Higher Harmonics AC Susceptibility Analysis of $FeSe_{0.5}Te_{0.5}$ Superconductor

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Abstract. The $FeTe_{0.5}Se_{0.5}$ sample is prepared through solid state-reaction route by encapsulation in an evacuated quartz tube at 750^0C. The resultant compound is crystallized in single phase tetragonal structure with P4/nmm space group. The transport measurement shows the sample is superconducting below 13K. The AC magnetic response of the studied sample is analyzed using a combined method of the fundamental (1^{st}) and the 3^{rd} harmonics AC magnetic susceptibility (ACMS) as a function of the temperature at different frequencies and with various applied DC magnetic fields. The frequency variation particularly affects the 3^{rd} harmonic components, which are more sensitive to the changes in the flux dynamic regimes. In addition to the study of AC third harmonic of the $FeSe_{0.5}Te_{0.5}$ as a function of both temperature and frequencies in a low applied magnetic field, we compare the observed behaviours with ideal critical state models and with those of other high T_c superconductors (HTSc).

INTRODUCTION

The study of magnetic properties plays an important role in understanding the mechanism of flux lines dynamics and act as one of the intriguing property in improving the application properties of the High Temperature Superconductors (HTSc). Critical state model (CSM) first predicted by Bean [1, 2] is widely used to investigate the higher harmonics of AC susceptibility. Despite the fact that a similar sort of data can be extracted with direct transport measurements, the high sensitivity of the AC susceptibility technique gives the chance to experience the low voltage region in the I-V characteristics, for example the Thermally Assisted Flux Flow (TAFF) regime. These investigations have demonstrated that the magnetic response of a superconductor can be both linear and nonlinear, which is characterized by the presence of higher harmonics [3-6].

If we discuss about the first harmonic, its real part is associated to the screening properties of the sample, and the imaginary part is proportional to the energy converted into heat during one cycle of AC field [7, 8]. On the other hand, the physical interpretations of the higher harmonics of the AC susceptibility as well as the differences in their curve shapes are still need simplification.

The 1^{st} and 3^{rd} harmonics AC susceptibility collectively give detailed information regarding different phenomena like the various dynamical processes flux flow, thermally assisted flux flow and flux creep [3, 9]; the Josephson (granular) character of the inter-granular ac magnetic response and the non-pinning processes and geometric surface barriers. Various Iron-based superconducting systems have already been studied through this technique focusing on vortex dynamics, granularity effects and the comparative analysis with the basic HTSc systems [3-6]. If we discuss about the ACMS harmonic analysis of chalcogenide systems, few studies are found, mostly focusing on a basic vortex dynamics comparison of FeSe and FeSe/Te bulks [10].

In this case, we present a detailed qualitative analysis of the AC magnetic response of $FeSe_{0.5}Te_{0.5}$ sample, made by analysing the behaviour of the fundamental and 3^{rd} harmonics susceptibility components (real and imaginary) as a function of temperature at different frequencies and superimposed DC fields and compared the observed behaviours with ideal CSM and with high T_c superconductors (HTSc) [3, 11].

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EXPERIMENTAL

The sample $FeTe_{0.5}Se_{0.5}$ is synthesized through standard solid state reaction route. The stoichiometric ratio of high purity (> 3N) Fe, Se, and Te are ground, pelletized and then encapsulated in an evacuated (10^{-3} Torr) quartz tube. The encapsulated tube is then heated at 750°C for 12 hours and slowly cooled to room temperature. The X-ray diffraction (XRD) are taken on Rigaku diffractometer with Cu K_α (λ = 1.54Å). Rietveld analysis was performed using the FullProf program. The transport and AC magnetization measurements are performed on a physical property measurement system (PPMS-14T) down to 2K.

RESULTS AND DISCUSSION

Figure 1 shows the observed and Rietveld fitted XRD pattern of the $FeSe_{0.5}Te_{0.5}$ sample. As no extra peaks of impurity are found so the sample is considered as homogeneous and pure. The sample is crystallized in tetragonal structure with P4/nmm space group with lattice parameters a = 3.791(3) Å, c = 6.0082(3) Å.

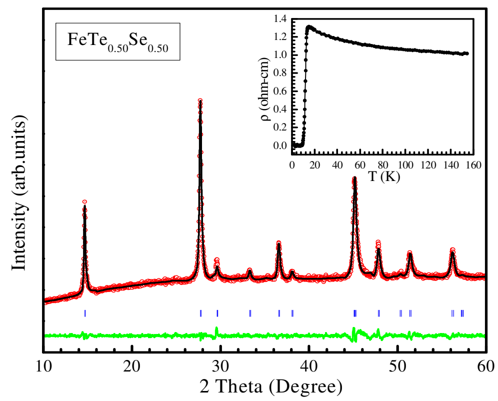


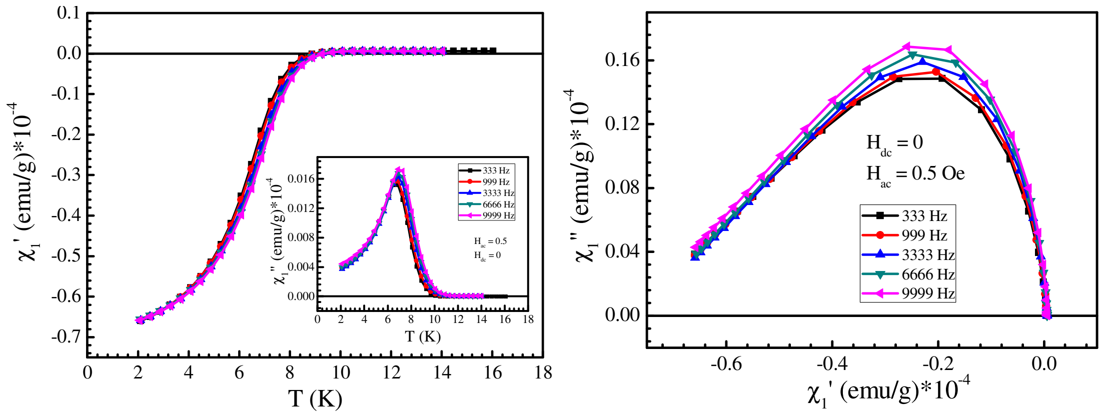
FIGURE 1: Rietveld fitted XRD pattern of $FeSe_{0.5}Te_{0.5}$ and inset shows ρ(T) of $FeSe_{0.5}Te_{0.5}$ sample.

Temperature dependence resistivity measurement of $FeSe_{0.5}Te_{0.5}$ sample is shown in the Inset. From room temperature to the superconducting transition, the sample shows semi metallic behavior. Then, it can be seen that the sample is superconducting around 14K. The onset temperature (T_c^{onset}) is found around 14K and the offset transition (T_c^{offset}) is around 8.7K.

Frequency dependence of AC magnetic susceptibility

The temperature dependence of the fundamental and 3rd harmonic ACMS components χ_3' have been also measured at fixed amplitude H_{ac} = 0.5 Oe but at different frequencies (333 Hz, 999 Hz, 3333 Hz, 6666 Hz, 9999 Hz) and H_{dc} = 0. As shown in fig. 2(a), the curve is dependent on frequency in the temperature range 3-10K. The T_c is around 14K which is independent of frequency. With increasing frequency the χ_1' little bit shifts towards higher temperature. This is clearer in inset part which is the imaginary component of χ_1'. The peak intensity of $\chi_1''(T)$ dependencies rises, and this is accompanied by the shift to higher temperatures. The difference between the peak temperature (T_p) at the highest frequency (9999 Hz) and that at the lowest frequency (333 Hz) is ΔT_p = 0.37 K. Similar behavior is characteristic for granular cuprates [11].

Figure 2 (b) presents the cole cole plots of 1st and 3rd harmonics ac susceptibility under varying frequency. The 1st harmonic is characterized by the Dome shaped curve where the inter and the intra-grain contributions can be separately observed: in both these contributions [5]. It is also examined that the signal increases with the frequency. The observed peaks and followed valleys in real parts of third harmonic decrease when the frequency increases. For the imaginary part, the high temperature minimum is suppressed and the followed bump increases with the frequency. The increasing height of the peak with the frequency both in the imaginary part of the 1st harmonics and in the maximum of the 1st harmonic Cole-Cole plots is the sign of a vortex glass phase, characterized by a combined flux creep, this behaviour is opposite to that as found by using the Kim-Anderson flux creep model [12]. Alternatively, for a clear identification of the vortex glass phase, it is also necessary to perform the analysis of the 3rd harmonic curves.



(a) (b)

FIGURE 2: Temperature dependence of (a) χ_1' and χ_1'' (inset) (b) Cole-Cole plots of χ_1'' (χ_1') at f = 333 Hz, 666 Hz, 3333 Hz, 6666 Hz and 9999 Hz at H_{ac} = 0.5 Oe for the $FeSe_{0.5}Te_{0.5}$.

The 3rd harmonic components (presented in fig. 3(a)) are even more sensitive to the frequency variation. Two peaks are seen, which corresponds to inter and intra-grain contribution. In the inter-grain part of real component χ_3' shows a reduction of the negative peak (closer to T_c) with the frequency, followed by an increase of the height and the width of the following minimum. The rapid change from negative to positive values is another reflection of the evolution from a stable pinning state (critical state) at the lowest frequencies to an increasing domination of the dissipative regimes at high frequencies.

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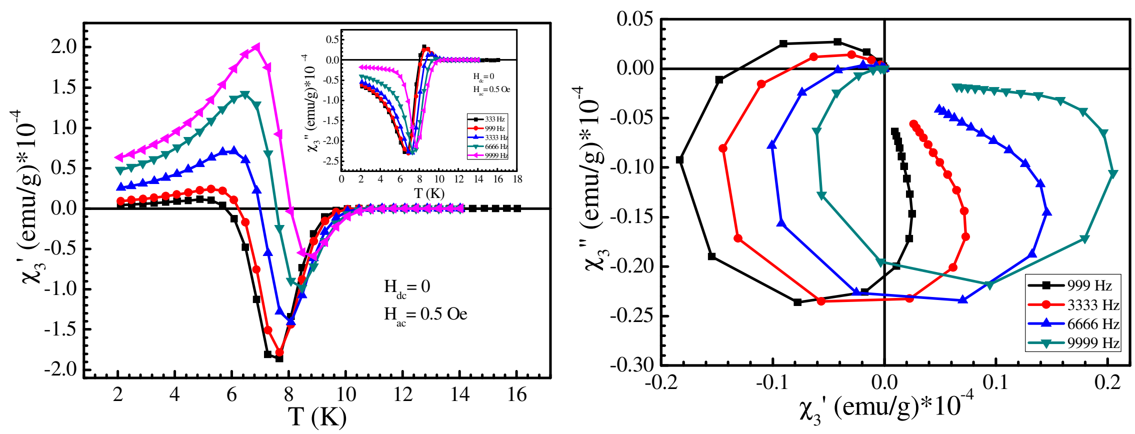

(a) (b)

FIGURE 3. (a) Temperature dependence of χ_3' and χ_3'' (inset) (b) Cole–Cole plot of χ_3'' (χ_3') at f = 999 Hz, 3333 Hz, 6666 Hz and 9999 Hz at H_{ac} = 0.5 Oe for the $FeSe_{0.5}Te_{0.5}$.

The imaginary component's χ_3'' features are also strongly influenced by the frequency change. Its initial positive (inter-grain component) peak diminishes and completely disappears at the highest frequency, together with almost constant increase of the following maximum (intra-grain) in negative direction, leading the curve shape to gradually deviate from the typical Bean critical state geometry. From the above results, we conclude that the vortices moving inside the grains react with applied ac field in different dynamical ways with respect to those moving across the grains.

Cole-Cole plots of third harmonics are presented on Fig.3b. The $\chi_3''(\chi_3')$ Cole–Cole plots (fig. 3b) rotate with frequency counter clockwise from the II to the IV quadrant, while a significant decrease of their area is produced. Closed loops tend to occupy the left half plane due to strong pinning and effective bulk screening. Their area decreases with the frequency as a result of increasing linear processes. At higher frequency the curve becomes likely to be Bean curves which closed loops are all staying in the right half plane. This type of behaviours cannot be explained in terms of standard vortex glass phase. Also, these results are opposite to the 3rd harmonic Cole-Cole plots of YBCO, in which, the curve occupy the left half plane on increasing frequencies, with an approximately constant area [12].

CONCLUSION

In summary, we analyzed the both 1st and 3rd harmonics of $FeSe_{0.5}Te_{0.5}$ sample which allows detecting the nonlinear flux creep in the inter-grain component. The frequency dependence observed in the imaginary part of the first harmonics, as a function of the temperature, as well as in the corresponding first-harmonic Cole-Cole plots may give some indication about the existence of a vortex glass phase. Additionally, the imaginary part of 3rd harmonics shows different shape of the intra-grain component, with the frequency dependency of inter-grain component of 3rd harmonics of the studied sample indicates that the vortex dynamics is changing with the external parameters.

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