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TEMPERATURE AND CONCENTRATION DEPENDENCE OF THE ELECTRICAL RESISTIVITY OF ZrCu AND ZrNi GLASSY ALLOYS

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Accurate measurements of the electrical resistivity of glassy ZrCu and ZrNi alloys have been performed in the temperature range 1.5 to 300 K. It is shown that the temperature dependence of resistivity is dominated by the quantum coherence effects and can be quantitatively described by the Fukuyama-Hoshino expression. The magnitude of resistivity is also at variance with the Ziman's model which is probably due to neglect of d-electron contribution in this theory.

Accurate measurements of the electrical resistivity of $Zr_{100-x}Cu_x$ ($26 \leq x \leq 71$) and $Zr_{100-x}Ni_x$ ($22 \leq x \leq 67$) glassy alloys in the temperature range 1.5 to 300 K have been performed. As illustrated in Fig.1 a linear in T ($T \leq 100$ K) and $T^{1/2}$ ($T \geq 100$K) dependence dominate the conductivity variation for all alloys. As already noted /1,2/ these temperature dependences are not consistent with the predictions of the diffraction model /3/ which was developed from the Ziman's theory /4/. Indeed, in an amorphous metal with a very short electronic mean free path the quantum coherence effects are expected to affect the conductivity variation. One of these effects, the incipient localisation is expected to contribute as $(D\tau_i)^{-1/2}$ (D is the diffusion constant and τ_i is the inelastic scattering time) to the change of conductivity over a broad temperature interval /1/. In a non-magnetic metal τ_i is determined by the electron-phonon interaction for which $\tau_i^{-1} \sim T^2$ at low temperatures and $\tau_i^{-1} \sim T$ for $T \geq \theta_D/3$ (θ_D is the Debye temperature) has been calculated /5/. Apparently, these predictions are in qualitative agreement with our data (Fig.1) At very low temperatures ($T \leq 15$ K) the other scatte-

ring mechanisms such as the electron-electron interaction (modified by the disorder) /6/, the superconducting fluctuations, the spin-orbit interaction and possibly the scattering on two-level systems (TLS) also contribute to the conductivity.

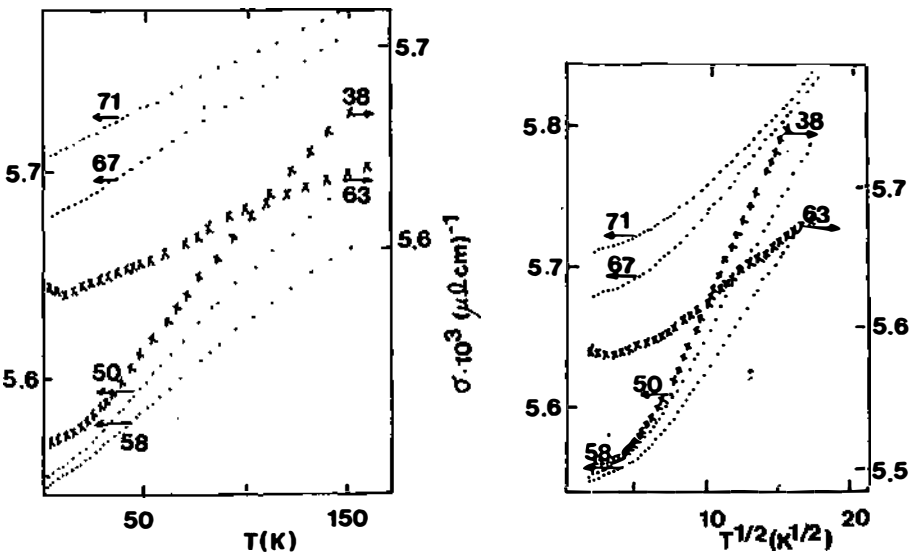

Fig.1: Conductivity for some ZrCu (•) and ZrNi (x) alloys vs T (a) and vs $T^{1/2}$ (b).

The measurements of the magnetoresistence enable one to verify the relation $\tau_i = \beta T^{-2}$ and also to determine the values of τ_i, and τ_{so} (the spin-orbit scattering time). Knowing these values one can use the Fukuyama-Hoshino expression /7/:

$$\Delta\sigma(T) = a\left[3(b+c^2T^2)^{1/2} - cT - 3b^{1/2} + dT^{1/2}\right] \qquad (1)$$

where $a = e^2/\pi h$, $b = (D\tau_{so})^{-1}$, $d = 0.65(1.33-2F^*-0.2)\,(2\pi k/Dh)^{1/2}$, $c = (4D\beta)^{-1/2}$, $F^* = x^{-1}\ln(1+x) - \lambda$, $x = (2k_f/k_o)^2$, λ is the electron-phonon coupling constant and k_o is the screening length, in order to deduce the conductivity variation arising from the quantum coherence effects. Equation (1) includes the contributions from the localisation, the spin-orbit scattering and from the electron-electron scattering. We used the magnetoresistance results for amorphous $Zr_{43}Cu_{57}$ alloy /8/ in order to deduce the corresponding τ_i, β and τ_{so}. The corresponding diffusion constant (D) has been determined from the Einstein relation by using the experimental conductivity and the density of states at the Fermi level /9/ values. Fig. 2 shows that (1) describes well the observed conductivity variation for $Zr_{43}Cu_{57}$ alloy. The magnetore-

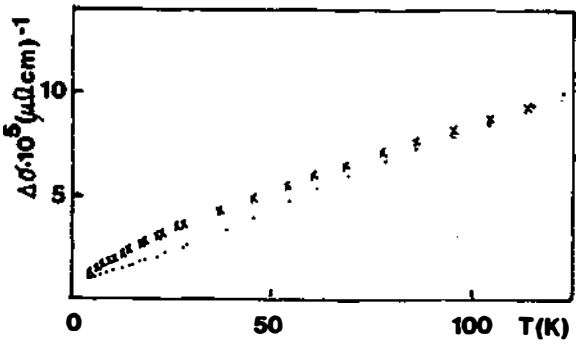

Fig.2: $\Delta\sigma$ vs T. (x) experimental values and (·) calculated values from eq. (1).

sistance measurements on other alloys will enable a detailed verification of the applicability of the Fukuyama-Hoshino expression to amorphous ZrCu and ZrNi systems.

Although the quantum coherence effects seem to dominate the conductivity variation in glassy ZrCu and ZrNi alloys, the magnitude of their resistivity is expected to be adequately described by the classical type of theory. The simplest such theory is the extended Ziman model /10/. In this model the resistivity of an alloy is:

$$\rho = \frac{12\pi\Omega_o}{e^2 h v_f} \int_0^{2k_f} dq q^3 \langle T_{alloy} \rangle^2 \qquad (2)$$

where $\langle T_{alloy} \rangle^2 = c_1 t_1^2 (1-c_1+c_1 a_{11}(q)) + c_2 t_2^2 (1-c_2+c_2 a_{22}(q)) + c_1 c_2 (t_1^* t_2 + t_1 t_2^*)(a_{12}(q)-1)$

and Ω_o is the atomic volume, v_f is the Fermi velocity, θ is the scattering angle, a_{ij} are the structure factors, c_i are the concentrations of the components and t_i are the t-matrices. $2k_f$ is determined by the integrated density of state /11,12/. By using the experimental structure factors for ZrCu /13/ and ZrNi /14,15/ alloys and the published phase shifts /16/ we calculated (assuming the dominant contribution from the resonant d-term) the electrical resistivities of several ZrCu and ZrNi alloys. The calculated values (Table 1) are considerably larger (from 1.6 to 3 times) than the measured ones. Although a good quatitative agreement between these values may not be expected because of the sensitivity of the expression (2) on the position of the maximum in the structure factor in respect to $2k_f$, the different concentration dependence of the calculated and measured resistivities for ZrCu alloys is disturbing. A possible origin of this discre-

Alloy	$2k_f \cdot 10^{-10}$ m	ρ_{calc}	ρ_{exp}	$(\rho_{calc}-\rho_{exp})\rho_{exp}^{-1}$
$Zr_{35}Cu_{65}$	2.88	280	171.5	0.63
$Zr_{50}Cu_{50}$	2.85	350	173.2	1.02
$Zr_{65}Cu_{35}$	2.82	420	167.2	1.51
$Zr_{37}Ni_{63}$	2.71	530	176.2	2.01
$Zr_{50}Ni_{50}$	2.87	330	181.0	0.82

Table 1 Calculated and measured resistivities in $\mu\Omega$cm

pancy is the neglect of the d-electron contribution to conductivity in the Ziman's theory, which may not be justified for the amorphous transition metal alloys with a high density of d-electron states at the Fermi level. Indeed recent calculation /17/ of the electrical resistivities of glassy ZrCu alloys (which includes the d-electron contribution to conductivity) yields a rather good quantitative agreement with the experimental values. Therefore, if seems likely that the classical theory can account for the magnitude of resistivity of our alloys, whereas the quantum corrections are required for the proper description of their variation of resistivity with temperature.

References:

/1/ M.Kaveh and N.F.Mott, J.Phys.C:Solid State Phys.,14(1981)L177
/2/ K.Šaub et al,Solid State Comm.,53(1985)269
/3/ P.J.Cote and L.V.Meisel,Phys.Rev.Lett., 39(1977)102
/4/ T.E.Faber and J.M.Ziman, Phil.Mag.,11(1965)153
/5/ M.A.Howson,J.Phys.F:Metal Phys.,14(1984)L25
/6/ B.L.Altshuler et al, Quantum Theory of Solids,Mir Publishers, Moskva 1982
/7/ H.Fukuyama and K.Hoshino,J.Phys.Soc.Japan,50(1981)2131
/8/ J.B.Bieri et al,Solid State Comm.,49(1983)849
/9/ P.Garoche and M.Bigot,Phys.Rev.B,28(1983)6886
/10/R.Evans et al, Phys.Lett.,35A(1971)57
/11/J.Lloyd,Proc.Phys.Soc.,90(1967)207
/12/E.Esposito et al,Phys.Rev.B,18(1978)3913
/13/H.S.Chen and Y.Waseda, phys.stat.solidi (a),51(1979)593
/14/S.Lefebvre,J.Phys.F:Metal Phys.,15(1985)L99
/15/T.Fukunaga et al,Proc.5th Int.Conf. on RQM p.475, Elsevier Science Publishers, Amsterdam 1985
/16/Y.Waseda and H.S.Chen,phys,stat.solidi (b),87(1978)777
/17/D.Nguyen-Manh et al, J.Phys.F:Metal Phys.,17(1979)999