Optical Spectroscopy of Spin Noise

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Introduction

Optical probes of spin and magnetization dynamics enjoy broad applications across the many atomic, semiconductor, and metallic systems in which spin-orbit interactions allow coupling between spin polarization and the optical (circular) polarization of light. Experimental techniques include powerful polarization-based spectroscopies of optical Faraday/Kerr rotation and circularly-polarized photoluminescence. Typically, the signals of circular anisotropy in these experimental approaches are proportional to some *intentionally* induced changes in the magnetization or spin polarization of the sample. In 1981, however, it was demonstrated that the spontaneous and random fluctuations of spin polarization that naturally occur in thermal equilibrium, can also be detected by sensitive optical Faraday rotation methods. In accord with the fluctuation-dissipation theorem, the frequency spectrum of this intrinsic "spin noise" (SN) should correspond to that of the linear susceptibility of the system and, therefore should contain the same information about magnetic and dynamic properties of the spin system as its magnetic resonance spectrum.

Results and discussion

Here we demonstrate that the SN-related fluctuations of the Faraday rotation (FR) probed at different optical wavelengths may be either correlated or not depending on whether or not they are contributed by the same spins. We show that this fact can be revealed in the optical spectra of the FR *noise*, which implies measuring the total spin noise power as a function of the probe light wavelength. In what follows these spectra will be referred to as optical spin noise (OSN) spectra, which are related to conventional time-averaged FR spectra in a nontrivial way. In particular, FR *fluctuations* do not necessarily vanish at optical wavelengths where the conventional time-averaged FR itself is zero.

The use of the probe wavelength as a tunable parameter establishes this technique as *optical spectroscopy of spin noise*. We show that this approach makes it possible, in certain cases, to reveal structure of optical transitions hidden in the linear optical spectra and thus opens new possibilities for noise-based techniques. We consider model situations wherein OSN spectra can distinguish or resolve optical transitions associated with the same or different spin subsystems. These situations include strongly inhomogeneously broadened optical transitions, where the differences between conventional FR and fluctuating FR noise spectra are revealed in the most spectacular form.

These new possibilities are illustrated by theoretical calculations and by experiments on paramagnets with different degrees of inhomogeneous broadening of optical transitions (atomic vapors of ^{41}K and singly-charged InGaAs quantum dots).

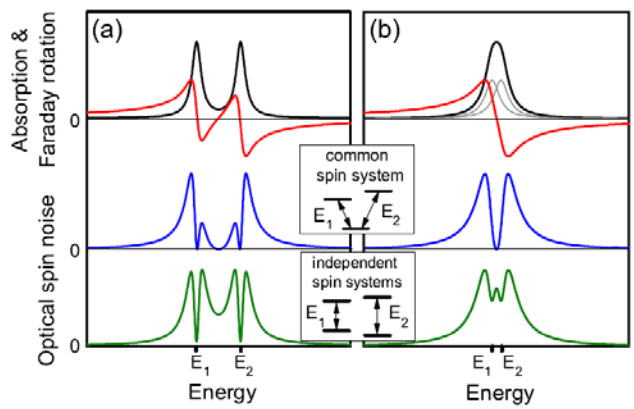

Figure 1. Modeled optical spectra of a spin system having two resolved (a) and unresolved (b) absorption lines. Top panels show absorption and conventional FR spectra. Middle and lower panels show the calculated OSN spectra when the two transitions originate from a common spin system (correlated spin fluctuations) or from independent spin systems (uncorrelated fluctuations).

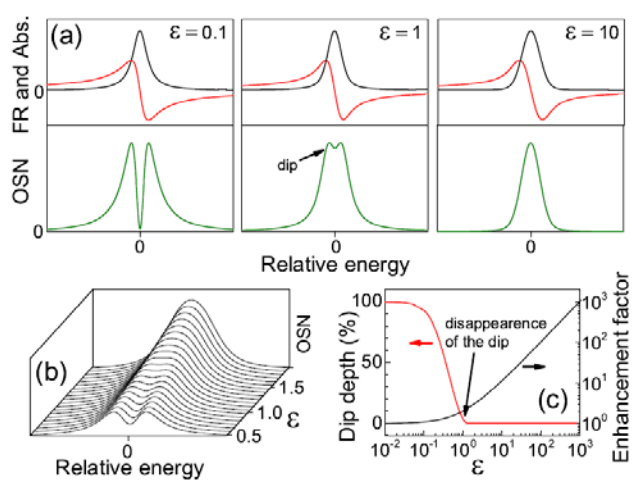

Figure 2. Calculated absorption, Faraday rotation, and OSN spectra for spin-dependent transitions exhibiting different ration, e, of inhomogeneous to homogeneous linewidth. Evolution of OSN spectra with increasing ratio e.

[1] V.S. Zapasskii *et al.*, *submitted*; arXiv:1206.4168v1