# Magnetic and electrical properties of single-crystal $La_{2-x}Sr_xCu_{1-y}Ni_yO_4$

Nobuaki Watanabe [a,1], Takahiko Masui [a,b], Yutaka Itoh [a,b], Takato Machi [a], Isao Kato [a], Naoki Koshizuka [a], Masato Murakami [a],

[a] *Superconductivity Research Laboratory, International Superconductivity Technology Center, 1-10-13 Shinonome, Koto-ku, Tokyo 135-0062,Japan*

[b] *Japan Science and Technology Corporation*

**Abstract**

We report the out-of-plane and in-plane magnetic susceptibility and resistivity of Ni-doped $La_{2-x}Sr_xCuO_4$ single crystals. Our data shows that in lightly Sr doped compounds the Néel temperature $T_N$ increased with increasing Ni concentration. As the temperature is lowered, the resistivity deviates from the impurity band conduction process and becomes dominated by the variable range hopping process associated with the evolving of antiferromagnetic ordering.

*Key words:* LaSrCuO; Ni; substitution effect; Neel temperature

## 1. Introduction

While it is well known that doped holes strongly disturb the long-range magnetic order, the detailed mechanism of the rapid suppression of the Néel temperature $T_N$ caused by hole doping is poorly understood. Recently, Hücker *et al*. reported that Zn impurities lead to an increase of the $T_N$ in slightly hole doped $La_2CuO_4$ polycrystals, and this increase of $T_N$ correlates with an increase of the resistivity[1]. More recently the increase of $T_N$ was also reported in Ni doped $La_{2-x}Sr_xCuO_4$ polycrystals by Kato *et al* [2].

We present results of the temperature dependence of the susceptibilities and resistivities for $La_{1.99}Sr_{0.01}Cu_{1-y}Ni_yO_4$ $(0 \leq y \leq 0.1)$ single crystals. At high temperatures, the resistivity is described within the impurity band conduction model. As the temperature is lowered, the resistivity behavior change to the variable range hopping model associated with the evolving of antiferromagnetic (AF) ordering.

[1] Corresponding author. E-mail: nabe@istec.or.jp

## 2. Experimental details

$La_{1.99}Sr_{0.01}Cu_{1-y}Ni_yO_4$ $(0 \leq y \leq 0.1)$ single crystals were grown by the Traveling-Solvent Floating-Zone (TSFZ) method. To reduce the excess oxygen all samples have been annealed for 50 h at 650 °C in pure Ar atmosphere. The magnetic susceptibility was measured using a superconducting quantum interference device (SQUID) magnetometer. The electrical resistivity was measured by the conventional four-probe method.

## 3. Results and discussion

Figure 1 shows the temperature dependence of the out-of-plane susceptibilities for $La_{1.99}Sr_{0.01}Cu_{1-y}Ni_yO_4$ $(0 \leq y \leq 0.1)$ single crystals. In contrast to the case of $x = 0$, in which the well-known linear decrease of $T_N$ is observed with increasing Ni content, $T_N$ was found to increase with Ni content for the Sr substituted crystals.

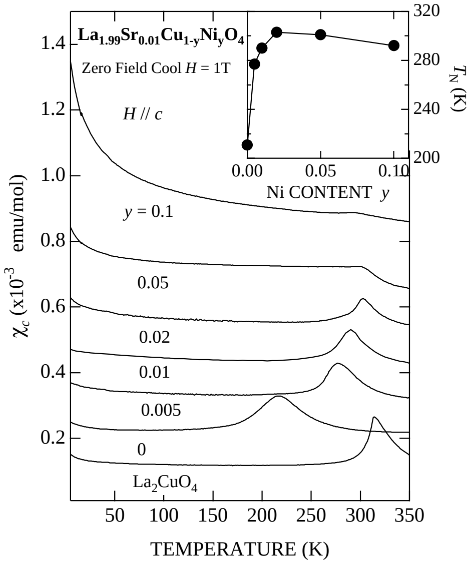


Fig. 1. The temperature dependence of the out-of-plane susceptibilities for $La_{1.99}Sr_{0.01}Cu_{1-y}Ni_yO_4$ ($0 \leq y \leq 0.1$) single crystals. The curves are offsets by $1 \times 10^{-4}$ emu/mol from top to bottom. Inset: The Néel temperature $T_N$ as a function of the Ni content for $La_{1.99}Sr_{0.01}Cu_{1-y}Ni_yO_4$.

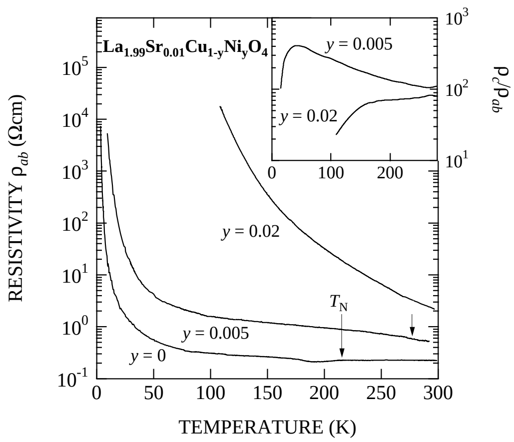


Fig. 2. The temperature dependence of the in-plane resistivity for $La_{1.99}Sr_{0.01}Cu_{1-y}Ni_yO_4$ ($y = 0$, 0.005 and 0.02) single crystals. Inset: Temperature dependences of the resistivity anisotropy ratio $\rho_c/\rho_{ab}$ for $La_{1.99}Sr_{0.01}Cu_{1-y}Ni_yO_4$ ($y = 0.005$ and 0.02) single crystals. The $\rho_c/\rho_{ab}$ shows that the 2D resistivity behavior changes to the 3D one at lower temperatures.

Hücker *et al.*[1] measured the electrical resistivity in Zn doping system and showed that Zn doping lowers the localization radius of the holes. Their conclusion was that as the holes become more mobile, the $T_N$ increases. In the framework of the frustration model Korenblit *et al.*[3] show the combined effects of hole doping and magnetic dilution more quantitatively.

Figure 2 shows the temperature dependence of the in-plane resistivity for $La_{1.99}Sr_{0.01}Cu_{1-y}Ni_yO_4$ ($y = 0$, 0.005 and 0.02) single crystals. All samples exhibit a semiconducting-like behavior. At high temperatures, the resistivity is described within the impurity band conduction (IBC) mechanism which shows temperature dependence as $\rho(T) \propto \exp(\varepsilon_a/kT)$. As the temperature is lowered, the resistivity is described within the variable range hopping (VRH) model. In VRH model, the resistivity shows the temperature dependence as $\rho(T) \propto \exp[(T_o/T)^\alpha]$, where $T_o$ is a characteristic temperature related to the localization radius of the holes. The values of $\alpha$ depend on the dimensionality of the system.

By analyzing the in-plane resistivity data, the $\rho(T)$ phase diagram for $La_{1.99}Sr_{0.01}Cu_{1-y}Ni_yO_4$ is summarized in Fig. 3. The $T_N$ is also plotted. The Ni content dependences of the crossover temperature from IBC to VRH appear to be similar to that of the $T_N$. This fact suggests that the temperature change of mechanism of the $\rho(T)$ is closely related to the evolving of AF ordering.

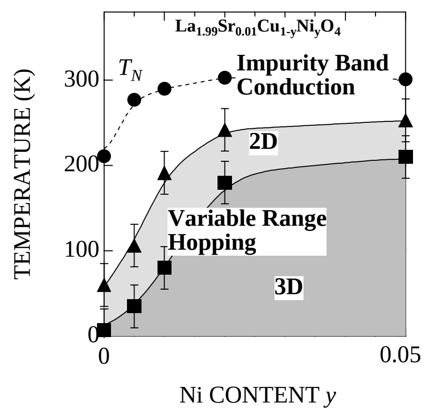


Fig. 3. $\rho(T)$ phase diagram for $La_{1.99}Sr_{0.01}Cu_{1-y}Ni_yO_4$. The Néel temperature $T_N$ is also plotted. The lines are guides to the eye. The temperature change of mechanism of the $\rho(T)$ is closely related to the evolving of antiferromagnetic ordering.


## Acknowledgements

This work is supported by NEDO.


## References


[1] M. Hücker *et al.*, Phys. Rev. B**59** (1999) R725.

[2] I. Kato *et al.*, in Meeting Abstracts of the Physical Society of Japan, Tokushima, 2001, Vol. **56**, p. 490 [in Japanese].

[3] I. Ya. Korenblit *et al.*, Phys. Rev. B**60** (1999) R15017.