Title
Properties of Conductors, Normal and Superconducting

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Publication Date
1998

LBNL 40976
SC MAG 607

CHAPTER SIX

ELECTRICAL CONSIDERATIONS

6.2 PROPERTIES OF CONDUCTORS, NORMAL AND SUPERCONDUCTING

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6.2.1 Normal Conductors

Resistivities for some common conductors and resistive materials at 0°C are given in Table 1 together with their temperature coefficients of resistance valid over the range ± 200 °C about 0° [1]

$$\rho(T) = \rho(0)(1 + \alpha \cdot \Delta T) \qquad (1)$$

Table 1

Mat'l	Ag	Cu	Fe	Al	NiCr†
ρ*	1.50	1.56	8.57	2.5	108
α**	0.41	0.43	0.65	0.44	0.021

†80Ni-20Cr * microhm-cm **per 100°C

Ag, Cu and Al are often used as the supporting matrix for superconductors also, carrying the whole current for a short while in the event of a "quench" of the superconducting state. Although the room temperature resistivity of these materials does not vary much with purity, the low temperature values are strongly dependent on impurity content, the state of cold work and the ambient magnetic field. These effects[2] are illustrated in Fig. 1 and 2.

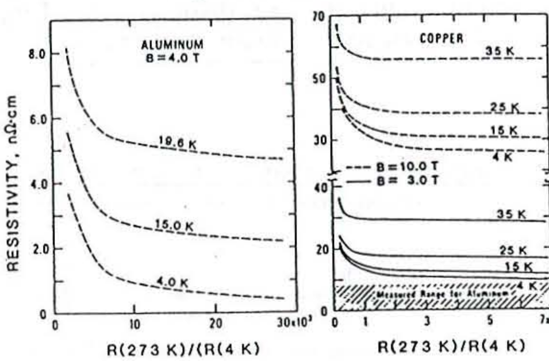

Fig. 1 Resistivity as a function of purity as measured with B⊥I configuration at several magnetic fields for Cu and Al.

The magnetoresistance effect for pure metals often follows Kohler's rule, Fig. 3.

$$\frac{\Delta\rho}{\rho} = f\left(\frac{B}{\rho(T)}\right) \qquad (2)$$

RRR is a measure of purity and is defined as the ratio of the resistivity at 273K to that at 4K in the normal state.

The effects of cold work on the RRR of high purity Cu and Al are shown in Fig. 4.

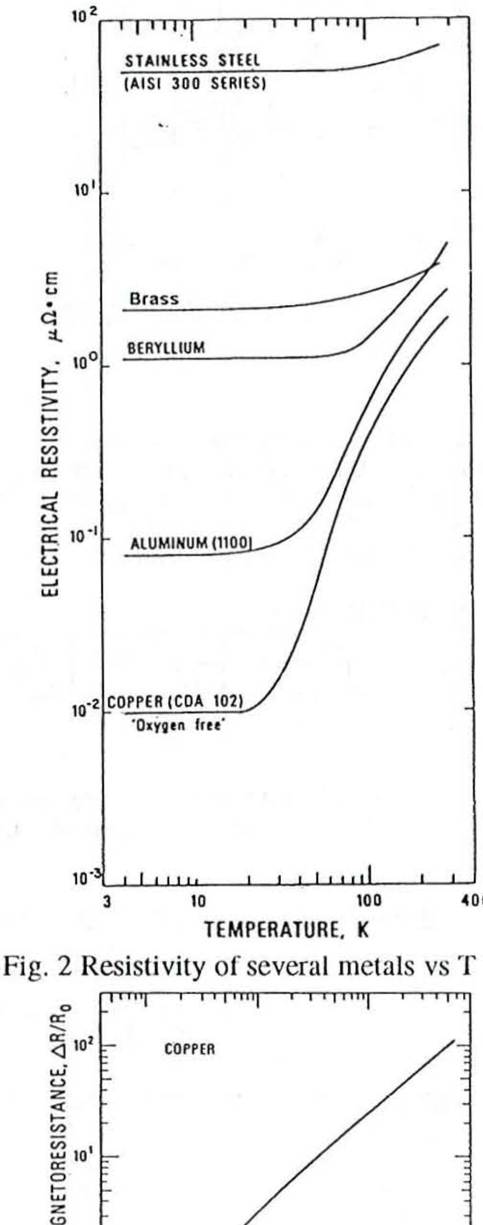

Fig. 2 Resistivity of several metals vs T

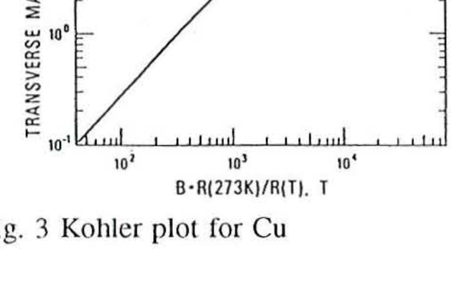

Fig. 3 Kohler plot for Cu

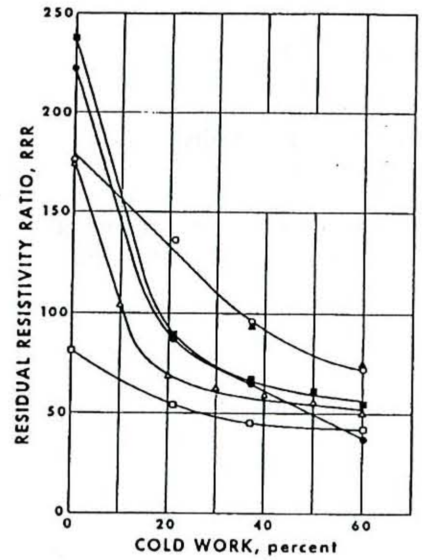

Figure 4. The residual resistance ratio, RRR, which is defined in the text, is shown as a function of the amount of cold work.

Fig. 4 Effects of cold work on RRR

Complete property measurements for high purity Cu can be found in the literature[3]. The resistivity of alloys are much less dependent on temperature as seen in Table 2

Table 2 RRR alloys

304SS	Invar	InconelX	6061Al
RRR=1.4	1.6	1.05	2.9

6.2.2 Superconductors

The superconducting elements are shown in Table 3 in their relation to the periodic table.

Hundreds of superconducting compounds have been cataloged[4]. The superconducting state exists only within the boundaries of a three dimensional surface in a space delimited by Temperature, T, Magnetic field, H and current density J as shown in Fig. 5. The discover of superconductivity at high temperatures in the copper oxides (1986)[5] has added hundreds more compounds to the superconducting material data base. Only a handful apear to possess the right combination of good intrinsic properties and fabricability that are necessary for practical devices (see 6.16).

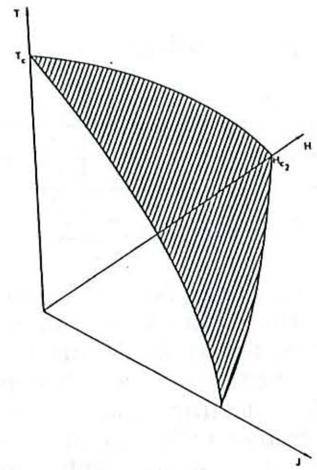

Fig. 5 Superconductivity exists within the critical J-H-T surface

The key intrinsic properties of some practical superconductors are displayed in Table 4. Critical current density is discussed in 6.16

Table 6.2.3.1 Approximate superconducting properties of selected superconducting materials [Ref. 5.2.2R4, Pg. 1031]

			Parameters at 4.2 K					
			Thermodynamic critical field, T, at					
Material	Type	Critical temperature, T_c at o T	$\mu_0 H_c$	$\mu_0 H_{c1}$	$\mu_0 H_{c2}$	Magnetic penetration depth (λ), nm	Coherence length (ξ) nm	Critical current density (J_c), $kA \cdot mm^{-2}$
Pb........	I	7.3	0.0803(a)	...	...	40	83	...
Nb	II	9.3	0.37	0.25	0.41	30	40	...
In........	I	3.4	.0281	...	...	...	...	...
Nb45-50-Ti .	II	8.9-9.3	0.16	0.009	10.5-11.0	500	10	3 (at 5 T)
Nb_3Sn	II	18	0.46	0.034	19-25	200	6	10 (at 5 T)
Nb_3Ge	II	23	0.16	0.004	36-41	650	4	10 (at 5 T)
NbN	II	16-18	0.16	0.004	20-35	600	5	10 (at 0 T)
$PbMo_6S_8$ ...	II	14-15	0.4	0.005	40-55	240	4	0.8 (at 5 T)
$YBa_2Cu_3O_7$	II	92	0.5	0.05(b)	60(b)	150(b)	15(b)	1 (at 77 K. 0 T)(d)
Sn	I	3.7	0.03	0.01(c)	>200(c)	1000(c)	2-3(c)	

(a) Thermodynamic critical field at 0 K. (b) Measured with field parallel to the c-axis. (c) Measured with field parallel to the *a-b* plane. (d) Epitaxial thin film, current in the *a-b* plane

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