Structural modification of MgO/CoFeB using a low energy ion beam from an assisted deposition source

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Ion Beam Assisted Deposition (IBAD) was already proposed as an alternative to the more conventional Physical Vapor Deposition (PVD) as a method to produce MgO/CoFeB MTJs in the range RxA~1 Ωμm^2 [1]. This deposition method has two main advantages over PVD :

1) The plasma is generated far from the sample being deposited, thus limiting the damage of deposited stack induced by energetic species in the plasma.
2) The energy of the ions and the number of ions are uncoupled parameters that can be controlled independently.

Despite the advantages of IBAD, PVD is still the deposition method producing better MgO/CoFeB MTJs. Still, transport results in stacks obtained by both methods are strongly system dependent and far from the theoretically predicted values for TMR (>1000% [2]).

For this work, MgO was deposited in a dual Ion Beam deposition system starting from an MgO ceramic target and using one of the ion beam guns to assist the deposition. The base deposition rate of MgO in the absence of an assistance beam was changed between 0.1Å/s and 0.3Å/s, using different parameter sets for the deposition gun. For each of these deposition conditions, the parameters of the assist gun were changed was well. The deposition rate of for each set of deposition and assist gun parameters was measured (Figure 1). The obtained results can be quantitatively understood with a simple model of the ion beam guns.

Both guns are Ion Beam Kauffman sources with an RF antenna being used to create the plasma inside a reactor (with Xe as process gas in the deposition gun and Ar as process gas in the assistance gun) biased with a positive voltage (V^+). The ions are then extracted from the reactor with a second negatively charged grid (V^-), as shown in Figure 1. It can be assumed that the number of ions per unit of time is proportional to I^+ and the energy of each incoming ion is proportional to V^+. Experimental values show that the base deposition rate, in the absence of an assistance beam, is proportional to the deposition gun ion beam power $[I^+ \times V^+]_{|deposition}$. When the assist gun power is large, a similar relation can be found. In this regime, the deposition rate during an Ion Beam Assisted Deposition decreases proportionally to the assistance gun ion beam power $[I^+ \times V^+]_{|assistance,}$ as expected with an ion beam etching away a fraction of the deposited material. A new regime is found when the number of ions per unit of time is increased and the energy per ion is decreased (high I^+ and low V^+). This regime can only be achieved using relatively large extraction voltages (V^-) and results in a reduced etching rate, signaling a change in the energy transfer process between the assistance ion beam and the deposited atoms (Figure 1).

The MgO layers deposited in the two assisted regimes were characterized by x-ray diffraction in samples made of glass // Ta 30Å / CoFeB 300Å / MgO 300 Å / CoFeB 300Å / Ta 30 Å. The experimental results show that the texture of MgO and CoFeB can be enhanced by carefully choosing the parameters of the assistance ion beam for each set of deposition parameters. Furthermore, the lattice constant of MgO can be tunned between 2.09Å and 2.12Å depending on the ratio between the deposition gun beam power and the assist gun beam power (Figure 2). A decrease in the width of the CoFeB peak observed when the MgO lattice constant is decreased indicates that the lattice mismatch at the MgO/CoFeB can be minimized by carefully choosing the ion beam assisted deposition conditions (Figure 2).

The impact of these structural modifications on the transport properties of MgO/CoFeB MTJs is currently being assessed.

References

[1] “Ion Beam Assisted Deposition of MgO barriers for Magnetic Tunnel Junctions”, S.Cardoso, R.J.Macedo, R.Ferreira, A.Augusto, P.Visniowsky, and P.P.Freitas, J.Appl.Phys., vol.103, pp.07A905-07A907, April 2008.

[2] “Spin-dependent tunneling conductance of Fe|MgO|Fe sandwiches”Butler et al., Phys. Rev. B 63, 056614 (2001).

Figures

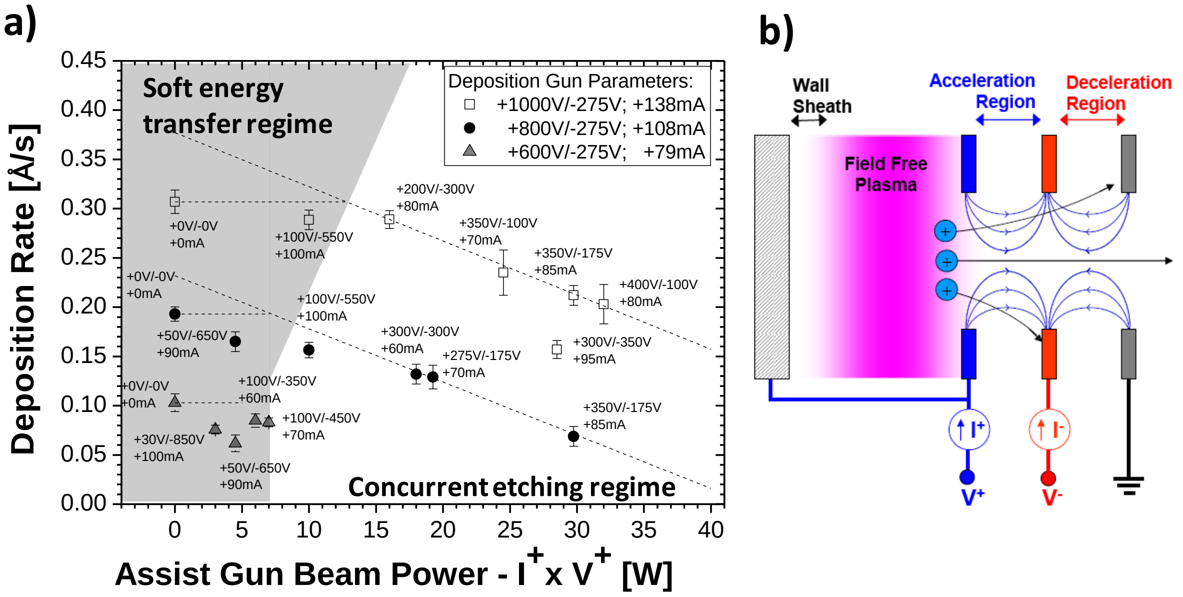

Figure 1 – Left : Deposition rate of MgO as a function of the assistance beam power for selected conditions of the deposition gun. The transition between the etching regime and a soft energy transfer mechanism is indicated. Right : schematic of the assist gun grids. The positive voltage V^+ is a measure of the ions kinetic energy and the positive current I^+ is a measure of the ion flux.

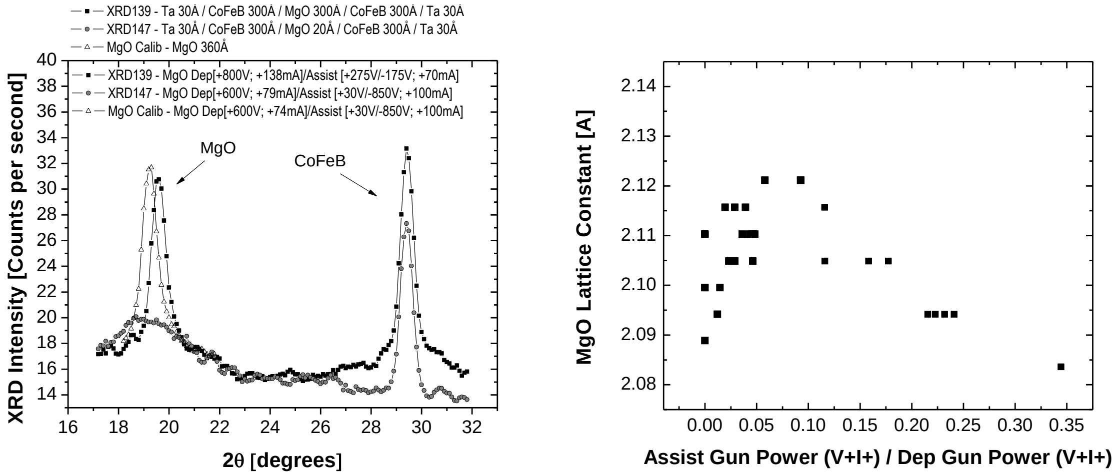

Figure 2 – Left : XRD diffraction spectrum of three different structures containing MgO and CoFeB for different deposition conditions of MgO. Notice the change in the MgO peak position as a function of the deposition conditions. The CoFeB peak width also depends on the CoFeB deposition conditions.
Right : MgO lattice constant as a function of the ratio between the assist gun power and the deposition gun power.