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Concept of a Bias-Field-Free Spin-Torque Oscillator Based on Two MgO-MTJs

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Abstract

We propose a novel spin-torque oscillator based on two MgO-MTJs with a shared free layer. By performing extensive micromagnetic modeling we found that the structure exhibits a wide tunability of oscillation frequencies from a few GHz to several ten GHz.

1. Introduction

New types of spintronics devices utilizing all-electrical magnetization manipulation by current, such as spin-torque transfer RAM and spin-torque oscillators, have been intensely developed based on MgO magnetic tunnel junctions (MTJs) with a large magneto-resistance ratio [1]. Spin-torque oscillators based on MTJs with in-plane magnetization [2] show high frequency capabilities, but still need an external magnetic field and/or are characterized by low output power level [3]. Oscillators on MTJs with perpendicular magnetization [4] and vortex-based oscillators [5] are shown to generate oscillations without external magnetic field, however, their low operating frequencies, usually below 2GHz, limit their functionality and application as a tunable oscillator [3]. In [6] we proposed a bias-field-free spin-torque oscillator based on an in-plane MgO-MTJ with an elliptical cross-section but not perfect overlap between the free layer and the fixed magnetic layers. However, a disadvantage of such an architecture is a narrow range of frequencies and their weak dependence on the current density. In this work we propose a novel spin-torque oscillator.

2. Results and Discussion

Fig.1 (inset) and Fig.2 show the investigated structures. All the nanopillars used consist of CoFeB(5nm)/ MgO(1nm)/ CoFeB(3.5nm)/ MgO(1nm)/ CoFeB(5nm) MTJs, with fixed layers 20×10nm^2 (a×b) and different free layer lengths ranging from 40nm to 70nm. Our analyses are based on the magnetization dynamics described by the Landau-Lifschitz-Gilbert-Slonczewski (LLGS) equation in the areas of current flow and the Landau-Lifschitz-Gilbert (LLG) equation otherwise [7]. The interaction between different areas occurs due to the magnetic exchange interaction and magnetostatic coupling.

First we investigated the switching process for a rectangular free layer 70×10nm^2. Fig.1 shows the dynamics of the magnetization component along the x-direction of the long axis as a function of time. The current density used for switching is equal to $1\cdot10^7$A/cm^2. Despite that the fixed layer covers only a part of the free layer, so the injection of spin-current occurs in a part of the free layer only 20nm long, it is still possible to switch the free layer magnetization. For demonstration of the switching process we show the magnetization dynamics of the free layer at different instances in Fig.3. We conclude that after applying the current a transversal domain wall is formed in the free magnetic layer close to the areas of the spin-current injection, the motion of which away from the MTJ eventually switches the free layer.

In order to prevent the switching of the free layer and to favor an oscillatory behavior, we have added to the system the second MgO-MTJ (Fig.2). Fig.4 shows the switching process in such a structure in detail. We find that, in contrast to the previously considered structure, the structure with the 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.5).

We also investigated the influence of the free layer geometry and the current densities through the MTJs on the oscillation occurence (Fig.6.). Our results indicate that increasing the length of the free layer and thus the distance between the MgO-MTJs shifts the area, where the oscillation is observed, towards the region with larger j_b/j_a ratio. Next we studied the influence of the current density j_b/j_a ratio on the oscillation frequency (Fig.7). Increasing the ratio j_b/j_a increases the frequency (Fig.7, right). Increasing j_a leads to an increase of the range for j_b, where stabile oscillations are observed (Fig.8).

3. Conclusions

We proposed a new concept of spin-torque oscillators based on two MTJs with a shared free layer, which show stable oscillations without external magnetic field. The operating frequency of stable oscillations can be tuned in a wide range by varying the currents densities flowing through the MTJs, making this structure attractive for many high frequency applications.

Acknowledgements

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References

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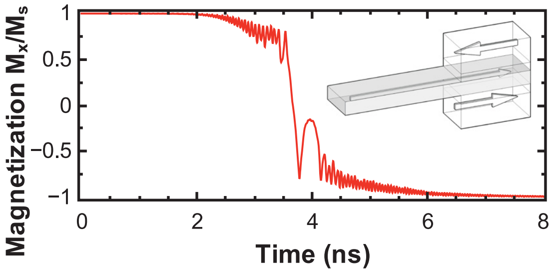

Fig. 1. Magnetization (x-component) as a function of time for a free layer of 70×10nm^2. (Inset) Schematic illustration of a penta-layer MgO-MTJ without complete overlap of the free layer and the fixed layers.

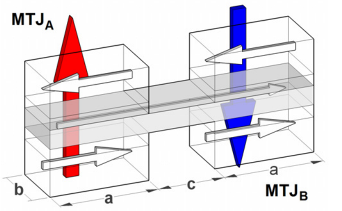

Fig. 2. Schematic illustration of a spin-torque oscillator based on two MgO-MTJs. Colored arrows indicate the positive direction of the current for each of the MgO-MTJs.

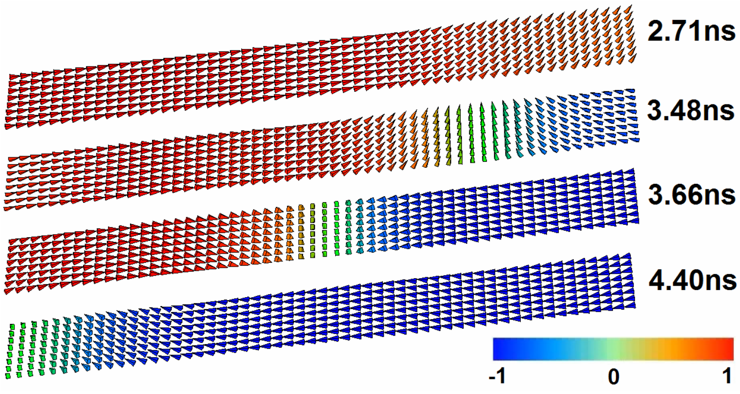

Fig. 3. Snapshots of the switching process for a penta-layer MgO-MTJ without complete overlap of the free layer and the fixed layers. The direction of the magnetization is shown by unit vectors. The color indicates the value of the component along the long axis.

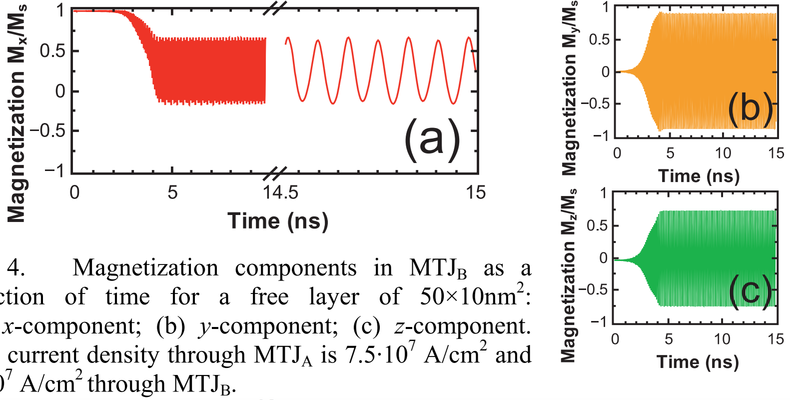

Fig. 4. Magnetization components in MTJ_B as a function of time for a free layer of 50×10nm^2: (a) x-component; (b) y-component; (c) z-component. The current density through MTJ_A is 7.5·10^7 A/cm^2 and 1·10^7 A/cm^2 through MTJ_B.

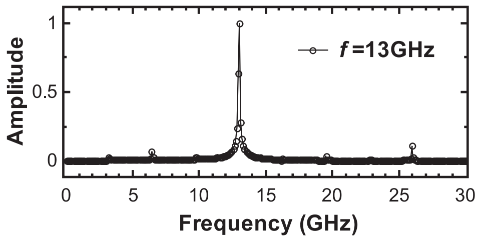

Fig. 5. Signal spectral density normalized to its maximum value. The current density through MTJ_A is 7.5·10^7 A/cm^2 and 1·10^7 A/cm^2 through MTJ_B. The peak of the amplitude is observed at a frequency of 13GHz.

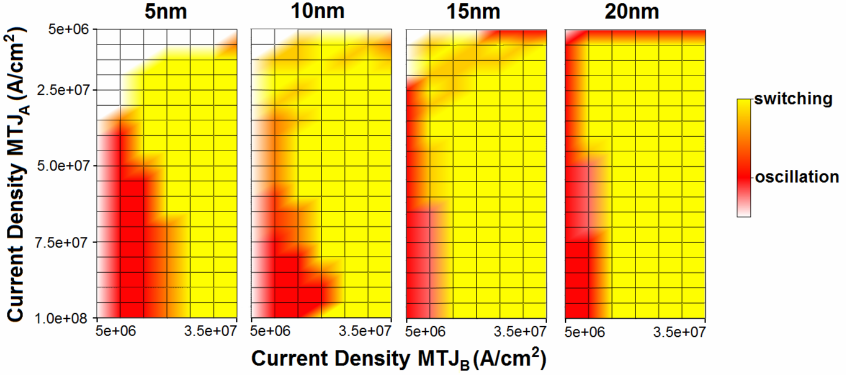

Fig. 6. Schematic illustration of the geometrical dependence of the oscillation regime on the current densities through MTJ_A and MTJ_B. The dependencies are shown for four lengths of the free layer: 45nm (c=5nm), 50nm (c=10nm), 55nm (c=15nm), 60nm (c=20nm).

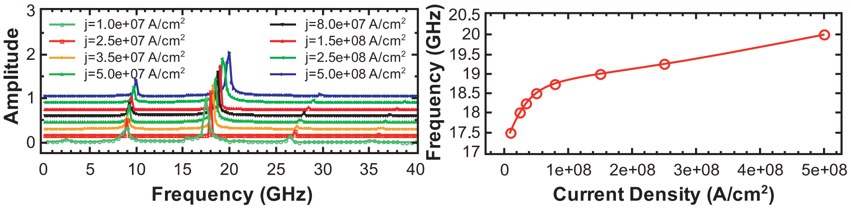

Fig. 7. (left) Signal spectral density normalized to its maximum value. The length of the free layer is 60nm (c=20nm). Current density through MTJ_A varies from 1·10^7 to 5·10^8 A/cm^2, while in MTJ_B it is fixed to 5·10^6 A/cm^2. For convenience the curves are shown with 0.15 offset in the amplitude for different values of the current density through MTJ_A. (right) Frequency as a function of current density.

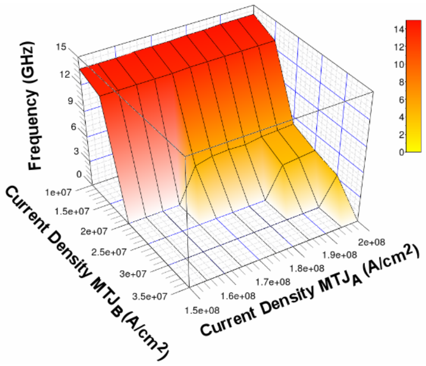

Fig. 8. Frequency as a function of current densities in MTJ_A and MTJ_B. Current densities through MTJ_A vary from 1.5·10^8 to 2·10^8 A/cm^2, while through MTJ_B from 1·10^7 to 3.5·10^7 A/cm^2. The length of the free layer is 50nm (c=10nm).