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VIEWPOINT

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Viewpoint

Can iron-based superconductors become the next generation of coated conductors?*

Soon-Gil Jung

Center for Quantum Materials and Superconductivity (CQMS) and Department of Physics, Sungkyunkwan University, Suwon 16419 Republic of Korea

E-mail: prosgjung@gmail.com

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This is a viewpoint on the letter by Dong Li *et al* (2020 *Supercond. Sci. Technol.* **33** 03LT01).

Superconductors are most important for use in applications requiring a high magnetic field because of their ability to conduct a large electric current without power dissipation. Large current-carrying capability of a superconductor has substantial advantages, especially in terms of weight and space, compared to normal metals [1, 2]. However, because of the difficulties associated with realizing superconductors with properties suitable for high-field applications, their practical applicability is limited. In this regard, NbTi (T_c: ~9 K), which requires expensive liquid helium for its operation, is currently the most widely used superconductor in the market [3]. One of the most critical factors for utilizing a superconductor in high-field applications is the improvement of the magnetic field performance of the critical current density (J_c) of the superconducting material. The power loss in type-II superconductors is mainly generated by the motion of the quantized magnetic flux lines, known as vortices, unlike the resistance that occurs in a normal metal.

A vortex of the magnitude $\phi_0 = h/2e$ starts to enter type-II superconductors when the applied magnetic field exceeds the lower critical field (H_{c1}) and the number of vortices is proportional to the applied magnetic field [4]. In addition, because the vortices in a superconductor can be moved by applying an electric current, which generates electrical resistance, restricting the motion of vortices is the key to improving the ability of the superconductor to conduct electric current without power dissipation.

The creation of flux (or vortex) pinning sites inside the superconducting material has been widely used to enhance the in-field J_c. Flux pinning, which leads to a frozen vortex state, is caused by local energy minima for the flux lines at weak or nonsuperconducting pinning sites. Vortices trapped at pinning sites can be retained up to $\boldsymbol{F}_L = \boldsymbol{F}_p$. Here, $\mathbf{F}_L = \mathbf{J} \times \mathbf{B}$ is the Lorentz force, which induces the vortex motion and $\mathbf{F}_p = -\mathbf{J}_c \times \mathbf{B}$ is the volume flux pinning force density [5].

A wide range of defects including point, line and bulk defects can act as flux pinning sites [5, 6]. However, because the effect of each pinning site is influenced by the fundamental properties of the specific superconducting system, the approach to increase the in-field J_c also depends on the type of superconducting material. For instance, grain boundaries are one of the most effective pinning sources for conventional superconductors, such as MgB_2 and Nb_3Sn [7, 8]. However, they cause J_c to deteriorate in high-T_c cuprate superconductors (HTSs) owing to the weak-link problem [9]. Although many

* This is a viewpoint on the letter by Dong Li et al (2019 Supercond. Sci. Technol. **32** 12LT01).

researchers have devoted considerable efforts to improve J_c in high magnetic fields, this remains an open issue because of complex vortex phenomena.

RE$Ba_2Cu_3O_{7-x}$ (*RE* = Y, Gd) HTSs are the most attractive superconducting materials with respect to commercial applications. This is because they have T_c values above the boiling point of liquid nitrogen (~77 K), high upper critical field (H_{c2}) values and large self-field J_c values. However, these materials are problematic in that they are strongly anisotropic and contain weak links, both of which continue to be major drawbacks for high-field applications [10]. In early 2008, the discovery of an iron-based superconductor (IBSC) with a T_c of ~26 K ($LaFeAsO_{1-x}F_x$) brought great excitement to the field of condensed matter physics because of its high T_c, despite containing the ferromagnetic element iron (Fe) [11]. Soon thereafter, a family of IBSC compounds was discovered, and their large H_{c2} and the superior field performance of J_c in spite of their relatively low self-field J_c make them promising candidates for practical applications requiring high magnetic fields, such as high field magnets, generators, fusion tokamaks and so on [12]. However, because most IBSCs contain the toxic element arsenic (As), IBSCs based on non-toxic elements, such as FeSe, would be more useful for real applications.

Even though the T_c of the binary compound FeSe is approximately 9 K, it can be enhanced significantly by applying pressure, ionic gating or chemical intercalation [13–15]. Among these methods to increase the T_c of FeSe systems, chemical intercalation is the most appropriate for practical applications. However, the intercalated FeSe compound is typically air and moisture sensitive. Thankfully, an air-stable (Li,Fe)OHFeSe system with a T_c as high as ~42 K was recently synthesized. In addition, high-quality (Li,Fe)OHFeSe superconducting films have also been successfully fabricated using a hydrothermal epitaxial technique [15]. These findings can be expected to encourage studies on their superconducting critical properties, such as J_c and H_{c2}, for real applications.

The Letter by Dong Li *et al* [16] reports their investigation of J_c of (Li,Fe)OHFeSe films and they discovered a route to improve the field performance of J_c. In particular, J_c of pure (Li,Fe)OHFeSe films is 0.03 MA cm^{-2} at 33 T, whereas the use of Mn as a dopant remarkably increases J_c to 0.32 MA cm^{-2} when exposed to the same magnetic field of 33 T. To the best of our knowledge, this is the highest J_c value among the IBSCs reported thus far and exceeds the J_c value (=0.1 MA cm^{-2}) which is a common benchmark for practical applications. Therefore, this work lays the foundation for the development of high-field applications of (Li,Fe)OHFeSe-coated conductors (CCs) because thin-film manufacturing technology forms the basis of the original technology for the production of CCs.

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ORCID iD

Soon-Gil Jung https://orcid.org/0000-0001-6517-0543

References

[1] Haran K S *et al* 2017 High power density superconducting rotating machines—development status and technology roadmap *Supercond. Sci. Technol.* **30** 123002
[2] Durrell J H, Ainslie M D, Zhou D, Vanderbemden P, Bradshaw T, Speller S, Filipenko M and Cardwell D A 2018 Bulk superconductors: a roadmap to applications *Supercond. Sci. Technol.* **31** 103501
[3] Patel D, Kim S H, Qiu W, Maeda M, Matsumoto A, Nishijima G, Kumakura H, Choi S and Kim J H 2019 Niobium-titanium (Nb-Ti) superconducting joints for persistent-mode operation *Sci. Rep.* **9** 14287
[4] Abrikosov A A 2004 Nobel Lecture: type-II superconductors and the vortex lattice *Rev. Mod. Phys.* **76** 975
[5] Kwok W K, Welp U, Glatz A, Koshelev A E, Kihlstrom K J and Crabtree G W 2016 Vortices in high-performance high-temperature superconductors *Rep. Prog. Phys.* **79** 116501
[6] Palau A *et al* 2018 Disentangling vortex pinning landscape in chemical solution deposited superconducting $YBa_2Cu_3O_{7-x}$ films and nanocomposites *Supercond. Sci. Technol.* **31** 034004
[7] Glowacki B A 2016 Pinning improvement of A15 applied superconducting materials *Acta Phys. Pol.* A **130** 531
[8] Matsushita T, Kiuchi M, Yamamoto A, Shimoyama J and Kishio K 2008 Essential factors for the critical current density in superconducting MgB_2: connectivity and flux pinning by grain boundaries *Supercond. Sci. Technol.* **21** 015008
[9] Hilgenkamp H and Mannhart J 2002 Grain boundaries in high-Tc superconductors *Rev. Mod. Phys.* **74** 485
[10] Wang G, Raine M J and Hampshire D P 2017 How resistive must grain boundaries in polycrystalline superconductors be, to limit J_c? *Supercond. Sci. Technol.* **30** 104001
[11] Kamihara Y, Watanabe T, Hirano M and Hosono H 2008 Iron-**b**ased **l**ayered **s**uperconductor $La[O_{1-x}F_x]FeAs$ (x = 0.05−0.12) with T_c = 26 K *J. Am. Chem. Soc.* **130** 3296
[12] Hosono H, Yamamoto A, Hiramatsu H and Ma Y 2018 Recent advances in iron-based superconductors toward applications *Mater. Today* **21** 278
[13] Lei B, Cui J H, Xiang Z J, Shang C, Wang N Z, Ye G J, Luo X G, Wu T, Sun Z and Chen X H 2016 Evolution of high-temperature superconductivity from a low-T_c phase tuned by carrier concentration in FeSe thin flakes *Phys. Rev. Lett.* **116** 077002
[14] Shi M Z, Wang N Z, Lei B, Shang C, Meng F B, Ma L K, Zhang F X, Kuang D Z and Chen X H 2018 Organic-ion-intercalated FeSe-based superconductors *Phys. Rev. Mater.* **2** 074801
[15] Huang Y *et al* 2017 Superconducting (Li,Fe)OHFeSe film of high quality and high critical parameters *Chin. Phys. Lett.* **34** 077404
[16] Li D *et al* 2019 Giant enhancement of critical current density at high field in superconducting (Li,Fe)OHFeSe films by Mn doping *Supercond. Sci. Technol.* **32** 12LT01