Weak superconducting fluctuations and small anisotropy of the upper critical fields in an Fe$_{1.05}$Te$_{0.85}$Se$_{0.15}$ single crystal

Takanori Kida$^{1,4}$, Masahiro Kotani$^1$, Yoshikazu Mizuguchi$^{2,3,4}$, Yoshihiko Takano$^{2,3,4}$, and Masayuki Hagiwara$^{1,4}$

$^1$KYOKUGEN, Osaka University, 1-3 Machikaneyama, Toyonaka, Osaka 560-8531, Japan
$^2$National Institute for Materials Science, 1-2-1 Sengen, Tsukuba 305-0047, Japan
$^3$University of Tsukuba, 1-1-1 Tennodai, Tsukuba 305-8577, Japan
$^4$JST, Transformative Research-Project on Iron Pnictides (TRIP), Chiyoda-ku, Tokyo 102-0075, Japan

We have investigated the temperature dependence of the resistive upper critical fields ($\mu_0 H_{c2}(T)$) for an Fe$_{1.05}$Te$_{0.85}$Se$_{0.15}$ single crystal, which exhibits superconductivity at $T_c \sim 14$ K, in magnetic fields of up to 55 T. Two-dimensional feature and superconducting fluctuations of the samples are found to be weak, because the resistive broadening effect on applied magnetic fields of up to 14 T is small. The Pauli paramagnetic effect is obviously evidenced by the strong suppression of the $\mu_0 H_{c2}(T)$ ($H \parallel ab$) curve and nearly isotropic $\mu_0 H_{c2}(0) \approx 47$ T is seen for both $H \parallel ab$ and $H \parallel c$. This fact is almost identical to the results of Fe$_{1+y}$Te$_{0.6}$Se$_{0.4}$ single crystals reported previously. We have discussed that the small anisotropy of the upper critical field at low temperatures in Fe$_{1+y}$(Te,Se) systems against the variation of the Te/Se ratio.

KEYWORDS: iron-based superconductor, Fe$_{1+y}$(Te,Se), upper critical field, anisotropy

The discovery of high-temperature superconductivity in the iron-pnictide LaFeAsO$_{1-x}$F$_x$ (abbreviated as the 1111-system) and related compounds has generated great interest in understanding the interplay of magnetism, superconductivity, and electrical structure. So far, several other groups of iron-based superconductors have been discovered, such as AeFe$_2$As$_2$ (abbreviated as the 122-system, Ae = alkali earth metals),$^2$ LiFeAs (abbreviated as the 111-system),$^3$ and tetragonal FeCh (abbreviated as the 11-system, Ch = chalcogen).$^4$ These iron-based compounds display a phase transition from antiferromagnetic to superconducting ground states tuned by chemical doping$^4$ or external pressure,$^5$ suggesting that the antiferromagnetic spin fluctuations of Fe play an important role in developing the superconducting ground states.$^2$ The 11-system superconductors, such as Fe$_{1+y}$Se,$^4,6$ FeTe$_{1-x}$Se$_x$,$^7$ and FeTe$_{1-x}$S$_x$,$^8$ are of great importance in understanding the mechanism of superconductivity in iron-based superconductors owing to their simple structures. Fe$_{1+y}$Se, which exhibits superconductivity at $T_c = 8$ K, has a tetragonal PbO-type structure ($P_4/nmm$) composed of

*E-mail address: kida@mag.cqst.osaka-u.ac.jp
stacked FeSe layers along the c-axis.\textsuperscript{4} The superconductivity in Fe\textsubscript{1+\delta}Se is significantly affected by external pressure\textsuperscript{6,9–11} and chalcogenide substitutions.\textsuperscript{7,8} In particular, an applied pressure of only up to 4.15 GPa drastically enhances its \( T_c \) to \( \sim 37 \) K (\( d \ln T_c / dP \sim 0.91 \)).\textsuperscript{9}

The pressure effect of superconductivity in Fe\textsubscript{1+\delta}Se is larger than that in other iron-based superconductors, e.g., the \( T_c \) of LaFeAsO\textsubscript{1–x}F\textsubscript{x} increases from 26 K at ambient pressure to 43 K at 4 GP (\( d \ln T_c / dP \sim 0.16 \)).\textsuperscript{5}

For a thorough understanding of the mechanism of superconductivity in iron-based superconductors, it is important to study the upper critical field (\( \mu_0 H_{c2} \)) because the \( \mu_0 H_{c2} \) provides information on anisotropy, coherent length, effective electron mass, and the pair-breaking mechanism. In general, high \( T_c \) superconductors show extremely high \( \mu_0 H_{c2} \) values. The temperature dependence of \( \mu_0 H_{c2}(T) \) in low magnetic fields is often a very poor guide to its intrinsic features at low temperatures. Therefore, transport measurements in very high magnetic fields and at low temperatures close to \( T = 0 \) K have provided useful information not only on \( \mu_0 H_{c2}(0) \) but also on the nature of the phase in the vicinity of a quantum phase transition point. Previously, we reported the temperature dependence of \( \mu_0 H_{c2}(T) \) on FeTe\textsubscript{0.75}Se\textsubscript{0.25} polycrystals,\textsuperscript{12} which showed a strong suppression effect at low temperatures due to the Pauli paramagnetic effect. In the present study, we performed electrical resistivity measurements of a single crystal of Fe\textsubscript{1.05}Te\textsubscript{0.85}Se\textsubscript{0.15} in magnetic fields of up to 55 T to discuss the anisotropy of \( \mu_0 H_{c2}(T) \). Recently, Fang \textit{et al.}\textsuperscript{13} and Khim \textit{et al.}\textsuperscript{14} reported the temperature dependence of \( \mu_0 H_{c2}(T) \) of Fe\textsubscript{1+y}Te\textsubscript{0.6}Se\textsubscript{0.4} single crystals. Therefore, we compare and discuss the \( \mu_0 H_{c2}(T) \)s on these Fe\textsubscript{1+y}(Te,Se) systems.

Single crystals of Fe\textsubscript{1+y}Te\textsubscript{1–x}Se\textsubscript{x} were grown with a self-flux method as described in ref.\textsuperscript{15}. After annealing, the present single crystal of Fe\textsubscript{1.05}Te\textsubscript{0.85}Se\textsubscript{0.15}, whose composition was determined by the energy dispersive x-ray spectroscopy analysis, was obtained from a precursor material with nominal composition FeTe\textsubscript{0.75}Se\textsubscript{0.25}. We prepared a sample with typical dimensions of 800×200×15 \( \mu \)m\textsuperscript{3} for electrical resistivity (\( \rho \)) measurements. The sample is mounted on a sapphire substrate (4×0.5×20 mm\textsuperscript{3}), which is a good thermal anchor. The temperature dependence of \( \rho(H) \) was measured by a dc four-probe technique in static magnetic fields of up to 14 T with a commercial superconducting magnet system (Oxford Instruments Ltd.). The electrical current direction was parallel to the \( ab \)-plane of the sample, and the magnetic field was applied along the \( ab \)-plane or the \( c \)-axis. The \( \rho(H) \) in pulsed magnetic fields of up to 55 T was measured by utilizing a non-destructive pulsed magnet. The duration of the pulsed magnetic field was about 40 msec.

Figures 1(a) and 1(b) show the temperature dependence of the \( \rho(H) \) in static magnetic fields of up to 14 T with increments of 2 T for \( H \parallel ab \) and \( H \parallel c \), respectively. The zero-field resistivity exhibits a superconducting transition at \( T_{c \text{onset}} = 14.1 \) K as shown in the inset of Fig. 1(a). Above \( T_c \), the zero-field resistivity of the present sample increases with decreasing
Fig. 1. (Color online) Temperature dependence of the electrical resistivity of a single crystal of Fe$_{1.05}$Te$_{0.85}$Se$_{0.15}$ in static magnetic fields of up to 14 T with increments of 2 T for (a) $H \parallel ab$ and (b) $H \parallel c$. The inset displays the temperature dependences of the zero-field resistivity in the $ab$-plane below 100 K.

temperature. Similar behavior was reported in the literature$^{13,16}$ on the transport properties of Fe$_{1.11}$Te$_{0.6}$Se$_{0.4}$ single crystals. This “semiconducting” behavior has been attributed to a weak charge-carrier localization due to a large amount of excess Fe in Fe$_{1+y}$Te$_{1-x}$Se$_x$ systems.$^{16}$

For the present sample, $T_c$ decreases with increasing magnetic fields for both $H \parallel ab$ and $H \parallel c$. The shifts of $T_c^{\text{onset}}$ for $H \parallel ab$ and $H \parallel c$ at 14 T from the zero field value are $\Delta T_c^{ab} = -1.5$ K and $\Delta T_c^{c} = -3.2$ K, respectively. The $\rho(H) - T$ curves for both $H \parallel ab$ and $H \parallel c$ shift parallel to the low temperature side with increasing magnetic fields without broadening, suggesting that the two-dimensional feature of the present sample is smaller than that of high-$T_c$ cuprates.$^{17}$ In general, the resistive-broadening effect of high-$T_c$ cuprates
is attributed to strong superconducting fluctuations due to the high two-dimensionality of the CuO$_2$-plane.\textsuperscript{17} In our results, however, a weak resistive-broadening is observed at higher magnetic fields for $H \parallel c$, which probably shows an effect from the vortex motion\textsuperscript{18} as well as reported results for iron-chalcogenide superconductors\textsuperscript{13,16} and other iron-pnictide ones.\textsuperscript{19}

Figures 2(a) and 2(b) depict the magnetic field dependence of the resistivities in the $ab$-plane at designated temperatures for $H \parallel ab$ and $H \parallel c$, respectively. The resistivities show no hysteresis between the field ascending and descending processes, indicating no measurable heating due to eddy currents induced in the sample caused by the pulsed magnetic field. Upon heating from the lowest temperature, the superconducting to normal state transitions shift to lower magnetic fields. The transition induced by applied magnetic fields is considerably broad. At $T = 1.4$ K, the values of the zero-resistivity field $\mu_0 H_{c2}^{\text{zero}}$ (10 \% of the normal state resistivity) for $H \parallel ab$ and $H \parallel c$ are $\sim 34$ T and $\sim 26$ T, respectively. It is expected that the appearance of finite resistivity with lowering magnetic field for $H \parallel c$ arises from dissipation associated with thermally activated vortex motion.\textsuperscript{18} The onset upper critical fields $\mu_0 H_{c2}^{\text{onset}}$ (90 \% of the normal state resistivity) at $1.4$ K for $H \parallel ab$ and $H \parallel c$ are almost equal; $\mu_0 H_{c2}^{ab} = 45$ T and $\mu_0 H_{c2}^{c} = 46$ T. Similar results were reported by Fang et al.\textsuperscript{13} and Khim et al.\textsuperscript{14} for Fe$_{1+y}$Te$_{0.6}$Se$_{0.4}$ single crystals.

Using the magnetic field and temperature dependences of the resistivity in static and pulsed magnetic fields, we show the field-temperature ($H$-$T$) phase diagram of the present sample in Fig. 3. The onset values of $\mu_0 H_{c2}(T)$ and $T_c(H)$ in the superconducting transitions were plotted. The solid and open symbols in Fig. 3 correspond to the data in the static and the pulsed magnetic fields, respectively. The slopes ($d\mu_0 H_{c2}/dT$) for $H \parallel ab$ and $H \parallel c$ at $T_{c}^{\text{onset}}(0)$ were $-17.2$ and $-5.2$ T/K, respectively, which were estimated by fit-

![Fig. 2](image-url)

Fig. 2. (Color online) Electrical resistivity $\rho(H)$ as a function of magnetic field of up to 50 T at designated temperatures for (a) $H \parallel ab$ and (b) $H \parallel c$. 
Fig. 3. (Color online) Field-temperature ($H$-$T$) phase diagram for a single crystal of Fe$_{1.05}$Te$_{0.85}$Se$_{0.15}$ for $H \parallel ab$ ($H_{c2}^{ab}$) and $H \parallel c$ ($H_{c2}^c$). The solid and open symbols correspond to the data in the static and pulsed magnetic fields, respectively. The broken lines represent the WHH prediction with only the orbital pair-breaking effect. The solid lines are added for eye-guides.
dence of the anisotropy coefficient $\Gamma(T)$ defined by $H_{c2}^{ab}(T)/H_{c2}^{c}(T)$ is shown in the inset of Fig. 3. The $\Gamma(T)$ decreases from $\sim 2.4$ near $T_c$ to $\sim 1$ at $T = 0$, monotonically. The $\mu_0 H_{c2}^{ab}(T)$, $\mu_0 H_{c2}^{c}(T)$, and $\Gamma(T)$ of Fe$_{1.05}$Te$_{0.85}$Se$_{0.15}$ are almost equal to those of Fe$_{1+y}$Te$_{0.6}$Se$_{0.4}$, indicating that the small anisotropy of the upper critical field at low temperatures is robust against the variation of the Te/Se ratio, at least in these samples. Similar isotropic behavior of the upper critical field at low temperatures has also been observed in the 122-system of iron-based superconductors. These results indicate that the small anisotropy of the upper critical field at low temperatures may be a general feature on the 11-system and the 122-system of iron-based superconductors, being consistent with band calculations and angle resolved photoemission spectroscopy (ARPES) results.

From the Ginzburg-Landau (G-L) theory, the coherent length tensor $\xi(0)$ is calculated from the extrapolated $\mu_0 H_{c2}^{ab}(0)$ and $\mu_0 H_{c2}^{c}(0)$ data using the relations given by $\mu_0 H_{c2}^{ab}(0) = \Phi_0 / 2 \pi \xi_{ab}(0) \xi_c(0)$, $\mu_0 H_{c2}^{c}(0) = \Phi_0 / 2 \pi \xi_{ab}^2(0)$, where $\Phi_0 = 2 \pi \hbar / 2 e \simeq 2.0678$ Tm$^2$ is the flux quantum. The obtained values are $\xi_{ab}(0) \approx \xi_c(0) \approx 26$ Å. Near $T_c$ ($T < T_c$), the $\mu_0 H_{c2}(T)$ and the $\xi(T)$ are phenomenologically proportional to $1 - (T/T_c)^2$ and $(1 - T/T_c)^{-1/2}$, respectively. Considering the temperature dependence of $\Gamma(T)$ and the strong suppression of $\mu_0 H_{c2}^{ab}(T)$, it is expected that $\xi_c(T)$ is much smaller than $\xi_{ab}(T)$ near $T_c$. The small $\xi_c(T)$ seems to correlate with the fact that $\Delta T_c^c$ is larger than $\Delta T_c^{ab}$.

Finally, we discuss the composition dependence of the upper critical fields on the Fe$_{1+y}$(Te,Se) systems. Figure 4 shows the temperature dependences of $\Delta \mu_0 H_{c2} = \mu_0 |H_{c2}^{ab} - H_{c2}^{c}|$ for $x = 0.4$, $y = 0.11$ in ref. 13, $x = 0.4$, $y \sim 0.03$ in ref. 14, and $x = 0.15$, $y = 0.05$ in the present study.

![Fig. 4. Temperature dependence of the $\Delta \mu_0 H_{c2} = \mu_0 |H_{c2}^{ab} - H_{c2}^{c}|$ for $x = 0.4$, $y = 0.11$ in ref. 13, $x = 0.4$, $y \sim 0.03$ in ref. 14, and $x = 0.15$, $y = 0.05$ in the present study.](image)
$H_{c2}^c$) for $x = 0.4$, $y = 0.11$ in ref. 13 (sample I), $x = 0.4$, $y \sim 0.03$ in ref. 14 (sample II), and $x = 0.15$, $y = 0.05$ in the present study (sample III). Khim et al.\textsuperscript{14} predicts that the sample II is close to the stoichiometric Fe(Te$_{0.6}$Se$_{0.4}$) with a minimal amount of excess and/or interstitial Fe by considering its metallic resistivity above $T_c$. In comparison with the resistivity results by Liu et al.,\textsuperscript{16} it is expected that the value of $y$ for sample II is close to 0.03. The $\Delta \mu_0 H_{c2}$ for all samples first greatly increase with decreasing temperature near $T_c$, reach maximum values of $6 \sim 10$ T, and then decrease with decreasing temperature. The $\Delta \mu_0 H_{c2}$ of sample I is larger than that of sample II in the mid-temperature region below $T_c$, indicating that the variation of excess Fe yields a difference in the temperature dependence of $\Delta \mu_0 H_{c2}$. The maximum position of $\Delta \mu_0 H_{c2}$ shifts to the low temperature side with increasing $y$. The Te/Se ratio of sample III is larger than that of sample II, although the values of $y$ for both samples are almost equal. The temperature dependence of $\Delta \mu_0 H_{c2}$ for sample III is similar to that of sample I, suggesting that the variation of the Te/Se ratio causes no change on the temperature dependence of $\Delta \mu_0 H_{c2}$. Both samples I and III show “semiconducting” behavior above $T_c$. It is expected that this behavior is attributable to non-stoichiometry, such as excess Fe and/or defects of chalcogen ions, in Fe$_{1+y}$Te$_x$(Te,Se) systems. Using the G-L coherent lengths, the temperature dependence of $\Delta \mu_0 H_{c2}$ is expressed as follows, $\Delta \mu_0 H_{c2} = \Phi_0(\xi_{ab} - \xi_c)/2\pi \xi_{ab}^2 \xi_c$. It may be possible that the $\Delta \mu_0 H_{c2}$ increases due to the decrease of $\xi_c$. However, it should be pointed out that those estimations are based on the one-band G-L theory which may not be valid for the multi-band compound, and much more information will be needed for further theoretical and/or experimental investigations and discussion on superconductivity in this system. Nevertheless, these samples show the common feature of $\mu_0 H_{c2}^{ab}(0) \approx \mu_0 H_{c2}^c(0)$ at low temperatures. More detailed investigation for the composition dependence of $\mu_0 H_{c2}(T)$ in Fe$_{1+y}$Te$_x$(Te,Se) systems is necessary to understand this fact.

In conclusion, we have performed electrical resistivity measurements on a single crystal of Fe$_{1.05}$Te$_{0.85}$Se$_{0.15}$, which exhibits superconductivity at $T_{c \text{ onset}} = 14.1$ K, in magnetic fields of up to 55 T. The $\rho(H) - T$ curves for both $H \parallel ab$ and $H \parallel c$ shift parallel to the low temperature side in magnetic fields of up to 14 T, suggesting that the two-dimensional feature and the superconducting fluctuations of the present sample are small. The slopes $(d\mu_0 H_{c2}/dT)$ for $H \parallel ab$ and $H \parallel c$ at $T_{c \text{ onset}}(0)$ are largely different, but both $\mu_0 H_{c2}^{ab}(T)$ and $\mu_0 H_{c2}^c(T)$ are extrapolated to $\sim 47$ T at $T \rightarrow 0$, which is consistent with the reported results for Fe$_{1+y}$Te$_{0.6}$Se$_{0.4}$ single crystals.\textsuperscript{13,14} The anisotropy coefficient $\Gamma(T)$ decreases from $\sim 2.4$ near $T_c$ to $\sim 1$ at low temperatures. The nearly isotropic upper critical field at low temperatures is robust against not only the variation of excess Fe but also that of the Te/Se ratio. The observation of the strong suppression in $\mu_0 H_{c2}^{ab}(T)$ supports the presence of the Pauli paramagnetic effect.
Acknowledgements

This work was partly supported by a Grant-in-Aid for “Transformative Research-project on Iron Pnictides (TRIP)” from the Japan Science and Technology Agency (JST), Grants-in-Aid for Scientific Research on priority Areas “High Field Spin Science in 100T” (No.451) and “New Materials Science Using Regulated Nano Spaces” (No.19051010) from the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan, and the Global COE Program (Core Research and Engineering of Advanced Materials-Interdisciplinary Education Center for Materials Science) (No. G10) from the MEXT, Japan.
References

1) Y. Kamihara, T. Watanabe, M. Hirano, and H. Hosono: J. Am. Chem. Soc. 130 (2008) 3296.
2) M. Rotter, M. Tegel, and D. Johrendt: Phys. Rev. Lett. 101 (2008) 107006.
3) M. Pitcher, D. Parker, P. Adamson, S. Herkelrath, A. Boothroyd, R. Ibberson, M. Brunelli, and S. Clarke: Chem. Commun. (2008) 5918.
4) F. C. Hsu, J. Y. Luo, K. W. Yeh, T. K. Chen, T. W. Huang, P. M. Wu, Y. C. Lee, Y. L. Huang, Y. Y. Chu, D. C. Yan, and M. K. Wu: Proc. Natl. Acad. Sci. U.S.A. 105 (2008) 14262.
5) H. Takahashi, K. Igawa, K. Ariii, Y. Kamihara, M. Hirano, and H. Hosono: Nature 453 (2008) 376.
6) Y. Mizuguchi, F. Tomioka, S. Tsuda, T. Yamaguchi, and Y. Takano: Appl. Phys. Lett. 93 (2008) 152505.
7) K. W. Yeh, T. W. Huang, Y. L. Huang, T. K. Chen, F. C. Hsu, P. M. Wu, Y. C. Lee, Y. Y. Chu, C. L. Chen, J. Y. Luo, D. C. Yan, and M. K. Wu: Europhys. Lett. 84 (2008) 37002.
8) Y. Mizuguchi, F. Tomioka, S. Tsuda, T. Yamaguchi, and Y. Takano: Appl. Phys. Lett. 94 (2009) 012503.
9) S. Masaki, H. Kotegawa, Y. Hara, H. Tou, K. Murata, Y. Mizuguchi, and Y. Takano: J. Phys. Soc. Jpn. 78 (2009) 063704.
10) S. Margadonna, Y. Takabayashi, Y. Ohishi, Y. Mizuguchi, Y. Takano, T. Kagayama, T. Nakagawa, M. Takata, and K. Prassides: Phys. Rev. B80 (2009) 064506.
11) S. Medvedev, T. M. McQueen, I. A. Troyan, T. Palasyuk, M. I. Eremets, R. J. Cava, S. Naghavi, F. Casper, V. Ksenofontov, G. Wortmann, and C. Felser: Nature Mat. 8 (2009) 630.
12) T. Kida, T. Matsumaga, M. Hagiwara, Y. Mizuguchi, Y. Takano, and K. Kindo: J. Phys. Soc. Jpn. 78 (2009) 113701.
13) M. Fang, J. Yang, F. F. Balakirev, Y. Kohama, J. Singleton, B. Qian, Z. Q. Mao, H. Wang, and H. Q. Yuan: Phys. Rev. B81 (2010) 020509(R).
14) S. Khim, J. W. Kim, E. S. Choi, Y. Bang, M. Nohara, H. Takagi, and K. H. Kim: cond-mat/1001.4017.
15) T. Kato, Y. Mizuguchi, H. Nakamura, T. Machida, H. Sakata, and Y. Takano: Phys. Rev. B80 (2009) 180507(R).
16) T. J. Liu, X. Ke, B. Qian, J. Hu, D. Fobes, E. K. Vehstedt, H. Pham, J. H. Yang, M. H. Fang, L. Spinu, P. Schiffer, Y. Liu, and Z. Q. Mao: Phys. Rev. B80 (2009) 174509.
17) R. Ikeda, T. Ohmi, and T. Tsumeto: J. Phys. Soc. Jpn. 60 (1991) 1051.
18) M. Tinkham: Introduction to Superconductivity (McGraw-Hill, New York, 1975).
19) Y. Jia, P. Cheng, L. Fang, H. Luo, H. Yang, C. Ren, L. Shan, C. Gu, and H. H. Wen: Appl. Phys. Lett. 93 (2008) 032503.
20) N. R. Werthamer, E. Helfand, and P. C. Hohenberg: Phys. Rev. 147 (1966) 295.
21) S. Kittaka, T. Nakamura, Y. Aono, S. Yonezawa, K. Ishida, and Y. Maeno: Phys. Rev. B80 (2009) 174514.
22) H. Q. Yuan, J. Singleton, F. F. Balakirev, S. A. Baily, G. F. Chen, J. L. Luo, and N. L. Wang: Nature 457 (2009) 565.
23) A. Yamamoto, J. Jaroszynski, C. Tarantini, L. Balicas, J. Jiang, A. Gurevich, D. C. Larbalestier, R. Jin, A. S. Sefat, M. A. McGuire, B. C. Sales, D. K. Christen, and D. Mandrus: Appl. Phys. Lett. 94 (2009) 062511.
24) I. I. Mazin, M. D. Johannes, L. Boeri, K. Koepernik, and D. J. Singh: Phys. Rev. B\textbf{78} (2008) 085104.
25) A. Subedi, L. Zhang, D. J. Singh, and M. H. Du: Phys. Rev. B\textbf{78} (2008) 134514.
26) P. Vilmercati, A. Fedorov, I. Vobornik, U. Manju, G. Panaccione, A. Goldoni, A. S. Sefat, M. A. McGuire, B. C. Sales, R. Jin, D. Mandrus, D. J. Singh, and N. Mannella: Phys. Rev. B\textbf{79} (2009) 220503(R).