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Physics of semiconductor

DETERMINATION OF EFFECTIVE MASSES OF ELECTRONS AND HOLES IN $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ SOLID SOLUTIONS FROM THE MEASUREMENT OF THE KINETIC COEFFICIENTS IN WEAK MAGNETIC FIELDS

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(Presented by Academician of NAS of Azerbaijan J.Sh. Abdinov)

Temperature dependence of electrical conduction $\sigma(T)$, Hall coefficient $R(T)$ and the coefficient of thermo electromotive force $\alpha(T)$ in $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ ($0 \leq x \leq 0.10$) solid solutions at 80-1000 K have been investigated. Effective masses of electrons and holes have been determined on the basis of kinetic parameters. It is found that starting from $x=0.05$ $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ solid solutions belong to narrow-gap semiconductors having high values of interaction matrix element.

Keywords: width of forbidden gap, effective mass, reduced chemical potential, narrow-gap semiconductors

It is shown in [1] that at room temperature solubility region up to 10% TlYbTe_2 is observed in the $\text{TlInTe}_2 - \text{TlYbTe}_2$ system on the base of TlInTe_2 . The characteristic property of crystals of $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ solid solutions is the presence of stoichiometric vacancies with high concentrations ($10^{18} - 10^{20} \text{sm}^{-3}$) in their crystal lattice and localized states related to them in the forbidden gap [1-6], and this value rises with the growth of mole fraction of ytterbium in the composition of solid solutions. The formation of solid solutions leads to changes in electron and lattice subsystems of a crystal causing static deformation of the lattice and disturbance of electron-phonon spectrum. With increasing concentration of solid solution vacance the average spacing of atoms of TlYbTe_2 dissolved substance attains the values at which interimpurity interaction begins to make a significant contribution to energy of TlInTe_2 solvent crystal [2] and this brings about the appearance of principally new properties not characteristic of the initial material. So, when doping TlInTe_2 some rare-earth elements (Gd, Pr, Nd, Eu, Dy, Yb) stabilization effect of Fermi level is evident while its position is determined only by the composition of alloy and does not depend on the concentration of doping impurities [1,3,7].

In research [4] have been investigated electrical properties of $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ at weak and strong electric fields and the authors observed

VAC change over. In research [5,6] temperature dependences of thermoelectromotive force and thermal conductivities of $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ solid solutions have been studied and normal processes and scattering on point defects are shown to play an active role in phonon scattering simultaneously with U-processes. The authors of researches [1-4] also have demonstrated that samples of $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ posse changing-over properties with electric memory and high thermoeffectivity.

Even though a number of researches [1-6] dealt with the study of electrical and thermal properties of $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ the said researches did not investigate the influence of ytterbium on energy spectrum of charge carriers. This problem is of special scientific and practical interest because a change-over from TlInTe_2 to $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ allows to improve thermoelectric properties at temperatures of $T > 600 \text{K}$ and create thermocouples for thermo generators as p-branch [8-11]. To stabilize the functioning of thermo generators special attention is centered on the study of electron spectrum of charge carriers [8]. For this reason the object of this research is the study of energy spectrum of charge carriers in $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ solid solutions. The present research has investigated temperature dependences of electrical conduction (σ), Hall coefficient (R) and thermo electromotive

force (α) in $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ solid solutions ($0 \leq x \leq 0,10$) at $80 \div 1000\text{K}$. The mentioned parameters σ , R and α were measured on samples with ohmic contacts at direct current [5] in constant magnetic fields up to 1200 A/m . The error of the measurements did not exceed 4-5%.

Results and discussion

Temperature dependences of electrical conduction $\sigma(T)$ of $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ solid solutions are displayed in fig.1. As seen from this figure, the $\sigma(T)$ dependences for different compositions of the solid solutions are substantially unlike one another. The intrinsic region of conduction for the initial compound TlInTe_2 begins at the temperature $\sim 700\text{K}$ while the intrinsic region shifts towards higher temperature in $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ solid solutions with increase in relative content of ytterbium in the compositions (Fig.1). From slopes of the curves $\lg\sigma(10^3/T)$ in high temperature region was assessed thermal width of the forbidden gap (E_{g_0}) at $T=0\text{K}$ for the investigated samples: it got revealed that as the content of relative quantity of ytterbium in compositions of the solid solutions becomes higher E_{g_0} changes from $0,70\text{eV}$ for the initial compound TlInTe_2 and to $0,54\text{eV}$ for $\text{TlIn}_{0,90}\text{Yb}_{0,10}\text{Te}_2$.

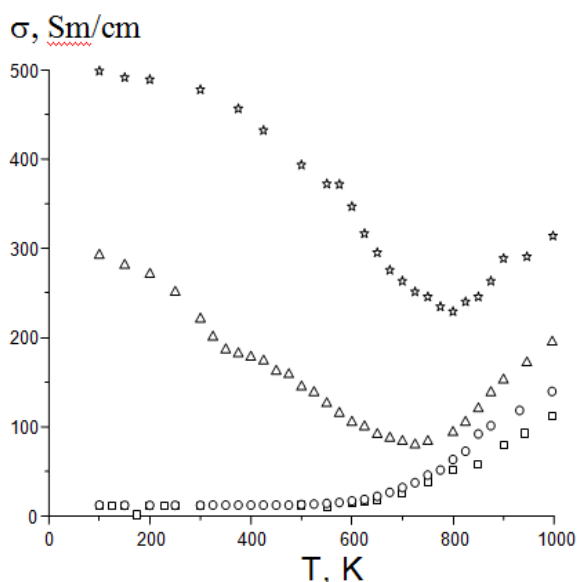


Fig1. Temperature dependences of electrical conduction in $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$;

□ - ($x=0$), ○ - ($x=0.02$), △ - ($x=0.05$), * - ($x=0.10$)

Figures 2 and 3 show temperature dependences of Hall coefficient $R(T)$ and thermoelectromotive force coefficient $\alpha(T)$ in $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ solid solutions. The signs of both coefficients are positive and this proves that conduction is completely provided by holes.

It is seen from fig.2 that Hall coefficient decreases in case of weak replacement of In atoms with Yb atoms and accordingly, hole concentration goes up. At $T > 760\text{K}$ the intrinsic region of conduction is detected on all samples. With the further increase in relative content of Yb in the compositions the intrinsic region of conduction shifts towards higher temperatures. This phenomenon is also observed on temperature dependence $\alpha(T)$, from where it is seen that before $T \sim 650\text{K}$ $\alpha(T)$ grows linearly and slowly diminishes with the coming of the intrinsic region. It can be seen from Fig.2-3 that starting from $x \geq 0.05$ the temperature course of $\sigma(T)$ and $\alpha(T)$ is of the same pattern as for narrow-gap semiconductors [9].

In these samples, the weak dependence $R(T)$ and the linear dependence of $\alpha(T)$ at $T \sim 650\text{K}$ indicates that the conductivity is one type of carrier that allows you to determine the effective mass of the holes (see table) [10].

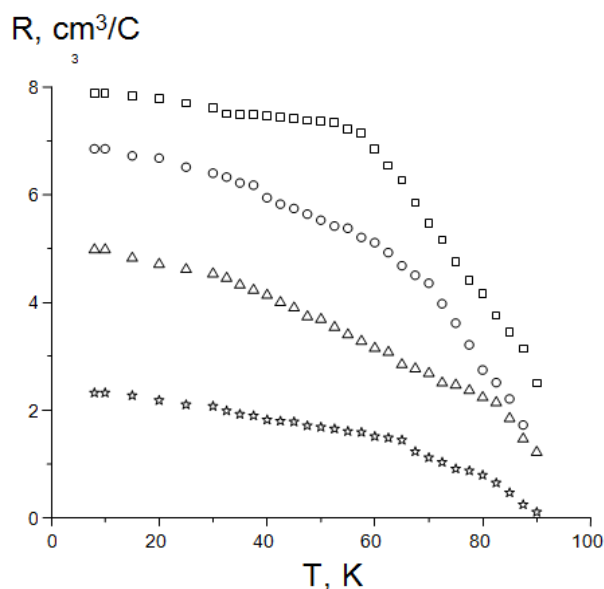


Fig.2. Temperature dependence of Hall coefficient (at $H=1200\text{ A/m}$) in

$\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$. Designations are the same as in Fig.1

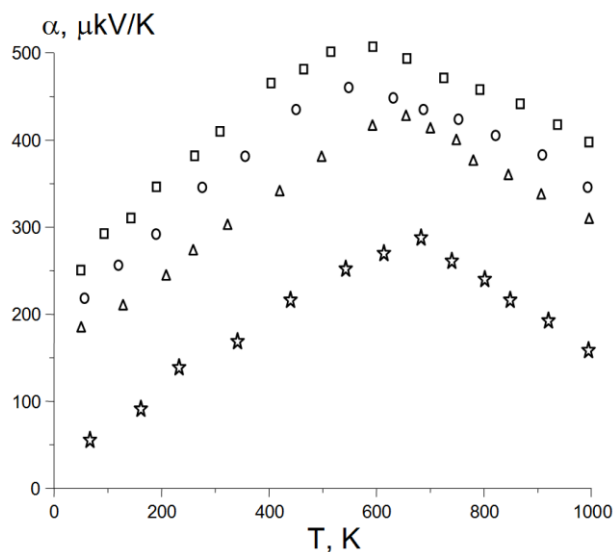


Fig.3. Temperature dependences of thermoelectromotive force in $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$. Designations are the same as in Fig.1

It was found that for all samples the effective mass of the holes in the temperature interval 100-650K is almost unchanged. This indicates that the valence band $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ obeys a quadratic dispersion law. It should be noted that so far has not been studied the energy spectrum of the conduction band in $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$.

Using the value of the effective mass of holes and assuming that the donor concentration $N_d = 0$ by the value of the Hall coefficient

at $T \leq 700\text{K}$ find acceptor concentration $N_a \sim 1,2 \times 10^{18} \text{cm}^{-3}$ (sample $x = 0.05$) and remove the degeneracy temperature of the gas at the hole $T_{nd} \sim 640\text{K}$.

As seen from this Table values of m_p^* , m_n^* in $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ are relatively less than in other solutions where lanthanides $\text{TlIn}_{1-x}\text{Ln}_x\text{Te}_2$ [11] are present. As is also seen from this Table there is mainly a correlation concerning the width of forbidden gap, effective mass (m_p^* , m_n^*) and matrix interaction element (P) in samples of $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$. The only factor that is not in line with the above said is that as compared to other narrow-gap semiconductors [9] a big effective mass of electrons in $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ may be related either to matrix interaction element or to crystalline structure. $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ solid solutions crystallize in tetragonal syngonia as well as the initial compound TlInTe_2 [12]. In this syngonia interaction of electrons with crystal lattice is insignificant [13]. On the basis of [13] it can be believed that high values of E_g and m_n^* are not due to crystalline structure. It can be expected that their values are conditioned by high value of matrix interaction element:

$$P = \left[\frac{3\hbar^2}{4m_0} E_g (1 - m_n^*) \right]^{1/2} \quad (1)$$

Table

Band parameters and the mobility of holes in the solid solutions $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$

Samples Parameters	T=100K				T=300K			
	x=0	x=0.02	x=0.05	x=0.10	x=0	x=0.02	x=0.05	x=0.10
E_g (eV)	0.70	0.66	0.62	0.54	0.68	0.63	0.59	0.51
m_p^*	0.55	0.52	0.48	0.43	0.53	0.51	0.46	0.40
m_n^*	0.040	0.036	0.034	0.031	0.037	0.033	0.032	0.030
$P \times 10^8$ (eV·sm)	4.1	4.0	3.9	3.6	4.0	3.9	3.8	3.5
$\mu_p \times 10^{-3}$ (sm ² /V·s)	210	230	1200	1350	180	195	1100	1250

It is seen from fig.2 that before $T \sim 650\text{K}$ the hole concentration rises to such extent that hole gas degeneration continues which is also characteristic of narrow-gap semiconductors [9]. This conclusion is confirmed by temperature dependences σ and R at $T \leq 640\text{K}$.

So, in the investigated temperature range $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ solid solution ($0 \leq x \leq 0,10$) has hole conduction at severely degenerated state of hole gas. The $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ valence band obeys square law of dispersion. At $T \geq 650\text{K}$ the intrinsic conduction region is observed and the nature of temperature dependences σ and α is explained by the presence of two types of charge carriers. Starting from $x=0.05$ the temperature course $\sigma(T)$ becomes obviously qualitatively and quantitatively different during transition from TlInTe_2 to $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$. This transition is supposed to be accompanied by the transition from a semiconductor to a narrow-gap semiconductor.

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ZƏİF MAQNİT SAHƏLƏRİNDƏ $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ BƏRK MƏHLULLARININ KİNETİK ƏMSALLARININ ÖLÇÜLMƏSİNDƏN İSTİFADƏ EDƏRƏK ELEKTRON VƏ DEŞİKLƏRİN EFFEKTİV KÜTLƏLƏRİNİN TƏYİNİ

F.F.Əliyev, V.İ.Eminova, Ü.M. Ağayeva

$\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ ($0 \leq x \leq 0,10$) bərk məhlullarında elektrikkeçirmə, Hall və termoelektrik əmsallarının (σ, R, α) temperatur asılılıqları ($\sigma(T), R(T), \alpha(T)$) 80-1000K temperatur intervalında tədqiq olunmuşdur. Bu kinetik əmsallar əsasında elektron və deşiklərin effektiv kütlələri təyin olunmuşdur. Müəyyən olunmuşdur ki, $x=0.05$ qiymətindən başlayaraq, $\text{TlIn}_{1-x}\text{Yb}_x\text{Te}_2$ bərk məhlulu özünü darzolaqlı yarımkeçirici kimi aparır.

Açar sözlər: qadağan olunmuş zonanın eni, effektiv kütlə, gətirilmiş kimyəvi potensial, darzolaqlı yarımkeçiricilər

**ОПРЕДЕЛЕНИЕ ЭФФЕКТИВНЫХ МАСС ЭЛЕКТРОНОВ И ДЫРОК В ТВЕРДЫХ
РАСТВОРАХ $TlIn_{1-x}Yb_xTe_2$ ИЗ ИЗМЕРЕНИЙ КИНЕТИЧЕСКИХ КОЭФФИЦИЕНТОВ
В СЛАБЫХ МАГНИТНЫХ ПОЛЯХ**

Ф.Ф. Алиев, В.И. Эминова, У.М. Агаева

Исследованы температурные зависимости электропроводности σ , коэффициента Холла R и коэффициента термо э.д.с. α в твердых растворах $TlIn_{1-x}Yb_xTe_2$ ($0 \leq x \leq 0,10$) при 80-1000 К. По данным кинетических параметров определены эффективные массы электронов и дырок. Установлено, что, начиная с $x=0.05$, твердые растворы $TlIn_{1-x}Yb_xTe_2$ относятся к узкозонным полупроводникам, обладающим высокими значениями матричного элемента взаимодействия.

Ключевые слова: ширина запрещенной зоны, эффективная масса, приведенный химический потенциал, узкозонные полупроводники