Magnetic ordering in layered high temperature superconductors
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Abstract

It is discussed the scenario of two-step magnetic ordering in layered HTS after charge ordering. At the temperature decreasing the transition from 3D Heisenberg spin behavior to 2D XY coupling of the Cu spins occurs in di-stripes. Further temperature decreasing leads to the spin glass transition at $T_g$.

keyword
charge ordering, magnetic ordering
2D XY-model, quasi 2D XY-model
hole concentration in $CuO_2$-planes
3D-spin glass transition

1. INTRODUCTION

The conclusion about the decisive role of fluctuational antiferromagnetic (AFM) excitations with 3D Heisenberg spin behavior in HTS has been substantiated reliably to now. The opening of a "spin pseudogap" on the Fermi surface was connected at first with strong AFM correlations. But later the propositions that the formation of the pseudogap as well as superconductivity are associated with charge ordering (dynamic analog of phase separation) were discussed (see reviews [1,2]) and were experimentally confirmed [3,4]. Simple example of charge ordering was observed in Bi2212, where in the Cu-O plane metallic (met-) stripes with orthorombic structure and the stripes of the dielectric (di-) tetragonal phase with a short range AFM correlations were found out at $T < T_{ch}$ ($T_{ch}$ is the temperature of charge ordering) [5]. In spite of essential anisotropy of exchange constants of in-plane ($J_0$) and enter-plane ($J_1$) interactions, $J_0/J_1 > 10^3$, strong AFM fluctuations in layered HTS prevent to 2D Heisenberg ordering in di-stripes. In this paper it is discussed the scenario of two-step magnetic ordering in layered HTS which is based on the known properties of 2D XY-model [6-7]. It is shown, that after charge ordering in Cu-O planes the transition from 3D Heisenberg spin behavior to 2D XY coupling of the Cu spins occurs at $T = T_{BKT} = T_{sp} < T_{ch}$ in the di-stripes, where $T_{BKT}$ is Berezinskii-Kosterlitz-Thouless temperature. Further temperature decreasing leads to the spin glass transition at $T_g$, which was predicted for quasi-2D XY-model in Ref.8.

2. RESULTS.

It is known that in 2D XY-model the phase transition occurs which leads to the formation of phase with power law decreasing of in-plane correlations, and to the peculiarities of temperature dependencies of the resistivity, magnetic susceptibility and specific heat at $T < T_{sp}$ [6]. For layered systems the order parameter of quasi-2D XY-model $q = 0$ at $T > T_{sp}$ and $q \sim J_1^{\Delta/(2-\Delta)}$ at $T < T_{sp}$, where $\Delta$ is scaling dimensionality [7].

If $p_{cr}$ is hole concentration in $CuO_2$-planes, at which the compound becomes the superconductor, and if the effective hole concentration in the di-stripes $p_{sh}^* < p_{cr}$, the
temperature of spin ordering, $T_{sp}$, may be large enough, $T_{sp}(p_{sh}) \sim T_N(p_{sh}^*)$ (here $p_{sh}$ is the hole concentration in $CuO_2$-planes and $T_N$ is the Neel temperature).

Taking into account that exchange constant $J_1 \ll J_0$, as well as that 2D XY spin ordering at $T_{sp}$ occurs independently in each di-stripe, order parameter $q \ll 1$ and the sample remains non-magnetized. But after influence of magnetic field weak summarized magnetization can be observed.

The temperature decreasing can lead to the 3D-spin glass transition at $T_g \ll T_{sp}$, if each di-stripe is considered as 2D XY-model with occasional anisotropy and if the coupling between layers has special form $J_1 \cos n(\Theta_{i+1} - \Theta_i)$ ( $\Theta$ is the angle which is determined the direction of spin in $i$-plane, $n$ is the anisotropy order). Such transition for quasi-2D XY-model was predicted for quasi-2D XY-model [8] and for HTS was observed at $\mu sR$ measurements [4].

3.DISCUSSION.

For magnetic compounds with high anisotropy of exchange constants the two step spin ordering is well known and the peculiarities of temperature dependencies of the resistivity, magnetic susceptibility and specific heat at temperature of 2D XY ordering were observed. The first indirect evidence that spins may cross over to 2D XY-like behavior at $T \sim 20$ K, was observed in neutron measurements of single crystal $La_{2-x}Sr_xCuO_4$ which is in the intermediate region of $x = 0.04$ with neither long range AFM order nor superconductivity [9]. There are enough experimental evidences of two step magnetic ordering in compounds with $p_{sh} < p_{cr}$ obtained in neutron and magnetic measurements, and $\mu sR$ studies ( see Ref.10 and references therein). Magnetic phase diagram as a function of $p_{sh}$ for $La_{2-x}Sr_xCuO_4$ and $Y_{1-x}Ca_xBa_2Cu_3O_{6.02}$ ($0 < x < 0.11$) was obtained in $\mu sR$ measurements [4]. The coexistence of spin glass state and superconducting state for hole concentration $0.06 < p_{sh} < 0.10$ was found out. The observations of the oscillations of attenuation decrement after influence of magnetic field and residual magnetization at 300 K in Bi2223 ceramics with 30 % Bi2212 are indirect evidences of 2D XY magnetic ordering and weak summarized magnetization of di-stripes (see Ref.11 and references therein). It should be interesting to carry out the measurements of $T_{sp}$ for $p_{sh} > p_{cr}$ such as were performed for $p_{sh} < p_{cr}$. These measurements of temperature of 2D XY magnetic ordering are seemed to very important and experimentally feasible step in studies of nature of HTS.

References
1. V.Barzykin and D.Pines, Phys.Rev. B 52, 13585 (1995).
2. S.G.Ovchinnikov, Usp.Fiz.Nauk 167, 1042 (1997); G.G.Sergeeva et al.Fiz.Nizk.Temp. 24, 1029 (1998)[Low Temp.phys. 24, 771 (1998)]
3. A.A.Zakharov et al. Physica C 223, 157 (1994)
4. Ch.Niedermayer et al. Phys.Rev.Lett. 80, 3843 (1998)
5. A.Bianconi and M.Missori, J.Phys.I (Paris),4, 361 (1994)
6. V.L.Berezinskii, JETP, 59, 907 (1970); ibid. 61, 1144 (1971). J.M.Kosterlitz, D.J.Thouless. J.Phys., C6, 1181 (1973)
7. V.L.Berezinskii, A.Ya.Blank, JETP,64, 723 (1973).
8. Vik.Dotsenko and M.V.Feigelman, JETP, 83, 345 (1982).
9. B.Keimer et al. Phys.Rev. B 46, 14034 (1992)
10. F.C.Chou et al. Phys.Rev.Lett. 75, 2204 (1995)
11. B.G.Lazarev et al. Fiz.Nizk.Temp.22, 819 (1996) [Low Temp.Phys 22, 4629 (1996)];