High-resolution magneto-optic Kerr effect for spintronics applications

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While the Kerr effect has been used extensively for the study of magnetic materials, it is only recently that its was shown to be a powerful tool for the study of more complex quantum matter. Since such materials tend to exhibit a wealth of new phases and broken symmetries, it is important to understand the general constraints on the possibility of observing a finite Kerr effect. In this presentation we will review the consequences of reciprocity on the scattering of electromagnetic waves. In particular, we will concentrate on the possible detection of the Kerr effect from chiral media with and without time-reversal symmetry breaking. We will show that in the linear regime, a finite Kerr effect is possible only if reciprocity is broken. We will then discuss possible Kerr effect detection for materials with natural optical activity, magnetism, and chiral superconductivity.

The above introduction will serve to introduce a novel technique for ultra high-resolution detection of the Kerr effect. The technique is based on the principles of a Sagnac loop, commonly used as the heart of high-resolution optical gyroscopes. In the most recent version, a single polarization maintaining fiber (PMF) is used to constitute a zero-area loop in which two counter-propagating beams use the two polarization states of the fiber as a waveguide. Emerging out of the fiber-strand, the two linear polarizations go through a quarter waveplate, and the resulting two circular polarizations interact with the material from which they are reflected back at normal incidence. The two reflected beams go back through the quarter waveplate into the fiber strand and interfere at the detector. Placing the detector next to the source with a directional circulator determining the emerging and returning beams, and with a reciprocal mirror in place of a sample, this interferometer is fully reciprocal and the output is identically zero (except for an instrumental offset that can be fully characterized before measurements commence.) Operationally, by modulating the two counter-propagating beams using an electro-optic phase modulator, and locking in on the modulation, the ratio of first and second harmonic outputs yields the desired phase shift, which is finite in the presence of any non-reciprocal effect along the optical circuit. Currently we have achieved shot-noise limited resolution of ~100 nanorad/$Hz^{1/2}$ at ~10 μW incident power, which allowed measurements at temperatures as low as 300 mK.

Finally, we will discuss applications of the Sagnac system to the study of unconventional superconductors, as well as magnetically-coupled topological insulators as possible platforms for future spintronics applications.