**Spin-dependent tunneling in CoFeB-MgO magnetic tunnel junctions**

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**Abstract**

In the last two decades we assisted to a boom of new classes of magnetically engineered nanostructured devices, which are suitable for advanced magnetic sensors (ultra sensitivity and sub-μm dimensions) and the long envisaged universal magnetic memory, Magnetic Random Access Memory (MRAM). One of such devices is the magnetic tunnel junction (MTJ), which exhibit the so called tunnel magnetoresistive (TMR) effect. The most basic MTJ structure consists of two ferromagnetic (FM) materials separated by an insulator layer usually designated as barrier. The thickness of these layers can be made very thin, a few nanometers or less.

We will present a detailed study on the physics of the underlying mechanisms that affect the spin-polarized transport in sputtered MTJs, based on the CoFeB/MgO/CoFeB trilayer structure with thin barriers (≤ 1 nm). This system has been intensively studied aiming practical applications because of the high RT TMR, high breakdown voltages, reproducibility, appropriate resistance-area products and crystal growth considerations. We have successfully studied pinhole-free MgO MTJs for barrier thicknesses as low as 0.85 nm and exhibiting RT TMR values above 100%. We have studied the characteristics of these MgO MTJs as a function of temperature [1,2] (Fig. 1), bias voltage [3, 4] (Fig. 2), barrier thickness (0.75 − 1.35 nm) [5] and CoFeB free layer thickness (1.55 − 3.0 nm) [6]. We show the presence of perpendicular magnetic anisotropy in the MTJs with the thinnest fabricated free layer, resulting in a strong out-of-plane magnetization component in zero-applied field (H). Angular dependent measurements of the tunnel conductance (G) and TMR (Fig. 3) display that a magnetic field range of ±150 Oe is sufficient to put the free layer magnetization perpendicular to the MTJ plane.

**References**

[1] J. Ventura et. al. Phys. Rev. B 78, 024403 (2008).
[2] J. M. Teixeira et al. J. Appl. Phys. 106, 073707 (2009).
[3] J. M. Teixeira et al. Phys. Rev. Lett. 196601, 5294 (2011)
[4] J. M. Teixeira et al. Appl. Phys. Lett. 100, 072406 (2012)
[5] J. M. Teixeira et al. Appl. Phys. Lett. 96, 262506 (2010)
[6] J. M. Teixeira et al. Phys. Rev. B 81, 134423 (2010).

**Figures**

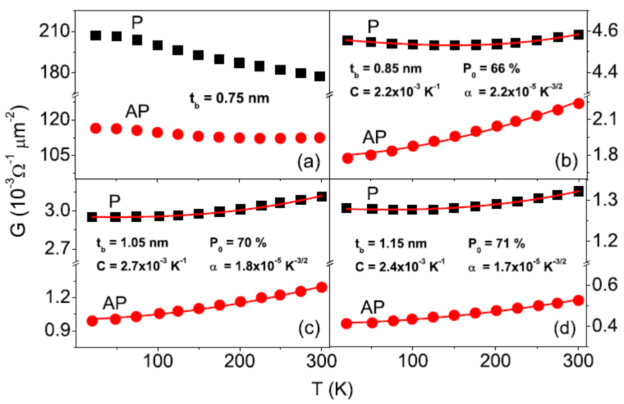

Fig. 1. Temperature dependence of the electrical conductance for selected MTJs with different free layer thicknesses. The solid lines are fits to the experimental data based on the direct elastic tunneling model.

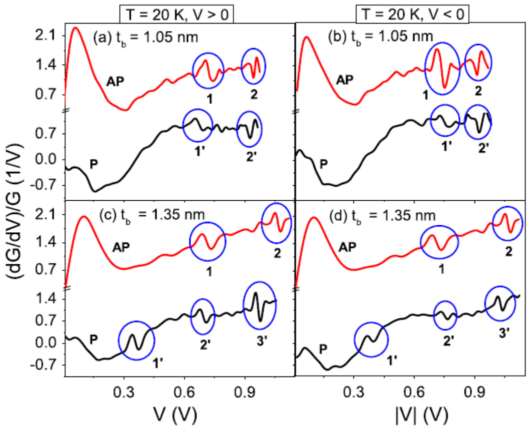


Fig. 2. Inelastic electron tunneling spectroscopy for magnetic tunnel junctions with different electrode thicknesses.

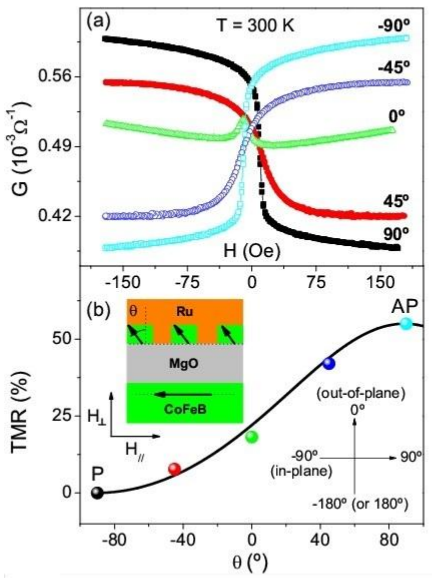


Fig.3: G(H) loops measured in the MgO MTJ with tfl = 1.55 nm and for different orientations of H. (b) TMR as a function of θ. Black line represent the calculated TMR(θ) dependence. The insets show the canted Mfl state of the MTJ discontinuous free layer and the angular orientations defined relatively to the MTJ out-of-plane axis.