Study of the Mechanism of High-T_c Superconductivity – Elucidating the Temperature-dependence of Hall Coefficient up to 1000 K –

Background

An important challenge in the study of strongly-correlated electron systems including high-T_c cuprates is to understand the fundamental nature of their transport properties, such as resistivity and Hall coefficient R_H. In conventional metals, R_H is independent of temperature and signifies the Fermi surface topology and carrier density, but in high-T_c cuprates R_H shows strong temperature dependences as well as a complicated doping dependence, which are generally believed to be too complicated to be quantitatively understood.

Objectives

In an effort to quantitatively understand the temperature dependence and the doping evolution of the Hall coefficient R_H in high-T_c cuprates and to elucidate the electronic structure of this system, we have measured R_H up to 1000 K for a wide doping range.

Principal Results

The $La_{2-x}Sr_xCuO_4$ (LSCO) system we study here is a prototypical high-T_c cuprates, where $x = 0$ is a parent charge-transfer (CT) insulator with the band gap Δ_{CT} called CT gap (Fig.1). We grew high-quality LSCO single crystals for a wide doping range and measure R_H in high accuracy up to 1000 K and obtained the following results:

1) We found that the temperature dependence of R_H for $x = 0$ can be analyzed in a rather conventional way based on the band picture, and an apparent energy gap Δ is obtained, which means that R_H at $x = 0$ is simply governed by two gaps. The lower-temperature part of the data tells us that there is a small concentration of impurity states located above the top of the valence band. What is new is that at high temperature above 500 K another activation process becomes active, which obviously corresponds to the activation across the CT gap (Fig.2).
2) Intriguingly, the behavior of R_H in doped case ($x = 0.01$ - 0.23) at high temperature clearly signifies that charge carriers are thermally activated over a sub-eV gap, likely associated with some CT excitations (Fig 3).
3) Our analysis of R_H allowed us to extract the thermal activation energy Δ for a wide doping range. The obtained x-dependence of Δ (Fig.4) demonstrated a systematic softening with increasing x. This result suggests that charge fluctuations over a gap remain important at high temperature in high-T_c cuprates deep into the superconducting doping range.

Overall, our data and analysis strongly suggest that charge fluctuation associated with a sub-eV gap should be taken into account when discussing the physics of high-T_c cuprates even at relatively low energy scales.

Future Developments

This study significantly advances our understanding of the temperature-dependence of Hall coefficient R_H in $La_{2-x}Sr_xCuO_4$ system. We plan to further address the origin of the thermal activation energy in this class of materials, which may gives us a clue to understand the mechanism of high-T_c superconductivity.

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Reference

S. Ono, Seiki Komiya, and Yoichi Ando, 2007, "Strong Charge Fluctuations Manifested in the High-Temperature Hall Coefficient of High-T_c Cuprates," Physical Review B, 75, 024515

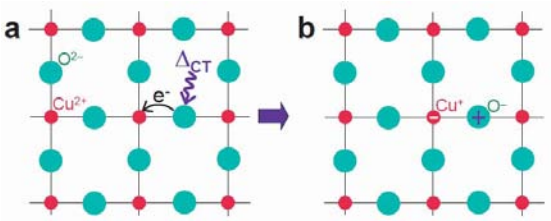

Fig.1 Charge-transfer (CT) excitation in the CuO_2 plane.

(a) A CT excitation with energy Δ_{CT} moves an electron from O^{2-} to Cu^{2+}.
(b) Creating a hole on O and an additional electron on Cu.

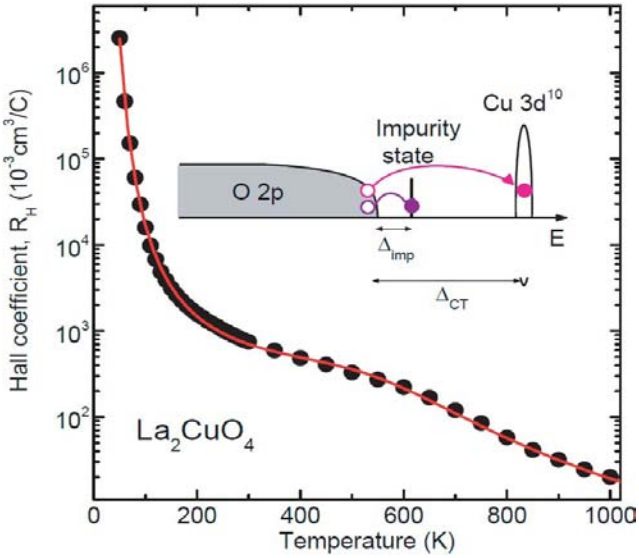

Fig.2 Temperature dependence of the Hall coefficient R_H for a high-quality La_2CuO_4 single crystal measured up to 1000 K. The red line is the fit to the data in a conventional way based on the band picture. It is clear that this fitting is essentially perfect, which means R_H for La_2CuO_4 is simply governed by two gaps. One is activation across the impurity-ionization gap and the other is another activation process across the CT gap. The inset shows a schematic energy diagram for the relevant band and states.

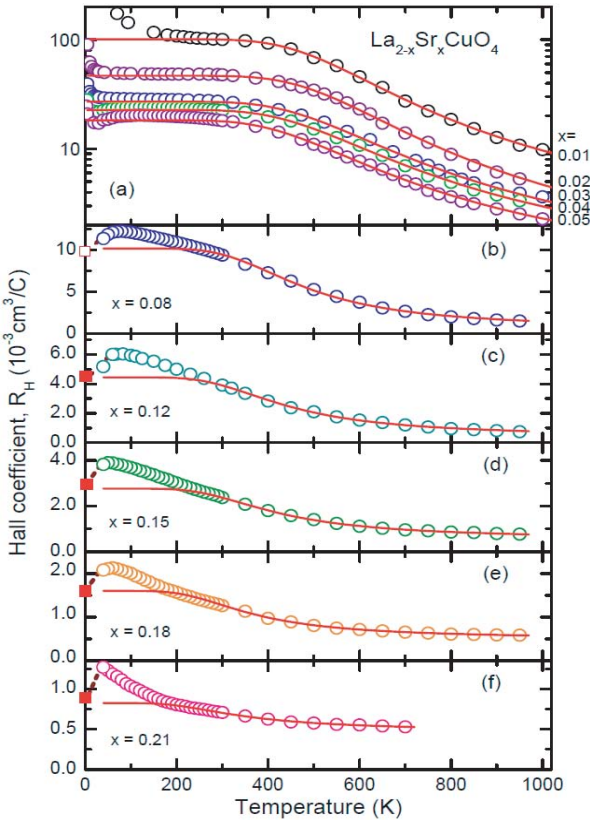

Fig.3 Temperature dependence of R_H for a series of high-quality $La_{2-x}Sr_xCuO_4$ single crystals measured up to 1000 K. The red lines are the results of the fitting, which we assume that the carriers are thermally activated across the gap. The fitting indeed gives good fittings for all x values at high temperatures. This observation strongly suggests that essentially the same thermal activation process is affecting the R_H behavior at high temperature even in the superconducting range.

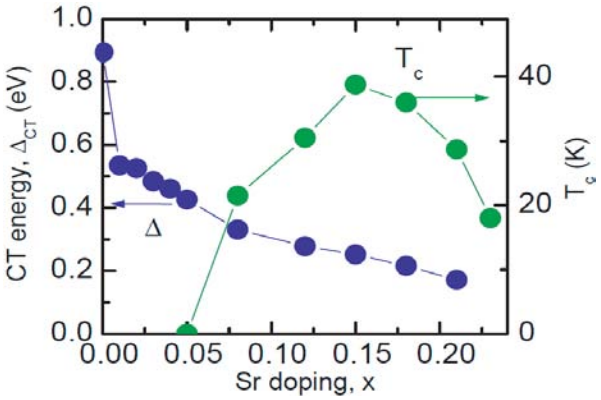

Fig.4 Sr-doping x dependences of the activation energy Δ and of the superconducting transition temperature T_c for $La_{2-x}Sr_xCuO_4$ single crystals. The obtained x-dependence of Δ demonstrates a systematic softening with increasing Sr-doping x.