THE ELECTRIC AND THERMOELECTRIC PROPERTIES OF Ag_2Se AT THE LOW TEMPERATURES

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In this work the temperature dependences of the conductivity- $\sigma\sigma(T)$, the Hall coefficient-*R(T)*, thermoelectromotive force-α_0 *(T)* of Ag_2Se at low temperatures have been analysed on the one type charge carriers and Kane low dispersion theory basis. It is established at the electron concentration $n \leq 6{,}9 \cdot 10^{18} cm^{-3}$ the carriers have been scattered by the ion impurities and the point defects, but at $n \geq 1{,}2 \cdot 10^{19} cm^{-3}$ its have been scattered on the ion impurities and heat vibrations of lattice. It is shown, that at T<30K the electron-electron interaction has elasnic character.

The set of the refs [1-3] is devoted to the electric and thermal properties of selenide of argentum. The authors [1,2] showed that the electron dispersion law in Ag(2)Se is subject to Kein's model and at T>80K the main scattering mechanism of carriers of current is the scattering on the ionized and acoustic phonons [3]. In the region 80 - 250K the electron and phonon shares of the heat conduction are studied [3] and it is established that the Lorentz number (L) in Ag_2Se is the essential less than Zommerfeld's one (L_0) and the interelectronic interaction becomes inelastic

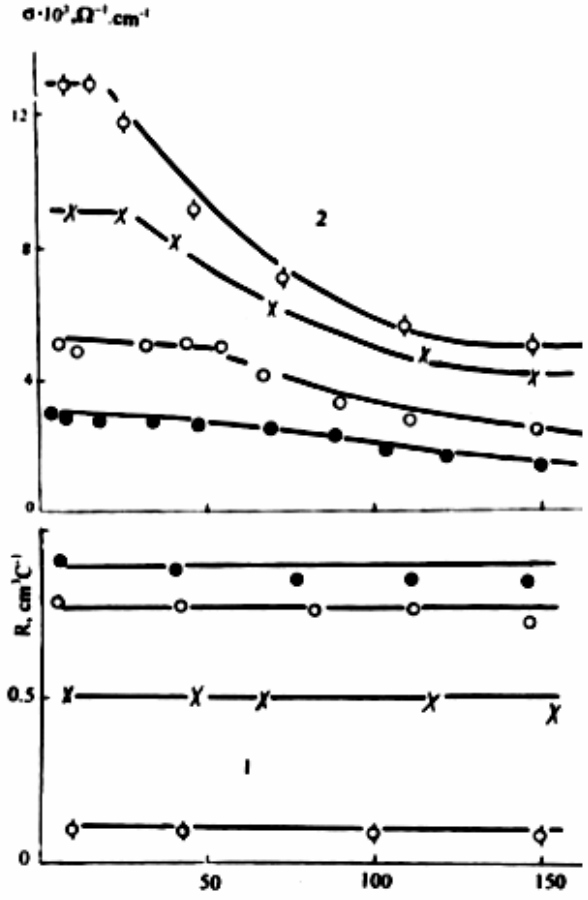

Fig.1.

Inspite of the fact that the given questions aren't studied at the low temperatures, nevertheless they represent the special interest for the studying of an electronic spectrum.

In present paper the temperature dependences of electric conduction $\sigma(T)$, Hall coefficient *R(T)* and thermoelectromotive force $\alpha_0(T)$ at the low temperatures are studied.

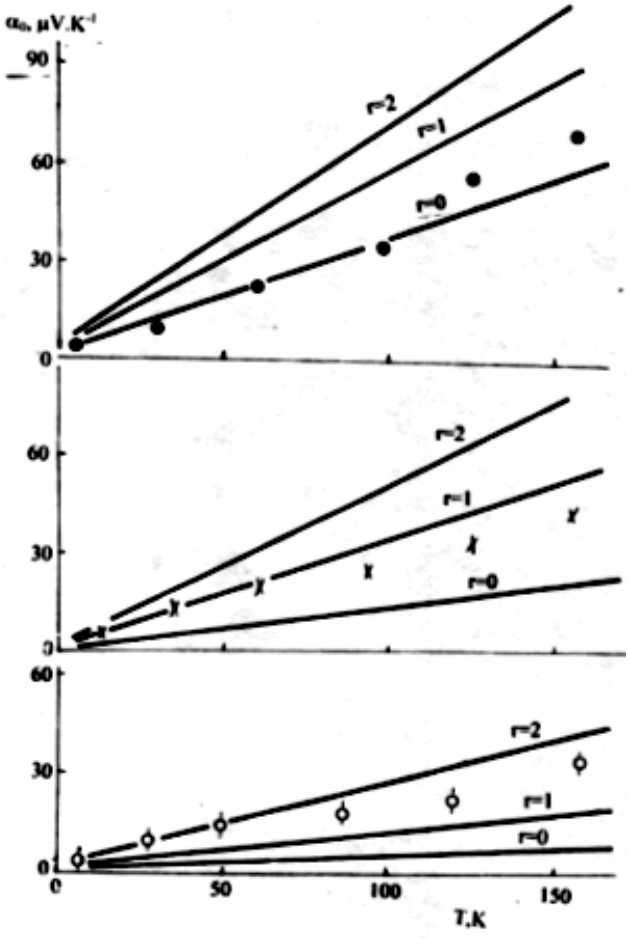

Fig.2.

The samples of Ag_2Se were obtained by the unified technology Ag_2Se [4]: the stoichiometric composition with the excess of Se and Ag up to ~0,2 at.%. The investigations are carried out by the methodics [5]. In fig. 1,2 the *R(T)* (1.1) and $\sigma(T)$ (1.2) are represented and $\alpha_0(T)$ is represented in fig.2. In all samples *R(T)* staies constant, but $\alpha_0(T)$ increases linearly, that is typical for strong degenerate gas. It is visible that at $n \sim 12 \div 20 \cdot 10^{18} cm^{-3}$ σ almost doesn't depend on T up to

T~2K. At T>20K σ increases with the temperature growth. With the electron concentration decrease σ depends on T very weakly up to T~150K. The weak dependence $\sigma(T)$ is caused by the weak temperature dependence of the electron mobility that is confirmed by the constant concentration in the investigated temperature interval. Usually the intensity of scattering on the scattering centers increases with the decrease of the concentration carriers [6].

For the conception of the given question, it is need to calculate the temperature dependence of the mobility of the carrier of charge. The mobility of carriers of current at the strong degeneration and Kein's dispersion law at the scattering on the acoustic phonons *(r=0)* and ions *(r=2)* is expressed by the following formulas [7]:

$$U_{ak} = \left(\frac{\pi}{3}\right)^{1/3} \frac{e\rho U_0^2 \hbar^3 n^{-1/3}}{E_d K_0 T (m*)^2} \frac{1}{f_{ak}} \qquad (1)$$

$$U_i = \frac{3\pi^2 \hbar^3 \chi^2}{2em*} \frac{1}{f_i} \qquad (2)$$

where p is the crystal density, U_0 is the strain lattice potential, E_d is the lattice deformation potential, m* is the effective electron mass on Fermi level, χ is the dielectric constant of the crystal (where p=7,6g/cm^3 [4], U_0=5·10^{5}cm/s, E_d=10eV [7], m*=0.18 m_0 [2], γ=16[7] correspondingly), and f are factors, taking into consideration the influence of unparabolic on the scattering probability, which are calculated by the following formulas [7]:

$$f_{ak}(p/p_0) = \frac{2.3}{12} - \frac{1}{20}\frac{p}{p_0} + \frac{10.3}{12}\left(\frac{p}{p_0}\right)^2$$

$$f_i(p/p_0) = a - \frac{b}{2} + \frac{1}{16}(b+3c) + \left[\frac{b}{2} - \frac{1}{8}(b+3c)\right]\left(\frac{p}{p_0}\right) + \frac{b+3c}{16}\left(\frac{p}{p_0}\right)^2$$

$$a = ln\left(1+\frac{1}{\xi}\right) - \frac{1}{1+\xi}; b = 4 + \frac{4\xi}{1+\xi} - 8\xi ln\left(1+\frac{1}{\xi}\right); c = 2 - 12\xi + \frac{4\xi}{1+\xi} + 12\xi^2 ln\left(1+\frac{1}{\xi}\right)$$

$$p = \left(\frac{m}{m^*} - 1\right); p_0 = \left(\frac{m_0}{m_n} - 1\right); \xi = \frac{e^2 m*}{\pi\hbar^2 \chi (3\pi n)^{1/3}} = \frac{1}{4K_f^2 r_s^2};$$

m_n is the effective electron mass on the conduction band bottom (m_n=0,08[7]), K_f is the quaziimpulse on Fermi level and r is the screening radius, which is defined for the strong degenerative semiconductors as follows [8]:

$$r_s = \left[\frac{\chi\hbar^2}{4m_n e^2}\left(\frac{\pi}{3n}\right)^{1/3}\right]^{1/2} \qquad (3)$$

where n is the concentration of electrons. The results of the calculation $U(T)$ for strong degenerative electron gas expressed by the following formulae with the use (1) and (2)

$$U = \left(\frac{1}{U_{ak}} + \frac{1}{U_i}\right)^{-1} \qquad (4)$$

are given in the fig.3(a.1) for n~7·10^{18}cm^{-3}.

From the fig.3(a.1) it is seen that $U(T)$ up to T<=35K staied constant. The $U(T)$ decreases with the temperature growth higher than 35K and the calculated values of electron mobility less than experimental in the given temperature interval. This can be connected with that in Ag_2Se the value r_s doesn't close to value of lattice constant. The divergence of the calculated and experimental dates needs to take into consideration the new scattering centers inside of U_{ac} in (4).

The authors [9] inform that Ag_2Se is characterized by the Frenkel defect (it is obvious that these defects are point ones), Ag vacancies in the interstices appearing because of the Ag atoms, disposed statistically in sublattice. It is need to take into consideration the contribution of mobility U_d, calculated with the help of the relaxation time at the scattering mechanism on the point defects for the standard band as in [8]

$$\tau_d(T) = \frac{\pi\hbar^4}{(2m_n k_0 T)^{1/2} m_n V_0^2 N_d}\left(\frac{\varepsilon}{k_0 T}\right)^{-1/2} \qquad (5)$$

where V_0 is the constant, characterizing the amplitude of δ-potential, N_d is the concentration of the point defects, which is defined by the following way: in the present time for the compounds $A^{I}_{2-x}B^{VI}$ there are two models of formation of possible Ray's [10] and Vei's [10] defects, in the each of which the dominating types of defects, causing the deflection from the stoichiometry are defined. In the first model it is proposed that creation of the deffect passes in two stages: the neutral vacancy of metal V_a appeares by the jump and then the ionization vacancy appeares and as a result the hole forms. Therefore, the complete? concentration of the defects is defined as $N_d=V_A+V^I_A$, and the concentration of the holes is $p=V^I_A$. In the second model it is possible the introduction

of atoms of metal in the interstices $A_i=A_i^*+n$, where A_i, A_i^* are concentrations of the neutral and ionized donors. The complete concentration of the defects is as follows

$$N_d=V_A+p-A_i-n \qquad (6)$$

where $p-n=V^1_A-A_i^*$, and p, n are defined in compliance with [8]

$$N_d = V_A + V^1_A - A_i - A_i^*$$

or

$$P = \frac{(2m_p k_0 T)^{3/2}}{4\pi^{3/2}h^3} F_{r+1}(\mu_p^*)$$

and

$$n = \frac{(2m_n k_0 T)^{3/2}}{3\pi^2 h^3} I^0_{3/2}(\mu_n^*, \beta) \qquad (7),$$

where m_p is the effective hole mass (m_p=0,54 [12]) $\beta=\varepsilon_g/k_0T$ is the parameter of the parabolitic band, ε_g is the width of the forbidden band (ε_g =0,18eV) [2], $\mu_p^*=\mu_p/k_0T$ and $\mu_n^*=\mu_n^*/k_0T$, μ_p and μ_n are chemicopotentials $F_r(\mu)$ and $I^m_{n,k}$ are the one-parametrical and two-parametrical Fermi integrals.? The chemicopotential μ_n is defined from the following expression [2],

$$\alpha_\infty = -\frac{k_0}{e}\left[\frac{I^1_{3/2,0}(\mu_n^*,\beta)}{I^0_{3/2,0}(\mu_n^*,\beta)} - \mu_n^*\right] \qquad (8)$$

and

$$\mu_p = -\varepsilon_g - \mu_n \quad , \qquad (9)$$

where α is the thermoelectromotive force of the electrons in the strong magnetic fields. Taking into consideration (8) and (9) in (7) one can define p and n, and then calculate N_d. Using the values N_d, V_0 and m_n in (5) the $\tau_d(T)$ is defined. The mobolity $U_d(T)$ is defined as in [7]:

$$U_d(T) = \frac{e\tau_d(T)}{m_n} \qquad (10)$$

Substituting $U_d(T)$ instead of $U_{ac}(T)$ in (4), we obtain:

$$U(T) = \left(\frac{1}{U_i} + \frac{1}{U_d}\right)^{-1} \qquad (11)$$

As it is seen from fig.3a the curve2 is corresponded with experimental one qualitatively. It means that in the rich in Se region, ie. where the argentum vacancies dominate, the scattering on the centres, consisting of the defects of the acceptor type is the dominate scattering mechanism. It can be expected that in this temperature region the ion radius of selen is less than wave length of the acoustic phonon [13]. From this figure it follows that at low temperatures for $n\leq 12{,}35\cdot10^{18}$sm^{-3} U doesn't depend on T that is correspond to the scattering on the ionized impurities. The U decreases proportionally to $T^{-\alpha}$, with the increase of the temperature, that shows on the active role of phonons in the scattering. By dates $U(T)$ the scattering on the acoustic and optical phonons is hardly differed quantitatively. The dominate scattering mechanism is better isolated from concentrational dependence $U(n)$. As it was shown in [14] the $U_{ac}\sim n^{-1}$, $U_{op}\sim n^{1/3}$, $U_i\sim n^{2/3}$. From this it follows that temperaturedependence of the ratio U_i/U_{ak} is defined by the temperature dependence $U_{ak}(U_i/U_{ak}\sim T)$. From the fig.3 it is seen that in dependence $U\sim T^\alpha$ the exponent α=0,6 and is almost doesn't depend on electron concentration ($n\leq 7\cdot10^{18}$sm^3 is exception).It means that in the temperature interval 20-100K the mechanism of electrons scattering has the mixed character. In comparison with the other narrow-band semiconductors the mobility of carriers of current in Ag(2)Se is small. The possible reason of this phenomena is the big effective electron mass [2] in this semiconductor.

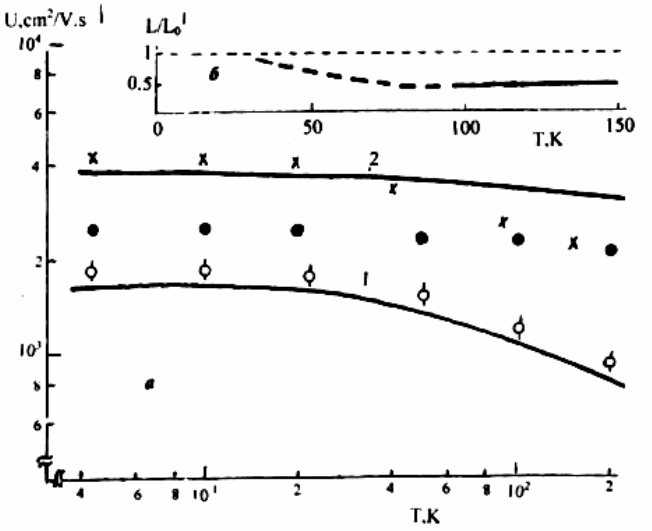

Fig.3.

From the fig.2 it is seen that in the interval 4-150K the animation effect of the electrons by the phonons isn't achieved. Taking into consideration n_0 and $\alpha_0(T)$ the dominated scattering mechanism can be established also. In the case of the one-band model the at the nonquadratic dispersion law and any degree of degeneracy α_0 is defined as:

$$\alpha_0 = -\frac{k_0}{e}\left[\frac{I^1_{r+1,2}(\mu_n^*,\beta)}{I^0_{r+1,2}(\mu_n^*,\beta)} - \mu_n^*\right]. \qquad (12)$$

In the fig.2 the results of $\alpha_0(T)$ calculation on the formulae (12) for the three samples are given. As it is seen the results, obtained about dominated scattering mechanism of current carriers in selenide of argentum agree with the dates [14]. The calculations show that at the different electron concentrations the dominated scattering mechanisms are different. This uncorresponding it is follows that the screening radius changes at the electron concentrations changing. Here it is also important the character of the interelectron interaction at the different scattering mechanisms [15]. In the ref 3 the temperature dependences of the experimental and calculated values L/L_0 for the set of the narrow-band semiconductors [16-18] are given, in particular for the values Ag_2 Te [19], being analog of Ag_2Se. It is also shown that at the decrease of temperature $L\rightarrow L_0$ the

interelectron interaction became elastic at the pure ion scattering realization. The analysis of temperature dependence of the mobility and other kinetic parameters (for example, $\sigma(T)$) show the dominated ion electron scattering at T<30K. Taking into consideration and by analogy to the listed narrow-band semiconductors the temperature dependence L/L_0 can be extrapolated even at the low temperatures (fig.3(б)).

So we can make the following conclusion that the given model with the strong degenerated of one type of current carriers and Kein dispersion law is completely describes electric and thermoelectric properties of Ag_2Se at low temperatures.

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Ag_2Se KRİSTALININ AŞAĞI TEMPERATURLARDA ELEKTRİK VƏ TERMOELEKTRİK XASSƏLƏRİ

Bir tip keçiricilik üçün Keyn modeli nəzərə alınmaqla dispersiya qanunu əsasında elektrikkeçirmə, Holl effekti və termoelektrik H.Q. tədqiq edilmişdir. Müəyyən olunmuşdur ki, $n \geq 1{,}2\cdot10^{19}sm^{-3}$ elektron konsentrasiyası üçün yükdaşıyıcılar, ion aşqarları və akustik fononlardan, $n \leq 6{,}9\cdot10^{18}sm^{-3}$ üçün isə ion aşqarlarından və nöqtəvi defektlərdən səpilirlər.Göstərilmişdir ki, T<30-də elektronelektron qarşılıqlı təsiri elastiki xarakter daşıyır.

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ЭЛЕКТРИЧЕСКИЕ И ТЕРМОЭЛЕКТРИЧЕСКИЕ СВОЙСВА Ag_2Se ПРИ НИЗКИХ ТЕМПЕРАТУРАХ

В работе анализированы температурные зависимости электропроводности- $\sigma(T)$, коэффициента Холла-$R(T)$ и термоэдс-$\alpha_0(T)$ в Ag_2Se при низких температурах в рамках теории с одним типом носителей тока и кейновским законом дисперсии, а также с учетом характера межэлектронного взаимодействия. Установлено, что для концентрации $n \leq 6{,}9\cdot10^{18}см^{-3}$ ток носителей рассеивается на ионах примеси и точечных дефектах, а для $n \geq 12\cdot10^{18}см^{-3}$ рассеяние происходит на ионах примесей и тепловых колебаниях решетки.Показано, что при T< 30K межэлектронные взаимодействия носят упругий характер

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