Quantization and thermal effects during the scalability of magnetic-nanobridge-based STT-MRAM towards sub-20-nm technology nodes

A.V. Popov[1], G.D. Demin[1,2], A.F. Popkov[1,2]

1. Moscow Institute of Physics and Technology (State University), Dolgoprudny, Russia, demin.gd@phystech.edu.

2. National Research University of Electronic Technology (MIET), Moscow, Russia, alexcoretex@gmail.com

An important criterion ensuring the extended scalability of nonvolatile magnetoresistive memory (STT-MRAM), based on spin-transfer-torque phenomena in magnetic tunnel junctions (MTJ), towards sub-20-nm technology node is the possibility to maintain high thermal stability (>80k_BT) when demonstrating low switching voltage (not more than 0.5 V) at reduced MTJ dimensions (Fig. 1a). It was found in [1, 2], that at such technology nodes a good thermal stability can be achieved by increasing the magnetic anisotropy field with the thickness of free layer. At the same time, Joule heating in the MTJ structure caused by the electrical current can additionally reduce the voltage thresholds needed for the magnetization reversal in STT-MRAM, which should be taken into account when considering current-induced magnetization dynamics of free layer at the nanoscale. As it was shown in [3] in the case of magnetic nanobridge Au/Co/Au/Co/Au, when the magnetic structure is scaled below 10 nm, the quantization of spin-transfer torquances (first derivatives of spin-transfer torques with respect to voltage) begin, which can lead to resonant magnetodynamic switching effects in the MTJ and requires to be studied.

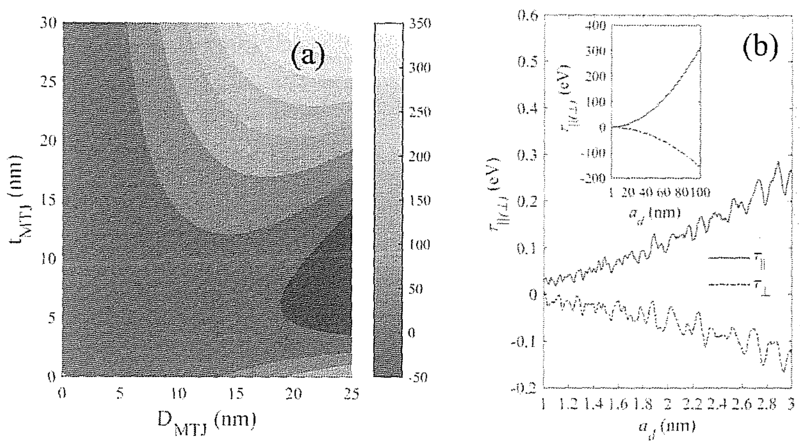

Fig. 1. (a) Dependence of the thermal stability factor on the dimensions of MTJ. (б) Quantization of the spin-transfer torques with scaling of the transverse dimensions of the magnetic nano-bridge.

In connection with the above, the complex development of a fundamentally new SPICE model of MTJ is needed, which takes into account both these nanoscale quantum and thermal effects, as well as the variation of magnetic and thermodynamic properties of MTJ with a change in its dimensions at sub-20-nm design rules. In this work we describe SPICE-compatible compact model of nano-sized MTJ for a given thermal stability factor depending on the given technology node, which, in turn, causes a change of the MTJ dimension. The spatial quantization of the spin-transfer torques in MTJ is also considered within this model when the transverse size of the MTJ cross-section scales below 10 nm (Fig. 1b). Implementation of the magnetization dynamics into the SPICE model of sub-20 nm MTJ is based on the equivalent circuit for the Landau-Lifshitz-Slonczewski-Bloch equation solver with an effective field term responsible for thermal calculations. This model can be useful for predictive simulation of STT-MRAM performance at advanced technology nodes. The work was supported by the Russian Science Foundation (project № 16-19-00181).

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