Abstract Submitted
for the MAR17 Meeting of
The American Physical Society

Phase-Resolved Detection of the Spin Hall Angle by Optical Ferromagnetic Resonance in Perpendicularly Magnetized Thin Films AMIR CAPUA, TIANYU WANG, SEE-HUN YANG, CHARLES RETTNER, TIMOTHY PHUNG, STUART PARKIN, IBM Almaden Res Ctr — Measurement of the spin Hall angle, especially for atomically thin systems with large magnetic anisotropies, is not straightforward. Here we demonstrate a hybrid phase-resolved optical-electrical ferromagnetic resonance method that we show can robustly determine the spin Hall angle in heavy-metal/ferromagnet bilayer systems with large perpendicular magnetic anisotropy. We present an analytical model of the ferromagnetic resonance spectrum in the presence of the spin Hall effect, in which the spin Hall angle can be directly determined from the changes in the amplitude response as a function of the spin current that is generated from a DC charge current passing through the heavy-metal layer. Increased sensitivity to the spin current is achieved by operation under conditions for which the magnetic potential is shallowest at the "Smit point". Study of the phase response reveals that the spin Hall angle can be reliably extracted from a simplified measurement that does not require scanning over time or magnetic field but rather only on the DC current. The method is applied to the Pt-Co/Ni/Co system whose spin Hall angle was to date characterized only indirectly and that is especially relevant for spin orbit torque devices.

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Date submitted: 08 Nov 2016 Electronic form version 1.4