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Analysis of Magnetic Phase Transformation in $La_{0.46}Sr_{0.54}MnO_3$ by Electron Holograpy

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Electron holography, by which the phase shift of the incident electrons is analyzed, visualizes the magnetization distribution in advanced magnetic materials [1]. But the phase shift arises from not only the magnetic field but also the electric field of the specimen. Therefore, for a precise observation of the magnetic microstructure, it is necessary to separate the phase shift due to the magnetic field from the original data. In this work, a method to extract the magnetic information from the reconstructed phase image of the hologram is introduced and it is applied to *in situ* observations of the magnetic phase transformation in $La_{0.46}Sr_{0.54}MnO_3$, which was fabricated by the two-stage solid-state reaction [2]. Electron holography experiments were carried out with a JEM-3000F transmission electron microscope, to which a special pole piece dedicated to observations of magnetic domains is attached [3]. The residual magnetic field at the specimen position is about 0.2mT.

The magnetization of $La_{0.46}Sr_{0.54}MnO_3$ is plotted as a function of temperature in FIG. 1. This specimen undergoes successive magnetic phase transformations; antiferromagnetic-to-ferromagnetic transformation near 200K, and ferromagnetic-to-paramagnetic transformation near 280K. Here we focus on the ferromagnetic-to-paramagnetic transformation. Figure 2(a) shows a conventional reconstructed phase image at 295K, where the specimen is in the ferromagnetic state. Although a large closure magnetic domain is visible, the phase shift due to the electric field is superposed in FIG. 2(a). If a reconstructed phased image is observed in the paramagnetic state (349K, FIG. 2(b)), the image provides only the phase shift by the electric field that is independent on temperature. Accordingly, the subtraction of FIG. 2(b) from FIG. 2(a) offers only the magnetic information. The result of the subtraction is given in FIG. 2 (c). Two closure domains are visible at c_1 and c_2 in FIG. 2(c), whereas that at c_2 is obscure in the conventional image of FIG. 2(a). This subtraction method was applied to the *in situ* observation of the ferromagnetic-to-paramagnetic transformation in $La_{0.46}Sr_{0.54}MnO_3$. As shown in FIG. 3, the region of the ferromagnetic phase (closure domains at c_1 and c_2) gradually shrinks with heating. In parallel, the distance of the white lines (contour lines), which reflects the magnetic flux density, is found to be widened due to the reduced spontaneous magnetization. It is interesting to see that the closure domain at c_1 splits into two parts (c_1 and c_1') with the same helicity of magnetic flux at 342K. These positions are presumably favorable centers for the closure domains, where lattic defects will play an important role to stabilize the closure domains.

References

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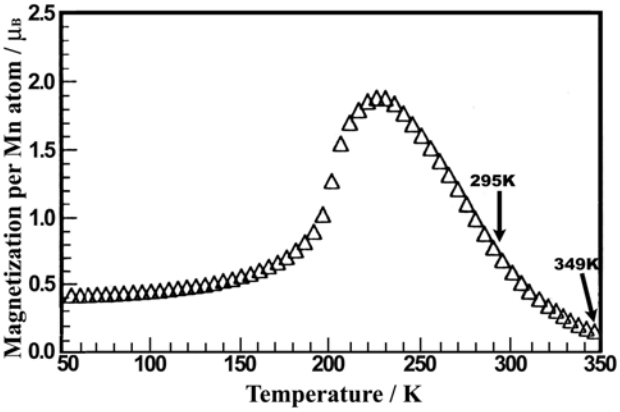

FIG 1. Temperature dependence of the magnetization in $La_{0.46}Sr_{0.54}MnO_3$ measured at the magnetic field of 1T.

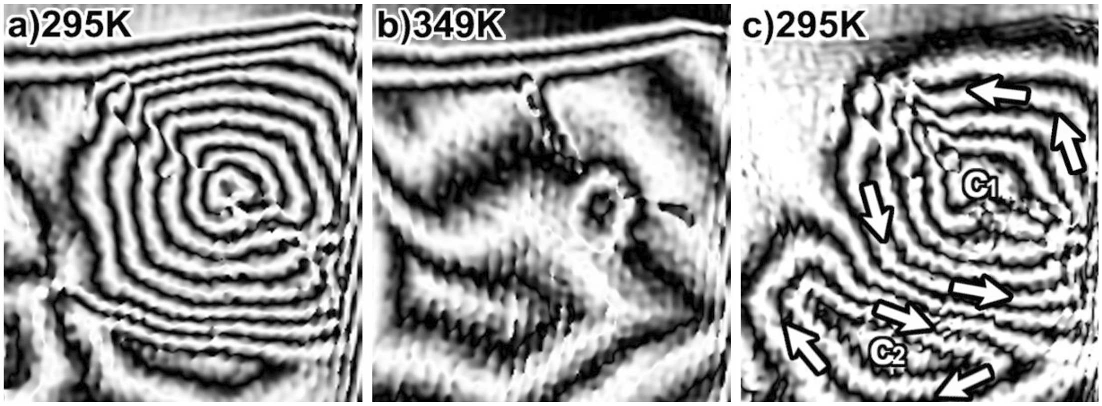

FIG 2. (a), (b) Conventional reconstructed phase images observed at 295K and at 349K, respectively. (c) Result of the subtraction of (b) from (a). Only the magnetic information is provided in (c). Arrows indicate the directions of the lines of magnetic flux.

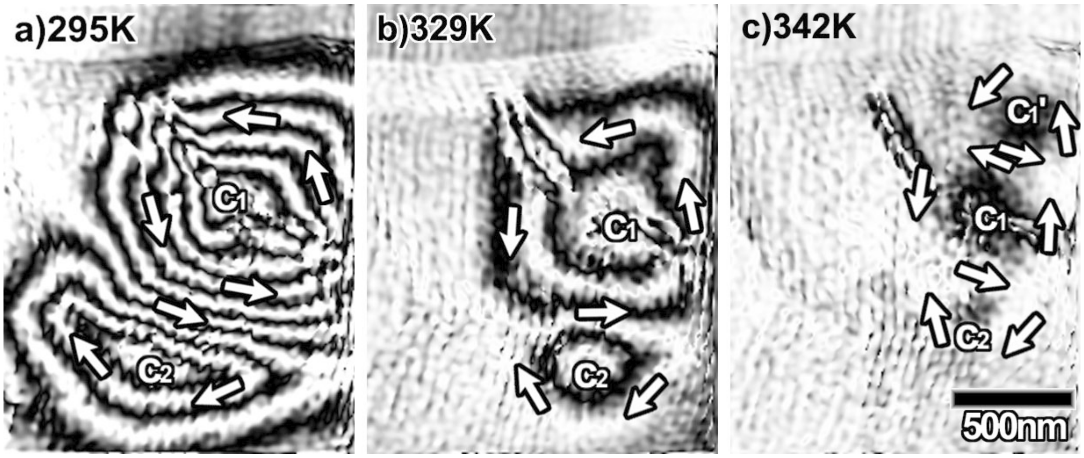

FIG 3. Change in the magnetic domains with the ferromagnetic-to-paramagnetic transformation. Observed at (a) 295K, (b) 329K, and (c) 342K, respectively.