Materials Science and Engineering B 126 (2006) 292–295

ENGINEERING
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Evidence of high dissipation in magnetization reversal processes of five Co/Cu bilayers

Santiago Serrano-Guisan *, Laurent Gravier, J.-Ph. Ansermet

Institut de Physique des Nanostructures, Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne-EPFL, Switzerland

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Abstract

Heat and charge transport perpendicular to the plane in five Co/Cu stacks are studied using AC temperature gradients in the presence of a DC current. Large peaks in AC voltage response versus applied field are observed. This effect, measured only in reversible magnetization reversal modes and at sharp values of magnetic fields, suggests that an extra dissipation process is produced at well-defined magnetic configurations.

Keywords: Thermoelectrics; Multilayer nanowires; Peltier effect

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1. Introduction

Giant magnetoresistance (GMR) [1–3] and magneto-thermoelectrical power (MTEP) [4] measurements in ferromagnetic layered nanostructures with the current perpendicular to the plane (CPP) geometry are usually performed to study spin-dependent transport [5–10]. GMR measurements reveal a spin accumulation process as they cross-magnetic layers whereas MTEP measurements express the spin asymmetry of the entropy carried by the charges [11]. However, just recently, the mixed effects of both currents have been measured in multilayered nanowires [12]. A new characterization was offered by monitoring an AC voltage induced by an oscillating heat source under a continuous charge current [12,13]. The observed response, called magneto-thermogalvanic voltage (MTGV) ratio, is much larger than GMR or MTEP ratios and can be accounted for as the contribution of the Peltier effect, produced at Co/Cu interfaces, to the overall resistance [13]. It implies that MTGV brings out information about the heat sink or source mechanisms involved at interfaces as we force carriers to cross them. Thus, MTGV may measure the spin relaxation processes experienced by conduction electrons at interfaces.

In order to gain a better understanding of these measurements with well-defined magnetic configurations, we present in this paper a study of the thermoelectrical properties of five Co/Cu bilayers nanostructures. Sharp and large responses at given fields have been observed in MTGV measurements. These peaks occur only at reversible magnetization modes, indicating enhanced losses at specific magnetic configurations.

2. Experimental

The samples are produced by electrodeposition techniques in tracked–etched polymer membrane templates [14,15]. The pores are typically 6 μm long and with an average diameter of 50 nm. Gold layers are sputtered on both side of the polymer membrane. Monitoring the potential between both gold layers in electrodeposition process allow us to limit the contact to a single nanowire [16]. We consider five bilayers of Co/Cu (5BL) of 10 nm each layer in a homogeneous Cu nanowire.

Three different measurement protocols were performed on these samples: (1) GMR measurements by conventional detection of the AC voltage due to an AC current source. (2) MTEP measurements by lock-in amplifier detection using a laser beam as an oscillatory heat source. (3) MTGV measurements that consist in measuring an AC voltage associated with the oscillatory heat source (∼22 Hz) as a function of an applied DC current.

3. Results

We performed GMR and MTGV measurements in 5BL samples. The external magnetic field is applied perpendicular and parallel to the wire axis (Figs. 1 and 2). GMR measurements (∼0.8% of GMR ratios) show that Co layers have a well-defined planar anisotropy. Thus, at perpendicular external magnetic fields we observe five different plateaux in resistance

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[*] Corresponding author. Tel.: +41 21 693 4523; fax: +41 21 693 3604.
E-mail address: santiago.serranoguisan@epfl.ch (S. Serrano-Guisan).

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doi:10.1016/j.mseb.2005.09.028

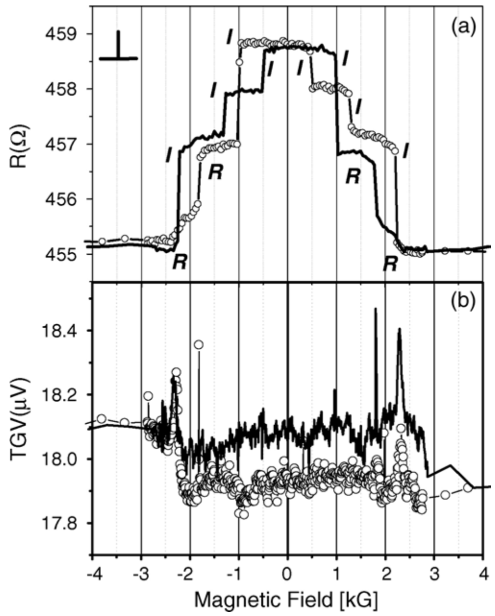

Fig. 1. GMR (a) and MTGV (b) measurements of a 5BL sample when magnetic field is perpendicular to the wire axis. Open dots (line) indicate(s) field sweep up (down). We observe five plateaux in resistance corresponding to five well-defined magnetic configurations. "R" ("I") refers to a reversible (irreversible) magnetization reversal mode of each jump of resistance. GMR ratio ∼0.8% whereas MTGV ratio of peaks ∼1.7%.

corresponding to five different magnetic configurations (Fig. 1a) whereas at parallel magnetic fields a typical magnetoresistance profile corresponding to homogeneous reversal magnetization process is observed (Fig. 2a). Minor loop measurements of magnetoresistance have been performed for both magnetic orientations. The reversible (R) or irreversible (I) character of each jump resistance is noticed in Figs. 1a and 2a. MTGV responses (Figs. 1b and 2b) show a roughly flat profile at both magnetic field orientations (plateau regime) that can be understood as a weak contribution to the spin-dependent Peltier effect [13] of 5BL structures. This regime is modified by the presence of

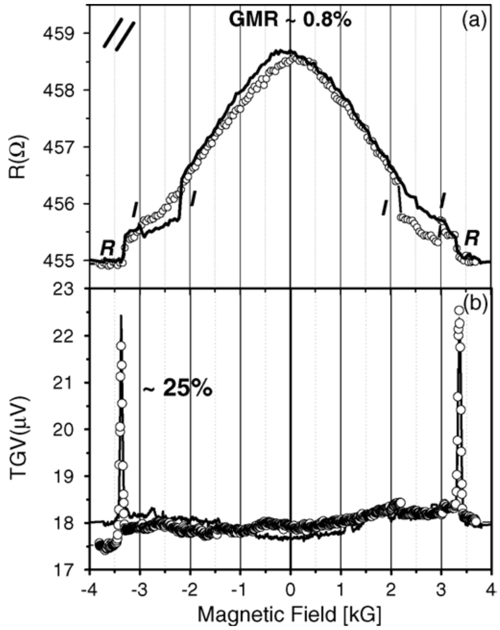

Fig. 2. GMR (a) and MTGV (b) measurements of a 5BL sample when magnetic field is parallel to the wire axis. Open dots (line) indicate(s) field sweep up (down). (a) "R" ("I") refers to a reversible (irreversible) magnetization reversal mode of each jump of resistance. (b) MTGV measurement shows much larger peaks than in perpendicular magnetic field orientation (MTGV ratio of peaks ∼25% !!!). These peaks are observed at ±3.35 kG.

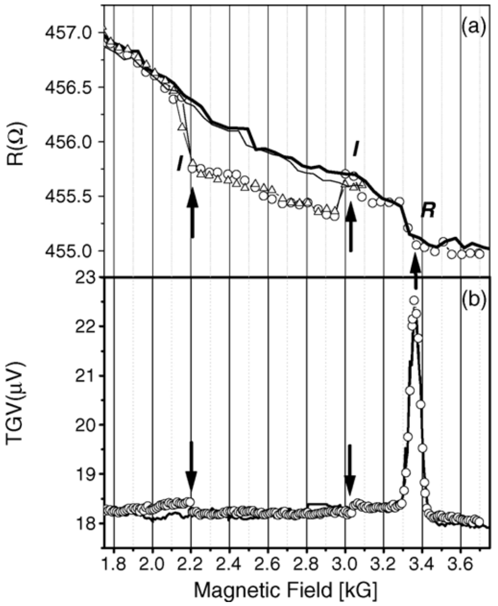

Fig. 3. Detailed picture of Fig. 2 (magnetic field from 1.75 to 3.75 kG). Open dots (line) indicate(s) field sweep up (down). (a) Two irreversible jumps ("I") of resistance are observed for 2.2 and 3.0 kG. Open triangles (thin line) indicate(s) field sweep up (down) for the second irreversible jump. (b) MTGV peak is observed at the reversible magnetization mode ("R") for ∼+3.35 kG. (c) Amplified picture of MTGV measurement at magnetic field values corresponding to the two irreversible jumps of resistance.

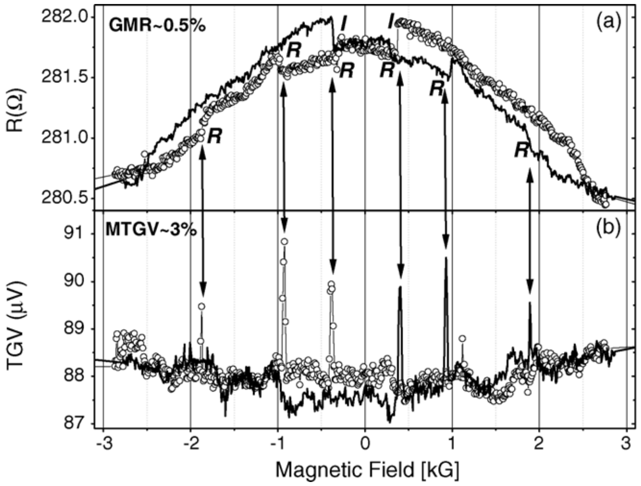

Fig. 4. Example of GMR (a) and MTGV (b) measurements for other 5BL sample at parallel magnetic field orientation. Open dots (lines) indicates field sweep up (down). "R" ("I") refers to a reversible (irreversible) magnetization reversal mode of each jump of resistance. Sharp and large peaks (∼3%) are observed at magnetic fields involving only reversible modes.

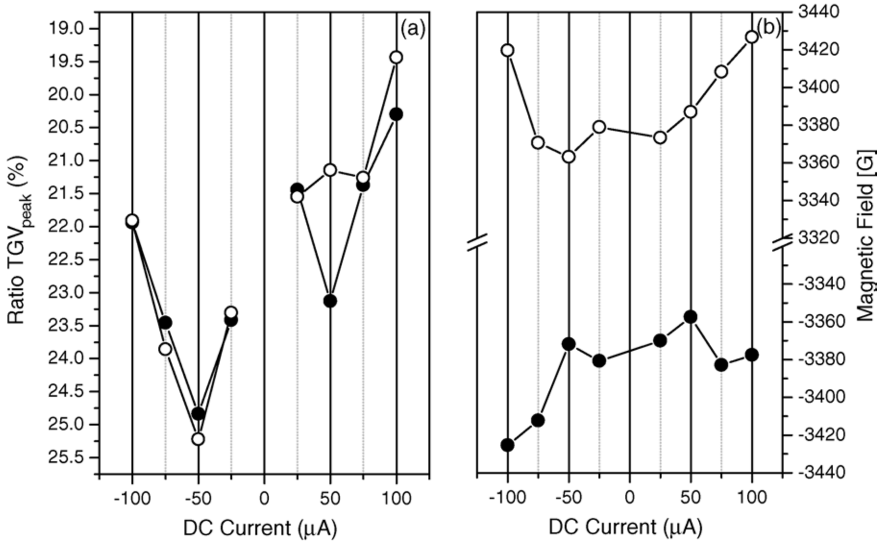

Fig. 5. (a) MTGV ratio ($|\mathrm{TGV}_{\mathrm{peak}} - \mathrm{TGV}_{\mathrm{plateau}}|/\mathrm{TGV}_{\mathrm{plateau}}$) of measured peaks vs. applied DC current. (b) Magnetic field peak (H_{peak}) dependence on DC current. Open (full) circles indicates positive (negative) peak (±3.35 kG).

large sharp peaks (up to ∼25% at parallel magnetic field orientation) observed when the magnetization reversal is reversible. A more detailed study of these peaks at parallel magnetic field orientation is reported in Fig. 3. GMR measurement (Fig. 3a) shows a reversible magnetization reversal with two irreversible jumps at 2.2 and 3 kG. MTGV measurement (Fig. 3b) shows that these irreversible jumps have no peak contribution but present weak shifts attributed to changes of the magnetic configuration. A sharp (100 G width) and large peak is observed only in reversible magnetization reversal mode at magnetic fields around ±3.35 kG. These values correspond to the initial and final states of the progressive magnetization reversal detected by GMR measurements. It implies that only specific magnetic configurations are involved in this effect. This behaviour has been verified in many other 5BL samples. An example is shown in Fig. 4. The magnetic field is applied perpendicular to wire axis and GMR measurements show a general progressive magnetization reversal process with one irreversible jump (Fig. 4a). This behaviour implies that Co layers do not have a well-defined anisotropy. MTGV measurement (Fig. 4b) confirms the existence of large sharp peaks at external magnetic field values corresponding to reversible magnetization processes.

MTGV measurements at different DC current values have been performed. Peaks are observed in all range of DC current values with almost a constant value of amplitude ratio (always between 20 and 25%, Fig. 5a). These peaks are proportional to DC currents. It confirms these MTGV peaks are measured via a Peltier effect. In addition, not significant dependence of magnetic field value of peaks (H_{peak}) on DC current has been observed (Fig. 5b). Tendencies observed for higher currents need to be confirmed.

4. Discussion and conclusion

We have performed MTGV measurements in 5BL samples. We showed that MTGV profile have two different regimes: a plateau regime due to spin-dependent Peltier effect of Co/Cu bilayers and large sharp peaks observed only when magnetization reversal is reversible. This effect points to a high dissipation process that occurs for specific magnetic configurations when Co layer magnetization is forced to turn out of alignment with one another. However, the nature of this dissipation process is not well understood. It could involve precession phenomena of the layer magnetization induced by a spin transfer mechanism which can occur because the magnetic field is close to the switching field value [17] or possible spin-wave emission processes [18].

To clarify the origin of this effect further measurements at high-density currents and at low temperatures (where the magnetic configurations are better defined) must be performed. It may also be necessary to study simpler magnetic systems like spin-valve nanostructures.

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