Behavior of Bi-2212 wires above liquid Helium temperature: critical current, irreversibility field and filaments coupling

A. Angrisani Armenio[1], A. Leveratto[2], G. De Marzi[1], A. Traverso[2,3], G Celentano[1], A. Malagoli[2]

[1] ENEA, C.R. Frascati, Via Enrico Fermi, 45, 00044 Roma, Italy. [2] CNR-SPIN, C.so Perrone 24, 16152, Genova, Italy.[3] Università di Genova, Via Dodecaneso 33, 16146, Genova, Italy.

In recent years, there has been a renewed interest in the suitability and use of the Bi-2212 wires in various fields of application. Many studies highlight the possibility to use Bi-2212 for high magnetic field magnets above 18-20 T.
The purpose of this work is to study the electrical properties of Bi-2212 wires at temperatures above liquid Helium. The samples were obtained via a novel process developed at CNR-SPIN based on an alternation of drawing and groove rolling (GDG). Two samples made by employing Nexans and the new Engi-Mat Bi-2212 precursor powders were investigated.
A first characterization was performed with the aim to evaluate the irreversibility field as a function of the temperature ($B_{irr}(T)$). The $B_{irr}(T)$ dependence was extracted from the bulk pinning force density obtained from the magnetic hysteresis loop *M-H* measurements performed at different temperatures with the magnetic field directed perpendicular to the sample longitudinal axis. These studies show the suitability of Bi-2212 wires for high magnetic field applications, with good stability of critical current, a non-abrupt decrease in the magnetic field in the range 8 - 12 K, and, most interestingly, an irreversibility field higher than 70 T at 10 K.
Second, by comparing the critical current densities obtained by electric transport and magnetic *M-H* measurements, by applying the Bean critical state model, we were able to describe the behavior of the filaments-connection bridges, typical in Bi-2212 wires. Moreover, we were able to determine the temperature and magnetic field conditions in which filaments within a bundle are electrically coupled, as well as the opposite limit in which single filaments behave as individual carrying current elements. We believe that the reported results can be considered of general validity and useful in magnet design.

Bi-2212 multifilamentary wire, Power in tube Technique (PIT) - Nexans (w-16N) and Engi-Mat (w-36E) powder Supplies

Bi-2212 Critical current and Irreversibility field

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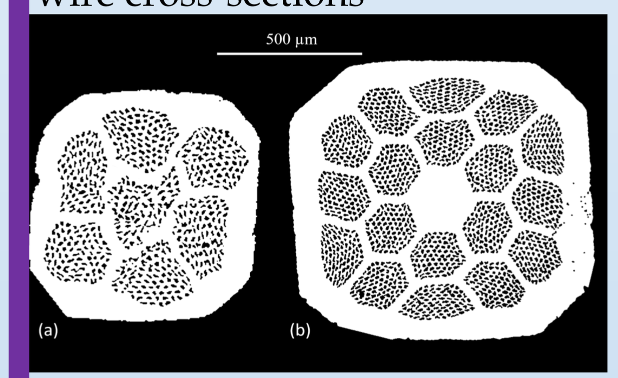
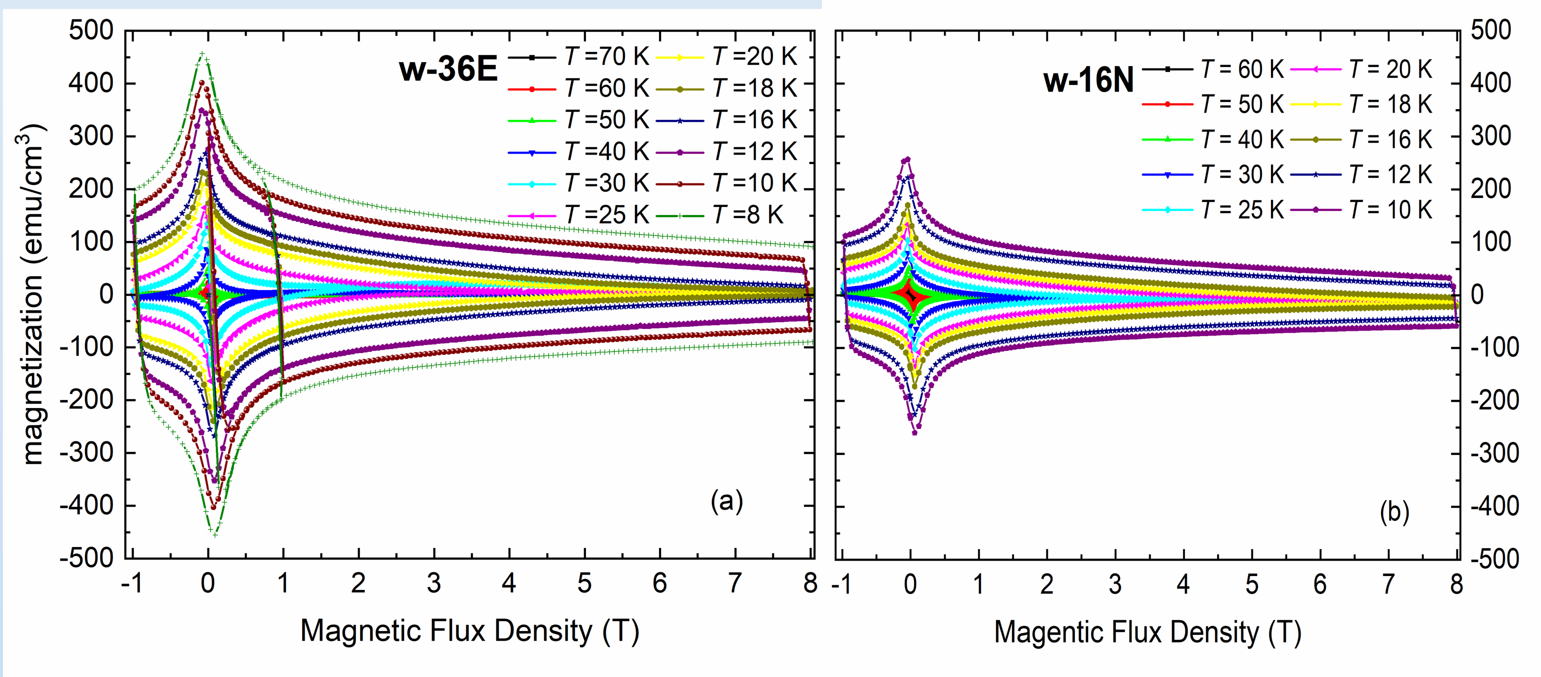
Optical images of w-16N (a) and w-36E (b) Ag/Bi2212 wire cross-sections



w-16N ϕ = 14.2 µm
85 × 7 d_B = 0.254 mm

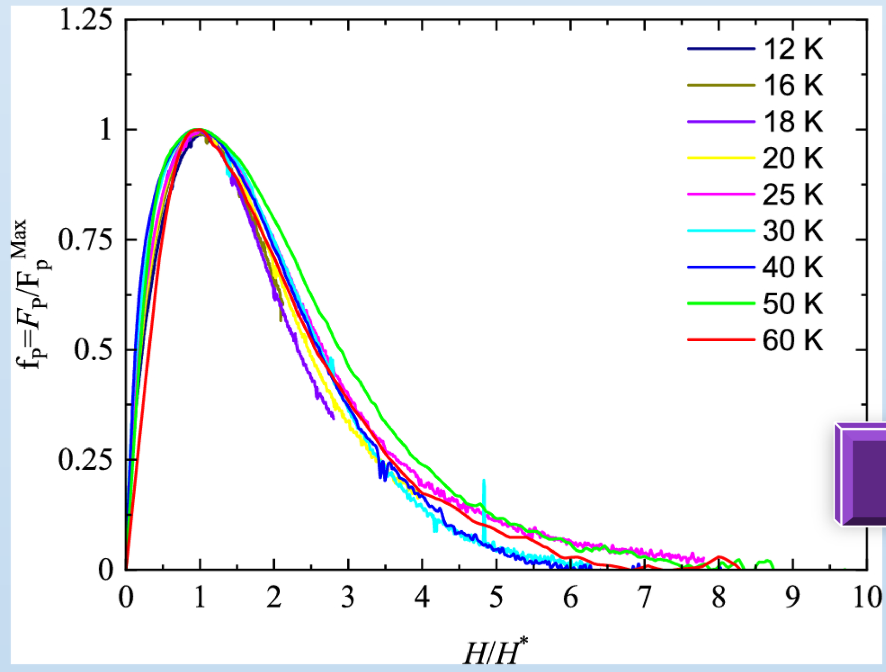
w-36E ϕ = 12.0 µm
85 × 18 d_B = 0.192 mm

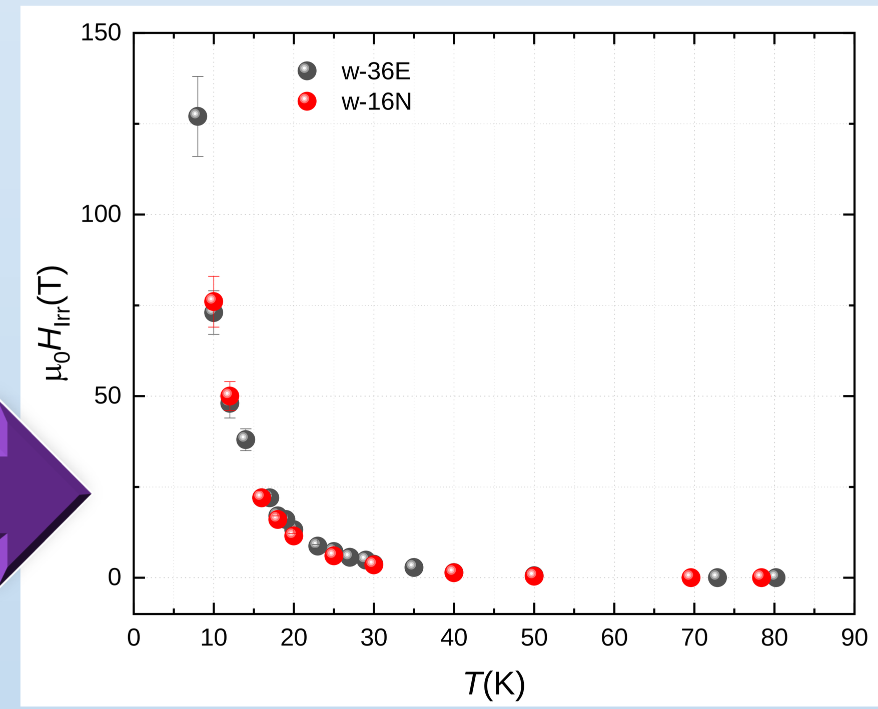


M-H, for both samples, a different temperature, ranging from 8 K to 70 K.
The value of the magnetization for the sample w-36E is greater than the sample w-16N, the better superconducting performances of the sample w-36E

Following the Kramer model

$$f_P(H/Hirr) = \frac{F_P}{F_{Pmax}} = a\left(\frac{H}{H_{irr}}\right)^p\left(1-\frac{H}{H_{irr}}\right)^q,\ a = \left(\frac{p}{p+q}\right)^{-p}\left(\frac{q}{p+q}\right)^{-q}$$



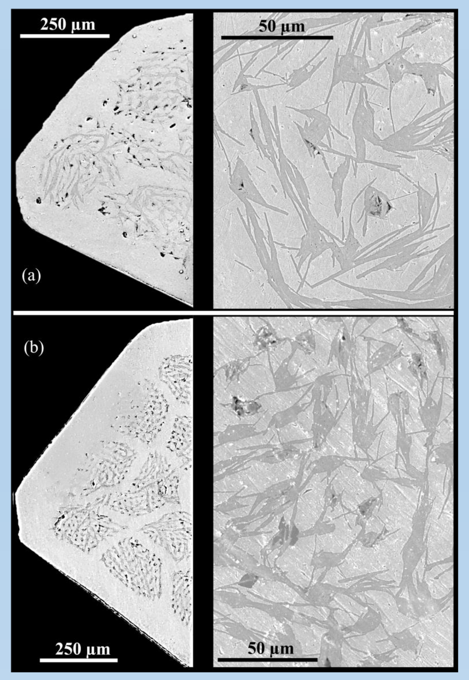


In spite of the significantly different J_C performances recorded in the two Bi-2212 wires, their $H_{irr}(T)$ curves exhibit very similar temperature behaviour and similar values.
These similarity can be explained considering that both wires exhibit similar vortex pinning mechanisms.
Hence, the origin of the discrepancy in $J_C(H)$ behaviours must be more likely ascribed to microstructural issues such as higher density and better grain connectivity rather than in improved pinning mechanisms

Conclusions

Bi-2212 wire can be suitable for high magnetic field applications around **10 K**, having good stability of J_C and an irreversibility field at **10 K higher than 70 T**.
These properties open a wide window of applicability in the temperature – field diagram. In fact, our original wires processed at **1 bar** show at **10 K a J_E = 500 A/mm² at 7 T** promising to be in line with the application requirements also at high field; however, the absolute values can even **rise** if we think of the wires processed at **50/100 bar (OP)**.

Bi-2212 Filaments Coupling



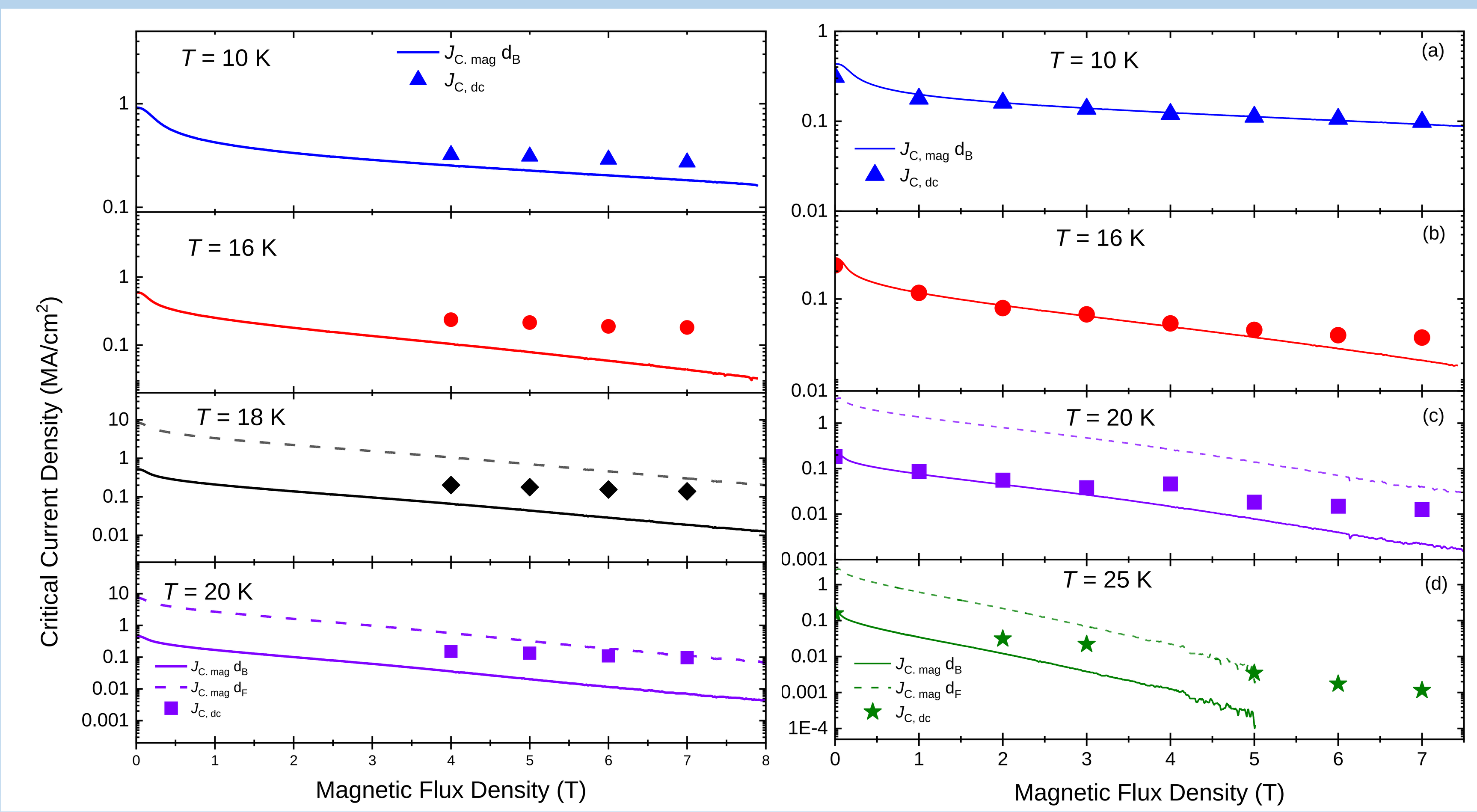
w-16N

w-36E

SEM micrographs of the transverse cross sections showing merged filaments with evidence of filament connection induced by growth across the Ag matrix that produces bridges among filaments.

Comparison between J_C data determined by electric **dc *I-V* characteristics** (**symbols**) and magnetic ***M-H* measurements** (**lines**)
Continuous line are the J_C calculated with the bundle diameter (d_B), and a dashed line for the value calculated with filament diameter (d_F)

w-36E **w-16N**



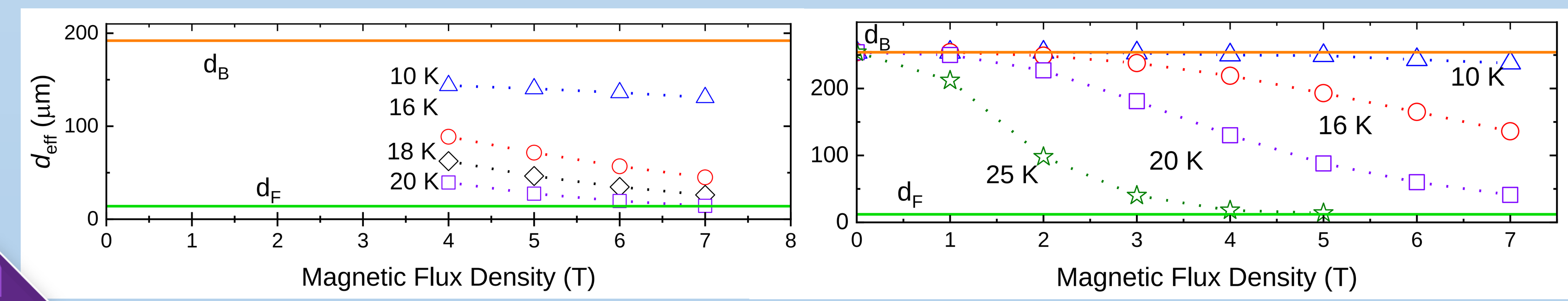
Usually, the geometry of screening currents flowing through the sample is well known. In fact, this method is often adopted for uniform and homogeneous samples in which the current path is not affected by extrinsic effects (grain boundaries, secondary phases, or cracks).
In those cases, shielding currents can flow over the entire bulk of the sample (if full penetration is achieved) and the current path is determined by the sample geometry.

$$J_{C,mag} = \frac{30\pi\,\Delta M}{4\,d}$$

In these case either $d = d_B$ of $d = d_F$ can't be use to match **dc *I-V* characteristics** and magnetic ***M-H* measurements**, for all the temperatures and applied magnetic fields investigated.

Direct calculation of the $d = d_{eff}(H)$ imposing $J_{C,mag} = J_{C,dc}$

w-36E **w-16N**



MATCH?

This analysis suggests that the domains of screening currents in such a multifilamentary wire are not fixed to a given value but conversely continuously change depending on **both** the **temperature** and **applied field** conditions within the interval $d_F \le d_{eff} \le d_B$.

Conclusions

- Similar features in both wires → the identified transport regimes are general in character for Bi-2212 multifilamentary wires and are not related to a specific sample.
- The combination of dc and magnetic J_C measurements is useful in the identification of bridges behavior and thus in AC losses evaluation and our findings can be of support for magnet design.
- The direct comparison of J_C curves allows the identification of **T- and H-ranges** within the two different regimes are valid as well as the interval of cross over between them.