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Quantifying Spin Hall Effects from Spin Pumping[1]

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Recent activity in spin transport research has included a focus on spin Hall effects, which arise from spin-orbit interactions. Spin orbit coupling in normal metals (NM) results in a conversion of pure spin currents into charge currents, which are perpendicular to both the spin current direction and the spin polarization. This phenomenon is known as the inverse spin Hall effect and it generates a voltage across a spin-current-carrying sample. The strength of the inverse spin Hall effect is characterized by a single dimensionless parameter, the spin Hall angle, which is materials-specific. Here we present a new method to quantify spin Hall angles for many different materials. We studied the inverse spin Hall effect in $Ni_{80}Fe_{20}$/NM bilayer structures by generating pure spin currents inside the NM layer through spin pumping at the $Ni_{80}Fe_{20}$/NM interface. Integrating a patterned $Ni_{80}Fe_{20}$/NM bilayer into a coplanar waveguide transmission line enables us to excite large angle magnetization precession in $Ni_{80}Fe_{20}$ via *rf* excitation, which in turn generates a *dc* spin current in the adjacent NM. A strong *dc* signal across the $Ni_{80}Fe_{20}$/NM is observed at the FMR position, and its magnitude is dependent on the power of the *rf* excitation and the direction of the applied magnetic field. We identified two distinct contributions to the *dc* voltage: one symmetric with respect to the FMR resonance position, and the other antisymmetric. Our analysis shows that the antisymmetric contribution is due to anisotropic magnetoresistance (AMR) in the $Ni_{80}Fe_{20}$ layer and is present even in single-layer $Ni_{80}Fe_{20}$ films. The second, symmetric, contribution to the *dc* voltage is attributed to the inverse spin Hall effect. The main advantage of our approach is that this second contribution scales with the device dimension and thus even small spin Hall signals can be detected with large accuracy. Using this approach we determined the spin Hall angle for Pt, Au and Mo by fitting the experimental data to a self-consistent theory, which accounts for both AMR and inverse spin Hall effect contributions.[2] Our technique allows to electrically detect the spin accumulation in the NM. Using this connection, we also showed that spin pumping is suppressed when MgO tunneling barrier is inserted at the $Ni_{80}Fe_{20}$/NM interface.[3]

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[2]O. Mosendz, J. E. Pearson, F. Y. Fradin, G. E. W. Bauer, S. D. Bauer, and A. Hoffmann, ArXiv:0911.2725.

[3]O. Mosendz, J. E. Pearson, F. Y. Fradin, S. D. Bauer, and A. Hoffmann, ArXiv:0911.3182