the diffraction lines, making it possible to assume, by analogy with [5 - 7], the existence of a structure transition with tetragonal strain $e \simeq -(3.1 \pm 1.2) \times 10^{-3}$. We note that the value of e lies between the values e for V_3Si and Nb_3Sn. The sign of e coincides with that for Nb_3Sn [7]. It is interesting that the nuclear-resonance investigations at 24°K clearly point to a change in the symmetry of the lattice in the same samples, which also indicates the presence of a transition [8] not observed in Nb_3Al [9]. This circumstance confirms the important role of correlation between the superconducting and martensitic transitions in high-temperature superconductors of the A-15 type.

The authors are grateful to A.G. Rabinkin for affording the possibility of measuring T_c, and to R.A. Sizov for recording the neutron diffraction patterns.

[1] B.W. Kodess, Phys. Stat. Sol. (a) 4, K109 (1971).
[2] G. Arrhenius, E. Corenzwitt, R. Fitzerald, G.W. Hull, H.L. Luo, B.T. Matthias, and W.H. Zachariasen, Proc. Nath. Acad. Sci. 61, 621 (1968).
[3] N.E. Alekseevskii, N.V. Ageev, and V.F. Shamrai, Izv. AN SSSR, Neorg. mat. 12, 2156 (1966).
[4] I. Rozoca, Zs. Physik. 237, 432 (1970).
[5] B.W. Batterman and C.S. Barret, Phys. Rev. 137, 3447 (1966).
[6] L.J. Viland, R.N. Cohen, and W. Rehlwald, Phys. Rev. Lett. 26, 7, 373 (1971).
[7] H.W. King, F.H. Cocks, and J.T.A. Pollock, Phys. Lett. A26, 2, 77 (1967).
[8] B.N. Kodess, V.B. Kurizin, and B.N. Tretjakov, Phys. Lett. 1 (1971) (in print).
[9] R.H. Willens, T.H. Geballe, A.C. Gossard, J.P. Maita, and A. Menth, Solid State Comm. 7, 837 (1969).

CRITICAL TEMPERATURE OF AMORPHOUS SUPERCONDUCTING FILMS

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Submitted 5 July 1971
ZhETF Pis. Red. 14, No. 5, 341 - 344 (5 September 1971)

Naugle and Glover [1] observed a decrease of the critical temperature of the superconducting transitions of amorphous (i.e., having very high resistance) films of Bi and Ga, condensed on a low-temperature substrate, in inverse proportion to their thickness d. This means that ΔT_c is proportional to the value of the normal resistance. In the present paper we propose an explanation for this effect, based on the assumption that the lowering of T_c is due to fluctuations of the electromagnetic field in the film.

We define the point of transition into the superconducting phase as the point where the ordering parameter ψ exhibits perturbations that increase with time. According to the nonstationary Ginzburg-Landau equation [2] we have

$$\frac{\partial \psi}{\partial t} + \Gamma\psi - D\left(\nabla - \frac{2ie}{c}A\right)^2\psi = 0, \tag{1}$$

where

$$\Gamma = \frac{8}{\pi}(T - T_{c0}), \quad D = \frac{1}{3}v_F\ell,$$

and ℓ is the mean free path. At $\vec{A} = 0$, the transition point $T = T_{c0}$ is determined from the condition $\Gamma = 0$. When the fluctuation fields $(\vec{A})$ are taken into account we have $<|\psi(t)|^2> \sim \psi_0^2 \exp(-2\Gamma t)\exp(-2\Gamma_1 t)$, where Γ_1 is proportional to the mean square of the fluctuating field. Hence $T_c = T_{c0} - (\pi/8)\Gamma_1 < T_{c0}$.

Let us consider a homogeneous initial perturbation $\psi = \psi_0 = \text{const}$ at $t = 0$ and let us calculate the value of $<|\psi|^2>$ at the instant t, expanding (1) in the amplitude of the field $\vec{A}$. We have

$$<|\psi(r,t)|^2> = \psi_0^2 e^{-2\Gamma t}(1 - \alpha(t)), \tag{2}$$

where the term $\alpha(t)$ is determined by the correlator $<A(r, t)A(r', t')>$. The fluctuations of the electromagnetic field in a homogeneous medium were considered in [3]. In the limit of a very large specific electric resistivity (ρ), formula (90.23) of the book by Landau and Lifshitz [3] gives

$$<E_i(r,t)E_j(r',t')> = -\frac{\rho T}{2\pi}\frac{\partial^2}{\partial x_i \partial x_j}\left(\frac{1}{R}\right)\delta|t - t'|, \tag{3}$$

where $R = |\vec{r} - \vec{r}'|$ and $\vec{E} = -(1/c)(\partial\vec{A}/\partial t)$. With the aid of this expression, all the necessary correlators can be readily calculated, and we obtain for small values of t

$$<|\psi(t)|^2> = \psi_0^2\left[1 - 2\Gamma t - \frac{e^2\rho TD}{\pi^2 d}\int\frac{d^2k}{(Dk^2)^2}\times\right.$$
$$\left.\times(2Dk^2t - 1 + e^{-2Dk^2t})\right]. \tag{4}$$

Making the substitution $Dk^2t = x$, we see that the integral written out here is proportional to t. However, expression (4) diverges logarithmically at large k. Allowance for the natural cutoff at $k \sim \xi^{-1}(0)$, where $\xi(0) = \sqrt{\xi_0 \ell}$ and $\xi_0 \sim v_F/T_{c0}$ leads to formula

$$<|\psi(t)|^2> = \psi_0^2\left[1 - 2\Gamma t - \frac{2e^2}{\pi\hbar}R_\square T t \ln(T_{c0}t)\right], \tag{5}$$

where $R_\square = \rho/d$ is the so-called "resistance per square" of the film.

The result can be interpreted in the following manner. We introduce the characteristic relaxation time t_0, defined as the value of t at which the square bracket in (5) vanishes. Introducing the dimensionless quantity $\varepsilon_0 = e^2R_\square/8\hbar$, we obtain asymptotically as $\varepsilon_0 \to 0$

$$t_0^{-1} = T_{c0}|(\tau - \varepsilon_0\ln|\tau|)|, \tag{6}$$

where $\tau = (T - T_{c0})/T_{c0}$. The point of transition into the superconducting phase is characterized by the fact that $t_0 \to \infty$. Setting (6) equal to zero we obtain asymptotically, at small ε_0, the value $\tau \simeq \varepsilon_0 \ln \varepsilon_0$, corresponding to an effective lowering of the critical temperature[1)]

$$\frac{\Delta T_c}{T_{c0}} = \frac{e^2R_\square}{8\hbar}\ln\frac{8\hbar}{e^2R_\square}. \tag{7}$$

Of course, this formula is valid with logarithmic accuracy.

[1)] A close expression (without the logarithm) was obtained earlier in our paper [4] devoted to a study of the properties of tunnel junctions at temperatures above T_c.

Equation (7) explains the results of [1]. The value of $e^2R_\square/8\hbar$ is $0.3 \times 10^{-4}R_\square$ (ohms), and the values of $\Delta T_c/T_{c0}$ obtained in [1] are $6 \times 10^{-4}R_\square$ for Bi and $\sim 10 \times 10^{-4}R$ for Ga. The difference factor ~ 20 can be attributed to the larger logarithm. In addition, the fact of lowering of T_c as a result of fluctuations of the order ψ has not been taken into account in (7)[2]. Neglecting for the time being the fluctuations of the field and taking into account the nonlinear term $\beta\langle|\psi|^2\rangle\psi$ in (1), we obtain after simple calculation a formula of the type (7), $\Delta T_c/T_{c0} \sim \varepsilon_1 \ln(1/\varepsilon_1)$, where $\varepsilon_1 \simeq 0.04e^2R_\square/\hbar$. ε_1 is approximately one-third of ε_0. This estimate is preliminary and will be improved in subsequent work. Simultaneous allowance for the fluctuations of the field and of the ordering parameter improves the agreement with the experimental data of [1] even more.

It is important to note that the quantity ε_0 introduced above differs only by a factor of 2 from the constant τ_0 of the Aslamazov-Larkin theory of fluctuation conductivity [5]. This means that the effect in question, besides fluctuations of the ordering parameter ψ [5], must be taken into account when determining the value of the "paraconductivity" of films above T_c. Fluctuations of the ordering parameter and of the electromagnetic field thus turn out to be equally important in the calculation of the additional contributions to the conductivity and other physical characteristics of films at temperatures above T_c.

It is qualitatively clear that the contribution to the paraconductivity, connected with the electromagnetic fluctuations, will be of the order of $\Delta\sigma/\sigma_N \sim (\varepsilon_0/\tau)\ln(\tau/\varepsilon_0)$. The resultant logarithmic divergences are similar to those taking place in the Maki theory [6], but now their elimination is not connected with unpairing effects, as in [7]. The expression given above for $\Delta\sigma$ explains the observations of [8], according to which the "unpairing constant" δ is proportional to the normal resistance ($\delta \sim \varepsilon_0$)[3].

In conclusion, I am sincerely grateful to G.M. Eliashberg for a fruitful discussion and for great help in the interpretation of the results. I am also grateful to I.M. Dmitrenko for discussions and for supplying the data of the Preprint [8].

[1] D.G. Naugle and R.E. Glover, Phys. Lett. 28A, 611 (1969).
[2] E. Abrahams and T. Tsuneto, Phys. Rev. 152, 416 (1966); L.P. Gor'kov and G.M. Eliashberg, Zh. Eksp. Teor. Fiz. 54, 612 (1968) [Sov. Phys.-JETP 27, 328 (1968)].
[3] L.D. Landau and E.M. Lifshitz, Elektrodinamika sploshnykh sred (Electrodynamics of Continuous Media), Gostekhizdat, 1957 [Addison-Wesley, 1959].
[4] I.O. Kulik, ZhETF Pis. Red. 10, 488 (1969) [JETP Lett. 10, 313 (1969)].
[5] L.G. Aslamazov and A.I. Larkin, Phys. Lett. 26A, 238 (1968); Fiz. Tverd. Tela 10, 1104 (1968) [Sov. Phys.-Solid State 10, 875 (1968)].
[6] K. Maik, Progr. Theor. Phys. 39, 897 (1968).
[7] R.S. Thompson, Phys. Rev. 1B, 327 (1970); J.E. Crow, R.S. Thompson, M.A. Klenin, and A.K. Bhatnagar, Phys. Rev. Lett. 24, 371 (1970).
[8] K. Kajimura and N. Mikoshiba, Fluctuations in the Resistive Transitions in Al Films, Preprint, 1970.

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[2]This fact was pointed out to us by G.M. Eliashberg.

[3]It can be said, of course, that in this case we are dealing with unpairing, since a lowering of T_c (7) takes place, but the unpairing mechanism is distinctive and was not considered earlier.