2020 45th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz) | 978-1-7281-6620-9/20/$31.00 ©2020 IEEE | DOI: 10.1109/IRMMW-THz46771.2020.9370370

Linear Dichroism in high temperature superconductors in THz range

D.K. George[1], J. Seo[1], H. Zhang[2], C. Zhang[2], T. Kirzhner[3], G. Koren[3], J.Y.T. Wei[2], A. Markelz[1] and J. Cerne[1]
[1]Department of Physics, University at Buffalo, SUNY, Buffalo, NY 14260 USA
[2]Department of Physics, University of Toronto, ON M5S1A7, Toronto, Canada
[3]Department of Physics, Technion, Haifa 32000, Israel

***Abstract*—We measure as a function of sample orientation, doping, temperature, and energy, the Faraday rotation of linearly polarized THz light by high temperature cuprate superconductors. We observe a linear dichroism signal which increases with decreasing frequency and may exhibit resonances in the THz (1-6 meV) range. Preliminary results also show strong temperature dependence to the Faraday rotation signal.**

I. INTRODUCTION

Optical anisotropies are reflections of the broken symmetries of a system and can yield valuable information about underlying physics and electronic states [1-3]. Optical symmetry breaking has been observed in cuprate high temperature superconductors [4, 5] and has been associated with the enigmatic pseudogap "phase." Here we have measured polarization anisotropies for the cuprate high temperature superconductor $YBa_2Cu_3O_{7-x}$ (YBCO) in the THz (1-6 meV) frequency range as a function of doping and temperature. We have detected linear dichroism (LD) which increases with decreasing frequency, similar to that which was observed in Ref [6], and exhibits possible resonances predicted by Ref [7] .

II. EXPERIMENT

The YBCO thin films used in this study were grown epitaxially on $LaSrAlO_4$ (LSAO) substrates using pulsed laser-ablated deposition. LSAO is transparent in the THz range and has tetragonal crystal symmetry, which eliminates any LD signals from the substrate. The films were 100 nm thick. Polarization rotations were measured using three wire grid polarizers (WGP) placed in a THz time-domain spectroscopy setup as shown in Fig. 1 and similar to Ref [8]. WGP1 acts as a clean-up polarizer for the linearly polarized THz pulses generated from the photoconductive antenna. WGP2 is placed on a rotation mount which is switched between +45° and -45° w.r.t to WGP1. WGP3 is fixed at +45°.

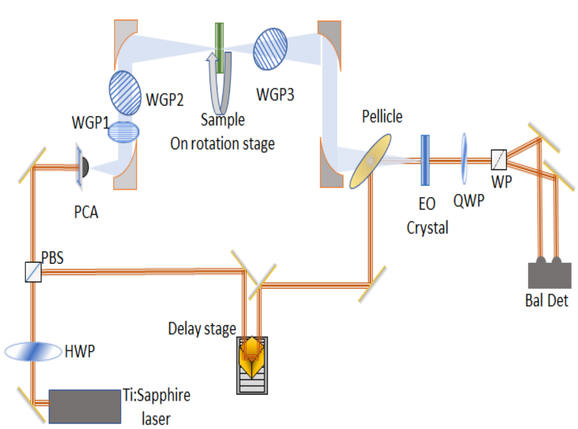

Fig. 1. THz TDS setup to measure Faraday rotation

THz pulses were recorded for perpendicular and parallel positions of WGP2 with respect to WGP3. The Fourier transform of the pulses from the two polarizer configurations give the perpendicular and parallel (with respect to the polarization incident on the sample) THz electric field as function of frequency. The ratio of the real part gives the Faraday rotation. In order to detect small rotations, the samples were fixed on a rotation stage (Thorlabs K10CR1) and Faraday polarization rotations were measured as a function of the sample orientation at an interval of 5 degrees. Amplitude of maximum Faraday rotation was obtained using a A fit to the calculated Faraday rotation as a function of sample orientation. The temperature dependence of the Faraday rotation was probed by placing the sample in a closed cycle cryostat. A preliminary measurement was done using sample UD70K at room temperature and at 30 K by rotating the sample for 360 degrees in roughly 22.5-degree intervals.

III. RESULTS

The polarization rotation is sinusoidal as a function of the angle between incident linear polarization with respect to the sample orientation and shows a 180° periodicity. This identifies the rotation as arising from linear polarization anisotropy. The amplitude of the LD signal was obtained by a least-squares fit of $\frac{\Delta\theta_F}{2}sin(2\phi+\varphi)$ to the Faraday signal vs. sample orientation angle ϕ. A representative fit for UD70K is shown in Figure 2.

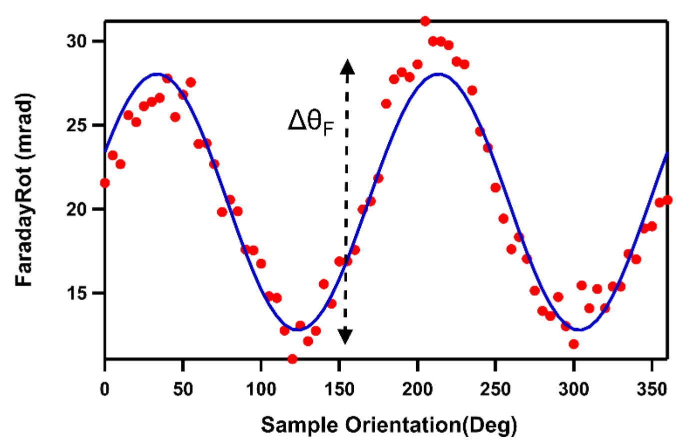

Fig. 2. Faraday rotation as a function of sample orientation for UD70K at room temperature. The peak-to-peak amplitude of the fit is represented by $\Delta\theta_F$

The strongest LD signals were found in mid-under-doped samples. The films in Fig. 3 are labeled as underdoped (UD), optimally-doped (OPD), and over-doped (OVD) followed by their superconducting transition temperature. $\Delta\theta_F$ is plotted as a function of energy for seven samples in Fig. 3. No LD signal was observed for the LSAO substrate.

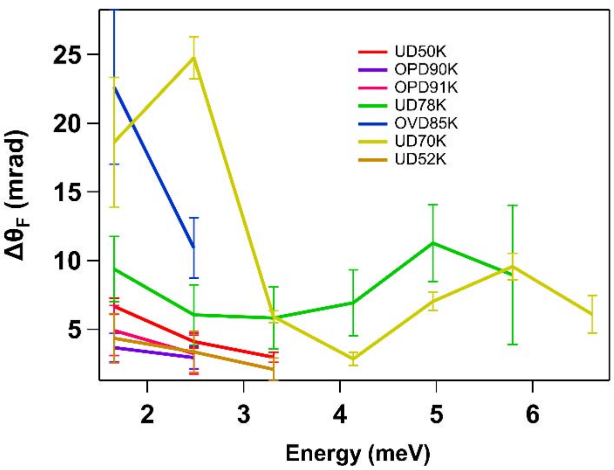

Fig. 3. $\Delta\theta_F$ plotted as a function of energy for a wide range of sample dopings at 300 K. Inset shows the Faraday rotation as a function of sample orientation for UD70K.

IV. CONCLUSION

Preliminary measurements for UD70K sample showed a significant increase in the LD signal at low temperature. For room temperature, the maximum rotation observed was on the order of 1.5 degrees while at 30 K, a rotation of 12 degrees was observed. For room temperature measurements, the LD signal increases strongly as energy decreases from 6 to 1 meV. This may be an indication that the origin of the LD signal could be 1D conducting “stripe” or nematic structures [6] causing the enhancement of the LD signal at THz frequencies (e.g., Ref. [7]). Initial measurements at 30 K suggest that the LD signal is strongly enhanced at low temperature.

ACKNOWLEDGEMENT

We gratefully acknowledge support from NSF-DMR Grant No. 1410599 (J.C.). A.G.M. and D.K.G. were supported by NSF Grant No. MCB 1616529 and DOE Grant No. DE-SC0016317. Work in Toronto was supported by NSERC, CFI-OIT, and the Canadian Institute for Advanced Research. J.Y.T.W. thanks Kejun Xu for laboratory assistance in Toronto.

REFERENCES

[1] W.-K. Tse and A. H. MacDonald, "Giant Magneto-Optical Kerr Effect and Universal Faraday Effect in Thin-Film Topological Insulators," *Physical Review Letters,* vol. 105, no. 5, p. 057401, 07/26/ 2010, doi: 10.1103/PhysRevLett.105.057401.

[2] M. Lawrence *et al.*, "Manifestation of PT Symmetry Breaking in Polarization Space with Terahertz Metasurfaces," *Physical Review Letters,* vol. 113, no. 9, p. 093901, 08/28/ 2014, doi: 10.1103/PhysRevLett.113.093901.

[3] R. Valdés Aguilar *et al.*, "Terahertz Response and Colossal Kerr Rotation from the Surface States of the Topological Insulator Bi2Se3," *Physical Review Letters,* vol. 108, no. 8, p. 087403, 02/22/ 2012, doi: 10.1103/PhysRevLett.108.087403.

[4] C. M. Varma, "Non-Fermi-liquid states and pairing instability of a general model of copper oxide metals," *Physical Review B,* vol. 55, no. 21, pp. 14554-14580, 06/01/ 1997, doi: 10.1103/PhysRevB.55.14554.

[5] J. Xia *et al.*, "Polar Kerr-Effect Measurements of the High-Temperature YBa2Cu3O6+x Superconductor: Evidence for Broken Symmetry near the Pseudogap Temperature," *Physical Review Letters,* vol. 100, no. 12, p. 127002, 03/28/ 2008, doi: 10.1103/PhysRevLett.100.127002.

[6] Y. Lubashevsky, L. Pan, T. Kirzhner, G. Koren, and N. P. Armitage, "Optical Birefringence and Dichroism of Cuprate Superconductors in the THz Regime," *Physical Review Letters,* vol. 112, no. 14, p. 147001, 04/09/ 2014, doi: 10.1103/PhysRevLett.112.147001.

[7] G. Koren and P. R. B. P. Lee, 174515 (2016),, "Observation of two distinct pairs fluctuation lifetimes and supercurrents in the pseudogap regime of cuprate junctions," *Phys. Rev. B,* vol. 94, , pp. 174515:1-10, 2016.

[8] R. Shimano, Y. Ikebe, K. S. Takahashi, M. Kawasaki, N. Nagaosa, and Y. Tokura, "Terahertz Faraday rotation induced by an anomalous Hall effect in the itinerant ferromagnet SrRuO 3," *EPL (Europhysics Letters),* vol. 95, no. 1, p. 17002, 2011/06/14 2011, doi: 10.1209/0295-5075/95/17002.