Pressure Dependence of Nernst Effect for La$_{2-x-y}$Nd$_y$Sr$_x$CuO$_4$

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Abstract. We have investigated the effect of stripe strength on Nernst effect for La$_{2-x-y}$Nd$_y$Sr$_x$CuO$_4$ single crystal under hydrostatic pressure. Hydrostatic pressure is known to quite effectively control the stripe strength without changing hole concentration and chemical disorder (Nd concentrations). In the pressure, we found a drastic enhancement of Nernst signal below superconducting fluctuation temperature ($T_{sfl}$~50K), where field dependence of Nernst signal become non-linear. This result indicates the suppression of the stripe strength by applying pressure lead to the enhancement of the superconducting fluctuation. As reported previously, we have clearly observed the upturn of the Nernst signal below structural transition temperature ($T_{ch}$~75K for y=0.4), indicating that the stabilization of the stripe order makes the Nernst signal large. On the other hand, upturn of Nernst signal around 150K would consider to the temperature where fluctuation of the stripe order (dynamic stripe) develops.

1. Introduction

Anomalous Nernst effect well above $T_c$ in high-$T_c$ cuprates is now a well-known experimental result, and it has long been discussed as a clue to the mechanism of superconductivity. It has been widely accepted that the large Nernst signal is attributed to the movement of vortices which survives far above $T_c$ [1]. On the other hand, enhancement of the Nernst effect by stripe order was recently reported in Nd or Eu doped La$_{2-x}$Sr$_x$CuO$_4$ [2]. Interpretation of the mechanism of superconductivity varies in accordance with the origin of anomalous Nernst signal. If we assume it to be vortex movement, we can consider that the superconducting gap opens far above $T_c$, although the long-range phase coherence is destroyed by vortex excitation. On the other hand, if the large Nernst signal would be a result of stripe order, it is considered that the superconductivity occurs near the quantum critical point where the competing orders, such as stripe order and/or charge order, cross in the phase diagram.

Previously, we have measured the Nernst effect of La$_{2-x}$Sr$_x$CuO$_4$ with controlling strength of the stripe order by Nd-doping and found that stabilization of the stripe order enhances the Nernst signal [3]. However, it is difficult to adjust hole concentration to exactly the same value in different Nd-doping samples. Here, we measured pressure dependence of the Nernst effect to confirm the above result. Hydrostatic pressure is known to quite effectively control the stripe strength with using the same sample [4].

2. Experiment

Single crystals of La$_{2-x-y}$Nd$_y$Sr$_x$CuO$_4$ (x=0.15, y=0, 0.2, and 0.4) were grown using the Traveling Solvent Floating Zone method. Grown boules were carefully cut into rectangular shape confirming the crystal axis by using X-ray laue camera. The hole concentration was confirmed by the absolute value
of the thermopower at room temperature. $T_c$'s determined by susceptibility were 23K, and 12K for $y=0.2$, and 0.4 respectively. For the samples of $y=0.2$ and 0.4, a structural transition from the orthorhombic (LTO) to low temperature-tetragonal (LTT) phases have been observed around 50K and 75K, respectively.

Nernst signal $e_y$ was measured in the Piston Cylinder type high pressure Cell (PCC) with Daphne7373 as a pressure medium. Figure 1 shows the picture of the Nernst measurement setup which is made to insert a Teflon pressure cell with diameter of $\phi=4\text{mm}$. Two copper plates were placed in PCC, and the sample (with dimensions $W=2$, $L=1.5$, $D=0.1\text{mm}$) was bridged between copper plates. Just beside the sample, two Cernox thermometers (LakeShore) were put on the copper plates. Temperature gradient was applied with using resistive heater (120Ω) which was pasted on one of copper plates. The magnitude of pressure was calibrated by measuring the superconducting transition temperature of Pb manometer. Since resistance of Cernox also changes with applied pressure, they are calibrated at each pressure before Nernst measurement.

Nernst signal $e_y$ is defined as the transverse electric field $E_y$ per unit temperature gradient $\nabla T$ ($e_y = E_y/\nabla T$). Since electric field and temperature gradient are expressed as $E_y=\Delta V/W$ and $\nabla T=\Delta T/L$ (where $\Delta V$ is transverse voltage, $\Delta T$ is temperature difference, $W$ is width, $L$ is length of sample) respectively, Nernst signal is deduced as $e_y=\Delta V/\Delta T*W/L$. To obtain larger Nernst voltage, the ratio of width and length $W/L$ should be larger, such as thickness should be thin in the case of Hall measurement.

Since heat flow in the sample would change according to surrounded atmosphere of the sample, we compare Nernst signal in vacuumed atmosphere and that in Daphne Oil without applying pressure. Figure 2 shows Nernst signal in various measurement setting. As seen in this figure, absolute values of the Nernst signal are almost the same at each temperature. Moreover, we measured Nernst signal without using pressure cell at 20K and confirmed its reproducibility. These results indicate that heat flow in the pressure medium is negligible compared to that in the sample. Surrounded atmosphere does not matter if transverse voltage and temperature gradient are definitely measured.

3. Results

Figure 3 shows temperature dependence of Nernst signal for (a) $y=0.2$ and (b) $y=0.4$ under hydrostatic pressure of 2GPa and 0GPa. Nernst signal for Nd-free LSCO ($y=0$) is also plotted for the comparison. As seen in these figures, Nernst signal drastically increase (more than 5 times larger in $y=0.4$) with applying pressure below $T_{sf} \sim 50K$ and it almost coincides with the curve of Nd-free LSCO $y=0$.

Hydrostatic pressure effect of Hall coefficient for Nd-doped LSCO was reported previously. There, the structural transition to LTT was completely suppressed by applying pressure up to 0.2GPa, and the confinement of charge carriers within stripes is relaxed due to weakening of pinning potential. Our
results are consistent with this result. Since LTT distortion is suppressed by pressure, the stripe strength become weaker. We consider that the suppression of the stripe strength by applying pressure enhances the superconducting fluctuation.

![Figure 3](image-url)  
Figure 3. Temperature dependence of Nernst signal under hydrostatic pressure of 0GPa and 2GPa. (a) $y=0.2$, (b) $y=0.4$.

Figure 4 shows Nernst coefficient $\nu$ as a function of temperature for different magnetic field at $y = 0$, 0GPa (a), $y = 0.2$, 2GPa (b), and $y = 0.4$, 0GPa (c). We can see field dependence of Nernst coefficients below $T_{sfc}$, indicating that non-linear Nernst signal against magnetic field occur below $T_{sfc}$. This result indicates that superconducting fluctuation develops below $T_{sfc}$ and it is destroyed by applied field. Interestingly, $T_{sfc}$ is the same in all samples although superconducting transition temperature $T_c$ (i.e. stripe strength) is different. As seen in figure 4c, absolute value of the Nernst signal actually increases at charge stripe order temperature.

![Figure 4](image-url)  
Figure 4. Temperature dependence of Nernst signal for different magnetic field.

4. Discussion
There are four characteristic temperature observed in temperature dependence of Nernst signal. They are, 1. Superconducting transition temperature $T_c$, 2. Charge stripe order temperature $T_{ch}$, 3. Superconducting fluctuation temperature $T_{sfl}$ that discussed above section, and 4. Onset temperature
$T_{\text{onset}}$ below which Nernst signal start to increase. As mentioned in Introduction, it is important to understand the origin of $T_{\text{onset}}$. Possible candidate discussed up to now is superconducting fluctuation or stripe fluctuation (dynamic stripe). This problem could replace to the problem “Where superconducting fluctuation begin to develop”. As discussed above section, we expect that superconducting fluctuation develops below $T_{\text{sfc}}$. Therefore, it is natural to consider that stripe fluctuation (dynamic stripe) develop below $T_{\text{onset}}$. Actually stripe order increase Nernst signal as Fig. 4(c).

The fact that $T_{\text{flc}}$ and $T_{\text{onset}}$ does not change with stripe strength (i.e. Nd-content or applying pressure) indicate an inhomogeneous nature of High-$T_c$ superconductor. Regardless of stripe strength, precursor of superconductivity would partially (inhomogeneously) develop below $T_{\text{sfc}}$. If stripe strength is strong, it is difficult to connect superconducting region throughout bulk sample, and then, $T_c$ decrease. On the other hand, when LTT distortion is strong, stripe fluctuation (dynamic stripe) easily ordered by pinning potential, and $T_{\text{ch}}$ increase, although stripe fluctuation would develop irrelevant to LTT distortion.

5. Conclusion

In order to investigate effect of the stripe strength on Nernst effect, we have measured Nernst signal under the Hydrostatic pressure. Drastic increase of Nernst signal under the $T_{\text{sfc}}\sim50\text{K}$ has observed. This result indicates that the suppression of the stripe strength by applying pressure causes the enhancement of the superconducting fluctuation. We conclude the superconducting fluctuation exist below $T_{\text{sfc}}\sim50\text{K}$, and then, onset temperature $T_{\text{onset}}\sim150\text{K}$ below which Nernst signal start to increase would be the temperature that stripe fluctuation (dynamic stripe) develops. Since stripe order also enhance Nernst signal, it is natural to consider $T_{\text{onset}}$ as starting temperature of stripe fluctuation (dynamic stripe).

References

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