IOP Publishing Superconductor Science and Technology
Supercond. Sci. Technol. **33** (2020) 030501 (2pp) https://doi.org/10.1088/1361-6668/ab6dc3

Viewpoint

The importance of understanding how nanorods in REBCO films affect the angular dependence of the critical current density at low temperature for high field applications

Francesco Rizzo
ENEA Frascati Research Centre, via E. Fermi 45, 00044 Frascati, Italy

This is a viewpoint on the letter by H Yamasaki (2019 *Supercond. Sci. Technol.* **32** 09LT01).

In the last decade, high temperature cuprate oxide superconductors (HTS) have acquired a fundamental role in as materials for practical applications [1, 2]. In particular, a growing interest has been addressed to $REBa_2Cu_3O_{7-x}$ (REBCO, where RE stands for rare-earth elements) based coated conductors (CCs). In fact, starting from liquid nitrogen temperature and downward until reaching liquid helium temperature, many applications have been developed in different regimes of the applied magnetic field: electric power transmission cables and fault current limiters (FCL) working at high temperature, around 77 K, and in self-field or low magnetic field regimes; generators, motors and superconducting magnetic energy storage devices (SMES) working in the low-to-mid 30 K–65 K temperature range and in a mid-to-high magnetic field regime; finally, at lower temperatures, high field magnets used in different areas of application.

In particular, the low temperature-high magnetic field operational interval is so important for high energy physics and nuclear fusion applications that it has drawn ever increasing interest in recent years from both the scientific community and from industry. The remarkable in-temperature dependence of the REBCO irreversibility field when the magnetic field, H, is applied parallel to the crystallographic c-axis [2] suggests a peculiar application of REBCO CCs for the realization of high and ultra-high field magnets working in the very low temperature regime (about 5 K) [3].

However, two main features need to be considered and their related effects assessed when considering REBCO superconductors for very high-field magnet applications. The first originates from the REBCO layered crystallographic structure, as this layered structure corresponds to a well-know anisotropic angular behaviour of the critical current density J_c. The J_c dependence on the direction of the applied magnetic field shows a pronounced maximum when the magnetic field is applied parallel to the a-b planes and a minimum when the field is applied parallel to the c-axis of the superconductor [4]. This J_c angular anisotropy needs to be carefully taken into account in the design process of a magnet in order to accurately evaluate the current carrying limits. The second aspect to be considered, when dealing with high field applications, is the worsening of the high current carrying capability of REBCO based CCs in a strong magnetic field background.

The way to deal with both these issues resides in the introduction of non-superconducting secondary phases, artificial pinning centres (APCs), in the REBCO CCs matrix. APCs are defects whose dimensions are comparable to the superconducting coherence length, allowing the deisgn to pin vortices in the superconductor and consequently, increase the J_c values in the presence of a magnetic field. Nowadays, APCs are mainly introduced by physical methods, like pulsed laser deposition (PLD) and chemical methods, like *in situ* metal-organic chemical vapor deposition (MOCVD) and *ex situ* chemical solution deposition (CSD). Accordingly, several APC nanostructures with different dimensional topologies can be realized in the REBCO matrix. The resulting pinning landscapes show characteristic regimes of optimized pinning performance in the temperature-magnetic field phase diagram [5].

In particular, focusing on columnar nanostructured secondary phases, these kinds of one-dimensional linear non-superconducting structures have been grown by both PLD [6] and MOCVD [7] methods in the REBCO matrix as a robust strategy for mitigating the angular anisotropy and improving the in-field current carrying performances. Several compunds including perovskite-like ($BaZrO_3$, $BaSnO_3$ and $BaHfO_3$) or double perovskite-like ($Ba_2Y(Nb/Ta)O_6$) have been investigated [6, 8–10], showing strong correlated pinning features in the J_c angular behaviour at liquid nitrogen temperature and very effective pinning capabilities in low-temperature regimes, resulting in the pinning force density exceeding 1 TN m^{-3}. However, the intensity of the correlated peak in the angular measurement of J_c decreases when lowering the temperature from 77 K to 30 K and disappears at 4.2 K. This feature, together with the J_c temperature behaviour in the low temperature regime, were explained as the predominant effect of isotropic strong pinning due to small point defects with linear size comparable to the superconducting coherent length [11]. The pinning capability of those defects should become effective in the very low temperature regime.

In the recently published letter [12], Yamasaki proposes an alternative interpretation of the correlated peak collapse in the J_c angular measurements at low temperature. J_c curves of MOCVD grown REBCO film with *c*-axis aligned $BaZrO_3$ nanorods measured at several temperature/magnetic field values [11–13] are analyzed considering a staircase-like penetration of the slant flux line in the superconducting film. This analysis takes into account the role of the strong correlated pinning contribution along the *a-b* planes, due to the presence of CuO chains and non-conducting BaO/YO layers in the REBCO unit cell, as the main low temperature pinning mechanism. The proposed model is in good agreement with experimental data. Additionally, starting from a simple model for the elementary pinning force f_p, the temperature dependence of J_c is evaluated when the magnetic field is applied parallel to the *c*-axis. The results support the claim of the work.

ORCID iDs

Francesco Rizzo https://orcid.org/0000-0002-7710-5084

References

[1] Larbalestier D, Gurevich A, Feldmann D M and Polyanskii A 2001 *Nature* **414** 368
[2] Obradors X and Puig T 2014 *Supercond. Sci. Technol.* **27** 044003
[3] Majakic G, Pratap R, Xu A, Galstyan E, Higley H C, Prestemon S O, Wang X, Abraimov D, Jaroszynski J and Selvamanickam V 2018 *Supercond. Sci. Technol.* **31** 10LT01
[4] Blatter G, Gershkenbein V B and Larkin A I 1992 *Phys. Rev. Lett.* **68** 875
[5] Feighan J P F, Kursumovic A and Macmanus-Driscoll J L 2017 *Supercond. Sci. Technol.* **30** 123001
[6] MacManus-Driscoll J L *et al* 2004 *Nat. Mater.* **3** 439
[7] Selvamanickam V *et al* 2010 *Supercond. Sci. Technol.* **23** 014014
[8] Mele P, Matsumoto K, Horide T, Ichinose A, Yoshida Y, Mukaida M, Horii S and Kita R 2008 *Supercond. Sci. Technol.* **21** 032002
[9] Tobita H, Notoh K, Higashikawa K, Inoue M, Kiss T, Kato T, Hirayama T, Yoshizumi M, Izumi T and Shiohara Y 2012 *Supercond. Sci. Technol.* **25** 062002
[10] Rizzo F *et al* 2018 *Nanoscale* **10** 8187–95
[11] Xu A, Braccini V, Jaroszynski J, Xin Y and Larbalestier D C 2012 *Phys. Rev.* B **86** 115416
[12] Yamasaki H 2019 *Supercond. Sci. Technol.* **32** 09LT01
[13] Selvamanickam V, Xu A, Liu Y, Khatri N D, Lei C, Chen Y, Galstyan E and Majkic G 2014 *Supercond. Sci. Technol.* **27** 055010