Investigation of fundamental and higher harmonic AC magnetic susceptibility of FeSe$_{0.5}$Te$_{0.5}$ superconductor

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Abstract

We present the complex harmonic magnetic susceptibilities $\chi_n = \chi'_n + i\chi''_n$ ($n = 1, 3$) of FeSe$_{0.5}$Te$_{0.5}$ polycrystalline superconducting sample. The ac magnetic susceptibility is measured as a function of various external perturbations such as temperature $T$, the ac magnetic field amplitude $H_{ac}$, frequency $\nu$, and the magnitude of dc bias field $H_{dc}$. The in-phase ($\chi'_n$) and out of phase ($\chi''_n$) components of the fundamental and third harmonics of ac susceptibility are found to vary as a function of ac driven field. Particularly, the curves shift toward lower temperatures with increasing $H_{ac}$. Contrary to ac magnetic field ($H_{ac}$), no noticeable change has been observed within the range of applied dc magnetic field ($H_{dc}$) of up to 20 Oe. At a fixed ac magnetic field of $H_{ac} = 0.5$ Oe, both parts of the third harmonics show frequency dependence. The imaginary part of the third harmonics, $\chi''_3$ shows a small peak followed by a negative minimum at lower temperatures. The small peak diminishes as the frequency increases. The negative minimum suppresses and shifts towards the higher temperatures as we increase the frequency. To better understand the ac magnetic response under the influence of various perturbations, we have analyzed the polar plots (Cole-Cole) of the complex ac susceptibility for both the harmonics. Our analysis suggests that the studied sample is in a vortex glass state, characterized by a collective flux creep within Bean’s model, while the Kim–Anderson model is ruled out.

1. Introduction

The discovery of superconductivity with moderately higher transition temperature ($T_c$) of above 26 K in LaFeAsO$_1$$_x$F$_{1-x}$, ($x \sim 0.11$) has triggered considerable amount of research activities in this class of materials [1]. Subsequently, by substituting La with a smaller ionic radii Sm, the maximum superconducting transition temperature ($T_c$) raised to 56 K, namely for the compound SmFeAsO$_1$$_x$F$_{1-x}$, ($x \sim 0.15$) [2, 3]. Many researchers have attempted to discover the superconductor in some crystal structures by replacing Fe with other 3d metals. The partial substitution of Fe by other 3d metal such as Co resulted in a low transition temperature. Also, total replacement of Fe by Co, in REFeAsO suppressed the superconductivity completely, and rather exhibited some interesting magnetic properties [4, 5]. Following these discoveries, five different families with the same or related crystal structures of superconductors have also been discovered, which include iron pnictide FePn (Pn = As, P) or iron-chalcogenide FeCh (Ch = Se, Te) as common layer [6]. The universal existence of Fe-Pn/Ch layer indicates that the active planar iron layer holds the key to high-temperature superconductivity in these materials.

In all the five different families of Fe-based superconducting materials, the binary FeCh-11 type (Ch = S, Se, and Te) system is structurally the simplest one with anti-PbO type, space group P4$_n$/nm. Due to the resemblance of FeCh with the FeAs, the FeSe is considered to be the key to understanding the fascinating physics of unconventional superconductivity in these materials. Although, the superconducting transition temperature of bulk FeCh-systems is much smaller as compared to FeAs based (REFeAsO/F) compounds at ambient...
conditions, the simple crystal structure and high tunability of transition temperature of Fe-Ch can be used to understand the mechanism of high-temperature superconductivity in Fe based superconducting materials. The FeSe$_{1-x}$Te$_x$ in off-stoichiometry form shows superconducting transition at $\sim 8$ K in ambient environment [7]. The superconducting transition temperature of FeSe increases remarkably from $\sim 8$ K to 37 K by applying hydrostatic pressure of around $\sim 9$ GPa [6–9]. Recently, the transition temperature is raised up to 110 K in FeSe monolayer on the STO substrate [10–12].

In last decade, the structural, electronic, morphological and basic mixed state properties of binary FeSe system had been studied extensively under both ambient environment and hydrostatic pressures along with on-site chemical doping [6, 8, 9, 13–16]. Moreover, their high upper critical field and relatively small anisotropies make them attractive materials for power and high-field applications at liquid helium temperatures [17–19]. For implementation of these materials for practical devices, a quantitative understanding of the nature of their superconducting and mixed state properties in terms of pinning and vortex dynamics is desired.

The complex magnetic susceptibility is an important technique to investigate dynamical magnetic properties of the vortex state and the non-linear processes related to flux pinning transport [20, 21]. The fundamental and higher harmonics of ac susceptibility collectively gives detailed information regarding different phenomena like the dynamical processes flux flow (FF), thermally assisted flux flow (Tcff) and flux creep [21, 22], in terms of the intra and inter grain superconducting properties and the non-pinning processes along with geometric surface barriers. Bean’s Critical state model (CSM) [23, 24] is widely used to investigate the higher harmonics of ac susceptibility for type II superconductors. According to this model, the higher harmonics appear due to the hysteretic relation between the magnetization and the applied magnetic field being caused by the flux pinning. The higher harmonics show different behaviors under various conditions such as variable ac field amplitude, the frequency of ac field, dc field and the temperature. Worth noting is the fact that the critical state model (CSM) fails to explain some issues related to ac susceptibility behavior of higher harmonics under various perturbations. In this scenario, it is necessary to consider the influence of linear; thermally assisted flux flow (TAFF), flux flow (FF) and non-linear; flux creep (FC) dynamical dissipative regimes along with the properties of different vortex lattice phases [22, 25, 26]. The linearity and non-linearity of the vortex lines diffusion depend upon the interrelation between ac and dc applied magnetic fields. Thus, the higher harmonics of complex susceptibility as a function of various ac and dc magnetic fields can provide useful insight into the nature of the dissipative processes, which govern the shape of the electric field (E)—current (J) characteristics in the superconductors [26, 27]. In this regards, the physical interpretation of higher harmonics of the ac susceptibility as well as the differences in their curve shapes is yet to be understood for various superconductors.

In this paper, we report a comprehensive study of the complex magnetic susceptibility of FeSe$_{0.5}$Te$_{0.5}$ polycrystalline superconducting sample. The fundamental and third harmonics of ac complex susceptibility has been studied as a function of temperature $T(2 \leq T \leq 15$ K), the ac magnetic field amplitude $H_{ac}$ (0.2 Oe $\leq H_{ac} \leq 5$ Oe), frequency $\nu (333$ Hz $\leq \nu \leq 9999$ Hz), and the magnitude of a superimposed dc field $H_{dc}$ (0 Oe $\leq H_{dc} \leq 20$ Oe) to understand the vortex dynamics and granularity effects of the superconducting and mixed state. The peak position of the imaginary part of complex ac susceptibility shifted towards lower temperatures values with increasing the applied ac magnetic field. Our detailed ac susceptibility results in terms of the variation of various harmonics with applied bias ac field and variation in frequency indicate that studied Fe chalcogenide superconductor follows the vortex glass state within Bean’s model, while the Kim–Anderson model is ruled out.

2. Experimental methods

The polycrystalline FeSe$_{0.5}$Te$_{0.5}$ sample is synthesized by standard solid-state reaction route using 3 N high purity of Fe, Se, and Te in their elemental form. The precursors were weighed in their stoichiometric ratio and then ground thoroughly using mortal pestle in a controlled atmosphere. The mixed material was pressed into a pellet and subsequently encapsulated in an evacuated quartz tube. Sealed and evacuated quartz tube was heat treated at 750 $^\circ$C for 12 h. Finally, the furnace is allowed to cool down to room temperature slowly. The X-ray diffraction (XRD) are taken on Rigaku diffractometer with Cu-K$_\alpha$ ($\lambda = 1.54$ Å) to check the phase purity of the sample. The crystal structure is refined by the Rietveld method using open source FullProf program. No other extra peaks of any parasitic phases are observed in the fitted data, hence the sample is considered as homogeneous and pure in phase. The details of the sample preparation, crystal structure, magnetic and electrical transport properties are reported elsewhere [14].

The ac-susceptibility measurements were carried on Quantum Design Physical Property Measurement System (PPMS), using its AC Measurement System (ACMS) option. The sample in the form of a rectangular slab was mounted on the experimental setup for measuring its magnetic response. The direction of the applied alternating ac and dc magnetic fields was along the long axis. The measurements have been carried out at the
various frequencies ($\nu = 333$ to 9999 Hz) and applied ac field magnetic amplitudes (0.0 to 5 Oe). The magnetic response was also collected under low range (0.0 to 20 Oe) dc applied magnetic fields.

3. Results and discussion

3.1. Phase purity (x-ray diffraction)
Fitted and observed room temperature powder X-ray diffraction (PXRD) patterns of the studied FeSe$_{0.5}$Te$_{0.5}$ sample are shown in figure 1. It is evident from this figure that the studied sample is free of any impurities within the XRD limit. The sample is crystallized in P4/nmm space group in tetragonal structure. The Rietveld refined lattice parameters are $a = b = 3.800(1)$ Å and $c = 6.019(3)$ Å. The lattice parameters are in good agreement with earlier reports on similar samples [7–9, 14–16]. The inset of figure 1 shows the ac susceptibility of the studied sample at amplitude of 0.5 Oe at 333 Hz. The real part clearly shows the diamagnetic transition around 9.5 K coupled with the peak in the imaginary part starting from the same temperature. It is clear from figure 1 that the studied sample is a bulk superconductor below 9.5 K.

3.2. AC magnetic response at different $H_{ac}$ amplitudes
Figures 2(a) and (b) depict the real ($\chi'$) and imaginary ($\chi''$) components for the fundamental and third harmonics of complex magnetic susceptibility as a function of temperature at different applied ac magnetic field of $H_{ac} = 0.2$ Oe–5 Oe. The frequency and dc bias field was fixed at 333 Hz and $H_{dc} = 0$ during this measurement. The in-phase (real) component of complex magnetic susceptibility, shows the superconducting transition temperature $T_c \sim 9.5$ K, which also coincides with the first positive signal of the imaginary component $\chi''$ (shown in the inset of figure 2(a)). As evident from figure 2(a), there is no observable change on the onset of diamagnetic transition within the limit of applied ac magnetic field. On the other hand, the peak temperature, $T_p$ (shown in the inset of figure 2(a)) of $\chi''$ is sharply decreased with increasing amplitude of ac applied field ($H_{ac}$). Both curves (see figure 2(a)) are strongly influenced by the increase of ac field amplitude. The absolute value of $\chi'$ is directly proportional to the applied ac field amplitude. Correspondingly, the height of the peak in the imaginary part (inset of figure 2(a)) increases with increasing $H_{ac}$, $T_p$ is found to linearly decreased from 8.5 K to 2.4 K as $H_{ac}$ increases from 0.2 to 5 Oe.

The sensitivity of ac susceptibility allows us to distinguish contribution of intra-granular superconductivity (individual grains become superconducting) and inter-grain superconductivity (connections/weak-links between the neighboring grains become superconducting). Generally, an intra-granular peak appears at a higher temperature just below the transition temperature and the lower temperature peak corresponds to inter-grain coupling [28]. Here, we do not observe separate peaks for both intra and inter granular superconductivity even at the lowest applied ac field (0.2 Oe) for our sample of interest, and rather a single diamagnetic transition is seen. All the curves expectedly shift towards lower temperatures with increasing magnetic field amplitude ($H_{ac}$), owing to the easier penetration of the flux into the sample. The shift in the peak with increasing field is
accompanied by a considerable increase in the height of the peak, especially for the highest amplitude. The third harmonics (both in the real and in the imaginary parts) do provide more sensitive information corresponding to the inter-grain (lower temperature) and intra-grain (near \(T_c\)) contributions for the studied sample. The real part of the third harmonic shows a single negative minimum, whereas the imaginary part shows one positive peak followed by a negative minimum. The small positive peak below \(T_c\) may be associated with crossover from critical state stable pinning to the domination of the dynamical regimes [28]. The subsequent minimum at lower temperature characterizes to be due the inter-grain contribution [29]. Both the minima in real and imaginary parts go more in-depth and shift towards lower temperatures by increasing \(H_{ac}\). As the \(ac\) applied field increases, the amplitude of the small positive peak in the imaginary part becomes more prominent, and the peak moves towards lower temperature. Interestingly, the third harmonics show (see figure 2(b)) opposite behavior to the one as being reported for \(Fe_{1.02}Se\) [15], but is somewhat similar to \(LaFeAsO_{0.92}F_{0.08}\) compound [29].

The Cole-Cole plots, \(\chi''(\chi')\) for fundamental and third harmonics obtained from figure 2 at different \(ac\) applied field amplitudes for studied \(FeSe_{0.5}Te_{0.5}\) sample are shown in figure 3. As evident from figure 3, the \(\chi''(\chi')\) plots are strongly influenced by the applied \(ac\) field amplitude. The peak height and broadness of the first harmonic increases with increasing \(ac\) applied field. Also, in Cole-Cole plots we have observed only one peak, which again shows that the observed \(ac\) magnetic response has only one contribution, which will be discussed in section 3.3. The third harmonics of \(FeSe_{0.5}Te_{0.5}\) (shown in figure 3(b)) show entirely different shape in comparison to the one as found in fundamental \(ac\) susceptibility of superconductors. It forms a closed contour with an ellipsoidal (lens) shape. The closed contour is mostly situated in the III quadrant, with a tiny

![Figure 2](image.png)

**Figure 2.** Real \((\chi')\) and imaginary \((\chi'')\) (inset component of (a) fundamental and (b) third harmonics of ac magnetic susceptibility for \(FeSe_{0.5}Te_{0.5}\) measured at various applied \(ac\) field \(H_{ac} = 0.2\) Oe, 0.5 Oe, 0.7 Oe, 1 Oe, 2 Oe and 5 Oe as a function of temperature. For this measurement the frequency, \(\nu = 333\) Hz was fixed, and no DC field was present \(H_{dc} = 0.0\) Oe. The solid lines through the points are to guide the eye only.
portion placed in the neighboring II and IV quadrants. No part of the curve is seen in I quadrant. Applied field amplitude triggered a visible change in the behavior of curve. At the highest amplitude, the curve occupies a large area as compared to the low field amplitude. The growth of area occupied by Cole-Cole plots with increasing magnetic field amplitudes reflects higher activity of dynamical processes determining the nonlinearity.

3.3. AC magnetic response at different frequencies

The temperature dependence of the fundamental and third harmonic of ac complex magnetic susceptibility at representative frequencies for studied FeSe$_{0.5}$Te$_{0.5}$ sample is shown in figure 4(a). The data for both the harmonics were collected at a fixed amplitude of ac field, $H_{ac} = 0.5$ Oe and zero bias dc field. The out-of-phase component ($\chi''_1$) of first harmonic shows only one peak as a function of temperature. This behavior is different from the general character of high-$T_c$ superconductors where inter- and intra-grain peaks can be observed separately [28]. Figure 4(a) shows that the diamagnetic transition of the in-phase component of susceptibility (main panel of figure). The effect of frequency is negligible on the real component of ac susceptibility. Whereas the peak of imaginary component $\chi''_1(T_p)$ rises and shifts towards the higher temperature with increasing frequency from 333 Hz to 9999 Hz. Adesso et. al. showed numerically that in both the cases, vortex glass as well as Kim–Anderson, the peak $\chi''_1(T_p)$ shifts towards the higher temperature with increasing frequency [30]. It is the height of the $\chi''_1(T_p)$ peak which distinguishes both the scenarios. The $\chi''_1(T_p)$ peak increases in a vortex.

Figure 3. The Cole-Cole plots, $\chi''(\chi')$ of FeSe$_{0.5}$Te$_{0.5}$ for (a) fundamental and (b) third-harmonic, measured at different ac drive field $H_{ac} = 0.2$ Oe, 0.5 Oe, 0.7 Oe, 1 Oe, 2 Oe and 5 Oe at fixed frequency $\nu = 333$ Hz and $H_{dc} = 0.0$ Oe. The solid lines are a guide for the eyes.
glass state while decreases in Kim-Anderson case, in which the vortices are still in a liquid phase (although highly viscous). It is clear from the inset of figure 4(a) that the height of the peak $\chi''_1(T_p)$ grows as we increase the frequency, which indicates that the studied system is in a Vortex glass phase.

We also study the influence of the frequency on the behavior of third harmonics of the ac magnetic susceptibility for studied FeSe$_{0.5}$Te$_{0.5}$ sample. Figure 4(b) shows the real and imaginary parts of third harmonics of the studied sample at various frequencies. The frequency dependence of the third harmonics of FeSe$_{0.5}$Te$_{0.5}$ is similar to the previously reported LaFeAsO$_{0.92}$F$_{0.08}$ superconductor [29]. It is evident from figure 4(b) that third harmonic components are even more sensitive to the frequency variation. At low frequency, the real part ($\chi'_3$) shows a negative minimum (closer to $T_c$) followed by a small but broad positive peak. As the frequency increases, the negative minima (closer to $T_c$) suppresses and shifts towards higher temperatures. The subsequent positive peak rises and shifts toward a higher temperature with increasing frequency. A crossover from positive to negative values is visible with the increase in frequency. The rapid change from negative to positive values indicates that the system is growing from a stable pinning state (critical state) at the lowest frequencies to the domination of the dissipative regimes at high frequencies [22, 25]. The imaginary component of third harmonics ($\chi''_3$) shows a small positive peak (maximum) near to transition temperature, which further followed by negative minima (valley) at a lower temperature. The imaginary component is also strongly influenced by applied frequency. The positive peak diminishes with increasing frequency and completely disappears at the

Figure 4. Real ($\chi'_1$) and imaginary ($\chi''_1$) (inset) component of (a) fundamental and (b) third harmonics of ac magnetic susceptibility versus temperature at representative frequencies, $\nu = 333$ Hz, 999 Hz, 3333 Hz, 6666 Hz, and 9999 Hz. The data have been collected at $H_{dc} = 0.0$ Oe and $H_{ac} = 0.5$ Oe constant field values. The solid lines are a guide for the eyes.
highest frequency (9999 Hz). The lower temperature minimum suppresses and moves to a higher temperature as frequency increases. The obtained curve is different from the Bean critical state geometry [30].

Figure 5(a) illustrates the Cole–Cole plots of the first harmonics for studied FeSe0.5Te0.5 sample. The Cole-Cole plots show a single peak. The peak height of the dome-shaped curves is directly proportional to the frequency, which is contrary to the Kim–Anderson model [30]. The growth in the height of Cole-Cole plots (see figure 5(a)) and the shift towards the higher temperature in the peak of imaginary signal (See figure 4(b)) as a function of frequency is consistent with the simulated vortex glass collective creep model reported in [30].

The Cole–Cole plots of third-harmonic as a function of frequency are shown in figure 5(b). As evident from the figure, the polar plots for the lowest frequency of 333 Hz are almost entirely in the left half. The Cole-Cole plots shift towards the right half quadrant with increasing frequency. The area of plots is somewhat unchanged with frequency, this is contrary to the impact of ac driven field (figure 3(b)). The Cole-Cole plots at higher frequencies appear to behave somewhat like the Bean curves, which are closed loops, all staying in third and fourth quadrants. Although the detailed ac susceptibility results in terms of the variation of various harmonics with applied bias ac field and frequency indicate the Fe chalcogenide superconductor to follow the vortex glass state within Bean’s model and the Kim–Anderson model is ruled out, further studies are needed for a complete understanding of the material [30]. In fact, the influence of granularity as evidenced from AC susceptibility studies on polycrystalline FeSe0.5Te0.5 has already been reported [31]. Also, the higher harmonics were reported and discussed by the same group later [32]. The current MS further discusses the Cole-Cole of third harmonic

Figure 5. (a) Fundamental and (b) third harmonic cole–cole plots $\chi''(\chi)$ for studied FeSe0.5Te0.5 at representative frequencies, $\nu = 333$ Hz, 999 Hz, 3333 Hz, 6666 Hz, and 9999 Hz. The measurement has been done at a fixed amplitude of $H_{ac} = 0.5$ Oe of the ac magnetic field and zero dc biased field. The solid lines are a guide for the eyes.
in framework of Kim Anderson and Vortex glass model. Some of the preliminary findings of this study were reported by us in a symposium, but without thorough analysis [33].

To understand the magnetic response of the studied sample more deeply, the analysis of frequency dependence of \( \chi'' \) peak was performed using Vogel-Fulcher law. According to Vogel-Fulcher law the frequency dependent spin freezing temperature, \( T_f \) (temperature of the \( \chi'' \) peak) can be described by

\[
\omega = \omega_0 \exp \left( \frac{-E_a}{K_B(T_f - T_0)} \right) \tag{1}
\]

where \( E_a \) is the activation energy for the relaxation process, \( \omega_0 \) is the characteristic frequency of the clusters, and \( T_0 \) is the Vogel-Fulcher temperature, which is the measure of inter-cluster interaction strength. The phenomenological Vogel-Fulcher (VF) law takes accounts of the interaction of magnetic clusters. In the absence of interaction i.e., \( T_0 = 0 \), the Vogel-Fulcher equation is transformed to the Arrhenius equation [35, 36] which describes the relaxation processes of non-interacting magnetic clusters as,

\[
\omega = \omega_0 \exp \left( \frac{-E_a}{K_B T_f} \right) \tag{2}
\]

The Vogel-Fulcher law (equation (1)) fit to the experimental data of the FeSe\(_{0.5}\)Te\(_{0.5}\) sample is shown in figure 6. It is evident from the figure (6) that the freezing temperature \( T_f \) and \( 1/\ln(\omega_0/\omega) \) follows the expected linear behavior. From the best linear fit, we obtained \( \omega_0 = 10^{12} \) Hz, \( E_a/k_B = 43.40 \) K, and \( T_0 = 4.66 \) K. Here, the quantity \( (T_f - T_0)/T_0 \approx 0.31 \) is an order of magnitude higher than those reported for canonical spin glasses while it is comparable to the cluster glass system. Hence, the fit of the experimental data of Vogel-Fulcher law indicates the presence of a spin-glass state in the studied sample.

3.4. AC magnetic susceptibility response at different dc biased (\( H_{dc} \)) fields

To gain more insight of the vortex dynamics of the studied FeSe\(_{0.5}\)Te\(_{0.5}\) sample, we have also measured the first and third harmonics at different dc biased magnetic field, \( H_{dc} = 5 \) Oe, 10 Oe, and 20 Oe (shown in figures 7(a) and (b)). The \( \chi_1'(T) \) shows a usual transition which is also shown in dc susceptibility. We want to emphasize that unlike to the first harmonic of ac magnetic susceptibility under varying ac magnetic field amplitudes, the dc applied field does not show any noticeable effect on both the real and imaginary part (inset of figure 7(a)). It should be noted that this result is valid within an applied magnetic field; the situation can be different in the higher field. All the curves show the same diamagnetic transition and \( \chi_1'(T) \) grows towards low temperature in the negative direction. The same behavior is followed in the imaginary component \( \chi''_1(T) \) as the peak position under any dc magnetic field remains unaffected.

Figure 7(b) shows the real component of the 3rd harmonic curve \( \chi_3'(T) \), having large initial minima, which remains same on increasing field amplitude \( H_{dc} \). One can say that it is unaffected by the applied dc magnetic field. Each curve is dominated by the following small maximum, which remains same on increasing field amplitude.
The inset of figure 7(b) shows that for the increasing $H_{dc}$, the small maxima (closer to $T_c$) of $\chi''$ remains unchanged. Further, the $\chi''_3(T)$ plots do possess an $H_{dc}$ independent valley like a deeper minimum shape. The polar plot (Cole-Cole) of fundamental and third harmonic obtained from the curves of figures 7(a) and (b) are shown in figures 8(a) and (b), respectively. The closed contour is mostly situated in the III quadrant, with a tiny portion placed in the neighboring II and IV quadrants. Interestingly, there is no visible change in the behavior triggered by an increase in $H_{dc}$.

4. Conclusion

In conclusion, the fundamental and third harmonics of the complex magnetic susceptibility has been studied for FeSe$_{0.5}$Te$_{0.5}$ superconducting polycrystalline samples as functions of temperature $T$, at various amplitudes, $H_{ac}$, and frequency, $\nu$ of ac magnetic field, and the magnitude of dc bias field $H_{dc}$. The absolute value of the diamagnetic signal and the peak height of $\chi''_1$ increased with the applied ac field, on the other hand, the peak temperature, $T_p$, shifts towards the lower temperatures as the ac field increases. The effect of frequency is negligible on the real component of ac susceptibility whereas the peak of imaginary component $\chi''_1(T_p)$ rises and shifts towards the higher temperature as frequency increases. The frequency dependence of $\chi''$ peak is fitted well with Vogel-Fulcher law indicating glassy nature of the system. The observed data showed strong inter-granular coupling in the studied sample. Further, our analysis suggested that the studied sample is in a vortex glass state, characterized by a collective flux creep within Bean’s model, while the Kim–Anderson model is ruled out.
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Figure 8. The Cole-Cole plots for the (a) first and (b) third harmonics, \( \chi_3' \) (\( \chi_3'' \)) of ac magnetic susceptibility of FeSe\(_{0.5}\)Te\(_{0.5}\), measured at different dc magnetic field \( H_{dc} = \) 5 Oe, 10 Oe and 20 Oe as a function of temperature with constant ac drive field \( H_{ac} = 0.5 \) Oe and frequency \( \nu = 333 \) Hz. The solid lines through the data are drawn to guide the eyes.
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