Stage N° : 1

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Title

Atomic layer deposition for tunnel barriers in magnetic tunnel junctions

Keywords
Spin-electronics; Magnetic memory ; MRAM ; STT-MRAM ; magnetic tunnel junctions

Summary
Atomic-layer deposition is a standard deposition tool on production lines for semiconductor chips, implemented for its particular suitability to deposit oxide layers conformally, with a very good homogeneity and excellent thickness control thanks to its self-limiting, well-defined chemical reactions of gaseous precursors adsorbed at surfaces. The processes for the high-k HfO2 material are especially well controlled for the production of oxide gates. Recently, Mantovan [1] reported the successful ALD fabrication of MgO barriers for MTJs whereas Liu [2] used an alumina-based ALD process, the two standard materials for MTJs. The first HfO2 barriers for MTJs have been reported by S. Fabretti et al [3]. The TMR ratio is sizable, which we view as a proof of concept for the technique, however remains an order of magnitude smaller than for the state-of-the-art PVD textured MgO used for spintronics: 10% has been obtained at room temperature so far. Our objective in this project is twofold: 1/ increase the magnitude of TMR in ALD-based MTJs beyond the current state-of-the-art 2/ characterize ALD MTJs on criteria crucial for applications, such as the scalability of the TMR ratio to small dot size, and the voltage breakdown, both being related to the material quality and homogeneity. We will consider MTJs with both MgO and HfO2 barriers, the former as a comparison with the well-established PVD MgO, the latter as a potential replacement material.

Full description of the subject
Since the discovery of the Giant Magneto-Resistance (GMR) effect in 1988 by Pr Albert Fert and Pr. Peter Grunberg, the Spintronic domain has become very attractive and challenging for many conventional technologies. The development of magnetoresistive stacks such as GMR-based Spin-Valves (1991) and later Magnetic Tunnel Junctions (1995) has revolutionized the magnetic component industry. Nowadays, the Magnetic Tunnel Junction (MTJ) is the core of all Spintronic components and can be compared in importance to the transistor for the micro-electronics industry. The magnetic Hard Disk Drive industry could remain competitive over more than five decades, thanks to fundamental and technological progress. Much enhanced MTJ based magnetic components have also been produced since 2000 based on textured MgO barriers, which are seriously challenging the mainstream CMOS technologies. The MRAM and its various generations is a typical example, but more recently magnetic nano-oscillator exploiting the spin-torque effect is another example of spintronic device that could deeply modify the RF architecture for mobile applications. In addition, the hybridization of MTJ with CMOS for reconfigurable logic is also a new vector of diversification for the spintronic business that is considered seriously for advanced hybrid CMOS-spintronic circuits.
Most of these new magnetic components are built around a Magnesium Oxide (MgO) based tunnel junction that can display a very high magnetoresistive signal compared with the first Aluminum-Oxide based technology. However, the impedance or the voltage constraints have led to continuously decrease the MTJ Resistance x Area (RA) product upon scaling, achieved through thinning the tunnel barrier. Today, the MgO PVD technology seems close to its physical limits around 1nm thickness. Thus, there is a need for enhanced barriers, with alternative methods for improved deposition morphology at the atomic scale, and also new oxide barriers with lower band gap to achieve a given RA

with a thicker barrier, to pursue the RA decrease. The substitute materials require, of course, to maintain a high magnetoresistive signal.
Our project intends to address this critical aspect by providing a new way of depositing tunnel barrier material that could offer better morphology control at atomic level, while retaining a large TMR ratio. This new barrier would be generic for various applications, namely spin-torque based MRAM, nano-oscillators etc.
Atomic-layer deposition is a standard deposition tool on production lines for semiconductor chips, implemented for its particular suitability to deposit oxide layers conformally, with a very good homogeneity and excellent thickness control thanks to its self-limiting, well-defined chemical reactions of gaseous precursors adsorbed at surfaces. The processes for the high-k HfO_2 material are especially well controlled for the production of oxide gates. Recently, Mantovan [1] reported the successful ALD fabrication of MgO barriers for MTJs whereas Liu [2] used an alumina-based ALD process, the two standard materials for MTJs. The first HfO_2 barriers for MTJs have been reported by S. Fabretti et al [3]. The TMR ratio is sizable, which we view as a proof of concept for the technique, however remains an order of magnitude smaller than for the state-of-the-art PVD textured MgO used for spintronics: 10% has been obtained at room temperature so far. Our objective in this project is twofold: 1/ increase the magnitude of TMR in ALD-based MTJs beyond the current state-of-the-art 2/ characterize ALD MTJs on criteria crucial for applications, such as the scalability of the TMR ratio to small dot size, and the voltage breakdown, both being related to the material quality and homogeneity. We will consider MTJs with both MgO and HfO_2 barriers, the former as a comparison with the well-established PVD MgO, the latter as a potential replacement material.
The project will benefit from an excellent match between the expertise of IFW Dresden in ALD materials including for MTJs, a newly dedicated setup and advanced structural characterization, and the expertise of SPINTEC for the nanofabrication (lithography and etching), electrical measurements and their analysis.

[1] R. Mantovan et al, J. Phys. D: Appl. Phys. 47, 102002 (2014)
[2] X. Liu, J. Shi, Appl. Phys. Lett. 102, 202401 (2013)
[3] S. Fabretti et al, Appl. Phys. Lett. 105, 132405 (2014)

Requested skills
Basics in Magnetism,

Possibility to follow with a PhD Yes