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Temperature-dependent electric noise level in different iron-based superconductors

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Abstract. A detailed characterization of the voltage-noise properties has been performed in $FeTe_{0.5}Se_{0.5}$ epitaxial thin films and Co-doped $BaFe_2As_2$ bilayers, deposited by pulsed laser deposition. In all the samples analyzed, the experimental voltage-spectral density has a 1/f noise component. Different behaviors are observed for the bias current and temperature dependencies of this 1/f noise, and are related to specific structural and electric transport properties of the two materials.

1. Introduction

Among the family of new Fe-based superconductors, iron chalcogenides and Co-doped $BaFe_2As_2$ (Ba-122) compounds are of interest for both basic physics and high-field applications. Since their discovery, great efforts have been made to determine their fundamental properties. In particular, the crystalline quality, the surface morphology and the electric transport of these superconducting thin films are generally influenced by several factors such as strain, defect formation and change in growth mode [1, 2].

Due to the high sensitivity at ambient air, experimental results obtained with different methodologies on various Fe-based samples are often inconsistent. For instance, the role played by layer thickness on the increase of the superconducting transition temperature T_c, and the pairing symmetry in pnictides and chalcogenides are still disputed [3, 4]. A possible reason for such discrepancies between experiments could be related to the type of analysis technique used. In this respect, electric noise spectroscopy has already revealed its potentiality for a sensitive and non-destructive analysis of transport processes in advanced materials, such as double perovskites [5], manganites [6], and electron-doped cuprate superconductors [7].

Triggered by this scenario, a detailed voltage-noise characterization of $FeTe_{0.5}Se_{0.5}$ and Co-doped Ba-122 thin films has been performed. The comparison of the experimental data, collected by analyzing several configurations and contacts geometries on patterned samples, allows to identify different fluctuation mechanisms. This may help to shed some light on the peculiar structural properties and electrical conduction processes in the two systems investigated.

2. Experiments

Pulsed laser deposition technique was used to prepare all the thin films here studied. $FeTe_{0.5}Se_{0.5}$ was deposited on single crystal substrates of lanthanum aluminate (LAO) with (001) orientation. The optimized fabrication parameters were: deposition temperature 550 °C, pressure 5×10^{-9} mbar, laser repetition rate 3 Hz, laser wavelength 248 nm, laser fluency 2 J cm^{-2}, spot size 2 mm^2, target-substrate distance 5 cm. Co-doped Ba-122/Fe bilayers were prepared by a two-step process, characterized by a room temperature deposition of Fe on MgO (001) single-crystalline substrates and by a subsequent deposition of Co-doped Ba-122 layers at 750 °C with a laser repetition rate of 10 Hz.

Atomic force microscope (AFM) measurements indicated that the surface was flat with a root mean square roughness of $\simeq$ 1 nm in the case of $FeTe_{0.5}Se_{0.5}$ (typical thickness $\simeq$ 150 nm) [3], and of $\simeq$ 0.8 nm in the case of Co-doped Ba-122 (typical thickness $\simeq$ 100 nm) [8]. Terraces with monoatomic steps of $\simeq$ 0.6 nm in size were resolved in scanning tunnel microscope (STM) images, confirming the good quality of the growth for both the compounds analyzed.

All the samples were patterned by standard UV photolithographic processes and Ar ion milling etching. During the etching process, the samples were cooled at -40 °C to prevent local heating and damage, due to losses of volatile species. The patterned geometry consists in a number of strips having different width (between 2 and 16 μm) and in plane orientation.

The experimental investigations were carried in a closed-cycle refrigerator, at temperatures between 8 and 325 K. A specific procedure was used to minimize the electrical noise generated by the contacts. All the details of the measurement setup and of the outlined procedure are illustrated in [9].

3. Results and discussion

Different transition temperatures have been measured for the two types of superconductors. As shown in Figure 1, for $FeTe_{0.5}Se_{0.5}$ thin films T_c, defined at 90% of normal state resistance, is 16.2 K, that is the same critical temperature as in bulk samples [3]. For Co-doped Ba-122, instead, the T_c is 24.0 K and improves with increasing thickness, as described in [8]. Linear I-V characteristics have been observed in the whole temperature range, and for all sample configurations. Possible Joule heating effects have been avoided by the pulsed measurement technique used.

The detailed investigation of the low-frequency voltage noise, whose spectral density traces are shown in Figure 2, has revealed the presence of an evident $1/f^{\gamma}$ dependence (with γ in the range between 1.02 and 1.14), for all the materials. A high-frequency background spectrum

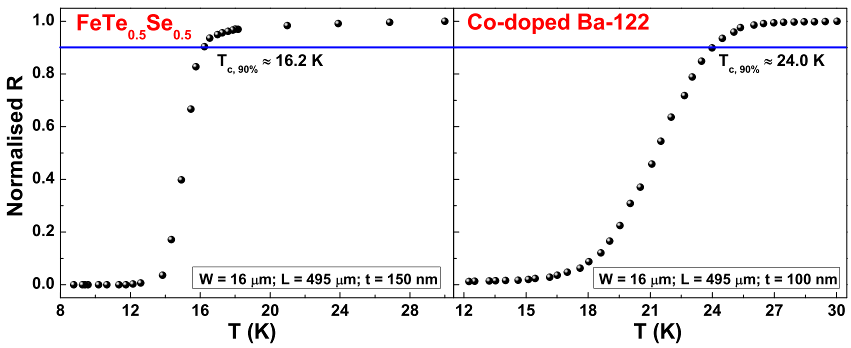

Figure 1. Resistance versus temperature dependence in the superconducting transition regions. The normalized resistance R is computed as $R(T)/R(30\ K)$. The critical temperature T_c is defined at 90% of normal state resistance.

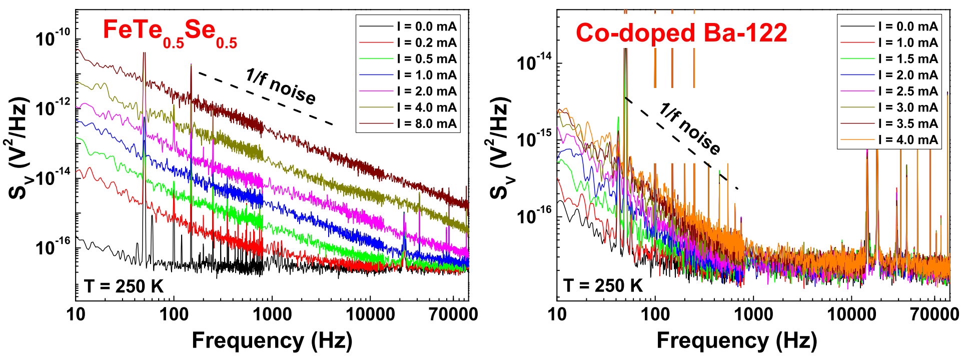

Figure 2. Low-frequency voltage-noise spectra of a 16-μm-wide strip taken at a temperature of 250 K and for different dc bias currents.

given by the electronic chain noise ($\approx 1.4{\times}10^{-17}$ V^2 Hz^{-1}) added to the sample Johnson noise is also visible in the experimental data of Figure 2.

Despite the similar frequency dependence of the measured spectral densities, $FeTe_{0.5}Se_{0.5}$ and Co-doped Ba-122 thin films show a different behavior in the bias current dependence of the 1/f noise amplitude. In Figure 3 a bias-activated noise region, at high applied electric fields and temperatures, is found for $FeTe_{0.5}Se_{0.5}$ and is characterized by a more than quadratic current scaling of the 1/f component. This is usually associated to an excess of fluctuations, ascribed to different physical mechanisms. One is sliding-charge density waves, which, however, in this material occurs at significantly lower temperatures [10]. A quadratic bias current scaling of 1/f noise is, instead, observed for Co-doped Ba-122 samples (see right panel in Figure 3 for details). This is interpreted in terms of a standard resistance fluctuations model, and can be expressed by the well-known empirical Hooge relation as [11]: $S_V\,(f){=}\alpha_H V^2/n\Omega f^{\gamma}$. Here, α_H/n is the normalized Hooge parameter, Ω the sample volume, γ the dimensionless frequency exponent, and $V{=}RI$ the dc voltage bias for Ohmic compounds. The parameter α_H/n, also identified as the noise level, can be extracted by a fitting procedure of the experimental data, as in Figure 3, in the whole investigated temperature range but only for low applied electric fields, in the case of $FeTe_{0.5}Se_{0.5}$ samples. A clear step-increase of the noise level is found in iron chalcogenides by increasing the temperature (see red points linked to left y-axis in Figure 4), probably related to the presence of a structural transition occurring in $FeTe_{0.5}Se_{0.5}$ below 100 K [10]. However,

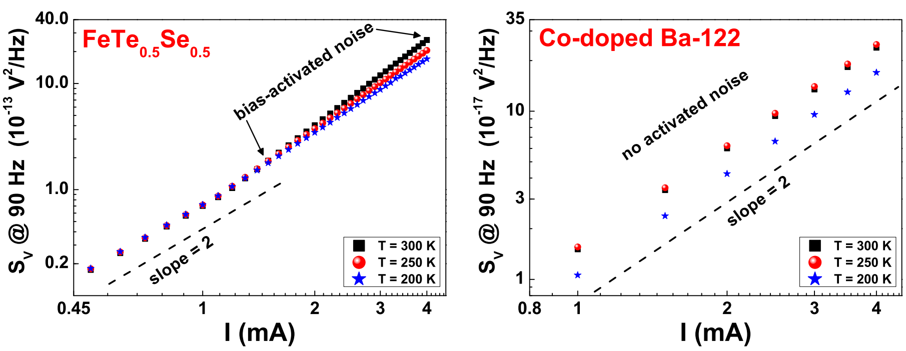

Figure 3. Bias current dependence of the 1/f noise amplitude at 90 Hz. Three different temperatures (300, 250, and 200 K) are shown.

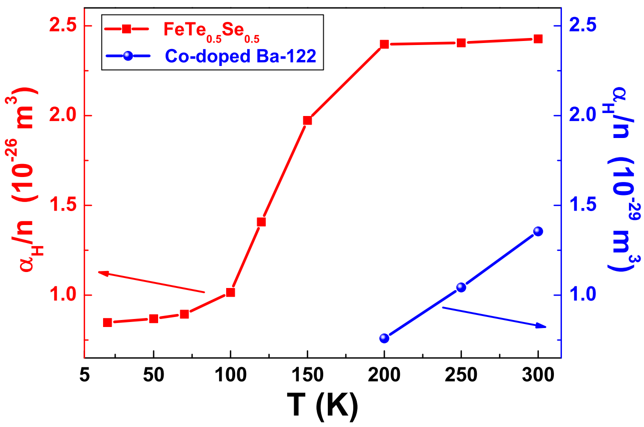

Figure 4. Temperature dependence of the normalized Hooge parameter. The left y-axis refers to $FeTe_{0.5}Se_{0.5}$ samples (red points); the right y-axis refers to Co-doped Ba-122 samples (blue points). The lines are only guides to the eyes. Below 200 K, in 122 samples the noise signal is lower than the experimental background level.

possible effects due to interband coupling cannot be excluded and require the development of a specific theoretical model for these type of superconductors. Lower values of the 1/f noise amplitude, instead, have been found in Co-doped Ba-122 superconductors (see blue points linked to right y-axis in Figure 4), indicating this material as more appropriate for future electronic applications.

4. Conclusions

The voltage-spectral density data, for all the investigated samples, show a 1/f noise component. Different behaviors are observed for the bias current and temperature dependencies in the two materials analyzed. In $FeTe_{0.5}Se_{0.5}$ superconductors, a noise level step-increase and a bias-activated nonlinear noise are found in the high temperature limit. This may be related to the presence of a structural transition occurring at $\sim$ 100 K. In Co-doped Ba-122 superconductors, lower values of the 1/f noise amplitude and of the electrical resistivity are observed. The temperature dependence of the noise level is very similar to that already found in metals. The experimental indications suggest that, the latter material is a better candidate for electronic applications.

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