, the primary role belongs to $A^{III}B^{V}$-type semiconductors, primarily gallium arsenide and indium phosphide, because they have wider band gaps than silicon. In this case, indium phosphide represents a particular interest due to its high radiation resistance.

The opportunities of the development of thermally stimulated voltaic processes in wide-band-gap semiconductors in the temperature range, which does not exceed remarkably room temperatures, 30–300°C, were considered. It should particularly be noted this refers exclusively to processes that occur with the simultaneous heating of the material under study. Thus, the experimental conditions exclude the possibility of the development of thermally stimulated voltaic effects caused by the development of temperature gradient in material; among other factors, the possibilities of the development of Seebeck, Peltier, and other effects are excluded.

The samples of tellurium-doped indium phosphide of n-type conduction grown by the Chokhral'skii method with the initial concentration of electrons $n_n = 7.0 \times 10^{17}$–1.4×10^{18} cm^{-3} were studied. The simple aluminum ohmic contacts were attached to these samples; from one side, they were continuous and, from the other side, they were attached as a ribbon. The results of the measurements of current and voltaic temperature dependences observed in the temperature range of 30–250°C are given in Figs. 1a and 1b.

As follows from Fig. 1, both current and voltage have a clear nonlinearity in the particular temperature

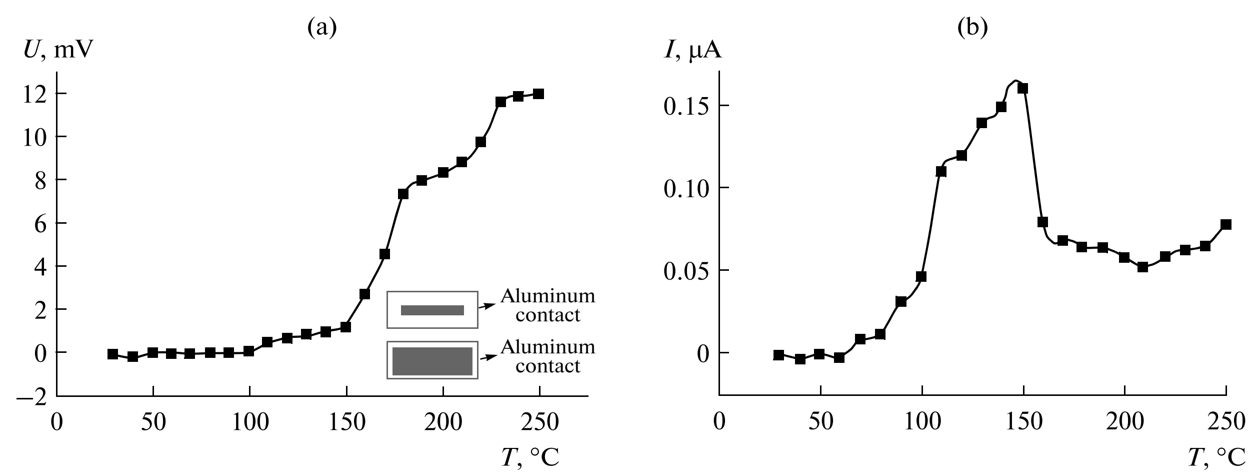

Fig. 1. Temperature dependences of (a) voltage and (b) current for n-type InP⟨Te⟩ sample with ohmic contacts (schematic representation of sample is given in Fig. 1a).

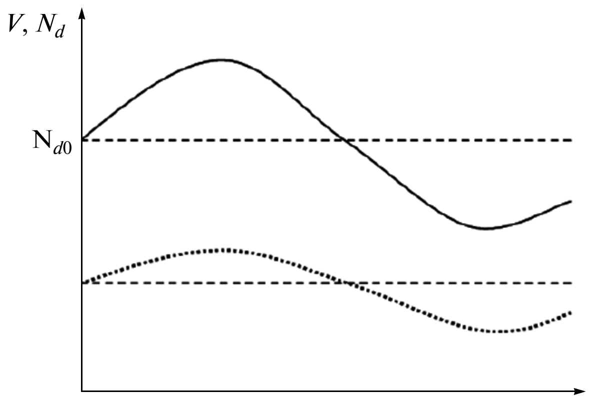

Fig. 2. Qualitative view of the distribution of vacancies V and donors N_d in sample.

range; the current begins to drastically increase at the temperature that is somewhat higher than 50°C; and voltage, at $T > 150°C$. It should particularly be noted that the observed dependences were obtained on the samples with simple aluminum ohmic contacts. This material was chosen for studies because EPR spectra show that, in wide-band-gap materials of the $A^{III}B^{V}$-type with n-type conduction grown according to the Chokhral'skii method, there are no free vacancies at room temperature [1]. In the $A^{III}B^{V}$ compounds with n-type conduction, cationic vacancies are fairly mobile and because they are in fact acceptors and usually negatively charged, they bind easily with shallow donors via Coulomb forces, which are introduced to obtain n-type conduction. In particular, in indium phosphide, this is the complex of indium vacancy + donor tellurium atom type. When the concentration of shallow donors in material is higher than the concentration of vacancies, all vacancies form complexes with these donors and there are almost no free vacancies. This is confirmed by the EPR studies because EPR signal related to vacancies is only observed in materials with p-type conduction, which is absent in n-type materials.

Based on these assumptions, i.e., considering that there are no free vacancies in the studied material and there are only complexes of the shallow donor + vacancy type, the processes that occur in this material upon exposure to various temperatures were considered. Using the considerations developed in the works of V.I. Fistul' and M.I. Sinder [2, 3] when calculating the diffusion impurity kinetics of the formation of mobile complexes, let us represent the equation of the free vacancy formation as the result of the decay of the complexes on exposure to temperature as follows:

$$D_V\frac{d^2V}{dx^2} + K(Q)V = 0, \qquad (1)$$

here, D_V is the coefficient of vacancy diffusion and $K(T)$ is the coefficient of vacancy formation, which directly depends on temperature.

When generating this equation, it was suggested that concentration of newly forming vacancies is very small and the decay of complexes proceeds more intensely with temperature than their formation. The solution of Eq. (1) describes the vacancy distribution in the sample under study:

$$V = C_1\cos(\omega x) + C_2\sin(\omega x), \qquad (2)$$

where $\omega = \sqrt{\frac{K(T)}{D_V}}$ is the frequency of forming distribution and C_1 and C_2 are integration constants, which are determined by the boundary conditions; i.e., $V = V(0)$ at $x = 0$, $V = V(d)$ at $x = d$ ($x = 0$ and $x = d$ are boundaries of sample). Equation (2) can be rewritten as follows:

$$V = V_0 + V^*\sin(\omega x), \qquad (3)$$

where V_0 is average concentration of vacancies and V^* is their variation amplitude.

The periodic distribution of vacancies, which act as acceptor recombination centers, unambiguously proves the possibility of the development of thermally stimulated self-organization in considered material [4–6]. We suggest that, as a consequence of uniform heating of this homogeneous sample, the decay of complexes of shallow donor + vacancy type proceeds and vacancies begin to distribute along sample periodically according to Eq. (3). It should be emphasized that, in this case, the equivalent number of free donors is released and the concentration of newly released donors is added to their initial concentration, which determines the type of conduction of the sample and can be represented as follows:

$$N_d = N_{d0} + N_d^*\sin(\omega x), \qquad (4)$$

where N_{d0} is initial concentration.

In addition, the distribution of the concentration of donors would repeat the vacancy distribution (Fig. 2). The appearance of the periodical vacancy distribution unambiguously confirms the formation of Dember-type internal electrical field as follows:

$$E_D = -\frac{kT}{q}\frac{1}{bn+p}\left(b\frac{dn}{dx} - \frac{dp}{dx}\right). \qquad (5)$$

Consequently, the free carriers formed at uniform heating would be separated by the formed potential barrier and generate the voltage $V_D = \int_0^d E_D dx$. Consequently, during heating, the isotype potential barrier of n–n^+ type is formed in studied material.

The free carriers appearing after uniform heating would partition between this barrier; this would cer-

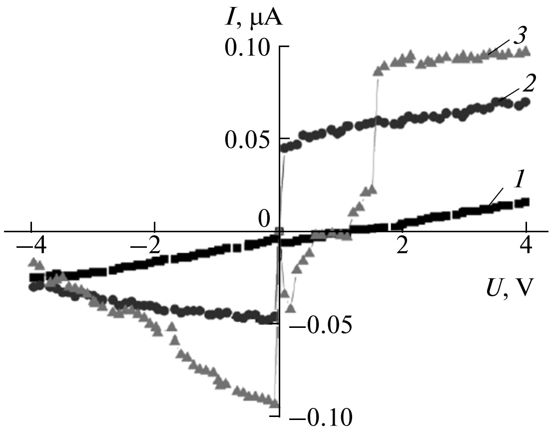

Fig. 3. Current-voltage characteristics of n-InP⟨Te⟩ structure with simple ohmic contacts measured in the temperature range of 30–250°C at (*1*) 25, (*2*) 100, and (*3*) 150°C.

tainly lead to the formation of thermally stimulated currents and voltages, which are given in Figs. 1a and 1b.

When the potential barrier is formed in homogeneous semiconductor material, the rectification of the current must occur; i.e., observed CVCs should certainly differ from ohmic. In order to verify this idea, the temperature dependences of CVCs of studied InP⟨Te⟩ structure with ohmic contacts were measured. The results of these measurements are given in Fig. 3.

Analogous results were obtained in n-type tin-doped gallium arsenide. The structures with simple ohmic contacts manufactured from this material had rectifying properties and generated currents and voltages at the temperatures $T > 30°C$ [7].

Thus, the performed studies prove the opportunity of developing thermovoltaic phenomena in n-type tellurium-doped indium phosphide. These phenomena would presumably be observed in $A^{III}B^{V}$ semiconductors grown according to the Chokhral'skii method that have n-type conduction at a fairly high concentration of shallow doping donors that set the type of conduction.

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