Numerical Study of Two-Terminal SOT-MRAM

Tomáš Hadámek[1,2], Nils Petter Jørstad[1,2], Wolfgang Goes[3], Siegfried Selberherr[2], Viktor Sverdlov[1,2]

[1] *Christian Doppler Laboratory for Nonvolatile Magnetoresistive Memory and Logic at the*
[2] *Institute for Microelectronics, TU Wien, Gußhausstraße 27-29, A-1040 Wien, Austria*
[3] *Silvaco Europe Ltd., Cambridge, United Kingdom*

Two-terminal (2T) spin-transfer torque random access memory (STT-MRAM) is readily commercially available, but its applicability is limited due to fairly slow writing speeds. Three-terminal (3T) spin-orbit torque MRAM (SOT-MRAM) overcomes the writing speed limit, however, the system complexity and cell size are significantly increased. In this work, we analyze 2T-SOT-MRAM [1], which is smaller than the conventional SOT-MRAM, but promises larger speed and demands less energy than standard STT-MRAM. The main difference to the STT-MRAM is an additional heavy metal (HM) layer underneath the magnetic tunnel junction (MTJ). The write current passes through both, the MTJ and the HM layer.

We fully couple magnetization, spin, charge, and temperature dynamics. The Landau-Lifschitz-Gilbert (LLG) and the Laplace equation are utilized for the solution of the magnetization and charge dynamics. The spin dynamics is described by a spin-drift diffusion model [2] and the spin Hall effect is included to allow for the SOT switching. We solve the heat flow equation and use the current density to determine the temperature increase in the structure and scale the properties of the magnetic materials accordingly. The equations are discretized and solved using the finite element method [3]. We analyze a perpendicular 2T-SOT-MRAM with a diameter of 40 nm. The HM is contacted through a metallic via to a long transmission current line. The MTJ is placed on the other side of the HM, and is connected through a metallic contact to the Si substrate. The whole structure is surrounded by an oxide layer.

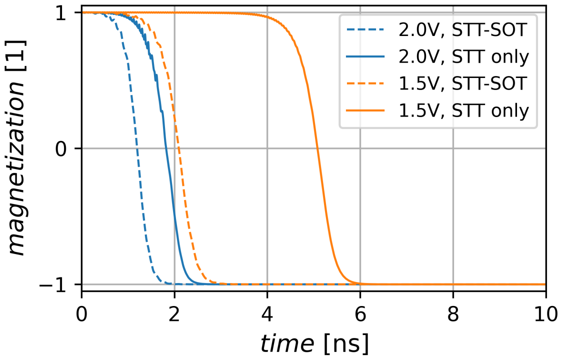

Figure 1: Comparison of the 2T-SOT-MRAM and a conventional STT-MRAM. The incubation time is significantly reduced.

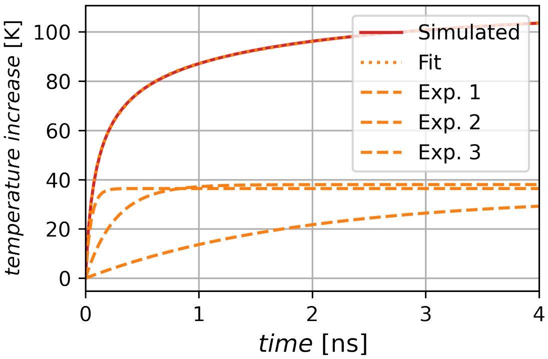

Figure 2: Average temperature increase in the FL at the beginning of the switching. Three different time constants can be observed.

Fig. 1 shows that the 2T-SOT-MRAM incubation time is significantly reduced in comparison to the STT-MRAM, due to the character of the torques. Unlike the STT, the SOT is directly present at the beginning of the switching, when the magnetizations are parallel/anti-parallel. Moreover, the switching voltage threshold, and hence the critical current, are also reduced due to the additional torque, in agreement with [1]. Fig. 2 shows the importance of proper temperature treatment. We observe three different time constants in our system. The increased temperature significantly reduces the magnetic anisotropy, mediates the switching, and further reduces the critical current.

References

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