

Bias-Field-Free Spin-Torque Oscillator Based on Two MgO-MTJs with a Shared Free Layer: Micromagnetic Modeling

Alexander Makarov, Viktor Sverdlov, and Siegfried Selberherr

Institute for Microelectronics, TU Wien, Gußhausstraße 27-29, 1040 Vienna, Austria

e-mail: Sverdlov@iue.tuwien.ac.at

New types of spintronics devices utilizing all-electrical magnetization manipulation by current, such as spin-torque transfer RAM and spin-torque oscillators, have been developed based on MgO magnetic tunnel junctions (MTJs) [1]. Spin-torque oscillators based on MTJs with in-plane magnetization [2] show high frequency capabilities, but still need an external magnetic field and are characterized by a low output power level [3]. Oscillators based on MTJs with perpendicular magnetization [4] and vortex-based oscillators [5] are shown to generate oscillations without external magnetic field, however, their operating frequencies are low, usually below 2GHz [3]. In this work we investigate - by means of extensive micromagnetic simulations - bias-field-free nano-oscillators based on two MgO-MTJs with a shared free layer with in-plane magnetization.

First we investigated a penta-layer MTJ structure with only half-elliptic pinned layers (Fig.1). Fig.2 shows the switching process in such a structure in detail. We find that the structure with half-ellipsis pinned layers develops stable oscillations with nearly constant amplitude. The Fourier transform of the signal is sharply peaked around the frequency $\sim 6.785\text{GHz}$ (Fig.3, top). We note that the frequency of the oscillations only slightly depends on the current value (Fig. 3, bottom). However, a problem is that despite the partial coverage of the free layer by the fixed layers, resulting in spin-current injection in only a part of the free layer (Fig.4, inset), the free layer magnetization switching still occurs at a wide range of current densities (Fig.4). The magnetization dynamics of the free layer at different instances during the switching process is shown in Fig.5. In order to prevent the switching of the free layer, thus improving an oscillatory behavior control, we have added the second MgO-MTJ to the system (Fig.6). Fig.7 shows the switching process in such a structure in detail. We find that, in contrast to the previously considered case, the structure with two MgO-MTJs demonstrates stable oscillations with a constant amplitude. The Fourier transform of the signal is sharply peaked around the frequency of 13GHz (Fig.8). The proposed structure can be used to fabricate bias-field-free nano-oscillators.

- [1] A. Fukushima et al., Trans. on Magn. **48** (2012) 4344.
- [2] Z. Zeng et al., Appl. Phys. Lett. **99** (2011) 032503.
- [3] C.H. Sim et al., J. Appl. Phys. **111** (2012) 07C914.
- [4] Z. Zeng et al., Sci. Rep. **3** (2013) 1426.
- [5] A. Dussaux et al., Nature Comm. **1** (2010) 8.

This work is supported by the European Research Council through the grant #247056 MOSILSPIN.

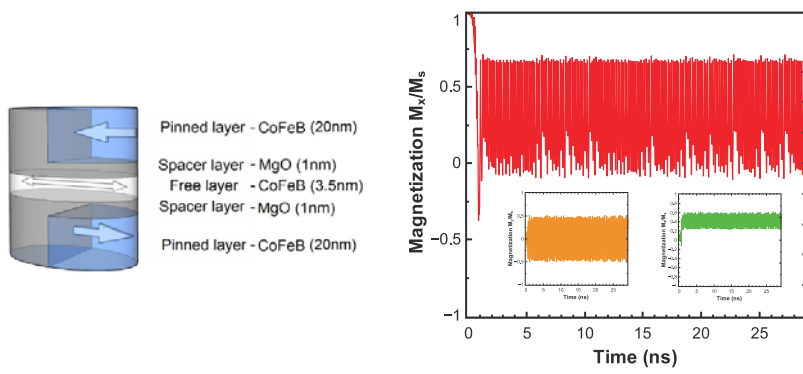


Fig. 1. Schematic illustration of a penta-layer MTJ with half-elliptic pinned layers.

Fig. 2. Averaged magnetization along the x , y (inset left), and z axis (inset right) as function of time.

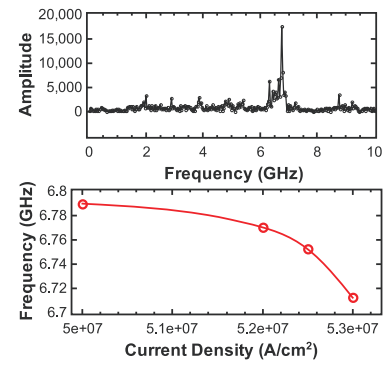


Fig. 3. (top) The signal's Fourier transform for a current density $5 \cdot 10^7 \text{ A/cm}^2$. (bottom) Frequency as function of current density.

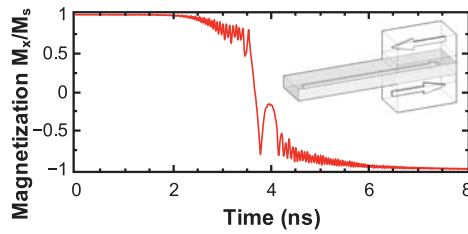


Fig. 4. Magnetization (x -component) as a function of time for a free layer of $70 \times 10 \text{ nm}^2$. (Inset) Schematic illustration of a penta-layer MgO-MTJ without complete overlap of the free layer and the fixed layers.

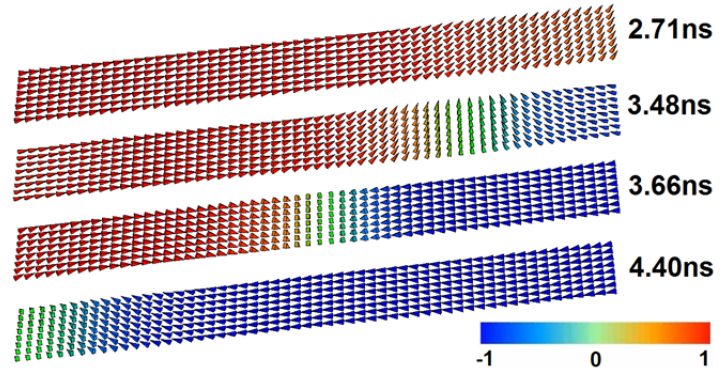


Fig. 5. Snapshots of the switching process for a penta-layer MgO-MTJ without complete overlap of the free layer and the fixed layers. The direction of the magnetization is shown by unit vectors. The color indicates the value of the component along the long axis.

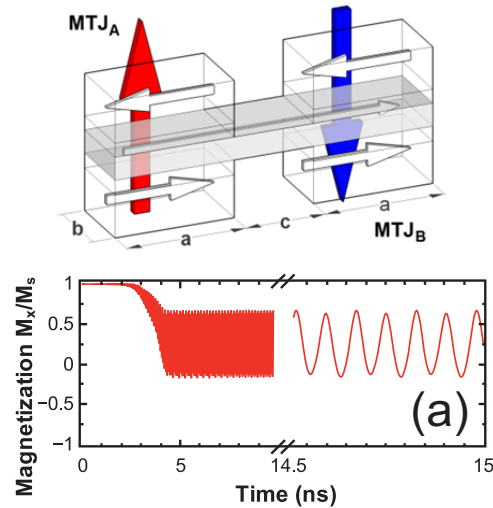


Fig. 7. Magnetization components in MTJ_B as a function of time for a free layer of $50 \times 10 \text{ nm}^2$: (a) x -component; (b) y -component; (c) z -component. The current density through MTJ_A is $7.5 \cdot 10^7 \text{ A/cm}^2$ and $1 \cdot 10^7 \text{ A/cm}^2$ through MTJ_B .

Fig. 6. Schematic illustration of a spin-torque oscillator based on two MgO-MTJs. Colored arrows indicate the positive direction of the current for each of the MgO-MTJs.

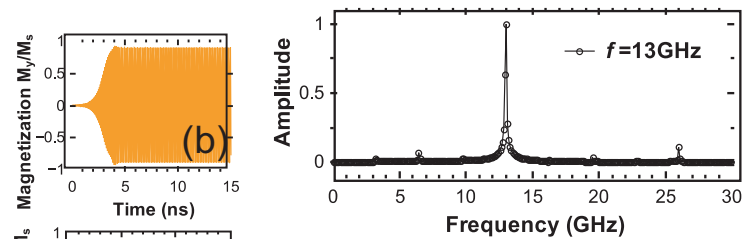


Fig. 8. Signal spectral density normalized to its maximum value. The current density through MTJ_A is $7.5 \cdot 10^7 \text{ A/cm}^2$ and $1 \cdot 10^7 \text{ A/cm}^2$ through MTJ_B . The peak is observed at the frequency 13GHz.