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SUPERCONDUCTING PENETRATION DEPTH IN AMORPHOUS $La_{70}Cu_{30}$

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It is shown that weak field penetration depth measurements can be used to determine the change in the normal and superconducting behaviour of amorphous samples, when heat-treated below the crystallization temperature. The results are used to discuss the validity of BCS-Gorkov relations, when applied to these materials.

In this work we present the measurements of the weak field penetration depth, $\lambda(T)$, of amorphous $La_{70}Cu_{30}$ superconducting system. The absolute value of $\lambda(T)$ and its temperature dependence determination provide useful information about the normal and superconducting properties of the material. These results together with the measurements of the resistivity ρ, critical magnetic field H_{c2}, and temperature T_c, allows the analysis of the applicability of the BCS-Gorkov expressions to this class of materials.

According to the Gorkov expression, H_{c2}, $\lambda(T)$ and the Ginzburg-Landau (G-L) parameter κ are related to the electron mean free path (emfp) ℓ, and resistivity ρ, through the following expressions:

$$H_{c2}(T) = \sqrt{2}\ 7.5\ 10^3\ \rho_o\ \gamma^{1/2}\ H_c(T)$$

$$\lambda(\ell,T) = \lambda_L(T)\ \sqrt{\xi_o/\ell}\ f(T) \propto \sqrt{\rho_o/T_c}\ f(T)$$

$$\kappa = (\lambda/\xi)_{T=T_c} = 7.5\ 10^3\ \rho_o\ \gamma^{1/2}$$

Here ρ_o is the residual resistivity, γ the coefficient of the electronic specific heat,

$$\xi(\ell,T) = 0.85\ \sqrt{\xi_o\ell}\ \left[T_c/(T_c-T)\right]^{1/2}$$

is the G-L coherence length, corrected by emfp effects, ξ_o and λ_L are the BCS coherence length and Landau penetration depth of a hypotetical equivalent material with an infinite emfp. In our discussion we assume the dirty limit and a local electrodynamic response, justified in these material where the long range crystalline order is destroyed and as a consequence, the emfp is of the order of interatomic distances. The function f(T) should be a universal function for a family of superconductors characterized by a certain electron pair interaction.

The amorphous samples were prepared in the same way as those described in Ref.1. By means of a systematic heat treatment we have been able to modify [1] the transport and thermodynamic properties of the metal at constant concentration retaining by all indications [2], the highly disordered state. We show that besides the normal properties of the material the change in superconductivity indicates that the microscopic modifications induced by heat treatment alter the superconducting electron pair interaction.

The experimental penetration depth $\delta(T)$, is measured by means of a SQUID, detecting the magnetic flux variation produced by the change in $\lambda(T)$, when the temperature is swept at constant magnetic field. The measurements were done taking precautions to assure that the sample was in the Meissner state. Under this circumstances the flux change was reversible with temperature. At low enough temperature, where no size effects were detectable, the experimental $\delta(T)$ equals $\lambda(T)$. One advantage almost unique in this type of materials is that the penetration depth at T=0 is so large that the measurement of the Meissner flux expulsion, together with the knowledge of the sample geometrical factor, allows the measurements of $\lambda(0)$ (in our case $\delta(0) = \lambda(0)$ in all samples). The G-L parameter κ is calculated using the penetration depth values and the coherence length obtained [1] from H_{c2}.

Figure 1 shows the values of $\delta(t)/\delta(0)$ as a function of $y = 1/(1-t^4)^{1/2}$ for a sample with an initial negative temperature resistance coefficient [1] before and after the heat treatment. Table I gives the $\lambda(0)$ and κ values corresponding to different annealing temperatures for the same sample together with results for a sample with initial zero temperature resistance coeficient [1].

In the BCS theory of superconductivity the temperature dependence, f(t), of λ is univocally related [3] to the superconducting energy gap, $\Delta(T)$. In Fig. 1 we have plotted that theoretical relation, where $2\Delta(0)/kT_c$ was left as a free parameter. The values $2\Delta(0)/kT_c = 4.5$ and $= 4.3$ were chosen to fit the low temperature data of the non annealed and heat treated samples respectively. In the same figure the theoretical relation for the weak coupling limit, $2\Delta(0)/kT_c = 3.5$ is plotted for comparison. It should be noticed that the annealed sample showed size effects at temperature close to T_c, $y > 1.7$, consistent with the fact that annealing increased $\lambda(0)$ by 60%, as indicated in Table I. The size effects were taken into account when plotting the full curve in the figure and are irrevelevant for the discussion that follows, based in the low temperature data, $y < 1.5$. The results indicate strong deviation from the weak coupling limit, in agreement with recent specific heat data [4] in a

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similar system. On the other hand the change in f(t) makes evident that annealing modifies the normal and superconducting behaviour of the material.

Using the Gorkov relations we have calculated γ_K from the ρ and κ values listed in Table I. This density of states does not coincide with that obtained [1] from H_{c2}. The discrepancy is more notorius at the end of the annealing process where γ_K increased faster [1] than γ_{Hc2}. The disagreement has its origin in a qualitative discrepancy that raises doubts about the applicability [5] of Gorkov relations to this class of materials. According to them the penetration depth should change as $(\rho_o/T_c)^{1/2}$. It is seen in Table I that $(\rho_o/T_c)^{1/2}$ either remains constant or decreases slightly at the begining of the annealing process to decrease even faster when the heat treatment is continued; on the contrary the penetration depth remains constant at the begining of the annealing process to increase when the heat treatment is proceed. The discrepancy should not be surprising since Gorkov relations are based in the description of the metal by a single s conduction band. Lanthanum has partially occupied d bands and consequently it seems difficult that the emfp, a transport property, can be combined with a length $\xi_o = \hbar v_F/kT_c$ defined in terms of equilibrium properties, to express $\xi_o/\ell \simeq \rho_o/T_c$. The results reported here together widt those of reference 1 show that heat treatment modifies the microscopic properties of the material, changing the normal and superconducting

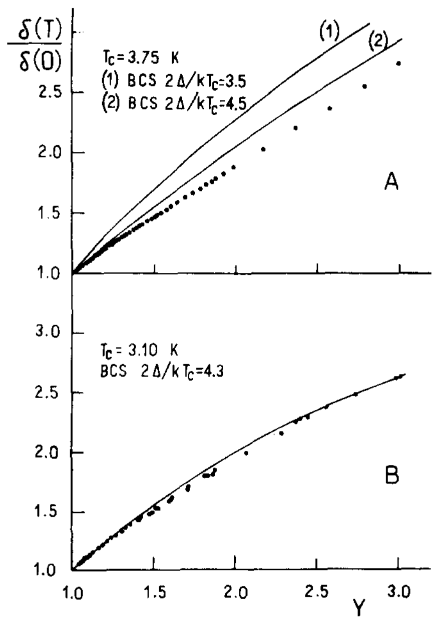

Figure 1 - Normalized penetration depth as a function of y for sample 2. A-sample as quenched. Curves (1) and (2) calculated as explain in the text. B-same sample after annealing. Curve calculated as in case A.

TABLE I: Measured changes of the critical temperature, residual resistivity and penetration depth, values obtained for G-L and gap parameter and calculated values of the density of states γ for two different samples with different heat treatments.

Samples	T_c/T_{ci}	$\lambda(o)$ (μm)	κ	$2\Delta(0)/kT_c$	ρ_o/ρ_{oi}	γ_K/γ_{Ki}
1	1	1.2	103	...	1	1 [a]
	0.93	1.7	127	...	0.87	2.0 [b]
2	1	0.90	70	4.5	1	1 [a]
	0.97	0.87	65	4.35	0.98	0.90 [c]
	0.91	0.90	61	4.5	0.93	0.88 [d]
	0.83	1.45	104	4.3	0.70	4.50 [e]

Sample 1: T_{ci}=3.86K; ρ_{oi}=150μΩcm; $\Delta\rho/\Delta T)_i \sim 0$. Sample 2: T_{ci}=3.75K; ρ_{oi}=174μΩcm; $\Delta\rho/\Delta T)_i > 0$.

[a] As-quenched samples

[b] 90/300 minutes at 40/50°C

[c] 430/300 minutes at 40/50°C

[d] 380/670 minutes at 50/60°C

[e] 2030 minutes at 60°C

behaviour of the disordered state. Any realistic description of the amorphous state should be able to take into account the evolution induced by heat treatment.

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