Time Reversal Symmetry Breaking and Charge Ordering in the Pseudogap phase of High-Temperature Superconductors

Aharon Kapitulnik
Departments of Physics and Applied Physics, Stanford University, Stanford CA 94305, USA.

One of the most challenging puzzles that has emerged within the phenomenology of the high-temperature superconductors (HTSC) is to understand the occurrence and role of the normal-state ``pseudogap" phase in underdoped cuprates. This phase exhibits anomalous behavior of many properties including magnetic, transport, thermodynamic, and optical properties below a temperature, T*, large compared to the superconducting (SC) transition temperature, T_c. To date, not only do we not know the origin of the pseudogap state, there is also no consistent experimental picture of its relation to superconductivity. While in one class of theories, T* represents a crossover into a state with preformed pairs with a d-wave gap symmetry, in other, T* marks a true transition into a phase with broken symmetry which ends at a quantum critical point. While at low-doping this phase may compete with superconductvity, it might provide fluctuations that are responsible for the enhanced T_c near its quantum critical point.

In this talk we will we present high-resolution linear-birefringence and magneto-optical (MO) [1] data on several HTSC systems. While the birefringence measurements accurately locate structural phase transitions and/or transitions into a charge-ordered phase, while an onset of a MO-Kerr effect indicates that time-reversal-symmetry (TRS) is broken below that temperature. The above effects exhibit a markedly stronger signal in the case of $La_{2-x}Ba_xCuO_4$ (LBCO) with x=1/8 [2]. For this system a first-order structural transition from an orthorhombic to tetragonal phase is accompanied by an onset of a Kerr signal. The signal then exhibits a weak inflection at the charge order transition, rises to a maximum around the spin-order transition, and decreases to a finite value when superconducting correlations are substantial. However, despite the sharp onset of the Kerr signal, hysteretic training effects are observed, indicating that TRS has been broken at much higher temperatures. Such an effect was previously observed in YBCO, especially close to x=1/8 doping [3] on single-layer BSCO [4], and has recently reported on similar LBCO crystals [5] These results, together with detailed magnetic studies on similar crystals [2] may point to a unique magnetic structure in the material that is strongly altered when charge-ordering takes place so as to allow the Kerr effect to be visible.

[1] Jing Xia, Peter T. Beyersdorf, Martin M. Fejer, Aharon Kapitulnik, Appl. Phys. Lett. 89, 062508 (2006).
[2] Jing Xia, Elizabeth R. Schemm, G. Deutscher, S.A. Kivelson, D.A. Bonn, W.N. Hardy R. Liang, W. Siemons, G. Koster, M.M. Fejer, and A. Kapitulnik Phys. Rev. Lett. 100, 127002 (2008).
[3] M. Hucker, G. D. Gu, and J. M. Tranquada, Phys. Rev. B 78, 214507 (2008).
[4] Lu Li, N. Alidoust, J. M. Tranquada, G. D. Gu, and N. P. Ong, Phys. Rev. Lett. 107, 277001 (2011).
[5] Rui-Hua He, M. Hashimoto, H. Karapetyan, J. D. Koralek, J. P. Hinton, J. P. Testaud, V. Nathan, Y. Yoshida, Hong Yao, K. Tanaka, W. Meevasana, R. G. Moore, D. H. Lu, S.-K. Mo, M. Ishikado, H. Eisaki, Z. Hussain, T. P. Devereaux, S. A. Kivelson, J. Orenstein, A. Kapitulnik, and Z.-X. Shen, Science 331, 1579 (2011).