Re-appearance of antiferromagnetic ordering with Zn and Ni substitution in $La_{2-x}Sr_xCuO_4$

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Abstract

The effects of nonmagnetic Zn and magnetic Ni substitution for Cu site on magnetism are studied by measurements of uniform magnetic susceptibility for lightly doped $La_{2-x}Sr_xCu_{1-z}M_zO_4$ (M=Zn or Ni) polycrystalline samples. For the parent x=0, Zn doping suppresses the Néel temperature T_N whereas Ni doping hardly changes T_N up to z=0.3. For the lightly doped samples with $T_N \sim 0$, the Ni doping recovers T_N. For the superconducting samples, the Ni doping induces the superconductivity-to-antiferromagnetic transition (or crossover). All the heavily Ni doped samples indicate a spin glass behavior at ∼15 K.

Key words: impurity effect; magnetic susceptibility; $La_{2-x}Sr_xCuO_4$; superconductor-to-antiferromagnet crossover

Although nonmagnetic impurity Zn substitution effect has been extensively studied for high-T_c cuprate superconductors and the parent Mott insulators, magnetic impurity Ni substitution effect has not been extensively studied relatively. Particularly, to our knowledge, there are a few studies for Ni doping effect in semiconducting regime ([1–4]). In this paper, we report a systematic study of Ni substitution effect on the polycrystalline samples of $La_{2-x}Sr_xCu_{1-z}M_zO_4$ in the parent antiferromagnet, the lightly doped insulators without long range order, and the relatively low-T_c superconductors, through measurement of uniform magnetic susceptibility χ. The polycrystalline samples were synthesized by a solid state reaction method. For comparison, we synthesized also $La_{2-x}Sr_xCu_{1-z}Zn_zO_4$ [5]. Here, we emphasize an importance of careful annealing process at 650 °C for 48 hours under Ar gas atmosphere. The uniform magnetic susceptibility was measured by a SQUID magnetometer. The Néel temperature T_N is determined by the maximum behavior, or the onset temperature of hysteresis of the magnetic susceptibility between zero field cooling (ZFC) and field cooling (FC). The spin glass temperature T_{SG} is defined by the low temperature sharp peak in the further hysteresis [6]. For non-superconducting samples, a magnetic field of 100∼1.0×10^4 Oe was applied, whereas for superconducting samples, a field of ∼ 100 Oe was applied.

Figure 1 shows Ni doping effect on the T dependence of magnetic susceptibility. We found the followings:

1) Up to z=0.3 for pure La_2CuO_4, Ni doping does not destroy the Néel ordering. Such a robust T_N to Ni doping is in contrast to a fragile T_N to Zn doping [7,3]. In Fig, 2, for comparison, T_N versus Ni or Zn content z is shown.

2) With further Ni doping z >0.3, the spin glass ordering appears at T_{SG} ∼15 K, probably due to Ni spin freezing. Hereafter, we call this Ni freezing temperature.

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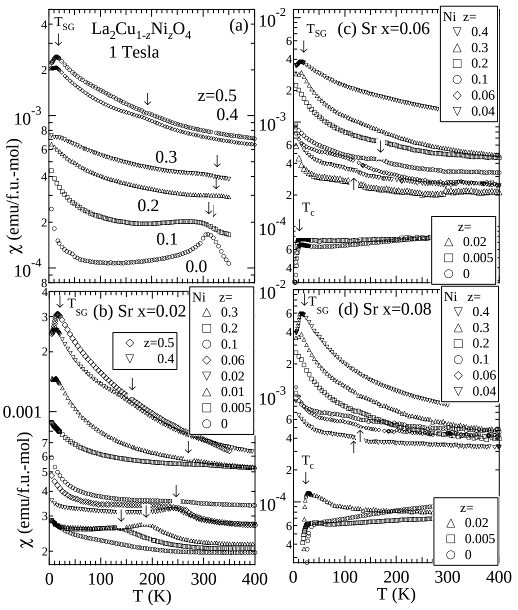

Fig. 1. Ni-doping effect on the ZFC *dc* magnetic susceptibility of $La_{2-x}Sr_xCu_{1-z}M_zO_4$; parent insulator x=0 (a), lightly doped non-superconducting x=0.02 without long range order at z=0 (b), lightly doped x=0.06 with relatively low T_c at z=0 (c), and x=0.08 at z=0 (d). The arrows without character indicate T_N's, the other arrows with character are T_c's, or T_{SG}'s. For simplicity, we do not attach all the arrows.

3) The Néel ordering, which is suppressed down to T_N <4.2 K by Sr doping x=0.02, recovers more rapidly and largely with Ni doping, than with Zn doping [5].

4) The superconductivity for Sr x=0.06 or 0.08 is easily suppressed by Ni doping. The Ni doping induces the superconductor-to-antiferromagnet transition (crossover) at z=0.02∼0.04. Further Ni doping for z >0.3 or >0.2 induces the spin glass state with T_{SG} ∼15 K.

5) The Ni freezing temperature with heavily Ni doping does not seem to depend on Sr doping level.

6) The Ni freezing temperature T_{SG} ∼15 K is about two times larger than the Ni-free, spin glass temperature T_g ∼7 K at Sr x=0.04 [6].

In Fig. 3, we summarize the magnetic phase diagram versus Ni content z at various Sr doping, which can be drawn from the preset study in Fig. 1. The magnetic impurity Ni doping yields rich phases through the order-to-disorder transition (or crossover) in antiferromagnetic correlation, the spin glass transition on Ni spin freezing, and the superconductor-to-insulator transition (or crossover). In conclusion, we demonstrate that Ni doping causes the above novel effects on the strongly correlated electron system $La_{2-x}Sr_xCuO_4$.

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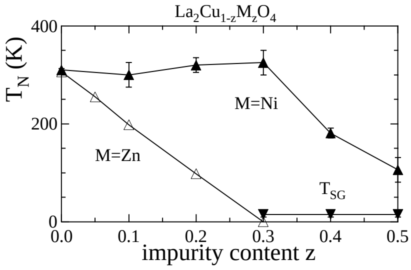

Fig. 2. $La_2Cu_{1-z}M_zO_4$: T_N versus M=Ni or Zn content z. The result is qualitatively consistent with Refs. [7,3].

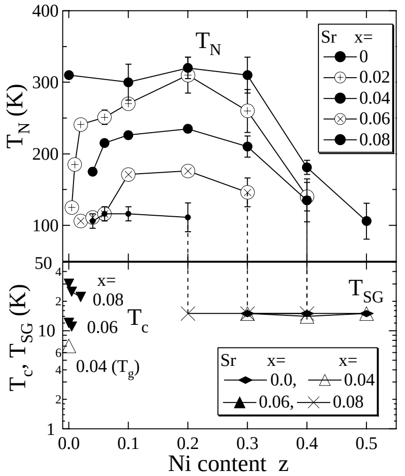

Fig. 3. Magnetic phase diagram of $La_{2-x}Sr_xCu_{1-z}M_zO_4$; T_N, T_{SG}, T_g, and T_c versus Ni content z at Sr doping. The solid and the dashed lines are guide for the eye.

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