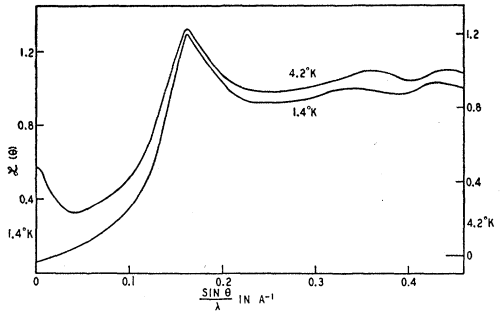

FIG. 2. Liquid structure factors for helium at 1.4° and 4.2°K. The ordinate scale on the left applies to the 1.4°K curve; that on the right to the 4.2°K curve.

unambiguously without consideration of the incoherent contribution.

Figure 2 shows the liquid structure factor curve at 4.2 and 1.4°K. In order that $\mathfrak{L}$ approach unity at 90° it was necessary to reduce the calculated incoherent scattering cross section of helium[5] by 10 percent. An overall increase of the calculated argon coherent scattering cross section by 10 percent would produce the same effect by reducing the proportionality constant for helium scattering, although of course the form of $\mathfrak{L}(\lambda,\theta,T)$ would be altered somewhat.

The liquid structure factor should approach zero scattering angle parabolically[6] with its limiting value given by $\mathfrak{L}(0°,T)=nkT\chi_T$, where n is the number density, k is the Boltzmann constant, T the absolute temperature, and χ_T the isothermal compressibility. Such a parabolic extrapolation for the experimental data in Fig. 2 yields a value for $\mathfrak{L}(0°,T)$ of 0.475 at 4.2°K and 0.065 at 1.4°K with a probable error of ± 7 percent as compared to 0.45 and 0.055 predicted by Goldstein in a private communication and approximately 0.6 at 4.2°K according to Tweet.[4]

Details of the experiment will be published shortly.

* This work was supported by a grant from the Research Corporation of New York.

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Electrical Resistivity Minimum and Structural Defects in Copper

R. W. SCHMITT AND M. D. FISKE
General Electric Research Laboratory, Schenectady, New York
(Received October 4, 1954)

BLEWITT, Coltman, and Redman[1] have reported that a resistance minimum was observed in pure copper upon introducing grain boundaries by straining a single crystal and subsequently annealing it. The original single crystal as well as the strained, unrecrystallized sample, however, did not show a minimum. The authors therefore proposed that the minimum in electrical resistivity may arise as a result of scattering or trapping at grain boundaries.

If this proposal were true, one might expect alterations in the grain structure of copper to produce changes in any resistivity minimum observed. Experiments done at this Laboratory indicate that no such effect occurs. These experiments consist of measuring the small minimum occurring in cold-drawn copper wires and in the same samples after they are subjected to annealing treatments. The copper is American Smelting and Refining Company high-purity copper,[2] samples $0-A$ having been prepared by swaging and cold drawing the original stock into wires, sample $0-B$ by chopping the stock into pieces and remelting in evacuated quartz tubes prior to swaging and drawing. The results are illustrated in Fig. 1, where $\rho_{\text{anom}}\equiv\rho_T-\rho_{4.2°\text{K}}$ *vs* temperature is plotted for the liquid helium temperature region. Earlier measurements on $0-A$ show no signs of a resistance minimum, whereas recent, more precise measurements show a slight minimum of the order of or less than that observed by MacDonald[3] in his pure copper (the quantity δ indicated in the figure represents approximately MacDonald's value of $\rho_{4.2°\text{K}}-\rho_{\min}$). The pertinent observation on this sample is that after being

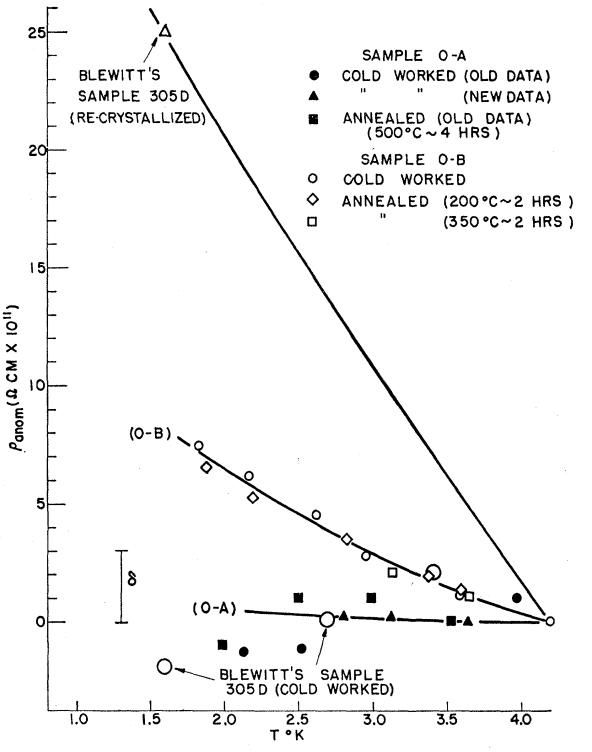


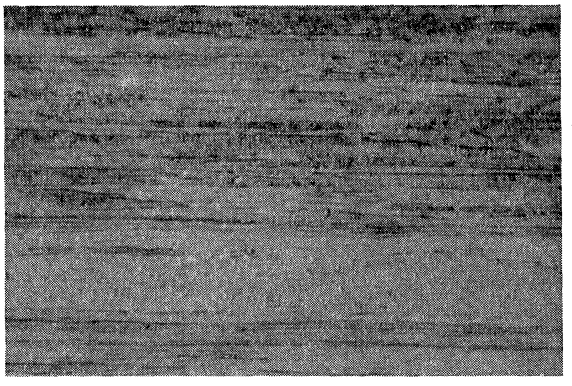
FIG. 1. $\rho_{\text{anom}}\equiv\rho_T-\rho_{4.2°\text{K}}$ *vs* temperature for copper samples.

TABLE I. Resistivities, electronic mean free paths (l), and grain diameter (d).

Sample	Temp. of anneal, °C	4.2°K Ωcm×10⁸	l cm×10³	d cm×10³
	Present data			
0−A	C.W.[a](new)	4.88	0.13	···
	C.W.(old)	4.18	0.16	···
	~500(old)	0.34	1.9	0.9
0−B	C.W.	5.09	0.13	···
	~200	1.18	0.55	···
	~350	0.81	0.81	0.9
	Blewitt *et al.*			
305D	C.W.	1.31	0.50	···
	~1000	0.91	0.72	10²

[a] C.W. = cold-worked.

annealed in high vacuum at approximately 500°K it does not show a larger ρ_{anom} than do the highly cold-worked samples. Figure 2 shows the microstructure of the sample in the highly cold-worked and annealed states. It is clear that the number and arrangement of grain boundaries has changed markedly during annealing. The results on sample 0−B also confirm that changes in grain structure play no detectable role in determining the magnitude of the resistance minimum,



(a)

(b)

FIG. 2. Microstructure of cold-worked and annealed samples 0−A. ×500. (a) Cold-worked; (b) annealed.

for here again there is no apparent change in ρ_{anom} between the cold-drawn wire and the annealed wires. In Table I are compiled the resistivities and electronic mean free paths, l, of our samples at helium temperature along with an approximate grain diameter, d, for some of the annealed samples. The grain diameters are of the same order of magnitude as the computed free paths, indicating that a considerable fraction of the residual resistivity likely arises from grain-boundary scattering in these cases.

Blewitt and co-workers' results on a worked single crystal and on the same sample after recrystallization are given in Fig. 1 and Table I. The mean free path in Blewitt's recrystallized samples is a small fraction of the grain size[4] of these samples.[5] Thus, grain-boundary scattering must contribute very little to the total residual resistivity of these samples—in contrast with the case of our recrystallized samples. It is possible, then, that the resistance minimum observed by Blewitt may arise from additional scattering centers present within the grains of his samples.

Koehler[4] points out that using the grain size of Blewitt's samples as a mean free path gives a computed resistivity roughly equal to only ρ_{anom} extrapolated to 0°K. This correspondence he takes as confirmation of the hypothesis that the resistance minimum may be the result of grain-boundary scattering. However, a similar argument with respect to our samples would lead one to expect ρ_{anom} in the annealed samples at 0°K to be of the same order of magnitude as the residual resistivity itself. This result is incorrect by about two orders of magnitude.

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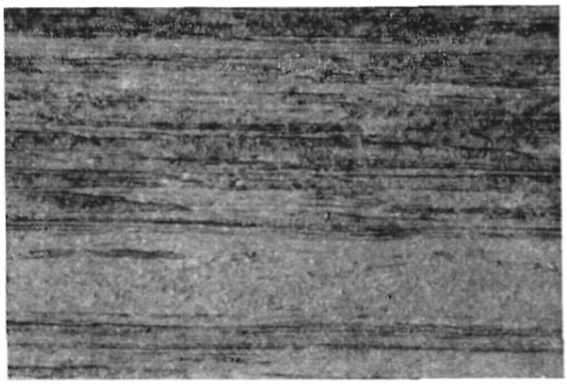
Electrical Resistivity Minimum Reported in Copper-Zinc Alloys

R. W. SCHMITT
General Electric Research Laboratory, Schenectady, New York
(Received October 4, 1954)

GERRITSEN and Linde[1] report that the addition of small amounts of zinc to copper gives rise to a resistance minimum. Experiments done at this Laboratory do not confirm this result, and we have found no resistance minimum in these low-percentage alloys that can be ascribed to the zinc. Our results are illustrated and compared with those of Gerritsen and Linde in Fig. 1, where $\rho_{\text{anom}} \equiv \rho_T - \rho_{4.2°\text{K}}$ is plotted *vs* temperature in the liquid helium temperature region. The curves attributed to Gerritsen and Linde are computations



(a)

(b)

FIG. 2. Microstructure of cold-worked and annealed samples $0-A$. $\times 500$. (a) Cold-worked; (b) annealed.