Spin transfer torque in magnetic tunnel junctions with wedge MgO barrier

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Introduction

High density and fast MRAM can be implemented using the spin transfer torque (STT) effect, i.e., layer magnetization reversal induced by a flow of a high density spin-polarized current through a MTJ. STT was introduced theoretically by Slonczewski and Berger [1] and experimentally demonstrated in spin valve GMR and TMR multilayer structures.

Aim

Crucial issues of STT in MTJs are a reduction of the critical current density, which is necessary for switching the junction and a reduction of the resistance area (RA) product. Here, we discuss the influence of MgO barrier thickness on the interlayer exchange coupling (IEC) energy and STT effect in MTJs with a MgO wedge barrier.

Sample preparation

A1. Deposition

- deposited using a Tiranis PVD cluster tool system from Singulatu Technologies
- DC and RF magnetron sputtering
- linear dynamic deposition (LDD) wedge technology
- the MgO barrier thickness between 0.62 and 0.96 nm along 8 inch wafer (slope rate of 0.017 nm/cm)
- base pressure before deposition was 10^-6 mTorr
- annealed in a high-vacuum furnace for 2h at 360°C

A2. E-beam lithography

- 2 step lithography process using e-beam lithography, ion milling, lift-off
- 3 sizes: [0.03 (160 x 250 nm), 0.08 (280 x 430 um), 0.13 um2 (280 x 620 nm)]

A3. Wafer level characterization

- for thick MgO barriers (down to 0.75 nm) the change of the TMR value is relatively small (from 170% to 150%)
- when the RA < 2 Ohmum^2 (0.7 nm MgO) the TMR starts to drop (the barrier imperfection)

Interlayer exchange coupling


\[
E = -J_{sc} M_{Ic} M_{Sc} \cos \theta_{Ic} - J_{ic} M_{Ic} \cos \theta_{Ic} - J_{sc} M_{Sc} \cos \theta_{Sc} - J_{ic} M_{Sc} \cos \theta_{Ic} - J_{sc} M_{Ic} \cos \theta_{Sc}
\]

- ferromagnetic IEC between the FL and RL
- Katayama [3] on epitaxial Fe(001)/ wedge MgO(001)/Fe(001) observed transition from a ferromagnetic to antiferromagnetic coupling below 0.8 nm

Current induced magnetization switching

C1. CIMS experiment

- the model of the critical current density presented in [4] does not explain quantitatively the values of the switching current observed in the experiment

C2. Conclusions

- higher switching current density was observed for the MTJ with 0.71 nm MgO
- the decrease of the critical current density with increasing barrier thickness can qualitatively be explained by an increase of tunneling spin polarization (TSP)
- more efficient spin filter effect in the thicker MgO barrier [5]
- TSP derived from the TMR ratio is 0.67 for the MTJ with 0.96 nm MgO and 0.58 for the MTJ with 0.71 nm MgO

C3. Outlook

- the model of the critical current density presented in [4] does not explain quantitatively the values of the switching current observed in the experiment

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