Proposal N° : **11**

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Title

Spin-Hall effect in chemically-grown metal/ferromagnetic bilayers

Keywords
Atomic layer deposition, electroless plating, spin-Hall effect

Summary
The integration requirements of the semiconductor industry pushes the development of three-dimensional technologies, such as the highly-multilayered NAND flash for charge memories. A similar push is perceptible for the emerging magnetic RAM, which otherwise would face limits of areal density in the mid-term future.
The purpose of the internship, which is fundamental and exploratory, is to investigate the suitability of chemically-grown metallic/ferromagnetic bilayers to exhibit a sizeable spin-Hall effect. Indeed, the spin-Hall effect is a key in efficient spintronic devices, allowing the conversion of charge current in a heavy-metal layer, into a transverse spin current in the adjacent ferromagnetic layer. On the other hand, this effect in metallic bilayers has only been demonstrated based on physical deposition, while truly three-dimensional spintronic requires alternative synthesis processes to deliver vertical structures with a high aspect ratio.

The work will involve interaction with chemists for the synthesis, structural and magnetic characterization, and transport measurements to extract the spin-Hall angle. The internship is an exploratory step coming with the perspective of a PhD to demonstrate new building blocks for three-dimensional spintronic, in the form of core-shell tubes, with application to current-induced domain-wall motion and magnonics in these novel structures. This action is done in a joint group between SPINTEC and Institut Néel, as well as expert chemistry groups in Germany (Erlangen and Darmstadt).

Full description of the subject

In order to fulfill Moore's law describing the expected exponential growth of areal density of semiconductor devices, there is a rising trend to build devices making use of the third dimension, so that more functions can be packed in terms of areal density, even though the lateral pitch remains constant when facing technological or physical limits. In spintronics, a proposal raised considerable attention about ten years ago: the race-track memory, a mass-storage device that would make use of dense arrays of vertical cylindrical wires. Domain walls would be the basis for coding bits of information, to be moved with spin-polarized current from/to write/read cells patterned at the surface of the array. So far, academic knowledge has been greatly developed on flat structures deposited and patterned by physical methods on wafers. Generally, the synthesis of a dense three-dimensional scaffolds is not possible by physical methods, and requires the use of various bottom-up techniques. The consideration of cylindrical wires is only emerging, fabricated by electrodeposition, as they are more challenging to fabricate and investigate. However, there is a need to fabricate multilayered structures, which are the basic building block of spintronics. This leads to the concept of core-shell and multilayered tubes in three dimensions, which is the background of the present proposal.

The Master internship will consider the demonstration of the spin-Hall effect in heavy metal/ferromagnetic metal bilayers grown by chemical methods. We will consider deposits on wafers for the first step, before shifting to tubes fabricated in nanoporous templates.

The first aspect concern material development and characterization. The first layer will be Pt, deposited using atomic layer deposition. The second layer will be Co, deposited using electroless plating. Both processes are

compatible for implementation in tubes at a later stage. These bilayers will be characterized structurally and magnetically. This involves atomic force microscopy for roughness, magneto-optical microscopy and magnetic force microscopy for domains and domains wall, magnetometry for magnetization and coercivity characterization.
The second aspect concerns characterization of the spin-Hall effect, which will be done with the harmonic hall voltage measurement technique, a robust method to quantify the spin orbit torques. We inject a low frequency ac charge current and detect the anomalous Hall effect. If the magnetization is fixed, the response is linear, and the hall voltage is oscillating exactly at the frequency of the current. If the charge current injected exerts a torque on the magnetization due to the injection of a spin current, the magnetization will no longer be fixed, but oscillate at the frequency of the current. This leads to a non-linear response, and hence to higher harmonics in the Hall voltage. The analysis of the higher harmonics response allows (by comparison to an external field) to quantify precisely the magnitude and the vectorial orientation of the Spin Orbit Torques, here, the spin-Hall effect and possibly interfacial Rashba effect.

The work lies in the frame of a tight and longstanding collaboration with Institut Néel and the Universities of Erlangen (Prof. J. Bachmann) and Darmstadt (Prof. W. Ensinger) as regards chemical synthesis. In practice, the student will participate in the chemical synthesis, assisted by chemical experts. The structural, magnetic and transport properties ate the core of the internship, and will be under the direct responsibility of the student. The student will be part of a larger group of persons working on the topic of magnetic nanowires and nanotubes between Spintec and Institut Néel, giving rise to regular group meetings.

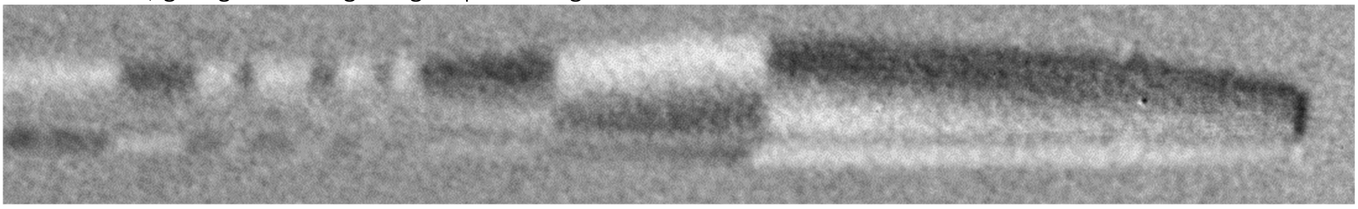

Illustration of the magnetic state observed in ferromagnetic single-shell tubes of ours, made by photo-emission electron microscopy (PEEM, a synchrotron-based techniques), demonstrating the existence of azimuthal domains of alternating circulation.

Requested skills

Experimental physics, taste for interdisciplinary interaction, understanding of material science and condensed matter physics.

Possibility to follow with a PhD Yes