"Listening" to the Spin Noise of Conduction Electrons in Bulk n:GaAs

Scott A. Crooker, Lili Cheng (NHMFL-LANL), Darryl L. Smith (T-11, LANL)

Not long after the discovery of nuclear magnetic resonance, Felix Bloch wrote in his seminal 1946 paper on *Nuclear Induction* that "Even in the absence of any orientation by an external magnetic field one can expect in a sample with N nuclei of magnetic moment μ to find a resultant moment of the order $N^{1/2}\mu$ because of statistically incomplete cancellation." Thirty-nine years later these small, random fluctuations within a nuclear spin ensemble -- spin noise – were directly observed by Sleator in a low-temperature nuclear quadrupole resonance study of ^{35}Cl nuclei in $NaClO_3$. Subsequently, interest in spin noise phenomena has been growing steadily, particularly in recent years as experimental detection sensitivities continue to improve and as the characteristic sizes of probed spin ensembles grow ever smaller. For example, proton nuclear spin noise was measured in liquid samples at room temperature, and spatial distributions of nuclear spin noise have been imaged, an important step towards an alternative and `passive' approach to magnetic resonance imaging (MRI) that is based on a system's intrinsic spin fluctuations alone.

We report a comprehensive study of stochastic electron spin fluctuations -- spin noise -- in lightly doped (n-type) bulk GaAs, which are measured using sensitive optical magnetometry based on off-resonant Faraday rotation (see Fig. 1a). Frequency spectra of electron spin noise are studied as a function of electron density, magnetic field, temperature, probe laser wavelength and intensity, and interaction volume. Electron spin lifetimes τ_s are inferred from the width of the spin noise spectra, and are compared with direct measurements of τ_s using conventional Hanle effect methods. Both methods reveal a strong and similar dependence of τ_s on the wavelength and intensity of the probe laser, highlighting the undesired influence of sub-bandgap absorption effects on the nominally `non-perturbative' spin noise measurements. As a function of temperature, the spin noise power increases approximately linearly from 1.5 to 30 K, as expected for degenerate electrons obeying Fermi-Dirac statistics, but with an additional zero-temperature offset. Finally, as the cross-sectional area of the probe laser shrinks and fewer electrons are probed, the measured Faraday rotation fluctuations due to electron spin noise are shown to increase, as expected.

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[1] S. A. Crooker, L. Cheng, and D. L. Smith, Phys. Rev. B, in press

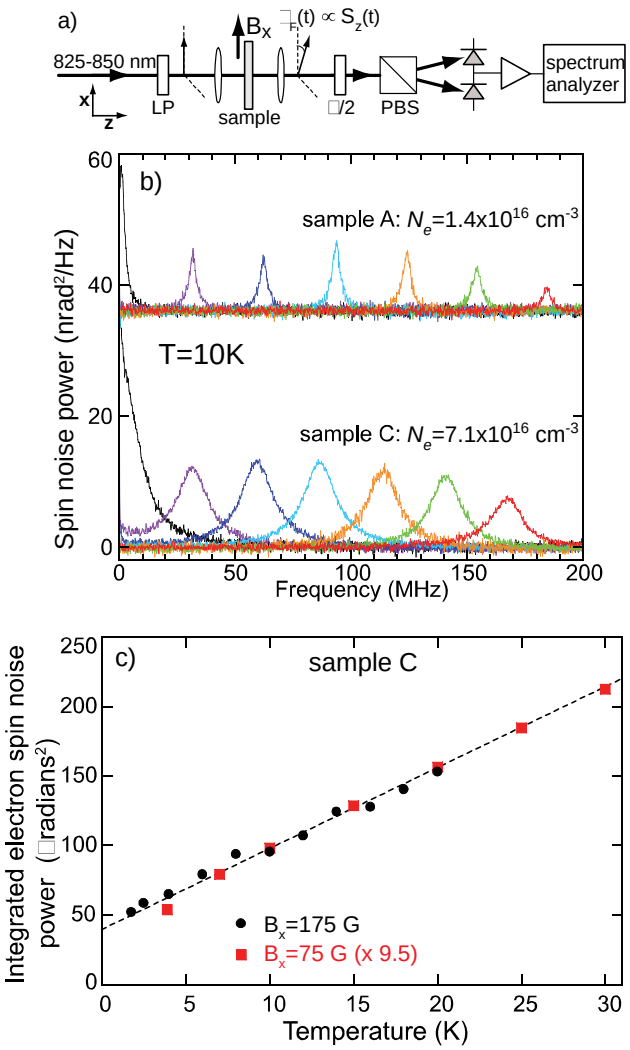

Figure 1. a) Experimental setup of the optical magnetometer. b) Electron spin noise in n:GaAs, at 0, 50, 100, 150, 200, 250, and 300 G. c) The T-dependence of the integrated spin noise power, which decreases linearly with decreasing temperature (as expected for an electron gas obeying Fermi-Dirac statistics), but with a zero-T offset.