ON THE INELASTIC CHARACTER OF THE ELECTRON-ELECTRON INTERACTION IN $Bi_{1-x}Sb_x$.

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The thermal conductivity $æ_{tot}(H)$, the Maggi-Righi-Leduc effect $\Delta æ(H)$, the transverse Nerst-Ettingsgausen effect ε_y, the electrical conductivity σ, the Hall effect R and the thermopower (t.e.p.) α have been investigated for two samples of $Bi_{0,88}Sb_{0,12}$ (doped 0,01 and 0,1 at % by Te) in 20-230 K temperature range. The temperature dependence of the Lorentz number L has been calculated by experimental values of $æ_e$ and thermomagnetic effect. As it turned out the L is less than its Zommerfeld value L_0 in the temperature range of 40-220 K. According to the results obtained for L it can conclude that in the solid solution $Bi_{0,88}Sb_{0,12}$ at strong degeneration the inelastic scattering of charge carriers is mainly connected by electron-electron interaction.

INTRODUCTION

The investigations of thermomagnetic effects showed itself long ego as the method for establishment of character of electron-electron and electron-phonon interactions [1-3]. In theoretical work [4] it is shown that thermomagnetic effects are most sensitive to inelastic character of electron scattering. According to the theory the analytic expressions of longitudinal and transverse thermomagnetic effects include the Lorentz number L from Widemann-Franz relation ($æ_e = L \cdot \sigma \cdot T$), the value in which shows the degree of the inelasticity.

In the works [1-3] it is established that the inelastic part reaches a high value in the semiconductors and semimetals with degenerated electron gas.

The same work is carried out for the pure Bi [5] also where the L is determined by extraction of electron part of the thermal conductivity in temperature interval 2-100K. It is shown that the bipolar thermal conductivity $æ_{bip}$ is great at T>80K. It turned out the L has become less than L_{0} at T<30K, and it is stipulated by the part of inelasticity.

We seem that this question for Bi and Bi-Sb system continues to be actual. All the more in the solid solutions the additional scattering centers both elastic and inelastic character can be displayed.

In this work in temperature interval 20-230K the thermal conductivity $æ_{tot}(H)$, the Maggi-Righi-Leduc effect $\Delta æ(H)$, the transverse Nerst-Ettingsgausen effect ε_y, the electrical cond. σ, the Hall effect R, the thermopower (t.e.p) α have been investigated for two samples of $Bi_{0,88}Sb_{0,12}$ doped by Te (0,01-0,1 at %) along C_3 axis. The strong thermomagnetic effects are provided by high values of mobility and concentration of electrons in these samples.

THE EXPERIMENTAL RESULTS

The fig.1 shows the magnetic field dependence on $\Delta æ\left(\frac{UH}{c}\right) = æ_{tot} - æ\left(\frac{UH}{c}\right)$ for the sample doped up to 0,01 at % by Te with $n \sim 5 \cdot 10^{18}$ cm^{-3}. The values of mobility U of electrons for this sample run up to the magnitude U=22·10^3 cm^2/V-sec at T=100K.

Such high mobility of electrons ensures the reaching of the limit value of $\Delta æ(H)$. In the sample doped up to 0,1 at % of Te ($n \sim 2 \cdot 10^{19}$cm^{-3}) $\Delta æ(H)$ does not reach saturation. Since, in the samples with high electron concentration one may not take attention to bipolar thermal conductivity $æ_{bip}$, then the limit value of $\Delta æ(H)$ might be take as electron part of thermal conductivity. For this sample the limit value of $\Delta æ(H)$ has been determined by extrapolation method from [1,6]. According to these data the contribution of $æ_e$, and $æ_{lat}$ ($æ_{lat} = æ_{tot} - \Delta æ_{\infty}$) have separated but the temperature dependence on the Lorentz number has been calculated by $æ_e$ values. As it turned out L is less than its Zommerfeld value ($L_0 = (\pi^2/3)\,(k/1)^2$) in the temperature interval of 40-220K, but $L \rightarrow L_0$ at T<40K.

The figures 2,3 shows the dependences on coefficients ε_y and $SH\,(\Delta T_y/\Delta T_x)$ on dimension less field $\frac{UH}{c}$. It is shown that these coefficients reach the maximum value at $\frac{UH}{c} \approx 1,2-1,4$ and decrease as $\sim\left(\frac{UH}{c}\right)^{-1}$.

As it was mentioned, the analytic expressions for $\Delta æ$ and SH in the case of strong degeneration of electron gas and for any character of scattering are represented as:

$$\Delta æ(UH/c) = \Delta æ_{\infty} \frac{(UH/c)^2 (L/L_0)^2}{1+(UH/c)^2 (L/L_0)^2} \qquad (1)$$

$$-SH\,(UH/c) = \frac{(UH/c)\;(L/L_0)}{1+\left[æ_L/(L_0 \sigma T)\right]\left[1+(UH/c)^2 (L/L_0)^2\right](L_0/L)} \qquad (2)$$

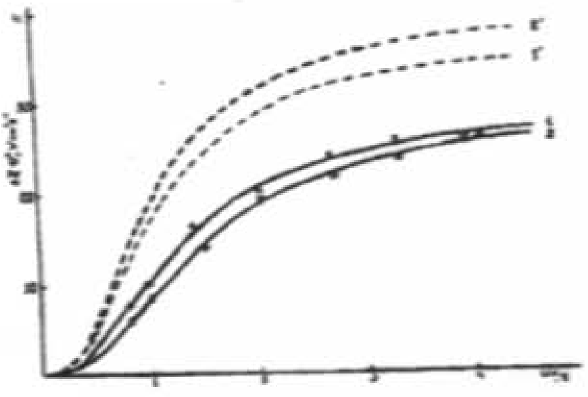

Fig. 1. The magnetic field dependence on $\Delta æ$ in the $Bi_{0,88}Sb_{0,12}$ for sample doped up to 0,01 at % by Te (2-205K at L/L_0 =0,65; 1-93K at L/L_0=0,75)

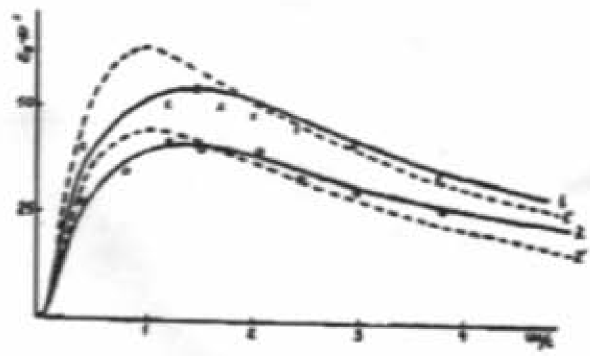

Fig. 2. The dependence on coefficient ε_y from field (1-205K; 2-93K)

$$\varepsilon_y = \frac{\Delta\alpha_\infty (UH/c)\,(L/L_0)}{(e/k)\left[1+(UH/c)^2 (L/L_0)^2\right]} \tag{3}$$

where $\varepsilon_y = (k/e)\,BQ_\perp$.

From this expressions it follows that L/L_0 ratio indicates the degree of inelasticity. At elastic scattering the ε_y and SH coefficients of transverse effects pass through maximum at $UH/c=1$, but inelastic scattering it occurs at $UH/c>1$.

In the figures 1, 2 and 3, besides the experimental data of the field dependence on $\Delta æ$, ε_y and SH, are data calculated by formula from (1)-(3) at corresponding value of L/L_0 ratio (solid lines).

The satisfactory agreement with the experiment has been reached the L/L_0 values obtained from $æ_\infty$. The obtained data of L/L_0 are represented in the fig.4.

DISCUSSION

The nature of inelastic mechanism of the interaction in more full form is described in the theoretical work [7]. According to this theory at strong degeneration of electrons ($\mu^*>>1$) and when the energy of longitudinal optical phonons is considerably less than the energy of electrons, but it is equal to kT ($\mu >> \hbar\omega_0$, $\mu_0 \sim kT$) approximately, the Lorentz number is presented as:

$$L/L_0 = [1+(W_{ee}/W_0 + (U/U_{op})\,((L_0/L)-1)_{op}]^{-1} \tag{4}$$

Here $W_0=(L\sigma T)^{-1}$ is thermal resistivity for the elastic scattering, W_{ee} is thermal conductivity due to the collision between carriers, U is the experimental value of the carrier mobility, U_{opt} is the mobility in case of scattering of carriers on optical phonons. Therefore, the term $(U/U_{op})\,((L_0/L)-1)_{op}$ involves inelasticity caused by the polar scattering of electrons on optic phonons, and the term

$$W_{ee}/W_0 = 2\pi^4 \frac{1^2 (k\cdot T)^2 (K_F \cdot r_{scr})^3 U\cdot n}{\varepsilon_\infty^2 \hbar^3 K_F^3 V_F^4} B(r) \tag{5}$$

takes into account electron-electron interaction where V_F is the velocity, K_F is quasi-momentum on Fermi level, $r_{scr} = \left(\frac{\varepsilon_\infty}{4\pi e^2 \rho(\mu)}\right)^{1/2}$ is the screening radius, corresponding to the dielectric constant ε_∞, $\rho(\mu) = \frac{3en\alpha_\infty}{\pi^2 k^2 T}$ is the density of states.

α_∞ is the thermal power in the strong magnetic field, n is the concentration of charge carriers. The expression for B(Z) is cumbersome and it is described in details in [7].

According to the results presented on fig. 4 it can conclude that in the solid solution $Bi_{0,88}Sb_{0,12}$ at strong degeneration the inelastic scattering of charge carriers is mainly connected with electron-electron interaction. The inelastic part connected with the polar scattering on optical phonons doesn't exceed 5-7%. As above noted in pure Bi the electron scattering has elastic character in interval of 80-100K. The inelasticity has been appeared at $T<30K$ [5]. It may suppose that in pure Bi the absence of elasticity is caused by the low concentration of electrons at high temperatures. This fact corresponds to the conclusions of the work [1-3] that in the narrow-band and gapless semiconductors at electron-electron interaction the inelasticity is displayed at thermal scattering of charge carriers and at their strong degeneration.

The absence of inelasticity at low temperatures in our case is also due to the high concentration of electrons. At the low temperatures the high concentration of electrons causes scattering on the ionized impurities which has elastic character of interaction. Evidently in the case of $Bi_{0.88}Sb_{0.12}$ this mechanism prevails at the high n over interstice mechanism. Of course it's not excepted that in the solid solution decreases the phonon part of thermal conductivity is significantly that creates favourable conditions for appearing of inelastic interaction. The present problem for Bi and solid solutions based on it has not been settled yet. These investigations should be extended on the wide range of temperatures, compositions and concentrations.

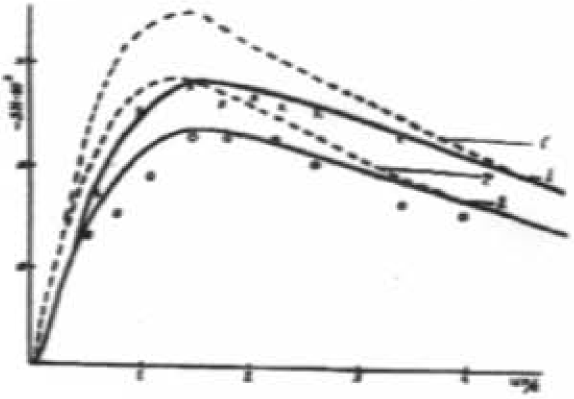

Fig. 3. The dependence on coefficient SH from field UH/c (1-205K; 2-93K)

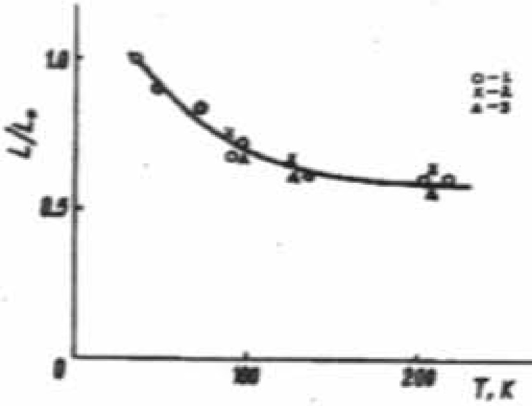

Fig. 4. The temperature dependence on L/L_0 in $Bi_{0.88}Sb_{0.12}$. The solid lines represent the theoretical curve, calculated from eq.4

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$Bi_{1-x}Sb_x$ BİRLƏŞMƏLƏRİNDƏ ELEKTRON-ELEKTRON QARŞILIQLI TƏ'SİRİNİN QEYRİ-ELASTİKLİYİ HAQQINDA

20-230K temperatur intervalında iki $Bi_{0.88}Sb_{0.12}$ (0,01 və 0,1 at.% Te ilə aşqarlanmış) nümunəsində istilikkeçirmə $æ(H)$, Maci-Riqi-Ledyuk effekti $\Delta æ(H)$, eninə Nernst-Ettinqshauzen effekti ε_y, elektrikkeçirmə σ, Xoll effekti R və termo e.h.q. , tədqiq edilmişdir. Termomaqnit effektinə və $æ_e$-in təcrübi qiymətinə görə Lorens (L) ədədinin temperatur asılılığı hesablanmışdır. 40-220K temperatur intervalında L-in L_0-Zommerfeld qiymətindən az olduğu alınmışdır. L-in alınmış qiymətlərinə görə belə qənaətə gəlmək olar ki, $Bi_{0.88}Sb_{0.12}$ bərk məhlulunda çox cırlaşmış halda yükdaşıyıcıların qeyri-elastiki səpilməsi elektron-elektron qarşılıqlı tə'sirinin nəticəsidir.

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О НЕУПРУГОМ ХАРАКТЕРЕ ЭЛЕКТРОН-ЭЛЕКТРОННОГО ВЗАИМОДЕЙСТВИЯ В $Bi_{1-x}Sb_x$

Проведено исследование теплопроводности $æ_{общ}(T)$, эффекта Маджи-Риги-Ледюка $\Delta æ(H)$, поперечного эффекта Нернста-Эттингсгаузена ε_y, Эффекта Холла R, электропроводности σ, термоэдс α для двух образцов $Bi_{0.88}Sb_{0.12}$ (легированных теллуром до 0,01 и 0,1 ат.%) в температурном интервале 20-230K. По данным термомагнитных эффектов и экспериментального значения $æ_э$ была вычислена температурная зависимость числа Лоренца L. Получено, что число Лоренца L меньше, чем его зоммерфельдовское значение L_0 в температурном интервале 40-220K. По полученным значениям L можно заключить, что в твердом растворе $Bi_{0.88}Sb_{0.12}$ при сильном вырождении неупругое рассеяние носителей заряда в основном связано с межэлектронным взаимодействием.

Редактор: М.И. Алиев