INFLUENCE OF COPPER PLASTIC DEFORMATION ON LOW TEMPERATURE THERMAL CONDUCTIVITY

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An analysis of experimental data of the thermal conductivity of deformed copper samples has been carried out. The results obtained have been compared with the thermal conductivity equation recommended for copper samples of differing chemical purities. Exact differences between the character of temperature dependence of the thermal conductivity of the copper of differing chemical purities and the differing degrees of plastic deformation have been obtained.

1. *Introduction*

There is a lack of systematic investigations of the plastic deformation influence on the thermal conductivity of metals in maximum range. The main efforts have been directed at explaining the influence of the chemical impurity concentration on the low temperature thermal conductivity of metals [1]. The impurity parameter β describing a low temperature range of the thermal conductivity is some measure of the impurity concentration. At the same time it involves information about the concentration of physical defects in the metals investigated. A change of the β parameter has been realised in this

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work by different degrees of the copper samples plastic deformation at 20 K. The aim of this paper is to present preliminary data on the influence of plastic deformation on the β parameter and compare it with its influence on chemical impurity concentration.

2. *Theoretical part*

A starting point of the analysis of experimental data is a thermal conductivity equation of metals at low temperatures [1]

$$\lambda_e = \left(\alpha' T^n + \frac{\beta}{T}\right)^{-1}, \tag{1}$$

where λ_e is the electronic part of the thermal conductivity coefficient of metals; α' — a coefficient occurring in an ideal thermal resistivity component caused by electrons scattered on phonons; n — a power exponent in temperature dependence of an ideal thermal resistivity component; β — a coefficient occurring in a residual thermal resistivity component caused by electron scattering on chemical impurities and physical defects.

The measurements of a thermal conductivity temperature dependence of a deformed copper sample have been described by Eq. (1) through an optimal choice of the values of α', n and β fitted by a computer by the least squares method. The average dispersion of the experimental points from the calculated curve was below 1%. According to the work [1], the α' coefficient changes depending on the chemical impurity concentration and gives the relation

$$\alpha' = \alpha'' \left(\frac{\beta}{n\alpha''}\right)^{\frac{m-n}{m+1}}, \tag{2}$$

where α'', m and n are the constants recommended [1] for individual metals and β is influenced by the chemical impurity concentration.

3. *Experimental part*

As a material elaborated in this paper, the experimental data of the work [2] have been used. Thermal conductivity measurements were made by steady state method. The samples were rod shaped polycrystals 2.5 mm diameter. For average temperature gradient measurements two Pb resistance thermometers have been used. The distance between thermometers was 30 mm. The errors of measured values were

(a) $\pm 0.5\%$ for heat flux,
(b) $\pm 0.2\%$ for temperature difference,
(c) $\pm 0.5\%$ for distance between thermometers,
(d) $\pm 0.8\%$ for sample cross section.

The whole error of λ_e measurements, considering also the error caused by parasitic heat losses, was about $\pm 3\%$. The experimental technique used was described in detail in work [2].

The copper samples designed by ECu 5 and ECu 6 consisted of the electrolytical copper of 99.90% purity. The sample marked CCu 1 is made of Chile copper. A chemical analysis shows the concentration of impurity in ppm. Ag — 12.5; Fe — 27.0; Pb — 22.7; Ni — 4.2; Bi — 0.2; C — 22.0. The samples were machine made from bulk material and annealed in a heater under vacuum in a quartz tube. ECu 5 was annealed for 2 h at 820°C and for 15 min at 1000°C, and ECu 6 and CCu 1 for 1 h at 400°C. After annealing the samples were cooled to room temperature for about 5 hours.

The dependence of the power exponent n on the β parameter is presented in Fig. 1. β is directly connected with a degree of the copper sample plastic deformation. The dependence of the α' coefficient on the β parameter for the three copper samples investigated is shown in Fig. 2. For comparison, the theoretical curve described by Eq. (2) in which α'', n and m values recommended for copper are substituted, has been marked, too. A relationship between the β parameter from Eq. (1) and the plastic deformation degree ε for two copper samples, is presented in Fig. 3. Figs 4 and 5 show the dependence of the temperature maximum T_m and the maximum of thermal conductivity λ_{em} on the degree of the plastic deformation ε, respectively, for the same two copper samples.

4. *Discussion*

The dependence $n(\beta)$, presented in Fig. 1, shows a maximum for a value of about 0.75 for the two copper samples ECu 5 and ECu 6 of 99.90% chemical purity. For the purest sample CCu 1 of 99.99% purity, the maximal value of $n(\beta)$ is considerably higher. The results qualitatively agree with the prediction of the Klemens theory [3]. For the value $\beta > 1.5$ $n \to 2$ but for the CCu 1 sample $n \to 3$ for $\beta \simeq 0.5$.

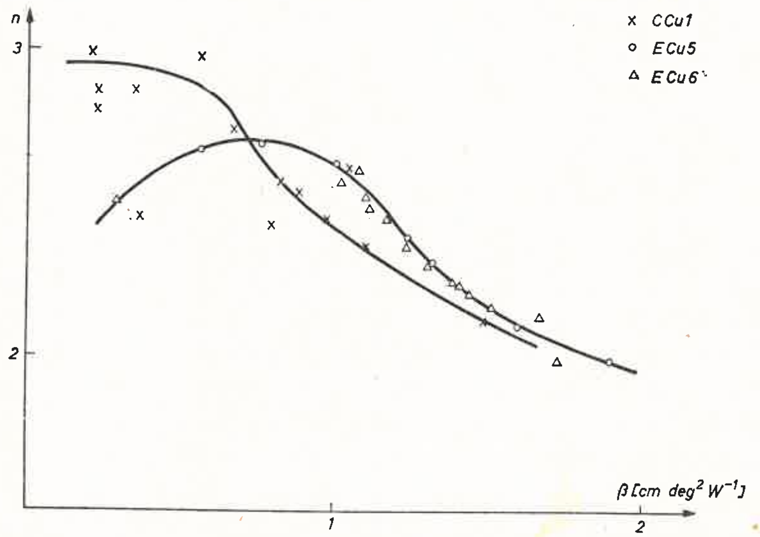

Fig. 1. Dependence of the exponent n on the β parameter for the copper samples investigated

Fig. 2 presents the $\alpha'(\beta)$ dependence which shows a very similar shape for the ECu 5 and ECu 6 samples. The purest CCu 1 sample exhibits quite a different shape of $\alpha'(\beta)$ with a minimum occurring for $\beta \simeq 0.5$. For comparison, the curve recommended for copper described by Eq. (2) has been marked in Fig. 2, too. The shape of the $\alpha'(\beta)$ recommended curve shows that the chemical impurity concentration change has a weak influence on an ideal part of the metal thermal resistivity. In the case of changing a copper sample degree of plastic deformation, this influence is considerably greater. It would suggest that the sample plastic deformation has a definite influence on the character of lattice vibrations.

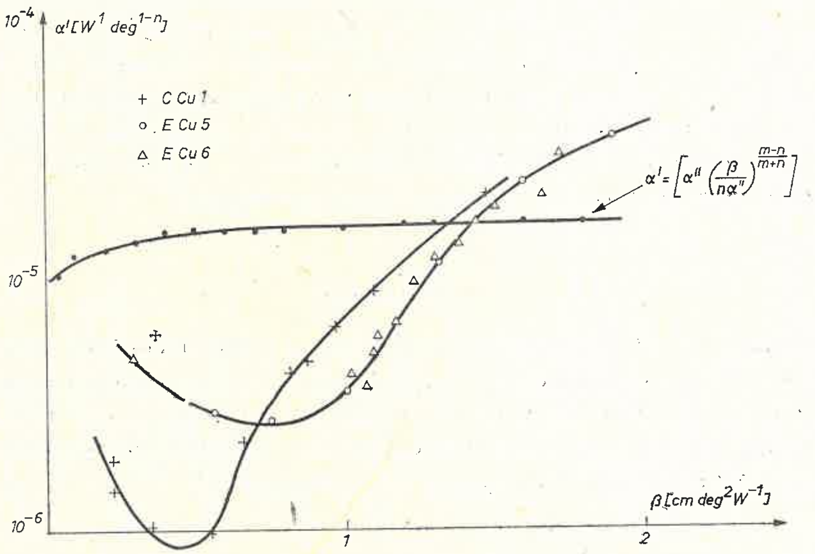

Fig. 2. Dependence of the α' coefficient on the β parameter for the copper samples investigated

Fig. 3 shows a change of the β parameter dependent on the plastic deformation degree ε of copper samples. The values β for $\varepsilon = 0$ are a qualitative measure of the chemical impurity concentration. With the plastic deformation rising from $\varepsilon = 0$ to $\varepsilon = 0.3$, one can observe the β increase of a similar kind for the ECu 5 sample and the purest CCu 1 sample.

It may be seen that keeping a sample deformed at room temperature for a few or more days leads to its thermal treatment what is noticed in the values decrease [2] (Fig. 3, point numbers from 10 to 14). The β value (point 11) in Fig. 3 has been obtained for CCu 1 sample after 5 days from the moment of deformation. The time between β value estimations for points 12, 13 and 14 was 14, 5 and 8 days, respectively. Besides room temperature storage the samples were each time annealed according to procedure described earlier. During the other thermal conductivity measurements the samples were not warmed up above 77 K.

Fig. 4 presents the linear increase $T_m(\varepsilon)$ for the ECu 5 sample while the purest CCu 1 sample exhibits considerable point scattering. $T_m(\varepsilon)$ increasing with the ε increase is in

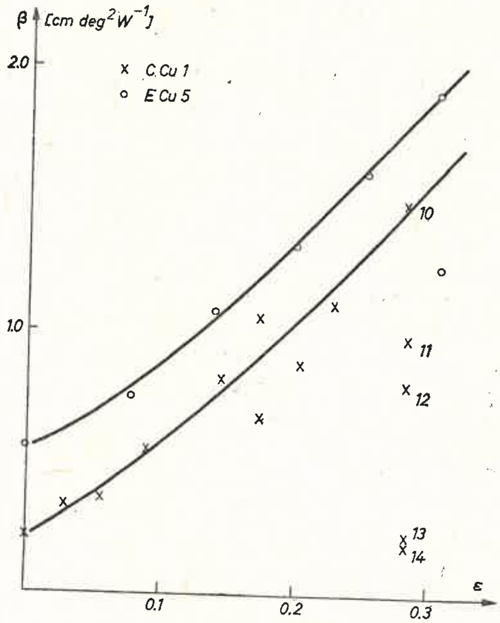

Fig. 3. Relationship between the β parameter and the plastic deformation degree ε for the copper samples investigated

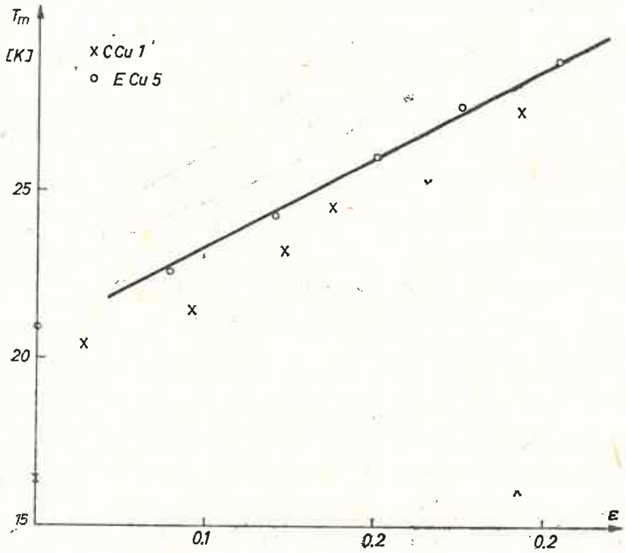

Fig. 4. Dependence of the temperature maximum T_m of thermal conductivity on the plastic deformation degree ε for the samples investigated

a qualitative agreement with a well known increase of T_m caused by the increase of the chemical impurity concentration.

Fig. 5 shows the λ_{em} change with the ε change for the ECu 5 sample (less strong dependence) and for the purest CCu 1 sample (more strong dependence in small values of ε range). For $\varepsilon > 0.3$ both $\lambda_{em}(\varepsilon)$ curves tends towards the same value what means the considerable overbalancing of the physical defects concentration influence above the chemical impurity influence.

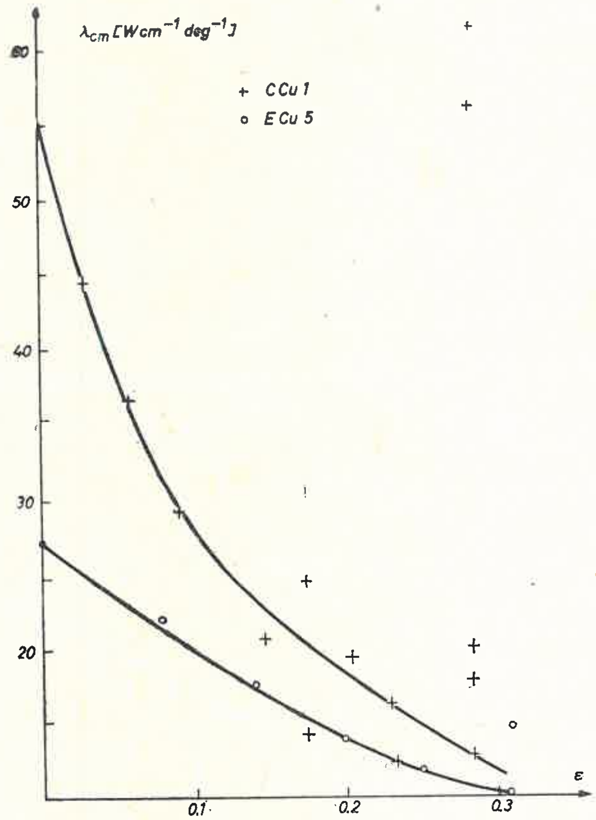

Fig. 5. Dependence of the maximum of thermal conductivity λ_{em} on the plastic deformation degree ε for the samples investigated

5. *Concluding remarks*

The analysis conducted in this work shows that the influence of chemical impurity concentration investigated on the low temperature thermal conductivity of metals is quite different from the plastic deformation influence on the thermal conductivity. A plastic deformation mainly produces linear dislocations while chemical impurities behave like electron scattering point centres and this may be treated as the main reason for the different influence. Further investigations of the physical defect influence on the low temperature metal thermal conductivity ought to be separately concentrated on the point defect influence and the linear dislocation influence in future.

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