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Local magnetoresistance of nanoconstrictions

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Abstract

In this paper, we investigate the local magnetoresistance of nanoconstrictions fabricated on thin magnetic films by e-beam lithography. The magnetoresistance is measured using electrostatic force microscopy (EFM) with tens of nanometer spatial resolution. We found a large positive MR within hundreds of nanometers around the constriction, if we go away from the constriction about 2 μm, a negative MR appears on both sides of the constriction. Therefore, by ordinary MR measurements through electric pads separated several or tens of micrometers it is almost impossible to detect the MR of a constriction because the addition of these two kinds of MR cancelled the contribution from the constriction.

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Keywords: Conductivity; Atomic force and scanning tunneling microscopy

1. Introduction

Because of many possibilities of application to devices, a large magnetoresistance (MR) has been searched during the past decades. In particular, much attention was given to the giant magnetoresistance (GMR) in magnetic multilayers [1,2]. In Atomic nanocontacts ballistic magnetoresistance (BMR) up to 300% was observed [3]. Also very large values of BMR values have been measured at room temperature in nanocontacts grown by electrodeposition [4–7]. These large values have been argued as being due to the movement of the contact under the application of a magnetic field [8]. Despite the stability and large values of BMR of this type of contacts, their structure and configuration make them difficult to integrate into a solid state commercial device. New efforts are oriented to reproduce such results in planar nanoconstrictions produced by e-beam lithography and thin film deposition [9]. From the measurements of these samples we found that the MR is the result of the cumulative effect of positive and negative MR contributions from different areas of the sample. In other words, the magnetoresistance of a sample measured between two point separated microns from the constriction, (Fig. 1(a)), does not tell us as to whether the MR is produced by a nanoconstriction or nanocontact is.

2. Measurements

The nanoconstrictions studied in this work were fabricated by a combination of optical and e-beam lithography. We use a simple bi-layer lift-off process in which we employ a double layer of a positive resist deposited by spin-coating techniques. For the bottom layer, LOR 3A 30% in weight was spun for 60 s at 2000 rpm. Subsequently, the resist was baked for 20 min in an oven at 180 °C. For the top layer, 2.5% PMMA 2041 was spun at 1800 rpm for 60 s. To generate the pattern, the sample was exposed using e-beam writer VB6 from Leica Cambridge Ltd at 100 keV and the employed dose ranged from 500 to 2000 μC/cm^2.

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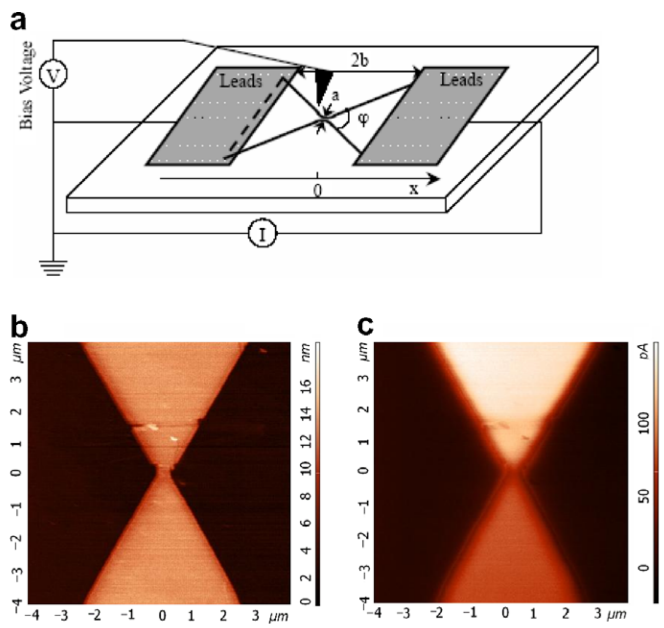

Fig. 1. (a) The schematic diagram of the experiment and sample in our investigation. (b) Typical topography of the sample is measured by atomic force microscopy. The constriction width is 220 nm and the thickness of the film is 11 nm: (c) The EFM image is measured at a 0.6 mA current. The contrast of the image clearly indicates the potential drop through the sample.

Subsequently a wet development step was carried out for 60 s in a 3:1 mixture of isopropyl alcohol: Methyl Isobutyl Ketone (IPA:MIBK) and flushed in IPA, then put in a 3:2 mixture of the developer CD26 and DI water for 60 s. The sample is finally flushed in DI water and dried with nitrogen. The typical geometry of the sample is shown in Fig. 1(b), measured by atomic force microscopy (AFM). The constriction is formed by two opposite triangles, thickness of the film is 11 nm, and width of the constriction is around 200 nm.

The schematic diagram of the experiment and sample structure is shown in Fig. 1. One end of the sample is connected to the ground of the atomic force microscope (AFM), and a constant voltage is applied to the cantilever. Electrostatic force microscopy (EFM) [10,11] uses a two-pass scanning mode to get the topography and the electrostatic force image at the same time. Fig. 1(c) shows the EFM image when passing a 0.6 mA current through the sample; the potential drop through the constriction is seen clearly.

Typical curves of the resistance as a function of the applied field (H) are shown in Fig. 2. The resistance is measured while applying a constant current of 0.2–2 mA and the magnetic field is applied on the plane of the film and perpendicular to the current. Fig. 2 shows the typical MR curve for the sample. These measurements were performed at RT (top of Fig. 2) and at 80 K (bottom) so that we can discard any possible leak of current through the Si substrate. The magnetoresistance here is estimated to be only about 1%. But the resistance is measured from the

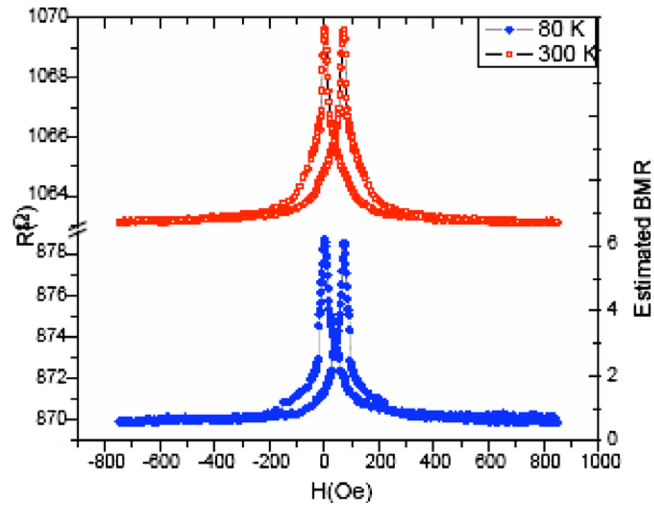

Fig. 2. Magnetoresistance of the sample is measured from the pads separated 8 μm for each other. Measurements at room temperature (red line) and low temperature (blue line) give a similar result of about 1% MR. (For interpretation of the references in colour in this figure legend, the reader is referred to the web version of this article.)

electric pads separated by 8 μm; it is incorrect to attribute this MR to the nanoconstriction. The domain wall MR of the nano constriction is complicated; both positive and negative MR experiments have been reported and explained theoretically. So it is very important to locate the MR measurement into a small area of a nanometer size.

The EFM technique has provided us with the ability to measure the MR located very near the constriction [12]. EFM is operated continuously with and without an external magnetic field. The passing current is kept at 0.6 mA. The magnetic field is 300 Oe in plane and perpendicular to the constriction. The potential drop along the symmetrical line with (blue line) and without (black line) a field is shown in Fig. 3(a). The curves here are the average of 10 consecutive measurements. In order to make out the difference in the two curves more obvious, we subtract the curve without the field from that with the field and smoothen out the fluctuations. The result is plotted in Fig. 3(b). We noticed that the difference around the constriction was very big and had a resonant shape. A Large positive MR takes place just around the constriction. Next to the constricition MR is negative on both sides, which concealed most of the constriction the MR if we measure from the pads. The MR estimated from Fig. 3(b) could be 66% between −300 nm and 300 nm around the constriction. This is a large value, especially taking into account that the constriction is 220 nm wide. If we look at this point more than 2 μm away from the constriction, the MR is too small to be measured by this technique because of the noise.

3. Discussion

The reason for the coexistence of positive and negative magnetoresistances should be searched from the domain