Simulations of heat gradients in magnetic tunnel junctions: Influence of pillar thermal conductivity and embedding oxide material.

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Abstract

MgO based Magnetic tunnel junctions (MTJ) are widely used nowadays in read heads and sensing devices consequence of their large tunnel magnetoresistance (TMR) up to 200% and large signal to noise ratios. Recently attention has been given to the effects of temperature gradients on MTJs, which generate a voltage via the Spin Seebeck Effect (SSE) [1,2,3]. Such effect can make a difference in a integrated CMOS device, where the MTJ will allow us to harvest the dissipated heat and recycle it into electricity to fuel another CMOS device, thus reducing the overall power consumption.
Up to now, several works focused on the optimization of materials in order to achieve larger SSE coefficients (μV/K) and thus improve the yield of energy scavenging. However, another important route targets the optimization of the temperature drop witin the structures, particularly between the different layers that compose the MTJ towards an increase in the produced voltage. To address the SSE, the heat is usually generated by a wire on top of the device or by laser pulses[1,4]. However, in both cases the device needs to be embedded in a protective oxide layer where most of the temperature drop takes place[4]. In this work we address the effect of geometry and materials on the temperature gradient that occurs at a MTJ, using 2D simulations by finite element method. Our structure is based on a standard MgO-MTJ of 250 nm as the ones nanofabricated at INESC-MN by electron beam lithography, ion milling etching and lift off [5] and shown in the cross-sectional transmission electron image (TEM) image of (Fig. 1). For the simulation studies the MTJ stack is composed of Si / SiO_2 / Cu (90 nm) / Ta (5 nm) / PtMn (20 nm) / CoFeB (2 nm) / Ru (0.75 nm) / CoFeB (2 nm) / MgO (1.5 nm) / CoFeB (3 nm) / Ta (10 nm) / Cu (30 nm) / Ru (8 nm) / Au (30 nm) / SiO2 (110 nm) / Au (100 nm) (Fig. 1). As simulation parameters we used the density ρ, thermal conductivity κ and heat capacity C_P as in Ref. [4]. As heat source we considered a 100 nm thick Au wire placed above the top contact of the MTJ as depicted in (Fig 1), with dimensions much larger than the pillar and insulated from the MTJ by a 110 nm thick SiO_2 layer. The bottom contact and the bottom of the Si wafer (substrate) act as heat sinks being fixed at room temperature. Our simulations of the heat transfer through the described system indicate that the main temperature drop inside the pillar occurs in the PtMn and in the MgO (Fig. 3), and virtually none in the CoFeB due to their much higher thermal conductivity. The pillar and the oxide laterally around it are in competition for the heat conduction. We conclude from our simulations that the relative magnitude of their conductivity do not matter much as long as $\kappa_{pillar} > \kappa_{oxide}$. The ΔT_{MgO} is indeed limited to a value of ~150mK and κ_{pillar} will only shift the absolute temperature at which the MgO will operate. Further improvements in the simulation will take into account the influence of the relative orientation of the ferromagnetic layer in the MTJ on the thermal conductivity of the device.

References

[1] M. Walter, J. Walowski, V. Zbarsky, M. Münzenberg, et al. Nature Materials, 10, 742–746 (2011)

[2] Z. H. Zhang, Y. S. Gui, L. Fu1, X. L. Fan, J. W. Cao, et al. Physical Review Letters 109 (3) (2012)

[3] J. M. Teixeira, J. D. Costa, J. Ventura, et al. Applied Physics Letters, 102, 212413 (2013)

[4] N. Liebing, S. Serrano-Guisan, K. Rott, et al. Journal of Applied Physics, 111, 07C520 (2012)

[5] A. V. Silva, D. C. Leitao, Z. Huo, R. J. Macedo, et al. IEEE Trans. Mag. 49 (2013) 4405

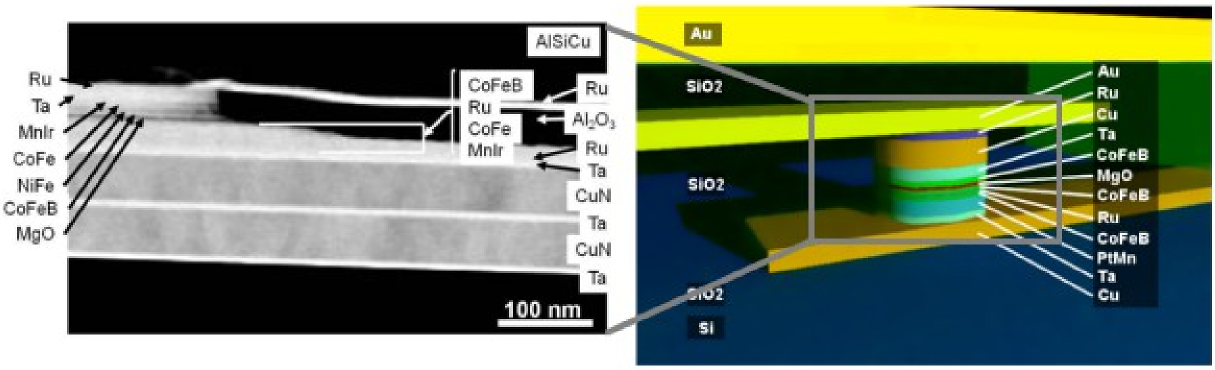

Figure 1: (left) TEM picture of an MTJ nanofabricated at INESC-MN, (right) Illustration of the MTJ considered in the simulations

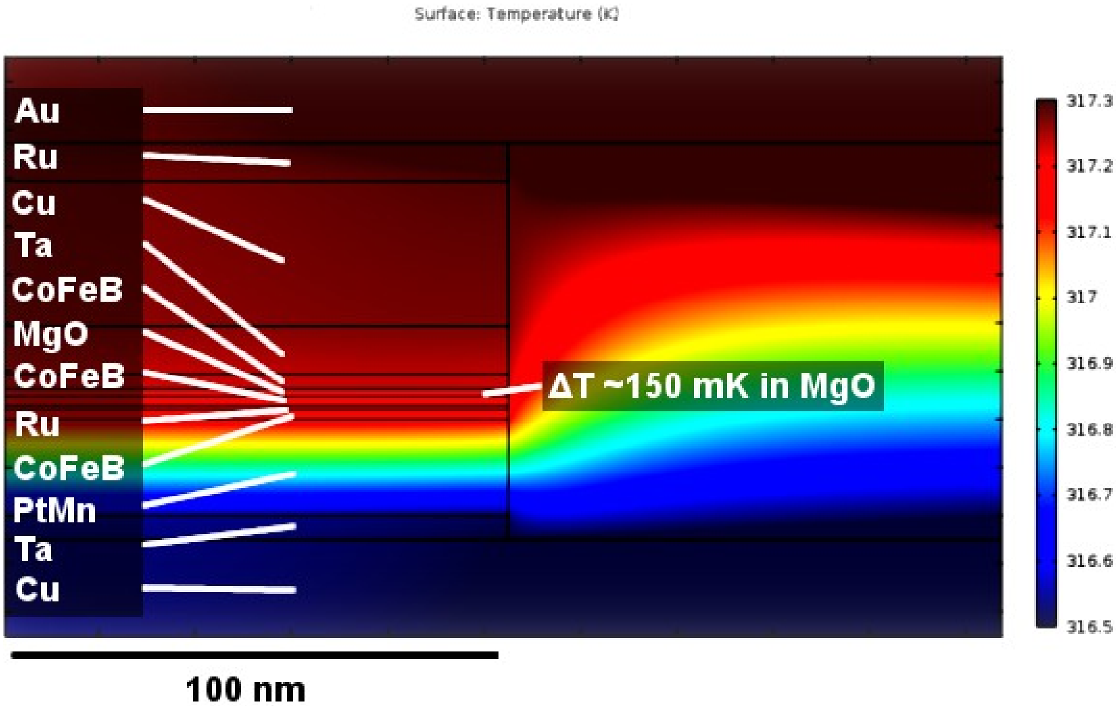

Figure 2: Temperature gradient through the pillar resulting from simulations