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Novel low-field magnetoresistive devices based on manganites

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Abstract

We present novel low-field magnetoresistive devices based on the ferromagnetic manganite $La_{0.7}Sr_{0.3}MnO_3$ operating in the current in plane (CIP) configuration. In these planar spin-valve devices, a focused Ga^+ beam is used to create pinning centers for magnetic domain walls. The spin-dependent scattering of polarized electrons at the domain walls (DW) is responsible for the magnetoresistance observed in the patterned tracks. The magneto-transport properties of these devices are interpreted within a model for DW magnetoresistance. Applications such as magnetic data storage can be envisaged for the structures we investigated.

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Keywords: Spin polarized transport; Nanoscale contacts; Magnetic devices

1. Introduction

The doped-perovskite manganites exhibit large negative magnetoresistance [1] (MR) in high magnetic field (several Tesla). In order to make these materials of practical utility, alternative approaches have been explored to achieve MR effect in low-magnetic field. Among them, the spin-dependent tunneling across a thin insulating barrier [2], and the spin-dependent transmission of polarized electrons across a DW [3].

The MR of devices working in current perpendicular to plane (CPP) mode depends on extrinsic factors such as interface quality, surface roughness, quality of the magnetic state of the manganite surface, etc., that limit their reproducibility. A way to overcome this problem is to fabricate planar artificial devices that rely on the electrical resistance exerted by a constrained DW. These planar artificial devices are characterized by the absence of any interfaces and large MR ratio is achievable in current in-plane (CIP) configuration. Here, we present electrical measurements carried out on $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) nanostructures patterned by focused ion beam (FIB). In these devices, two DWs are pinned by nanoconstrictions at the border of a nanobridge and are responsible of the measured MR.

2. Experimental

The devices were fabricated from epitaxial 100 nm thick LSMO films deposited by RF magnetron sputtering on (1 1 0)-oriented $SrTiO_3$ (STO) substrates. We chose to use (1 1 0)-oriented substrates in order to achieve a stress-induced in-plane anisotropy that makes the hysteresis loop sharper when the external field is applied along the [0 0 1] easy axis. Detailed fabrication process and structural and magnetic characterizations have been presented elsewhere [4,5].

The films were patterned into 5 μm wide, 100 μm long tracks parallel to the easy magnetization axis (Fig. 1a) by standard UV lithography and argon (Ar)-ion milling. The pattern provides any track with connections and contact pads for standard four-points current–voltage (*I–V*) and resistance (*R*) measurements. The samples were then

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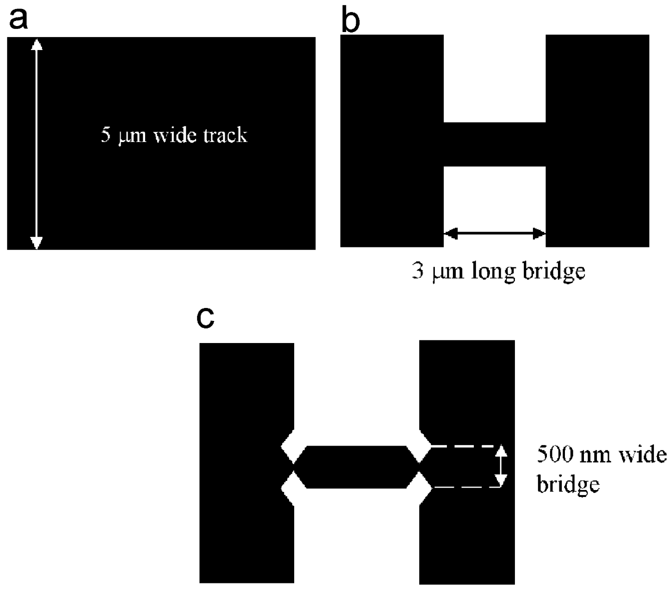

Fig. 1. Schematic of the fabrication process: (a) argon-ion milling of 5 μm wide tracks, (b) FIB milling of 3 μm long, 500 nm wide bridges and (c) FIB milling of nanoconstrictions at the bridge borders.

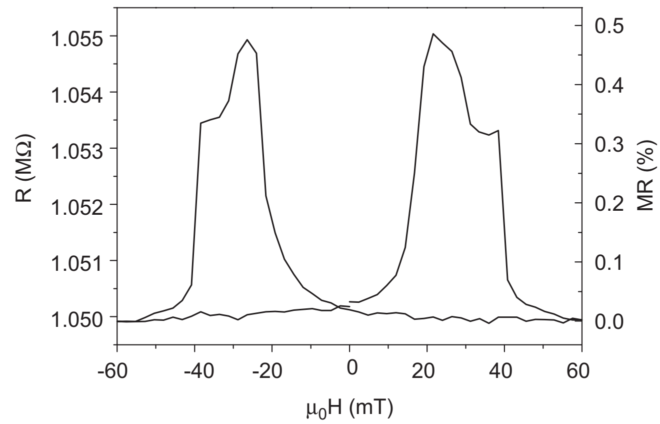

Fig. 2. CIP-*R(H)* at $T = 4.2\,\mathrm{K}$ of a patterned bridge with nanocontrictions.

processed in a dual-beam FIB/SEM with gallium (Ga) ion source. The tracks were narrowed down to 500 nm with a beam current of 10 pA to achieve nanobridges 3 μm long (Fig. 1b). The sidewalls of the nanobridges were then cleaned with a beam current of 1 pA. This makes the sidewalls more vertical due to the smaller spot size and removes excessive Ga implantation. The aspect ratio ($3 \times 500\,\mathrm{nm}$) of the narrowed bridges was chosen so as to have a pinning effect by shape anisotropy after the patterning with 1 pA beam current of two constrictions 30–50 nm wide at the bridge borders (Fig. 1c).

3. Results and discussion

Fig. 2 shows the resistance vs. field $R(H)$ recorded at $T = 4.2\,\mathrm{K}$ with the field H applied parallel to the track. Starting from $H = -60\,\mathrm{mT}$, the resistance have a sharp increase at $H = +20\,\mathrm{mT}$, which is the measured coercive field of the unpatterned LSMO film. This first phase corresponds to the reversing of the magnetization in the regions outside the central bridge, the latter having higher reversing field because of the geometrically induced shape anisotropy. The amplitude of the change of R is too large to be attributed to anisotropic magnetoresistance (AMR), which is measured to be, in the field of interest, 0.1% in our films [4]. Moreover, the AMR effect in epitaxial films is smooth and lacking of switching features.

The sharpness and the amplitude of the increase of R suggest that the two DWs formed at the nanoconstrictions are responsible for the detected change of R. Since the nanoconstriction is shorter than the unconstrained DW width, the DW will be similar in size to the nanoconstriction [6]. Also, the wall will tend to be pinned in the constriction. The narrower the DW, the exponentially larger the magnetoresistance (MR) that can be observed. When the DW becomes thin enough, such that the conduction-electron spins cannot follow completely the local magnetization direction, the DW exerts an additional resistance on a spin-polarized current passing through[7]. This is consistent with the smaller (~0.1%) MR measured at the same temperature on the devices with 50 nm wide constrictions.

This first increase is followed by two decreases. This seems to indicate that the depinning of the two previously formed DWs is not simultaneous. This behavior is partially due to the difference in effective in-plane anisotropy constant $K_\perp$ in the bridge and connecting arms. This constant incorporates both the anisotropy term due to spin–orbit interaction and the effect of demagnetizing field. The field is more efficient in depinning the DW that is pushed towards the connecting arm (lower coercivity zone) rather than that is pushed towards the bridge (higher coercivity zone). This is not surprising and well demonstrated in Ref. [8]. It is important to notice that the unsimultaneous depinning of the DWs is possible because of the size of the bridge, which is too big to form a single domain.

The *R(H)* curve in Fig. 2 is not symmetric. The switching fields seem to depend on the relative directions of biasing current and external-applied field. The reason of it is likely to be a different contribution of the polarized-biasing current in the depinning of the two DWs (DW dragging effect). Further investigations are going to be carried out to clear it up.

4. Conclusion

We have fabricated planar pseudo-spin-valve devices based on mechanically stable double constrictions. The devices show magnetoresistance that we attributed to spin scattering of polarized electrons at the geometrically constrained DWs. A DW-dragging effect is at play in the devices. This effect is of great interest because it could be exploited to switch the logic state of artificial planar spin-valves used as bit cells in magnetic non-volatile random access memories.

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