TEMPERATURE DEPENDENCE OF THE UPPER CRITICAL FIELD IN HIGH-TEMPERATURE SUPERCONDUCTORS: LOCALIZATION EFFECTS.

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It is shown that the anomalous temperature dependence of the orbital part of the upper critical field H_{c2} observed for epitaxially grown films of high-temperature superconductor $Bi-Sr-Cu-O$ (in wide temperature interval) can be satisfactorily explained by the influence of localization effects in two-dimensional (quasi-two-dimensional) case.

In a recent paper Osofsky et al. [1] presented the unique data on the temperature dependence of the upper critical field of high-temperature superconductor $Bi_2Sr_2CuO_y$ in wide temperature interval from $T_c \approx 19K$ to $T \approx 0.005T_c$, which has shown rather anomalous dependence with negative curvature at any temperature. It is sharply different from the standard behavior of BCS-model, as well as from that predicted by the model of compact charged Bosons (bipolarons) [2]. The aim of the present work is to demonstrate that the observed dependence of $H_{c2}(T)$ can be satisfactorily explained by localization effects in two-dimensional (quasi-two-dimensional) model in the limit of sufficiently strong disorder [3], which can be guessed from rather wide superconducting transition in films studied in Ref.[1].

Below we shall limit ourselves by description of purely two-dimensional case because the appropriate dependences for quasi-two-dimensional system differ only very slightly for the relevant values of parameters of the model [3]. The general approach to H_{c2}-behavior in strongly disordered systems was given in Ref. [4].

We shall be interested only in the case of magnetic field perpendicular to the highly conducting planes. From the standard approach to superconducting transition in external magnetic field [5] we obtain the following equation for temperature dependence of $H_{c2}(T)$:

$$ln\frac{T}{T_c} = = 2\pi T\sum_{\varepsilon_n}\left\{\frac{1}{2|\varepsilon_n| + 2\pi D_2(2|\varepsilon_n|)\frac{H}{\Phi_0}} - \frac{1}{2|\varepsilon_n|}\right\} \quad (1)$$

where $\Phi_0 = \frac{\pi c}{e}$—is magnetic flux quantum, T_c—is BCS transition temperature in the absence of magnetic field, $D_2(2|\varepsilon_n|)$—the generalized diffusion coefficient in Cooper channel, $\varepsilon_n = (2n+1)\pi T$ is Fermionic Matsubara's frequency.

It is seen from Eq.(1) that the anomalies in behavior of the upper critical field are related to the frequency dependence of diffusion coefficient which becomes non-trivial close to the Anderson metal-insulator transition. Within the approach based upon self-consistent theory of localization [6,7] the coupled system of equations for generalized diffusion coefficients in magnetic field for the two-dimensional case was proposed in Ref.[8]. The dimensionless disorder parameter which governs its solutions is the usual $\lambda = \frac{1}{2\pi E\tau}$, where E is the Fermi energy and τ is the mean free time between scattering events.

It is easy to see that the anomalies of the upper critical field due to the frequency dependence of diffusion coefficient will appear only for temperatures $T \ll \frac{e^{-1/\lambda}}{\tau}$ [3]. For higher temperatures we obtain the usual behavior of "dirty" superconductors. Superconductivity survive in a system with finite localization length if the follow-

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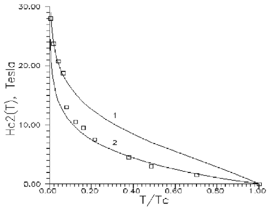

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Figure 1. Fig.1 Temperature dependence of the upper critical field: Theoretical curve (1) is given for the case of $\frac{e^{-1/\lambda}}{T_c\tau} = 2$, $\lambda = 0.18$, while the curve (2) is for $\frac{e^{-1/\lambda}}{T_c\tau} = 20$, $\lambda = 0.032$. Cyclotron mass m is assumed to be equal to that of the free electron. Squares—experimental data of Ref. [1].

ing inequality holds $T_c \gg \lambda\frac{e^{-1/\lambda}}{\tau}$ [3], which is equivalent to the well known criteria [9] of the smallness of Cooper pair size compared with localization length. The most interesting (for our aims) limit of relatively strong disorder is defined by $T_c \ll \frac{e^{-1/\lambda}}{\tau}$, so that in fact we are dealing with pretty narrow region of λ's when $\lambda\frac{e^{-1/\lambda}}{\tau} \ll T_c \ll \frac{e^{-1/\lambda}}{\tau}$. In this case the upper critical field is defined by the equation ($\gamma = 1.781$)[3]:

$$ln\left(\frac{\gamma}{2\pi}\frac{e^{-1/\lambda}}{\tau T}\right) = (1 + 4\pi\frac{D_0}{\Phi_0}\frac{\tau H_{c2}}{e^{-1/\lambda}}) \times$$
$$\times \ln\left(\frac{\gamma}{2\pi}\frac{e^{-1/\lambda}}{\tau T_c}(1 + 4\pi\frac{D_0}{\Phi_0}\frac{\tau H_{c2}}{e^{-1/\lambda}})\right) \qquad (2)$$

from which we can directly obtain the $T(H_{c2})$—dependence. The appropriate behavior of the upper critical field for two sets of parameters is shown in Fig.1.

The dependence of $H_{c2}(T)$ demonstrates negative curvature and H_{c2} diverges for $T \to 0$. This weak (logarithmic) divergence is connected with our neglect of the magnetic field influence upon diffusion and can be suppressed taking it into account [3], though this effect is important only for very low temperatures.

In Fig.1 we also show the experimental data for H_{c2} from Ref.[1]. Unfortunately, the values of the ratio $\frac{e^{-1/\lambda}}{T_c\tau}$ for the second curve, while corresponding to quite reasonable values of λ, lead to unrealistic (too small) values of $T_c\tau$. For the first curve situation is much better though the size of electron damping on the scale of T_c is still very large which corresponds to strong disorder. The detailed discussion of these parameters is actually impossible without the knowledge of additional characteristics of the films studied in Ref. [1].

These results demonstrate the relatively good agreement between our theory and experiments of Ref.[1] and apparently further illustrate the importance of localization effects for the physics of high- temperature superconductors [10].

REFERENCES

[1] Osofsky M.S., Soulen R.J., Wolf S.A., Broto J.M., Rakoto H., Ousset J.C., Coffe G., Askenazy S., Pari P., Bozovic I., Eckstein J.N., Virshup G.F., Ginzton E.L.—Phys.Rev.Lett., **71**, 2315 (1993)
[2] Aleksandrov A.S., Krebs A.B.—Uspekhi Fiz. Nauk **162**, 1 (1992)
[3] Kuchinskii E.Z., Sadovskii M.V.—Superconductivity: Physics, Chemistry, Technology **6**, 1119 (1993)
[4] Kuchinskii E.Z., Sadovskii M.V.—Superconductivity: Physics, Chemistry, Technology **4**, 2278 (1991)
[5] De Gennes P.G. Superconductivity of Metals and Alloys. W.A.Benjamin, NY, 1966.
[6] Vollhardt D., Wölfle P.—Phys.Rev. **B22**, 4666 (1980)
[7] Sadovskii M.V.—Soviet Scientific Reviews. Ed. by I.M.Khalatnikov, v.7, p.1, Harwood Academic Publ., NY, 1985.
[8] Yoshioka D., Ono Y., Fukuyama H.—J.Phys.Soc.Japan **50**, 3419 (1981)
[9] Bulaevskii L.N., Sadovskii M.V.—J.Low-Temp.Phys. **59**, 89 (1985)
[10] Sadovskii M.V.—In "Studies of High-Temperature Superconductors". Vol.11. Ed. by A.V.Narlikar. Nova Science Publishers, NY, 1993.