SPINTEC SPIN IN ELECTRONICS

SPINTRONIQUE ET TECHNOLOGIE DES COMPOSANTS
Unité de recherche associée
CEA / CNRS URA 2512

HEAT DISSIPATION EFFECTS ASSOCIATED WITH SPIN TRANSFER WRITING IN MRAM DEVICES

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MOTIVATION

Joule heat dissipation that occurs during the application of current pulses of density ~ 5 x 10^6 A/cm^2, as required for switching the magnetization of a free ferromagnetic layer by spin transfer effect, has not yet been quantitatively evaluated. Particularly important in case of Magnetic Tunnel Junctions (MTJ), the heating effect of a current pulse can reduce the switching current density, enhance the spin transfer-assisted magnetic noise and broaden the linewidth of the spin transfer-induced magnetization excitations. The calculation of the MTJ temperature profile during the application of a current pulse requires the knowledge of the thermodynamic parameters of the MTJ layers.

GOAL

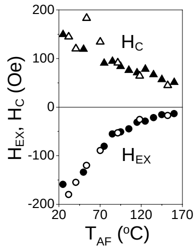
Elaborate a model of heat diffusion in an MTJ stack that correlates the thermodynamic parameters of the junction layers (heat capacity, thermal conductivity) to a set of directly measurable quantities: (a) **the cooling time constant τ_{TR} of the junction subsequent to the application of a current pulse**; (b) **the proportionality constant α between the power of the heating pulse and the stationary temperature reached by the junction layers during the application of a current pulse.** Comparison between the theoretical and experimental values of τ_{TR} and α allows the "calibration" of the MTJ thermodynamic parameters.

1-D model of heat diffusion in the MTJ. Temperature regimes during the application of a current pulse.

$$T_{AF} = T_{RT} + \alpha P_{HP}\left[1 - \exp\left(-\frac{t}{\tau_{TR}}\right)\right]$$

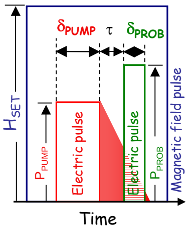
$$\alpha = \frac{d_{TB}}{2k_{TB}S}$$

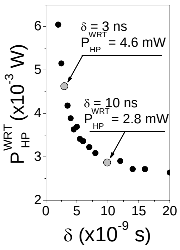
$$\tau_{TR} = \frac{d_{TB}}{2k_{TB}}\left(\sum_i c_i\rho_i d_i + c_{TB}\rho_{TB}d_{TB}\right)$$

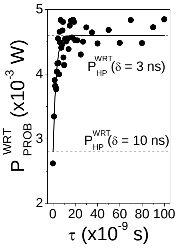


stationary regime

$\alpha=10^5$ K/W



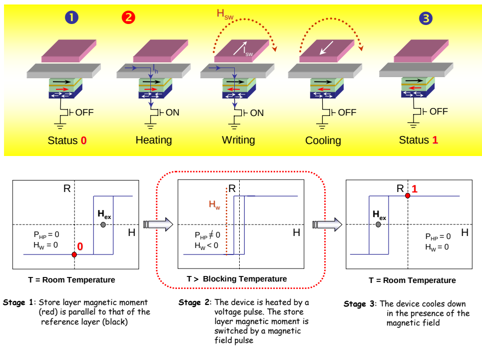




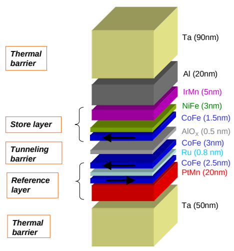
transient regime

$\tau_{TR}=2.7$ ns

Principle of MRAM-TAS

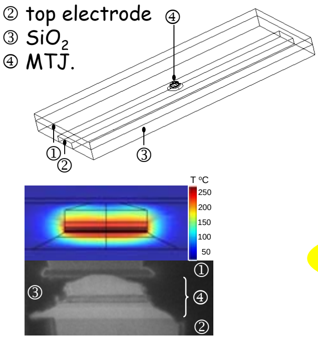


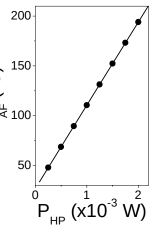
Sample structure

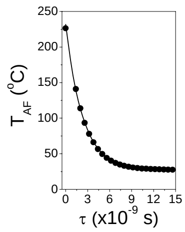


3-D simulations (COMSOL) of heat diffusion in the MTJ

① bottom electrode
② top electrode
③ SiO_2
④ MTJ.



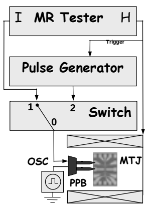


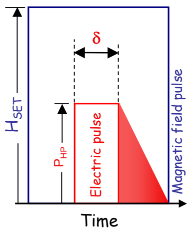


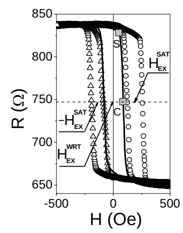
$\alpha=8.4\times10^4$ K/W

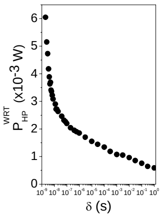
$\tau_{TR}=2.3$ ns

Experimental setup and measurement procedure

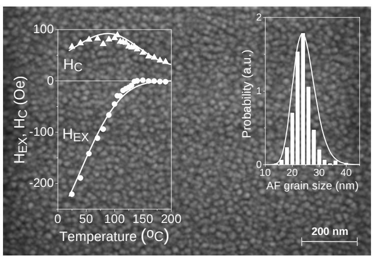


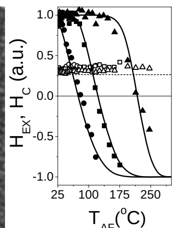




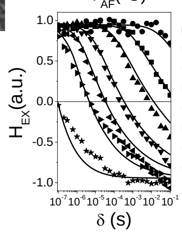


Exchange bias as temperature probe





δ=
(●) 1 s
(■) 10^{-3} s
(▲) 10^{-7} s

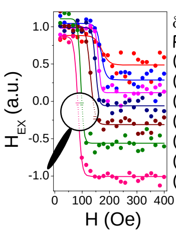


P_{HP}=
(●) 0.38 mW -> 58 °C
(■) 0.69 mW -> 85 °C
(▲) 0.92 mW -> 105 °C
(▼) 1.24 mW -> 133 °C
(◄) 1.47 mW -> 153 °C
(►) 1.7 mW -> 173 °C
(★) 2.24 mW -> 220 °C

$$T_{AF} = T_{RT} + \alpha P_{HP}$$

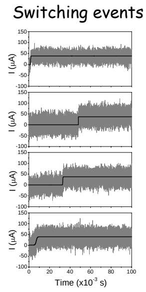
$\alpha=8.7\times10^4$ K/W

Time-domain study of the F/AF switching

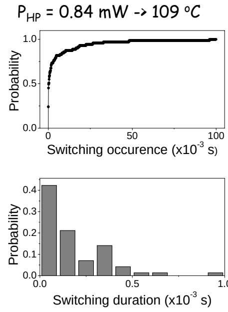


δ= 1 ms
P_{HP}=
(●) 0.8 mW
(●) 0.91 mW
(●) 1.02 mW
(●) 1.15 mW
(●) 1.3 mW
(●) 1.48 mW
(●) 1.64 mW

Switching events



P_{HP} = 0.84 mW -> 109 °C



CONCLUSIONS

1) Exchange bias of an F/AF bilayer can be used to probe the temperature of a film in contact with the F/AF bilayer.
2) Switching of the F/AF does not appear to be instantaneous, leading to a time dependent coercivity of the F/AF bilayer.
3) During the application of a current pulse, two temperature regimes of the MTJ were evidenced: an initial transient regime (of width $3\tau_{TR}$) followed by a stationary regime ($T=T_{RT}+\alpha P$).
4) The estimated values of thermal conductivities k and specific heat capacities c of the MTJ layers, based on the Widemann-Franz and Dulong-Petit laws, are reliable as suggested by the agreement between the experimental and theoretical values of τ_{TR} and α. The estimated k and c can be used for calculating the temperature profile of an arbitrary layer structure.

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