Magnetic Nature of a Ni Dopant in $La_{1.85}Sr_{0.15}CuO_4$: Pseudogap and Spin-glass Behavior

A. Malinowski, V. L. Bezusyy, R. Minikayev, W. Paszkowicz, P. Dziawa, Y. Syryanyy, M. Sawicki

Instytut Fizyki PAN, al. Lotników 32/46, 02-668 Warszawa

The relationship between the normal-state pseudogap and superconducting gap in cuprates is still an open question. Different impurities, magnetic and non-magnetic ones, introduced into Cu-O planes are used to probe both gaps. The nominally magnetic Ni dopant is known to have a weaker effect on superconductivity than nominally non-magnetic Zn. As regard to electrical transport in the normal state, quasiparticle scattering at Ni was found to be predominantly non-magnetic. Just recently, Ni was claimed do not disturb the spin-1/2 network in Cu-O planes for concentration smaller than hole concentration in the system and, based on this, a magnetic-impurity picture for Ni dopant in superconducting cuprates was completely disqualified [1]. However, our study shows that so definitive statement is not correct.

The DC and AC magnetic measurements in the field up to 5 T and in the temperature range from 2 K up to 400 K were carried out on the polycrystalline samples of $La_{1.85}Sr_{0.15}Cu_{1-y}Ni_yO_4$ (LSCNO) covering the whole doping range $0 \leq y \leq 1$ and synthesized with the use of a conventional solid-state reaction method.

Temperature-dependent part of magnetic susceptibility χ for small y can be decomposed into two parts: one, describing the spin-1/2 AF network in terms of the universal curve $F(T/T_{max})$ proposed without parameterization for $La_{2-x}Sr_xCuO_4$ by Nakano, and second, the Curie term, attributed to the additional magnetic moment introduced by Ni ions. Initially, the energy E_g below which the pseudogap starts to open increases with Ni content, y, from E_g/k_B=430 K for y=0 to about 480 K for y=1.2%. This may mean Ni-induced enhancement of the pseudogap, as observed in the optical conductivity of another cuprate [2], or just shifting in the phase diagram caused by Ni acting as holes absorber, as suggested in [1]. Magnetic moment introduced by Ni is equal to 0.7 μ_B per Ni ion up to y=0.07, and next increases abruptly to 1.65 μ_B/Ni for y between 0.17 and 0.70.

However, this tiny paramagnetic moment for y<0.07 does not mean that Ni acts only as hole absorber for small Ni concentration, as claimed in [1], but disturbs network of Cu spins as well. Clearly, we observed the spin-glass (SG) behavior in LSCNO system for the first time. The ZFC and FC curves for all samples with y>0.05 reveal irreversibility of χ below T_g. The decay of remnant magnetization below T_g with time is described by a stretched-exponential function. In accordance with scaling theory, all of the data for y=0.25 and y=0.50 samples, taken at around T_g at different fields, collapse onto two separate curves – one for $T<T_g$ and second for $T>T_g$ - when plotted as $q|t|^{-\beta}$ vs. $B^2|t|^{-\beta-\gamma}$, where q is the spin-glass order parameter and $t=(T-T_g)/T_g$. The obtained critical parameters are close to these observed for the canonical SG systems. Below T_g, the real part of AC susceptibility, χ', exhibits logarithmic frequency dependence, typical for glassy states with a broad distribution of random potential. Sensitivity of maximum of $\chi'(T)$ to the frequency is weak, in opposition to strong dependence expected for blocking of independent magnetic clusters, as in the case of conventional superparamagnets. All these features taken together reveal that system undergoes a true SG transition at T_g. T_g grows with y from 2.5 K for y=0.06 up to 23 K for y=1. Variation of T_g with y is linear below y=0.25 and T_g extrapolates to 0 K for $y \rightarrow 0$. This strongly suggests that SG phase extends into superconducting region of LSCNO phase diagram. Thus, Ni frustrates the magnetic network of Cu spins even at the smallest concentration, acting as magnetic dopant in this cuprate superconductor.

[1] H. Hiraka et al., Phys. Rev. Lett. **102**, 037002 (2009)
[2] A.V. Pimenov et al., Phys. Rev. Lett. **94**, 2270003 (2005)