

# Depression of the Superconducting Transition Temperature in Neutron Irradiated $\text{La}_2\text{CuO}_{4+\delta}$

Koh-ichi Ueda <sup>a,1</sup>, Takao Kohara <sup>a</sup>, Moritami Okada <sup>b</sup>, Hisao Kodaka <sup>b</sup>, Kiyomi Miyata <sup>b</sup>, Satoshi Watauchi <sup>c</sup>, Isao Tanaka <sup>c</sup>

<sup>a</sup>*Div. of Mater. Sci., Grad. School of Sci., Himeji Inst. of Tech., Kamigori-cho, Hyogo 678-1297, Japan*

<sup>b</sup>*Research Reactor Institute, Kyoto University, Kumatori-cho, Osaka 590-0494, Japan*

<sup>c</sup>*Center for Crystal Science and Technology, Faculty of Engineering, Yamanashi University, Kofu, Yamanashi 400-8511, Japan*

---

## Abstract

The influence of neutron irradiation to the superconductivity of the oxygen loaded  $\text{La}_2\text{CuO}_{4+\delta}$ , which were prepared from one single crystal of  $\text{La}_2\text{CuO}_4$ , was investigated. The neutron irradiation were performed at 10 K. The superconducting transition temperature ( $T_c$ ) dropped monotonously with increasing the neutron fluence. The depression rate of  $T_c$  was  $-1.3 \text{ K}/10^{17} \text{ n/cm}^2$ . A rise of  $T_c$  could not be observed by the neutron irradiation.

*Key words:* superconductivity;  $\text{La}_2\text{CuO}_4$ ; neutron irradiation ;

---

## 1. Introduction:

$\text{La}_2\text{CuO}_4$  is well known as one of the parent materials of high-temperature superconductors. Superconductivity may be achieved either by partial replacement of La with divalent elements or by introducing excess oxygen atom into the matrix. On the other hand, superconductivity developed by neutron irradiation was previously reported by Yoshida and Atohe [1]. They proposed the following scenario for the bulk superconductivity. In  $\text{La}_2\text{CuO}_4$  light oxygen atoms are preferentially displaced to form oxygen interstitials and vacancies through a collision sequence. The oxygen interstitials may produce  $\text{O}_2^-$  super oxide ions at the end of a collision sequence or in the local oxygen-rich regions with similar condition to the oxygen loaded  $\text{La}_2\text{CuO}_{4+\delta}$ . Here  $\delta$  means the amount of the excess oxygen. Since their experiment was performed on  $\text{La}_2\text{CuO}_4$ , their scenario may be realized only around  $\delta = 0$ . It is difficult for our oxygen loading apparatus to adjust the  $\delta$  to the critical amount where

the superconductivity appears. So, we try to study the influence of the neutron irradiation to the excess oxygen ( $\text{O}_2^-$  ion) in  $\text{La}_2\text{CuO}_{4+\delta}$ .

## 2. Experimentals:

A single crystalline sample of  $\text{La}_2\text{CuO}_4$  was employed to determine the superconducting transition temperature ( $T_c$ ) clearly. The single crystalline sample was made at Yamanashi University by Traveling Solvent Floating Zone method. The rod of single crystal was cut into 1.2 mm cubes with a diamond blade. Then, these cubic samples were annealed under pure oxygen gas of 0.2 GPa at 873 K for 10 hours in a test tube type cylinder. Amounts of excess oxygen ( $\delta$ ) were estimated as about 0.03 by an increase of the sample weight after the oxygen annealing.

The neutron irradiation experiments were carried out at 10 K using the low-temperature irradiation loop facility (LTL) at the Kyoto University Reactor (KUR). The samples were set at two positions of different neutron fluence (fast neutrons  $5.9$  and  $2.4 \times 10^{16} \text{ n/cm}^2$ ;

---

<sup>1</sup> E-mail: ueda@sci.himeji-tech.ac.jp

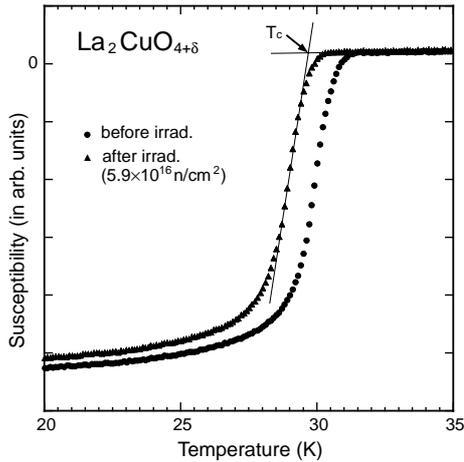


Fig. 1. The temperature dependence of ac susceptibility of a single crystalline sample.

thermal neutrons  $3.0$  and  $5.5 \times 10^{17} \text{ n/cm}^2$ ; gamma-rays  $7.4$  and  $5.0 \times 10^8 \text{ R/cm}^2$ , respectively) in the irradiation cryostat of LTL.

Ac susceptibility measurements were performed to determine the  $T_c$  of samples.  $T_c$ 's of all samples were measured before and after the irradiation to clarify the influence of the irradiation. Before the irradiation, samples were cooled with keeping the same cooling rate in the LTL. On the other hand, the irradiated samples were kept in  $\text{LN}_2$  for about one month to reduce radioactive ray before measuring  $T_c$ . Samples were handled at  $\text{LN}_2$  temperature to keep their thermal history.

### 3. Results and Discussion:

Fig.1 shows the typical temperature dependence of the ac susceptibility ( $\chi$ ) of one sample. Closed circles and triangles indicate the data taken before and after the irradiation, respectively. The  $T_c$  was determined by the intersection of the drawn slope line at the steepest part of the  $\chi$  and by the normal-state  $\chi$  value.

Fig.2 shows the  $T_c$  normalized to the value measured before the irradiation against the fast neutron fluence. The value of  $T_c$  decreases monotonically with no remarkable changes of the Meissner diamagnetization. The  $T_c$  drops by irradiation at a rate of  $-1.3 \text{ K}/10^{17} \text{ n/cm}^2$ . Previously, it has been observed that the depression rate was almost the same ( $-1 \text{ K}/10^{17} \text{ n/cm}^2$ ) in our heavily irradiated (fast neutron fluence were  $2.8 \times 10^{17}$  and  $7 \times 10^{17} \text{ n/cm}^2$ ) polycrystalline samples in the Hydraulic conveyor at KUR [2]. Although there is a difference of  $T_c$  in each material, this depression rate is much larger than those ( $-2.7 \text{ K}/1.3 \times 10^{18} \text{ n/cm}^2$ ,  $-3.0 \text{ K}/10^{18} \text{ n/cm}^2$ , and  $-0.4$

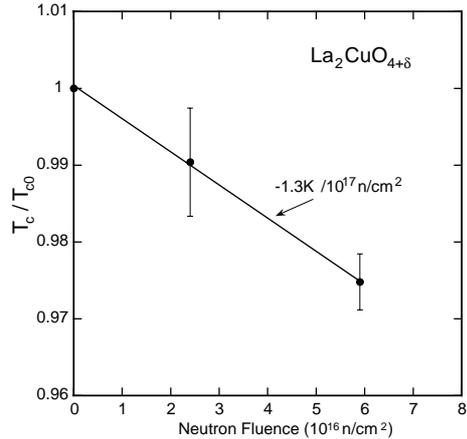


Fig. 2. Dependence of the  $T_c$  on fast neutron fluence. The  $T_c$  is normalized to the value before irradiation ( $T_{c0}$ ).

$\text{K}/10^{18} \text{ n/cm}^2$ ) of  $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$  [3],  $\text{YBa}_2\text{Cu}_3\text{O}_7$  [4] and  $\text{V}_3\text{Si}$  [5], respectively. In comparison with  $\text{V}_3\text{Si}$ , oxide superconductors are strongly affected by the neutron irradiation. This effect is probably due to that oxide superconductors contain oxygen atom and have layer structures. Furthermore,  $\text{La}_2\text{CuO}_{4+\delta}$  shows larger depression rate than  $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$ . This difference is likely ascribed to the loaded oxygen, which are situated interstitially between atoms and causes superconductivity by hole doping.

Finally, in  $\text{La}_2\text{CuO}_{4+\delta}$  the neutron irradiation suppresses the superconductivity strongly rather than enhances it. The enhancement of the superconductivity by the scenario was not realized around  $\delta = 0.03$  in  $\text{La}_2\text{CuO}_{4+\delta}$ .

### Acknowledgements

This work has been carried out in part under the Visiting Researcher's Program of the Research Reactor Institute, Kyoto University.

### References

- [1] H. Yoshida, K. Atobe, *Physica C* **156** (1988) 225.
- [2] K. Ueda *et al.*, *KURRI Prog. Rep.* (1994) 94.
- [3] S.T. Sekula *et al.*, *Jpn. J. Appl. Phys.* **26**, Suppl. 26-3 (1987) 1185.
- [4] J.R. Cost *et al.*, *Phys. Rev. B* **37** (1988) 1563.
- [5] H. K pfer *et al.*, *Z. Phys. B – Condensed Matter* **69** (1987) 167.