Femtosecond spectroscopy in a nearly optimally doped Fe-based superconductors FeSe$_{0.5}$Te$_{0.5}$ and Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$/Fe thin film

To cite this article: C Bonavolontà *et al* 2014 *J. Phys.: Conf. Ser.* **507** 012004

View the article online for updates and enhancements.

Femtosecond spectroscopy in a nearly optimally doped Fe-based superconductors $FeSe_{0.5}Te_{0.5}$ and $Ba(Fe_{1-x}Co_x)_2As_2$/Fe thin film

C Bonavolontà[1,2], L Parlato[1,2], C de Lisio[1,2], M Valentino[1,2], GP Pepe[1,2], I Kazumasa[3], F Kurth[3], E Bellingeri[4] , I Pallecchi[4] , M Putti[4], C Ferdeghini[4], G A Ummarino[5], F Laviano[5]

[1]Department of Physics, University of Naples "Federico II", Italy
[2]CNR-SPIN, Piazzale Tecchio 80, 80125 Naples, Italy
[3] IFW Dresden, P. O. Box 270116, 01171 Dresden, Germany
[4]CNR-SPIN, Corso Perrone 24, 16152 Genova, Italy
[5]Dipartimento di Fisica and CNISM, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

E-mail: bonavolo@na.infn.it

Abstract: Femtosecond spectroscopy has been used to investigate the quasi-particle relaxation times in nearly optimally doped Fe-based superconductors $FeSe_{0.5}Te_{0.5}$ and optimally doped Ba-122 thin films growth on a Fe buffer layer. Experimental results concerning the temperature dependence of the relaxation time of such pnictides both in the superconducting state are now presented and discussed. Modelling the T-dependence of relaxation times an estimation of both electron-phonon constant and superconducting energy gap in the excitation spectrum of both Fe(Se,Te) and Ba-122 compounds is obtained.

1.Introduction

The recent discovery of superconductivity with transition temperature T_c up to 55 K in iron–pnictide systems [1,2]] has sparked enormous interest in this class of materials. Investigations on this new class of superconductors have revealed a lot of similarities to cuprates, for instance, layered structures, a multiband nature, high upper critical fields and a short coherence length. A common phase diagram for Fe–pnictides suggests the existence of an antiferromagnetic spin density-wave (SDW) ground state that is stabilized by Fermi-surface nesting [3] as well as by strong antiferromagnetic (AFM) spin interactions along the Fe-square-diagonal [4,5].

The coexistence of superconductivity and magnetism in the phase diagram suggests that magnetism plays an important role in determining the superconducting properties and in forming electron Cooper pairs. Then, the importance of the spin degrees of freedom for the superconducting pairing interaction becomes immediately apparent, and investigating the Fe-pnictide compounds from the point of electron-phonon and spin-charge interactions is therefore beneficial for understanding the nature of the superconducting coupling in the doped compounds.

Time-resolved spectroscopy is considered an efficient and useful technique to study the nature of the electronic excitations in superconductors [2] and more recently also in iron pnictides [3,4]. This technique gives information on the low-lying electronic structures, and potentially on the pseudo-gap, due to its capability to distinguish between scattering processes characterized by different relaxation dynamics [5]. In particular, the transient reflectivity change as a function of the time

delay (in the ps range) between the pump and the probe beams hitting the same region of the sample is clearly dependent on the electron relaxation processes which restore the equilibrium. Pump-probe fast spectroscopy has been already proposed for estimating the electron-boson constant λ in novel pnictides materials as in the case of $BaFe_{0.92}Co_{0.08}As_2$ ($\lambda = 0.12$) [6], $BaFe_2As_2$ [7] ($\lambda = 0.15$), and $SmFeAsO$ [8] ($\lambda = 0.18$). This technique can be considering complementary to other conventional techniques (i.e. point contact spectroscopy) to evaluate the superconducting energy gap.

In this work we use a time-resolved spectroscopy on $FeSe_{0.5}Te_{0.5}$ (Fe-11) thin films and optimally Co-doped $BaFe_2As_2$ (Ba-122) epitaxial thin films grown on Fe-buffered MgO(001) substrates to infer about the value of the energy gap in the quasi-particle density of states and the strength of the electron-boson interaction which characterize the superconducting state.

2. Materials and experimental set up

The Fe(Se,Te) films were deposited on single crystal lanthanum aluminates (001) substrates in a ultra high vacuum pulsed laser deposition (PLD) system using as a target a bulk polycrystal with a sharp resistive transition with an onset at T=16.2 K. further experimental details about the sample fabrication are found in [9]. The thin $Fe(Se_{0.5}Te_{0.5})$ films has a thickness of about ≈ 150 nm and the critical temperature of the film was about 19K.

The Co-doped Ba-122/Fe bilayers on MgO substrate were prepared by pulsed laser deposition under ultra high vacuum condition (base pressure of 10^{-9} mbar). The nominal Co content was x=0.08 in $Ba(Fe_{1-x}Co_x)_2As_2$. The respective layer thickness of Co-doped Ba-122 and Fe are 100 nm and 20 nm. In-situ reflection high energy electron diffraction confirmed that both, Fe and Co-doped Ba-122, were grown epitaxially with smooth surface. The detailed films preparation can be found in Ref. [10]. The critical temperature, T_c, defined as 90% of the normal state resistance was T_c=26.3K,

Time resolved spectroscopic measurements were performed using a standard pump-probe technique, based on mode-locked Ti:sapphire laser, delivering pulses at 82 MHz repetition rate, with 810 nm center wavelength, 100 fs duration. The sample was mounted on a cold finger in a temperature controlled liquid helium continuous flow optical cryostat, operating down to 5K. Further details on experimental details can be found in [11]. The photoinduced normalized reflectivity change $\Delta R/R$ was measured using a weaker probe pulse (1:20 the ratio between probe and pump beam) at a variable delay time, and as a function of the temperature. The pump fluences were about 5 $\mu J/cm^2$ and 1.6$\mu J/cm^2$ for the Fe-11 and Ba-122 sample, respectively. The different fluences are chosen because of the different signal to noise ratio of the signals due to the different samples surface reflectivity.

3. Results and discussion

In figure 1 the normalized reflectivity change $\Delta R/R$ as a function of the delay time between the pump and probe pulse at different temperatures is reported, in the case of Fe(Se,Te) and Ba-122/Fe thin films, respectively.
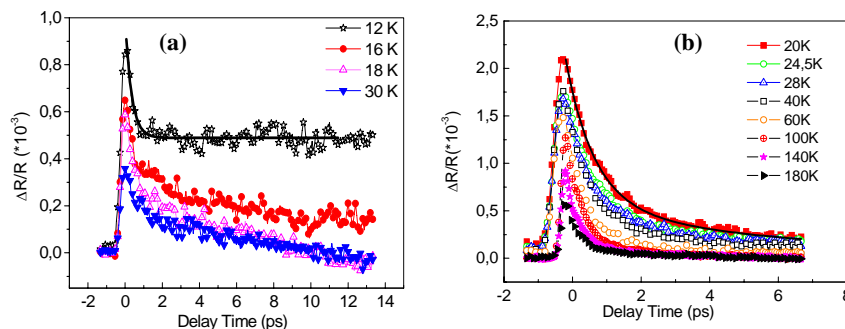

Figure 1. (a) The photoinduced reflectivity $\Delta R/R$ vs delay time at different temperatures related to the FeSeTe compound; (b) The $\Delta R/R$ vs the delay time at temperatures ranging from 20K to 180K, measured in Ba-122/Fe. The black solid lines in figure 1(a)-(b) represent the single and double-exponential fit curves used to estimate the relaxation time for Fe(Se,Te) and Ba-122/Fe, respectively.

To estimate the relaxation time τ the experimental curves have been fitted by a single and double-exponential function (see the solid line in figures 1(a) and (b)) for the Fe(Se,Te) and Ba-122/Fe thin films, respectively. Since for both Fe-pnictides samples the relaxation time (in particular the slowest time for the Ba-122/Fe thin film) shows a peak close to the critical superconducting temperature T_c, as reported in figures 2(a) and (b), the electron relaxation time data were analyzed according to a temperature dependence of quasiparticle recombination time in a superconductor with a temperature-dependent energy gap $\Delta(T)$ below T_c as described by the equation (1) [12]:

$$\tau_R = \frac{A}{\Delta(T)^2} \ln\left\{ \left(\frac{B}{\Delta(T)^2} + e^{-\frac{\Delta(T)}{k_B T}} \right)^{-1} \right\} \qquad (1)$$

where A and B are physical constant related both to phonon characteristic energies and the normal density of states $N(0)$ of the Fe-11 and Ba-122 compound, and $\Delta(T)=\Delta_0[1-(T/Tc)]^{0.5}$ is the temperature dependence of the superconducting energy gap.
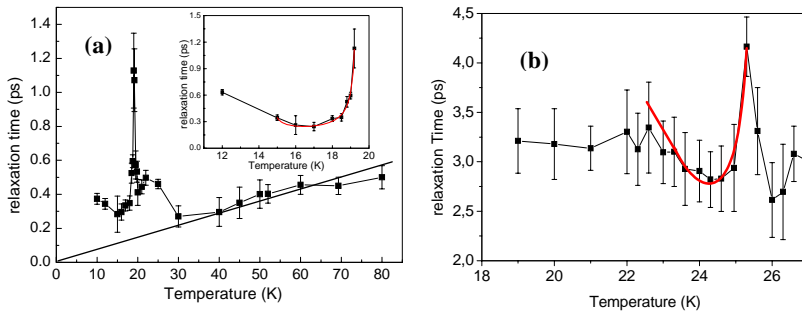

Figure 2. The relaxation time τ as a function of temperature for the sample with $T_C=19.1$ K and thickness of 150nm. The inset in figure 2(a) shows the fitting procedure applied to the decay time for $T<T_C$. The solid line in figure 2(a) represents the linear dependence between the relaxation time and the temperature starting from T=30K. (b) relaxation time τ_{slow} extracted from double-exponential decay fits of $\Delta R/R$ data in Ba-122/Fe.

In the case of FeSeTe sample, the fitting procedure, showed in the inset of figure 2(a), applied to experimental points recorded at $T <T_c$, gives $\Delta_0=4.1 \pm 0.4$meV for the superconducting energy gap extrapolated at T=0K, a value which corresponds to $2\Delta_0/k_BT_c = 4.9 \pm0.5$. This is in agreement with similar determinations already reported by specific heat [13] and Scanning Tunneling spectroscopy measurements [13]. The pre-factor $A\approx2.9 \pm 0.1$ 10^{-14} eV s cm^{-1} in eq.(1) can be written also as follows [14], $A=\hbar \omega_{ph}/12\Gamma_{ph}$ where ω_{ph} is a typical phonon frequency, Γ_{ph} is its characteristic phonon line-width. According to Subedi *et al* [14] we can assume $\Gamma_{ph}=2$cm^{-1}, and then estimate the characteristic phonon frequency $\omega_{ph}=32.4\pm0.4$ cm$^{-1}= 4.0\pm0.1$ meV.

Moreover, using a linear approximation for τ vs T behavior also at T>80K, according to[15]:

$$\tau = \frac{\pi k_B T}{3\hbar\lambda <\omega^2>} \qquad (2)$$

where $\lambda<\omega^2>$ is the second moment of the Eliashberg function, $\alpha^2F(\omega)$. The equation is expected to be valid for energy higher than $\hbar\omega_0$, where ω_0 is the characteristic Eliashberg –function phonon frequency. Looking at figure 2(a), in the range T>50K, and assuming a similar slope also at larger temperature, we obtain $\lambda<\omega^2>= 10\pm2$ meV^2, which corresponds to an electron-phonon coupling constant $\lambda\sim0.6\pm0.1$ (calculated using ω_{ph} previously obtained from the parameter A). We consider this feature only a remarkable element of consistency even if we are not completely within the range of validity of the proposed theory. Moreover, the same results can be obtained using a two-temperature model, as reported in a previous work [16].

For the Ba-122/Fe sample, from the fitting analysis using eq.(1), the value of superconducting gap $\Delta_0=3.67 \pm 0.13$meV that corresponds to $2\Delta_0/k_BT_c = 3.4 \pm 0.1$ has been evaluated. In previous time-resolved studies on SmFeAs(O,F) [17,18] and Ba-122 [7,18] iron pnictides superconductors, $2\Delta_0/k_BT_c$ ranging from 3 to 3.7 have been estimated. Our result is in agreement with the superconducting gap value estimated with other techniques [6,7,19]. In addition to evaluate the

electron-phonon coupling constant for the Ba-122/Fe, we use again the value of the fit parameter in eq.(1), namely A =22.2e-15 eV s cm^{-1} to calculate the phonon frequency ω_{ph}, where $\Gamma= 4$cm^{-1} [6]. In this way ω_{ph}=127.2 cm^{-1}=15.77 meV and considering $\lambda\langle\omega^2\rangle\sim50$meV^2 from inelastic neutron data[20], the electron-phonon coupling constant is about λ=0.18. This results is in agreement with that obtained for Co optimally doped Ba-122 and SmFeAsO compounds [20,21].

4. Conclusions

In conclusion, we report femtosecond spectroscopy measurements in a nearly optimally doped Fe-based superconductor FeSe$_{0.5}$Te$_{0.5}$ with T$_c$≈19K and Ba(FeCo)As with T$_c$ ≈26K. Our results indicate the existence of temperature dependence of quasiparticle recombination time in the superconducting state and a temperature-dependent energy gap $\Delta(T)$ at T<T_c. The fitting procedure gives for the Fe(Se,Te) sample Δ_0=4.1±0.4meV for the superconducting energy gap, and an electron-phonon constant λ≈0.6, while for the Ba-122/Fe Δ_0=3.67±0.13meV and λ≈0.18. These results are in very good agreement with values of the superconducting energy gap and electron-phonon coupling constant obtained with other techniques (i.e. Angle Resolved Photoemission Spectroscopy (ARPES)) and predicted by theoretical models [6,19,21] applied to the pnictides compounds.

References

[1] Kamihara Y, Watanabe T, Hirano M and Hosono H 2008 *J. Am. Chem. Soc.* **130** 3296

[2] Ren Z A 2008 *Mater. Res. Innovat.* **12** 105

[3] Mazin I I, Singh DJ, Johannes M D and Du MH 2008 *Phys. Rev. Lett.* **101** 057003

[4] Yildirim T 2008 *Phys. Rev. Lett.* **101** 057010.

[5] Gadermaier C, Alexandrov A S, Kabanov V V, Kusar P, Mertelj T, Yao X, Manzoni C, Brida D, Cerullo G and Mihailovic D 2010 *Phys.Rev.Lett.* **105** 257001

[6] Mansart B, Boschetto D, Savoia A, Rullier-Albenque F, Bouquet F, Papalazarou E, Forget A, Colson D, Rousse A, and Marsi M, 2010 *Phys Rev. B* **82**, 024513

[7] Chia E E, Talbayev D, Jian-Xin Zhu, Yuan H Q, Park T, Thompson J D, Panagopoulos C, Chen G F, Luo J L, Wang N L, and Taylor A J, 2010 *Phys. Rev. Lett.* **104**, 027003

[8] Mertelj T, Kusar P, Kabanov V V, Stojchevska L, Zhigadlo N D, Katrych S, Bukowski Z, Karpinski J, Weyeneth S, and Mihailovic D, 2010 *Phys. Rev. B* **81**, 224504

[9] Bellingeri E, Pallecchi I, Buzio R, Gerbi A, Marrè D, Cimberle M R, Tropeano M, Putti M, Palenzona A, and Ferdeghini C, 2010 *Appl. Phys. Lett.* **96**, 102512

[10] Kurth F, Iida K, Trommler S,Hanisch J, Nenkov K, Engelmann J, Oswald S, Werner J,Schultz L, Holzapfel B and Haindl S 2013 *Supercond. Sci. Technol.* **26** 025014

[11] Pepe G P, Parlato L, Marrocco N, Pagliarulo V, Peluso G, Barone A, Tafuri F, Scotti di Uccio U, Miletto F, Radovic M, Pan D, Sobolewski R, 2009 *Cryogenics* **49**, 660

[12] Demsar J, Podobnik B, Kabanov V V, Wolf T and Mihailovic D, 1999 *Phys. Rev. Lett.* **82**, 4918

[13] Sales B C, Sefat A S, McGuire M A, Jin R Y, and Mandrus D, 2009 *Phys. Rev. B* **79**, 094521

[14] Subedi A, Zhang L, Singh D J and Du M H, 2008 *Phys. Rev. B* **78**, 134514

[15] Allen P B, 1987 *Phys.Rev. Lett* **59**, 1460

[16] Bonavolontà C, Parlato L, Pepe G P, de Lisio C, Valentino M, Bellingeri E, Pallecchi I, Putti M and Ferdeghini C, 2013 *Supercond. Sci. Technol.* **26**, 075018.

[17] Mertelj T, Kabanov VV, Gadermaier C, Zhigadlo N D, Katrych S, Karpinski J and Mihailovic D, 2009 *Phys. Rev. Lett.* **102** 117002

[18] Torchinsky D H, Chen G F, Luo J L, Wang N L and Gedik N 2010 *Phys.Rev.Lett.* **105** 027005

[19] Stojchevska L, Mertelj T, Jiun-Haw Chu, Fisher I R, Mihailovic D, 2012 *Phys. Rev. B* **86**, 024519

[20] Kumar S,Harnagea L,Wurmehl S, Buchner B and Sood A K, 2013 **arXiv:1209.3551v2**

[21] Ummarino G A, Tortello M, Daghero D, Gonnelli R S, 2009 *Phys. Rev. B* **80**, 172503