Lattice dynamics and electron-phonon coupling in iron pnictide superconductors

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The mechanism leading to high temperature superconductivity is a key open issue in solid-state physics and has driven a huge activity in the scientific community, from both theoretical and experimental points of view. The recent discovery of a new class of high temperature superconductors, namely the iron pnictide superconductors, has risen even new fundamental questions on the electrons pairing mechanisms, due to the presence of an itinerant magnetic phase in the phase diagram competing with the superconducting phase, which is absent for example in cuprate. In order to unveil the mechanisms characterizing iron pnictide superconductors, one of the key points is to understand the role played by the lattice dynamics in the competition with the other degrees of freedom of the crystal. Besides, the measurement of the electron-phonon coupling might discriminate the validity of the Bardeen-Cooper-Shrieffer (BCS) theory for this class of superconductors.

Here, we report the study of ultrafast transient reflectivity on iron pnictide $Ba(Fe_{1-x}Co_x)_2As_2$, using a pump and probe scheme with a 40 fs laser pulse, as function of both doping and initial crystal temperature [1]. The measurements show the signature of the electrons and lattice dynamics, in particular of a coherent A_{1g} optical phonon mode. We highlight in the transient reflectivity the presence of a double relaxation dynamics between electrons and phonons. We attribute the first dynamics to the interaction of the electrons with a preferential subset of phonons, while the second dynamics is a thermalization within all the phonons, which can be described by a three temperatures model. These measurements allow estimating the second moment of the Eliashberg function, from which we recover the value of the electron-phonon coupling. Interestingly, this value cannot explain the observed critical temperature T_c = 24 K within a standard BCS framework, therefore suggesting that electron-phonon coupling is not responsible for electrons pairing in these compounds.

It is well accepted that the selective excitation and detection of one phonon mode gives major insights on the role of this particular mode to the electrons pairing. However, an exhaustive investigation would require the measurement of the behavior of other phonon modes as well. In particular, in the case of iron pnictide, it has been observed by conventional Raman spectroscopy that the E_g phonon mode undergoes a splitting at the magnetic phase transition, suggesting a relevant phonon-spin interaction. In order to be able to extend our measurements to phonon mode with E_g symmetry in iron pnictide, we have also studied how to control a prototype E_g symmetry vibration, namely the shearing mode in graphite and multilayer graphene. We were able to excite and detect such an interlayer vibration also for the case of bilayer graphene [2], which represents the single harmonic oscillator from which the entire relevant phonon dynamics is build up in the three dimensional crystal. We will show these results and discuss their extension to the study of iron pnictide superconductors and to other types of experiments.

[1] B. mansart et al., Physical Review B 80, 172504 (2009) and 82, 024513 (2010)
[2] D. Boschetto et al., Nano Letters (2013)