Simultaneous Study of Local Magnetization and Resistivity in Phase-Separated Manganites

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Abstract

We performed magneto-optical imaging on $Pr_{1-x}Ca_xMn_{1-y}Cr_yO_3$ ($x = 0.35$, $y = 0.03$) concomitantly with transport measurements. Non-uniform distribution of magnetization due to phase-separation is visualized. Temporal evolution of the images revealed much faster relaxation in highly magnetized region than the average over the sample. In the inhomogeneous phase-separated state, we observed telegraph noise in resistivity which suggests the existence of switcher domains.

Key words: manganite, phase separation, metal-insulator transition

1. Introduction

Manganites with perovskite-type structure are extensively studied because of their colossal magnetoresistance effect [1]. In this system, doping of mobile carrier causes ferromagnetism in metallic phase due to double-exchange interaction. Furthermore, orbital and lattice degrees of freedom coupled with those of spin and charge realize various phases in manganites against the change of carrier concentration. Recent theoretical calculations revealed that the electronic system becomes unstable at a certain carrier concentration against the fluctuation of charge density, and hence, causes phase separation (PS) [2]. The PS has now been widely recognized in several transition-metal oxides and it attracts considerable attention. In manganites, PS into ferromagnetic metal and paramagnetic (or antiferromagnetic) insulator can cause metal-insulator transition in a percolative way. Although there have been several real-space observations of PS [3,4], simultaneous observations of local magnetization and transport properties are still lacking.

We performed magneto-optical (MO) observations in $Pr_{1-x}Ca_xMn_{1-y}Cr_yO_3$ ($x = 0.35$, $y = 0.03$) (PCMCO) concomitantly with transport measurements. Cr-substitution for Mn is known to collapse charge ordering [5], and result in macroscopic PS at moderate doing [6]. In this study, we provide real-space magnetic images in PS states and introduce the temporal evolution of magnetism and transport properties.

2. Experimental

Crystals of PCMCO were grown by the floating-zone method. Samples for measurements were cut perpendicular to one of the principal axes of the pseudo-cubic crystal, and polished with 0.5 μm diamond slurry. To remove surface strain, we annealed the samples 10 hours at 1000 °C in oxygen atmosphere. MO observations were performed with a garnet indicator mounted on the sample [7]. Based on the Faraday effect, we observed local flux density normal to the sample surface (B_z) by a polarizing microscope within typical exposure time of 3 s. Resistivity measurements were performed by the standard four-probe method.

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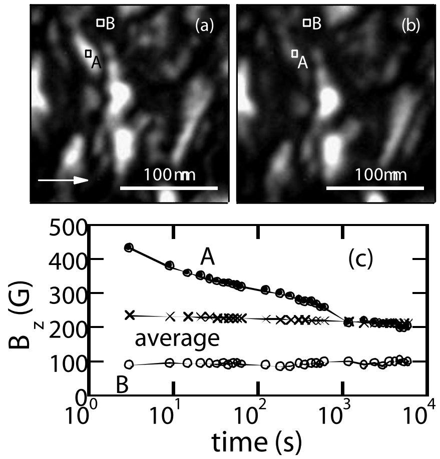

Fig. 1. MO images in PCMCO at 55 K taken (a) just after removal of external field and (b) 6,000 s later. A white arrow in (a) indicates the direction of external field. (c) Temporal variation of local magnetization in area A and B together with the average over the image.

3. Results and discussion

Figure 1(a) shows a MO image in PCMCO at 55 K. At this temperature, magnetization shows significant hysteresis between cooling and heating processes. Here, we first cooled the sample down to 10 K under a magnetic field of 4 kOe and then heated up to 55 K to achieve non-equilibrium state before starting the MO observation. Figure 1(a) is the image taken just after the removal of the field (field direction is shown by an arrow). The brighter (darker) region in the image corresponds to larger (smaller) B_z. Inhomogeneous distribution of B_z in Fig. 1(a) reflects the PS into ferromagnetic and antiferromagnetic regions. Owing to the spatial resolution limit of a few micrometers, our system cannot resolve single domain in the PS state, but visualizes the difference in density of ferromagnetic domains. 6,000 s later, the brighter region A becomes darker, whereas the dark region B remains unchanged (Fig 1(b)). This temporal evolution is demonstrated in Fig. 1(c) together with average B_z over the image. Using the saturation moment of 3.62 μ_B / Mn, the initial magnetization corresponds to 400 ferromagnetic domains with the size of 100 nm in diameter in the area of A (8μm $\times$ 8μm). In region A, the B_z decreases to almost a half of the initial value in 6,000 s.

In such inhomogeneous system, percolative metal-insulator transition can take place. Hess *et al*. observed *switcher* behavior in their transport measurements in the vicinity of the percolation threshold [8]. In our PCMCO, we also observed the telegraph noise at 57 K that is characteristic of *switcher* behavior (Fig. 2(a)). Figure 2(b) shows a MO image taken at this temperature. Although we observed inhomogeneous distribution of magnetization, we could not resolve the switching domain. Creation or annihilation of one ferromagnetic switching domain with the size of 100 nm will cause change in B_z of 3 G in an area of 5μm $\times$ 5μm, which could be resolved by our system if the switcher domain locates close to the surface. To visualize the switching domain, further study on thinner sample than the present one (100 μm) will be desirable.

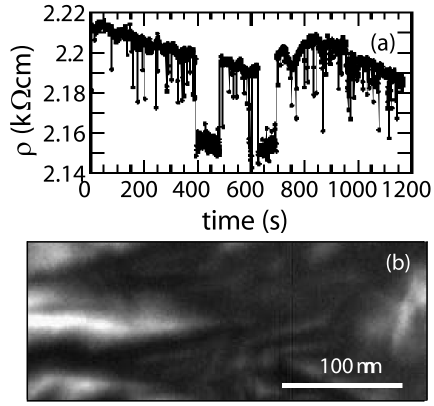

Fig. 2. (a) Temporal variation of resistivity in PCMCO at 57 K. (b) A MO image simultaneously taken with the resistivity measurement in (a).

In conclusion, we studied local magnetization and transport properties on phase separated manganite of $Pr_{1-x}Ca_xMn_{1-y}Cr_yO_3$ ($x = 0.35$ and $y = 0.03$). Relaxation of magnetization is not homogeneous and is interpreted by annihilation of ferromagnetic domains in the phase-separated state.

Acknowledgements

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