Spin Hall Effect in $CaRuO_3$

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Principal Investigators: Daniel Ralph, Darrell Schlom

Users: Neal Reynolds, Hari Nair, Nathaniel Schreiber

Affiliations: Laboratory of Atomic and Solid State Physics, Materials Science and Engineering; Cornell University

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Contact: dcr14@cornell.edu, schlom@cornell.edu, ndr37@cornell.edu

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

Abstract:

The spin Hall effect results in the generation of pure spin current that flows transverse to an applied electric field in non-magnetic materials. Recent experimental and theoretical work has shown that the presence and evolution of heavily-renormalized, flat, quasi-particle bands near the Fermi level can dramatically influence the magnitude of the spin Hall effect. $CaRuO_3$ is a so-called "Hund's metal" in which electron correlation due Hund's rule coupling is relevant. These strong correlations along with the large octahedral distortions in $CaRuO_3$ results in the emergence of flat quasi-particle bands below 120 K and a change in sign of the Hall coefficient below ~ 50 K — indications of non-trivial modifications of the Fermi surface by the quasi-particle bands as temperature is decreased. In this report we discuss the measurement of the spin Hall effect in $CaRuO_3$/Permalloy ($Ni_{80}Fe_{20}$, Py) bilayers as a function of temperature.

Summary of Research:

The spin Hall effect arises from spin-dependent interaction with a material's band structure, so-called "intrinsic" contributions, and spin-dependent scattering off of impurities in a given material, so-called "extrinsic" contributions. Intrinsic contributions to the spin Hall effect are large when in materials with strong spin orbit coupling and when the Fermi level lies within avoided crossings opened up by the strong spin orbit coupling. Materials that are expected to have large intrinsic spin Hall effects are then the late transition metals (those with 5d valence) [1], and the f-valent lanthanides [2] and actinides. Very recent work in a rare-earth Kondo lattice system has suggested that the presence of Kondo-derived heavy quasi-particle bands near the Fermi level can drive an enhancement of the spin Hall effect. The understanding of this enhancement, however, is complicated by the fact that the Kondo physics also gives rise to an enhancement of the 4*f* orbital bands near the Fermi level, which has been shown to independently enhance the spin Hall effect [2].

To understand the contribution of the strong correlation on the enhancement of the spin Hall effect without 4*f* orbitals present, we examine the spin Hall effect in calcium ruthenium trioxygen ($CaRuO_3$) as a function of temperature, because it exhibits pockets of flat quasi-particle bands starting at 120 K and below. The evolution of the Fermi surface due to these bands culminates in a reversal of the Hall coefficient at ~ 50 K. Given the sensitivity of the intrinsic spin Hall effect to the material's band structure, we expect that as temperature is decreased from room temperature we will observe a change in the spin Hall effect at these temperatures.

$CaRuO_3$ was grown on a neodymium gallium trioxygen ($NdGaO_3$) substrate using molecular beam epitaxy (MBE) in collaboration with the Schlom group. Films were then taken to a sputter deposition system to deposit Permalloy (Py) and an aluminum capping layer. Micron-scale devices were patterned out of the films via photolithography using the 5x g-line stepper, and argon ion milling was 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.

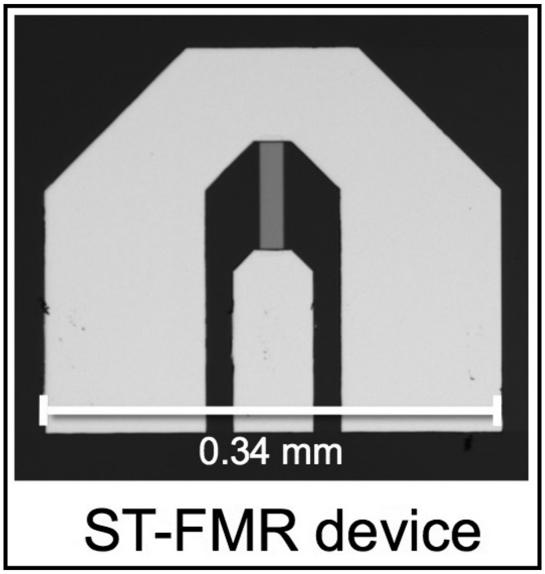

Figure 1: An optical image of a finished device used to measure the spin Hall effect via ST-FMR.

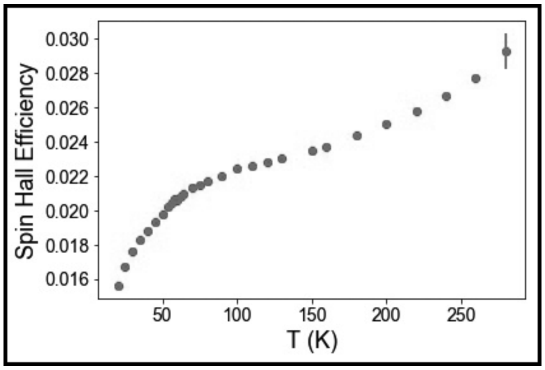

Figure 2: Spin Hall effect efficiency as a function of temperature measured by ST-FMR of a $CaRuO_3$/Py bilayer. The spin Hall effect decreases going from 280 K to 20 K with an inflection points at ~ 120 K and a slope change vs T at ~ 50 K consistent with the onset of the quasi-particle bands and the Hall effect coefficient sign reversal observed in $CaRuO_3$, respectively.

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 Py layer that then leads to a measurable 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 gradual decrease of the spin Hall effect with temperature, but with an inflection point ~ 120 K, consistent with the onset of the quasi-particle states, and a change in slope at ~ 50 K, commensurate with the change in Hall effect coefficient sign (Figure 2).

References:

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