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RESONANCE SCATTERING OF ELECTRONS IN Ag_2Te AT LOW TEMPERATURE

F.F. Aliyev R.A. Hasanova E.R. Hasanov

Institute of Physics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan, farzali@physics.ab.az

Abstract- It were investigated that the temperature dependencies of electric conductivity σ and Hall coefficient R of p–Ag_2Te in 4.2~200 K temperature is in interval for acceptor concentration $N_a \leq 6\text{x}10^{16}$ cm^{-3}. The minimum $\sigma(T)$ were observed for all samples in ~50-80 K temperature interval. It was observed that the deeper of minimum is increased with N_a decrease. It was shown that the part resonance scattering of electrons in minimum of $\sigma(T)$ and maximum of $|\alpha_n(T)|$ region is 16-18%. Temperature relationships of electric conduction σ, Hall coefficient R, and thermoelectric power α_0 in p-Ag_2Te over a 4.2~200 K temperature interval $N_a \leq 6\text{x}10^{16}$ cm^{-3} have been studied. The minimum $\sigma(T)$ over a temperature interval between ~50-80 K is observed on all samples. It is found that the depth of minimum $\sigma(T)$ increases with decreasing N_a. It is demonstrated that a contribution of resonance scattering of electrons in the area of minimum $\sigma(T)$ and maximum $|\alpha_n(T)|$ is 16-18%.

Keywords: Resonance Scattering, Electric Conductivity, Hall Coefficient, Acceptor Concentration.

I. INTRODUCTION

It is related in [1] that resonance scattering of electrons on acceptor impurities does not take place in n-Ag_2Te at the donor concentration of $N_d \geq 6.2\text{x}10^{16}$ cm^{-3}. In [2] electrical and thermo electrical properties of p-Ag_2Te in samples with the acceptor concentration of $N_a \geq 6.25\text{x}10^{16}$ cm^{-3} are investigated. At such concentrations of N_a indications of resonance scattering of electrons on acceptor impurities in p-Ag_2Te make their appearance. The manifestations of the mentioned phenomenon in Ag_2Te at concentrations of $N_a \leq 6.25\text{x}10^{16}$ cm^{-3} have not been studied as yet.

II. RESULTS AND DISCUSSIONS

The present research is dedicated to the study of electrical and thermo electrical properties of p-Ag_2Te in samples with the acceptor concentration of $N_a \leq 7.8\text{x}10^{16}$ cm^{-3}. *N* all the samples of p-Ag_2Te in two peculiarities are observed on temperature relationship of electric conduction $\sigma(T)$ in the 4.2-200 K temperature range: a plateau at T<40K and a minimum at $T \approx 65$K (Figure 1).

As can be seen from Figure 1, the depth of minimum $\sigma(T)$ increases with reduction in N_a and it is about 7% for $N_a \approx 7.8\text{x}10^{16}$ cm^{-3} and about 30% for $N_a \approx 4.2\text{x}10^{16}$ cm^{-3}.

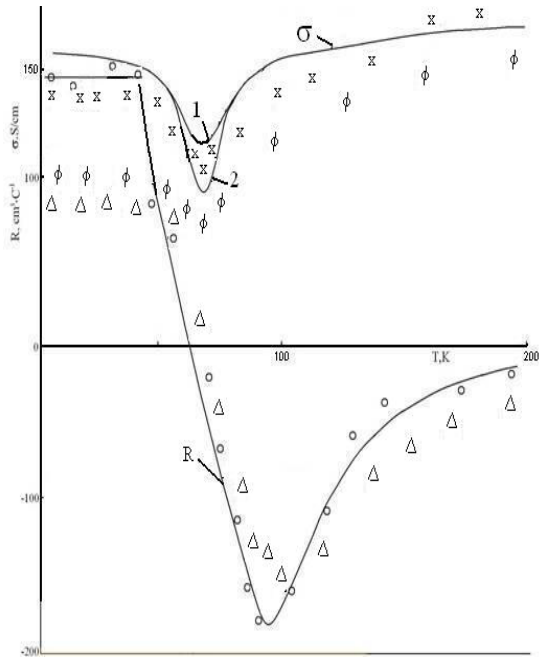

Figure 1. Temperature relationships of electric conduction σ and Hall coefficient R in p-Ag_2Te,
Experimental points: ϕ, x (electric conduction) - o, Δ (Hall coefficient) for concentration of $p = 7.8\times10^{16}\text{cm}^{-3}$, $p' = 4.2\times10^{16}\text{cm}^{-3}$, respectively and solid lines are design points for concentration of $p' = 4.2\times10^{16}\text{cm}^{-3}$
1- electron and hole scattering on ionic and acoustic vibrations,
2- resonance scattering of electrons on acceptor impurities and hole scattering on acoustic vibrations of the lattice

At T<40K Hall coefficient R does not depend on temperature, at $T \geq 40$K it diminishes and changes its conduction sign from *p* to *n* when T is about $T \approx 65$K, then it passes through maximum at $T \approx 80$K (Figure 1). The temperature course of thermo electric power $\alpha_0(T)$ fully conforms to the course of $R(T)$, i.e. before $T \approx 40$K, α_0 linearly increases with temperature, at $T \approx 65$K, α_0 changes its sign, then a dependent $\alpha_0(T)$ goes through minimum at $T \approx 80$K (Figure 2). The course of $\sigma(T)$, $R(T)$ and $\alpha_0(T)$ at the concentration of $N_a \approx 6.25\text{x}10^{16}$ cm^{-3} is analyzed [2].

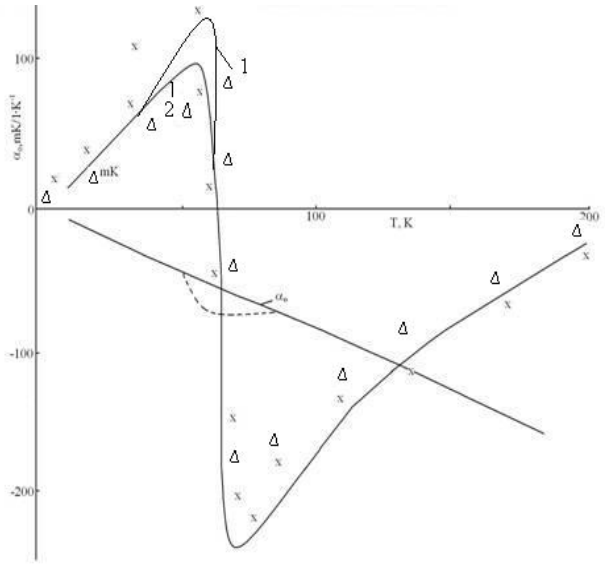

Figure 2. Temperature relationship of thermo electromotive force $\alpha_0(T)$ in p-Ag_2Te. Experimental points: symbols are the same as in Figure 1 and solid lines are design ones for concentration of $p' = 4.2\times10^{16}\,\mathrm{cm}^{-3}$
1- electron and scattering on ionic and acoustic vibrations,
2- resonance scattering of electrons on acceptor impurities and hole scattering on acoustic vibrations of the lattice

To reveal the cause of the depth of minimum $\sigma(T)$ dependence on N_a we shall perform an analysis of σ and α_0 within a two-zone model. As it is known, σ and α_0 for two types of charge carriers are determined from Equation (1).

$$\sigma = e\left(nU_n + pU_p\right) = \sigma_n + \sigma_p \ , \ \alpha_0 = \frac{\alpha_p\sigma_p - \alpha_n\sigma_n}{\sigma_p + \sigma_n} \qquad (1)$$

where U_n, U_p, n, p, σ_n, σ_p, α_n and α_p are nobilities and concentrations of electrons and holes, partial electro conductivities and thermo electric power, respectively. Calculation of temperature relationship $U_n(T)$ and $U_p(T)$ in a sample of N_a=4.2x10^{16} cm^{-3} in case of charge carrier scattering on ionic centres to the procedure in [2]; electron concentration was calculated from Equation (2).

$$n = \frac{n_i^2}{p_0 + n_i} \qquad (2)$$

where n_i is intrinsic concentration determined from $n_i = 4.9\times10^{15}\left(\frac{m_n m_p}{m_0}\right)^{\frac{3}{4}} T^{\frac{3}{2}} \exp\left(\frac{-\varepsilon_g}{2k_0T}\right)$ and $p = p_0 + n_i$ is the total hole concentration. Here p_0 is determined from $R(T)$, where R does not depend on temperature. By solving (2) electron concentration in the temperature interval under study is determined. It is found in paper [3] that valence zone is parabolic and then p is determined according to [2].

$$p = \frac{\left(2m_p k_0 T\right)^{\frac{3}{2}}}{3\pi^2\hbar^3} F_{3/2}\left(\mu_p^*\right) \qquad (3)$$

It is found in [4, 5] that dispersion law for electrons conforms to Kane model, in this case electron concentration is determined in the following way.

$$n = \frac{\left(2m_n k_0 T\right)^{\frac{3}{2}}}{3\pi^2\hbar^3} I_{3/2}^0\left(\mu_n^*, \beta\right) \qquad (4)$$

where m_n and m_p are effective masses of electrons and holes, $F\left(\mu^*\right)$ and $I_{3/2}^0\left(\mu^*, \beta\right)$ are one and two parameters of Fermi integrals, $\mu^* = \frac{\mu}{k_0T}$, μ is chemical potential, $\beta = k_0T/\varepsilon_g$ is parameter characterizing non-standard nature zone. The partial thermo electric power for both cases are determined as:

$$\alpha_p = -\frac{k_0}{e}\left[\frac{F_{r+2}\left(\mu_p^*\right)}{F_{r+1}\left(\mu_p^*\right)} - \mu_p^*\right]$$
$$\alpha_n = -\frac{k_0}{e}\left[\frac{I'_{3/2,0}\left(\mu_n^*, \beta\right)}{I^0_{3/2,0}\left(\mu_n^*, \beta\right)} - \mu_n^*\right] \qquad (5)$$

μ_p^* and μ_n where determined in (3) and (4), α_p and α_n where calculated on their basis from the Equation (5). The partial σ_n and σ_p were determined from the given n, p, U_n and U_p afterwards $\sigma(T)$ and $\alpha_0(T)$ were calculated using (1) (Figures 1 and 2). It is seen from Figures 1 and 2 that in the 50-70 K range the design curves of $\sigma(T)$ and $\alpha_0(T)$ do not quantitatively agree with the experimental ones. These disagreements can be analyzed firstly by analyzing $\sigma(T)$. As seen from Figure 3, at T≤40K hole mobility U_p depends on temperature quite little while electron mobility U_n goes up with temperature in accordance with the law U_n~$T^{1.5}$.

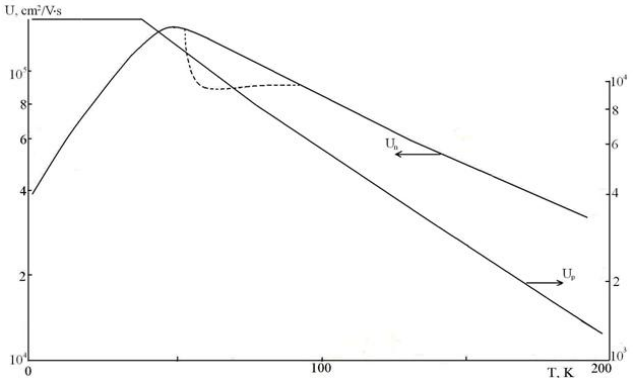

Figure 3. Temperature relationship of electron $U_n(T)$ and hole $U_p(T)$ mobility in p-Ag_2Te, Dotted lines are due to electron scattering on acceptor centres

Such behavior of the motilities demonstrates that at low temperatures charge carriers scatter on ionized impurities [1,2], after T>40K the scattering takes place on acoustic vibrations of lattice thanks to which $\sigma(T)$ decreases in our opinion, the depth of minimum $\sigma(T)$ which is observed during experiments may be related to an abrupt decrease in U_n in the 50-65K temperature range. It can be expected that electrons not only scatter on ionized impurities and acoustic phonon (electron gas is not degenerated in this range) but also additional scattering mechanism is present.

At low temperatures the average thermal energy of electron is much less than the donor level energy $E_d << k_0T$ (ε_g=0.035 eV, E_d=0.002 eV and E_a=0.004 eV [6]). With increase in temperature entrapment of electrons on acceptor states grows higher leading to a reduction in conduction electron number at T<65K. It develops intensively provided that Fermi level is located in a narrow area close to E_a. When it is considered that the temperature relationship is ε_g=(0.035-7x10^{-5} T·K^{-1}) eV, it can be expected that $\mu \to E_a$. It allows to suppose that in this case electrons simultaneously scatter on acceptor centres (resonance scattering) as well.

At resonance scattering $\sigma_{rez.}$ takes the form [7]:

$$\sigma_{рез.} = \frac{\left(3\pi^2\right)^{1/3} e^2 p^{1/3}}{4\pi\hbar N_i} \cdot \frac{m_d^*}{m_n} \cdot \frac{\Gamma_d}{\gamma} \left\{ 1 + tg^2 \left[\pi \left(k - \frac{1}{2} \right) \right] \right\} \quad (6)$$

where m_d^* is effective masses of state density, p is hole concentration in valence zone, Γ_d is width of donor impurity band, γ is broadening of resonance level at the expense of impurity and zone states hybridization. If the broadening of level is completely due to non-stationary of impurity states then Γ_d/γ=1, $k = \frac{1}{2} + \frac{\left(N_a - p\right)}{2N_i}$, where N_a and N_i are concentrations of acceptors and impurity that had created a band the middle of which corresponds to the energy E_d. If $\mu \to E_a$ it can be assumed that $m_d \to m^*$, where m^* is effective mass of electrons at Fermi level $\left(m^* = 0.03m_0\left[8\right],\ m_n^* = 0.02m_0\left[2\right]\right)$. The width of Γ_d is determined from [7].

$$\rho_i(\varepsilon) = \frac{N_i}{\pi} \cdot \frac{\Gamma_d}{\left(\varepsilon - \varepsilon_i\right)^2 + \left(\Gamma_d/2\right)^2} \quad (7)$$

where $\rho_i(\varepsilon)$ is density of impurity states, N_i is concentration of impurity creating the band the middle of which corresponds to the energy ε_i. In the first approximation it can be taken that $\varepsilon_i \approx \left(E_d - \mu\right)/2$, at $T << \frac{E_d}{k_0}$, $N_i \approx \frac{\left(2m_n k_0 T\right)^{3/2}}{3\pi^2\hbar^3} \exp\left(-\left(\varepsilon_d - \mu\right)/2k_0T\right)$.

When $K = \frac{N_a}{N_d} >> 1$, K is compensation degree. $\rho_i(\varepsilon)$ is determined [9]:

$$\rho_i\left(\varepsilon\right) = \frac{N_d}{\gamma_0\sqrt{\pi}} \exp\left(-\varepsilon^2/\gamma_0^2\right) \quad (8)$$

where $\varepsilon \approx e^2/\chi r_d$ is energy of Coulomb interaction at the mid-distance between donors, χ is dielectric permittivity and $r_d = \left(\frac{4\pi}{3} N_d\right)^{-1/3}$ is the average between donors.

$$\gamma_0 = 0.026\varepsilon_d \left(N'_A/N'_d\right)^{1/4} \quad (9)$$

where N'_A and N'_d are concentrations of additional one-charge acceptors and donors not creating impurity levels. From (7), (8) and (9) $\Gamma_d \approx$0.2 meV was obtained.

The broadening of band impurity level at the expense of impurity-zone transitions is determined from [10]:

$$\gamma = \hbar/t \quad (10)$$

where t is the average life time of a carrier in impurity state relative to the transition to zone. Proceeding from the detail equilibrium principle one can equate frequencies of direct (zone-impurity) and reverse (impurity-zone) transitions [11]:

$$\frac{\rho_z}{\tau} = \frac{\rho_i}{t} \quad (11)$$

where τ is the average life time of a carrier in zone state relative to the transition to impurity and ρ_z is density of zone states:

$$\rho_z = \frac{\left(2m_n\right)^{3/2} \mu^{1/2}}{2\pi\hbar^3} \quad (12)$$

and at low temperatures ($k_0T << \Gamma_d$), τ depends on a scattering parameter

$$r = \left.\frac{\partial \ln \tau}{\partial \ln \varepsilon}\right|_{\varepsilon = E_d} \quad (13)$$

where $r = \frac{2\mu\left(\mu - \varepsilon_i\right)}{\left(\left(\mu - \varepsilon_i\right)^2 + \left(\Gamma_d/2\right)^2\right)}$.

A quantity r has a minimum and a maximum at $\mu = \varepsilon_i \pm \Gamma_d/2$. A value of t=6.6x10^{-12} sec was computed using values of ρ_z, τ and ρ_t. σ_{rez} (Figure 1) was computed with consideration for values of Γ_d, γ and k in (6). It was seen from Figure 1 that σ_{rez} decreases less at the scattering on acoustic phonons.

Impurity states of Ag atoms (E_d=2 meV) are located higher than the conduction band bottom; it could be expected that from T~50K. However, at low temperatures ($T << \frac{E_d}{k_0}$) and donor concentrations of $N_d \geq$6.2x10^{16} cm^{-3} in Ag_2Te resonance scattering does not manifest itself. In this temperature range ($T << \frac{E_d}{k_0}$) electron scattering in the samples with $N_d \geq$6.2x10^{16} cm^{-3} (concentration of additional Ag atoms) is considerably weaker than in the samples with $N_d \geq$4.2x10^{16} cm^{-3} which can be explained by resonance scattering. With increase in Te atom content donor N_d concentration diminishes due to compensation. It leads to a decrease in an interval of donor smearing temperature and degeneration of electron gas reduces too.

A strong dependence of impurity state density on energy brings about a sharp and non-monotonous energy dependence of relaxation time for resonance scattering which significantly affects the thermo electric power α_0 [9-12]. With concentration for non-parabolic of conduction band in Ag_2Te a value of thermo electromotive force is determined according to [7]:

$$\alpha_{rez.} = \frac{k_0}{e} \cdot \frac{\pi^2}{3} \cdot \frac{k_0 T}{\mu} \left(\gamma_p + \frac{3}{2} \cdot \frac{1+2y}{1+y} - \frac{2y}{1+2y} \right) \quad (14)$$

where $y = \mu/\varepsilon_g$. Calculation of $\alpha_p(T)$ from (13) in the 50-70 K range is shown in Figure 2.

It is seen from Figures 1 and 2 that consideration for resonance scattering in p-Ag_2Te leads to an increase in design values of α_n and electrical resistance by about 16-18%. It follows from the ratio of the level γ broadening at the expense of hybridization of impurity and zone states of γ to the full width of Γ_d band, i.e. $\gamma/\Gamma_d \approx 0.8$. As distinct from n-$Ag_2Te$, resonance scattering of electrons on acceptor impurities is detected in p-Ag_2Te at donor concentrations of $N_d \leq 4.2 \times 10^{14}$ cm^{-3}. The cause of an increase in resonance scattering contribution with decreasing N_a on $\sigma(T)$ may stem from the fact that a reduction in concentration of Te atoms to (formation of Ag vacancy or addition of Te atoms to Ag_2Te and their subsequent ionization always lead to p-type conduction [12]) results in a decrease in the width of prohibited zone ε_g and broadening of resonance level γ. There is a number of papers [13-14], in which various values for ε_g in Ag_2Te are presented. As the authors of [13] have obtained $\varepsilon_g \leq 6$ meV in the region of intrinsic conduction, there applied reason to believe in a possibility of slot less state in Ag_2Te at low temperatures. The authors of [14] have shown that Ag_2Te becomes slot less in the T>500K temperature range. With consideration for negative value of temperature coefficient of the energy gap width ε_g it is evident that at lesser ε_g values acceptor level goes into conduction band. For this reason resonance scattering of electrons occurs and the depth of minimum $\sigma(T)$ increases (Figure 4).

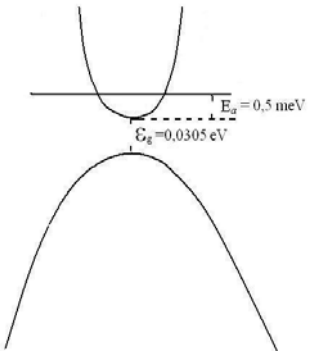

Figure 4. Zone structure of p-Ag_2Te at T=65K

Now we will find out the cause of $\sigma(T)$ increase and of the change of $\alpha_0(T)$ and $R(T)$ sign at T>65K. Calculations have demonstrated that at T<65K Fermi energy [2] is somewhat less than energy of acceptor basic state ΔE_a and due to this electron concentration at the acceptor level n_a (where $n_a = N_a[1+\frac{1}{2}\exp-\frac{E_a+\mu}{k_0T}]^{-1}$) remains constant.

III. CONCLUSIONS

With further growth in temperature (at $K_0T > E_a$) the number of vacant places on acceptors reduces, i.e. generation of n_a starts and the process of electron excitation passes from valence zone to conduction band. The principal role in conduction within this temperature interval is played by concentration of n_a ($n_a >> n_i$) which rises exponentially at T>65K and that causes an increase in σ and the change of α_0 and R.

REFERENCES

[1] F.F. Aliyev, E.M. Kerimova and S.A. Aliyev, "Electrical and Thermoelectric properties of p-Ag_2Te", Semiconductor, Vol. 36, No. 8, pp. 869-873, 2002.
[2] F.F. Aliyev and M.B. Jafarov, Semiconductors, Vol. 42, No. 11, pp. 1270-1273, November 2008.
[3] S.A. Aliyev, F.F. Aliyev, AS USSR News, Inorgan. Mater., Vol. 24, No. 21, pp. 341, 1988 (in Russian).
[4] S.A. Aliyev, U.H. Sugunov, M.I. Aliyev, FTP, Vol. 7**,** No. 10, pp. 2024, 1973 (in Russian).
[5] F.F. Aliyev, "Electrical and Thermoelectric Properties of p-Ag_2Te in the β-phase", Semiconductor, Vol. 37, No. 9, pp. 1057-1060, 2003.
[6] V.I. Kaydanov, S.A. Nemov, Yu.I. Ravich. FTP, Vol. 26, No. 2, pp. 201, 1992 (in Russian).
[7] S.A. Aliyev, F.F. Aliyev, AS USSR News, Inorgan. Mater., Vol. 21**,** No. 11, pp. 1869, 1985.
[8] B.I. Shklovsky, A.L. Efros, "Electronic Properties of Doped Semiconductors", M., Nauka, 416, S.A. Nemov**,** Yu. I. Ravich**,** FTP, Vol. 22, No. 8, pp. 1370, 1988 (in Russian).
[9] V.I. Kaydonov, S.A. Nemov. FTP, Vol. 15, No. 3, pp. 542, 1981 (in Russian).
[10] H. Rau, J. Rhys. Chem. Sol., Vol. 35, No. 11, pp. 1553, 1974.
[11] L.S. Koroleva, V.Yu. Martynov, P.P. Petrov, "TchSU Halcogenid and Oxygen Containing Semiconductors", The Second All-Union Conference, Vol. 11, pp. 47, 1986 (in Russian).
[12] S.A. Aliyev, Z.F. Agayev, R.I. Selimzade, Semiconductor, Vol. 42**,** No. 12, pp.1383-1387, 2008.

BIOGRAPHIES

Farzali (Fazil oglu) Aliyev was born in Azerbaijan, 1953. He graduated from Ganja State University (Ganja, Azerbaijan). Currently, he works as leader scientific researcher of Institute of Physics in Azerbaijan National Academy of Sciences (Baku, Azerbaijan).

Rahila (Aydin qizi) Hasanova was born in Azerbaijan, 1978. She graduated from Baku State University (Baku, Azerbaijan) in 2000. Currently, she works as scientific researcher in Institute of Physics of Azerbaijan National Academy of Sciences (Baku, Azerbaijan).

Eldar (Rasul oglu) Hasanov was born in Azerbaijan, 1939. He graduated from Azerbaijan State University (Baku, Azerbaijan). He works as chief of department in Institute of Physics of Azerbaijan National Academy of Sciences (Baku, Azerbaijan).