Superconductor Science and Technology

VIEWPOINT

Constructing high field magnets is a real tour de force

To cite this article: Jan Jaroszynski 2019 *Supercond. Sci. Technol.* **32** 070501

IOP Publishing

Superconductor Science and Technology

Supercond. Sci. Technol. **32** (2019) 070501 (3pp)

https://doi.org/10.1088/1361-6668/ab1fc9

Viewpoint

Constructing high field magnets is a real tour de force

Jan Jaroszynski

National High Magnetic Field, Laboratory, Tallahassee, FL, 32310, United States of America

E-mail: jaroszy@magnet.fsu.edu

This is a viewpoint on the letter by Dongliang Wang *et al* (2019 *Supercond. Sci. Technol.* **32** 04LT01).

Following the discovery of superconductivity in 1911, Heike Kamerlingh Onnes foresaw the generation of strong magnetic fields as its possible application. He designed a 10 T electromagnet made of lead–tin wire, citing only the difficulty in obtaining 'relatively modest financial support' for his laboratory in Leiden. However, he soon found [1] that superconductivity disappears in the presence of a magnetic field above a critical value H_c, or a current density above a critical limit, J_c. For all known superconductors of the time, these critical values were low, making fabrication of strong magnets impossible.

It took half a century, and the investigation of thousands of different superconducting metals, compounds, and alloys [2], until the useful superconductors Nb_3Sn [3] and NbTi [4], with a high H_c and J_c, were found. Within a short time, kilometer lengths of Nb_3Sn wire were fabricated and the first 6 T 'supermagnet' was tested the same year. During the following decades, these low temperature superconductors (LTS) entered their industrial phase. NbTi magnets are the most widely used, taking ~80% of the market, while NbTi + Nb_3Sn magnets are used where fields above 10 T are needed. The record magnetic field generated by LTS is 23.5 T [5].

Meanwhile, a microscopic theory of superconductivity (Bardeen–Cooper–Schriffer) in 1957 [6] made it possible to understand the phenomenon of LTS, however, this new theory had only a minor impact on the search for new superconducting materials.

After the discovery of high-temperature superconductors (HTS) in 1986 [7], it took around 30 years to construct prototypes of 32 T [8], and more [9], only partially HTS magnets. Despite intensive efforts by the HTS community, high-temperature superconductivity still lacks a widely accepted microscopic model.

At present, long superconducting wires are only produced from six superconductors: NbTi, Nb_3Sb, MgB_2, Bi2223, Bi2212 and REBCO. Only wires of Nb compounds are used industrially, with intensive work on Nb_3Sn optimization still under way. The other materials are still considered in the research and development phase.

Thus, the discovery of a new class of iron based superconductors (IBS) in 2008 [10] opened the doors to a new perspective for microscopic models. Intensive studies show that IBS phenomenology and superconducting parameters bridge the gap between conventional superconductors and cuprates and may be helpful in explaining the latter. From a practical point of view, IBS are ideal candidates for applications. Indeed, some of them have quite a high critical current density, even in strong magnetic fields, and a low superconducting anisotropy. Moreover, the cost of IBS wire can be four to five times lower than that of Nb_3Sn, making it more expensive than NbTi, but with much higher critical parameters than Nb_3Sn. Attempts to make a superconducting wire started immediately, using either the powder-in-tube (PIT) [11–13] or coated conductor [14, 15] methods.

The paper by Wang *et al* [16] reports on the first test of a coil made of $Ba_{0.6}K_{0.4}Fe_2As_2$ (Ba122) wire at a very high field of 24 T. Ba112 is very brittle, similar to the six other useful superconductors, besides NbTi. To overcome this, the powdered elements Ba, K, As, and Fe, were chemically reacted, powdered, loaded into a silver tube, and drawn. Seven such tubes (a natural number for the closest packing hexagonal geometry) were bundled into an AgMn tube and drawn again into a 1.65 mm diameter wire. To increase J_c, the wire was rolled into a 0.33 mm thick and 4.5 mm wide tape. This 4.5 m long tape was coiled and heat treated at 850 °C to sinter the powder. The PIT method, coupled with heat treatments after the coil is wound, is the same process used for advanced superconductors such as Nb_3Sn, resulting in wires with hundreds (thousands in NbTi) of tiny strands of superconductors in a metal matrix, which is beneficial for magnet quench properties and low AC losses.

Here, a seven-filamentary Ba122/Ag/AgMn tape showed a critical current of 26 A in 24 T, retaining 40% of its zero-field value. This value corresponds to a J_c close to 10^4 A cm^{-2} in Ba122 strands and a roughly 20 A mm^{-2} technical current density. These values are lower in comparison with IBS thin films grown on crystalline substrates ($>10^6$ A cm^{-2}) or the best Ba122 tapes (around 10^5 A cm^{-2} at 10 T). However, this is an important result, because at such high fields, coiled wires suffer from high tensile hoop stress that pushes them to the limits of their mechanical strength. In this high stress regime, critical current densities and critical fields are not what limit the generation of very high fields, these are forces exerted to the superconducting wires. Here, the Ba122/Ag/AgMn tape coil survived these forces.

The National High Magnetic Field Laboratory is supported by the National Science Foundation Cooperative Agreement No. DMR-1644779 and the State of Florida.

ORCID iDs

Jan Jaroszynski https://orcid.org/0000-0003-3814-8468

References

[1] Kamerlingh Onnes H 1914 Further experiments with liquid helium. I. The Hall-effect and the magnetic change in resistance at low temperatures. IX. The appearance of galvanic resistance in supraconductor, which are brought into a magnetic field at a threshold value of the field *KNAW, Proc., 16 II, 1913–1914* (Amsterdam) pp 987–92

[2] Hulm J K, Kunzler J E and Matthias B T 1981 The road to superconducting materials *Phys. Today* **34** 34–43

[3] Kunzler J E, Buehler E, Hsu F S L and Wernick J H 1961 Superconductivity in Nb_3Sn at high current density in a magnetic field of 88 kgauss *Phys. Rev. Lett.* **6** 89

[4] Berlincourt T G and Hake R R 1962 Pulsed-magnetic-field studies of superconducting transition metal alloys at high and low current densities *Bull. Am. Phys. Soc.* **II** 408

[5] Polenova T and Budinger T F 2016 Ultrahigh field NMR and MRI: science at a crossroads. Report on a jointly-funded NSF, NIH and DOE workshop, held on November 12–13, 2015 in Bethesda, Maryland, USA *J. Magn. Reson.* **266** 81–6

[6] Bardeen J, Cooper L and Schriffer J R 1957 Theory of superconductivity *Phys. Rev.* **108** 1175

[7] Bednorz J G and Miller K A 1986 Possible high Tc superconductivity in the Ba-LaCu-O system *Z. Phys.* B **64** 189–93

[8] Weijers H W, Markiewicz W D, Gavrilin A V, Voran A J, Viouchkov Y L, Gundlach S R, Noyes P D, Abraimov D V, Hannahs S T and Murphy T P 2016 Progress in the development and construction of a 32 T superconducting magnet *IEEE Trans. Appl. Supercond.* **26** 4300807

[9] Trociewitz U P, Dalban-Canassy M, Hannion M, Hilton D K, Jaroszynski J, Noyes P, Viouchkov Y, Weijers H W and Larbalestier D C 2011 35.4 T field generated using a layer-wound superconducting coil made of $(RE)Ba_2Cu_3O_{7-x}$ (RE = rare earth) coated conductor *Appl. Phys. Lett.* **99** 202506

[10] Kamihara Y, Watanabe T, Hirano M and Hosono H 2008 Iron-based layered superconductor $La[O_{1-x}F_x]FeAs$ ($x = 0.05$–0.12) with $Tc = 26$ K *J. Am. Chem. Soc.* **130** 3296

[11] Ma Y 2012 Progress in wire fabrication of iron-based superconductors *Supercond. Sci. Technol.* **25** 113001

[12] Gao Z, Togano K, Matsumoto A and Kumakura H 2015 High transport Jc in magnetic fields up to 28 T of stainless steel/Ag double sheathed Ba122 tapes fabricated by scalable rolling process *Supercond. Sci. Technol.* **28** 012001
[13] Weiss J D *et al* 2012 High intergrain critical current density in fine-grain $(Ba_{0.6}K_{0.4})Fe_2As_2$ wires and bulks *Nat. Mater.* **11** 682–5
[14] Si W, Han S J, Shi X, Ehrlich S N, Jaroszynski J, Goyal A and Li Q 2013 High current superconductivity in $FeSe_{0.5}Te_{0.5}$-coated conductors at 30 tesla *Nat. Commun.* **4** 1347
[15] Iida K, Sato H, Tarantini C, Hänisch J, Jaroszynski J, Hiramatsu H, Holzapfel B and Hosono H 2017 High-field transport properties of a P-doped $BaFe_2As_2$ film on technical substrate *Sci. Rep.* **7** 39951
[16] Wang D, Zhang Z, Zhang X, Jiang D, Dong C, Huang H, Chen W, Xu Q and Ma Y 2019 First performance test of 30 mm iron-based superconductor single pancake coil under 24 T background field *Supercond. Sci. Technol.* **32** 04LT01