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Ferromagnetic domain structure in colossal magnetoresistive manganite; $La_{1-x}Sr_xMnO_3$ (x=0.12)

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Ferromagnetic (FM) domain structure in the colossal magnetoresistive manganite, $La_{1-x}Sr_xMnO_3$ with x=0.12, was investigated by the low-temperature Lorentz microscopy. It is found that two types of FM domain structures appeared in the low-temperature phase characterized as the FM insulator phase. One is a large plate-shaped FM domain structure with the Bloch-type magnetic domain walls and the other is a wavy stripe-shaped FM domain structure with the several hundreds nanometer size in width. These two distinct FM domain structures depend strongly on the crystal orientation. In addition, dynamical behavior of the FM domain structure with the application of the magnetic field was demonstrated.

Key words: magnetic domain structure, colossal magnetoresitance, manganite, Lorentz microscopy.

1.INTRODUCTION

Manganite perovskites with the chemical formula $A_{1-x}B_xMnO_3$ (where A is a rare-earth and B is an alkali-earth atom) have attracted considerable attention because they show a wide diversity of ground states and some anomalous phase transitions.[1] The most dramatic phenomena is the magnetic-field- induced insulator-to-metal (MI) transition, which is referred to as the colossal magnetoresistance (CMR) effect.[1] $La_{1-x}Sr_xMnO_3$ shows a variety of ground states , which depend strongly on the Sr concentration (x).[2] In particular, the ground state in $0.10<x<0.17$ is identified as the ferromagnetic (FM) insulator phase with the trigonal structure (space group:P1).[3] The CMR effect is found in $La_{1-x}Sr_xMnO_3$ with the Sr content (x) between 0.10 and 0.30.[2] Recently it is reported that magnetic domains and magnetic domain walls have strong influence on the magnetic and electric properties in mangnites.[4] Thus, an examination of the magnetic domain structure should be needed for a proper understanding of the unusual magnetic and/or electric properties such as the CMR effect and the MI transition in $La_{1-x}Sr_xMnO_3$.

Lorentz microscopy is one of the powerful tools to observe the FM domain structure with a high spatial resolution. There exist two observation modes in Lorentz microscopy. The schematic description of these two observation modes is shown in Fig.1.[5] One is the Fresnel (out-of-focus) mode, which is used when the magnetization in the materials is randomly distributed and dynamical behavior of the FM domain structure under the application of the magnetic field is examined. The other is the Foucault (displaced aperture) mode, which has advantage of taking images with high spacial resolution of nano-meter scale. The latter mode gives us some useful information on the relation between the FM domain structure and the crystal orientation. In the present work, we use the two observation modes in Lorentz microscopy, in order to examine details of the FM domain structure in the CMR manganite, $La_{1-x}Sr_xMnO_3$.

2.EXPERIMENTAL METHOD

A $La_{1-x}Sr_xMnO_3$ single crystal with x=0.12 grown by the floating-zone method was used in this work. Specimens for Lorentz microscopy observation were prepared by the Ar-ion thinning techniques. The observation was carried out by using the Hitachi HF-3000F Lorentz microscopy equipped with the Liquid He cooling holder. No magnetic field was applied to the observed sample inside the microscopy.

3.RESULTS and DISCUSSION

First of all, we investigated the FM domain structure at low temperature around 17K in $La_{0.88}Sr_{0.12}MnO_3$. The low-temperature phase in $La_{0.88}Sr_{0.12}MnO_3$ is characterized as the FM insulator phase. Figure 2 shows typical FM domain structure obtained by the Fresnel mode at 17K. As shown in Fig.2(a), the regular arrangement of characteristic straight-lines with the bright and dark contrast can be seen. This characteristic straight-lines with the bright and dark contrast are due to

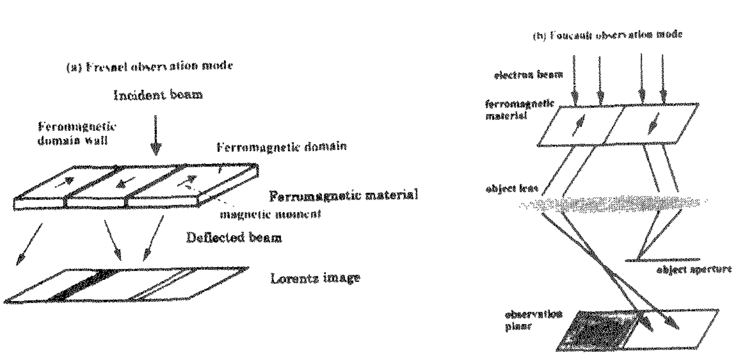

Figure.1 :Schematic description of the observation mode in Lorentz microscopy.
(a) Fresnel mode (b) Foucault mode

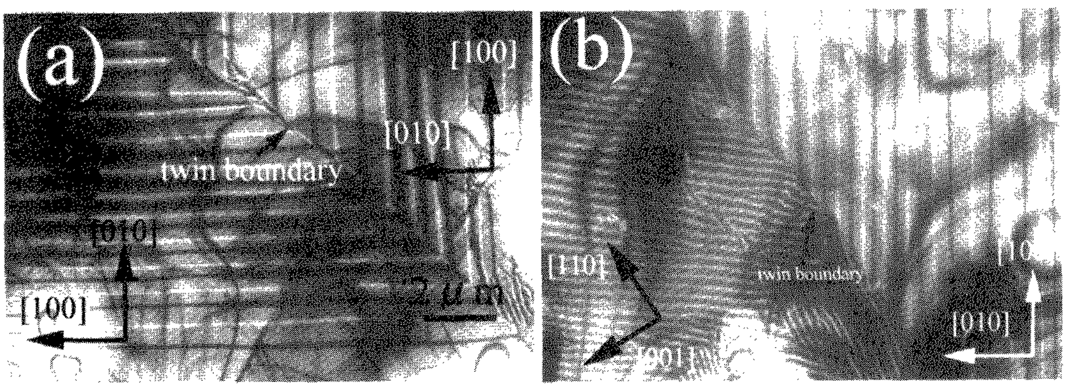

Figure 2; FM domain structure in the FI insulator phase of $La_{0.88}Sr_{0.12}MnO_3$. The images (a) and (b)are taken at 17K, respectively.

the FM domain walls. On the other hand, the boundary indicated by an arrow (A) in Fig.2(a) corresponds to the twin boundary, which appeared in the trigonal structure with the space group P1. The twin boundary is almost parallel to the (110) plane, where the indexes are based on the high-temperature orthorhombic structure with the space group Pbnm. As evident in Fig.2(a), the FM domain walls are almost parallel to the [100] direction. In addition, it is found that a different type of the FM domain structure appears in the FI phase. Figure 2(b) also shows a FM domain structure in the FM insulator phase at 17K. In the right side of Fig.2(b), the large plate-shaped FM domain structure, which is identical to that in Fig.2(a), can be seen. In addition, the stripe-shaped FM domain structure appears in the left side. We checked the crystal structure in the region, where the stripe-shaped FM domain structure appears, by obtaining the electron diffraction pattern. As a result, it is understood that the stripe-shaped FM domain structure exists in the a-c plane and the FM domains elongate along the [111] direction. The boundary indicated by an arrow is identified as the twin boundary. From these experimental results, it is found that two different types of the FM domain structure appear in the FI phase of $La_{0.88}Sr_{0.12}MnO_3$. One is the large plate-shaped FM domain structure with the micron size in width and the other is the wavy stripe-shaped FM domain structure with the several hundreds nanometer size in width. These FM domain structures depend strongly on the crystal structure.

In order to examine the orientation of the magnetic moment in the FM domain structure, the Foucault observation mode was used. Figure 3 is an image obtained by using one of the two split-out electron beam spots, which is called the Foucault image. Note that a split-out of the direct electron beam is shown in Fig.3(b). The split-out of the direct electron beam is caused by the Lorentz force in the each FM domains. In the Foucault image, the FM domain in itself gives rise to the bright and dark contrast. As shown in Fig.3, the plate-shaped

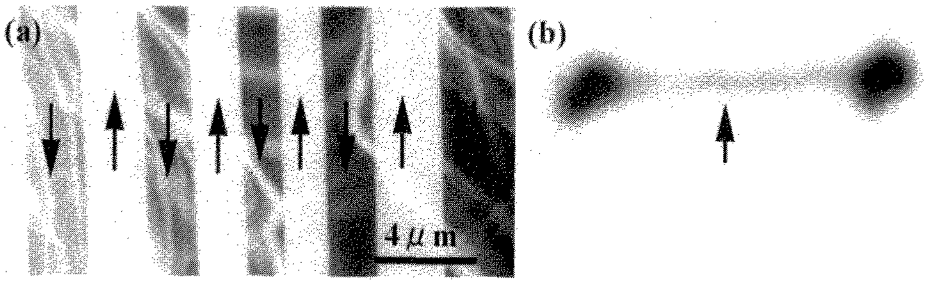

Figure 3: (a)FM domain structure obtained at 80K by the Foucault observation mode. Arrows show the direction of the magnetization in each FM domains. In (b), split-out direct beam spots are shown. An arrow shows the presence of the characteristic diffuse streak.

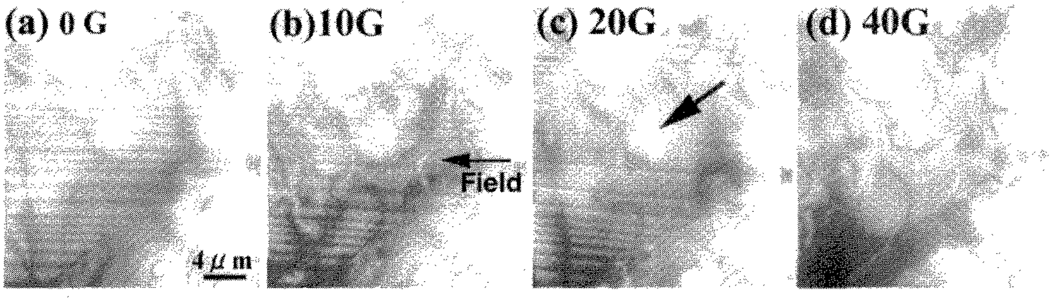

Figure 4: Change in the FM domain structure with the application of the magnetic field. The magnitude of the applied magnetic field is (a) 0 gauss, (b) 10 gauss, (c) 20 gauss and (d) 40 gauss, respectively. All the images are taken at 80K, respectively.

FM regions with the bright and dark contrast arrange alternatively. We analyzed both the image contrast and the way of the split-out of the direct beam shown in Fig.3 and determined the orientation of the magnetic moment in each FM domains. Arrows in Fig.3 show the orientation of the magnetic moment in each FM domains. As shown in Fig.3, the magnetic moment in the neighboring FM domains is oriented in the opposite direction. That is, the FM domain structure shown in Fig.3(a) is characterized as the 180 degree FM domains. In addition, characteristic diffuse scattering between the split-out electron beam spots is found, as indicated by an arrow in Fig.3(b). This means that the type of the FM domain walls in the plate-shaped FM domain structure is identified as the Bloch-type domain wall.[5]. The plate-shaped FM domain structure should be identified as the 180 degree domain structure with the Bloch-type domain wall.

In order to elucidate change of the FM domain structure by applying the magnetic field, the real-time observation was carried out. Figure 4 shows change in the FM domain structure with the application of the magnetic field in $La_{0.88}Sr_{0.12}MnO_3$. When the magnetic field of 10 gauss is applied to the plate-shaped FM domains, firstly the separation between each FM domains is spread out. On further applying the magnetic field of 20 gauss, the FM domains with the magnetic moment parallel to the applied magnetic field start to increase at the expense of the FM domains with the opposite magnetic moment, as shown by an arrow in Fig.4(c). Finally, the multiple FM domains changed into the single one by applying the small magnetic field of 40 gauss.

4. SUMMARY

We succeeded in observing the FM domain structure in the CMR manganite, $La_{0.88}Sr_{0.12}MnO_3$, by the low-temperature Lorentz microscopy. We found the two types of characteristic FM domain structure in the FI phase of $La_{0.88}Sr_{0.12}MnO_3$. One is the large plate-shaped MD structure consisting of the 180 degree domains with the Bloch-type magnetic walls. This FM domain structure changes easily into the single domain by the application of the magnetic field. The other is the wavy stripe-shaped FM domain structure with the several hundreds nanometer scale, which is elongated along the [111] direction. The FM domain structure depends strongly on the crystal orientation.

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