Key parameters for strong a-axis grain growth in narrow filament cavities of Bi-2212 round wires

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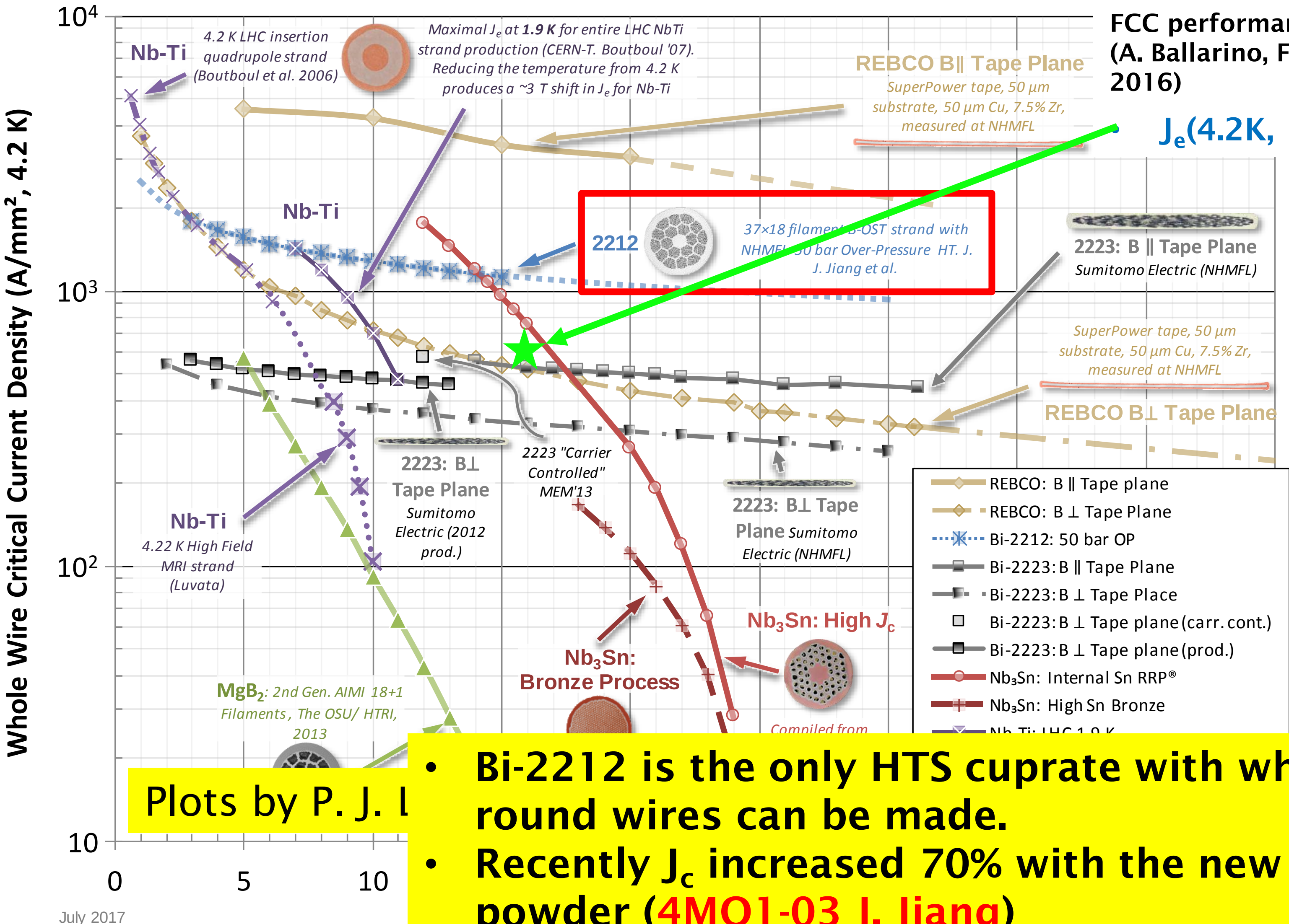
** Now at CERN, Switzerland*

Superconducting magnets over 16 T need HTS

FCC performance target for Nb_3Sn (A. Ballarino, FCC Workshop April 2016)

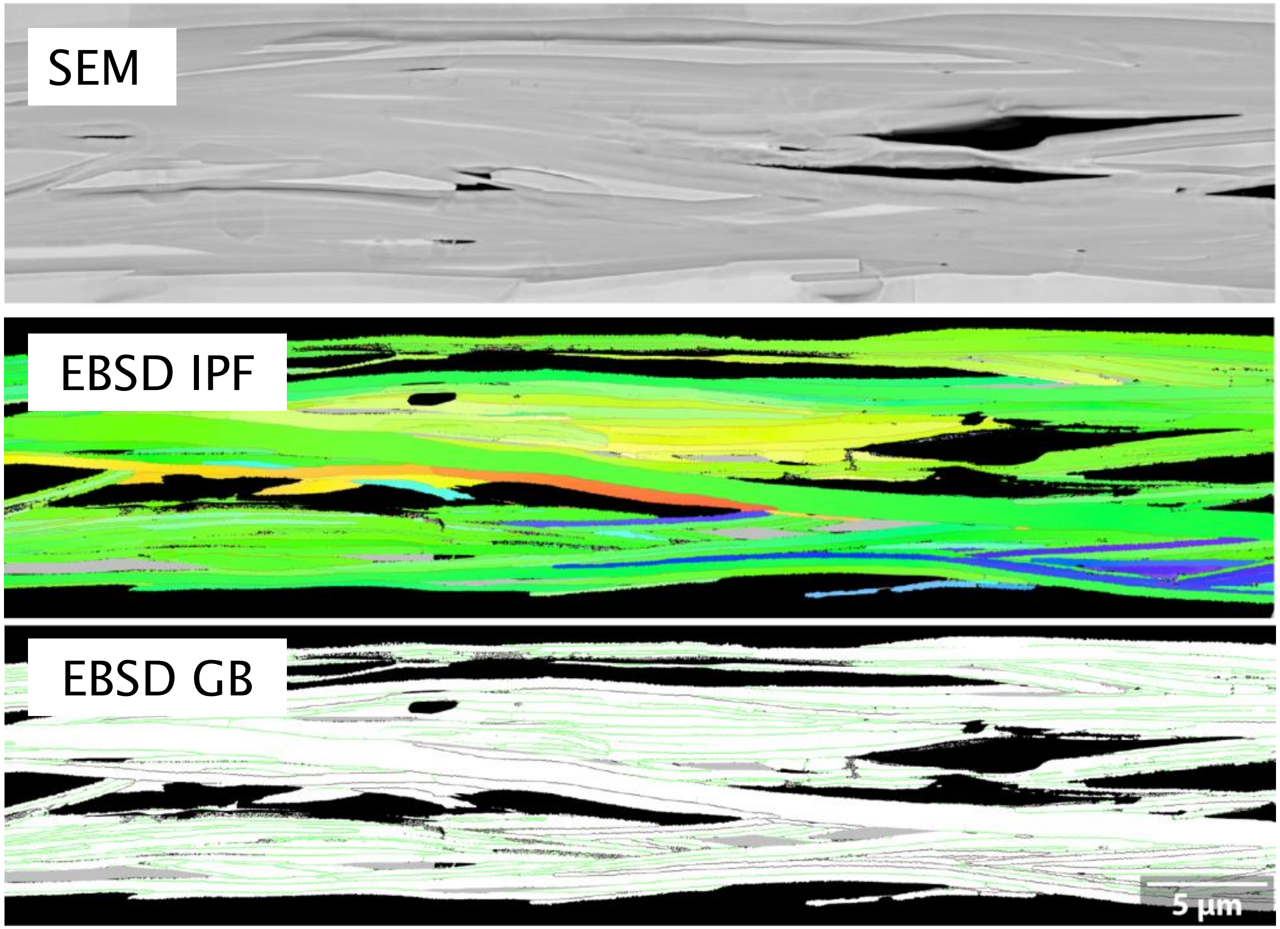
$J_e(4.2K, 16T) = 600\ A/mm^2$

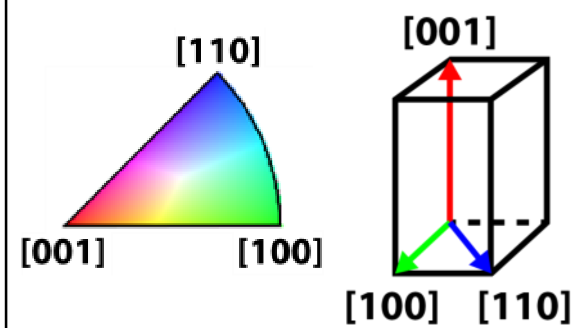


Plots by P. J. L

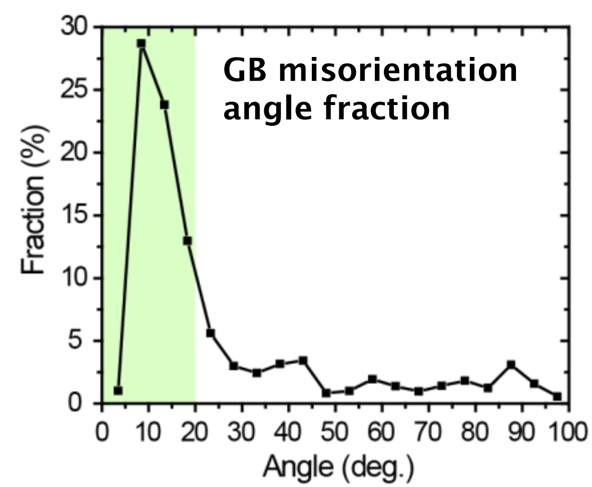
- **Bi-2212 is the only HTS cuprate with which high J_c round wires can be made.**
- **Recently J_c increased 70% with the new US-made powder (4MO1-03 J. Jiang)**
- **Why is high J_c possible in Bi-2212 round wires?**

Bi-2212 grain alignment along the wire direction is the key for high J_c/J_e



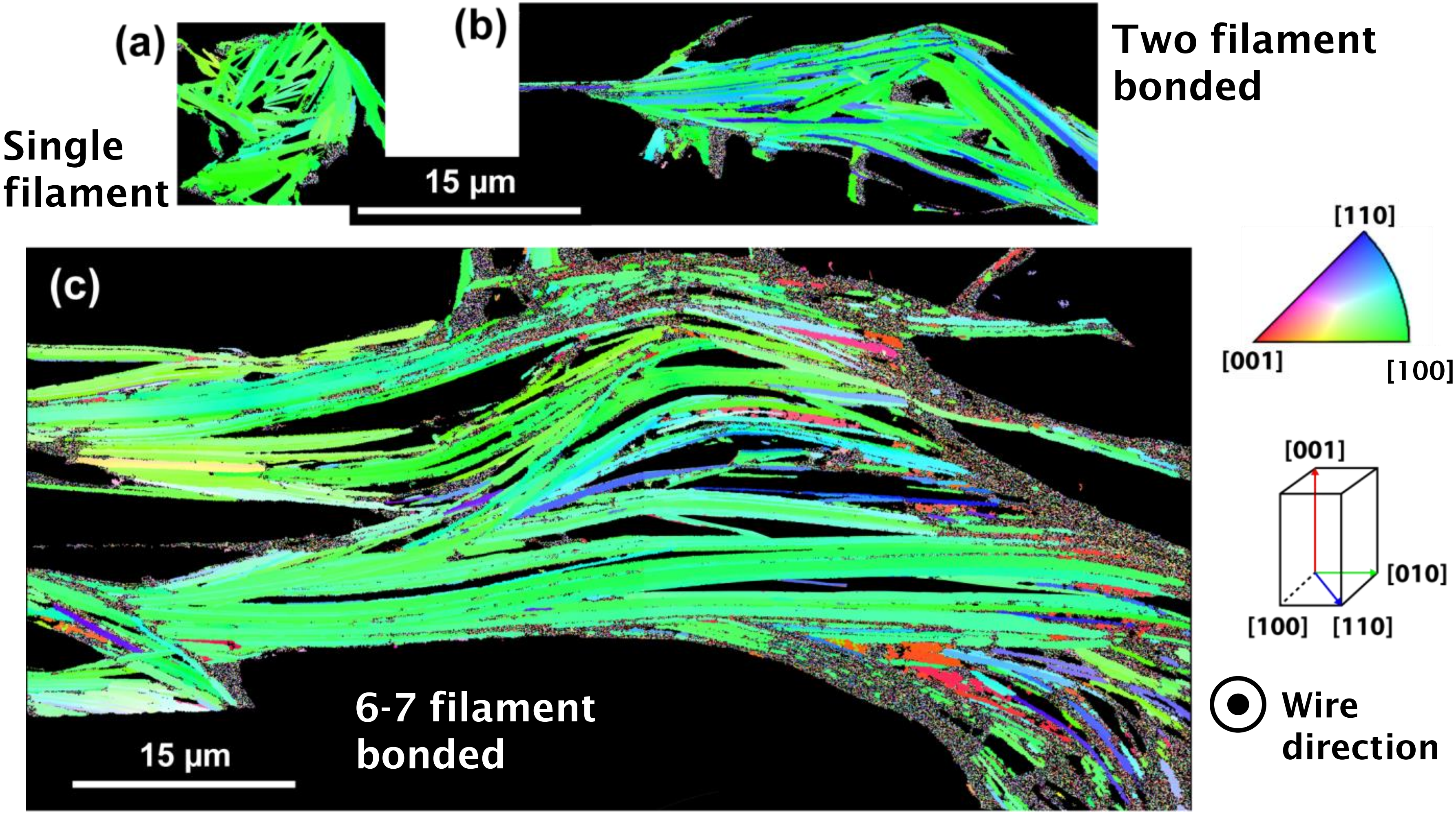


Inverse pole figure color coding and crystallographic direction in Bi-2212

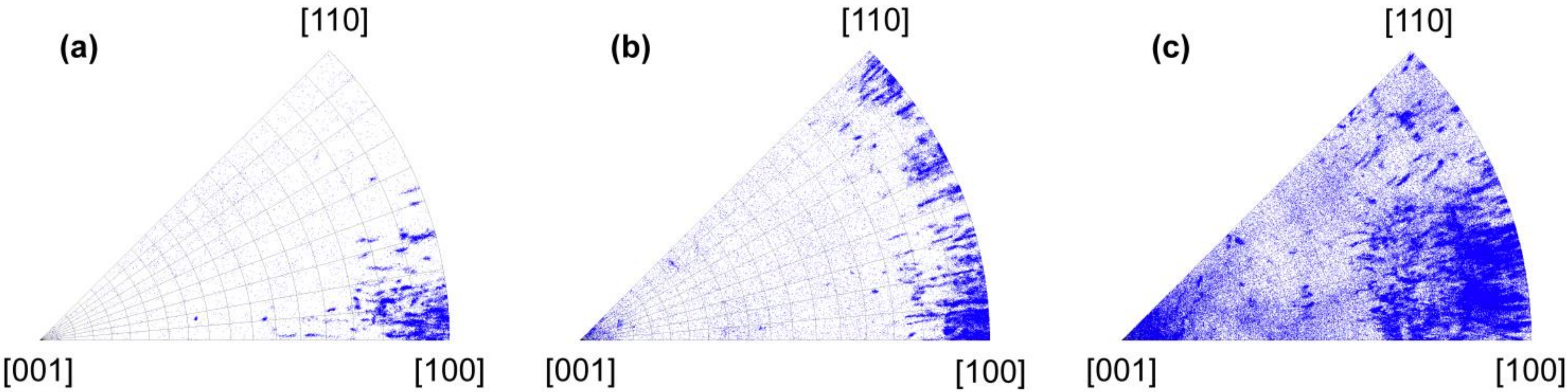


- 0.3-1.0 μm thin, 50-300 μm long grains
- Majority of GB misorientation are <20˚ by quasi-biaxial grain alignment

Same scale comparison of grain structure in different transverse cross-sections of filaments



Comparison of inverse pole figures along the wire direction - The more filament bonding, the more degradation of a-axis texture



Single filament

Two filament bonded

6-7 filament bonded

- **IPF along the wire direction of the IPF grain maps in the previous slide.**
- **FWHM of a-axis texture in a single filament is <10°. When the two filaments merge in one, it allows more distribution of in-plane grain misorientation. The 6-7 filaments bonded into the large one, the grain misorientations distribute >25° in both in-plane and out-of-plane, presumably degrading J_c most significantly.**

Cooling rate changs the grain size

<u>Design of Experiments (DoE) Conclusions</u>
(37x18 and 27x7):

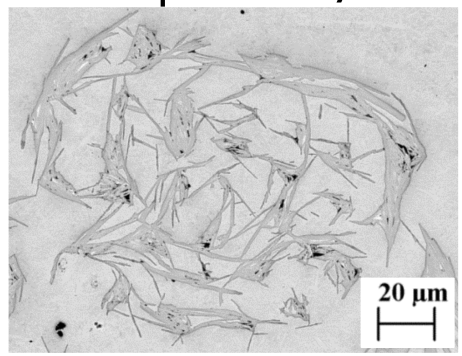
- Cooling rate R_F and Time in melt t_{melt} affect I_C the most

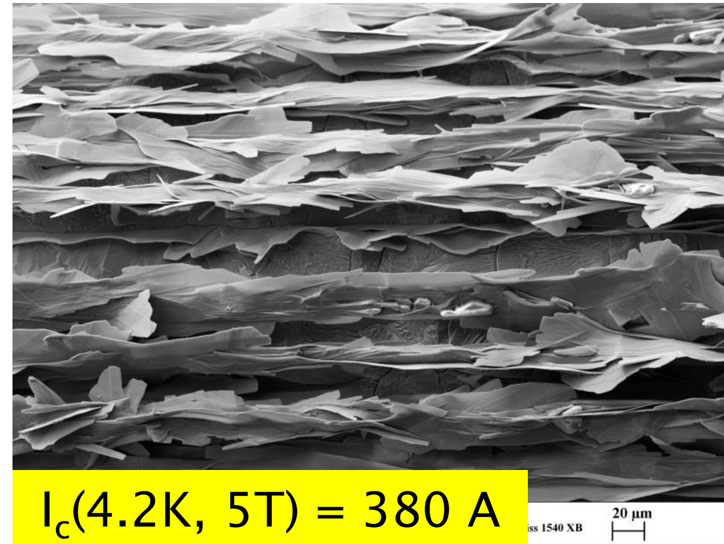
Cooling rate R_F controls:
- Amount of second phases
- Amount of 2212
- Filament coupling
- Grain size
- Grain alignment
- 2212 connectivity along the length

M. Matras, *PhD thesis* at FSU (2016)

Slow cooling

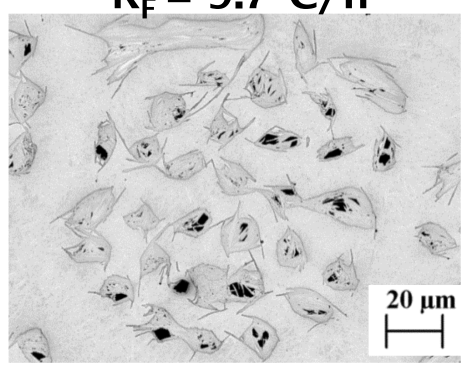
R_F = 1.3°C/h

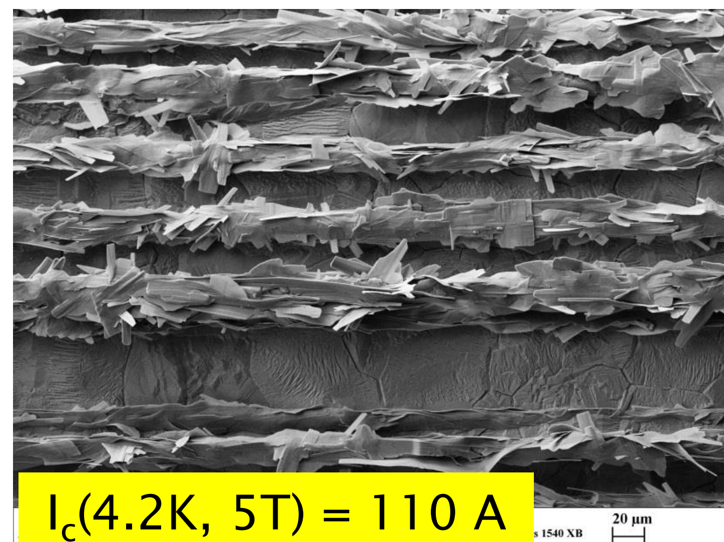




Fast cooling

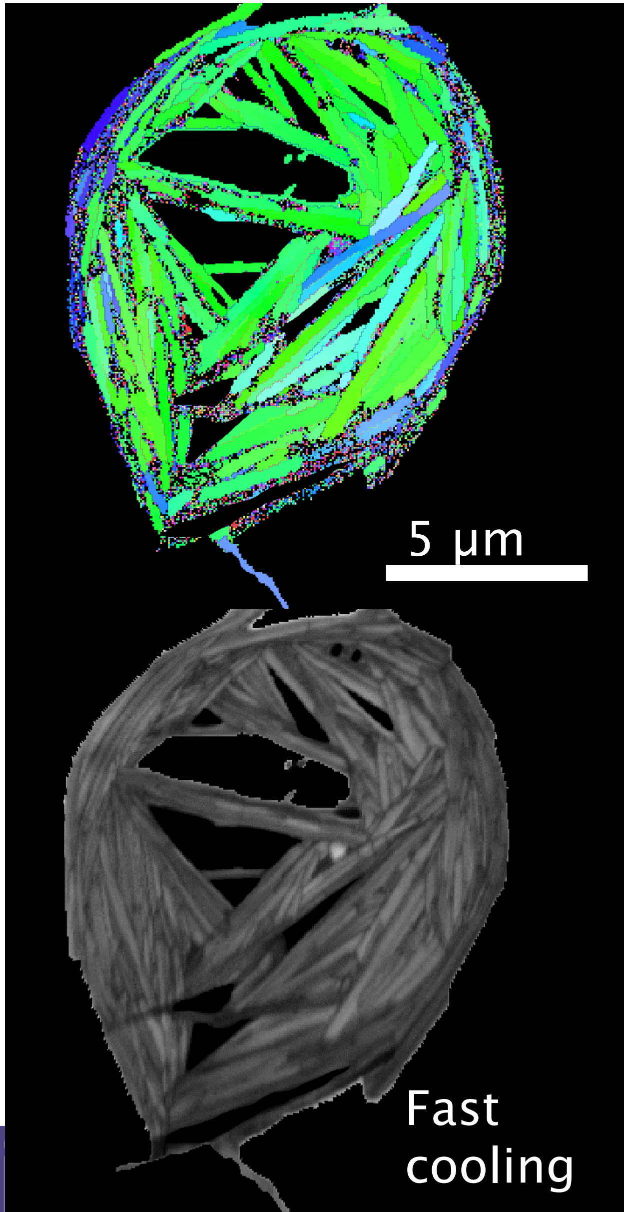
R_F = 9.7°C/h

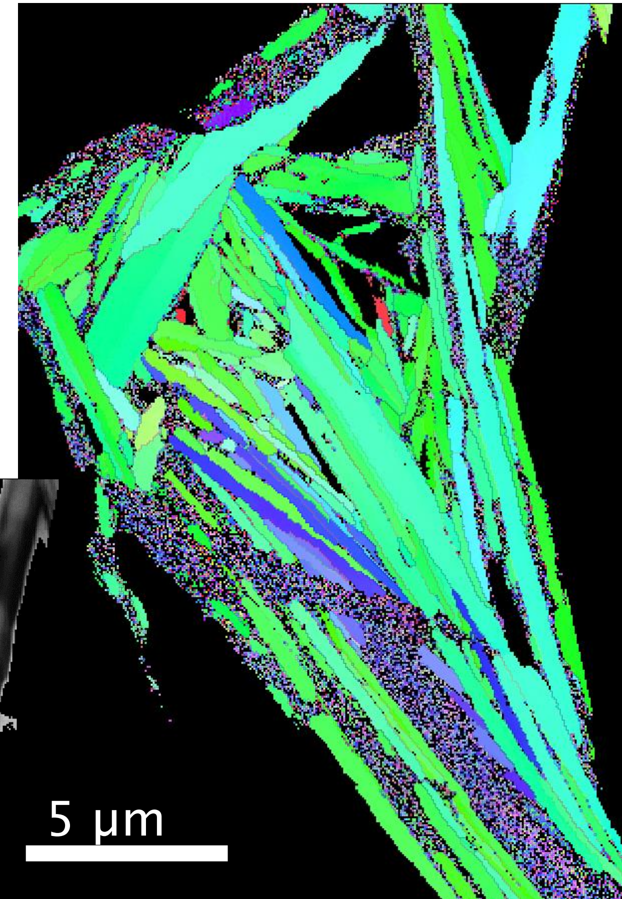


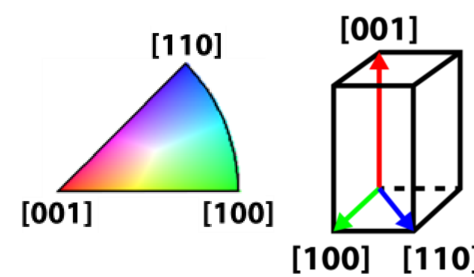


Cooling rate appears not to affect a-axis grain nucleation

Large Bi-2212 grains doesn't form by fast cooling, perhaps spoiling the grain connectivity along the filament length

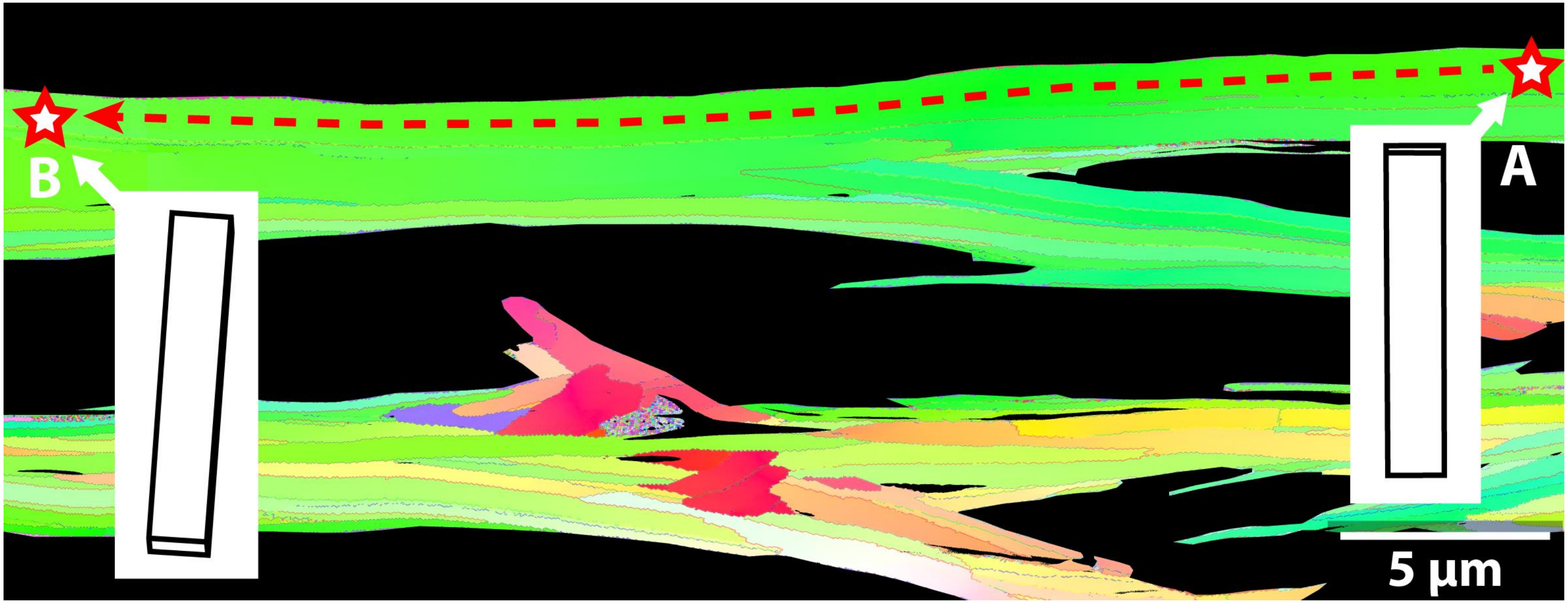






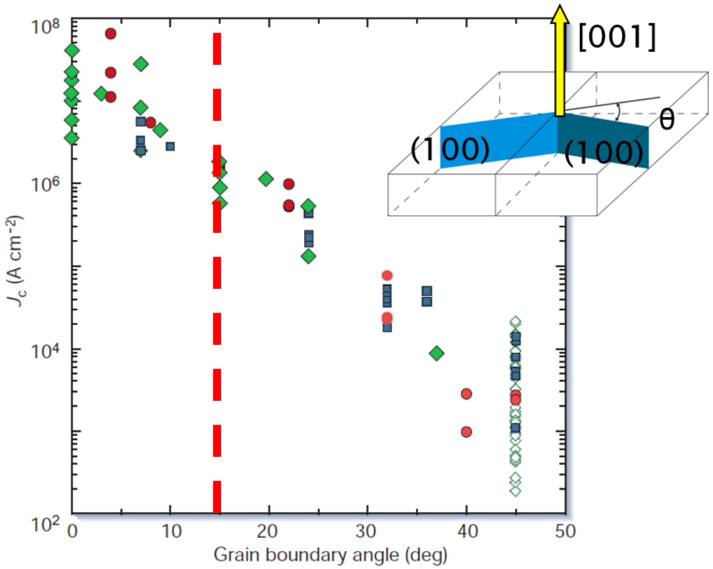
EBSD by A. Oloye

The long and thin Bi-2212 grains can plastically twist during growth



- One long grain can twist and change the grain orientation up to ~30˚
- Larger grains allow more twisting to decrease GB misorientation along the filament direction

Why don't the15° GBs in Bi-2212 show weak connectivity?



- The bicrystal experiments of HTS cuprates indicates that 15° GBs are still high angle, and would be weakly coupled
- But high J_c Bi-2212 RWs don't show a signature of weakly coupled GBs
- Is Bi-2212 special among the HTS cuprates?

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- Does oxygen overdoping strengthen the connectivity of grain boundaries?

Development of high critical current density in multifilamentary round-wire $Bi_2Sr_2CaCu_2O_{8+\delta}$ by strong overdoping

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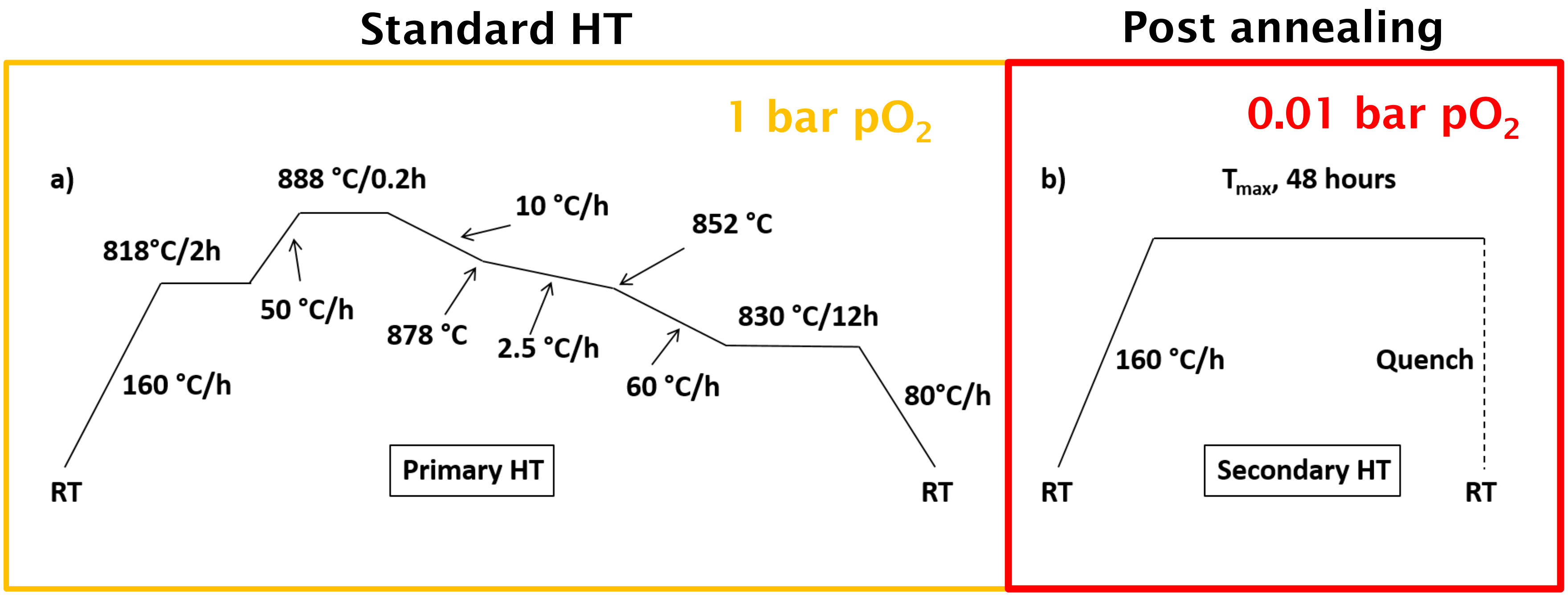
$Bi_2Sr_2CaCu_2O_{8+\delta}$ is the only cuprate superconductor that can be made into a round-wire conductor form with a high enough critical current density J_c for applications. Here we show that the J_c(5 T,4.2 K) of such Ag-sheathed filamentary wires can be doubled to more than 1.4 $\times 10^5$ A/cm^2 by low temperature oxygenation. Careful analysis shows that the improved performance is associated with a 12 K reduction in transition temperature T_c to 80 K, an increase in flux pinning, and particularly a significant enhancement in intergranular connectivity. In spite of the macroscopically untextured nature of the wire, overdoping is highly effective in producing high J_c values. © *2009 American Institute of Physics*. [doi:10.1063/1.3242339]

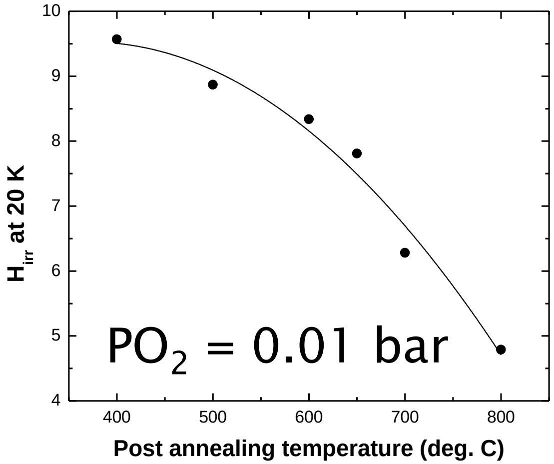
Post annealing in low oxygen atmosphere underdopes Bi-2212

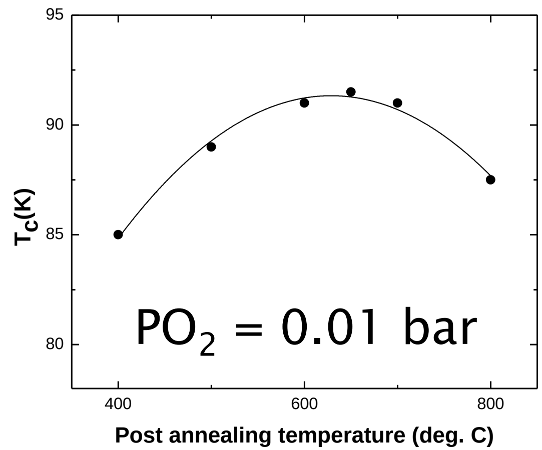


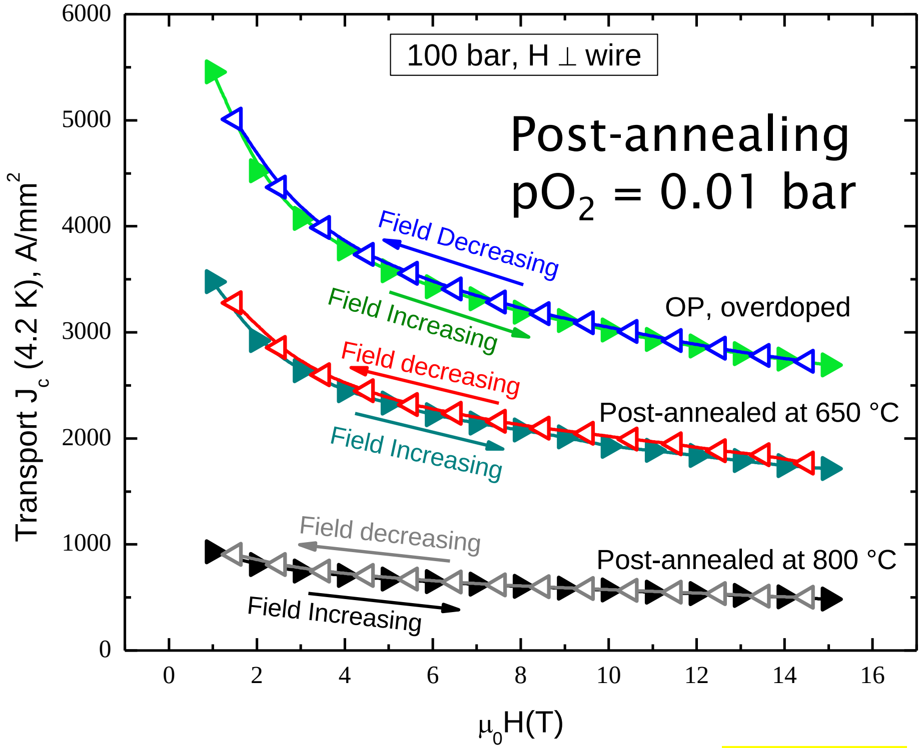
Can we make the GB coupling weaker by underdoping?

Y. Oz

Underdoping affects T_c, H_{irr}, J_c







Y. Oz

- **But no J_c hysteresis was observed in significantly underdoped samples**
- **Was the GB connectivity not affected by underdoping?**

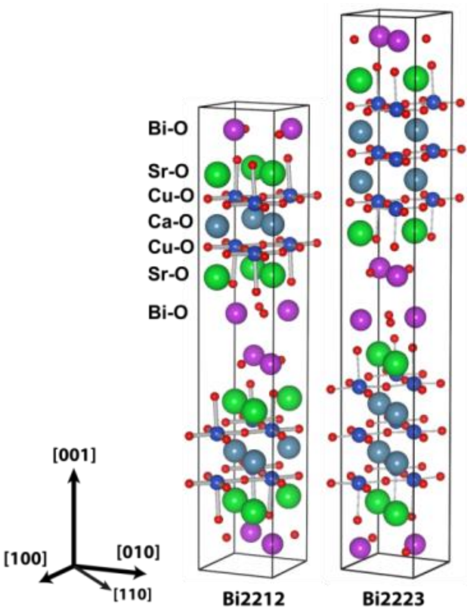
Conclusion

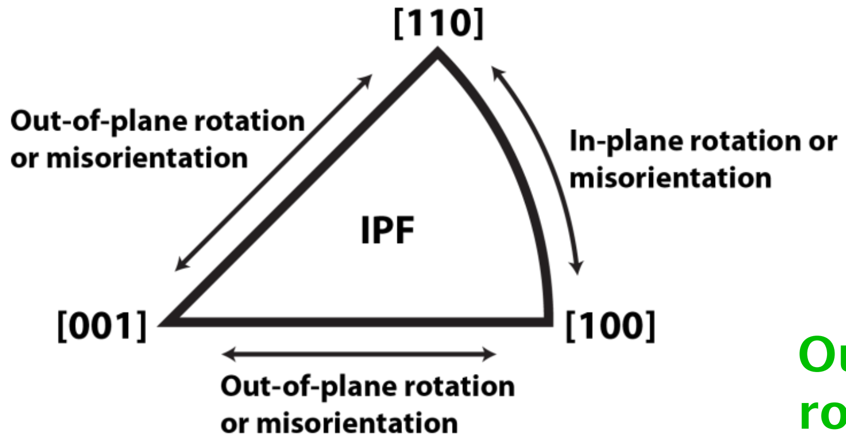
- Bi-2212 has the unique quasi-biaxial grain structure
  - Strong a-axis (NOT c-axis) texture, although prior deformation (wire drawing) can play no role in the grain growth
  - Surprisingly in-plane misorientation is ~15˚ too
- Bi-2212 quasi-biaxial texture development is dependent on filament cavities
- Cooling rate affects the grain size, but doesn't affect very much on the a-axis texture development
  - The larger grain size, the more plastic twisting to decrease GB misorientation along the wire direction?
- Bi-2212 under oxygen-overdoped, possibly enhancing the carrier density at the GBs, but the underdoping experiments could not alter the GB connectivity

Acknowledgements

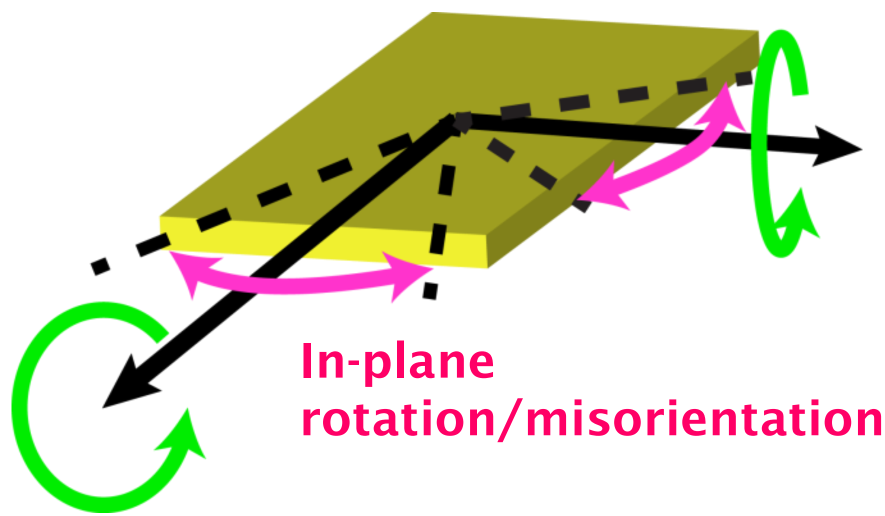
- Supported by the US DOE Office of High Energy Physics under grant number DE-SC0010421, and by the NHMFL, which is supported by NSF under NSF/DMR-1157490 and by the State of Florida.
- All Bi-2212 round wires were fabricated by Bruker-OST

Texturing analysis: Anisotropic BSCCO crystal defines in-plane and out-of-plane misorientation





Out-of-plane rotation/misorientation



In-plane rotation/misorientation

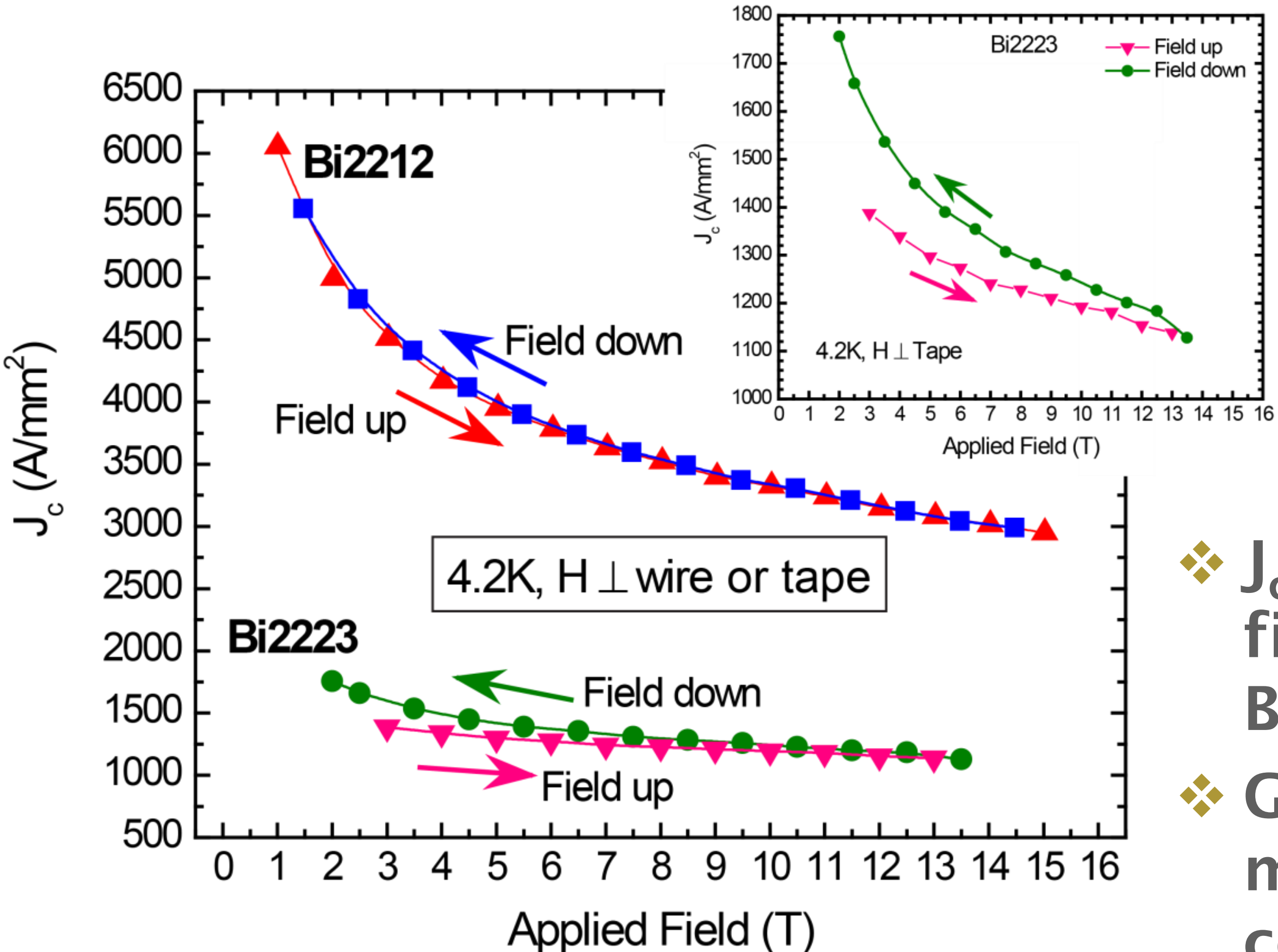
Out-of-plane rotation/misorientation

Electron Backscatter Diffraction Orientation Imaging Microscopy for grain orientation mapping

	Scanning electron microscope (SEM)	Optical microscope			g TEM M)
	~15-500K x	up to ~1500 x			M x
	~1-2 nm	> 0.5 μm			Å
	Surface	Mostly surface			ssion
	Yes	n/a			
	Yes	n/a	Yes	Yes	n/a

- ~~One of the analytical capabilities in SEM~~
- **Sophisticated polishing is required**
  - The surface to be scanned must be contamination-free

J_c of Bi2212 round wire is 3 times higher than that of Bi2223

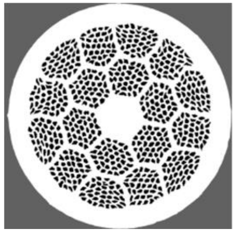


$Bi_2Sr_2Ca_2Cu_3O_x$ (Bi2223) conductors

Flat tape

$Bi_2Sr_2Ca_1Cu_2O_x$ (Bi2212) conductors

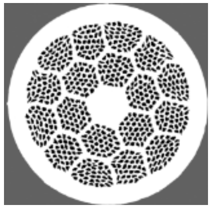
Round wire

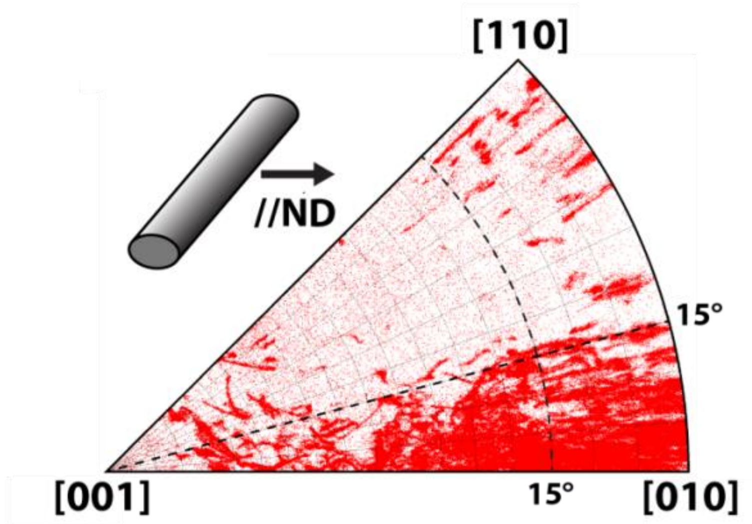


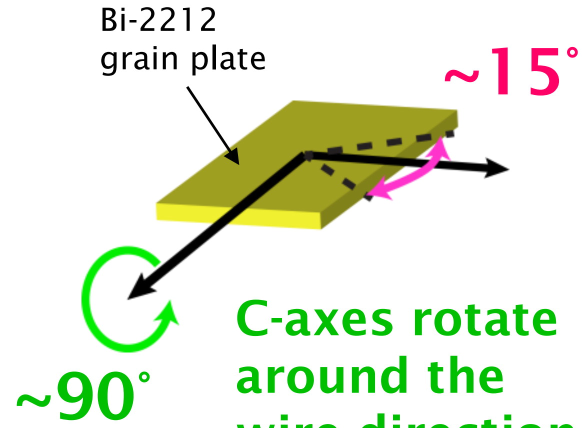
- J_c hysteresis in field is absent in Bi2212
- GBs in Bi2212 is more strongly coupled

Jiang and Abraimov

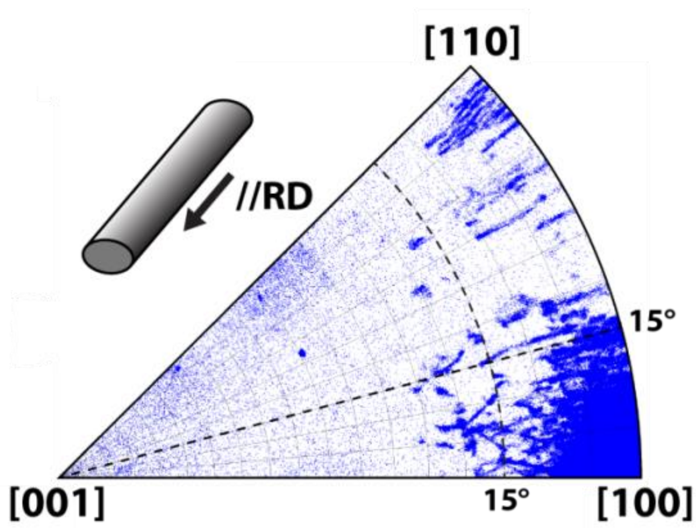
Inverse pole figures revealed quasi-biaxial texture in Bi-2212 filaments

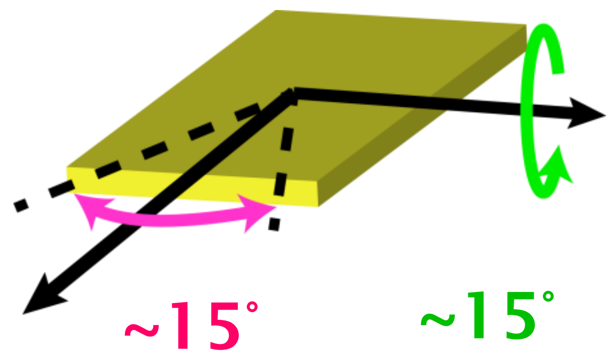






C-axes rotate around the wire direction





~15° in-plane and out-of-plane misorientations