Charge Ordering of CMR and High-T_c Superconductivity Material under the Influence of External Magnetic Field

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We have used high energy synchrotron X-ray at BESSRC beam line 11ID-C to study the CMR $Pr_{0.55}(Ca,Sr)_{0.45}MnO_3$ and high-T_c superconducting material Bi2212. Since both projects are related to transition metal oxides, we will describe in detail our results after an introduction of the background materials, this will serve as the basis for our future direction of investigations.

1. Introduction

Understanding the metal-insulator transition in strong correlated transition oxides (TMOs) poses the most challenges in the physical sciences today[1]. This is because TMOs are often characterized by the physical complexity resulting from the coexistence and competition between different kinds of order involving charge, orbital, lattice and spin degrees of freedom[2]. The relationship between those degrees is often synergistic and nonlinear. The balance between competing phases is very subtle and small change in the composition and external conditions (magnetic field, hydrostatic pressure or temperature) can produce large changes in the physical properties. For example, in the prototype CMR material of $Pr(Ca,Sr)MnO_3$, the ground states can be tuned from metallic to insulating state in zero magnetic field simply by tuning the relative concentration of Ca^{2+} and Sr^{2+} ions. Although the study of perovsite-structured Mn-based materials possessing coupled spin-charge-lattice degrees of freedom has been underway for decades, understanding the microscopic mechanism which is responsible for the amazing properties of those transition oxides is still at the frontier of condensed matter physics. Since most Mott insulator such as the parent compounds of High-T_c superconductors and CMR manganites have long range AF ordering, it is nature to ask what role magnetism has on the anomalous properties of these materials. Neutron scattering has been a successful probe to study the magnetic properties of these materials. However, the weak neutron beam flux requires large sample volume and relative long experimental time. Thus, we have proposed to utilize the high energy synchrotron X-ray to study the

2. Methods and Materials

We choose beam line 11ID-C to carry out the X-ray experiment because of the following reasons,

a) the high energy of 115keV ensure the X-ray to penetrate the samples, gives the bulk properites just like neutron scattering experiments.

b) high resolution of X-ray ensure we get detailed information of structure change under the influence of external parameter (temperature and magnetic field).

c) Beam-line 11ID-C has equppied with a 7 Tesla horizontal magnetic field cryostat which enable the study under the application of exteranl magnetic field.

The material we choose to study is,

a): $Pr_{0.55}(Ca,Sr)_{0.45}MnO_3$, this high quality single crystal is provided by our Japanese collaborator Tomioka's group, extensive transport and magnetic measurements have been done to ensure the high cystalline quality.

b): underdoped $Bi_{2.1}Sr_{1.9}CaCu_2O_{8+\delta}$ with T_c=82K, the sample is provided by Ando's group, the sample is also characterized to be high quality.

3. Experimental Results

3.1. Charge ordering (CO) under the influence of external magnetic field in CMR manganites $Pr_{0.55}(Ca,Sr)_{0.45}MnO_3$

The $Pr_{1-x}Ca_xMnO_3$ compounds have insulating ground states for all x concentrations, by substituting of Ca with Sr (change the band width of one electron e_g), the ground states of $Pr_{0.55}(Ca_{1-y}Sr_y)_{0.45}MnO_3$ changes from a metallic ground state (for y>0.25) to insulating ground state (for y<0.25)[3]. With the application of modest magnetic field (a few Tesla), the insulating ground state material can be tuned into metallic phase and cause CMR effect[4]. We deliberately choose the sample closing to the metal-insulator phase boundary with y=0.15 and study how the charge ordering play a role in the metal-insulator transition. The temperature dependence of sample under various magnetic fields reveals that the transport properties are directly correlated to the charge odering in the material, as shown in Fig. 1

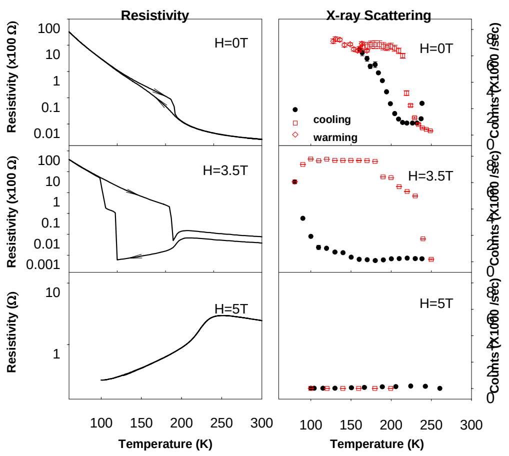

Figure 1 the temperature dependence of charge ordering under external mangetic field of H=0, 3.5 and 5 Tesla. Also shown is the resistiviy of the same sample in the corresponding magnetic fields.

We also observed the incommensurate-commensurate (IC-C) transition as sample temperature is approaching T_N(Fig. 2), indicating anti-phase boundary is forming and charge ordering is not of long range. Those results indicate the true charge-ordering nature in transition-metal oxides is far more complex than earlier established Goodenough pictures. It remains a challenge to understand the ionic charge state in mixed-valence oxides.

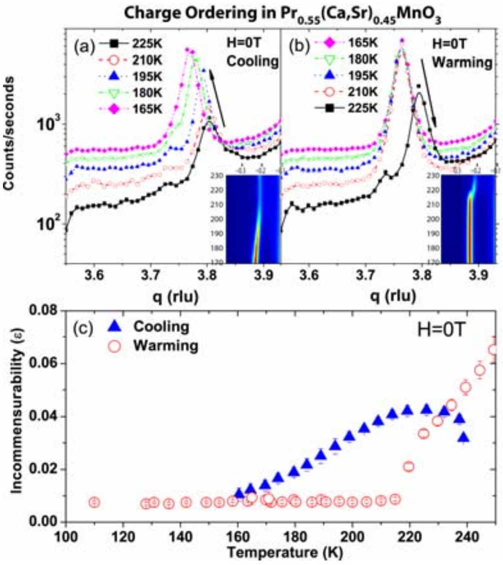

Figure 2 Top panels: representative charge ordering peaks at different temperatures, the temperature evolution of peak position are plot in the insets. Bottom panel, incommensurability (defined as offset value from commesurate peak position) v.s. temperature as samle is thermal cycled. The high resolution X-ray experiments ensure the accurate determination of peaks positions.

3.2. High Tc superconductivity sample $Bi_{2.1}Sr_{1.9}CaCu_2O_{8+\delta}$

In previous STM study [5,6], a four unit-cell periodic pattern of quasi particle states has been observed in Bi2212 samples. It was attributed to the charge ordering introduced by vortex cores. Since STM measurement is surface sensitive technique, it would be worthwhile to examine if the observed charge ordering are intrinsic bulk properties. The motivation of synchrotron X-ray experiment is to clarify if we can observe similar charge ordering super-lattice structure with application of a magnetic field. We have chosen an under-doped Bi2212 sample with TC=82K to study the magnetic field effect on charge ordering state. In Fig. 3, the [hk0] reciprocal plane near (500) is displayed using both image plates and detector. The stripe like modulation only long (110) direction indicates the sample is detwinned.

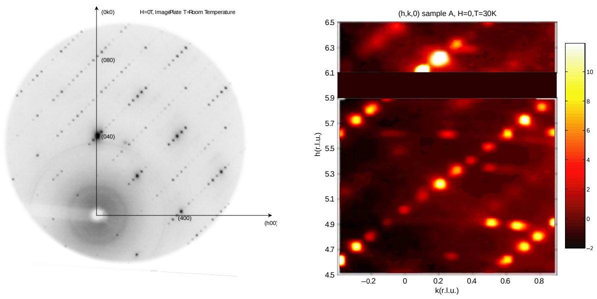

Figure 3 High resolution image plate (left) and detector data (right) indicate the sample is not twinned. Based on the reciprocal space data, we choose a small range of (h, k, 0) zone under different fields and compare their differences.

Figure 4 shows the X-ray data in the (h,k,0) plane with magnetic field of H=0, 3.5 and 6.5 Tesla at T=4K. The difference between data in the field and in zero field are displayed in Fig. 5. To our surprise, the subtraction data clearly shown some stripe like feature along some particular q direction (along (100) direction).

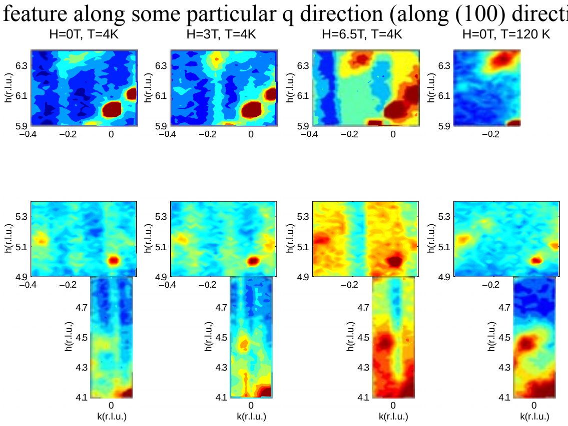

Figure 4 hk scans at H=0, 3.5 and 6.5 Tesla at T=4K and H=0 Tesla at T=120K. The field is ramped to zero before the sample is warmed to 120K.

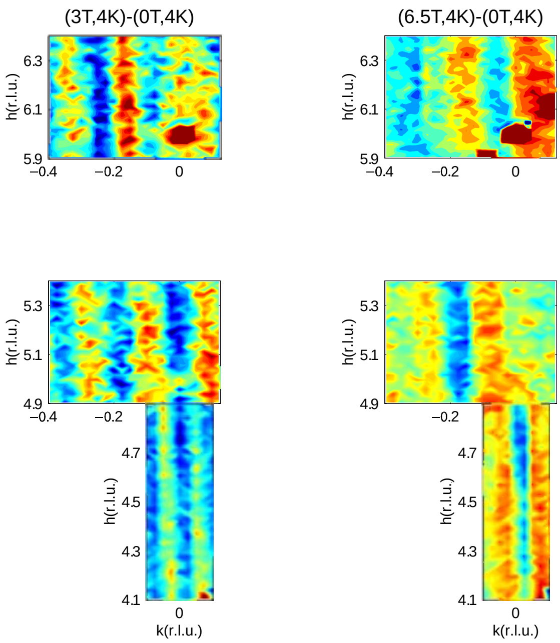

Figure 5 The difference between field data(H=3 and 6.5T) and zero field data in hk plane. Notice the reciprocal space are correctly scaled.

Discussion

We have identify the charge ordering in the $Pr(Ca,Sr)MnO_3$ single crystal under the influence of magnetic field. The results are directly correlated to the resistivity measurements of the sample, indicating the transport properties of the system are controlled by the localization of charge carriers. In addiction, the high resolution X-ray data reveal the CO in the system are not truly long ranged even at the lowest temperature in the absence of magnetic field, consistent with the picture that anti-phase boundary is formed during sample cooling process. However, the neutron scattering data suggest the correlation lengths of anti-ferromagnetic ordering are much longer than that of CO-OO. The current results challenge the classic Goodenough picture which Mn^{3+} and Mn^{4+} ions are ordered alternatively forming checkerboard-like pattern.

In Bi2212 sample, we have successfully identified the magnetic field influence on the charge ordering pattern on hole-doped high T_c superconductivity material, the extra wave vector modulation along the (h00) direction shows much differences compared to the previous STM data. Due to the limitation of beam time, we have not fully understood to how the charge ordered states are affected by the magnetic field. Further characterization is still in progress.

Acknowledgments

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