Spin Hall Effect in YbAl₃

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Primary CNF Tools Used: 5x G-line stepper, AJA sputter deposition tool, Heidelberg DWL2000

Abstract:
The spin Hall effect results in a spin current that flows transverse to an applied electric field in non-magnetic materials, and that can be used to apply an efficient spin-transfer torque in magnetic memory devices. Recent experimental and theoretical work has shown that the magnitude of the spin Hall effect should be enhanced by the presence of 4f-derived bands near the Fermi level. YbAl₃ is a rare-earth mixed-valence system, in which the ytterbium (Yb) 4f states become increasingly itinerant at low temperatures. This is accompanied by a shift of the 4f derived bands towards the Fermi level and an enhanced 4f contribution to the YbAl₃ Fermi surface, as temperature is lowered. In this report we discuss the measurement of the spin Hall effect in LuAl₃/YbAl₃/Fe/Al multilayers as a function of temperature.

Summary of Research:
The spin Hall effect arises from spin-dependent interaction of electrons with the electronic band structure of a given material, the so-called “intrinsic” contributions, and from asymmetric spin scattering off of impurities, the “extrinsic” contributions. Intrinsic contributions to the spin Hall effect are generally large when the material has large spin-orbit coupling and avoided crossings at the Fermi level. Materials that are expected to have large intrinsic spin Hall effects are then the late transition metals (those with 5d valence), and the f-valent lanthanides and actinides. Much work measuring the spin Hall effect in the 5d metals has indeed shown a large spin Hall effect [1], but it is only recently that any work has been to corroborate this understanding in the lanthanide (4f) metals [2]. To further our understanding of the effect of the 4f orbital-derived bands on the intrinsic spin Hall effect, we measured the spin Hall effect as a function of temperature in YbAl₃, a material system in which the 4f-derived bands move through the Fermi level and become itinerant as temperature is decreased. Because of this temperature dependence of the 4f-derived states, we expect that the intrinsic spin Hall effect should increase as the temperature of the YbAl₃ is decreased.

LuAl₃/YbAl₃/Fe/Al multilayers were grown on MgO substrate using molecular beam epitaxy (MBE) in collaboration with the Schlom group. Micron-scale devices were patterned out of the films via photolithography using the 5x g-line stepper. Argon ion milling was then used to define the devices. Ti/Pt liftoff leads were applied via photolithography, again with 5x g-line stepper, and the AJA sputter deposition tool. An optical image of a finished device is shown in Figure 1.

Measurements of the spin Hall effect as a function of temperature were done using spin torque-ferromagnetic resonance (ST-FMR) [3,4] in a custom He-flow cryostat. ST-FMR uses a microwave frequency signal (6-20 GHz) to excite resonant dynamics of the magnetic Fe layer that then leads to a measureable voltage that is proportional to the strength of the spin Hall effect. We report the strength of the spin Hall effect as a dimensionless efficiency calculated as the ratio of the measured spin current to applied charge current. We find a strong enhancement of the spin Hall effect as temperature is decreased, consistent with the hypothesis that the f-orbital-derived states should enhance the spin Hall effect as their presence at the Fermi level is increased (Figure 2).
Figure 1: An optical image of a finished device used to measure the spin Hall effect via ST-FMR.

Figure 2: Spin Hall effect efficiency as a function of temperature measured by ST-FMR of a LuAl$_3$/YbAl$_3$/Fe/Al multilayer. A strong increase in the spin Hall effect efficiency is observed going from 300 K down to 10 K.

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