Designing pinning in coated conductors with a view to accelerator magnets

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Acknowledgments

eurotapes

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KIT
Karlsruhe Institute of Technology

IFW
Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden

ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

BRUKER

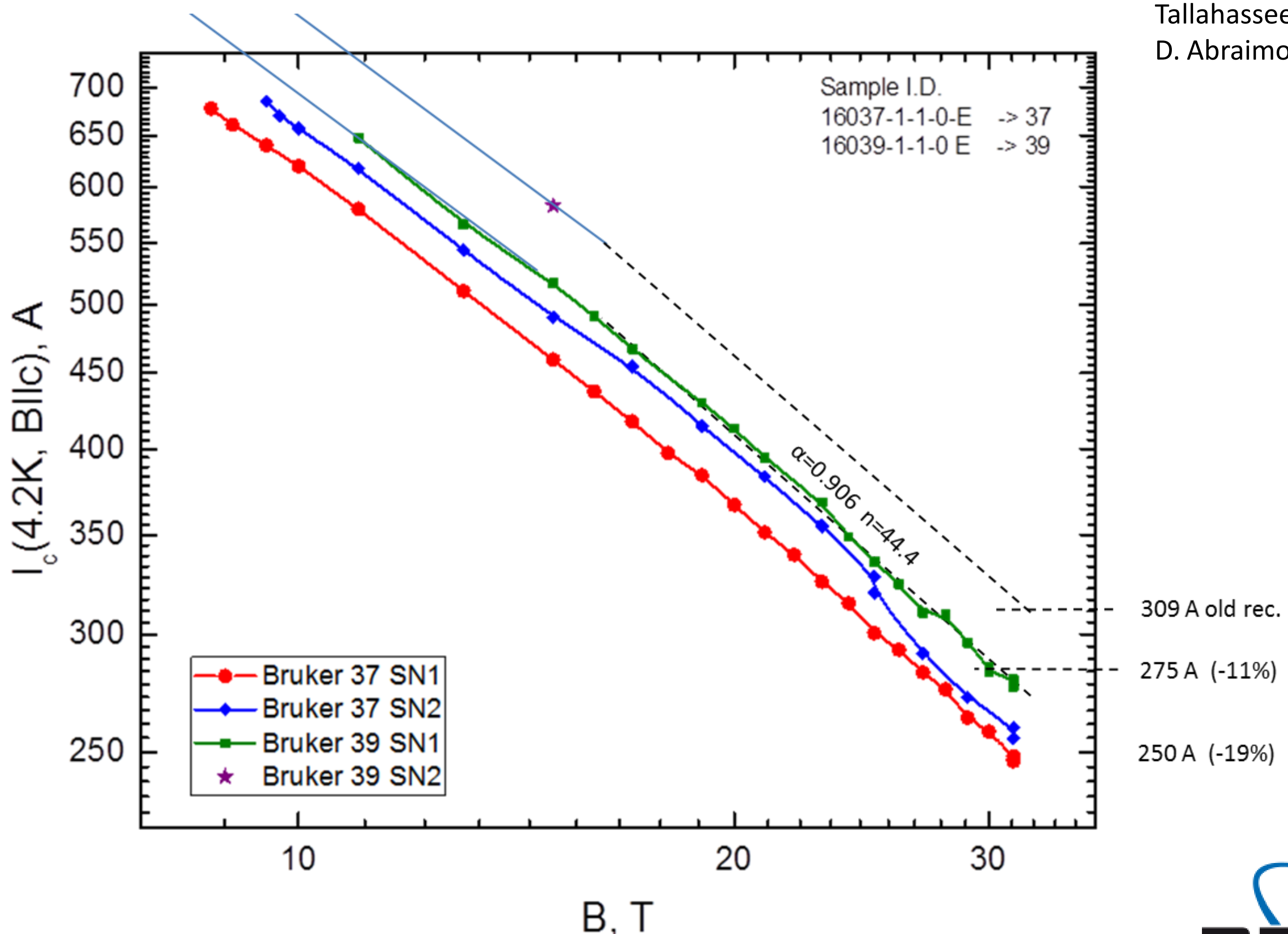
REBCO excellent for generating high fields

- Today's REBCO CC is an amazing conductor for high field magnets
  - 40 T today, 3 all superconducting 26-27 T magnets demonstrated in K, J and USA, 32 T expected soon
  - No Insulation (NI) is allowing (small) magnets to operate at the 1000 A/mm^2 level safely
- 4 K magnets deliver "Pull" – but can they deliver profitability?

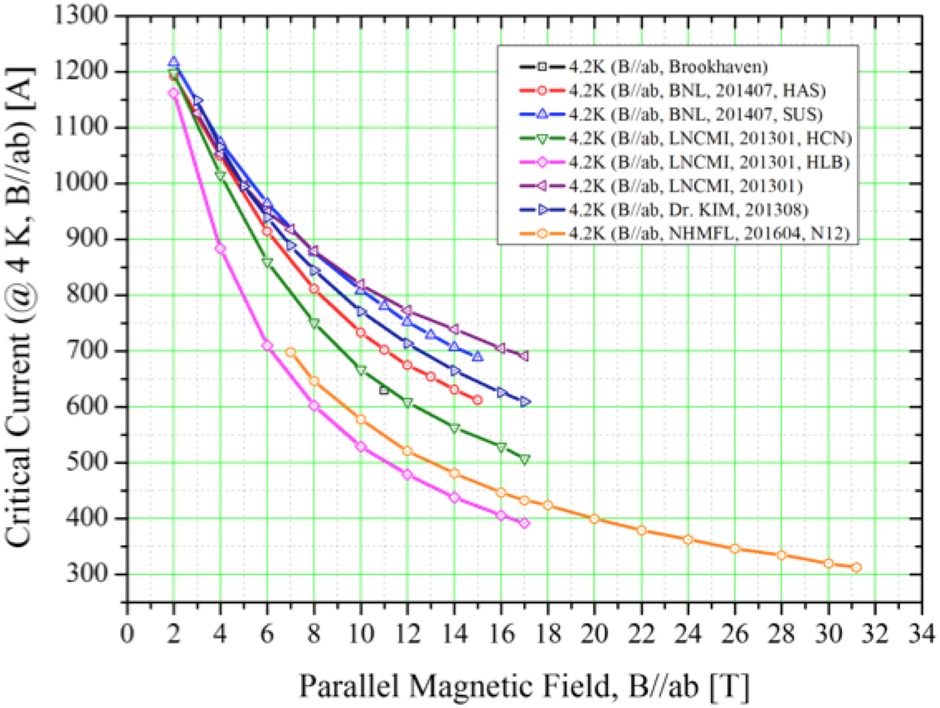
David Larbalestier, 1PL Plenary Talk to the Applied Superconductivity Conference, Denver CO September 5, 2016 39/55

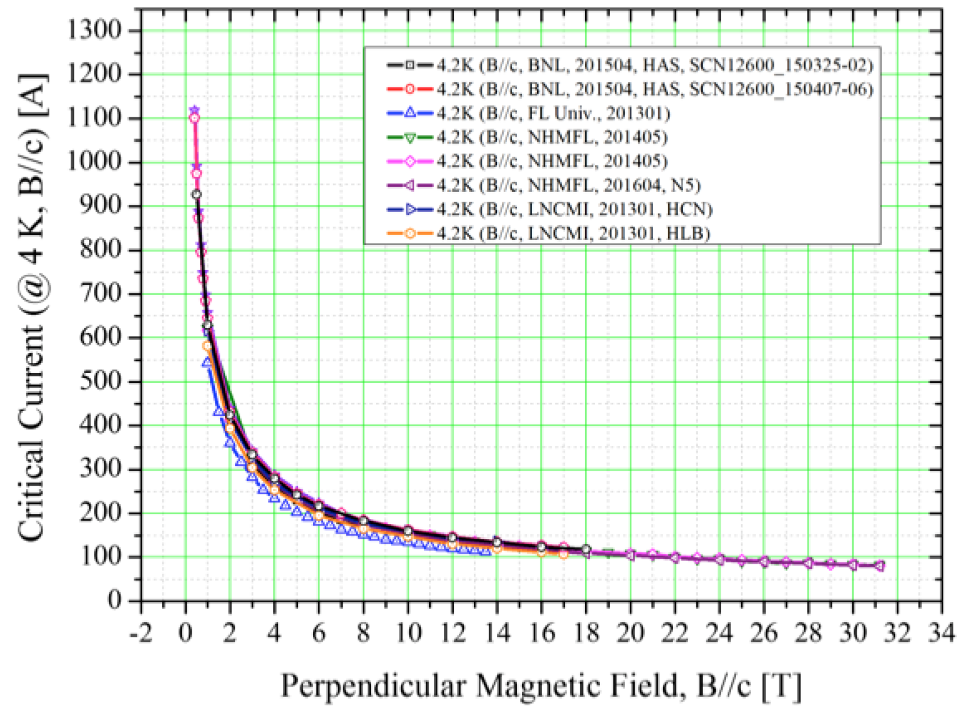
Bruker: Processing up-scaling: 602-609 m long tapes: Tapes have 'mixed' pinning centres

Recent measurements at Tallahassee, Jan 24, 2017, D. Abraimov, D. Larbalestjer



In field properties at 4.2 K upto 31 T (without APC)





- Large variation @ B// ab-plane.
- Homogeneous and small slope at high field(> 15 T) @ B// c.
- All the data were measured with 4 mm width tape.

SuNAM

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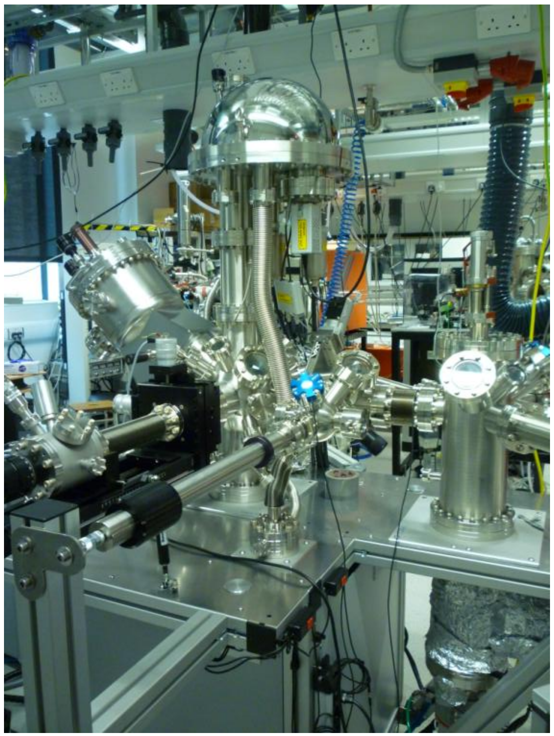
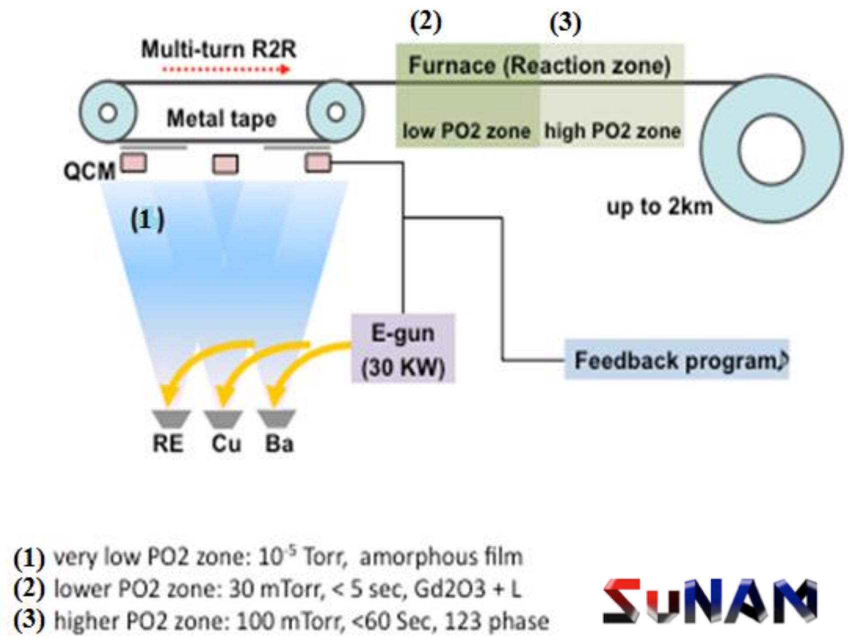
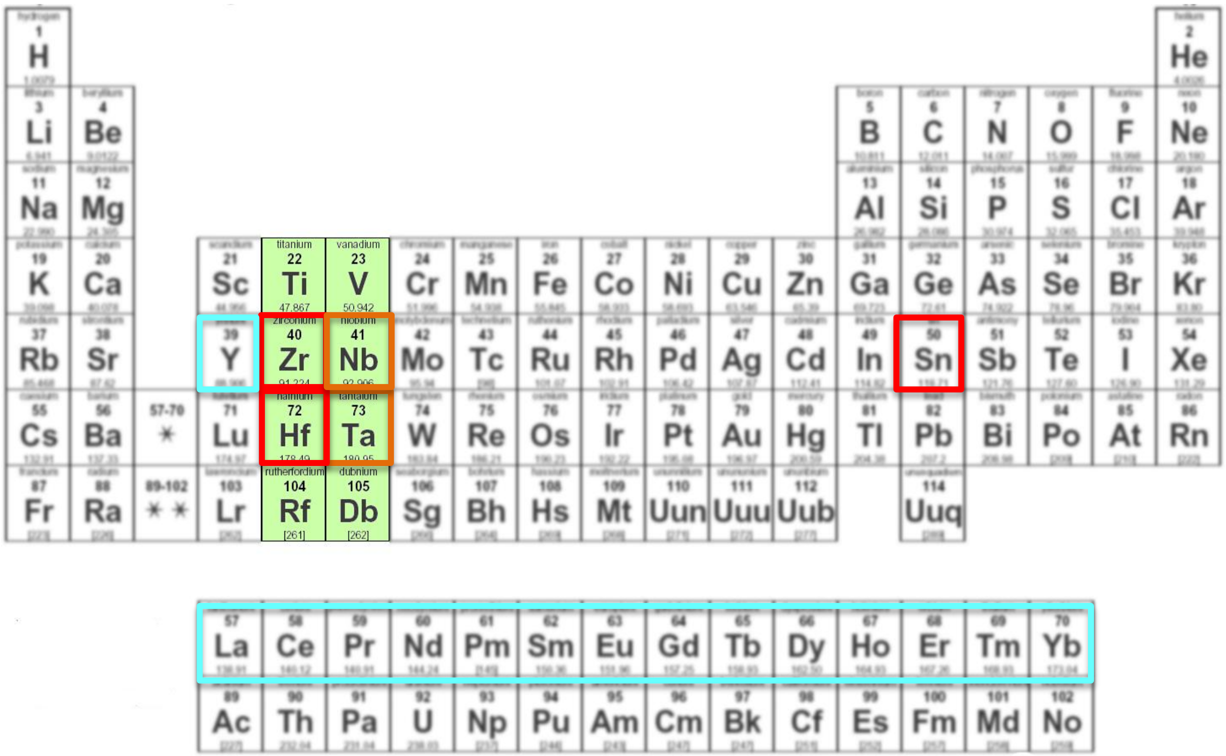
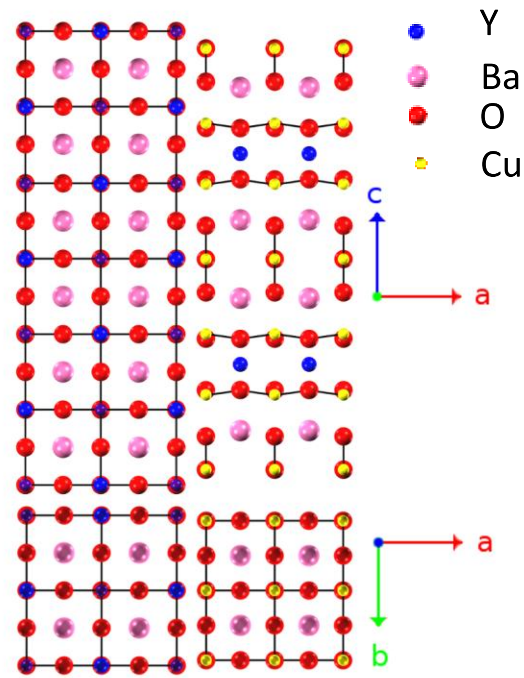
I will discuss pinning developed with PLD but this is applicable also to physical vapour, e.g. e-beam, MOCVD





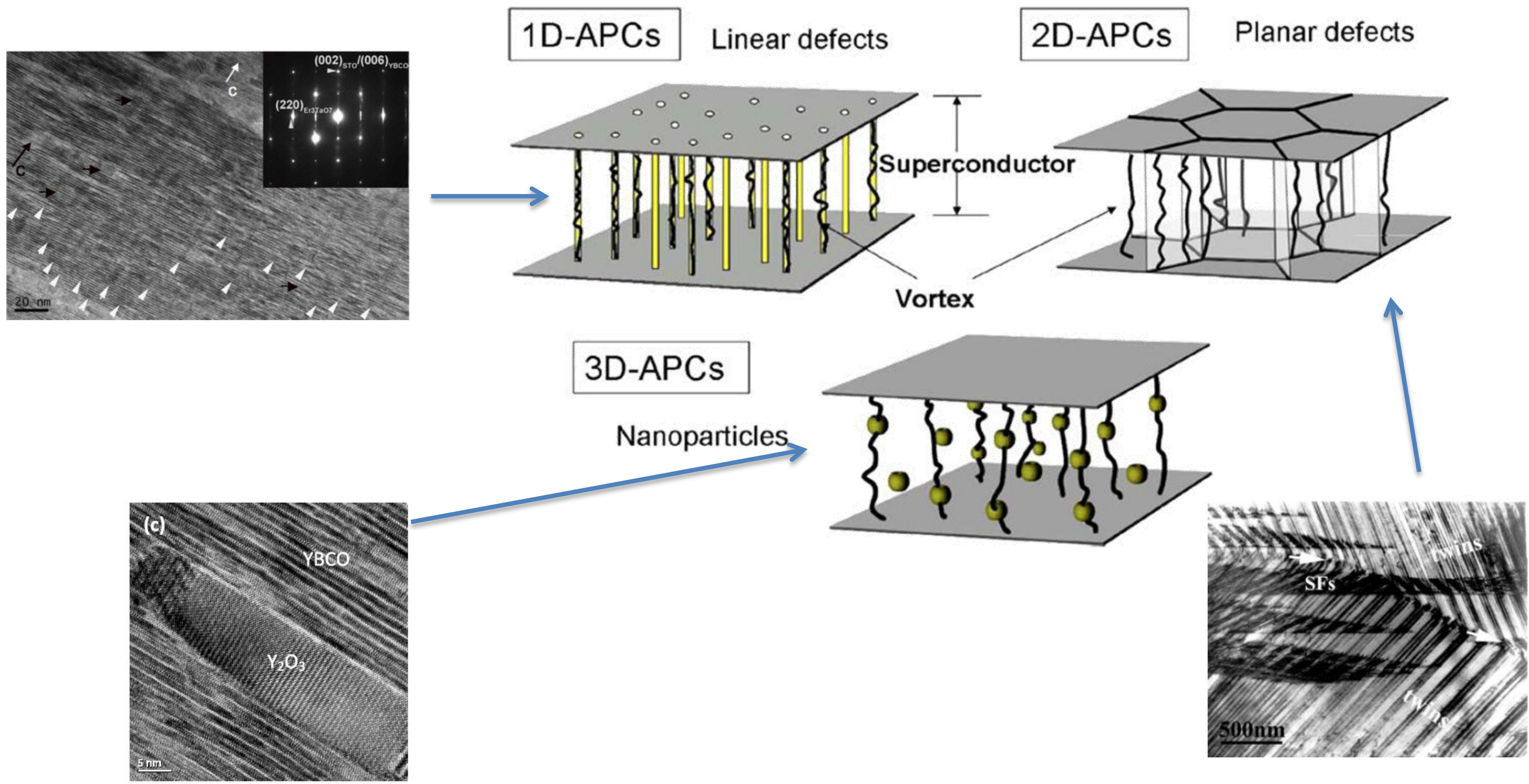
Choosing your pinning additions
(perovskites based on Ba, rare earth oxides)





$Ba(Zr,Hf,Sn)O_3$ $Ba_2Y(Nb,Ta)O_6$ RE_2O_3

The different types of pinning centres in PVD-grown films



H Zhou et al, Sup Sci Tech, Vol 22, 2009
J Gazquez et al, Sup Sci Tech, Vol 25, 2012
Matsumoto et al, IEEE Trans. Appl. Supercon, 19 (3) 2009

Designing the pinning landscape- what's important?

Geometry, distribution, strain with matrix

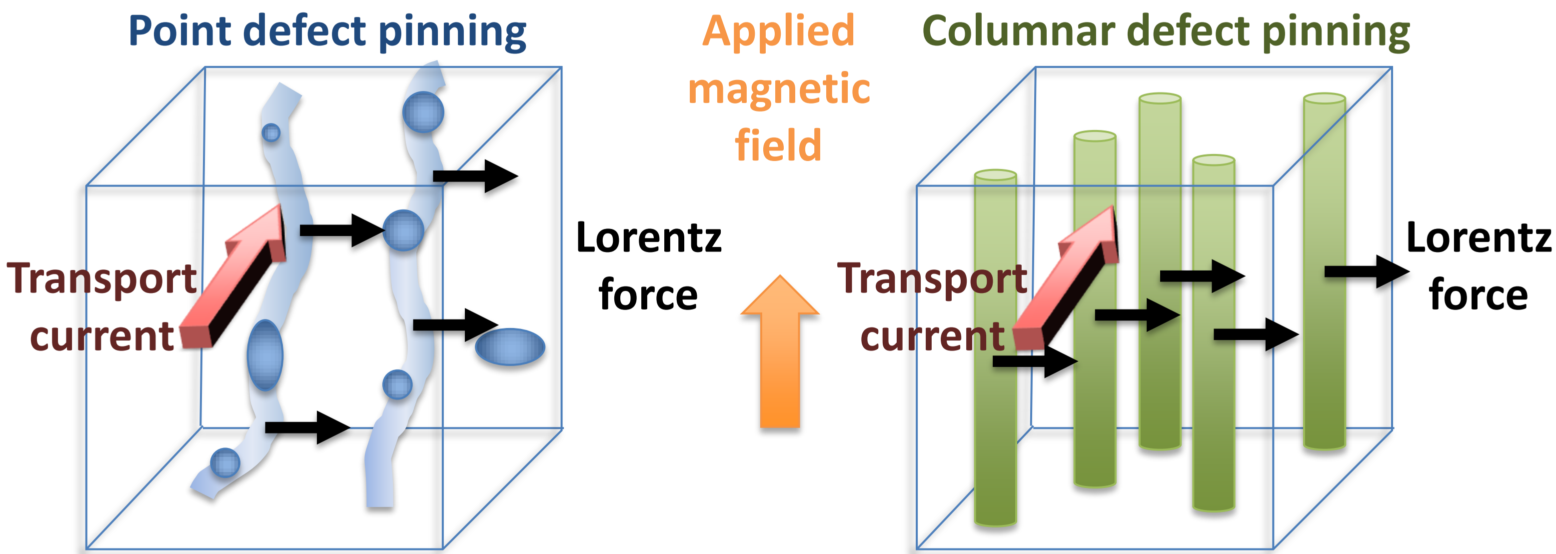
– Chemistry of pinning addition (or combination of additions)

– % addition

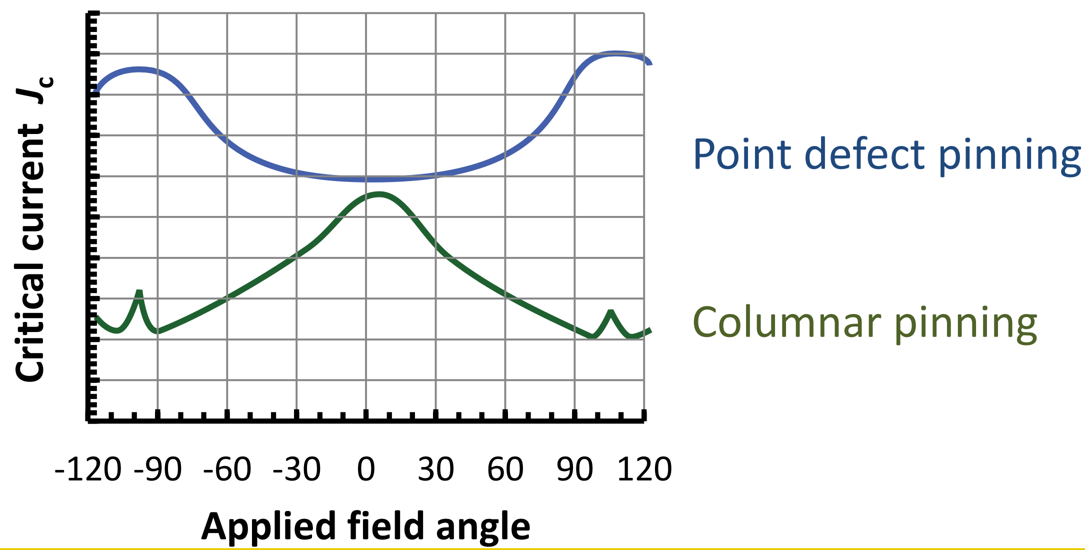
- Q. How do processing conditions (growth method, growth rate, growth temperature) influence above?

- A. Need to understand basic materials chemistry *and* nucleation and growth

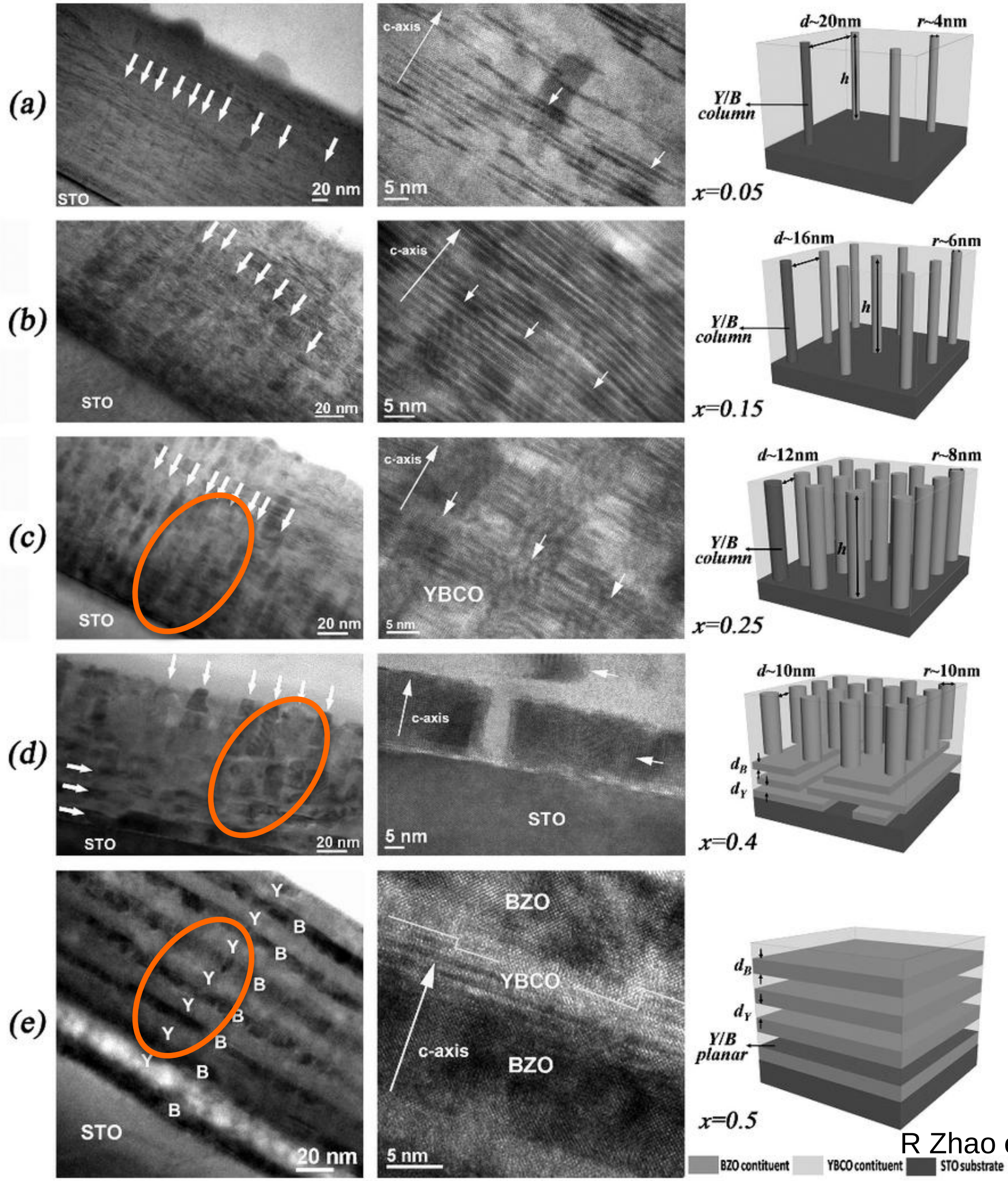
Defect types and how they behave with *H* (~77K)

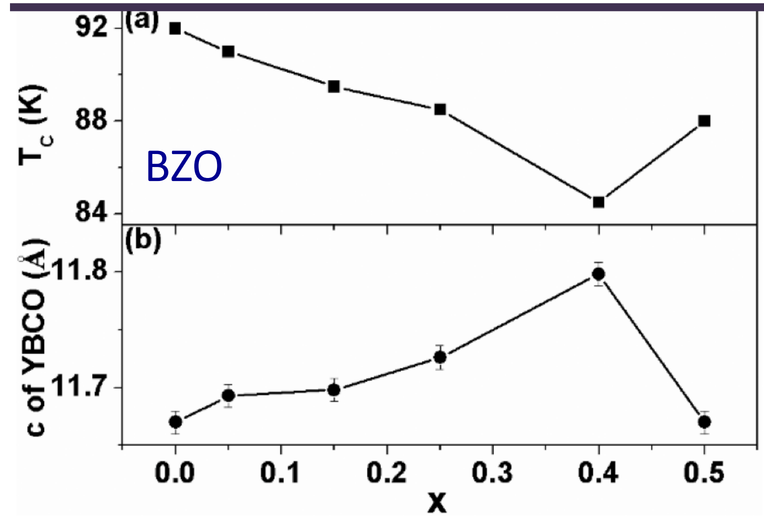


For higher field applications things are different. Point defects very important. Mixed microstructure good for a wide range of temperature and field.



Mixed defect structure can be engineered by playing with thermodynamics and kinetics

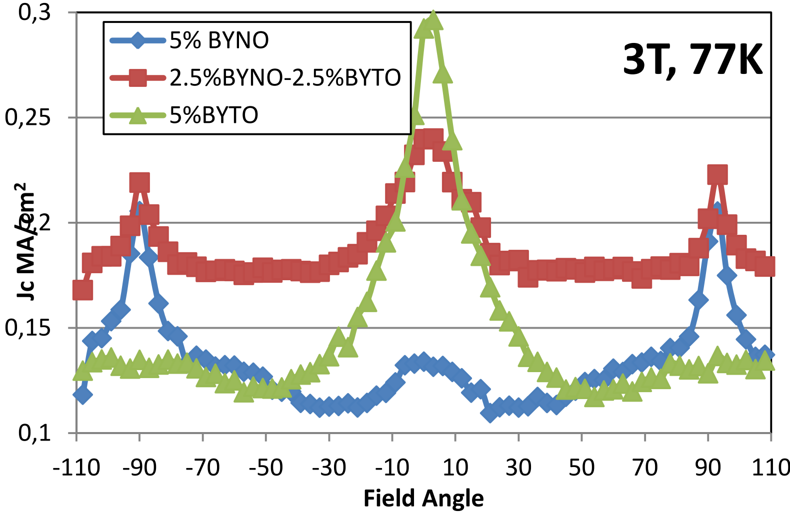




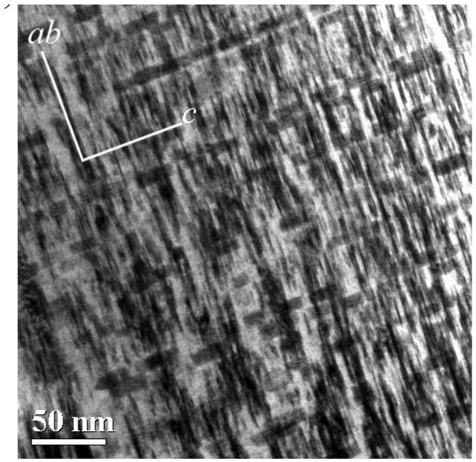
Higher % additions should be very good for higher field, lower temperature applications.

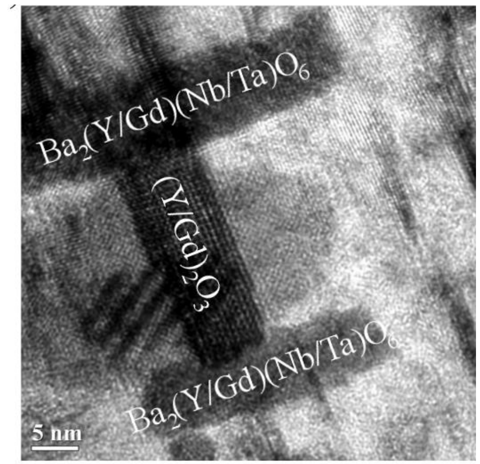
R Zhao et al Advanced Functional Materials. Vol. 33. 5240, 2014
Y Zhu et al, J Mater Res, Vol 27, No 13, 2012
C.V. Varanasi et al, J Mater Res, Vol 23, No 12, 2008

At 77K, BYNO and BYTO columns + RE_2O_3 gives superior angular properties over a wide angular range



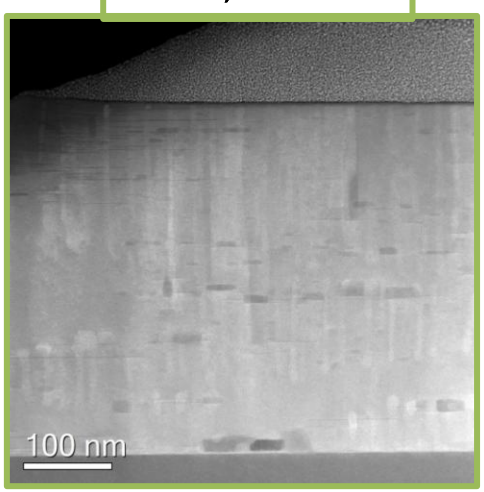
$Ba_2Y(Nb,Ta)O_6$



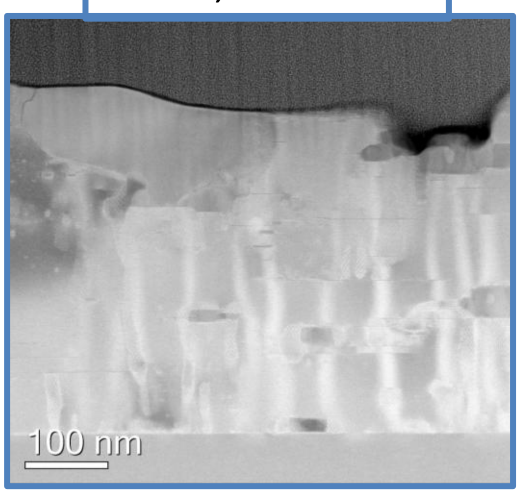


G. Ercolano et al. Superconductor Science & Technology. Sep 2011;24(9)

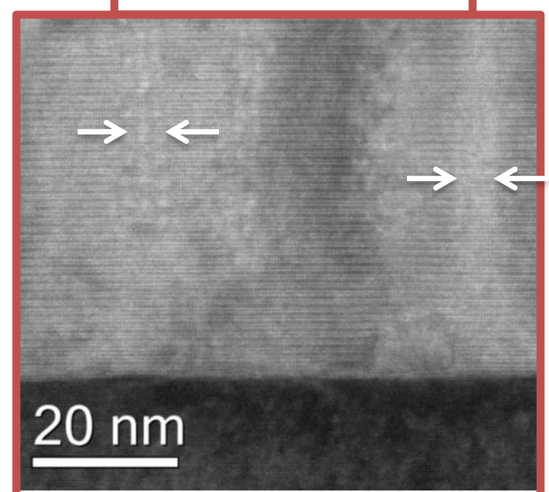
BYTO, 5 nm



BYNO, 10-20 nm



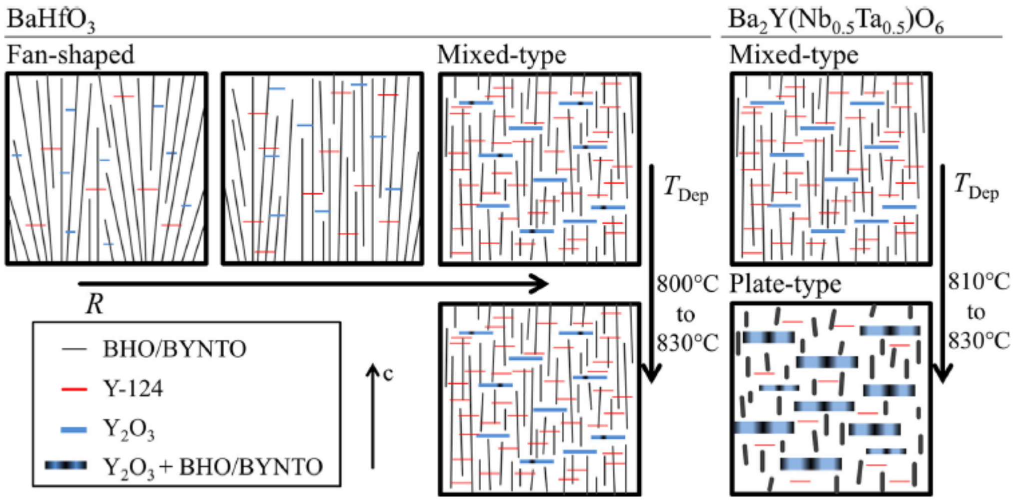
BYNTO, ~ 8 nm



A. Melendin, S. van Tendeloo, UA

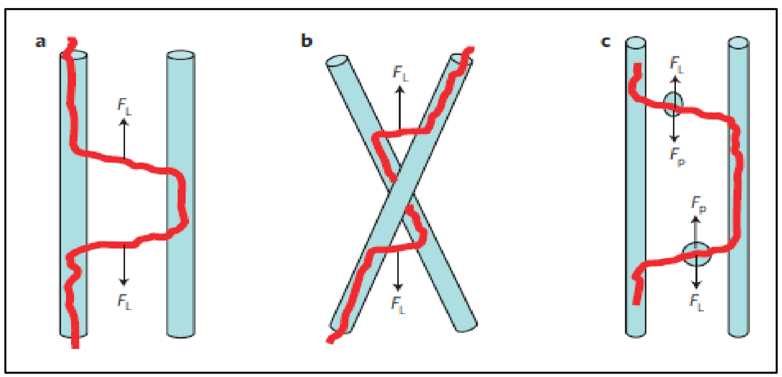
Good control of variety of pinning nanostructures for 77K optimisation on metal

ENEA, UCAM, KIT

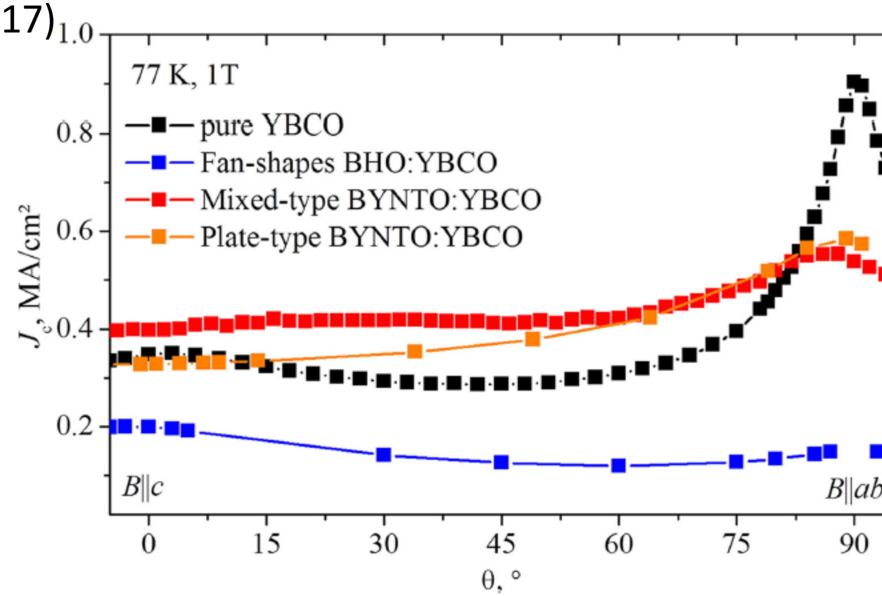


M Sieger et al, IEEE Tran. Appl. Supercon. 27,4, (2017)

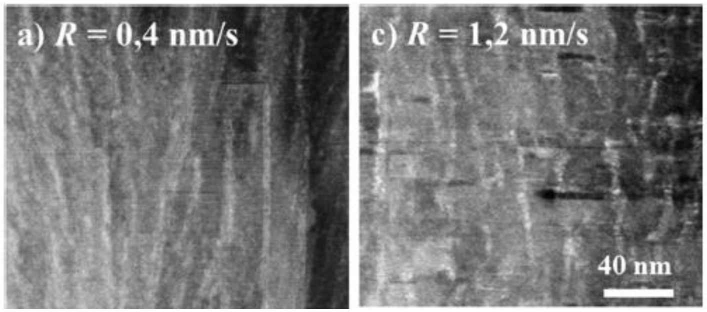
Control shape/distribution by changing deposition rate and temperature (on ABAD YSZ), > 1 μm thickness



B Maiorov et al, Nat. Mat. (8) (2009)

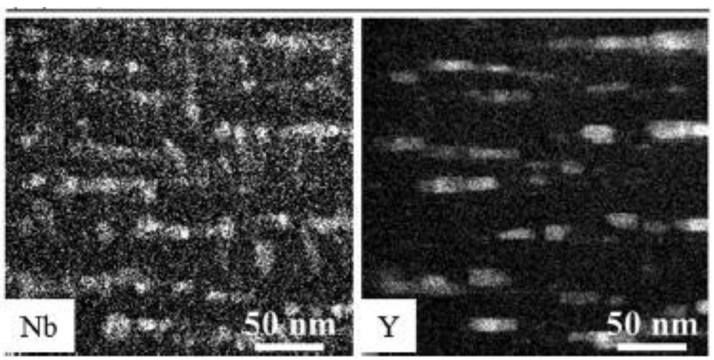


Good control of variety of pinning nanostructures for 77K optimisation

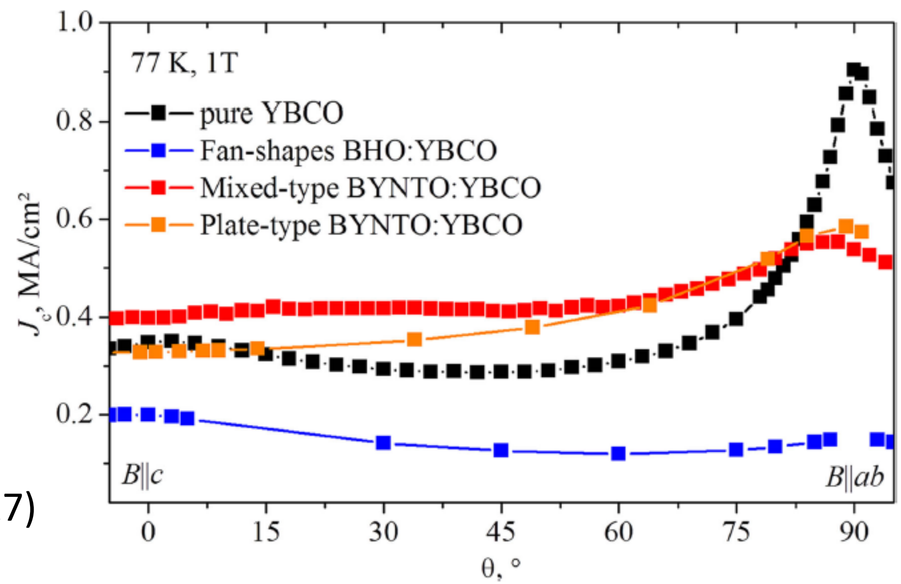


Splayed columns

Mixed columns and plates



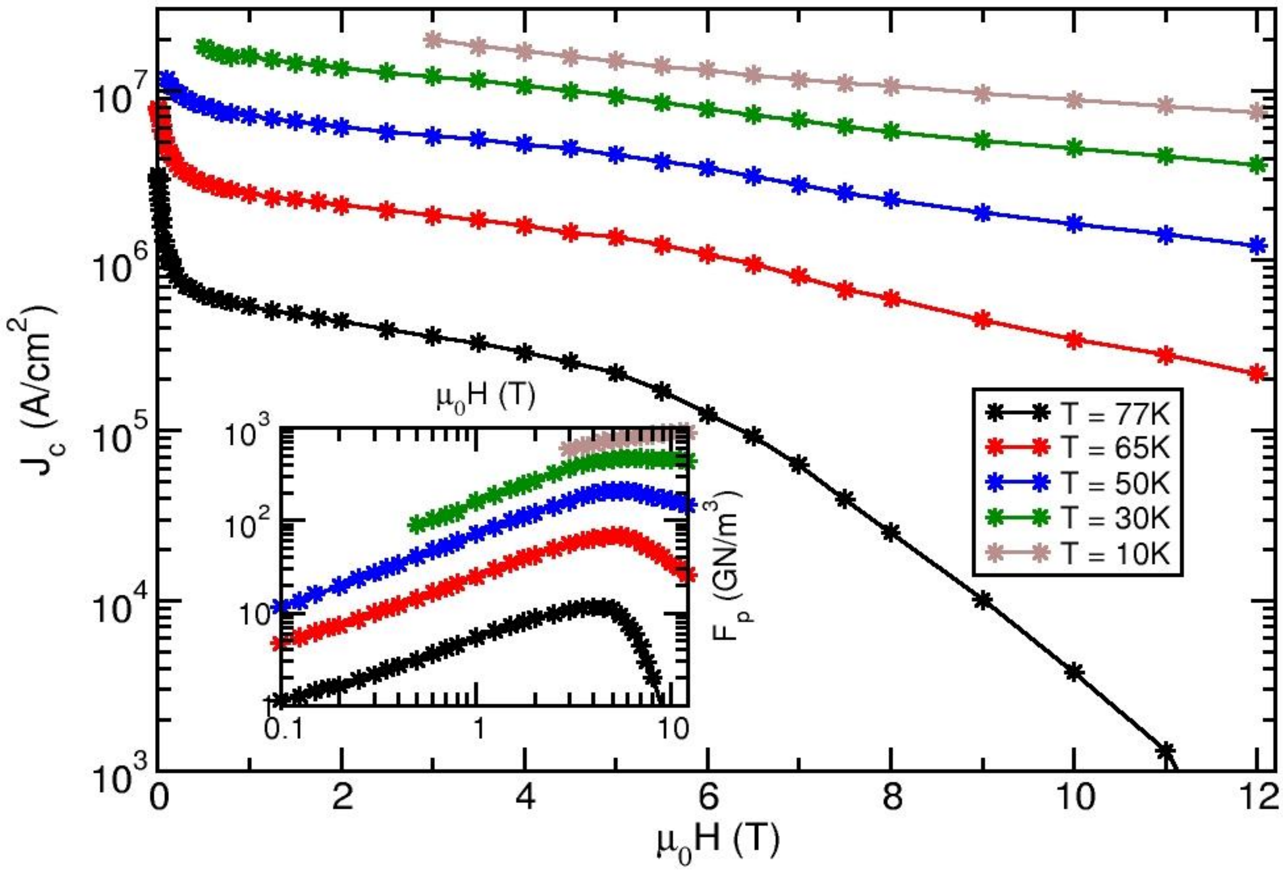
Plates



M Sieger et al, IEEE Tran. Appl. Supercon. 27,4, (2017)

BYNTO behaves very well over a wide field regime. Up to 10K, 12T, the data looks very good, but still not studied at very high fields or 4K

500 nm thick films



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F. Rizzo er al., under review 2017

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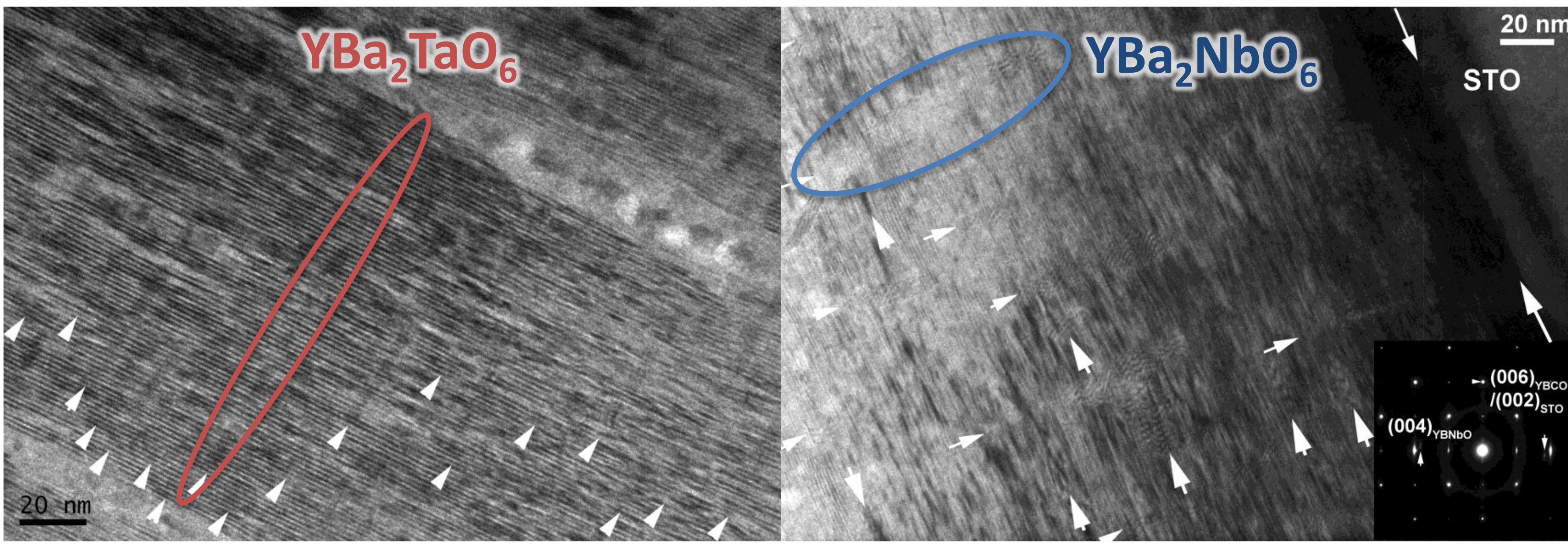
Kinetics of pinning addition growth most important for dimensional control.
4 important factors: Binary oxide m.p., complexity of phase, % addition, whether source is in film

Comparing Nb, Sn, Ta, Zr which form the perovskite pinning centres:

Lattice parameters similar (4.20-4.22 Å) as are ionic radiil (Nb being smallest (0.64 Å).

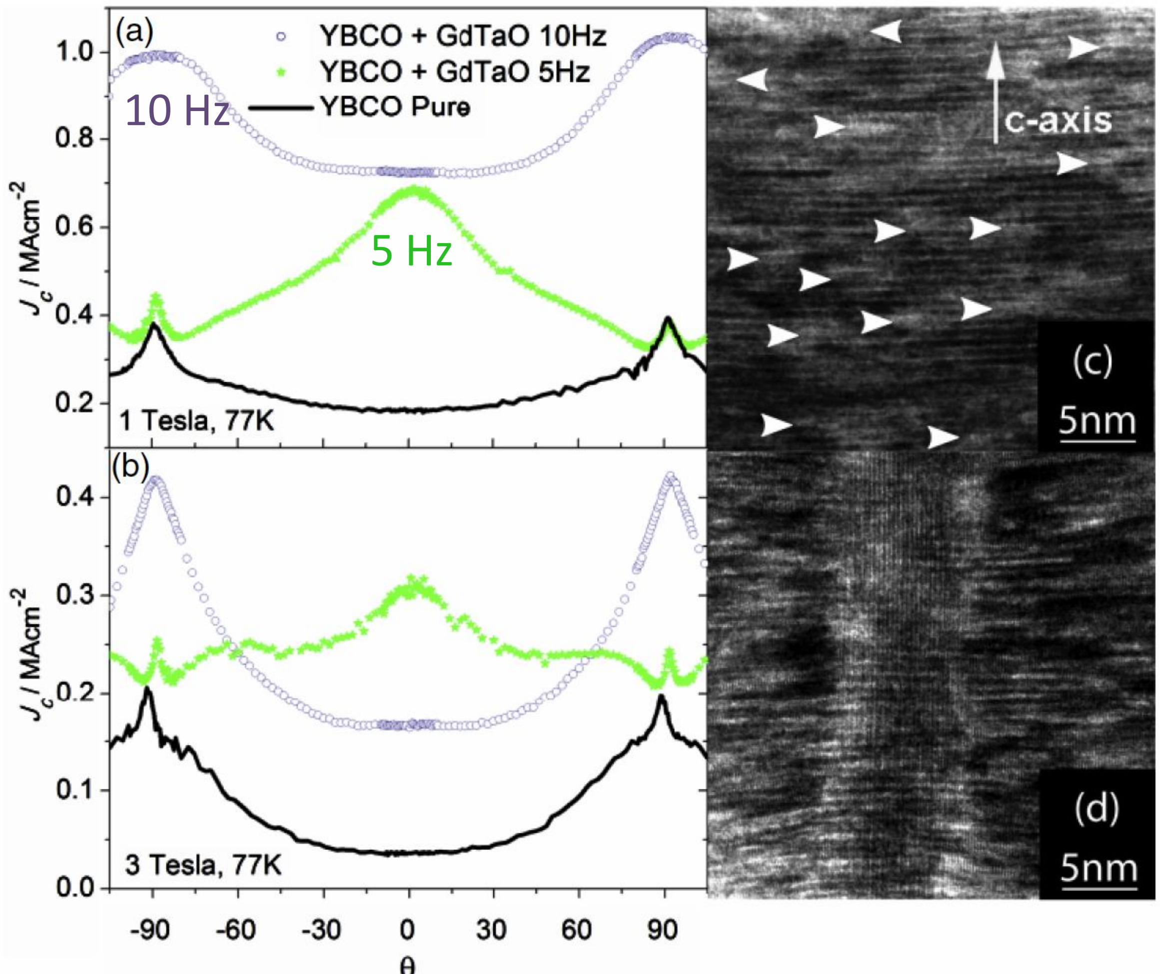
Melting points (°C): **Nb**2O5= 1512C , **Sn**O2 =1630C, **Ta**2O5 =1872C , **Zr**O2 = 2715C

Tantalate is the finest, since creating DP rather than SP is kinetically limiting.



For very high fields, we need dense, very fine, random NP

Tantalates ideal as m.p. of Ta_2O_5 high and DP ("poor kinetics") → hence low mobility

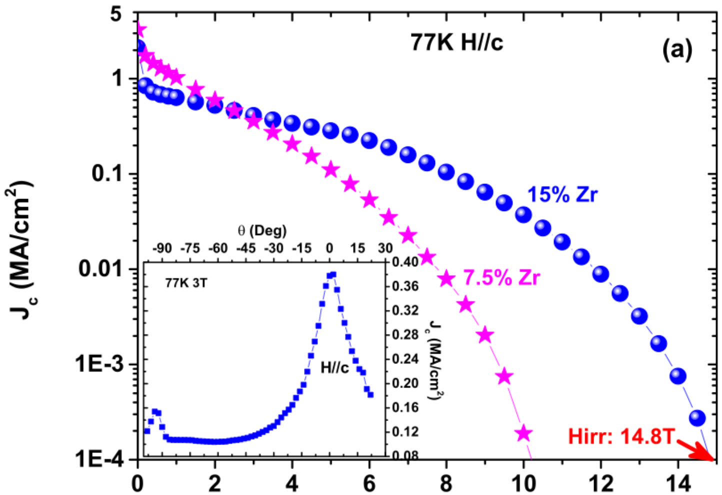


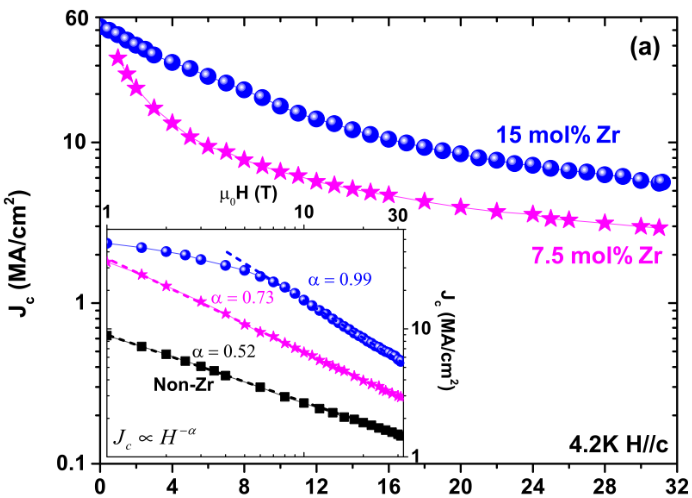
10 Hz: NPs

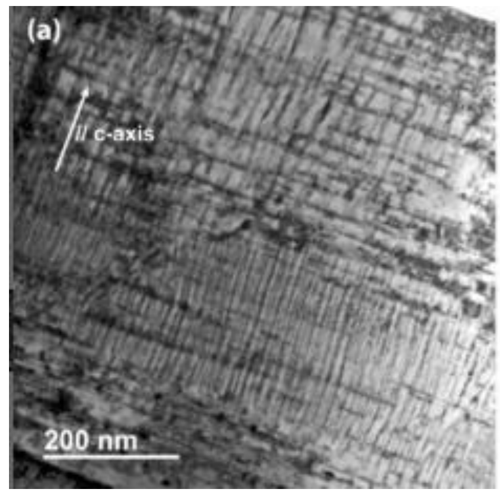
5 Hz: Rods and NPs

S.A. Harrington et al. Nanotechnology 21 (2010) 095604

High levels of Zr work well both for 77K and 4.2K
A lot of other pinning additions should do so as well







Zr addition

↓

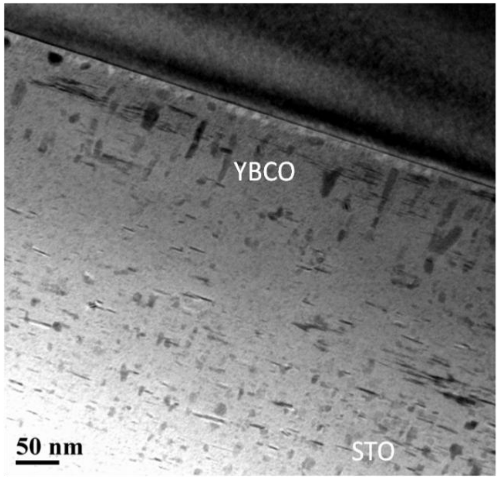
Off stoichiometry

↓

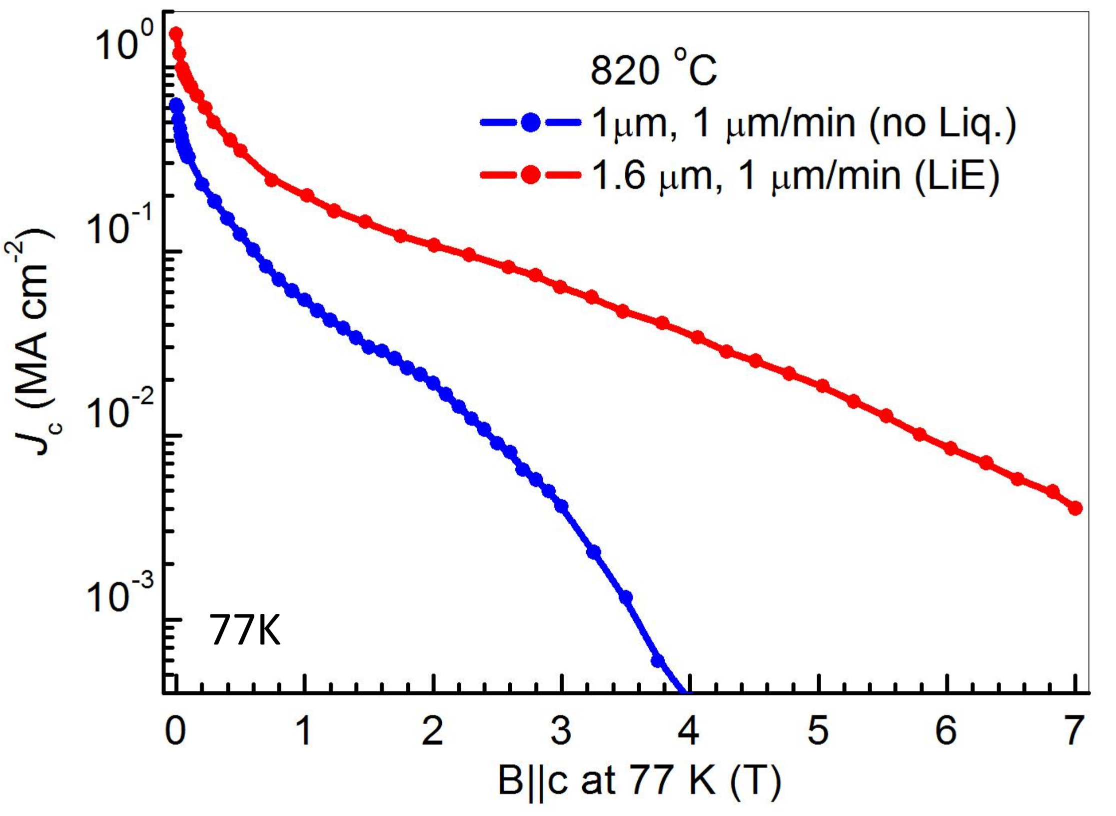
$BaZrO_3$ forms leaving matrix RE_2O_3 and CuO rich

Xu et al. APL Materials 2 04611 (2014)

Finally: **Cost of conductor very important**. **Need fast-grown conductors.** This can be done with liquid additions while still maintaining strong pinning



BYNO + liquid-in-epitaxy (LiE) processed YBCO. Good 77K performance at very high growth rates (1 μm/min)



BYNO still self assembles in presence of liquid at very fast growth. An *additional* 'poor kinetics' phase needed for high field, low T

Next stages

Much work to be done for low T, high field applications. Most work has been done for 77K, but the regimes are very different.

- Pinning centre size and distribution influenced by their chemistry.

- Mix of random and correlated is good for most regimes of field and temperature below 77K and at high fields.

- Very fine nanostructures needed. This means high melting point binary precursors of the perovskite B-site ion. Otherwise, you need to grow too fast and that is detrimental to YBCO crystallinity.

- High performance, cost-effective conductors are essential. Strong pinning and reduced cost by fast liquid growth should be considered *together*.