Signatures of Enhanced Superconducting Phase Coherence in Optimally Doped ($Bi_2Sr_2Y_{0.08}Ca_{0.92}Cu_2O_{8+\delta}$), Driven by Midinfrared Pulse Excitations

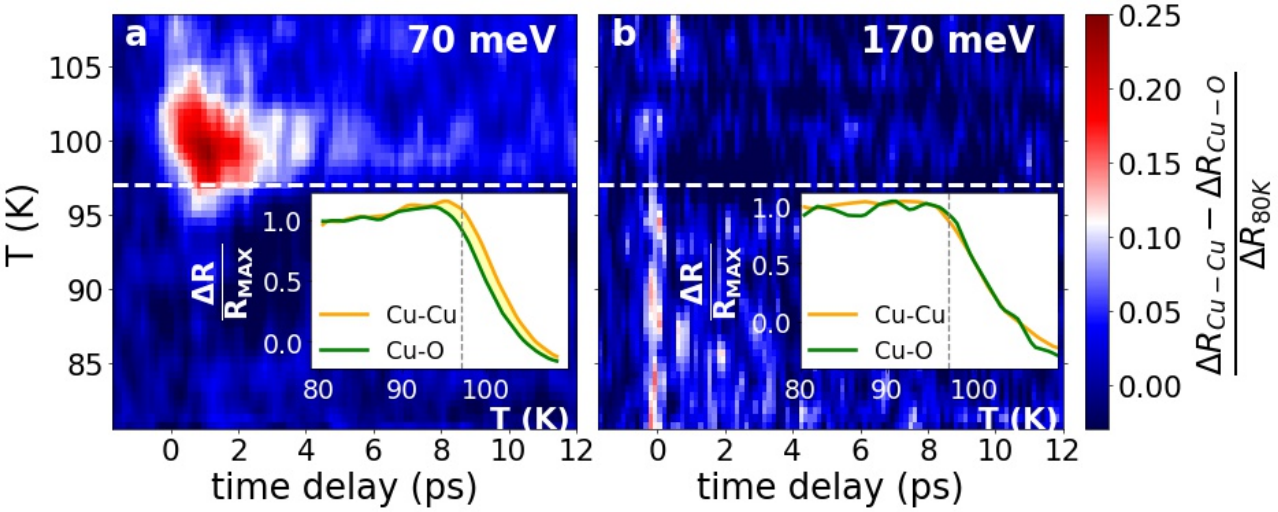
The capability to control material properties on short timescales is one of the key challenges of modern condensed matter physics. This possibility becomes even more attractive in the case of intriguing material phases, such as superconductivity. As a matter of fact, despite the evolution of non-equilibrium spectroscopies of the last two decades have increased our understanding of the physics of strongly correlated materials, after more than 30 years from its discovery, High Temperature Superconductivity is still discussed and a clear and unanimous explanation of the origin of the phenomenon is still lacking. Moreover, the understanding of the phenomena at the basis of this effects could affect several technological applications, from the need for fast digital circuits and for speeding up computer performances, to the detection of very low magnetic fields, with implication in geology (mineral exploration and earthquake prediction), medical sciences (neuron activity and magnetic resonance), oil prospecting and, of course, research.

We focused our research on cuprates, a class of materials known for displaying unconventional superconductivity at relatively temperatures, and on which various studies have shown the possibility of turning off (and, to some extent, on) superconductivity by ultrashort light pulses. In our work, we reveal that light pulses characterized by long wavelength (and a peculiar polarization) can induce, for a very short time interval (1-2 ps), a state displaying superconductivity even above the critical temperature, i.e. in conditions where superconductivity is not observed at equilibrium.
In particular, we performed pump-probe experiments on optimally doped yttrium substituted Bi2212 ($Bi_2Sr_2Y_{0.08}Ca_{0.92}Cu_2O_{8+\delta}$), a material characterized by a superconducting phase below T_c=97 K, a pseudogap phase from T_c to T*=135 K and a strange metallic phase for higher temperatures. The sample has been excited by ultrashort mid-infrared pump pulses, with photon energy of 70 meV, about twice of the superconducting gap, that is the value of energy required for the lowest electronic excitation of the system at 0 K. The second fundamental parameter of the experiment is the pump polarization, which can be rotated along two different crystallographic directions, that is, parallel to the Copper-Copper (Cu-Cu) or Copper Oxygen (Cu-O) axis. The difference between two measurements at the same excitation photon energy, but different pump polarization, shows that low photon energy excitations polarized along the Cu-Cu axis are able to enhance the dynamical signal associated to superconductivity. The effect is not observed for higher photon energies (see Figure 1).

The experiments are complemented by an effective model, based on a Hamiltonian inspired by BCS theory (the one used to describe conventional superconductivity), accounting for the anisotropy of the superconducting gap in the reciprocal space, typical of non-conventional superconductors
The model ascribes the observed enhancement of the superconducting response to the possibility of increasing the phase coherence of the superconducting state in the material by applying a suitable electric field in specific directions of the copper-oxygen planes (see Figure 2 b and c). Such finding opens the route to the control of the onset of quantum coherence in complex materials through a properly designed electric field.

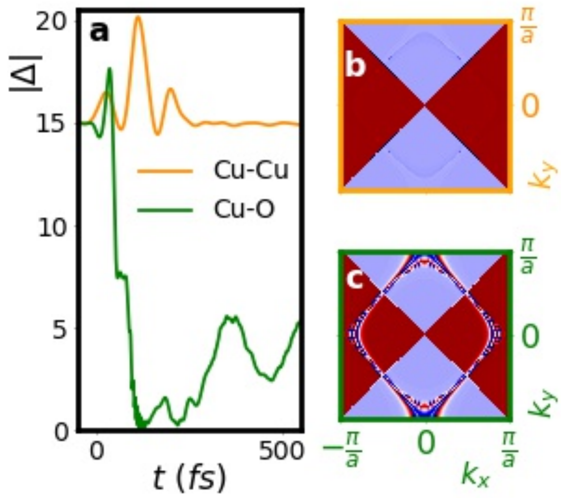
Figure:

<u>Fig 1</u>:



Difference between the transient reflectivity due to Cu-Cu and Cu-O polarized pump in time and temperature, induced by excitations with (a) 70 and (b) 170 meV pump photon energies. The dashed lines highlight the critical temperature Tc. The insets represent the response as a function of temperature at 1 ps time delay for Cu-Cu (orange line) and Cu-O (green line) polarized pump excitations for low and high pump photon energies (a and b, respectively). The gray dashed lines mark Tc.

<u>Fig 2</u>:



Results of the effective model: (a) gap amplitude dynamics as a function of the excitation polarization (parallel to the Cu-Cu or Cu-O axis.) The increase of the signal associated to superconductivity due to low photon energy excitations polarized along the Cu-Cu axis is predicted by the model. (b) and (c) represents the phase of the pair operator expectation value, a quantity associated to the coherence of Cooper pairs, in the First Brillouin Zone for excitation polarized along the Cu-Cu and Cu-O axis respectively.

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