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INFLUENCE OF THE POTENTIAL FLUCTUATIONS ON THE CONDUCTION OF In_2Te_3 AND $Hg_3In_2Te_6$ COMPOUNDS

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Current-voltage characteristics (I–V) of the In_2Te_3 and $Hg_3In_2Te_6$ compounds under warming electric field in dependence on doping have been investigated. It is shown that I–V are caused by two mechanisms: carrier heating and decrease of conductivity activation energy while percolation level is also decreasing. Characteristic space and energy sizes of random potential, which modulates the bottom of conduction band and their dependence on the doping impurity type were estimated.
Key words: stoichiometric vacancies, potential fluctuations, percolation level.

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In_2Te_3 and $Hg_3In_2Te_6$ compounds are semiconductor crystals that have a zinc-blend lattice containing high concentration ($5.5\cdot10^{21}$ and $2.7\cdot10^{21}$ cm^{-3} respectively) of stoichiometric vacancies. On the one hand such defectiveness of cation sublattice leads to a distortion of periodicity and potential field. It causes localized state formation in energy gap, arising the tail of absorption edge [1,2] and static negative S-type differential resistivity [3] as well, that approaches the object investigated to unordered semiconductors [4]. On the other hand, crystallochemical peculiarities of semiconductors with stoichiometric vacancies cause specific, but very useful properties for practical applications such as wide spectrum ranges of photoconductivity (0.74–3.5 eV) and transparency (2–25 μm), wide temperature range (T>150 K) of intrinsic conductivity, electrical inactivity of introduced impurities and high irradiation resistance of parameters to external radiation. In_2Te_3 and $Hg_3In_2Te_6$ crystals are perspective materials for fabrications of photodiodes, optical filters, X-ray and nuclear radiation detectors [5], that makes it actual to investigate semiconductors with stoichiometric vacancies. Further study of phenomena caused by stoichiometric vacancies will lead to a significantly deeper understanding of the properties of semiconductors with uncompleted lattices.

The object of the present work is to investigate the influence of doping on I–V of In_2Te_3 and $Hg_3In_2Te_6$ compounds and to determine why I–V deviates from real conductivity in positive differential resistance region. We used the In_2Te_3 samples, undoped and doped with Fe, Mn and Cu up to the concentration of $5\cdot10^{20}$ cm^{-3} and $Hg_3In_2Te_6$ samples, doped with Fe, Cu, and Sn up to the concentration of $8\cdot10^{19}$ cm^{-3} and undoped ones to perform the measurements. Because of high values of the energy gap E_g and stoichiometric vacancy concentration In_2Te_3 specimens had greater electrical resistivity than that of $Hg_3In_2Te_6$ specimens. Inspite of a high impurity level the resistivity of doped specimens remains within proper dispersion range of resistivity distribution along the ingot at the absence of special doping. The I–V were measured at room temperature in continuous current regime for massive specimens with the width of 0.02–0.2 cm. It was noticed that type of contacts has no essential influence on I–V curves. Figures 1 and 2 plot the experimental (points) dependencies of current density j versus the electric field E. One can see that in weak fields the dependence is linear $j=\sigma_0E$, which means that Ohm's law takes place. At electrical fields that exceed some critical value E_{cr} the situation changes and the Ohm's law is not being fulfilled any longer for the specimens investigated. It turned out that doping of our crystals leads to a decrease of critical field value E_{cr} (see Table 1).

Compounds	σ_0, Ohm^{-1}cm^{-1}	a^2, cm^2/V^2	b	v	E_{cr}, V/cm	r, cm	V_0, eV
In_2Te_3	$1.4\cdot10^{-7}$	$1.3\cdot10^{-6}$	0.017	0.86	3834	$6.7\cdot10^{-6}$	0.274
In_2Te_3 <Cu>	$1.3\cdot10^{-7}$	$4\cdot10^{-5}$	0.024	0.86	3493	$7.4\cdot10^{-6}$	0.525
In_2Te_3 <Mn>	$4.4\cdot10^{-7}$	$2.8\cdot10^{-4}$	0.042	0.92	1837	$1.4\cdot10^{-5}$	0.554
In_2Te_3 <Fe>	$3.3\cdot10^{-7}$	$1.6\cdot10^{-4}$	0.036	0.96	2830	$9.1\cdot10^{-6}$	0.494
$Hg_3In_2Te_6$	$9.1\cdot10^{-4}$	0.946	0.179	0.86	52.6	$4.9\cdot10^{-4}$	0.317
$Hg_3In_2Te_6$ <Fe>	$6.3\cdot10^{-4}$	0.306	0.271	0.86	41.9	$6.2\cdot10^{-4}$	0.592
$Hg_3In_2Te_6$ <Cu>	$1.1\cdot10^{-3}$	0.228	0.258	0.86	38.2	$6.8\cdot10^{-4}$	0.476
$Hg_3In_2Te_6$ <Sn>	$8.8\cdot10^{-4}$	0.275	0.273	0.86	34.4	$7.5\cdot10^{-4}$	0.475

Table 1. Parameters of In_2Te_3 and $Hg_3In_2Te_6$ crystals and coefficients of (1).

It is known [6,7] that deviation from Ohm's law might be due to carrier heating phenomenon and decrease of conductivity activation energy because of percolation level reduction as well. Considering this, the formula for I–V curve can be written in the following form:

$$j = \sigma_0 E \sqrt{\frac{2}{1+\sqrt{1+8a^2E^2}}}\ \exp(bE^{1/(1+v)}), \tag{1}$$

$$b = \frac{1}{kT}\left(\frac{1}{4}erV_0^v\right)^{1/(1+v)}, \tag{2}$$

where σ_0 is electrical conductivity in the weak electric field $E < E_{\rm cr}$, a^2 is a quantity describing carrier heating at the presence of acoustic phonons [6], r is space size of random potential, V_0 is random potential amplitude, v is critical index of percolation theory [7].

Figures 1 and 2 show that experimental I–V curves are well described by dependence (1) in all the investigated range of the electrical field tension. Using the fact that experimental and calculated values of current density must coincide, we determined parameters of formula (1), values of space size and random potential amplitudes, using expression [7]:

$$eE_{\rm cr}r \leq kT. \tag{3}$$

Obtained parameters are presented in the Table 1.

Critical index for different specimens appears to be close to the theoretical value $v_{\rm th} = 0.88$ [7]. The obtained amplitudes of random potential that fulfills $V_0 \gg kT$, allow us to consider potential fluctuations studied to be large-scale and proves that the real conductivity

$$\sigma \sim \exp\left\{-\left(V_p - \mu\right)/kT\right\}$$

is caused by activation of electrons from Fermi level μ to percolation level V_p of conduction band, which is distorted by random potential. At electrical fields $E > E_{\rm cr}$ activation energy decreases that causes percolation level reduction. It leads to an increase of charge carrier concentration, rises the value of σ and makes I–V dependence non-linear. It is obvious that doping leads to an essential increasing of energy and space size of random potential that indicates the increase of unordering of In_2Te_3 and $Hg_3In_2Te_6$ structures under impurity injection [7].

Therefore, using experimental and theoretical calculations we confirmed in this work the existence of intrinsic random potential with sufficiently large amplitudes and space size in undoped the In_2Te_3 and $Hg_3In_2Te_6$ crystals. The existence of this large-scale potential can influence considerably on galvanomagnetic, optical and photoelectrical phenomena in the In_2Te_3 and $Hg_3In_2Te_6$ compounds. It is necessary to study of this phenomenon further.

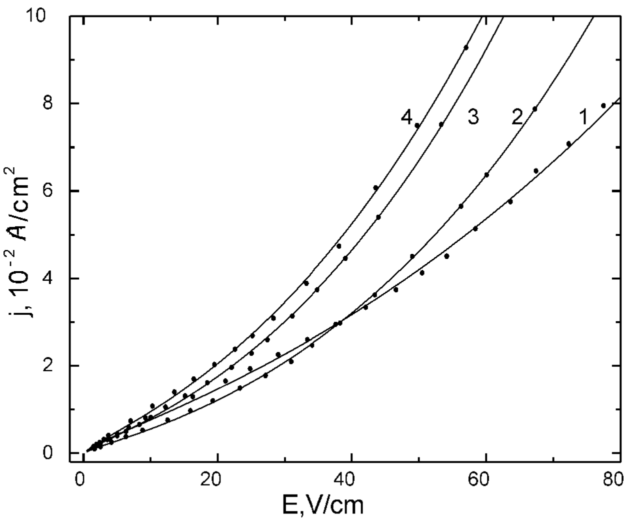

Fig. 1. Current-voltage charactaristics of undoped (1) and doped Cu (2), Fe (3), Sn (4) $Hg_3In_2Te_6$ samples. Impurity concentration is $8 \cdot 10^{19}$ cm^{-3} for all the samples. Solid lines represent results of theoretical calculations with formula (1).

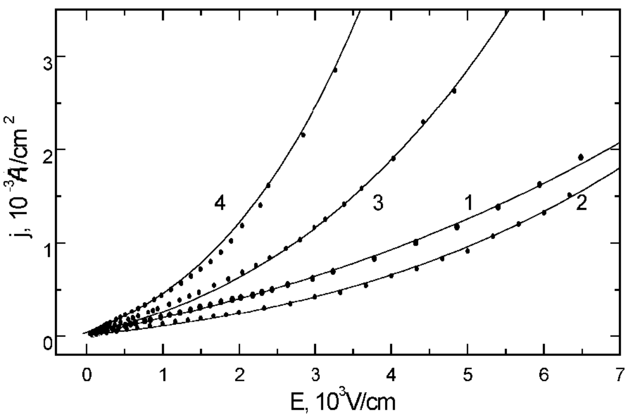

Fig. 2. Current-voltage charactaristics of undoped (1) and doped Cu (2), Fe (3), Mn (4) In_2Te_3 samples. Impurity concentration is $5 \cdot 10^{20}$ cm^{-3} for all the samples. Solid lines represent results of theoretical calculations with formula (1).

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ВПЛИВ ФЛЮКТУАЦІЙ ПОТЕНЦІЯЛУ НА ПРОВІДНІСТЬ СПОЛУК In_2Te_3 І $Hg_3In_2Te_6$

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Досліджено вольтамперні характеристики (ВАХ) у сполуках In_2Te_3 і $Hg_3In_2Te_6$ в ділянці гріючих електричних полів залежно від леґування. Показано, що ВАХ зумовлені двома механізмами: наявністю розігріву носіїв та зменшенням енерґії активації провідности при пониженні рівня протікання. Оцінено характерні просторові й енерґетичні розміри випадкового потенціялу, який модулює дно зони провідности, та їхню залежність від типу леґуючої домішки.