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Quantifying Spin Hall and Rashba effect contributions to spin-orbit toque in magnetic bilayers

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Electrical control of magnetism has been energized by recent observation of spin-orbit torques in magnetic bilayers made of a heavy metal (HM) and ferromagnet (FM). It has been demonstrated that the spin-orbit torques driven by an in-plane current can switch magnetization, manipulate magnetic domains and excite magnetization auto-oscillation. However, the microscopic mechanism for the spin-orbit torques is still under debate. The question being whether the dominating spin-orbit coupling (SOC) arises from the HM/FM interface due to the Rashba effect or arises in the bulk of HM due to the spin Hall effect, or a combination of the two. It has been theoretically demonstrated that both the Rashba effect and the spin Hall effect generate a field-like torque (T_{SOF}) and damping-like torque (T_{SOT}) on the magnetization, with only quantitative differences. Therefore, an accurate method to determine the T_{SOF} and T_{SOT} with various thicknesses of the FM and HM are needed. We present a newly developed, magneto-optic-Kerr-effect based spin-orbit torque magnetometer that measures both T_{SOF} and T_{SOT}, which can have both spatial and time resolution. We observed both T_{SOF} and T_{SOT} are nonlocal and does not require direct contact between FM and HM ...[1, 2]. By engineering the interface which modifies the Rashba interaction, we are able to show the co-existence of spin Hall and Rashba effect as well as quantify both contributions to spin-orbit torques [1].

[1] Fan, X., H. Celik, J. Wu, C. Ni, K.-J. Lee, V.O. Lorenz, and J.Q. Xiao, *Quantifying interface and bulk contributions to spin-orbit torque in magnetic bilayers.* Nature Communication, 2014. **January 9**: p. ncomms4042.
[2] Fan, X., J. Wu, Y.P. Chen, M.J. Jerry, H.W. Zhang, and J.Q. Xiao, *Observation of the nonlocal spin-orbital effective field.* Nature Communications, 2013. **4, April 30**.

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