# Mesoscopic effect observed in $YBa_2Cu_3O_{7-\delta}/La_{0.67}Sr_{0.33}MnO_3$ tunnel junctions

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**Abstract**

Transport properties of $YBa_2Cu_3O_{7-\delta}/La_{0.67}Sr_{0.33}MnO_3$ tunnel junction are studied at ultra-low temperature. The conductance spectra showed pronounced size dependence, *i.e.*, the sharp zero-bias peak transited to a peak-and-dip structure as the junction size becomes smaller ($\sim 10\mu m$). The peak-and-dip structure is sensitive to applied magnetic field, and the dip position moves as the magnetic field increases. These results suggest that mesoscopic effects such as the phase coherent effect and Aharanov-Bohm effect coexist in the present junction, even though YBCO and LSMO have strongly correlated electron system.

*Key words:* Zero-bias anomaly; Phase-coherent transport ; Mesoscopic effect ; YBCO

## 1. Introduction

Transport properties of transition metal oxides have attracted much attention because various electronic phases are available based on the oxide including high-$T_c$ superconductors and ferromagnets. One of the possibility is to fablicate the hybrid structure made of Cu and Mn oxides in order to realize new functionality in superconducting electronics. The possibility of the realization of three terminal devices and memories have been pointed out. On the other hand, the controllability of the oxide is extremely low due to unstable oxygen contents and the understanding of boundary states is quite difficult due to the strong correlation. We have recently succeeded in fabricating $YBa_2Cu_3O_{7-\delta}/La_{0.67}Sr_{0.33}MnO_3$ (YBCO/LSMO) junctions with an ideally clean interface[1], and we are trying to clarify the basic transport properties between $d$-wave superconductor and ferromagnets. In this paper, the transport of relatively small junctions ($\sim 10\mu m$) are studied at ultra-low temperature region in order to answer the question whether the mesoscopic effects and $d$-wave superconductivity coexists or not.

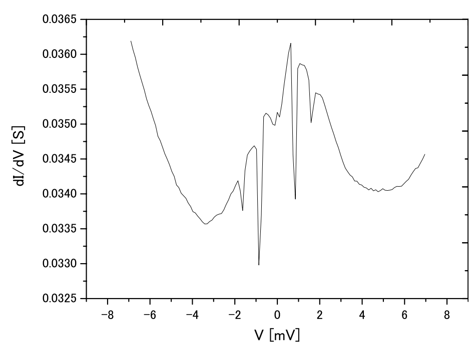


Fig. 1. The conductance spectra of a junction of which size are $15\mu m \times 10\mu m$ measured at 115 mK without magnetic field is shown. In this figure, a broad peak which center is shifted about 1mV, and a peak-and dip structure is observed.

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## 2. Experimental Details

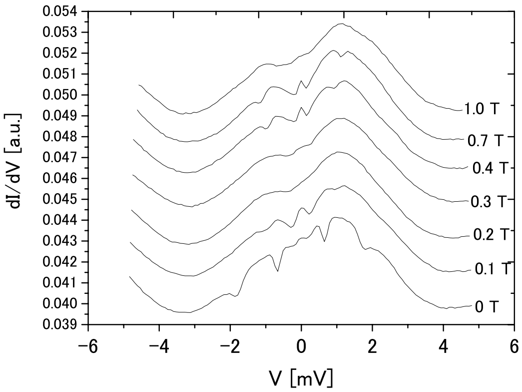


Fig. 2. (a) The magnetic field dependence of the conductance spectra of small junction measured at 100mK is shown. Junction size is about $15\mu m \times 15\mu m$. The magnetic field is applied up to 1.0 T and applied to parallel to $CuO_2$ layer. In this figure, the conductance spectra are shifted for clarify.

The YBCO/LSMO tunnel junctions in the present study have been fabricated by laser sputtering and conventional photo-lithography. Junctions with different sizes, $40\mu m \times 30\mu m$ (large junction) and less than $15\mu m \times 10\mu m$ (small junction) have been fabricated on the same process to check the size dependence. In the present junction, both out-of-plane and in-plane interfaces exist between YBCO and LSMO, and the ratio of the current amplitude for each direction is about 2:1. The conductance spectra are measured with a dilution refrigerator using conventional four-terminal setup with lock-in amplifier.

## 3. Results and Discussion

Transport property of large junctions showed the presence of sharp single zero-bias peak (ZBP) which reflects the $d$-wave pairing symmetry of high-$T_c$ superconductors (data not shown here). As the temperature goes down, the peak appears at below 50K, and the peak becomes sharper as the temperature goes down. This feature is consistent with theoretical formula in BTK (ballistic) regime[2–4]. On the other hand, for small junctions, the features are drastically changed. The conductance spectra show the presence of a broad peak of about 1mV shifted from zero, which is though to have similar origin with above ZBP because it survives relatively higher temperature. In addition to the broad peak, minute peak-and-dip structure appears whose energy levels are symmetric with respect to zero bias level as shown in Fig. 1. Since the latter feature appears below 3K, the origin of the peak-dip can be regarded as the phase coherent transport due to mesoscopic junction size. In other words, the junction transits from ballistic regime to diffusive regime by decreasing the junction size and lowering the temperature [5,6].

In order to clarify the transport properties in detail, magnetic field responses of the present junction has measured. The magnetic field dependence of large junction showed the zero-bias conductance peak, which is never disappeared up to 7T. However, for the small junction, the conductance spectra are sensitive even to small magnetic field as shown in Fig. 2. In the cases of conventional superconductors, two different magnetic field response have been reported thus far, Ag/Nb micro-strip junction [7] and InGaAs/Nb junctions [8]. In the response of the present junction, since the peak-and-dip structure survives up to 1T, the origin of present peaks is more similar to that observed in Ag/Nb junction. However, the periodical response shown in Fig. 2 did not detected in Ag/Ng junctions. We believe that the magnetic field response of small junction is attributed to the phase coherent tunneling coupling with the A-B effect [9]. Unintentional structures, such as grain boundaries in LSMO films, may be responsible for the A-B effect. More detailed study is in progress.

In conclusion, the mesoscopic effect coexisting with $d$-wave pair potential in YBCO/LSMO have been successfully observed. We believe that the present result is a starting point of possible gauge devices made of strongly correlated electron system.

## References


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