Time-domain observation of the coupling between charge carriers and bosonic fluctuations in high temperature superconductors

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One of the main open questions about high-T_c superconductivity regards the origin of the pairing mechanism. A long-standing debate is whether the coupling between quasiparticles arises from a *retarded* boson-mediated interaction acting on a finite time scale (i.e. of the order on the inverse of the cutoff energy of the bosonic spectrum) or it is the result of an *instantaneous* Coulomb interaction [1].

Here we study the transient optical response of a cuprate superconductor (Y-doped Bi2212) in the visible-near IR spectral region (0.75-2.4 eV) with unprecedented temporal resolution (~20 fs), in order to investigate possible retardation effects in the dynamics of electron-boson scattering. After the interaction with a pump pulse, high-energy carriers are impulsively photo-injected and thermalize by exchanging energy with the bosonic degrees of freedom i.e. magnetic fluctuations and phonon modes. This exchange energy process involves a heating of the bosonic excitations and consequently a change of the electron-boson scattering rate resulting in a transient broadening of the Drude peak. The broad spectral coverage of the probe beam combined with the high temporal resolution, allow to monitor the transient change of the optical response due to change of the Drude response.

We find that the transient reflectivity change displays an extremely rapid but finite rising time of about 16 fs [2]. We attribute this fast dynamics to a rapid and efficient coupling between carriers and bosonic modes. These results show that, on a time scale much faster than the characteristic electron-phonon relaxation time (i.e 100 fs), the photoexcited carriers are already coupled with bosonic excitation of electronic origin. The extracted timescale is in a good agreement with the relaxation time between photo-excited carriers and short-range antiferromagnetic excitations, which has been estimated by numerical simulations based on the t-J model [2].

As a comparison, we measure the transient optical response of the weakly correlated superconductor MgB_2 where the pairing is mediated exclusively by phonons. Here we find that build up dynamics is significantly slower meaning that the photoexcited carriers exchange their excess energy with phonon modes on a longer timescale [3].

References

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