INVESTIGATION OF THE PHENOMENA OF CHARGE AND HEAT TRANSFER IN YTTRIUM SINGLE CRYSTALS AT LOW TEMPERATURES

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Submitted April 23, 1968

Zh. Eksp. Teor. Fiz. 55, 1595–1597 (November, 1968)

We investigated the anisotropy of the electric and thermal conductivity (σ, κ) and the thermal emf (α) of pure single crystals of yttrium at low temperatures. In the interval from 300 to 3°K, the anisotropy of σ changed from 2.2 to 3.9, and the anisotropy of α from 1.5 to 0.5. The anisotropy of κ increases with decreasing temperature and has a maximum value of 2.7 at 10°K.

IN connection with success in obtaining pure single crystals of yttrium, it was of interest to investigate the charge and heat transfer phenomena in different directions of this anisotropic metal at low temperatures, when the perfection of the crystal becomes manifest most strongly.

Yttrium has a hexagonal close-packed lattice with parameters a = 3.65 Å and c = 5.73 Å. Experimental data on the thermal conductivity κ are contained in[1-4], on the electric conductivity σ in[1,5,6], on the thermal emf α in[7], on the Hall effect in[8-10], and on the magnetic susceptibility in[6,11-13]. The experimental data on the anisotropy of the physical properties of yttrium are confined to the electric conductivity[5] and to the Hall coefficient[8].

In the present work we investigated two single crystals of yttrium in the form of long rods ($l \approx 60$ mm, diameter 6 mm), oriented parallel (sample 1) and perpendicular (sample 2) to the principal axis of the crystal.

The thermal conductivity κ and the thermal emf α were measured by the stationary heat flow method in a vacuum chamber immersed in a thermostating liquid (nitrogen, oxygen, hydrogen, helium). The temperature was measured at two points of each sample with the aid of copper-constantan thermocouples in the region T = 20–300°K and with Allen-Bradley carbon resistors in the region T = 2–30°K[1)].

The yttrium single crystals were grown without a crucible by zone melting in vacuum (residual pressure $\sim 5 \times 10^{-5}$ mm Hg). To ensure sterility, the metal was molten by high-frequency currents. The metal rod used to grow the single crystals was made from distilled yttrium. A single crystal of definite crystallographic orientation was grown on a suitable primer.

According to the data of chemical, chemical-spectral, microprobe, and gas analysis it was established that the impurity contents in the investigated yttrium single crystals amounted to (in wt.%): Cu ~ 0.002, Fe ~ 0.001, O_2 ~ 0.15, Gd ~ 0.01, Dy < 0.001, H_2 < 0.001, Tb < 0.001, Ho < 0.001, and N_2 ~ 0.12. The microprobe analysis revealed local inclusions of small amounts of silicon.

[1)] A more detailed description of the experimental procedure is contained in [14].

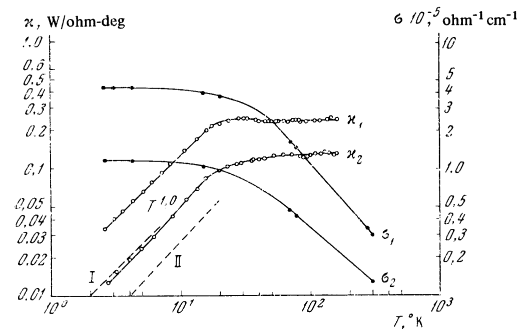

FIG. 1. Experimental curves of the temperature dependence of the electric conductivity σ, and the thermal conductivity κ for two yttrium single crystals with longitudinal (1) and transverse (2) orientations. The dashed lines show the experimental results of [2] (curve II) and of [3] (curve I)

Figure 1 shows the experimental curves for the electric conductivity σ and thermal conductivity κ in two principal directions of the crystal. The Lorentz number $L = \kappa/\sigma T$ obtained from these data is shown in Fig. 2. Figure 3 shows the results of an investigation of the thermal emf α, measured relative to copper. In Fig. 4 we compare the data on the anisotropy of the investigated physical properties of yttrium.

The ratio of the resistance at room temperature to the resistance at liquid-helium temperature, $\rho_{293}/\rho_{4.2}$ amounted to 14.5 and 8.9 for samples 1 and 2, respectively. The residual resistance was 2.3 and 8.7 μohm-cm, respectively. The same result was obtained for two thin samples cut parallel and perpendicular to the principal axis of the crystal from the bulky sample 1, thus serving as a control on the correctness of the determination of the anisotropy of the kinetic coefficients measured on two separately prepared

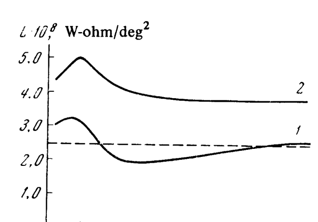

FIG. 2. Temperature dependence of the Lorentz number $L = \kappa/\sigma T$ for two single crystals of yttrium with longitudinal (1) and transverse (2) orientation.

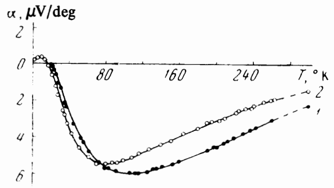

FIG. 3. Experimental curves of the temperature dependence of the thermal emf for two yttrium single crystals of longitudinal (1) and transverse (2) orientation.

samples with different crystallographic-axis orientations.

The temperature dependence of the thermal conductivity κ at 20°K has the usual form of the electronic thermal conductivity of a metal at low temperatures: $\kappa \sim T$. The anisotropy of the thermal conductivity changes from 1.75 at $T = 150°K$ to 2.7 at $T = 10°K$.

For sample 1, the Lorentz number turned out to be close to its Sommerfeld value ($L_0 = 2.45 \times 10^{-8}$ W-ohm/deg^2). The presence of a maximum on the L(T) curves may be connected with the participation of the phonon thermal conductivity.

For a detailed quantitative discussion of the results it is necessary to know the structure of the energy spectrum of the carriers and the mechanism of their interaction with phonons and crystal defects. At the present time there are no experimental data capable of revealing directly the form of the Fermi surface of yttrium. A theoretical approach to the solution of this question indicates that this surface has a very complicated form[15].

We are grateful to V. M. Muzhdaba for help with the measurements and N. I. Moreva for supplying the polycrystalline yttrium for growing the single crystals.

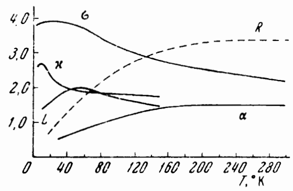

FIG. 4. Plots of the temperature dependence of the anisotropy of the electric conductivity σ, the thermal conductivity κ, the thermal emf α, and the Lorentz number L. The figure shows the ratios of the corresponding quantities for sample 1 to the quantities for sample 2. The dashed line shows the plot of the anisotropy of the Hall coefficient in accordance with [8].

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Translated by J. G. Adashko
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