All-optical Pump-probe Experiments on YBCO and LBCO Crystals

SLAC NATIONAL ACCELERATOR LABORATORY

Will Hettel[1+], Giacomo Coslovich[2+], Scott Wandel[2+]

[1]University of California at Santa Barbara.

[2]Linac Coherent Light Source, SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025, USA.

[+]Contact: wjhettel@gmail.com; gcoslovich@slac.stanford.edu; wandel@slac.stanford.edu

Introduction

Pump-probe reflectivity experiments use pulsed lasers to measure dynamics in materials. The laser beam is split in two, one beam used as a "pump" and one as a "probe." The pump beam induces a change in the state of the material, which often changes its reflectivity. This change of state can involve different properties such as superconductivity, the charge order of the material, and of many more. The intensity of the probe beam is measured after reflecting off of the material, which serves as a measurement of the material's reflectivity. By changing the relative arrival times of the pump and probe pulses, one can observe the state of the material as a function of time.

Keywords: pump-probe, materials, dynamics, optical measurements

Methods/Research

The setup is shown in Figure 1. A beam from an 800 nm laser consisting of 50 femtosecond pulses at 120 Hz is split using a 50/50 beamsplitter to create the pump and probe beams. The relative arrival time between pump and probe pulses is controlled by a retroreflector on a motorized stage which modifies the path length of the pump beam (red). The intensity of each beam is controlled by a half-wave plate and polarizer. The pump beam's waveplate is on a motorized mount to have easy and accurate control of fluence. The pump beam is focused to a 1 millimeter diameter on the sample (inside the cryogenic chamber), while the probe (blue) is focused to a 0.5 millimeter diameter. The reflection of the probe beam is then measured by a photodiode.

The relative change in reflection (ΔR/R) caused by the pump beam is generally on the order of 10^-3 and can be as low as 10^-5. Therefore, simply measuring the total reflection of the probe beam is not enough to resolve a signal. In order for these small changes in reflection to be seen, the pump beam is periodically blocked by an optical chopper. ΔR/R then appears as a modulation on top of the total intensity of the reader at the pump beam's frequency. The amplitude of this modulation is extracted by a lock-in amplifier, which reads the diode signal and multiplies it by a sine wave at the frequency that the chopper transmits.

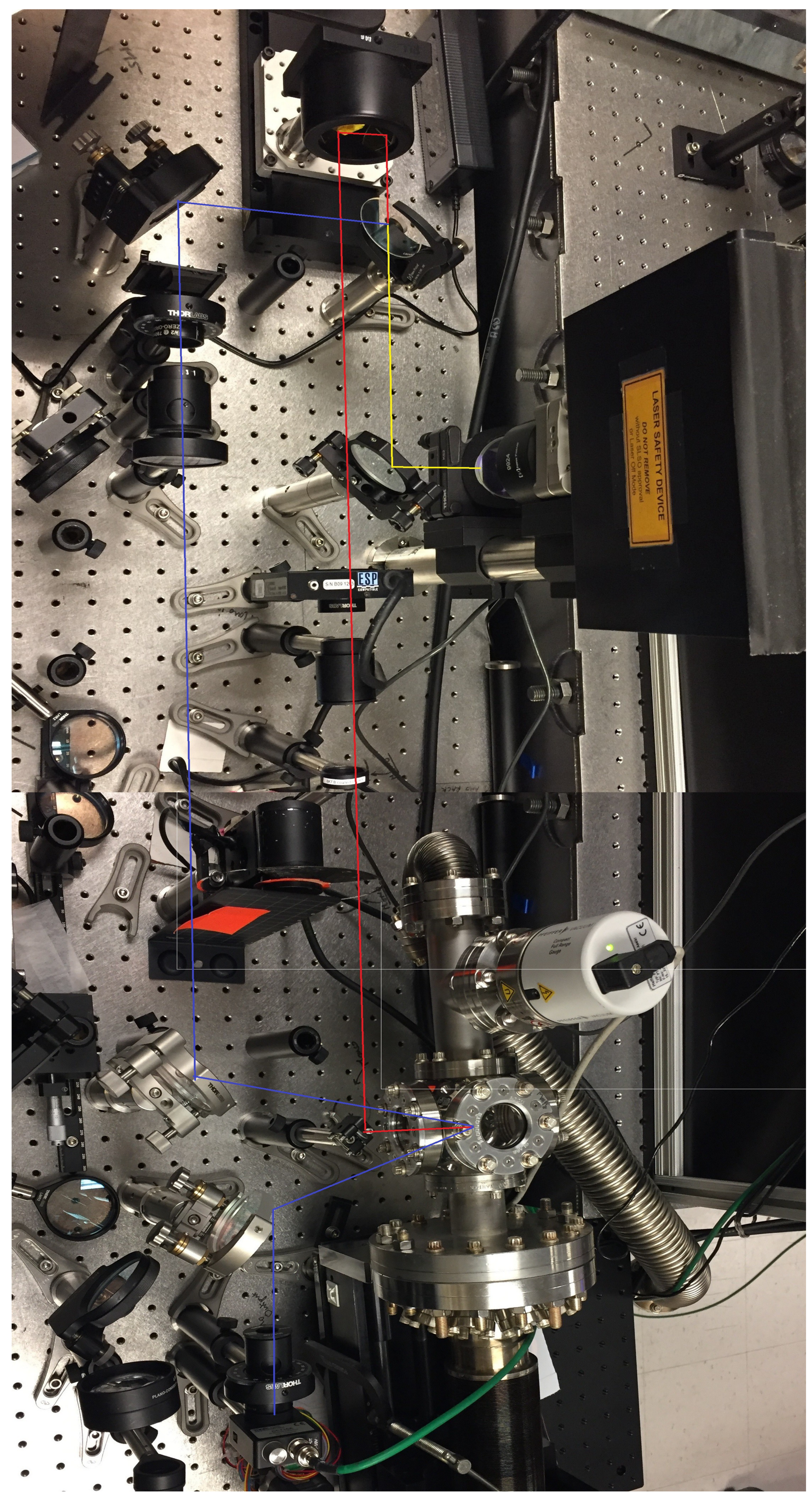

Figure 1. The 800 nm pump-probe setup. The incoming beam (yellow) is split into a pump beam (red) and probe beam (blue). The pump beam reflects off of a retroreflector, then passes through a half-wave plate, polarizer, lens, and chopper before reaching the sample in the cryogenic chamber. The probe beam passes through a filter (to reduce energy), half-wave plate, polarizer, and lens before reflecting off of the sample and being measured by a photodiode. A polarizer is placed in front of the photodiode to reject the vertically polarized pump beam and transmit the horizontally polarized probe beam.

All motor control and data acquisition is done with LabVIEW. First the pump beam waveplate is moved to the desired position, then the output voltage of the lock-in amplifier is read as the retroreflector is moved to a series of positions. As the data is acquired, ΔR is plotted as a function of the relative arrival time of the pump and probe beams. The user can control the start and end times of each scan, step size, number of samples to average at each point, and desired positions of the pump beam waveplate. The user may choose to take multiple scans in a row at one waveplate postion, or up to 9 scans in a row at different waveplate positions. As each scan finishes, an average of the completed scans is plotted. When all scans are complete, the data from the individual scans as well as the average are saved. The user may also add a waiting time before data acquisition on each position to allow the lock-in to adjust to the new modulation amplitude.

Reflectivity data on YBCO and LBCO, two high-temperature superconductors, are shown in Figure 2 and Figure 3. The measurements were taken in support of the LL09 (Coslovich) LCLS experiment in SXR and in preparation for the LP42 (Abbamonte) LCLS experiment in SXR, respectively. For the YBCO measurements, 800 nm pump and 800 nm probe beams were used, and the amplitude of ΔR/R corresponds to the destruction of its superconducting state. For the LBCO measurements, 800 nm pump and 400 nm probe beams were used, and the amplitude of ΔR/R corresponds to a change in charge order of the material. The 400 nm probe beam was produced by the addition of a second harmonic generation crystal and a color filter to the probe arm.

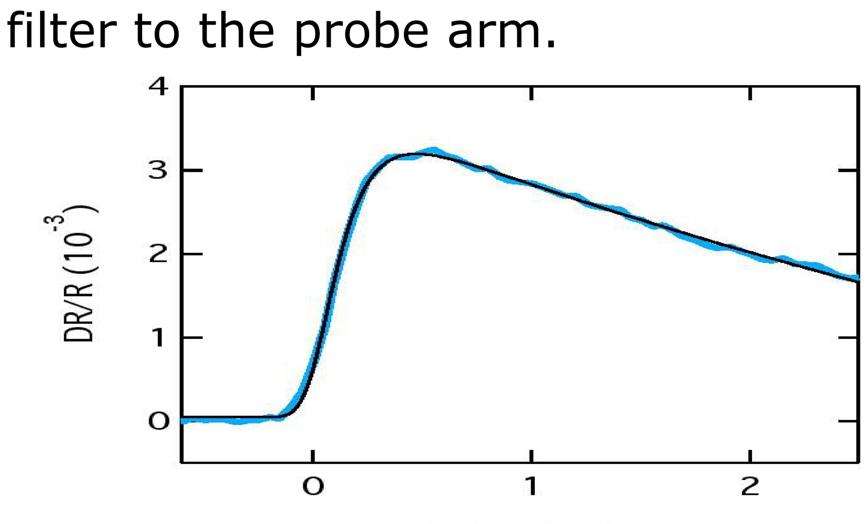

Figure 2. Averaged data from YBCO measurements with 800 nm pump and 800 nm probe. The signal represents the destruction of the superconductive state of the material.

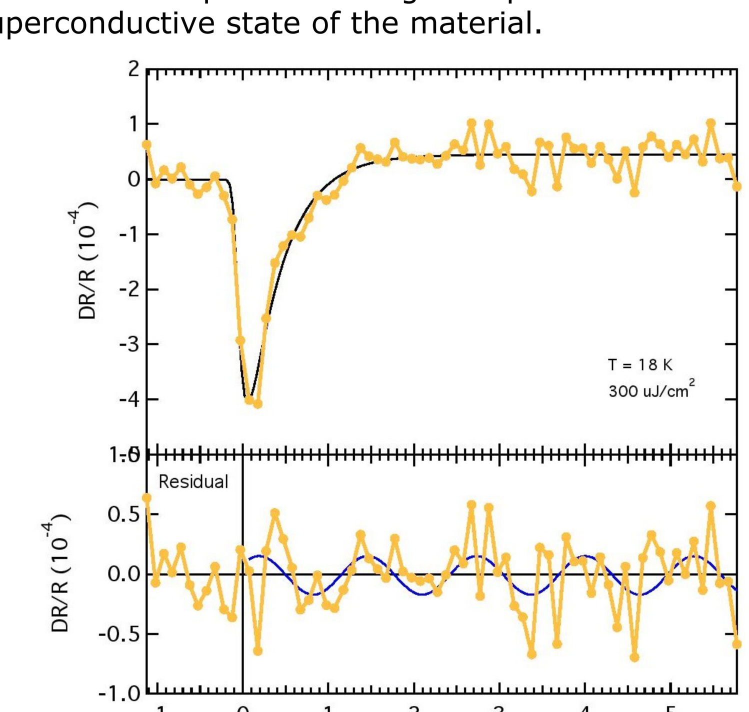

Figure 3. Averaged data from LBCO measurements with 800 nm pump and 400 nm probe. The signal represents a change of charge order in the material. There is some evidence of oscillations on top of the exponential signal but the noise due to the low frequency of the laser is too great to make a conclusion.

Conclusions

A pump-probe setup was built and optimized to take measurements on samples inside of a cryogenic chamber, along with the LabVIEW software to control and acquire data from the system. 800 nm pump wavelength was used, and 800 nm and 400 nm probe wavelengths were used. Dynamics of the superconductive state in a YBCO sample and the charge order in an LBCO sample were measured.

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