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Lithography-free study of spin torque

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ABSTRACT

We developed a non-lithographic technique to contact sub-100 nm nanowires for spin transfer torque experiments. Co/Cu multilayers were grown by electrodeposition in nanoporous commercial polycarbonate membranes from a Co/Cu bath. A home-made sample holder allows bottom and top electrical contacts to be made to individual nanowires in the CPP geometry. Experimental evidence of the spin transfer torque effect is given for $(Co/Cu)_n$ multilayers by recording d*V*/d*I* spectra as a function of the DC current amplitude.

1. Introduction

As predicted by Slonczewski [1] and Berger [2] in 1996, a spin polarized current can transfer its angular momentum to a ferromagnet, inducing a torque on its magnetization. Thereby, the magnetic moment can switch to another stable state or oscillate around its equilibrium position at microwave (MW) frequencies. This phenomenon, known as spin transfer torque (STT), is extremely interesting for its potential applications in the fields of data storage and current-driven MW oscillators.

The high current density required for STT necessitates study on nanoscaled objects, implying many technical issues. In the last few years, the most widely used technique for fabricating nanostructures for STT studies is sputtering deposition followed by e-beam lithography [3–6]. These procedures allow high-quality nanopillars to be obtained and electrically contacted in the current-perpendicular-to-plane (CPP) configuration. Nevertheless, the use of ultra-high vacuum techniques and lithography makes the sample synthesis a complicated and expensive process. Alternative processes have been proposed, like point contact geometries on evaporated films [7] or template synthesis [8]. In the latter case, electrical contacts are typically achieved with a nanoindentor.

In this work we propose an original technique for STT experiments on multilayered nanostructures. Nanowires are synthesized by electrodeposition and electrically contacted without the use of any lithography processing or point contact technique. Fully available commercial materials and relatively simple procedures make the technique low cost and flexible. The proposed setup for STT effects is experimentally validated by recording the d*V*/d*I* of electrodeposited Co/Cu multilayers, as a function of the DC current amplitude. This technique opens up very attractive prospects to realize magnetoresistive devices connected in series from the perspective of phase-locking experiments.

2. Technique

Co/Cu multilayers are grown by electrodeposition in commercial ion-track-etched polycarbonate membranes of 6 μm in thickness [9,10]. The electroplating is performed in the conventional tree electrodes method. The membranes have sub-micron sized pores with a density of 6×10^6 pores/cm^2. The sample fabrication is realized as follows: we first sputter a gold layer on one side of the membrane. This metallic side of the membrane is then mounted on a metal pin. The system membrane/pin (sample holder) is isolated by a teflon cup and dipped into the electrolyte. The deposition in the pores is performed by connecting this sample holder to the working electrode of the electrochemical cell and applying the appropriate potential. Co/Cu structures are deposited from a single bath of 0.5 M/l $CoSO_4$, 0.01 M/l $CuSO_4$, and 0.7 M/l H_3BO_3. Cobalt and copper, having a different reactivity, can be alternatively deposited by changing the cell voltage. A cyclic voltammogram of the bath yields the optimized potentials of −0.3 and −1.0 V for the Cu and the Co, respectively. The deposition rates of both materials are calibrated by measuring the time to fill the membrane at these two potentials. Because of its higher reactivity, the Cu will be co-deposited with the Co. Its small concentration in the bath prevents the presence of too many impurities in the Co layers [11]. The Co layers were found to contain 15% of Cu [12].

The electrodeposition is stopped after Cu bumps have formed on the membrane surface, indicating the pores have been filled. The sample holder with the filled membrane is plugged into a standard SMA female connector and sealed by a metallic cup. This

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cup holds a screw with a soft gold wire (25 μm in diameter) soldered on its tip. When approaching the membrane with the screw, the gold wire moves across the surface until it contacts an individual nanowire. This system allows several different examples of the nanostructures to be contacted and studied in a single electrodeposited membrane sample. The setup geometry ensures the CPP configuration and the nanowire dimensions allow a current density as high as 10^7 A/cm^2, by the injection of fractions of a mA. Moreover, a proof of the microwave capabilities of the setup is given elsewhere, through a study of the STT-induced ferromagnetic resonance [13].

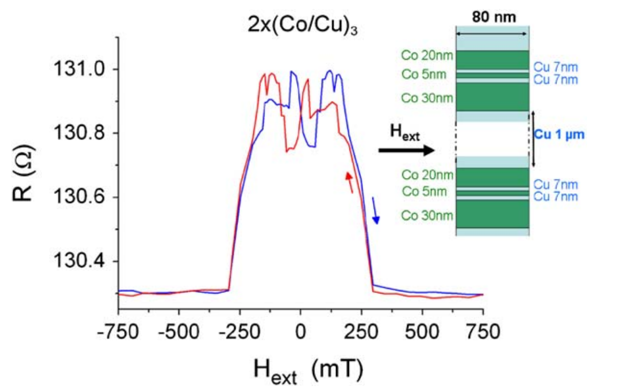

Fig. 1. Magnetoresistive curve of the double pentalayer nanowire for a magnetic field applied in the plane of the layers.

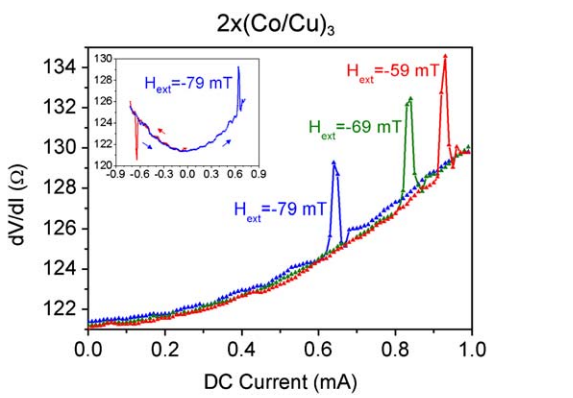

Fig. 2. dV/dI spectra of the Co/Cu pentalayer, as a function of the injected DC current. The spectra are registered for different values of H_{ext}. In the inset is reported a spectrum for positive and negative current slope. The inset units are the same as for the main graph. Data are shown upon return from cycling at negative current, as indicated in the inset.

3. Results

The described procedure for template synthesis allows the number of Co/Cu bilayers in a nanowire to be varied, from 2 up to few hundred. The flexibility in the sample fabrication and the simplicity of the contact procedure make the setup an interesting tool for STT studies. A convenient way to show the STT-capabilities of the setup is to record dV/dI spectra [7] of a nanowire, under high-density DC current. We performed the measurements on different multilayered structures, embedded in nanowires of 80 nm diameter. The first sample consists of two $Co_{30\,nm}/Cu_{7\,nm}/Co_{5\,nm}/Cu_{7\,nm}/Co_{20\,nm}$ pentalayers in series, separated by 1 μm of Cu (inset Fig. 1). A first characterization of the structure is given by its magnetoresistive curve in the CPP geometry for a magnetic field (H_{ext}) applied in the plane of the layers (Fig. 1). The structure presents a ΔR_{max} (difference between the resistances of the parallel and antiparallel configurations) of about 0.7 Ω, on a baseline resistance of 130 Ω. Note that the total resistance is mainly determined by the Cu nanowire, while the pentalayer resistance is only few Ohms.

The dV/dI spectrum of the sample has been recorded for different values of H_{ext}. The field is swept from negative to positive values, following the blue hysteresis curve of Fig. 1. The current range is limited by the heating of the nanowire.

For some critical current values we observe peaks, followed by a dV/dI baseline change, depending on the current direction (Fig. 2). Moreover, critical current amplitude is shown to depend on H_{ext}. In the investigated range of fields the critical current amplitude decreases when H_{ext} is increased. These are typical features of STT effects. Because of the complex geometry of our system the interpretation of this result is beyond the scope of this article, but the critical current behavior has to be related to both the amplitude of the external field and the relative orientations of the magnetic layers [14].

Similar experiments have been performed on 250 bilayers of $Co_{10\,nm}/Cu_{10\,nm}$ (Fig. 3a) and on a double pseudo-spin-valve structure (two $Co_{40\,nm}/Cu_{5\,nm}/Co_{5\,nm}$ trilayers, separated by 1 μm of Cu) (Fig. 3b). The results suggest the potential of this technique for investigating STT physics, as a function of the number of magnetic layers. In the case of 250 bilayers (Fig. 3a), we observe a complicated feature compared to the pseudo-spin-valve. This could arise from the broad distribution of switching fields [15] of

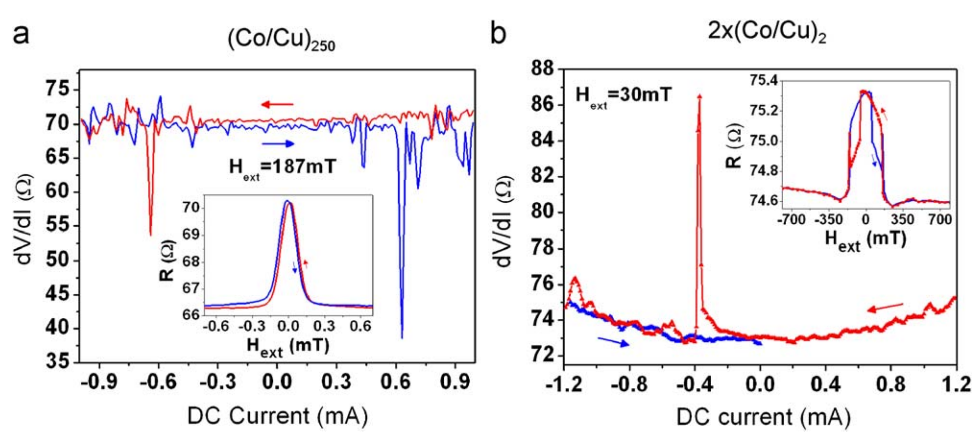

Fig. 3. dV/dI spectra as a function of DC current for (a) 250 bilayers of $Co_{10\,nm}/Cu_{10\,nm}$, (b) two $Co_{40\,nm}/Cu_{5\,nm}/Co_{5\,nm}$ pseudo-spin-valves separated by 1 μm of Cu. The two insets show the magnetoresistive curves of the two structures, for a magnetic field applied in the plane of the layers.

each layer and the complexity of the couplings among the layers. Nonetheless, the technique should be explored further since, as shown with the 250 bilayers, it allows making many nanostructures in series, with customizable layer thickness, separation distance and number of bilayers.

4. Conclusions

In conclusion, an original, simple and low-cost technique for STT experiments is presented. Template synthesis on commercial materials has been used to grow sub-100 nm multilayered nanostructures. A simple method for contacting nanowires is presented and validated by experimental evidence of the STT effect in Co/Cu pentalayers. The effectiveness of this technique for synthesizing and making electrical contacts on different structures is tested by showing d*V*/d*I* spectra of 250 (Co/Cu) bilayers. An important potential use for this technique is in growing and establishing electrical contacts to several microwave oscillators connected in series for phase-locked experiments.

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