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LATTICE THERMAL CONDUCTIVITY COMPONENT OF BRASSES IN THE TEMPERATURE RANGE 30—300 K

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An analysis of microscopic mechanisms of the scattering of the lattice thermal conductivity component of brasses in the temperature range above the thermal conductivity maximum (30–100 K) was performed. It was shown that the FT linear term versus temperature corresponds to phonon-phonon and phonon-point defect scattering. The thermal resistivity term E is independent of temperature and corresponds to phonon-dislocation nucleus scattering. It was shown that the constant F decreases and the constant E increases with increasing electric residual resistivity. The lattice thermal conductivity component of brasses can be accounted for on the basis of the Wiedemann–Franz law in the temperature range 100–300 K.

1. Introduction

The atoms dissolved in a metal or an alloy produce a great number of point defects. One may expect that some thermal resistivity is determined by phonon-point defect scattering. It appears that the lattice thermal conductivity λ_1 of alloy composition is relatively unsensitive to low admixture concentration in the considered temperature range. This suggests that the λ_1 value is limited mainly by U processes [1]. This assumption is correct for alloys of low concentration of admixture atoms. For high admixture concentrations the contribution to lattice thermal resistivity resulting from existence of dissolved atoms may be observed.

The main aim of this paper is a systematic presentation of microscopic mechanisms of phonon scattering in the temperature range 30–100 K and a short discussion of the lattice thermal conductivity of brasses in the temperature range 100–300 K.

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The thermal conductivity measurements have been performed by the stationary steady-state method. A detailed description of the investigated brass samples may be found in [5].

We hope that our investigations of brasses will help towards better understanding of the physics of heat transport in binary alloys.

2. *Lattice thermal conductivity in the temperature range 30–100 K*

2.1. Phonon-phonon and phonon-point defect scattering

Klemens suggests [2] that only in the vicinity of the maximum of the lattice thermal conductivity component does the pure effect of phonon-phonon scattering take place. At higher temperatures this effect appears together with phonon-point defect scattering. The thermal resistance of both these scatterings is linear with temperature.

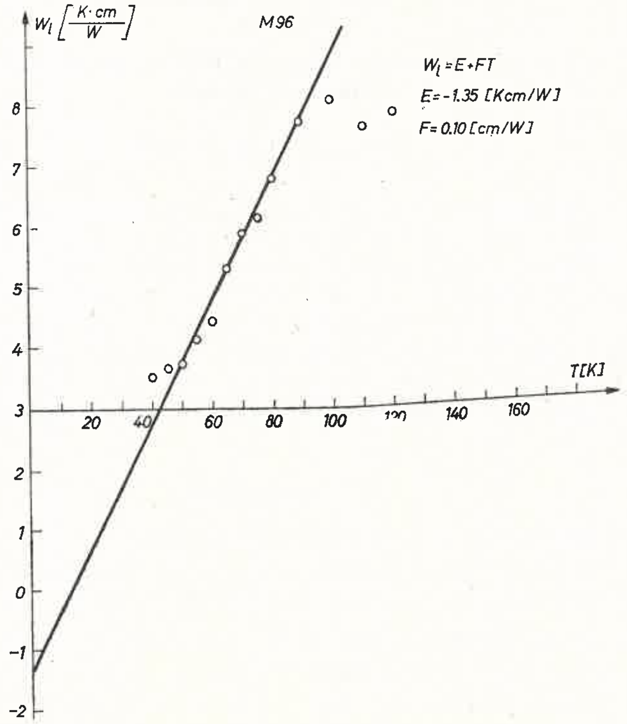

Fig. 1. Thermal resistivity dependence on temperature for brass sample M 96 in the range 40–140 K

In figures 1 and 2 the dependences of thermal resistivity on temperature are presented for two selected brass samples. This dependence is described by the equation

$$W_l = FT \pm E. \tag{1}$$

The FT term denotes the thermal resistivity caused by phonon-phonon and phonon-point defect scatterings. The E term will be the subject of later considerations.

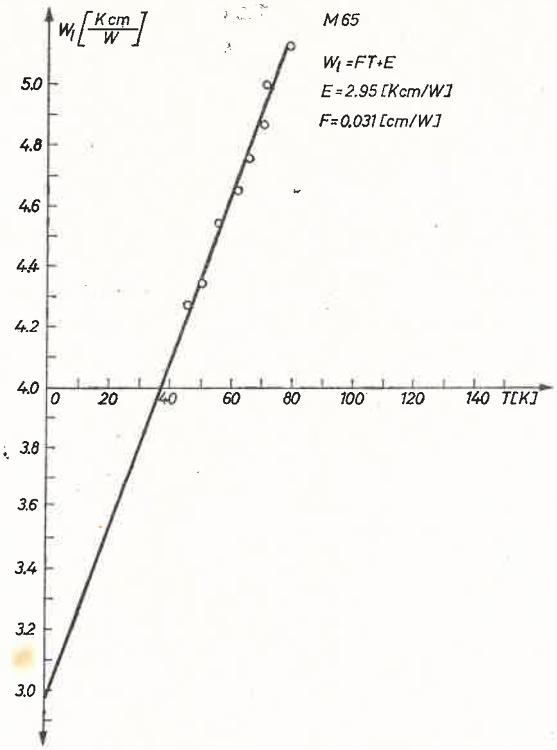

Fig. 2. Thermal resistivity dependence on temperature for brass sample M 65 in the range 40–100 K

The values of the F and E parameters for particular samples are shown in Table I. The second column in Table I includes the total resistivities caused by phonon-phonon and phonon-point defect scattering. The third column includes thermal resistivities caused by phonon-phonon scattering and the fourth column contains the thermal resistivities determined by phonon-point defect scatterings.

TABLE I

The ratios of thermal resistivities and temperature reciprocals for investigated CuZn samples

Samples	$W_s T^{-1} = F$ [cm/W]	$W_u T^{-1}$ [cm/W]	$W_p(\text{obs}) T^{-1}$ [cm/W]	$W_p(\text{calc}) T^{-1}$ [cm/W]	E [cm K/W]	$\frac{W_p(\text{calc}) T^{-1} \times 10^{-6}}{\varrho_0}$ [$W^{-1}\Omega^{-1}$]
M 97*	0.280	0.028	0.252	0.005	−6.50	0.310
M 96	0.100	0.028	0.072	0.006	−1.35	0.050
M 90	0.130	0.028	0.102	0.016	−2.00	0.055
M 86*	0.107	0.028	0.079	0.020	−1.70	0.032
M 85	0.034	0.028	0.006	0.025	2.10	0.002
M 70	0.029	0.028	0.001	0.050	2.78	0.0003
M 65*	0.031	0.028	0.003	0.058	2.95	0.0009
M 63	0.031	0.028	0.003	0.062	3.02	0.0007

In Fig. 3 the dependence of the F and E coefficients of Eq. (1) on sample purities was shown, as determined by residual resistivity ϱ_0. One may observe the decrease of F with increasing ϱ_0. For highly doped samples (M 63, M 65, M 70, M 85) the $F(\varrho_0)$ dependence is very weak. F does not strongly depend on the degree of sample purity for zinc concentration in the interval from 37% to 15%.

The separation of phonon-phonon and phonon-point defect collisions can be performed only in an approximate manner for the whole range of admixture concentrations. The admixture concentration influence on the value of thermal resistivity of phonon-phonon

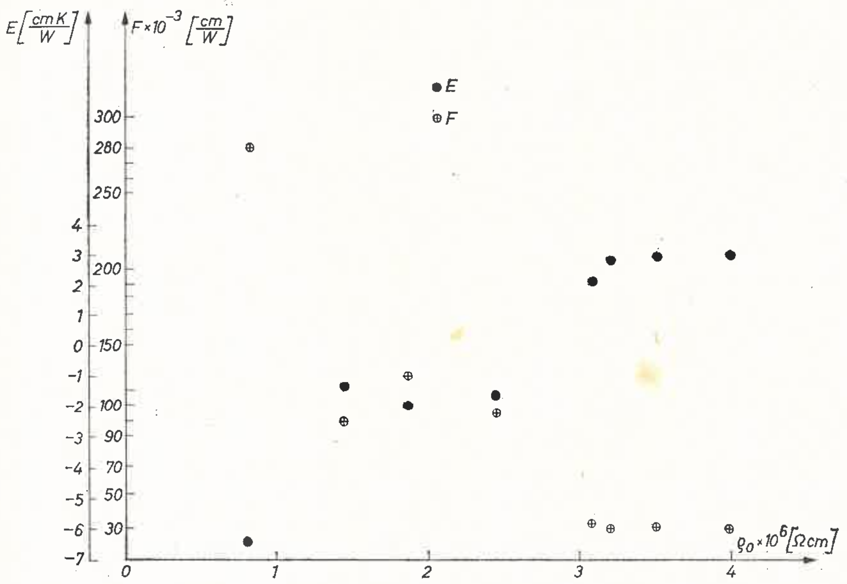

Fig. 3. The dependence of F and E constants of Eq. (1) on the residual resistivity of brass samples

scattering is not yet known. The authors of the present paper assume after [3] that W_uT^{-1} measured for pure copper (0.06% Fe) and equal to 0.028 cm/W is equal to W_uT^{-1} for all investigated samples. The remaining part of the observed thermal resistivity determines the thermal resistivity of the phonon-point defect collisions W_p. In Table I, in the fifth column the values of $W_p(\text{calc})T^{-1}$ products are given. The $W_p(\text{calc})T^{-1}$ has been calculated on the basis of Eq. (1)

$$W_pT^{-1} = \frac{3(2\pi)^2a^3}{0.9hv^2}\,S^2n, \tag{2}$$

where a^3 is atomic volume of the basic metal, h — Planck's constant, v — phonon velocity, n — the concentration of point defects connected with one atom.

$$S^2 = \tfrac{1}{12}\left(\frac{\Delta M}{M}\right)^2,$$

where M is average mass of the basic metal atom, ΔM — point defect mass.

The value of $W_p(\text{calc})T^{-1}$ increases with admixture concentration and for the M 85, M 70, M 65* and M 63 samples exceeds the value of $W_p(\text{obs})T^{-1} = W_1T^{-1} - W_uT^{-1}$. This was observed for alloys of CuAu [4] and for dielectrics [1]. The $W_p(\text{calc})T^{-1} > W_p(\text{obs})T^{-1}$ dependence appearing for M 97*, M 96, M 90 and M 86* samples has also been observed by the authors of [3, 1]. For M 70, M 65* and M 63 samples $W_p(\text{calc})T^{-1}$ even exceeds $W_p(\text{calc})T^{-1} = F$.

Despite doubt about $W_p(\text{calc})T^{-1}$ absolute values calculated from Eq. (2) one may notice that direction of $W_p(\text{obs})T^{-1}$ changes is opposite to expected.

The fact that $W_p(\text{obs})T^{-1}$ depends on admixture concentration is very interesting. With increasing admixture concentration $W_p(\text{obs})T^{-1}$ decreases while E increases. It appears that with increasing admixture concentration the number of active point defects diminishes. The question arises: what happens to the remaining admixture atoms?

If ϱ_0 and $W_p(\text{obs})$ would be determined only by electron and phonon-collisions with admixture atoms, then the ratio $W_p(\text{obs})T^{-1}/\varrho_0$ (seventh column in Table I) would be constant independent of admixture atom concentration [4]. It results from Table I that this ratio decreases with admixture concentration increasing and $W_p(\text{obs})T^{-1}$ decreases. It may mean that point defects scatter electrons and phonons in different ways. This is one of the possibilities of explain the observed behaviour.

In the case of the investigated brasses ϱ_0 is determined not only by electron-point defect scattering but also by electron-dislocation scattering and ϱ_0 grows with dislocation density [5]. Admixture atoms, not being the points of dislocation blocking, have migration properties and can diffuse in the dislocation strain field and lay along their lines. In this way admixture atoms are blocked by dislocation.

In the considered temperature range the resistivity of phonon-dislocation scattering is negligibly small so the admixture atoms restrained by dislocations are not the effective factor of phonon scattering.

In view of this model the fact that $W_p(\text{obs})T^{-1}$ decreases with admixture concentration can be understood. The dislocation density grows with ϱ_0. The more the dislocations, the more the number of restrained admixture atoms is. It seems that the greatest number of point defects (admixture atoms) is blocked in the field of dislocation strain or represents the stable points for dislocation.

2.2. Phonon scattering on dislocation cores

The E term of Eq. (1) which is the component of thermal resistivity independent of temperature, is determined by phonon scattering on dislocation cores [1]. The number of dislocations grows with admixture atom concentration hence the growth of thermal resistivity E of phonon-dislocation nuclear scattering (sixth column of Table I) is obvious. On the other hand the fact that the E sign changes is not elucidated. The growth of E is associated with the simultaneously decreasing thermal resistivity of phonon-point defect scattering. It suggests that the thermal resistivity E increases at the cost of W_p. Fig. 3 demonstrates that the thermal resistivity E increases with ϱ_0 for growing residual resistivity of brass samples.

3. Lattice thermal resistivity in the range 100–300 K

In the majority of works concerning the separation of coefficient thermal conductivity components of alloys, this separation has been conducted from liquid helium temperatures to about 100 K. There is no consistent opinion till now about the thermal conductivity separation components for temperature above 100 K, because there is no generally accepted separation model.

If one assumes that the Wiedemann–Franz law is valid for alloys in the whole liquid helium temperature range [6–9] then one will obtain thermal conductivity component temperature plots in the temperature range 4.2–300 K as it has been demonstrated in [9]. The lattice component of brass thermal conductivity after reaching its maximum in the temperature range 30–40 K decreases as $(FT \pm E)^{-1}$ with increasing temperature.

In the temperature range 90–130 K the lattice component reaches a rather flat and wide minimum and then grows monotonically. In the temperature range 230–300 K lattice thermal conductivity grows linearly with temperature.

4. Conclusions

The following microscopic mechanisms of phonon scattering were in the temperature range above the maximum of lattice thermal conductivity component of brasses 30–100 K (figures 1 and 2): (*i*) Phonon-phonon scattering, of which the thermal resistivity changes linearly with temperature. (*ii*) Phonon-points defect scattering of which the thermal resistivity also changes linearly with temperature. (*iii*) Phonon-dislocation core scattering of which the thermal resistivity is independent of temperature.

It was stated that the decrease of the constant F in Eq. (1) (the phonon dissipation on phonons and point defect) with ϱ_0 residual resistivity growing for brass samples (Fig. 3).

It was shown that the growth of thermal resistivity E is caused by phonon scattering on dislocation cores with ϱ_0 increasing for brass samples (Fig. 3).

The assumption of the validity of the Wiedemann–Franz law permits us to perform the separation of lattice components of brass thermal conductivity also in the temperature range 100–300 K.

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