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# Effect of Angular Dependence of STT on Dynamical Coupling between Ferromagnets in Symmetric Spin-valves

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Current-induced magnetization dynamics via the spin-transfer torque (STT) [1] has been widely studied because of its interesting physics and potential for the application such as high frequency microwave oscillation devices. Recently, Urazhdin [2] reported a theoretical study on the current-induced magnetization dynamics of a spin-valve structure where none of two ferromagnets is pinned. In this case, both ferromagnets could be excited by STT and are dynamically coupled with each other. He found that this dynamic coupling between two ferromagnets through the STT could yield high dynamical efficiency of STT. It is because the efficiency of STT changes depending on the relative angle between the magnetizations of two ferromagnets. In order to study the current-induced magnetization dynamics of two ferromagnets which are coupled by the STT, it is necessary to consider the angular dependence of the STT, which has been neglected in ref. [2].

In our study, we show that the angular dependence of STT substantially affects current-induced magnetization dynamics of perfectly symmetric spin-valve where two ferromagnets are excited and dynamically coupled. We first calculate the angle-dependent STT by means of the drift-diffusive model [3] and simulate the dynamics of two ferromagnets using the Landau-Lifshitz-Gilbert (LLG) equation including STT-term in the macrospin assumption. We consider two bilayer structures which have NiFe (Permalloy, Py) and Co as a ferromagnetic layer, respectively (SV_Py (=Py(3)|Cu(8)|Py(3)) and SV_Co (=Co(3)|Cu(8)|Py(3)), all in nanometers). Two bilayers are attached to finite Cu layers of 60 nm-thick. Because of a large difference of the spin diffusion length between Py and Co, the two structures show a fairly different angular dependence of STT as depicted in Figure 1.

Figure 2 shows the precession frequency as a function of the injected current when no external field is applied. In contrast to the conventional spin-valve where one of two ferromagnets is pinned, we observed zero-field microwave oscillations in broad ranges of the current in both structures. The precession frequencies of SV_Co are in general higher than those of SV_Py. Interestingly, in some ranges of the current, the 2nd harmonic shows a higher power than that of the fundamental precession frequency. In SV_Py, this current range showing a higher power of the 2nd harmonic is rather narrow, whereas in SV_Co, it is wide, which results from the difference in angular dependence of STT and allows high frequency microwave signal.

To summarize, we find that the unpinned symmetric spin-valve structure allows zero-field microwave oscillations and its magnetization dynamics is substantially affected by the angular dependence of STT. Recently, an experimental study has been performed for almost symmetric spin-valve structure [4], but in that case, one of ferromagnets is left unpatterned, which breaks the symmetry. Our results indicate that the symmetric spin-valve (for instance, the same material/thickness and all patterned sample) could allow a different class of the current-induced magnetization dynamics when the angular dependence of STT is properly designed.

## References

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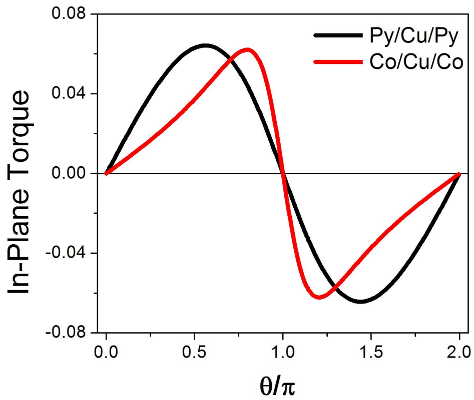


Figure 1. Angle-dependent STT for SV_Py (black line) and SV_Co (red line).

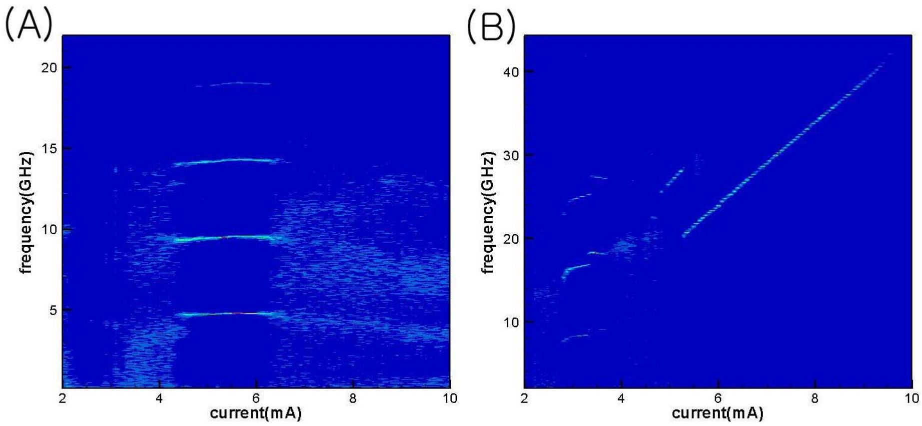


Figure 2 . Spectral intensity for MR due to the dynamics of magnetization of two ferromagnets for (A) SV_Py structure and (B) SV_Co structure.