Magneto-optical Kerr effect in laser-patterned $La_{2/3}Sr_{1/3}MnO_3$ epitaxial thin films

M. Bibes[a)]
Institut de Ciència de Materials de Barcelona, CSIC, Campus de la UAB, E-08193 Bellaterra, Spain and Laboratoire de Physique de la Matière Condensée, Institut National des Sciences Appliquées, Complexe Scientifique de Rangueil, 31077 Toulouse Cedex 4, France

D. Hrabovsky
Laboratoire de Physique de la Matière Condensée, Institut National des Sciences Appliquées, Complexe Scientifique de Rangueil, 31077 Toulouse Cedex 4, France

B. Martínez
Institut de Ciència de Materials de Barcelona, CSIC, Campus de la UAB, E-08193 Bellaterra, Spain

A. R. Fert
Laboratoire de Physique de la Matière Condensée, Institut National des Sciences Appliquées, Complexe Scientifique de Rangueil, 31077 Toulouse Cedex 4, France

V. Trtík and M. Varela
Department de Física Aplicada i Òptica, Universitat de Barcelona, Avinguda Diagonal 647, 08028 Barcelona, Spain

J. Fontcuberta
Institut de Ciència de Materials de Barcelona, CSIC, Campus de la UAB, E-08193 Bellaterra, Spain

In this study, we have performed magneto-optical Kerr effect (MOKE) measurement on epitaxial $La_{2/3}Sr_{1/3}MnO_3$ thin films containing artificial interfaces created by laser-patterning the $SrTiO_3$ substrate. The observed increase of the resistivity and of the high-field magnetoresistance when measuring the films across the interface arrays are related to the reduction of the magnetization of the interfaces with respect to the rest of the film. As observed by the local MOKE probe, the structural disorder in the manganite film induced by the underlying patterned substrate leads to a large spin disorder responsible for a strong high-field susceptibility of the resistance. [DOI: 10.1063/1.1362647]

I. INTRODUCTION

Magnetotransport measurements through artificial grain boundaries formed either by bicrystalline,[1,2] step-edged,[3] or laser-patterned[4] substrates have provided clear evidence that a large magnetoresistance (MR) develops at the interface. In this study, we report on magneto-optical Kerr effect (MOKE) measurements of arrays of artificial interfaces created on epitaxial $La_{2/3}Sr_{1/3}MnO_3$ (LSMO) thin films. One and five 40 μm wide track interfaces have been patterned by pulsed laser impacts onto single-crystalline strontium titanate substrates, and characterized by x-ray diffraction and various imaging techniques. By focusing the laser spot of the magneto-optical system and sweeping through the arrays, we explore the change of the local magnetic properties of the manganite film. It is found that the magnetization at the distorted regions is substantially reduced with respect to that of the film far from the interface. These results are discussed and correlated with magnetotransport measurements.

II. EXPERIMENT

A single-crystalline $10\,\mathrm{mm}\times 10\,\mathrm{mm}$ $SrTiO_3$ (STO) substrate has been patterned by a 248 nm pulsed laser beam focused through a $\times 25$ demagnifying Swarschild type objective. This allowed us to set the spot diameter to about 40 μm. Tracks were formed on the substrate by moving it with respect to the laser so as to form a 5 mm long track parallel to the [100] direction of the STO. The movement of the substrate during the patterning process was chosen so that the spot impacts overlap and define a continuous track. Single tracks and arrays of five parallel tracks were patterned on the same substrate.

After this step, a LSMO film 20 nm thick was deposited on top of the patterned substrate by pulsed laser deposition from a stoichiometric target.[5] The crystallographic quality of the film was checked by x-ray diffraction θ–2θ and ϕ scans. The film exhibited full in-plane and out-of-plane epitaxy. The rocking curve around the (002) reflection was as narrow as 0.01°.

Magnetotransport measurements were performed in the 10–350 K temperature range and with a applied field H up to 70 kOe in a Quantum Design PPMS. Previously gold pads were patterned by dc sputtering with the objective of reducing the contact resistance.

The Kerr effect measurements were performed in the 40–320 K temperature range by using an experimental setup we briefly describe below. The sample was located onto the cold finger of a cryogenerator coupled to a temperature con-

[a)]Author to whom correspondence should be addressed; electronic mail: bibes@icmab.es

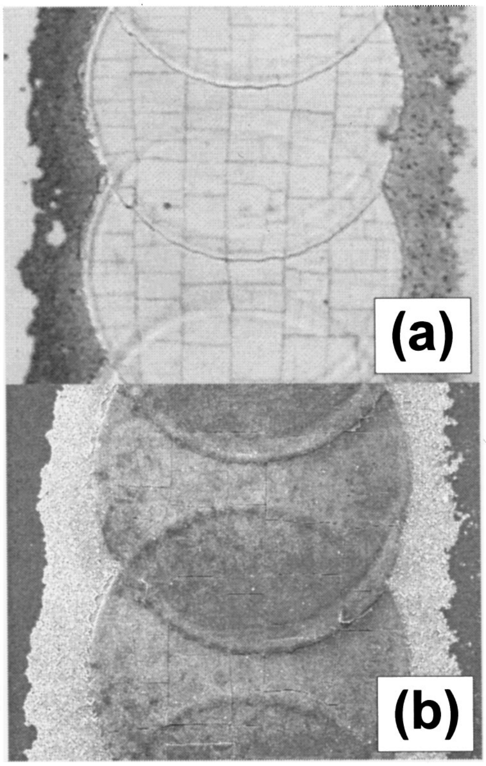

FIG. 1. Optical image of a 40 μm track in the $SrTiO_3$ substrate (a). SEM image of the same track in the LCMO film (b).

troller. The pressure in the experimental chamber was set to a primary vacuum and the pump was stopped during the measurements in order to limit the noise in the signal. Two glass windows allowed us to point the beam of a linearly polarized He–Ne laser at the sample and to retrieve the reflected beam whose two orthogonal polarization components were separated by a Wollaston bisprism. The intensity of these two outcoming beams was read by two photodiodes and the difference between the two signals was recorded as a function of the magnetic field (applied in the plane of the film). This signal difference–the Kerr signal–is proportional to the Kerr angle and thus to the magnetization. For each Kerr cycle, the intensity of the reflected beam was also recorded and used to normalize the Kerr signal. This allowed us to cancel the effect of variations in the sample surface reflectivity.

In order to characterize different regions of the sample, the laser focusing system was coupled to a micrometric positioner which allowed us to move the spot with a precision of about 20 μm.

III. RESULTS

Figure 1(a) shows an optical image of a $SrTiO_3$ substrate after the patterning of a 40 μm wide track but prior to the manganite film deposition. Regular cracks roughly parallel to the [100] and [010] directions of the STO can be observed inside the damaged area while on the sides a region about 3 μm wide appears to present a high structural disorder.[4] The overlapping between each laser impact is about 25% and guarantees the continuity of the track. After the deposition of

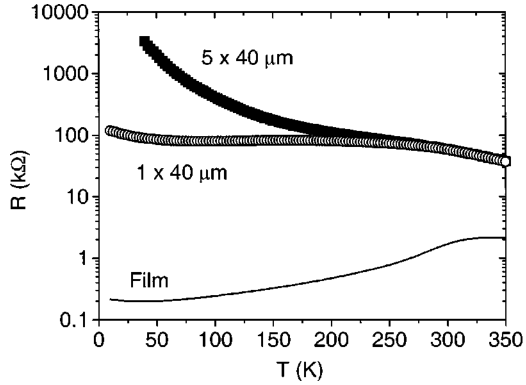

FIG. 2. Temperature dependence of the resistance of the film, a 10 μm track, and an array of five 40 μm tracks.

the manganite layer, scanning electron microscopy (SEM) was used to image the film. Figure 1(b) displays details of the 40 μm wide track. One important point is that the features observed for the substrate are reproduced in the manganite film, especially the oriented cracks and the debris zone on the sides. We expect the crystallographic disorder in these regions to be high both in the STO and the LSMO. If so, the magnetic and transport properties of the manganite should be greatly affected since this material is extremely sensitive to structural modifications.[6]

We now pass on to the transport characterization of the tracks. Figure 2 shows the temperature dependence of the resistance of the film, of one 40 μm wide track and of an array of five 40 μm wide tracks. Where the film shows the typical metal-to-insulator transition ($T_p \approx 320\,\mathrm{K}$), this feature is almost washed out for the 40 μm wide track, whereas the five 40 μm wide track array is insulating down to the lowest temperature at which it could be measured. At low temperature, the presence of one 40 μm wide track in the current path increases the resistance nearly 4 orders of magnitude. This proves that in the track, regions with very high resistivity are present.

Figure 3 collects data from resistance versus field measurements performed at 70 K. The film shows a low (about 12%) high-field magnetoresistance (HFMR) and no low-field magnetoresistance (LFMR). This indicates that the magnetic disorder is small and confirms the good quality of epitaxy.

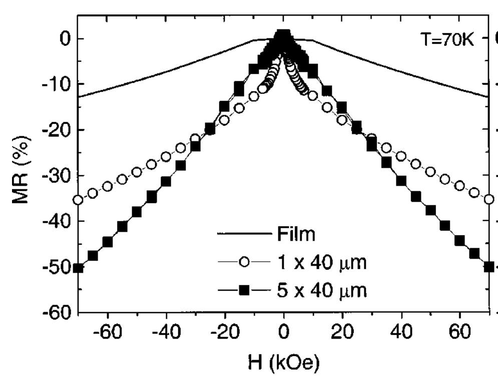

FIG. 3. Field dependence of the magnetoresistance of the film a 40 μm track, and an array of five 40 μm tracks at 70 K.

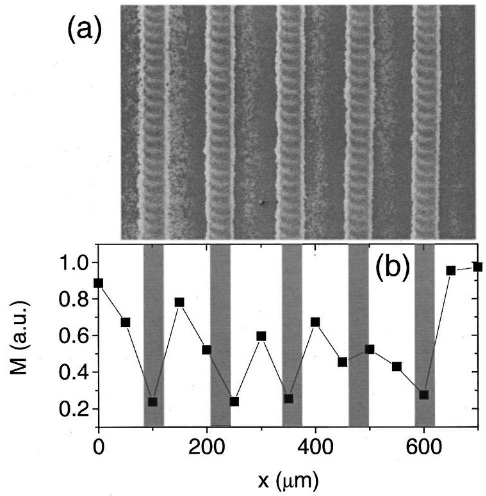

FIG. 4. SEM image of the five 40 μm tracks array (a). Kerr signal in function of the laser spot position on the film (b).

When measuring through the 40 μm-wide track, a substantial LFMR (some 10%) develops, accompanied by a rather strong HFMR (35% at 70 kOe) and high-field susceptibility $\partial MR/\partial H \approx 2.5\times10^{-3}\,\mathrm{Oe}^{-1}$. For the array of five tracks, the LFMR is nearly absent but the HFMR is even larger (50% at 70 kOe) with $\partial MR/\partial H \approx 6.5\times10^{-3}\,\mathrm{Oe}^{-1}$. This huge increase of the HFMR related to the presence of tracks on the current path show that in these regions the spin disorder is very large. As observed in ceramic samples with different grain sizes,[7] when the structural disorder increases, the magnetic disorder is larger leading to a strong high-field susceptibility of the resistance.

In order to quantify this magnetic disorder, we have performed MOKE measurements. After setting the system at 150 K, we have swept the spot across the array of five 40 μm wide tracks. We started the measurement at some 100 μm from the first track and moved the spot with a step of 50 μm. In the hysteresis cycles obtained, the magnetization in the track is always smaller than that measured far from the array, at any field value. In Fig. 4(b) we plot the value of the normalized Kerr rotation at remnance. An almost periodic oscillation of the Kerr signal is obtained and the curve shows well-defined peaks closely coincident with the tracks position. This can be appreciated by comparing the position of the tracks in a SEM of the array [Fig. 4(a)] and the Kerr-signal spot position dependence [Fig. 4(a)].

This decrease of the magnetization inside the tracks indicates that the magnetic disorder is high. This has to be related to the observed structural disorder and magnetotransport properties. Indeed, the structural modifications induced by the laser patterning on the substrate appear to be also present in the manganite. As revealed by the Kerr effect measurements, the magnetization inside these regions is smaller than outside them (in the film). This has to be explained by the presence of noncollinear spins that prevent a good propagation of the double-exchange ferromagnetic coupling. Similarly, the subsequent magnetic disorder enhances the resistivity of the tracks and increases the high-field susceptibility.

IV. CONCLUSION

In summary, we have shown that laser-patterned artificial interfaces induce a large increase of the resistivity and magnetoresistance of $La_{2/3}Sr_{1/3}MnO_3$ thin films. The magnetization of the patterned region has been probed by Kerr effect measurement and was found to be clearly lower than that of the rest of the film. We have related this result to transport data and argued that in these regions the ferromagnetic coupling is weakened and the spin disorder is large, which leads to an increase of the resistivity and of the high-field magnetoresistance.

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