Artificial vs. Intrinsic Pinning in YBCO Second-Generation Coated Conductors.

BROOKHAVEN NATIONAL LABORATORY

CPMS Seminar October 23 2006

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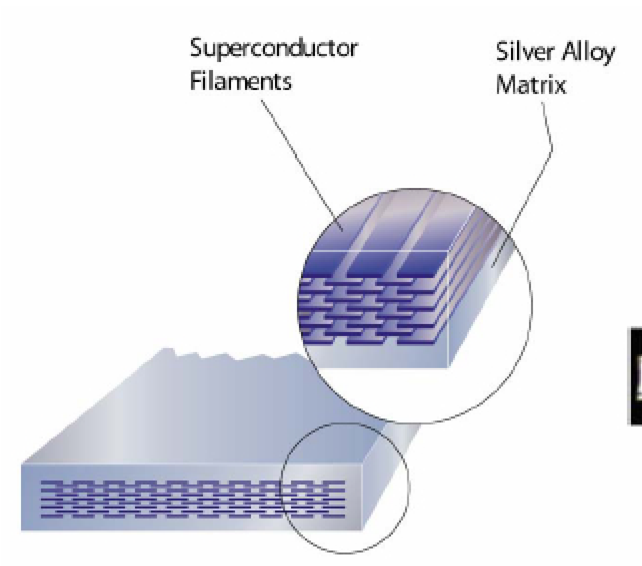
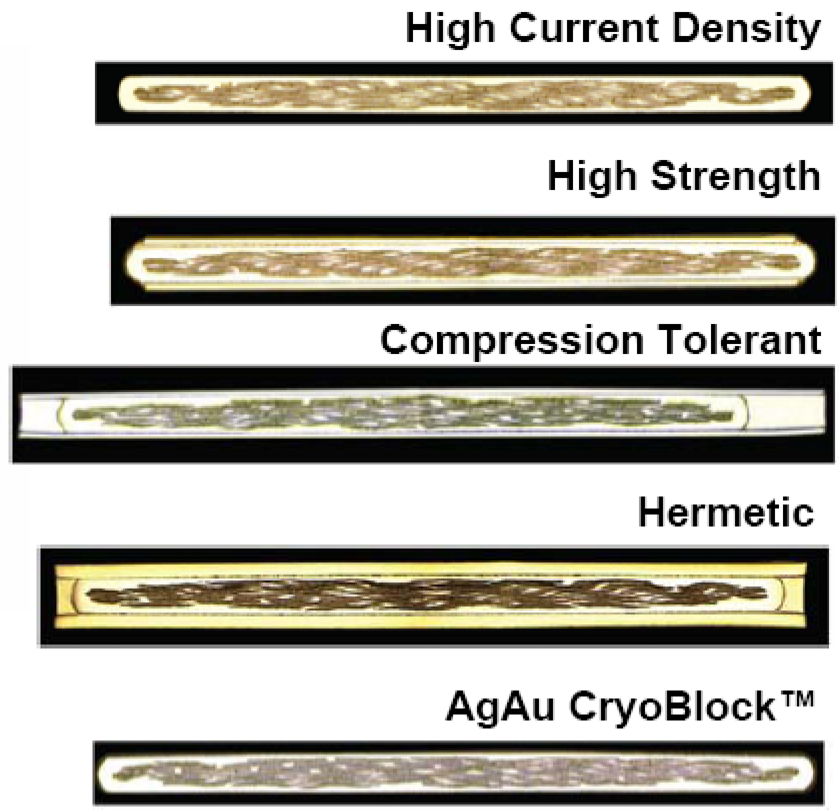
Two challenges of HTS:

- What is the mechanism of HTS?
- How can we start making money of HTS?

First-generation (1G) HTS conductor: BiSrCaCuO-Ag tape (AMSC products shown)



Basic Building Block

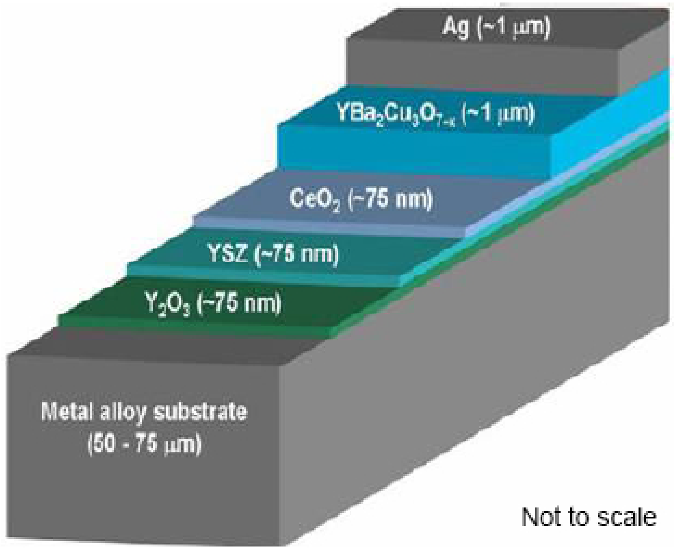


Second-generation (2G) HTS conductor: YBCO tape (AMSC products shown)

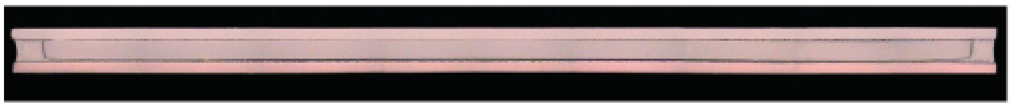
RABiTS / MOD 2G Strip Architecture

- **Substrate: Ni-5%W alloy**
  - Deformation texturing
- **Buffer stack: Y_2O_3/YSZ/CeO_2**
  - High rate reactive sputtering
- **YBCO**
  - Metal Organic Deposition of TFA
- **Ag**
  - DC sputtering

Width 1 cm → 4 cm → 10 cm

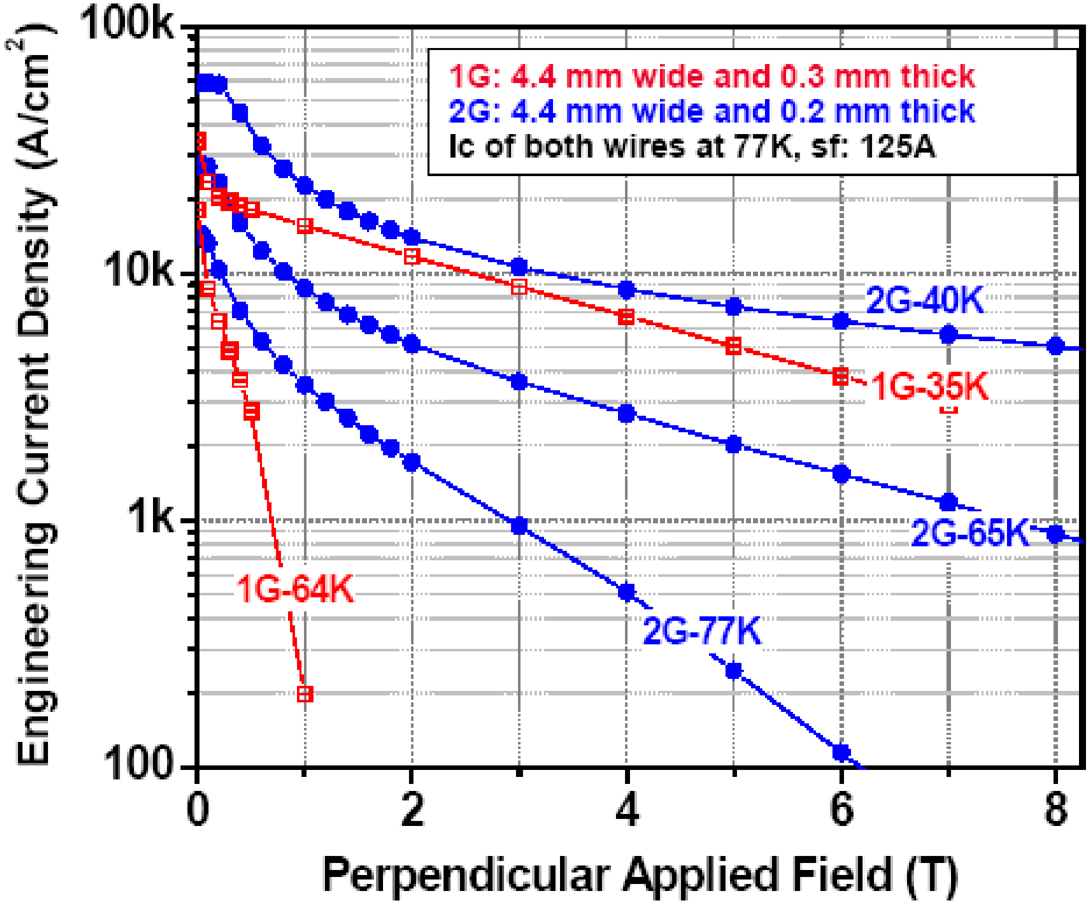


344 superconductors are American Superconductor's new 3-ply, 4.4 mm wide second generation HTS wires.

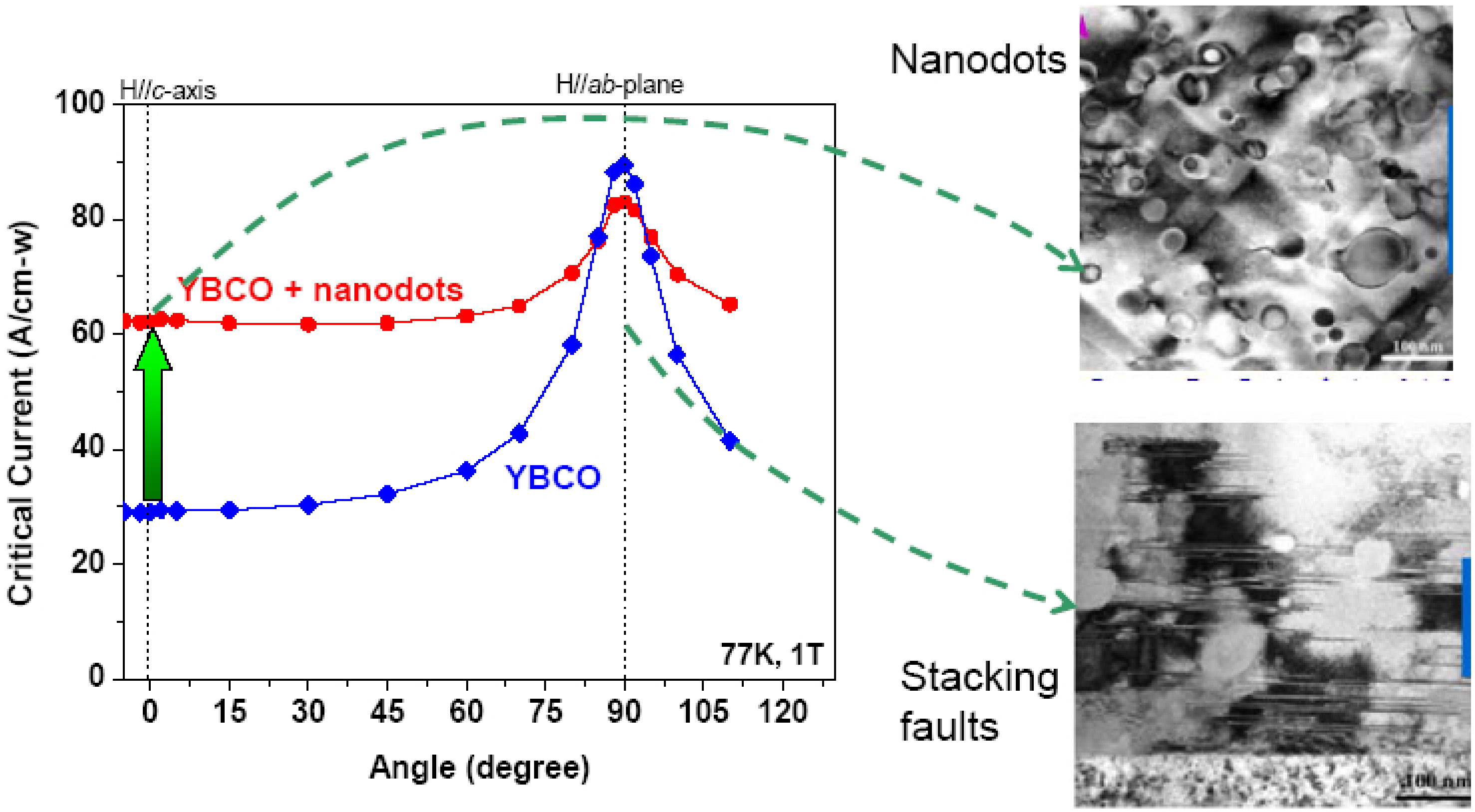


Why industry is switching to 2G wire.

1G Wire: 125A, 4.4 mm width → 2G Wire: 125A, 4.4 mm width

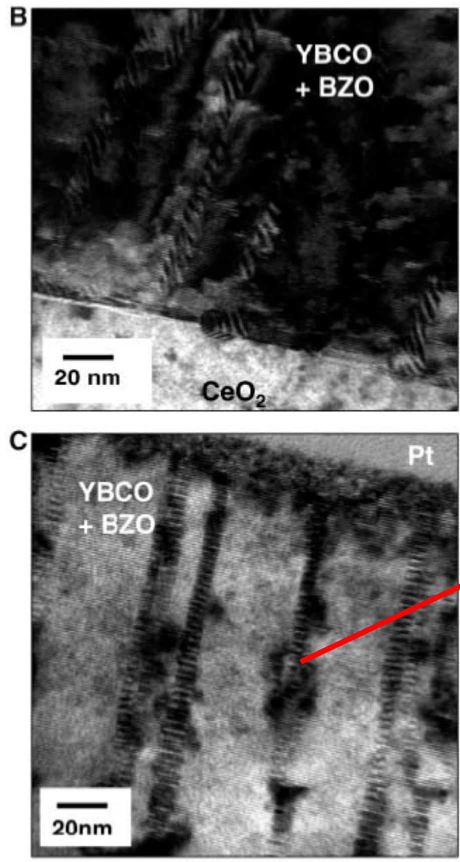


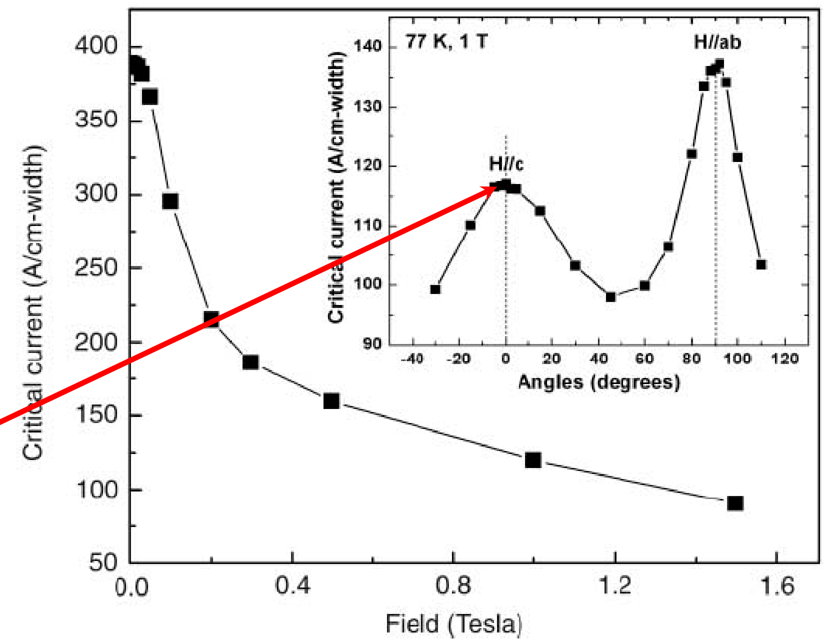
Artificial pinning centers: DyO nano-dots.



AMSC presentation at DOE peer-review 2006.

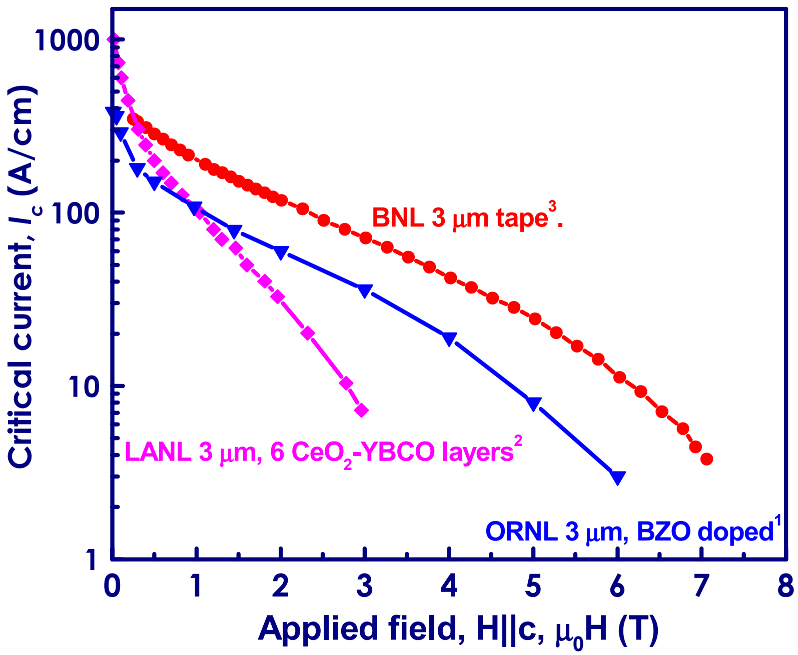
Artificial pinning centers: BZO nano-rods.



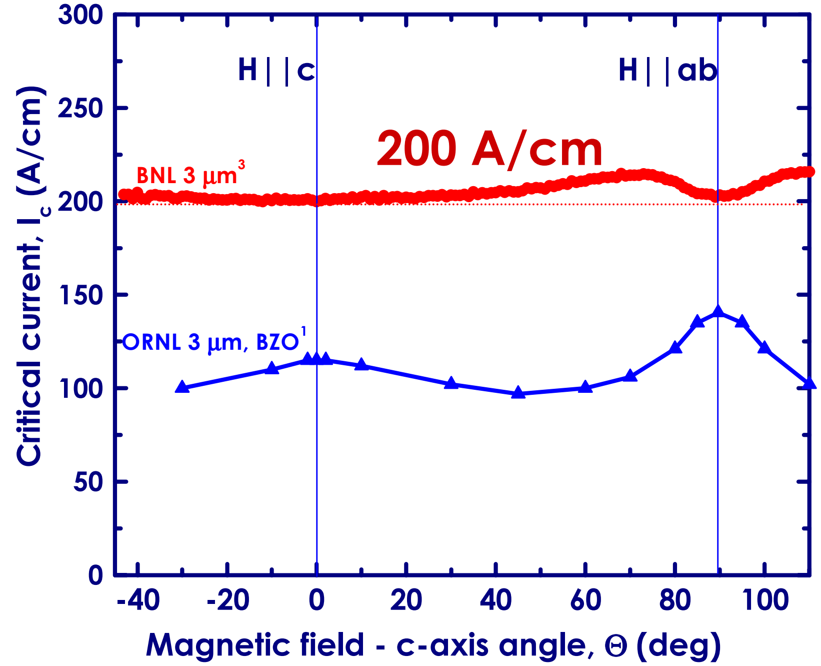


PLD deposited YBCO with BZO columnar structures, S. Kang, et al. *Science*, 311, p. 1911 (2006).

Performance of 3 μm films in liquid nitrogen.



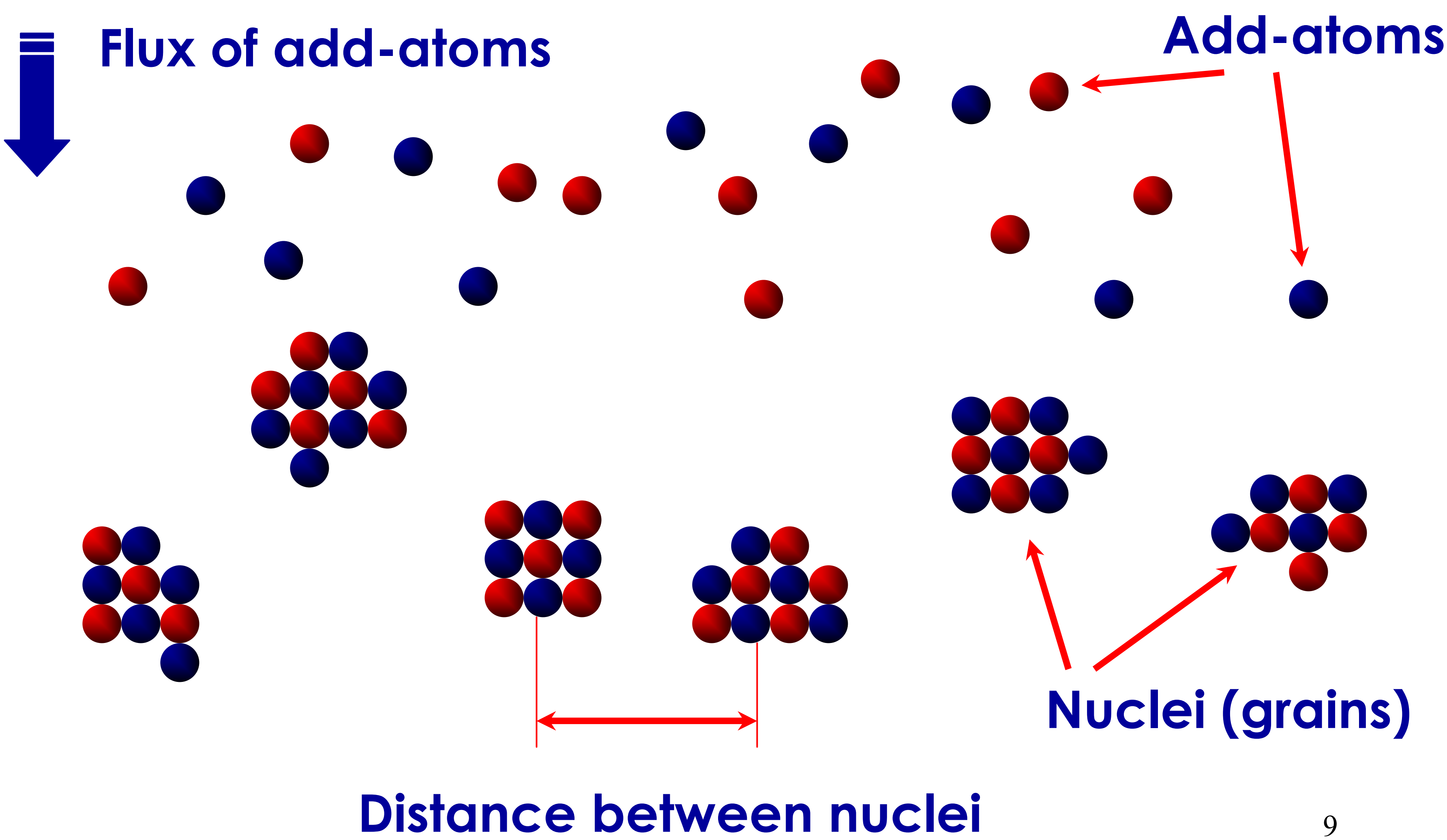
1 Tesla field



[1]PLD deposited YBCO with BZO columnar structures, S. Kang, et al. *Science*, 311, p. 1911 (2006).
[2]X. Jia, S. R. Foltyn, P. N. Arendt, and J. F. Smith, *Appl. Phys. Lett.*, 80, p. 1601, (2002).
[3]Transport J_c measurement by L. Civale and B. Maiorov, LANL.

✓ **BNL 3 μm sample exhibited very strong isotropic pinning, which was combined with high T_c.**

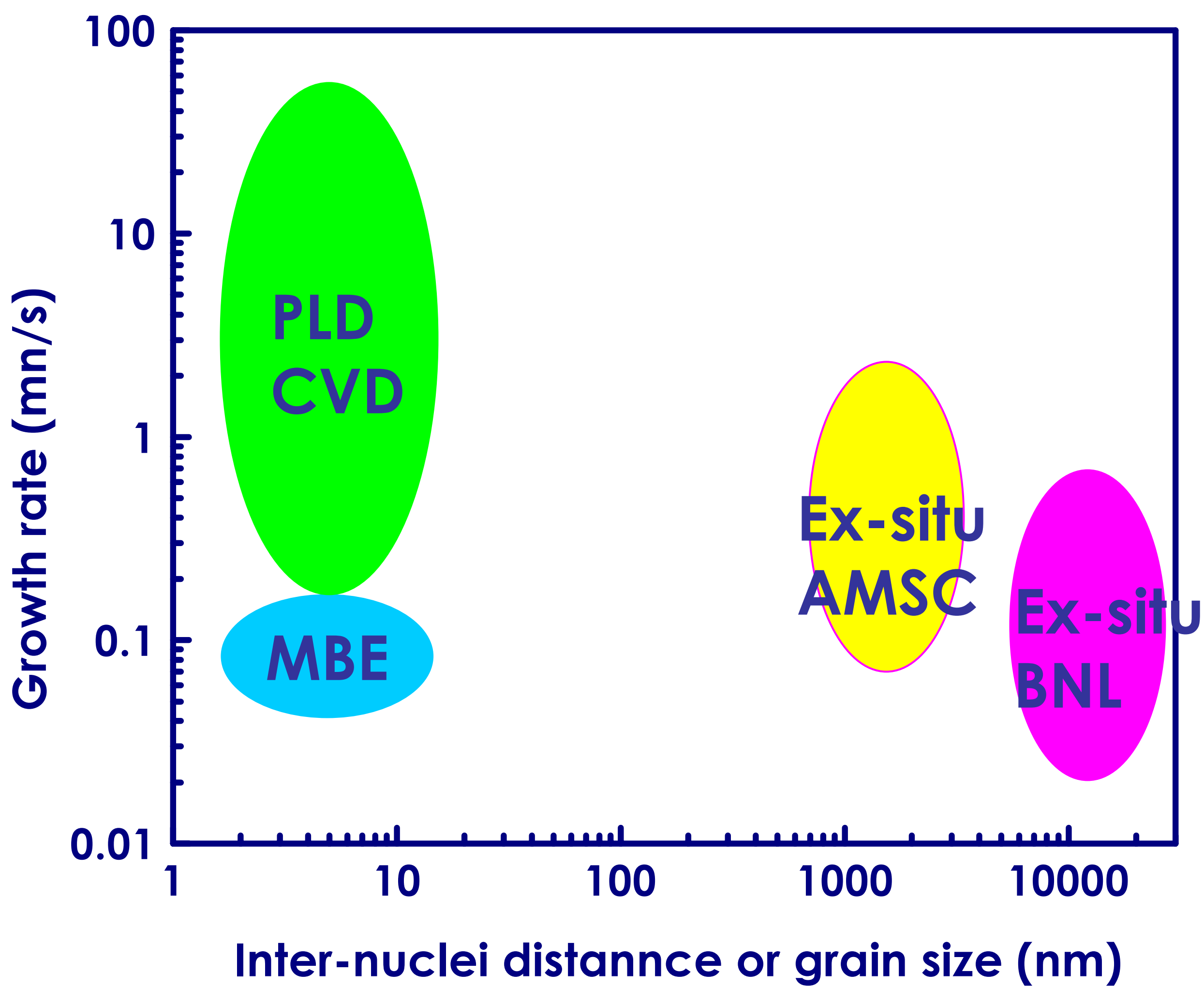
How do we make materials?



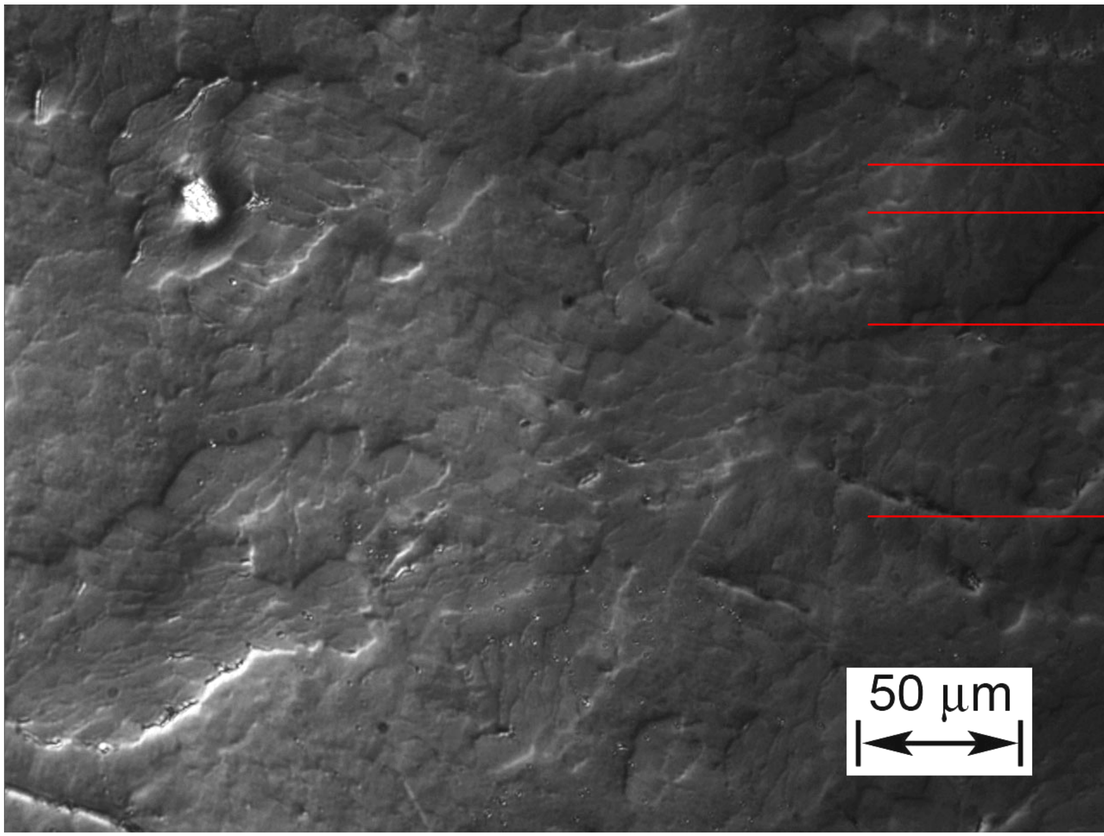
Two metrics of material-building process:

- Flux of add-atoms, or growth rate (nm/s).
- Distance between the nuclei, or grain size (nm).

Grain size vs. growth rate diagram.

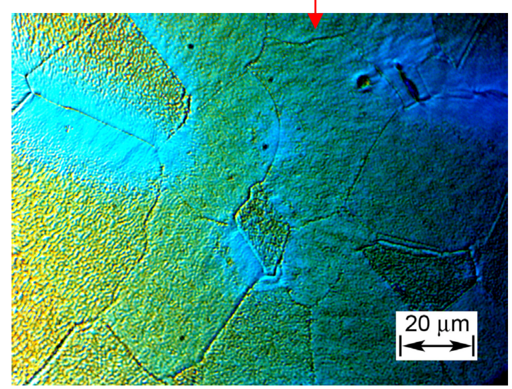


Typical morphology of a thick film sample.

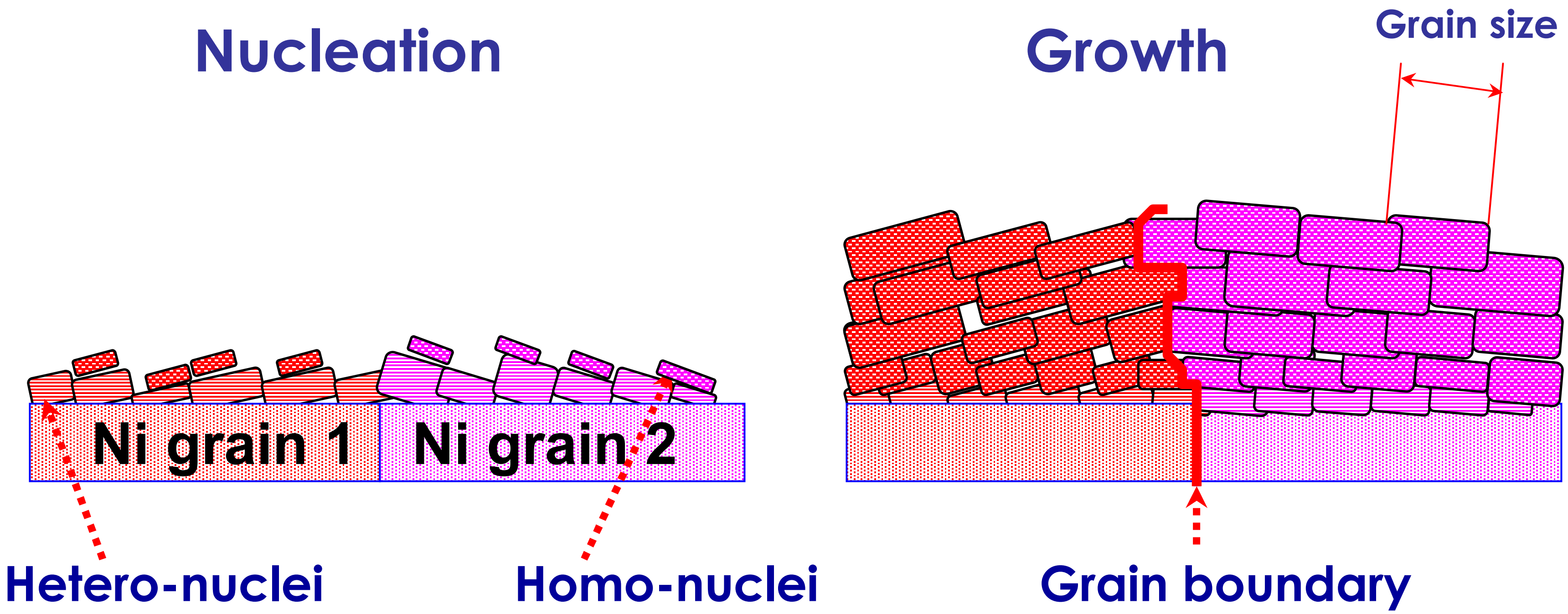


YBCO grain
≈ 15 µm

Substrate Ni grain
≈ 50 µm



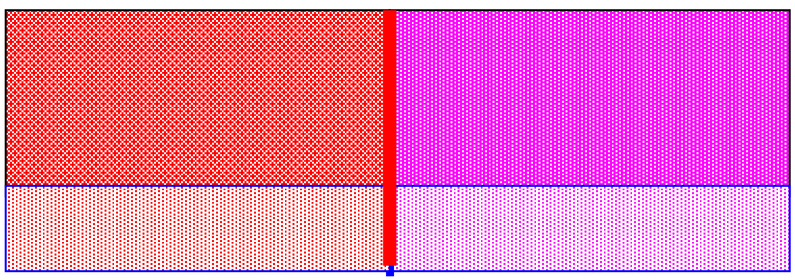
Growth of c-axis oriented layer: Grain boundary morphology.

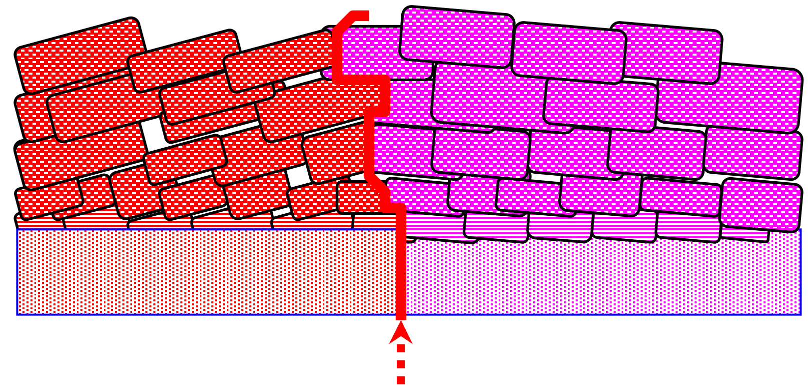


- ✓ After the nucleation stage the growth proceeds as series on nucleation-merging events.

- ✓ The gain boundary meanders over distance equal to the grain size.

Straight vs. meandering grain boundary.

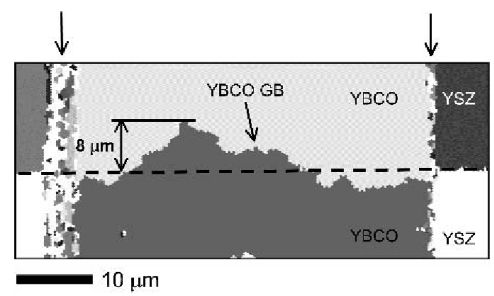




Grain boundary

Very small sub-grain
Straight grain boundary
PLD, MBE

Large sub-grain
Meandering grain boundary



Feldmann et al,
"Evidence for extensive grain boundary meander and overgrowth of substrate grain boundaries in high critical current density ex situ YBa2Cu3O7-x coated conductors", JMR, 80 (2005).

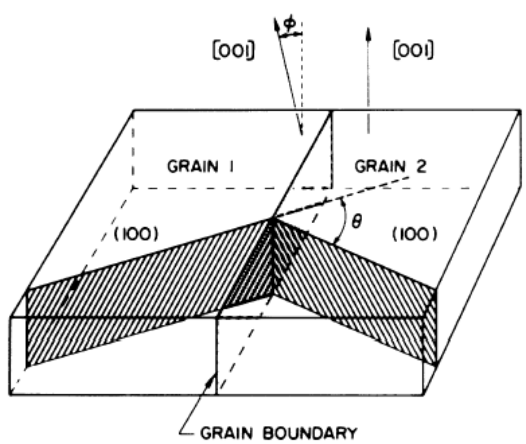
What's wrong with a straight grain boundary?

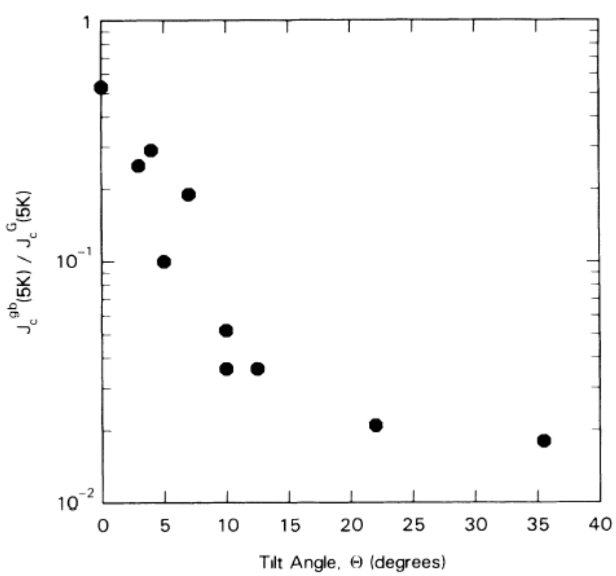
VOLUME 61, NUMBER 2 PHYSICAL REVIEW LETTERS 11 JULY 1988

Orientation Dependence of Grain-Boundary Critical Currents in $YBa_2Cu_3O_{7-\delta}$ Bicrystals

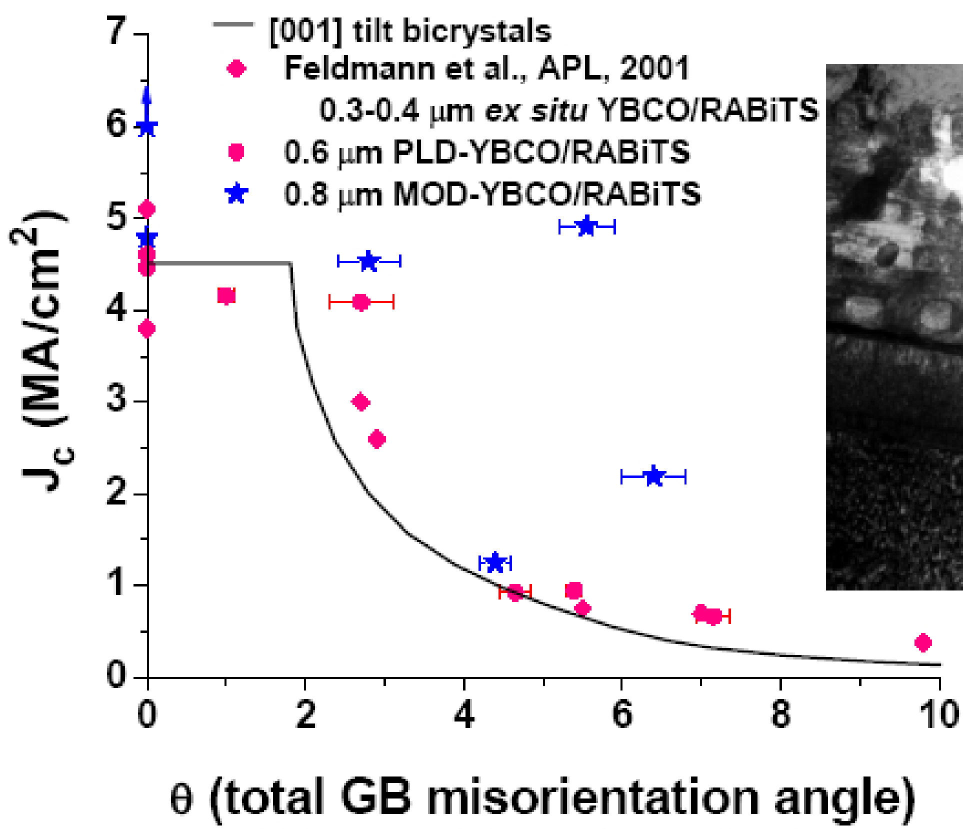
D. Dimos, P. Chaudhari, J. Mannhart, and F. K. LeGoues
Thomas J. Watson Research Center, IBM Research Division, Yorktown Heights, New York, 10598

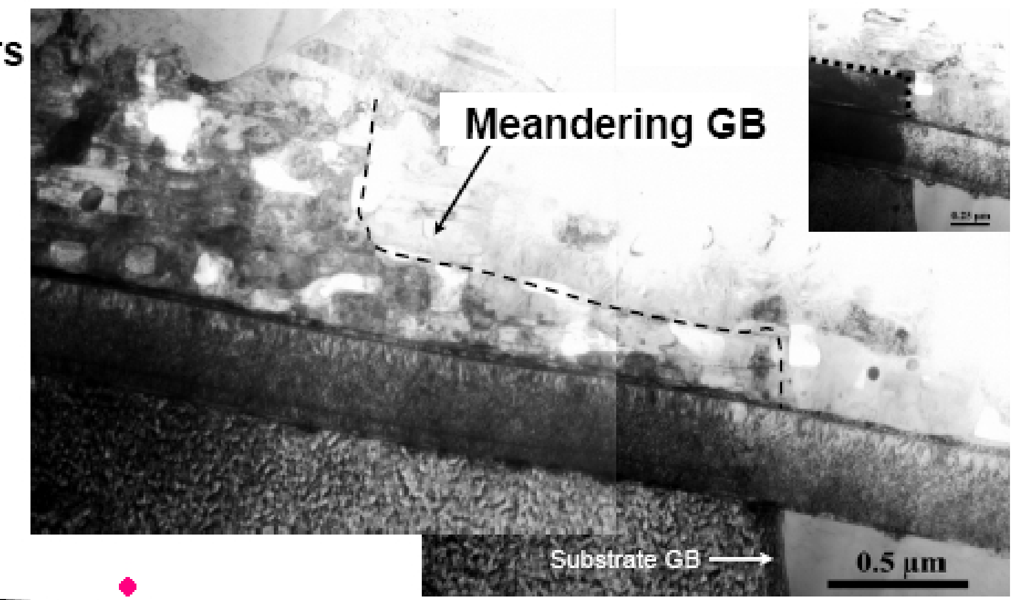
(Received 4 May 1988)





Sub-grains make GB to meander, thus they tolerate much higher misorientations.



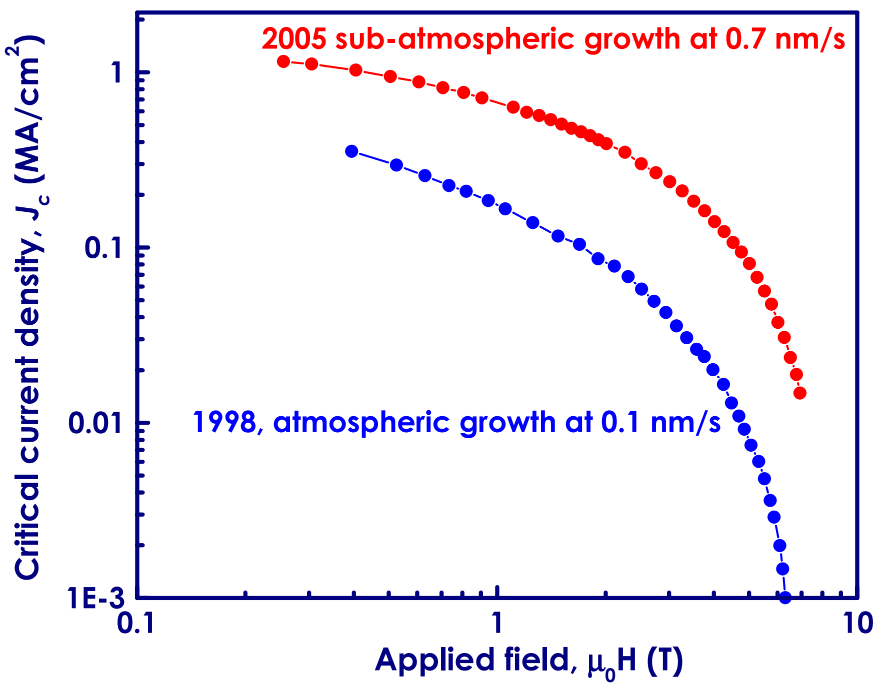


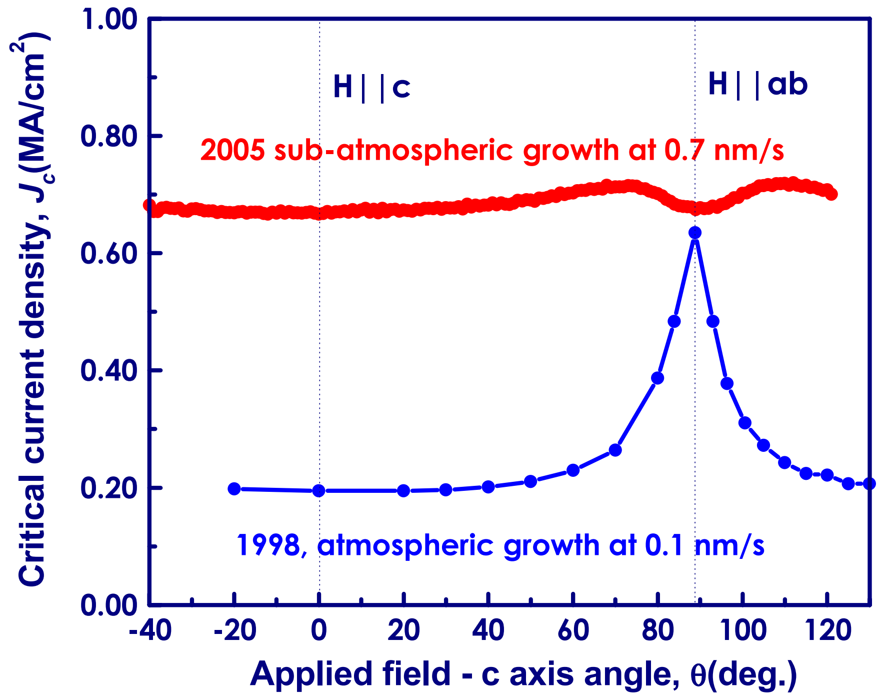
Holesinger, Feldmann, Goyal

In-plane texture is excellent in RABiTS

Growth rate effect: improvement of pinning.

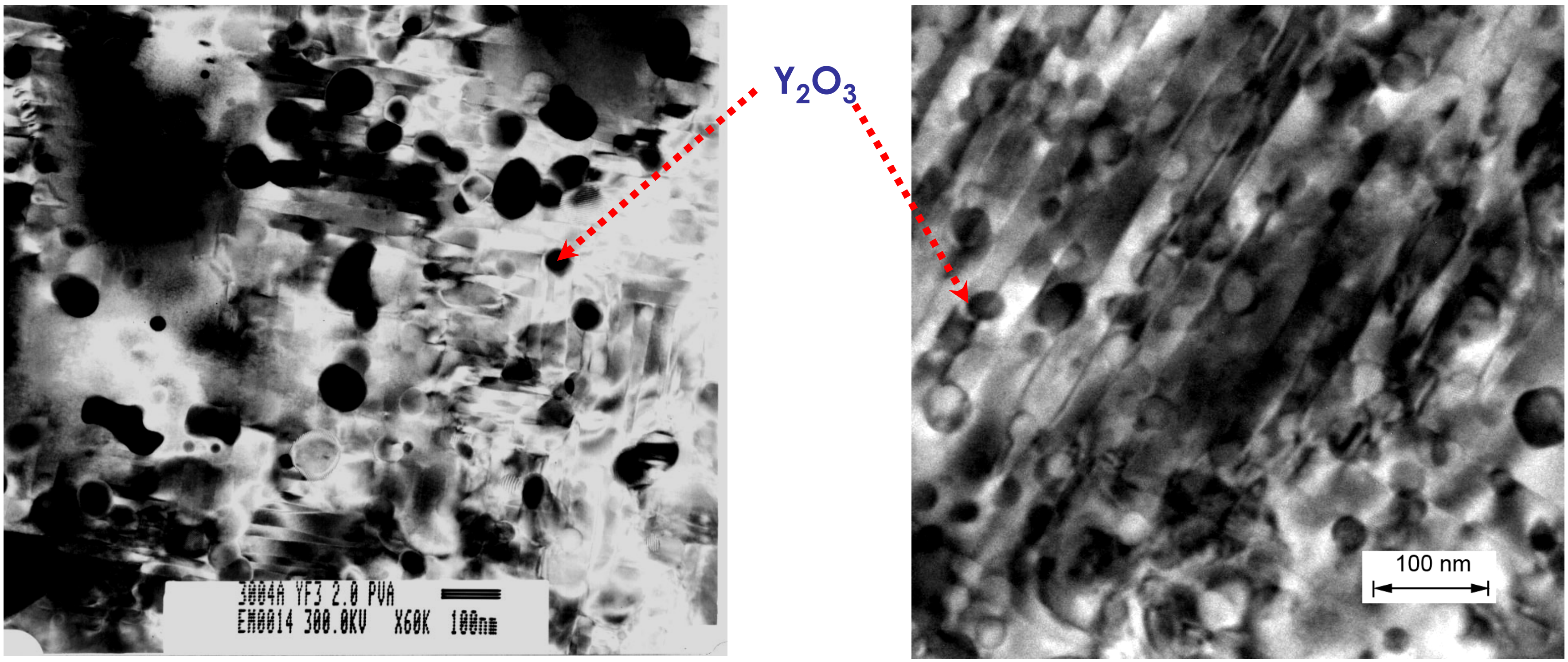
Growth temperature: 735 °C





✓ Fast growth and low growth temperature: two key ingredients for strong isotropic pinning.

Comparison: TEM plane view of atmospheric and sub-atmospheric processed 3 μm samples.

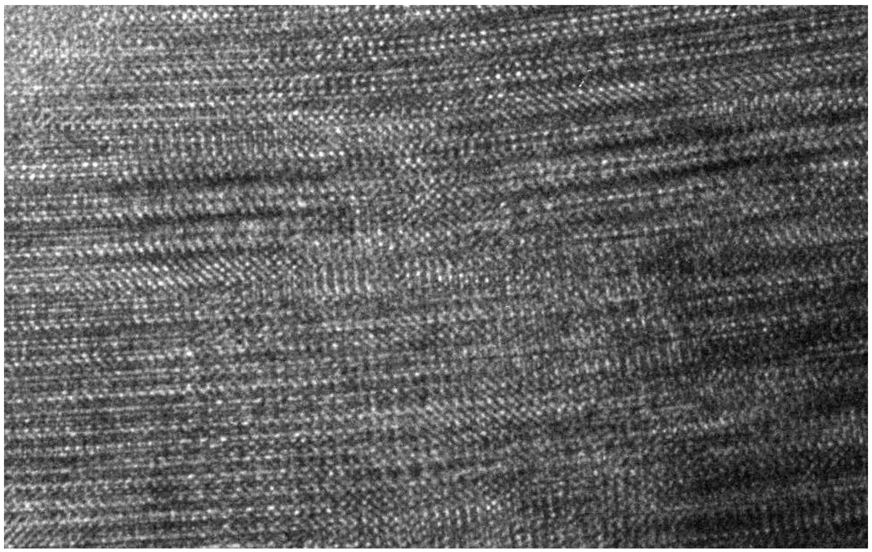


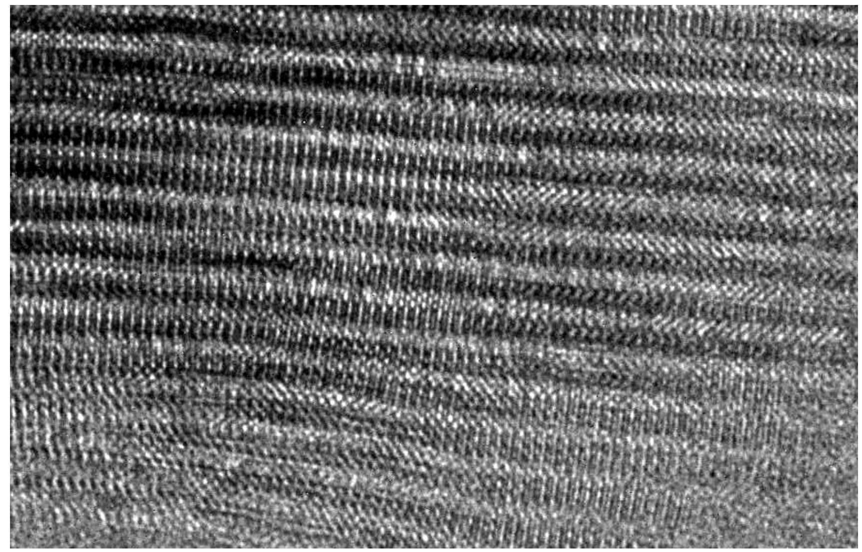
1998, atmospheric growth at 0.1 nm/s

2005 sub-atmospheric growth at 0.7 nm/s

- ✓ Density of obvious defects (precipitates) is about the same.
- ✓ Is there something we don't see in plane-view TEM?

Possible source of pinning in granular samples. YBCO plane distortion.

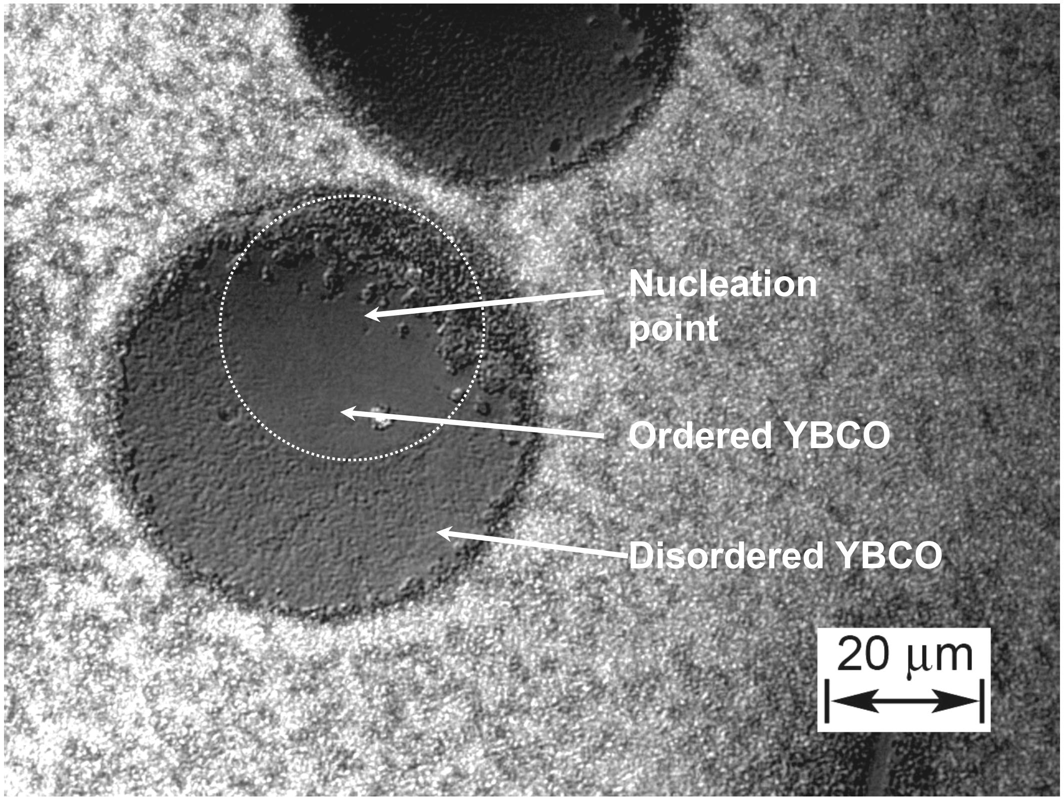




TEM cross section by Li-Hua, CFN.

Fast growth of relatively large grains introduces Strong isotropic pinning which does not degrade Tc.

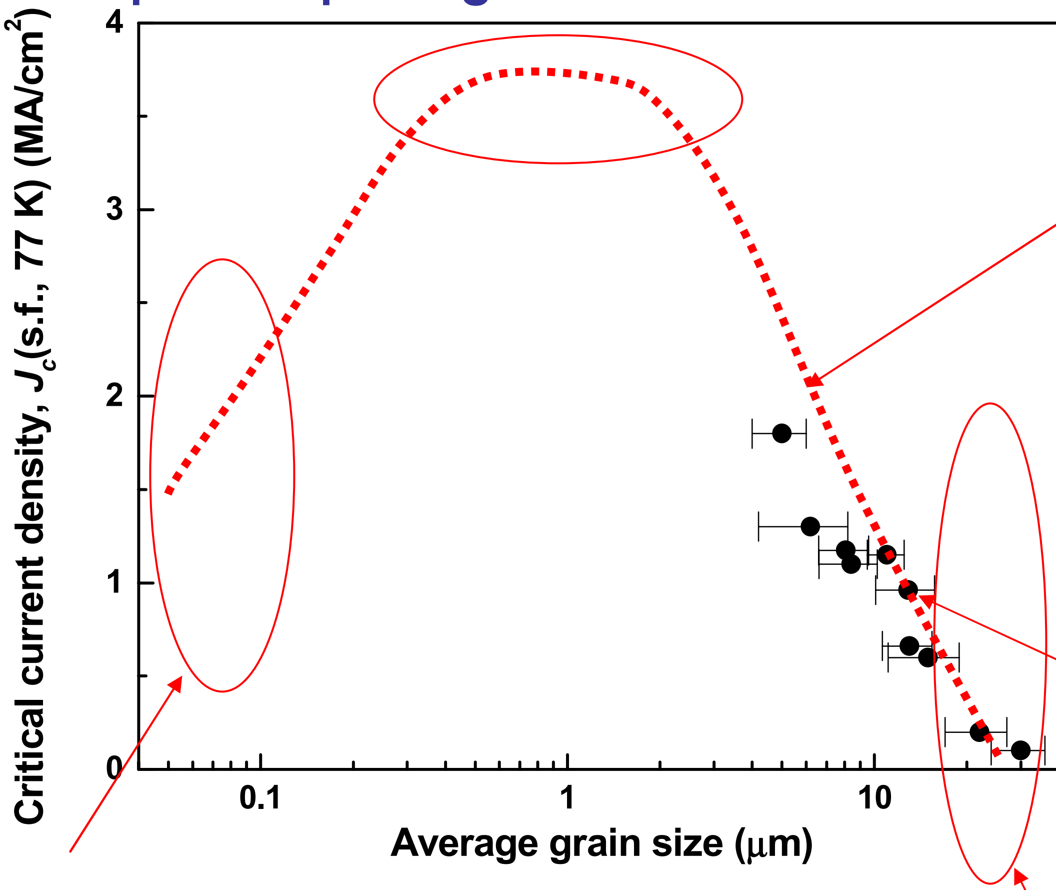
Grains cannot be too big: Structure degrades rapidly if they are over 20 μm.

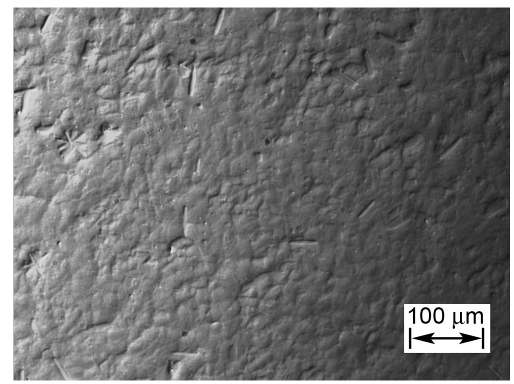


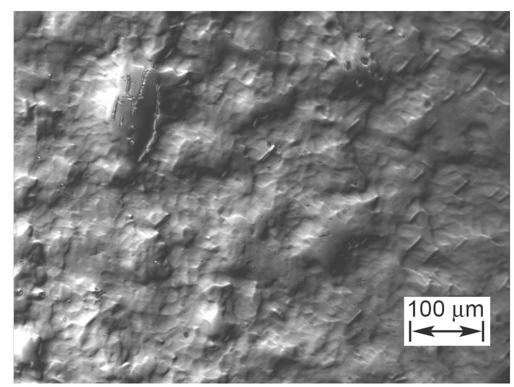
Isolated grain imbedded in precursor.

Critical current vs. the grain size.

Optimum pinning and well-connected GB



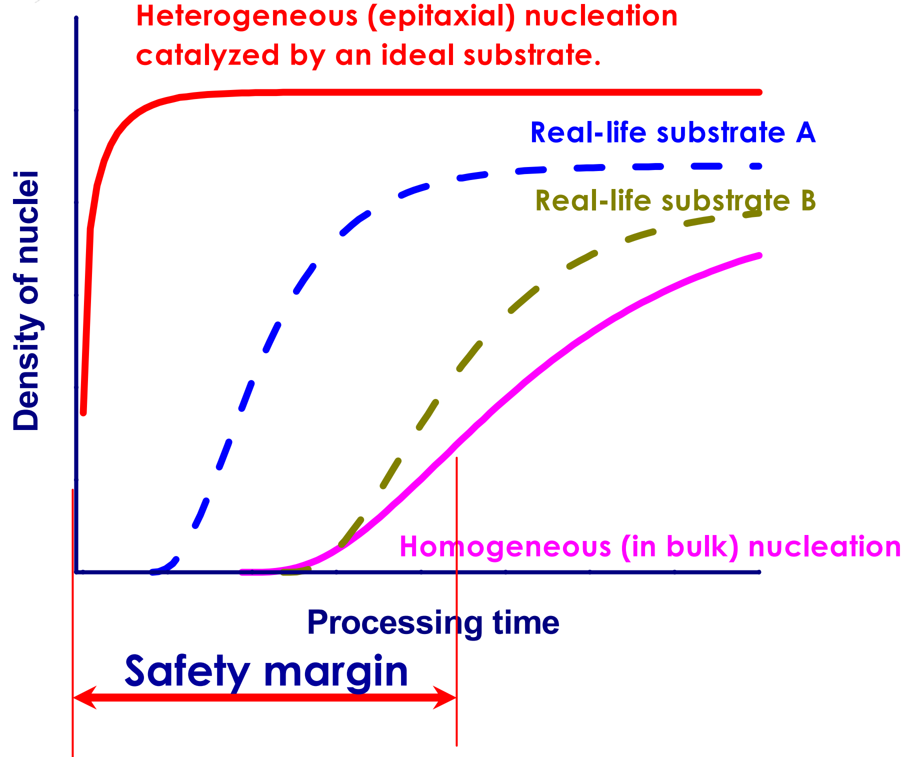


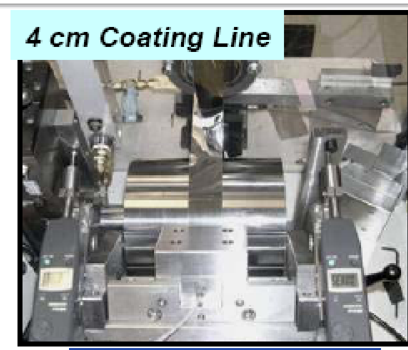


Structure too perfect,
Poorly connected GB

Poor structure

Why is it difficult to reduce the grain size? Epitaxy on non-ideal substrates.





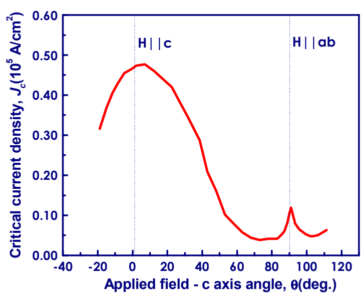

Dual-Layer Reactive Sputtering System

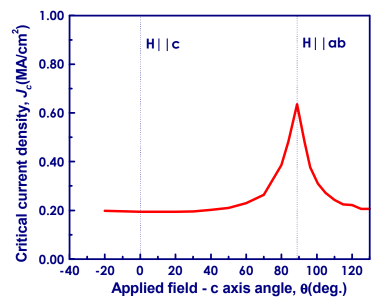
✓ For an ideal substrate, rate of epitaxial nucleation is much higher than homogeneous one. Large safety margin.

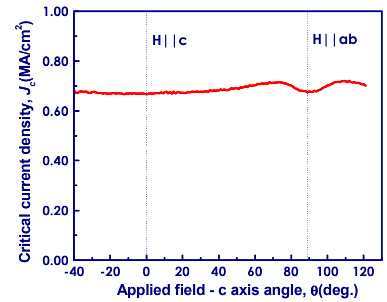
✓ Real-life substrates are not so effective catalysts and the safety margin may be very low, especially for thick films.

Post-conclusion notes.

Critical current anisotropy in un-doped YBCO







Low S.
Flux-grown perfect crystals.
Point-like pinning by O^{-2} vacancies.

Intermediate S.
Atmospheric processing,
Pinning by extended defects (stacking faults etc.).

High S.
Sub-atmospheric processing,
Isotropic pinning.

Decomposition — $S = \Delta\mu/kT$ (supersaturation) — Growth

Equilibrium

Is there a "critical rate"?

Metallurgic example: quenching of eutectoid (0.83%C) steel

Tensile strength, psi
Yield strength, psi
Hardness, Rockwell C
Elongation, per cent
Reduction of area, %