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Spin-torque ferromagnetic resonance in arbitrarily magnetized thin films

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The spin Hall effect (SHE) in non-magnetic metals can be used to generate spin-transfer-torque (STT), subsequently inducing ferromagnetic resonance (FMR) in magnetic thin films; this experimental method is termed spin-torque ferromagnetic resonance (ST-FMR). Most ST-FMR experiments that are reported have an applied magnetic field in the plane of the sample and the research focuses on material combinations that have large and efficient STT. The most common way ST-FMR signals are detected is through an anisotropic magnetoresistance (AMR) rectification process. In this work we will present ST-FMR results in thin films where the magnetization has both an in-plane and out-of-plane component. The arbitrary magnetization direction is achieved by tipping the applied magnetic field out of the sample plane. We find that when the material system is a permalloy/Pt bilayer, ST-FMR signals are not mirror-symmetric upon magnetic field reversal [2]. This is because the combination of both a STT from the bulk SHE and the Oersted field-like torque from the device do not drive the dynamics in the same manner when the field is reversed. We interpret our results in the Py/Pt experiment by extending an already established ST-FMR lineshape model to describe the general case of arbitrarily magnetized films. We compare and contrast our Py/Pt experiment with another system we measured, a Py/MoS_2 bilayer. For the Py/MoS_2 system, in-plane experiments suggest that a large STT is present and are comparable to what is observed for the more traditional Py/Pt system [3]. On the other hand, the out-of-plane experiment for the Py/MoS_2 system is qualitatively very different from Py/Pt. Our results suggest that ST-FMR experiments for arbitrarily magnetized magnetic films are useful in characterizing STT generated from interface rather than bulk effects. Work at Northwestern was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Materials Science and Engineering Division under grant number DE-SC0014424. Work at Argonne was supported by the U.S. Department of Energy, OS, Materials Science and Engineering Division. Lithography was carried out at the Center for Nanoscale Materials, which is supported by DOE, OS-BES under Contract No. DE-AC02-06CH11357.

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[2]J. Sklenar *et al*, Submitted
[3]W. Zhang, J. Sklenar *et al*, Submitted