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-THZ46771.2020.9370641

Infrared symmetry breaking in $YBa_2Cu_3O_{7-x}$ as a function of energy, doping, and temperature

J. Seo[1], T. Gujar[1], J. Barber[1], H. Zhang[2], C. Zhang[2], T. Kirzhner[3], G. Koren[3], J.Y.T. Wei[2], 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 explore the symmetry-breaking in cuprate high temperature superconductors (HTS) as a function of energy (117-2330 meV), doping, and temperature (30-300 K). We measure the Faraday rotation angle θ_F of transmitted radiation through thin $YBa_2Cu_3O_{7-x}$ (YBCO) films as the sample is rotated. We observe two-fold rotational symmetry in θ_F, which is associated with linear dichroism (LD) that can be generally associated with symmetry breaking. The LD signal shows a peak in the few hundred meV range and is strongest in under-doped films.**

I. INTRODUCTION

The rich behavior of cuprates is evident from their complex phase diagram, consisting of numerous competing phases, each with their own broken symmetry. Although symmetry-breaking in cuprate HTS has been theoretically predicted long ago [1], it is only recently that THz [2], near-infrared [3], and mid-infrared [4] polarization-sensitive spectroscopy measurements have discovered the presence of linear and circular polarization anisotropies in cuprate HTS. We have measured linear polarization anisotropies for a number of YBCO thin films grown on $LaSrAlO_4$ substrates over a broad frequency range. The frequency dependence of these optical anisotropies may be crucial to resolving the microscopic origin of the broken symmetry. For example, since metals typically have a higher conductivity at lower frequencies, one may expect that metallic stripes could produce larger optical anisotropy as the probe frequency decreases. The strongest LD signal is found in under-doped films, although it is also observed in optimally- and over-doped samples. The LD signal is consistent with an electronic nematic order [5] which is decoupled from the crystallographic axes. All the HTS samples show a 180° periodicity of the θ_F with respect to the sample orientation.

II. RESULTS

Figure 1a) and b) show the energy dependence from 117-2330 meV of $\Delta\theta_F$ (the peak-to-peak amplitude of the θ_F vs sample orientation oscillation, as shown in the inset of Fig. 1b) for YBCO films measured at 300 K and 30 K, respectively. The films in Fig. 1 are labeled as underdoped (UD), optimally-doped (OPD), and over-doped (OVD) followed by their superconducting transition temperature. For all the YBCO samples at 300 K, except OVD 85 K, $\Delta\theta_F$ increases as the probing energy increases from 117 meV toward 300 meV, and then decreases by 2330 meV. There is a clear peak in $\Delta\theta_F$ near 400 meV in the underdoped samples. $\Delta\theta_F$ plateaus above 600 meV. The LD signal for OVD 85 K is smaller and decreases monotonically with energy above 117 meV toward 2330 meV. The LD signals for the optimally doped films are even smaller and show a small enhancement below 600 meV. We use Fourier transform infrared (FTIR) spectroscopy to study a broad range of energies to verify whether there is a peak near 400 meV. The FTIR measurement for UD 70K at 300 K confirms the existence of the peak near 400 meV. Similar behavior is observed at 30 K in Fig. 1b). Figure 2 shows the temperature dependence of

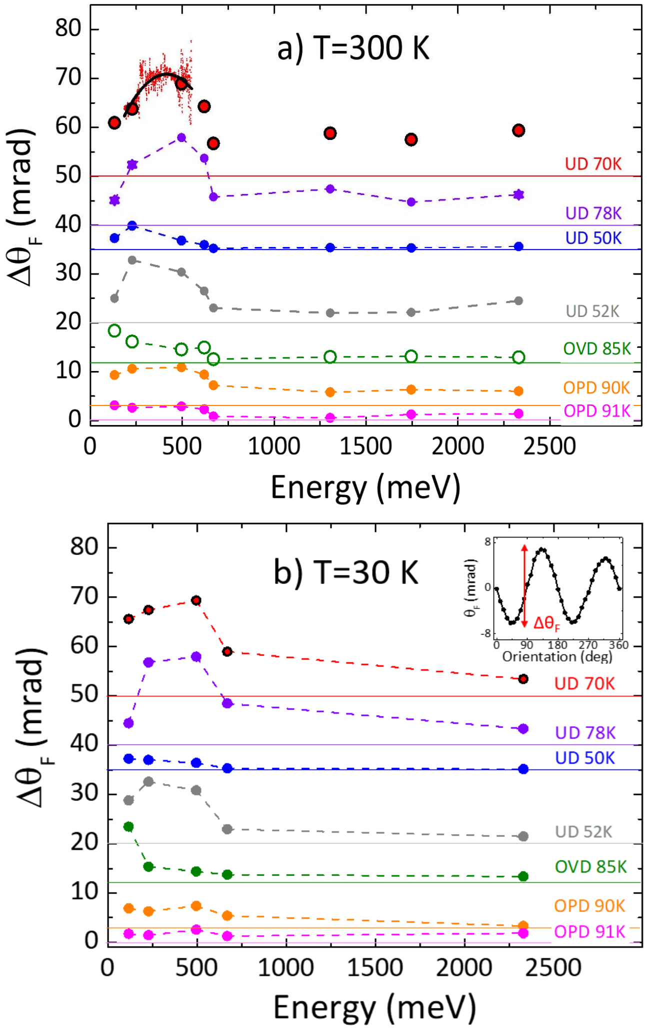

Figure 1. Energy dependence of the $\Delta\theta_F$ for various YBCO films at a) 300 K and b) 30 K. The symbols are from measurements using discrete laser lines. The solid red line for UD 70K from 150-500 meV is a second-order polynomial fit to broadband FTIR measurements. Inset in (b) shows the θ_F as a function of the sample orientation and how $\Delta\theta_F$ is defined.

$\Delta\theta_F$ for UD 70 K and UD 78 K at two different energies. At 132 meV, $\Delta\theta_F$ for both samples increases when samples are cooled while at 496 meV, the changes in $\Delta\theta_F$ over the same temperature range are much smaller. The small oscillations in the signals at 496 meV are probably due to random drift.

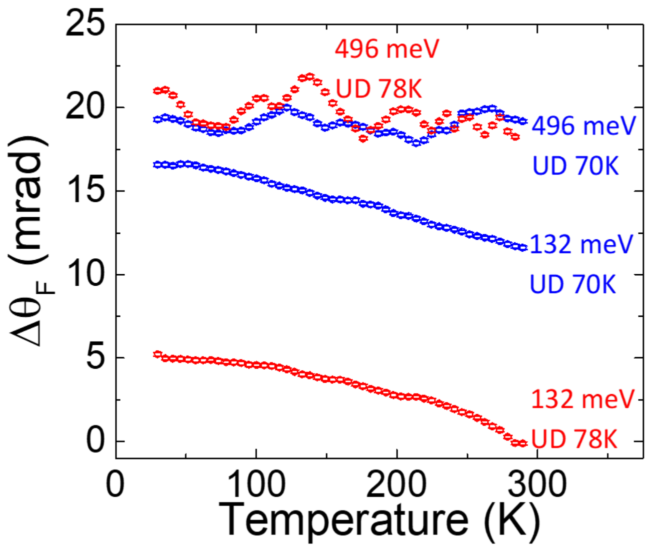

Figure 2. Temperature dependence of $\Delta\theta_F$ for two under-doped samples at two different energies with error bars.

III. CONCLUSIONS

In summary, we have investigated the energy and temperature dependence of the LD signals from 117 to 2330 meV and from 30 to 300 K, respectively. We have shown that there is a peak in the LD signal near 400 meV in the underdoped and optimally-doped samples while in the overdoped sample the LD signal monotonically decreases as frequency approaches to 2330 meV, with a dramatic rise below 200 meV. The FTIR measurement for UD 70K at 300 K confirmed the existence of the peak near 400 meV. This resonance in the LD signal may provide important clues for resolving the microscopic mechanism responsible for the anisotropy. What is causing this effect? It is important to note that the LD signal mostly increases with decreased doping and if the signal originates from the greater conductivity of Cu-O chains, the trend would be opposite since underdoped samples have less metallic chains compared to the overdoped samples. The simplest explanation of the LD behavior found here could be in terms of 1-D conducting "stripes" or nematic structures, where conductivity is high along the wire-like stripes and low in the perpendicular direction. According to the Drude model, we expect to observe a large Faraday rotation at low frequency, where the difference in conductivity along and perpendicular to the stripes should be greater. At the high frequency, we expect to observe a smaller Faraday rotation due to the decreased conductivity along the stripes. As we have seen in Figure 1, we do not see conductivity anisotropy that simply increases as frequency goes to zero. We see a peak at 400 meV, which cannot be due to simple metal wires. However, OVD 85 K seems to agree to the Drude model, and this may not be too surprising since overdoped HTS behave more like normal metals.

We hope that our findings will not only help provide new answers to old puzzles in cuprate HTS, but will also reveal some new questions that will stimulate further research into these fascinating materials.

ACKNOWLEDGEMENT

Work done at the University at Buffalo was supported by NSF DMR Grants No. 1410599 (J.C.). Work in Canada was supported by NSERC, CFI-OIT and the Canadian Institute for Advanced Research.

References

1. Varma, C.M., *Non-fermi-liquid states and pairing instability of a general model of copper oxide metals.* Physical Review B, 1997. **55**: p. 14554–14580.
2. Lubashevsky, Y., et al., *Optical Birefringence and Dichroism of Cuprate Superconductors in the THz Regime.* Physical Review Letters, 2014. **112**(14): p. 147001.
3. Xia, J., et al., *Polar Kerr-Effect Measurements of the High-Temperature* $YBa_2Cu_3O_{6+x}$ *Superconductor: Evidence for Broken Symmetry near the Pseudogap Temperature.* Physical Review Letters, 2008. **100**: p. 127002
4. Mukherjee, A., et al., *Linear dichroism infrared resonance in overdoped, underdoped, and optimally doped cuprate superconductors.* Physical Review B, 2020. **102**(5): p. 054520.
5. Wu, J., et al., *Spontaneous breaking of rotational symmetry in copper oxide superconductors.* Nature, 2017. **547**(7664): p. 432-435.