pISSN 1229-3008 eISSN 2287-6251
Progress in Superconductivity and Cryogenics
Vol.21, No.4, (2019), pp.6~8
https://doi.org/10.9714/psac.2019.21.4.006

Magnetic field detwinning in FeTe

Younsik Kim[a,b], Soonsang Huh[a,b], Jonghyuk Kim[c], Youngjae Choi[c], and Changyoung Kim[a,b,*]

a Department of Physics and Astronomy, Seoul National University, Seoul, 08826, Korea
b Center for Correlated Electron Systems, Institute for Basic Science, Seoul, 08826, Korea
c Department of Physics, Yonsei University, Seoul, 03722, Korea

(Received 6 November 2019; revised or reviewed 3 December 2019; accepted 4 December 2019)

Abstract

Iron-based superconductors (IBSs) possess nematic phases in which rotational symmetry of the electronic structure is spontaneously broken. This novel phase has attracted much attention as it is believed to be closely linked to the superconductivity. However, observation of the symmetry broken phase by using a macroscopic experimental tool is a hard task because of naturally formed twin domains. Here, we report on a novel detwinning method by using a magnetic field on FeTe single crystal. Detwinning effect was measured by resistivity anisotropy using the Montgomery method. Our results show that FeTe was detwinned at 2T, which is a relatively weak field compared to the previously reported result. Furthermore, detwinning effect is retained even when the field is turned off after field cooling, making it an external stimulation-free detwinning method.

Keywords: iron-based superconductors, detwinning

1. INTRODUCTION

Iron-based superconductors (IBSs) have attracted much attention due to various phase transitions and their possible relation to the superconductivity [1]. Among these phases, the nematic phase where the rotational symmetry of the electronic structure is spontaneously broken has been intensively studied since it also appears in other unconventional superconductors such as cuprates [2, 3] and heavy fermion superconductors [4, 5]. Thus, understanding the mechanism of the nematic phase can be key to constructing a unified theory for unconventional superconductivity.

In the nematic phase of IBSs, orthorhombic domains perpendicular to each other are formed, resulting in twin domains [6]. As a result, the measurement of a twinned sample produces mixed signals from the two different domains [7]. In order to obtain the intrinsic symmetry-broken signal from the nematic phase, detwinning of the sample is essential. Applying uniaxial strain is a widely accepted method to detwin IBSs. Mechanical clamp [6, 8] and piezo electric device [7] are developed to apply uniaxial strain. However, the uniaxial strain not only detwins the sample but also acts as an external stimulation that breaks the symmetry [9, 10]. Therefore, it is hard to distinguish if the symmetry broken signal is from the nematic phase or not since the external strain itself already breaks the symmetry.

Here, we report an external stimulation-free detwinning method that can measure the signals only from the symmetry broken phase. We applied a magnetic field upon cooling to detwin and proved it by measuring resistivity anisotropy upon heating. In order to avoid the magnetoresistance effect, the magnetic field was turned off before the sample was measured. Our result shows that the field cooling detwinning method requires a smaller magnetic field than the previously reported zero-field cooling detwinning method [11]. Furthermore, once the detwinned domain is formed by a magnetic field, the domain is sustained even if there is no external field.

2. EXPERIMENTS

High-quality single crystals of FeTe were synthesized by the self-flux method as described elsewhere [12, 13]. The obtained crystals have a rectangular shape and show flat shiny (001) surface. The resistivity measurements were carried out on Quantum Design (QD) Physical Property Measurement System (PPMS). Montgomery method was employed to measure the in-plane resistivity anisotropy of FeTe [14, 15]. Four electrodes were attached to the corners of the rectangular sample, as shown in Fig. 1(a) and 1(b). An external magnetic field was applied along the in-plane a/b direction. Since the magnetic field can only be applied in z-axis direction in the PPMS, samples were attached vertically. In order to prevent the magnetic field from affecting the resistivity, the resistivity was measured at the zero magnetic field upon heating after the initial field cooling.

3. RESULTS AND DISCUSSION

Fig. 2 (a) shows the resistivity of FeTe single crystal. The drastic change in the resistivity near 70K is owing to the structural and magnetic transitions of FeTe [17, 18]. Twin domains formed below the transition temperature (70K)

---

* Corresponding author: changyoung@snu.ac.kr

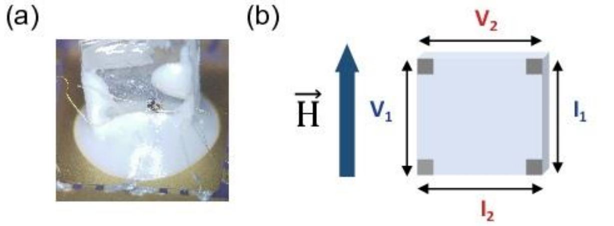

Fig. 1. (a), (b) The photograph and schematic of the resistivity measurement setup. Four electrodes are attached on the corners of the sample to measure the resistivity along both directions of the sample simultaneously. An in-plane magnetic field is applied to detwin the sample.

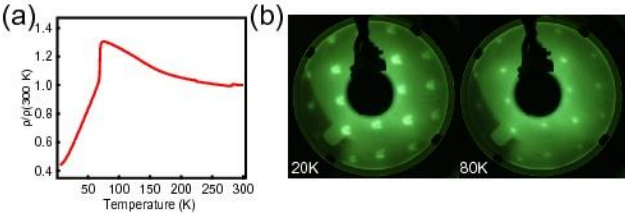

Fig. 2. (a) Temperature-dependent resistivity of FeTe. (b) Temperature-dependent low energy electron diffraction (LEED) pattern. The single spot at 80K (T>T_S) data is divided into four spots at 20K (T<T_S).

was checked by using low energy electron diffraction (LEED). By forming orthorhombic twin domains, the single spot on 80K data is divided into four spots on 20K data (See Fig. 2 (b)) [16].

Temperature-dependent resistivity data from FeTe detwinned under various magnetic fields are shown in Fig. 3 (a). All the data were taken with the magnetic field turned off after the initial field cooling. The sample gets detwinned during the field cooling process. For 0 and 0.5 T data, there is no noticeable difference between ρ_a and ρ_b below the structural transition temperature, whereas a clear deviation can be seen for 2 and 4 T data. This result implies that a 2 T magnetic field is sufficient to detwin FeTe under field cooling while 0.5 T is not enough. The size of anisotropy in the 2 and 4T data is similar, which means the entire sample was almost fully detwinned at 2 T. In addition, once the sample is detwinned, the detwinning was sustained even if there is no external field.

Normalized resistivity anisotropy is shown in Fig 3 (b). Near the structural transition temperature, the resistivity anisotropy of FeTe gradually diminishes as the temperature increases. This is different behavior from that of mechanically detwinned sample for which resistivity anisotropy remains even above the structural transition temperature [17, 18]. This is because the external strain for a mechanically detwinned sample sustains the detwinned domain. Without the external field to align the orthorhombic domain, the magnetically detwinned sample recovers twin domain due to thermal fluctuation when the temperature approaches the structural transition temperature.

The underlying detwinning mechanism of FeTe with an external magnetic field is from the anisotropy in the in-plane magnetic susceptibility in the nematic phase [11]. If the magnetic field is applied along the higher susceptibility direction, it will have lower energy compared to the case for which the magnetic field is applied along the lower susceptibility direction. Therefore, under an in-plane magnetic field, the degeneracy between twin domains is lifted and the twin domains are aligned to the energetically favorable direction.

From the hysteric behavior in the twinning-detwinning process, it can be inferred that there is a potential barrier to change one domain to the other, which means the required magnetic field to induce the detwinned state starting from the normal state is smaller than that starting from twinned state. A previous work on magnetic field detwinning reported that the Co-doped $BaFe_2As_2$ was partially when a magnetic field of 14 T was applied to twinned state [11]. On the other hand, FeTe was almost fully detwinned under 2 T during the field cooling process. Even though the systems under comparison are different, the drastic difference in the required magnetic field to detwin the

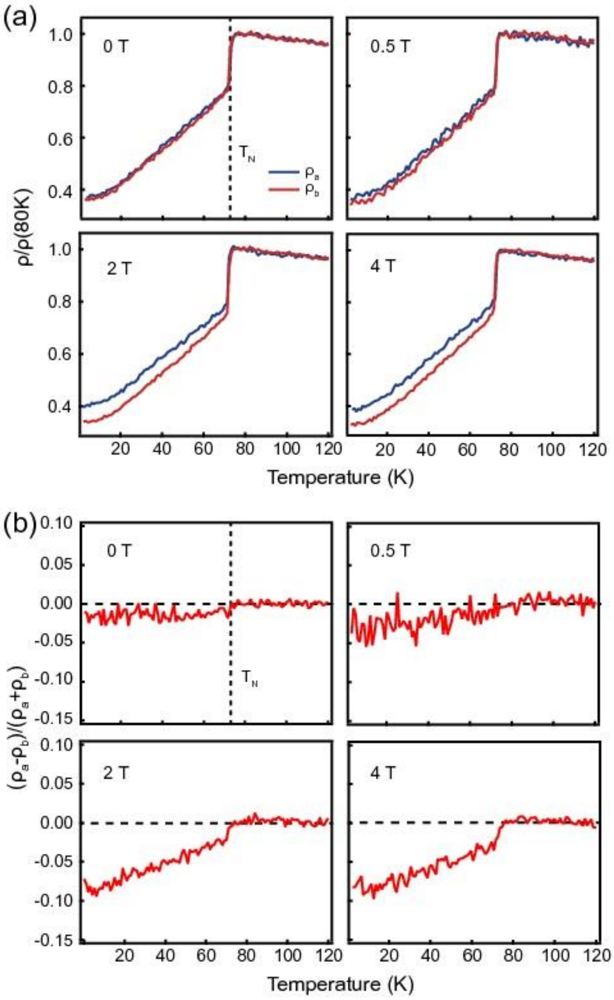

Fig. 3. (a) Temperature dependent resistivity from a detwinned FeTe. The blue and red line denotes resistivity along the a- and b-direction respectively. The data are obtained under zero magnetic field condition. The applied magnetic field in the field cooling process is shown in the figure. (b) Temperature dependent resistivity anisotropy of FeTe.

sample can only be explained by the difference in the experimental method. It is reminiscent of ferromagnetic materials; the magnetic field required to align the ferromagnetic domain is much smaller if the system is field cooled from the normal state than aligned in the ferromagnetic state.

There have been various reports that external strain affects the electronic structure of IBSs, changing the nematic transition temperature [9, 10, 19]. Limited information on nematic phase may be obtained from a strain-detwinned sample since it is the sum of the strain-induced effect and the nematic signal. By taking advantage of the hysteric behavior of the nematic twin domain, a detwinned state without external stimulation is possible, which allows us to observe the pure nematic phase of IBSs and reveal its relation to the superconductivity.

4. SUMMARY

We report on a new approach to detwinning IBSs by using an external magnetic field. Detwinnig effect of FeTe is confirmed by resistivity anisotropy. The sample was almost fully detwinned at 2 T. The required magnetic field to detwin is much smaller compared to the field needed for the previously reported method. External stimulation-free detwinning is achieved once the sample is detwinned by a magnetic field and the magnetic field is turned off at low temperature.

ACKNOWLEDGMENT

This work was supported by the Institute for Basic Science in Korea (Grant No. IBS-R009-G2)

REFERENCES

[1] R. M. Fernandes, A. V. Chubukov, and J. Schmalian, “What drives nematic order in iron-based superconductors?,” *Nat. Phys.*, vol. 10, pp. 97-104, 2014.

[2] Y. Ando, K. Segawa, S. Komiya, and A. J. P. r. l. Lavrov, “Electrical resistivity anisotropy from self-organized one dimensionality in high-temperature superconductors,” *Phys. Rev. Lett.*, vol. 88, pp. 137005, 2002.

[3] B. Phillabaum, E. Carlson, and K. A. J. N. c. Dahmen, “Spatial complexity due to bulk electronic nematicity in a superconducting underdoped cuprate,” *Nat. Commun.*, vol. 3, pp. 915, 2012.

[4] H. Ikeda, et al., “Emergent rank-5 nematic order in URu2Si2,” *Nat. Phys.*, vol. 8, pp. 528, 2012.

[5] R. Okazaki, et al., “Rotational symmetry breaking in the hidden-order phase of URu2Si2,” *Science*, vol. 331, pp. 439-442, 2011.

[6] J. -H. Chu, et al., “In-plane resistivity anisotropy in an underdoped iron arsenide superconductor,” *Science*, vol. 329, pp. 824-826, 2010.

[7] S. S. Huh, et al., “Lifted electron pocket and reversed orbital occupancy imbalance in FeSe.”, *arXiv:1903.08360*.

[8] M. Yi, et al., “Symmetry-breaking orbital anisotropy observed for detwinned $Ba(Fe_{1-x}Co_x)_2As_2$ above the spin density wave transition,” *Proc. Natl. Acad. Sci. U.S.A.*, vol. 108, pp. 6878-6883, 2011.

[9] E. Blomberg, et al., “Effect of tensile stress on the in-plane resistivity anisotropy in BaFe2As2,” *Phys. Rev. B*, vol. 85, pp. 144509, 2012.

[10] C. Dhital, et al., “Effect of uniaxial strain on the structural and magnetic phase transitions in $BaFe_2As_2$,” *Phys. Rev. Lett.*, vol. 108, pp. 087001, 2012.

[11] J. -H. Chu, et al., “In-plane electronic anisotropy in underdoped $Ba(Fe_{1-x}Co_x)_2As_2$ revealed by partial detwinning in a magnetic field,” *Phys. Rev. B.* , vol. 81, pp. 214502, 2010.

[12] P. Maheshwari, R. Jha, B. Gahtori, and V. Awana, “Magnetism, Structural and magnetic properties of flux-free large FeTe single crystal.” *J. Supercond. Nov. Magn.*, vol. 28, pp. 2893-2897, 2015.

[13] P. Maheshwari and V. Awana, “Flux free single crystal growth and characterization of $FeTe_{1-x}S_x$ (x=0.00 and 0.10) crystals,” *AIP Conference Proceedings*, vol. 1953, pp. 070010, 2018.

[14] H. C. Montgomery, “Method for Measuring Electrical Resistivity of Anisotropic Materials”, *J. Appl. Phys.*, vol. 42, pp. 2971, 1971.

[15] B. F. Logan, S. O. Rice, and R. F. Wick, “Series for Computing Current Flow in a Rectangular Block”, *J. Appl. Phys.*, vol. 42, pp. 2975, 1971.

[16] P. H. Lin, et al., “Nature of the bad metallic behavior of $Fe_{1.06}Te$ inferred from its evolution in the magnetic state,” *Phys. Rev. Lett.*, vol. 111, pp. 217002, 2013.

[17] J. Jiang, et al., “Distinct in-plane resistivity anisotropy in a detwinned FeTe single crystal: Evidence for a Hund's metal,” *Phys. Rev. B.*, vol. 88, pp. 115130, 2013.

[18] T. Nakajima, et al., “Two kinds of in-plane resistivity anisotropy in $Fe_{1+\delta}Te$(δ=0.09) as seen via synchrotron radiation x-ray diffraction and in situ resistivity measurements,” *Phys. Rev. B*, vol. 91, pp. 205125, 2015.

[19] Y. K. Kim, et al., “Existence of orbital order and its fluctuation in superconducting $Ba(Fe_{(1-x)}Co_{(x)})_2As_2$ single crystals revealed by x-ray absorption spectroscopy,” *Phys. Rev. Lett.*, vol. 111, pp. 217001, 2013.