Second Harmonic Generation Prospectus

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Background:

The creation of the laser in 1960 led to the invention of a new field of physics, nonlinear optics. When an incident electric field is strong enough, the resulting polarization of a dielectric material is no longer linear. Instead, if the polarization is expanded as a Taylor Series, one finds there are now relevant higher order terms which provide a nonzero contribution to the total polarization. The first nonlinear term of the expansion determines the second harmonic generation (SHG) of the system. In order for this term to appear, a broken symmetry within the system is required. In the bulk of the material, this requires that the structure of the material is non-centrosymmetric. However, inversion symmetry is necessarily broken at a surface or interface between two media with varying structural compositions. Because of this necessary break in symmetry, the SHG signal risen to become a powerful tool as a surface probe in such techniques as surface spectroscopy due to its surface specificity and non-invasion nature as a measuring technique.

The explanation offered by BCS theory to describe conventional superconductors relies on the pairing of electrons by an electron-phonon interaction. This interaction allows the electrons of a superconducting material to condense to a lower energy (superconducting) state at temperatures below approximately 30k. The critical temperature of high temperature superconductors is well above this physical limit, leading to the need for a new theory to describe this behavior. One such theory has been proposed by theorist C.M. Varma, in which a condensation of the electronic wavefunction within the material below a certain critical temperature accounts for the superconducting behavior observed. If this condensation occurs, it will create a broken symmetry within the material which will be detectable by probing the sample for the generation of a second harmonic signal. It is the purpose of this project to test the validity of this theory for the mechanism of high temperature superconductivity and attempt to move closer to a concrete explanation for this phenomenon.

Goals:

The primary focus of this project is to use second harmonic generation (SHG) as a probe to study semiconductor and highly-correlated electronic systems, such as high-temperature superconductors. SHG is a powerful tool for measuring surface and bulk properties of these materials because of its sensitivity to band structure and surface preparation, simplicity, and non-invasive nature. This technique will be implemented by using a cavity-dumped Ti:Sapphire oscillator, liquid Helium bath optical cryostat, and a sensitive photon-detection device. In order to complete this project, these three aspects of the project must be completely characterized. The remainder of this document presents a month-by-month timeline of the project.

Progress:

Currently, I am characterizing the birefringence of the cryostat windows at room temperature. Since the Ti:sapph is still not operational, I have purchased an 800 nm polarized laser diode which I am now using to conduct the experiment. Initial results show that the windows do indeed have some birefringence at room temperature when circular light is passed through them. Oddly, when linear polarization of any orientation is used, no birefringence is observed, which is inconsistent with the expected results. I have begun building a computer program which will be able to identify the polarization state of the light both before and after it passes through the cryostat windows. This should allow me to determine the birefringence of the windows and hopefully corrected their effect using a quarter and half waveplate. In the immediate future, I plan on revisiting my initial findings to make sense of the inconsistent birefringence I previously found in order to completely characterize the windows. Once characterized, I will cool the cryostat down using liquid nitrogen (as most of the thermal strain placed on the windows will occur within this temperature range, though liquid helium will be used in the actual experiment) and determine if the strain relieving mounts for the windows are able to relieve the pressure which was previously placed on the windows when cooled down, which added unwanted birefringence to the windows and complicated the process of providing truly circular light at the sample.

SHG Timeline:

September—December, 2010:

- Increase Ti:Sapphire oscillator pulse peak power by decreasing repetition rate
    - Implement cavity dumping in oscillator
- Characterize cryostat window birefringence at room temperature
- Re-write current SHG LabVIEW program to record signal from SRS830 lock-in amplifier and a TDS2024B digital oscilloscope
- Characterize cryostat window birefringence at 5 K
    - Measure deviation of HeNe laser polarization when passing through cryostat windows
- Devise new data normalization scheme using two-photon absorption in a GaAsP photodiode
    - Calibrate photodiode response by comparing signal to pulse intensity and width using an autocorrelator

December, 2010:

- Rebuild SHG experimental setup
    - ***Components***: oscillator output collimation; dispersion compensation using prism pair; normalization scheme; beam pointing and focusing into cryostat; SHG signal collection

January – April, 2011:

- Study bulk and surface SHG from Silicon
    - Measure SHG response as a function of temperature, excitation wavelength, and excitation polarization

May – July, 2011:

- Study SHG from high-temperature superconductor
    - Use circular polarization to probe inversion and time-reversal symmetry

August – October, 2011:

- Start writing honors thesis
- Determine honors committee

November, 2011:

- Submit honors thesis
- Send thesis to committee

December, 2011:

- Defend honors thesis

SHG References (so far)

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