Frequency Dependence Study of a Bias Field-Free Nano-Scale Oscillator

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INTRODUCTION

Oscillators represent a fundamental building block in modern electronics. They are required in measurement, navigation, communication systems, etc. The periodicity of their output signals is exploited for clocking digital circuits, generating electromagnetic waves, as a reference source for system synchronization, and much more. Spin torque nano oscillators are very appealing as cost effective on-chip integrated microwave oscillators due to their nano-scale size, frequency tunability, broad temperature operation range, and CMOS technology compatibility [1]. Recently, we proposed a bias field-free nano-scale oscillator [2]. The structure consists of three anti-ferromagnetically coupled stacks (two for excitation A, B and one for readout Q) and a shared free magnetic layer, where the eigenmode excitations take place (see Fig. 1). Micromagnetic simulations showed a current regime, where the structure exhibits large and stable in-plane oscillations in the GHz range without the need of an external magnetic field or an oscillating current (see Fig. 2 and Fig. 6). In this work the dependence of these oscillations on the shared free layer geometry at a fixed input current is studied.

THEORY AND SIMULATION SETUP

In order to keep the gained results comparable with the results from [2], the same structure and parameters were employed ($30\,\mathrm{nm}$ width, $120\,\mathrm{nm}$ length, and $3\,\mathrm{nm}$ thickness). But instead of tuning the input current and keeping the aspect ratio constant, the length, width, and thickness of the shared free layer were independently varied. The respective structures are modeled by the Landau-Lifshitz-Gilbert equation [3]. The torque arising from the polarized electrons acting on the local magnetization is described by [4].

RESULTS

Fig. 3 shows that increasing the layers' length decreases the precession frequency. This is consistent with geometrically controlled resonance conditions, where a longer oscillation path leads to a lower frequency. But also changing the layer width (see Fig. 4, $\Delta f/\Delta w \approx 1.75\,\mathrm{MHz/nm}$) and thickness (see Fig. 5, $\Delta f/\Delta z \approx -780\,\mathrm{MHz/nm}$) influences the precession frequency significantly. While variations in the layer width influence the precession frequency a factor of 10 less than length variations, changes in the layer thickness lead to a huge shift. Reducing the layer thickness leads to an increase of the shape anisotropy along the z direction. This contribution opposes and weakens the out-of-plane anisotropy of the free layer and leads to a pronounced shift to in-plane oscillations for thinner free layers (cf. Fig. 6 and [5]).

CONCLUSION

It has been shown that the precessional frequency can be controlled by the dimensions of the shared free layer. It is most efficient to change the layer thickness to control the precessional frequency, but also changing the layer length can be exploited.

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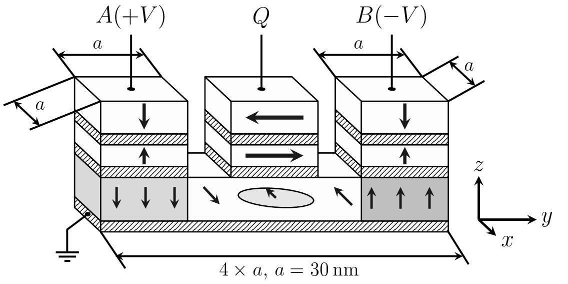

Fig. 1. The initial shared free layer is $30\,\mathrm{nm}$ wide, $120\,\mathrm{nm}$ long, and $3\,\mathrm{nm}$ thick. While changing only one of the free layers dimensions, the others are kept at their initial length. The input current was set constant to $10^{12}\,\mathrm{A/m^2}$ and an out-of-plane uni-axial anisotropy $K_1 = 10^5\,\mathrm{J/m^3}$ in the free layer was assumed.

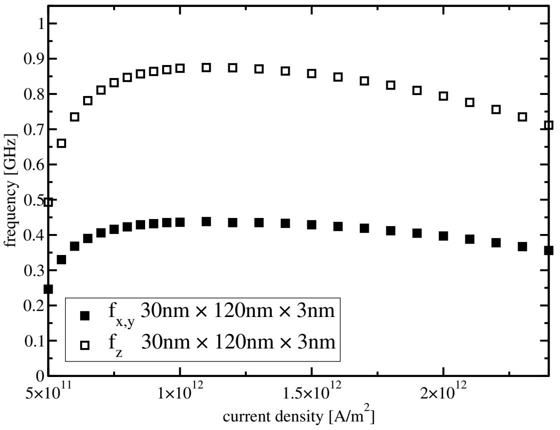

Fig. 2. Resonance frequencies in xy-plane and z-direction as a function of the applied current density. The layer length, width, and thickness remain unchanged at $120\,\mathrm{nm}$, $30\,\mathrm{nm}$, and $3\,\mathrm{nm}$, respectively.

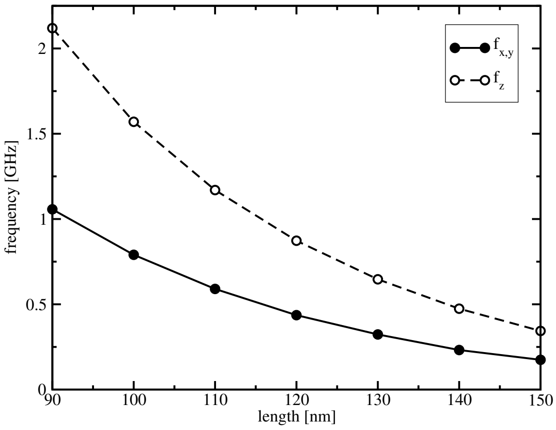

Fig. 3. Resonance frequencies in xy-plane and z-direction as a function of the shared free layer length. The layer width and thickness remain unchanged at $30\,\mathrm{nm}$ and $3\,\mathrm{nm}$, respectively.

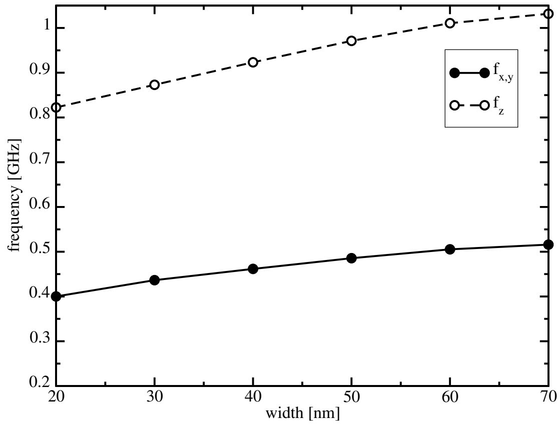

Fig. 4. Resonance frequencies in xy-plane and z-direction as a function of the shared free layer width. The layer length and thickness remain unchanged at $120\,\mathrm{nm}$ and $3\,\mathrm{nm}$, respectively.

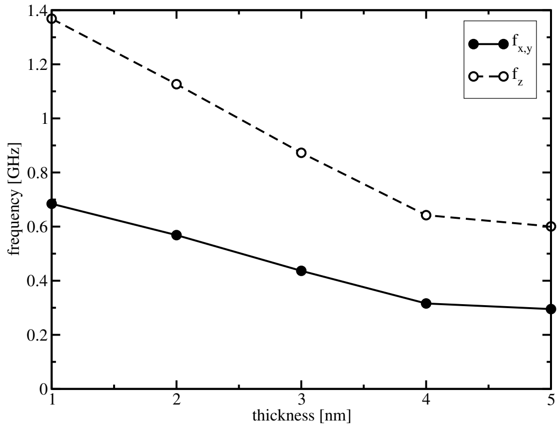

Fig. 5. Resonance frequencies in xy-plane and z-direction as a function of the shared free layer thickness. The layer length and width remain unchanged at $120\,\mathrm{nm}$ and $30\,\mathrm{nm}$, respectively.

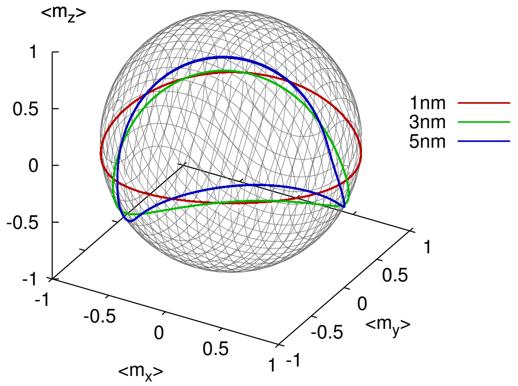

Fig. 6. Normalized pseudo macro spin magnetization oscillations of $<\vec{m}(t)>$ as a function of time. One can see the thinner the shared free layer, the weaker the net out-of-plane anisotropy and thus the more circular the precession path.