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Ultrafast quasiparticle dynamics of $FeTe_{0.75}Se_{0.25}$ superconductor

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Abstract: The electron-phonon coupling constant ($\lambda \approx 0.45$) obtained from femtosecond pump-probe reflection measurements suggests that a phonon-mediated process cannot be the dominant mechanism for superconductivity of $FeTe_{0.75}Se_{0.25}$.

1. Introduction

The mechanism of high temperature superconductivity is one of the most important open issues in condensed matter physics. Recently, the Fe-based superconductors (FeSCs) have been attracting a great deal of attention because FeSCs have a high transition temperature despite the existence of magnetic elements, which have been believed to compete with superconductivity [1]. One of questions concerning on the mechanism is the role of electron-phonon coupling, which is a key factor of conventional Bardeen-Cooper-Schrieffer (BCS) superconductivity.

Time-resolved spectroscopy has been very instrumental inelucidating the nature of the electronic excitations in superconductors, particularly cuprates and recently also iron pnictides. Moreover, the relaxation kinetics can give us valuable information on the electronic structure and electron-phonon coupling. The electron-phonon coupling can be obtained from transient optical reflectivity [2, 3].

In this paper, we studied ultrafast quasiparticle dynamics of a $FeTe_{0.75}Se_{0.25}$ single crystal, which is the so-called "11-type" FeSCs having a simple structure, using femtosecond time-resolved reflection measurements. we measured the coherent lattice vibration measurement methodusing a pump-probe time-resolved reflectance to obtain detailed information about the coherent lattice vibration and the quasiparticle dynamics.

2. Experiment

The sample used wad a single crystal of $FeTe_{0.75}Se_{0.25}$, which was grown by the self-flux method. The critical temperature (T_C) for superconducting transition was obtained to be 13 K. The sample was cleaved along the c-axis in order to obtain clean and flat surfaces.

We carried out pump-probe reflectivity measurements using a mode-locked Ti:sapphire oscillator delivering laser pulses at wavelength centered 800 nm and 80 MHz repetation rate. The pulses duration was approximately 7.5 fs. A continuous flow helium-gas cryostat allowed us to cool the samples down to ≈12 K. The fluences of the pump and probe pulses were 18 and 7 μJ/cm^2, respectively. The eletrooptic (EO) sampling configuration was used [4].

3. Results & discussion

Figure1 shows the transient optical reflectivity of the $FeTe_{0.75}Se_{0.25}$ single crystal at sample temperature of 12 K. The transient reflectivity response consists of a fast increase and a coherent artifact at zero delay and a successive oscillation. The fast increase corresponds to the excitation of electrons by the pump pulse and possible coherent artifact.

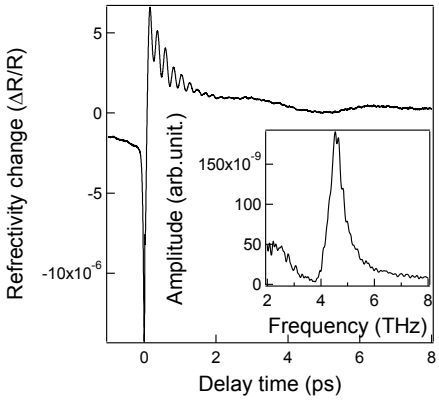

Fig. 1 Transient optical reflectivity at the pump fluence *F = 18 μJ/cm^2 and 12 K.* The Fourier spectrum of the transient reflectivity shows a peak at 4.5 THz, which can be assigned to the A_{1g}-mode optical phonon.

Then the relaxation dynamics occurs and the recovery of the initial value takes place within several picoseconds. The Fourier spectrum of the transient reflectivity shows a peak at 4.5 THz, which can be assigned to A_{1g}-mode coherent phonons (an inset in Fig. 1). The transient reflectivity response was fitted well with an exponential decay and a damped oscillation. The frequency of the A_{1g} phonons are obtained to be 4.5 THz, and the relaxation times of electrons and phonons are obtained to be 1.2 and 0.62 ps, respectively.

The relaxation time of the photoinduced quasi particles in a metal is governed by transferring energy from electron to phonon with electron-phonon coupling strength λ[5].

$$\frac{1}{\tau_e} = \frac{3\hbar\lambda < \omega^2 >}{\pi k_B T_e} \tag{1}$$

where τ_e is the electron relaxation time, $\lambda < \omega^2 >$ is the second moment of the Eliashberg function, k_B is the Boltzman constant, and T_e is electron temperature. In the low-temperature the relaxation time of Eq. (1) represents the electron-phonon scattering relaxation in local equilibrium. The electron temperature can be described by [6]

$$T_e = < \sqrt{T_i^2 + \frac{2(1-R)F}{l_s \gamma} e^{-\frac{z}{l_s}}} \tag{2}$$

where T_i is sample temperature (12 K), R is the unperturbed reflectivity at 800 nm (0.5), F is the pumping fluences (18 μJ/cm^2) and γ is the linear coefficient of heat capacity (39 mJ/mol/K^2) due to the electronic subsystem[7]. The mean value is taken for the depth z going from the crystal surface

down to the skin depth l_s (128 nm). Thus T_e was 21 K in this experiment. When these parameters are used, an electron-phonon (A_{1g} mode) coupling strength $\lambda \approx 0.12$ can be estimated by Eq. (1). The most natural choice is to take the frequency of the fully symmetric A_{1g} mode, which is coherently excited by our photoexcitation and consequently efficiently coupled.

$$T_c = \left(\frac{< \quad >}{1.2}\right) \exp\left\{-\frac{1.04(1+\lambda)}{\lambda - \mu^*(1+0.62\lambda)}\right\} \tag{3}$$

With this value for λ, we can evaluate the critical temperature T_C using the McMillan formula, derived for frequency of A_{1g} and moderate an electron-phonon coupling [8]. Taking $< \hbar \quad >= 18.6$ meV and $\mu^* = 0$, we obtain the maximum value of $T_C = 0.11$ K, which is lower than the actual T_C (about 13 K). Therefore, the electron pair formation cannot be explained only by electron-lattice interactions in $FeTe_{0.75}Se_{0.25}$.

4. Conclusion

Ultrafast dynamics of electrons and phonons have been studied using the femtosecond time-resolved reflectivity measurements in the $FeTe_{0.75}Se_{0.25}$ single crystal at 12 K. The coherent A_{1g} phonons of were observed. The relaxation times for photo-excited electrons and A_{1g} phonons were obtained. Using the obtained parameters, we estimated the electron-phonon coupling strength $\lambda \approx 0.12$. The calculated critical temperature T_C using the McMillan formula is much lower than the actual T_c, which suggests that the electron pair formation cannot be explained only by electron-lattice interactions in $FeTe_{0.75}Se_{0.25}$.

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