IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2013
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

High current superconductors: overcoming the materials challenges to achieve power applications

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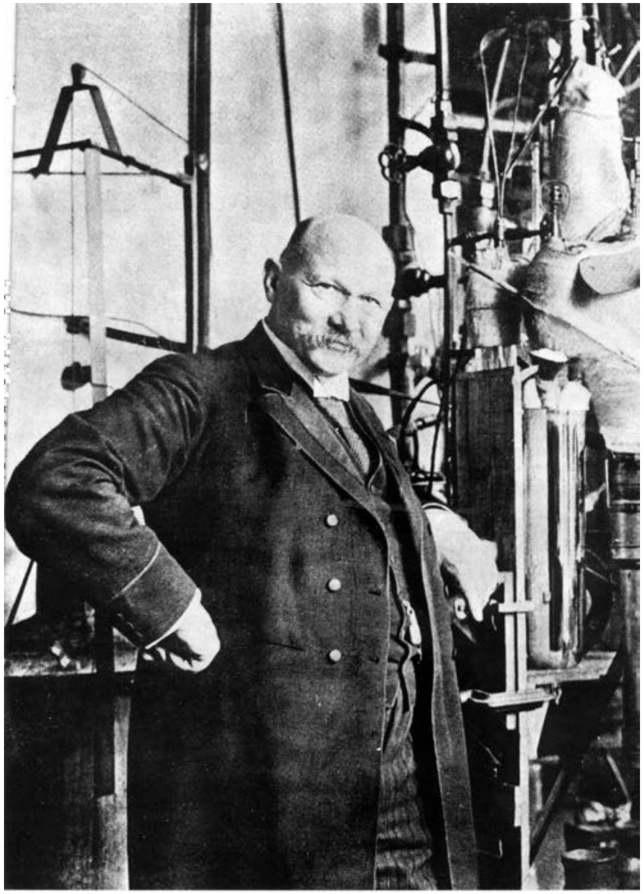
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

ICMAB

CSIC

> 100 years of superconductivity



K. Onnes (1911)

I have a dream!

- Electricity transport at long distances without losses
- Generate high magnetic fields (10 T at that time). Can we jump to the 40 – 50 T magnets?
- Massive electrical energy storage ?

Are we close to Onne's dreams?

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

A new electrical energy paradigm

The Energy Future: new paradigm

- Change in Energy Production
- Increase in Electricity Generation
- Increase in Renewables

Will result in

- More energy exchange and transport
- More energy storage
- More flexible generation
- Demand for new solutions

What could be the benefit, the application and the future of HTS energy applications?

Is superconductivity a solution to a problem? Are we ready?

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Superconductivity: a timely opportunity?

- Where our electrical system requires the use of superconductivity ?

- Real advantages versus other technologies? Where are we essential?

- Are we ready?. Right materials and a reliable engineering?

- What can we achieve with the existing materials and technologies? How far are we from the required cost / performance ratio?

- Do we still need new materials? What performances would make real breakthroughs?

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

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HTS in power engineering: conventional vs novel systems with new functionalities

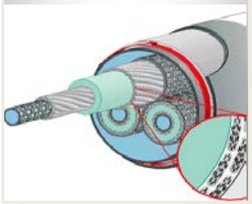
- Highest current densities without (dc) or reduced losses (ac)
- High magnetic fields can be generated

Reduced Weight/Volume → Higher Power Densities
Reduction of Losses → Better Efficiencies

Optimization of Conventional Systems

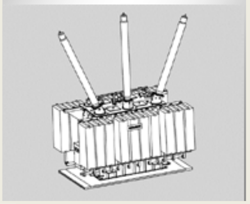
Novel Applications

Cable



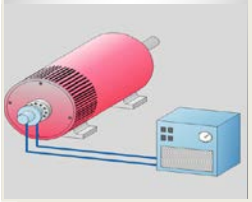
Higher Power Density Retrofit

Trans-former



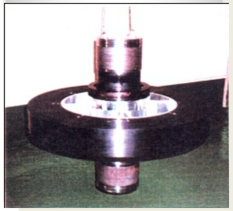
Energy Savings
Life
Safety

Motor Generator



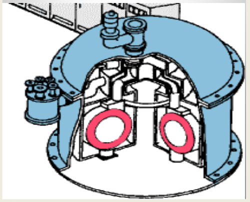
Volume, Weight
Energy Savings

Flywheel



Energy Density
Energy Savings
Safety

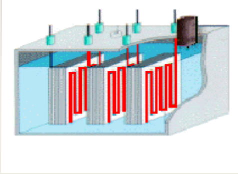
Sc. Magn. Energy Storage (SMES)



Availability
Savings of Ressources

Fault Current Limiter

Siemens



Novel Power Grids
Savings of Ressources
Power Quality

Courtesy of H.C. Freyhardt

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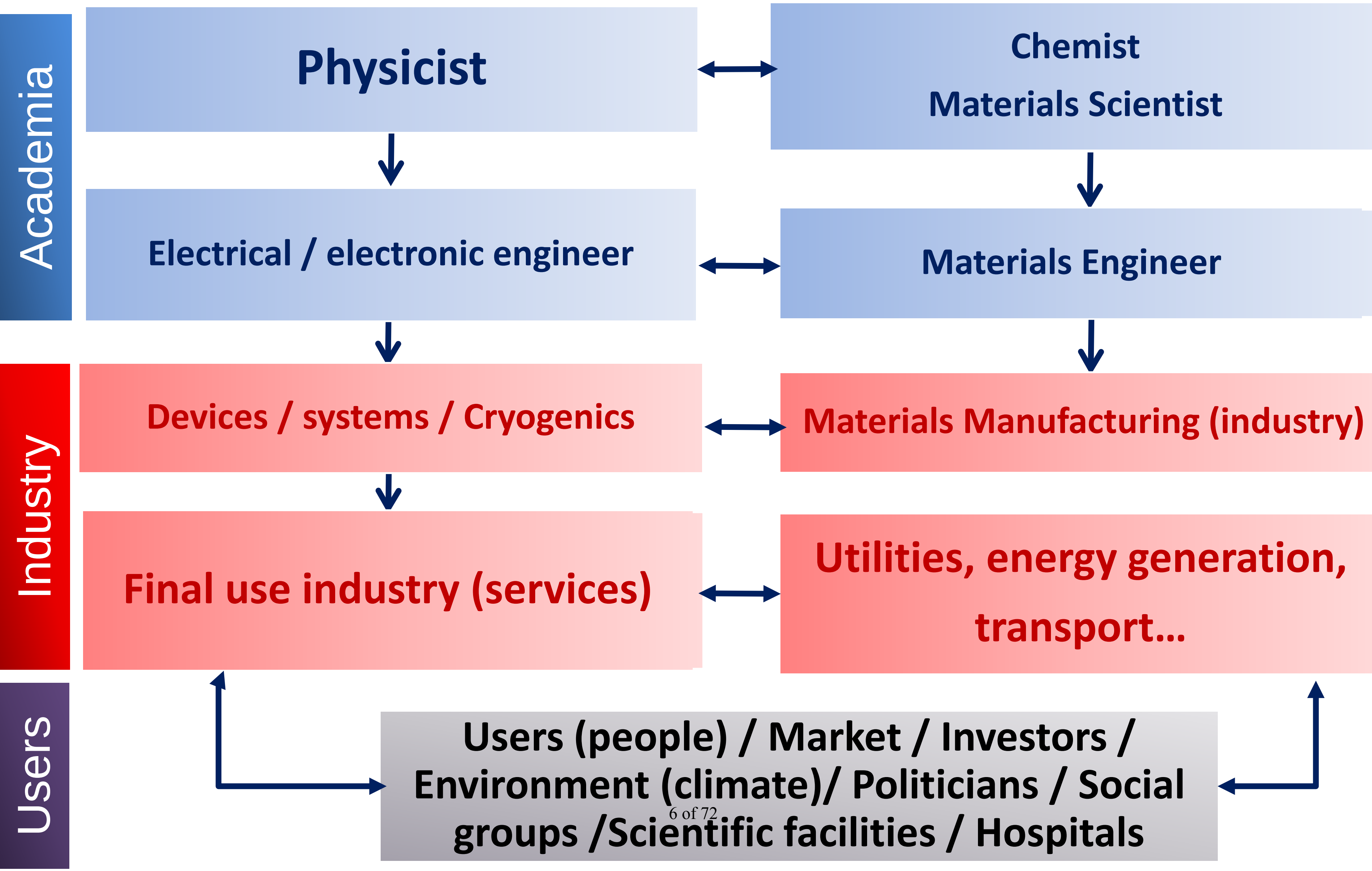
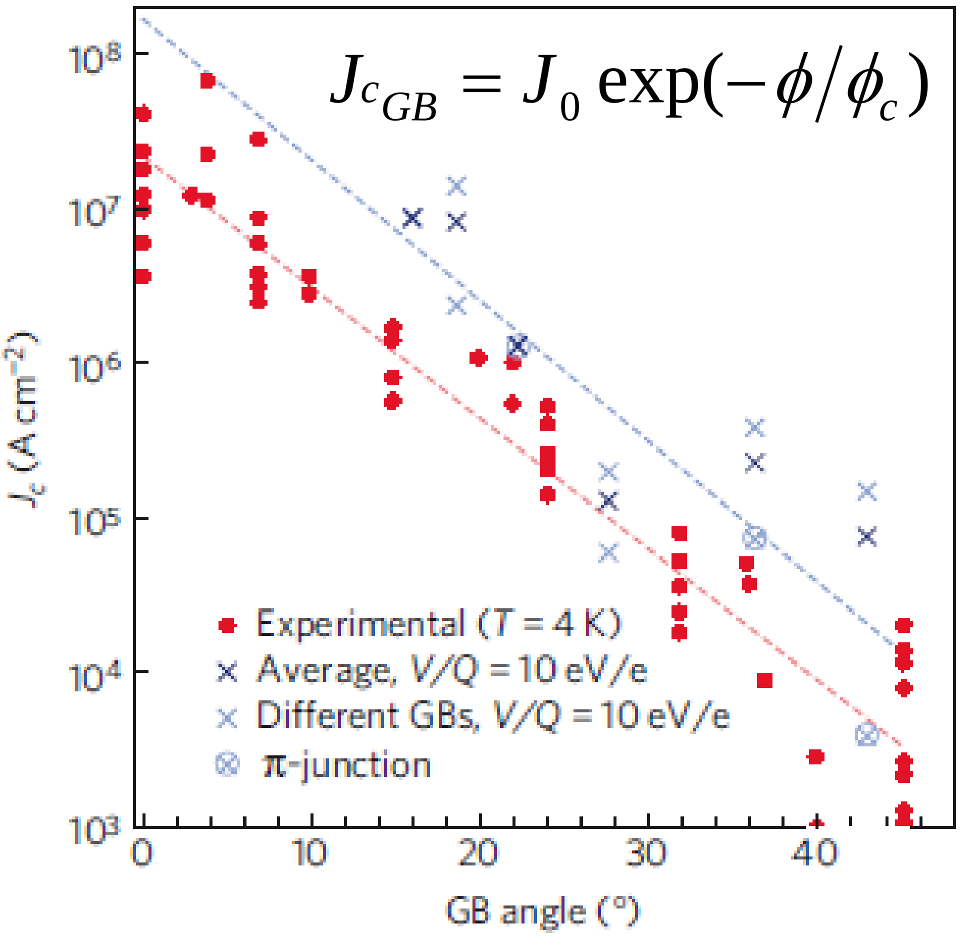
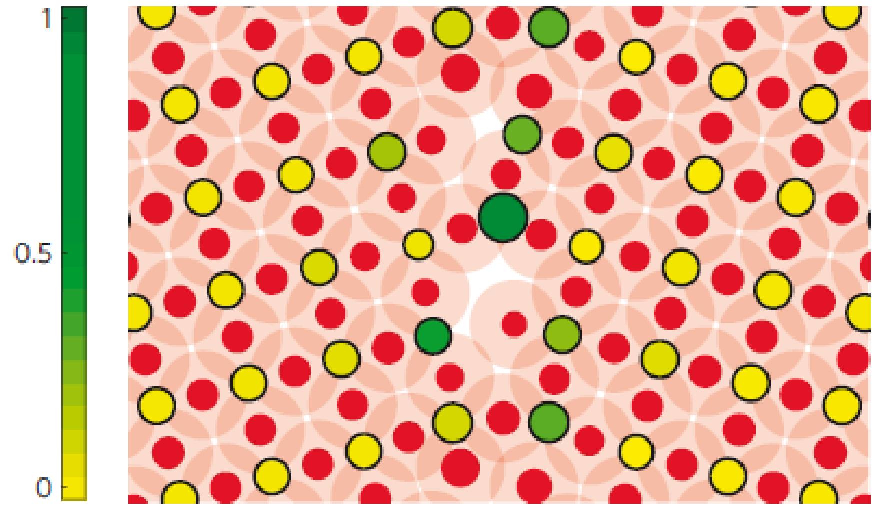
The long and winding road: from discovery to applications



Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

HTS main issues: grain boundary problem





Charge imbalance at the GB depresses J_c at the interface (t – J model calculations)

- **Charging of CuO_4 squares: screening length similar to interatomic distances**
- **Supercurrents flow through regions between distorted regions**
- **Conductors rely on current percolation through grain boundaries**

S. Graser, P.J. Hirschfeld, et al, Nature Physics 6, 609 (2010)
F. A. Wolf et al, Phys. Rev. Lett. 108,117002(2012)

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2013
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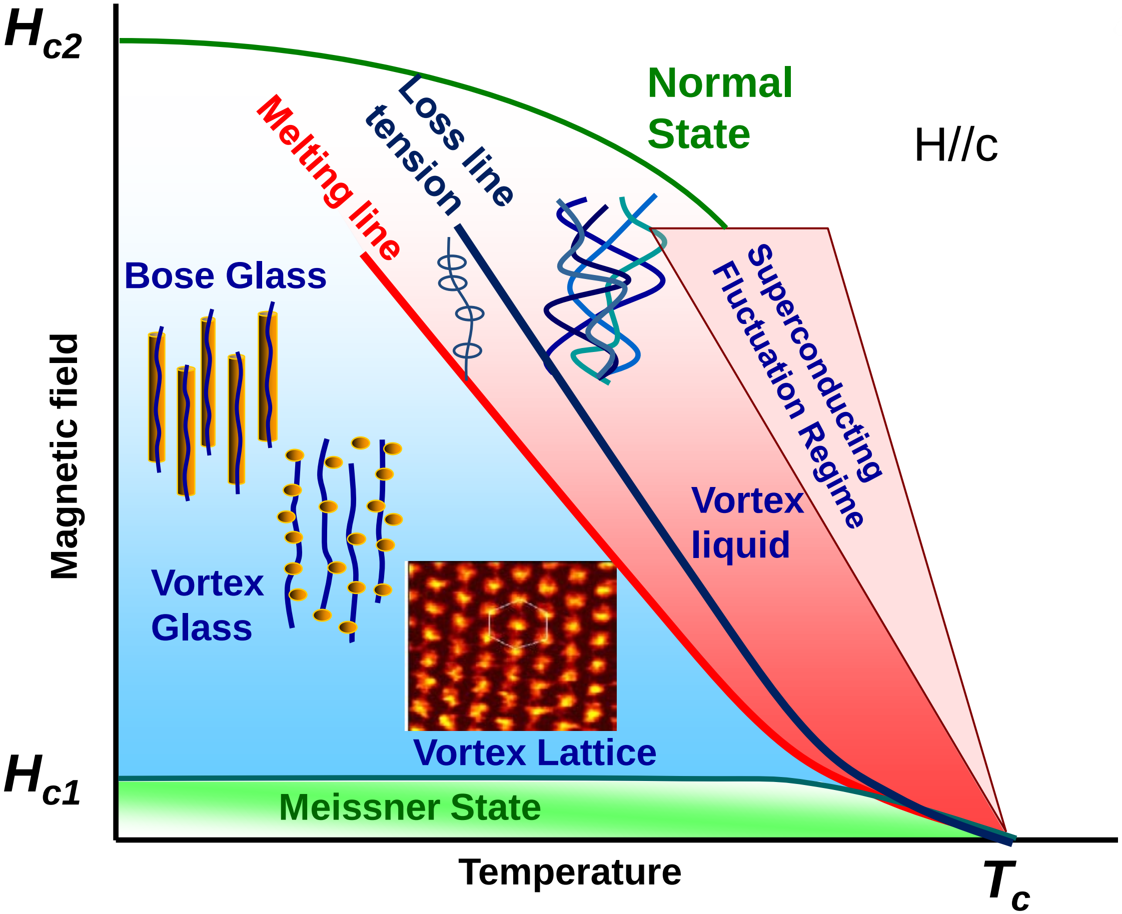
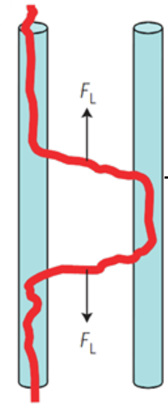
HTS main issues: vortex physics

Control of vortex motion → Nanometric defects ~ ξ (nm)

Intrinsic upper limit of Irreversibility line: loss of vortex line tension





Double Kink excitation

$$U(T,H) = A\frac{\Phi_o^2}{4\pi^2}\frac{\gamma}{\kappa}\frac{1}{\lambda_{ab}}\left(\frac{H_{c2}(T)-H}{H_{c2}(T)}\right)$$

Energy cost of deformation at different H

$$U(T,H) \approx kT$$

Maximal excitation of a bulge

YBCO: T=77K : H_l H 1.5 H_m ~ 14 T

$$H_l(T) = H_{c2}(T)\left[1-(g/A)t(1-t)^{-1/2}\right]$$

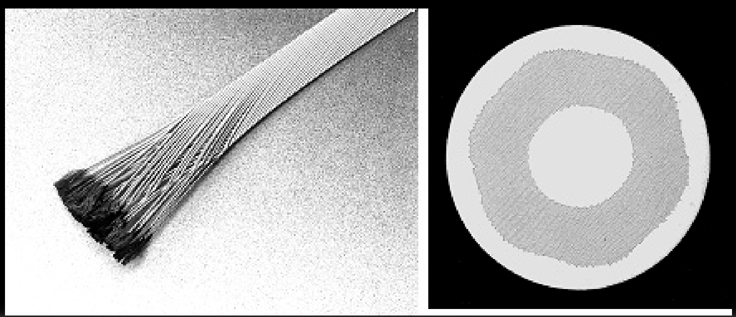
J. Figueras, X. Obradors et al., Nature Physics 2, 402 (2006)

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Superconducting Wires & Tapes

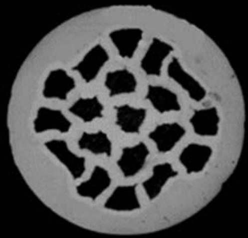
Metallic

NbTi (Nb_3Sn etc.)



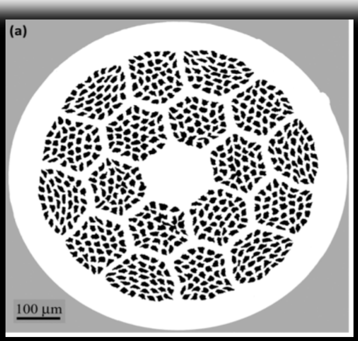
Metallic

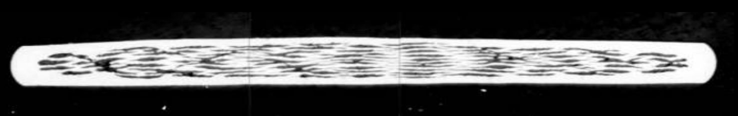
MgB_2 / Fe based



Oxide

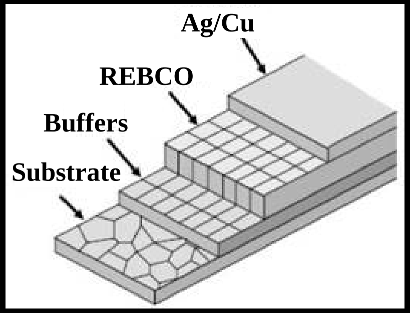
Bi2223
Bi2212





Oxide

YBCO

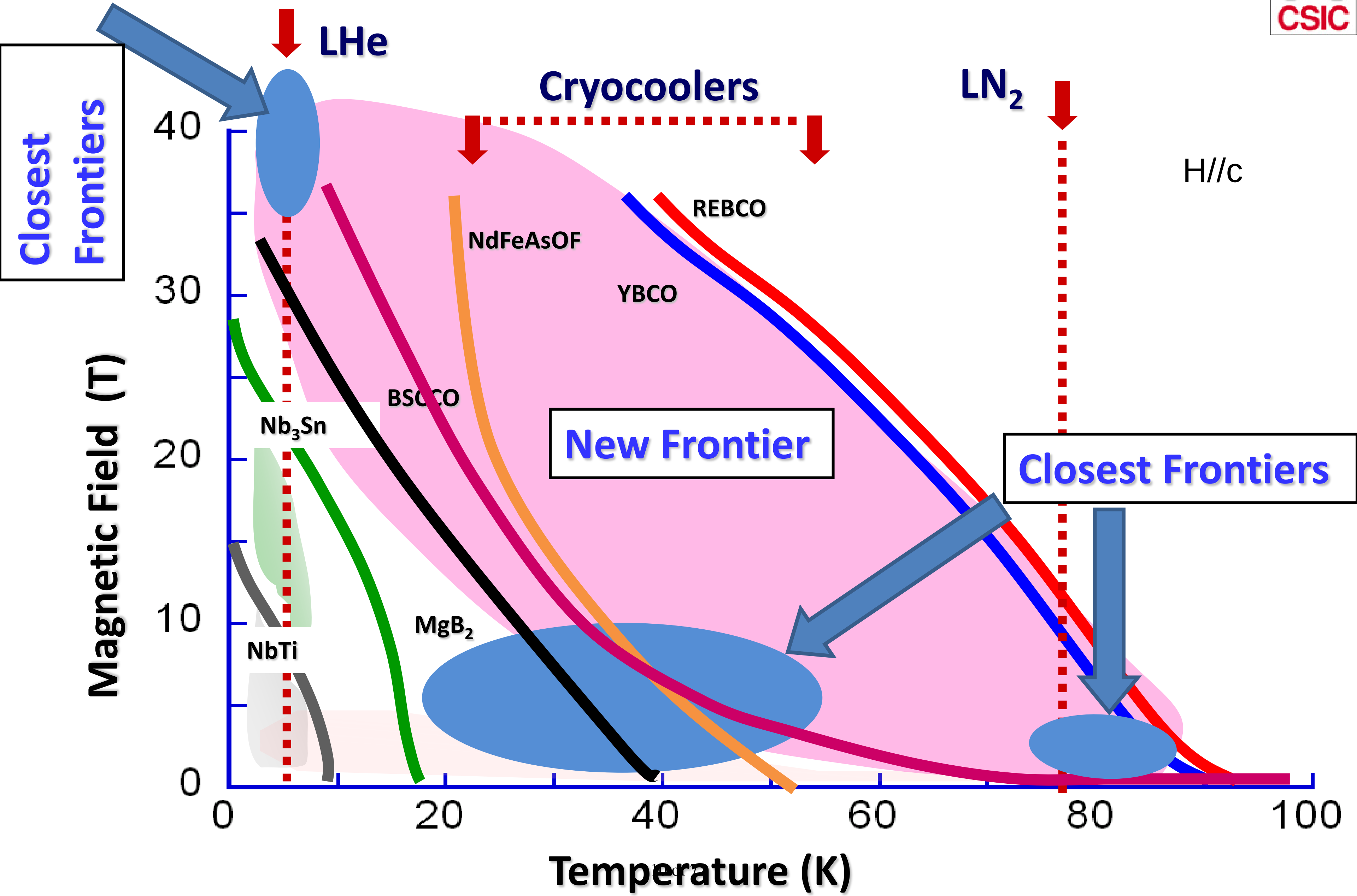


Only a few materials allows wire manufacturing !

Courtesy of T. Izumi

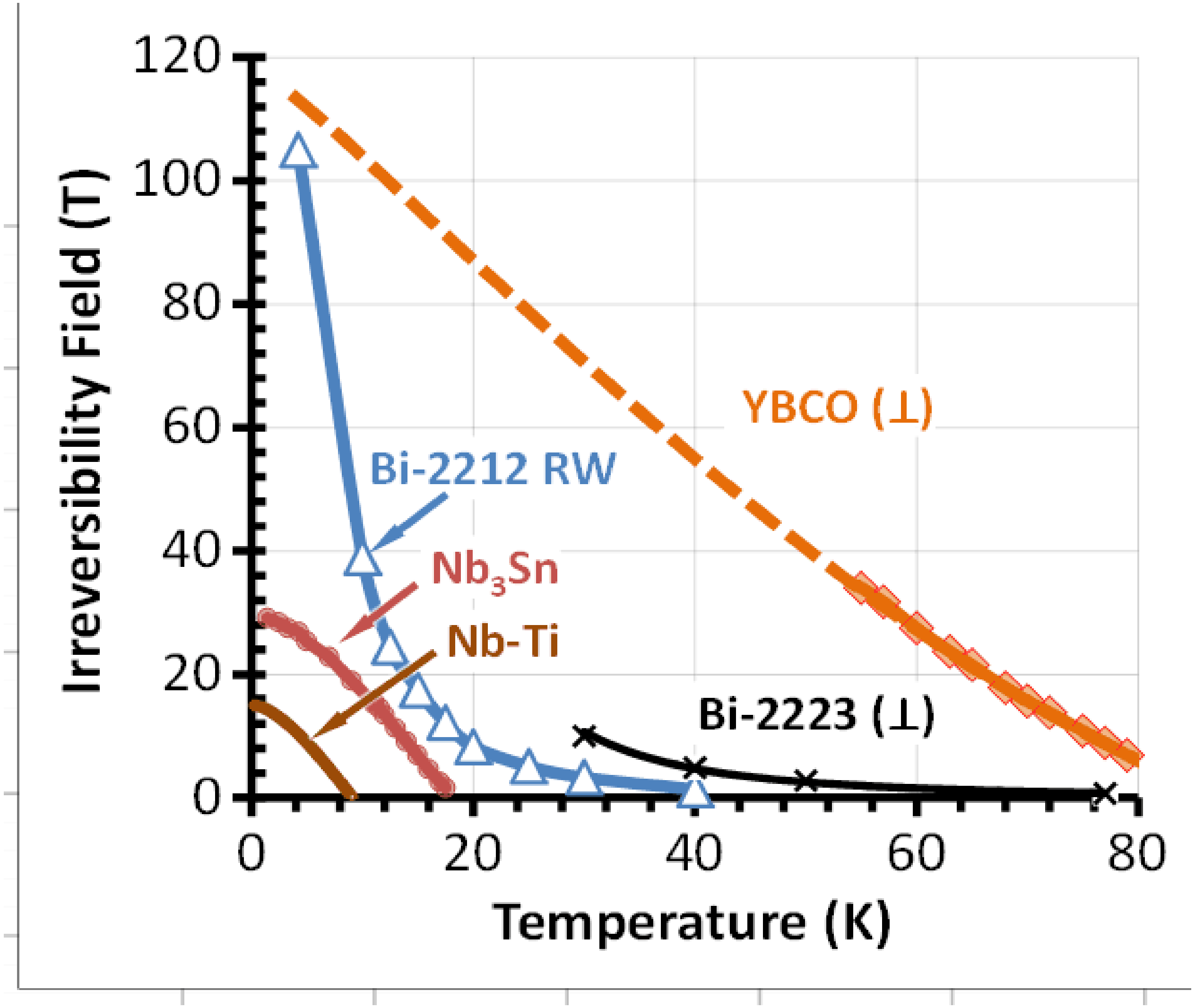
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

New frontiers for applications



Adapted from M. Matsumoto

Conductors at ultrahigh fields and low temperatures



4.2 K

Several HTS conductors can be suitable for ultrahigh field magnets

YBCO has the highest J_c

Bi2212 round wire is also very appealing

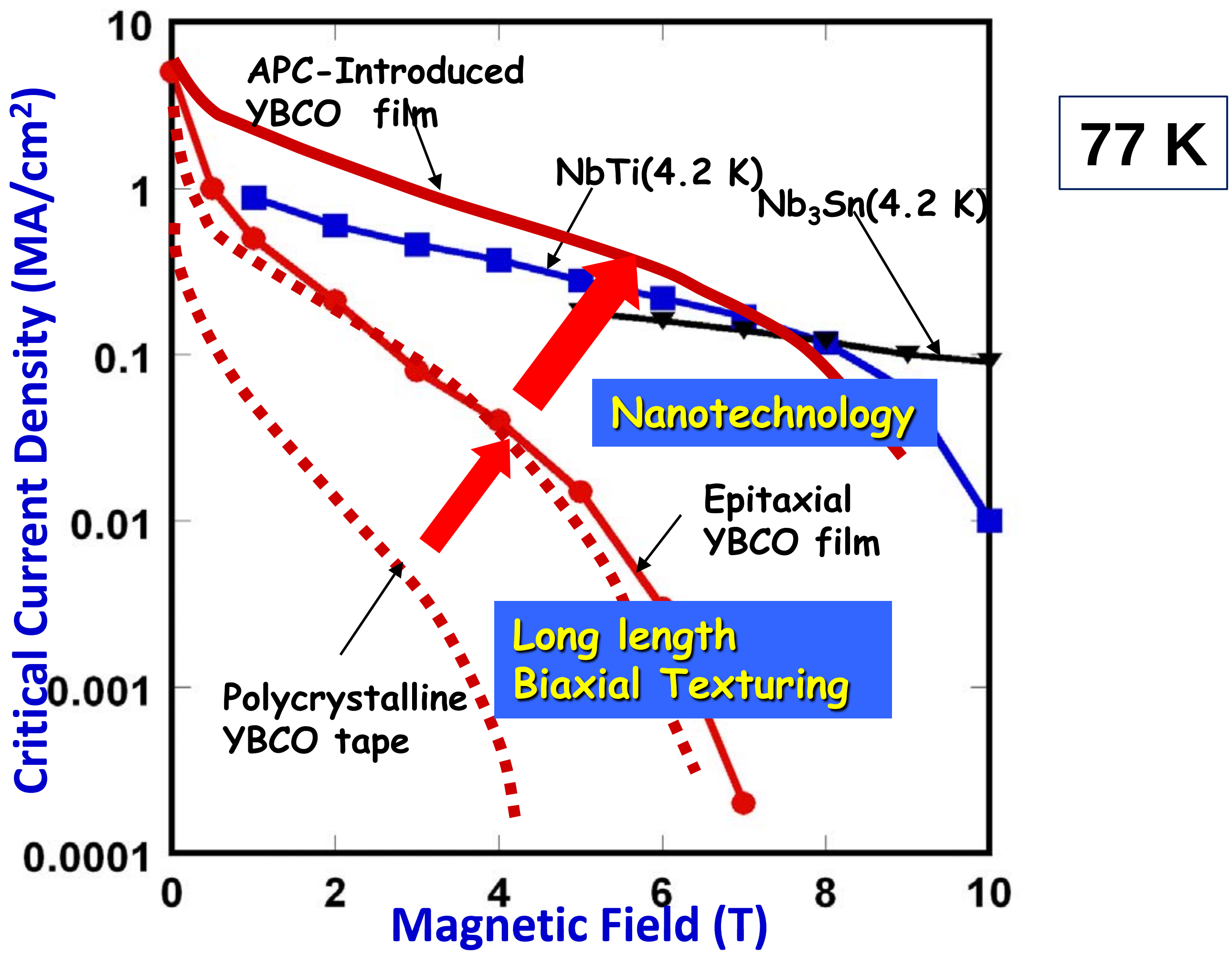
32 T magnet at Tallahassee

Courtesy of D. Larbalestier

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

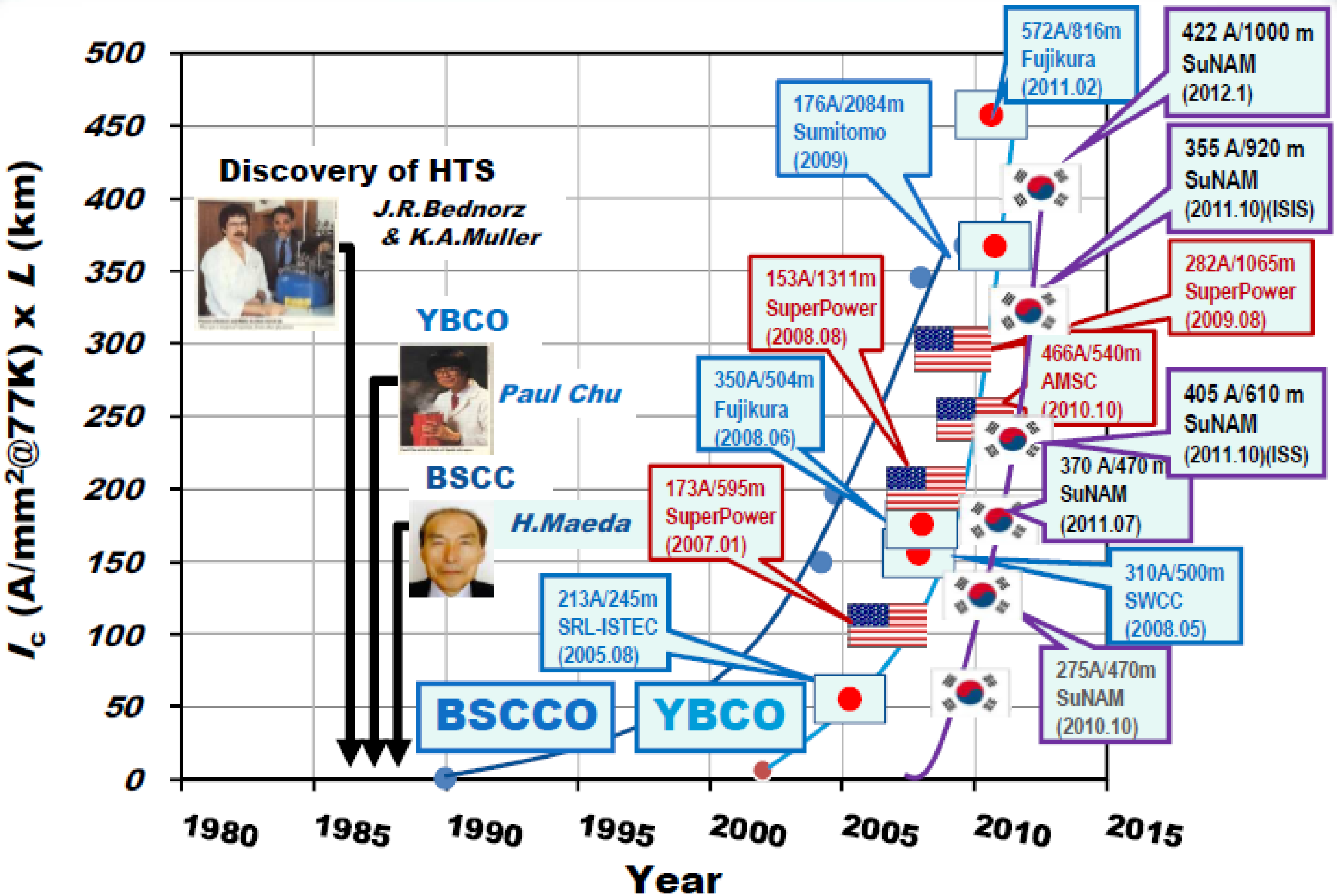
CC's: HTS materials for power applications

J_c breakthroughs



Courtesy M. Matsumoto

10 years of coated conductors

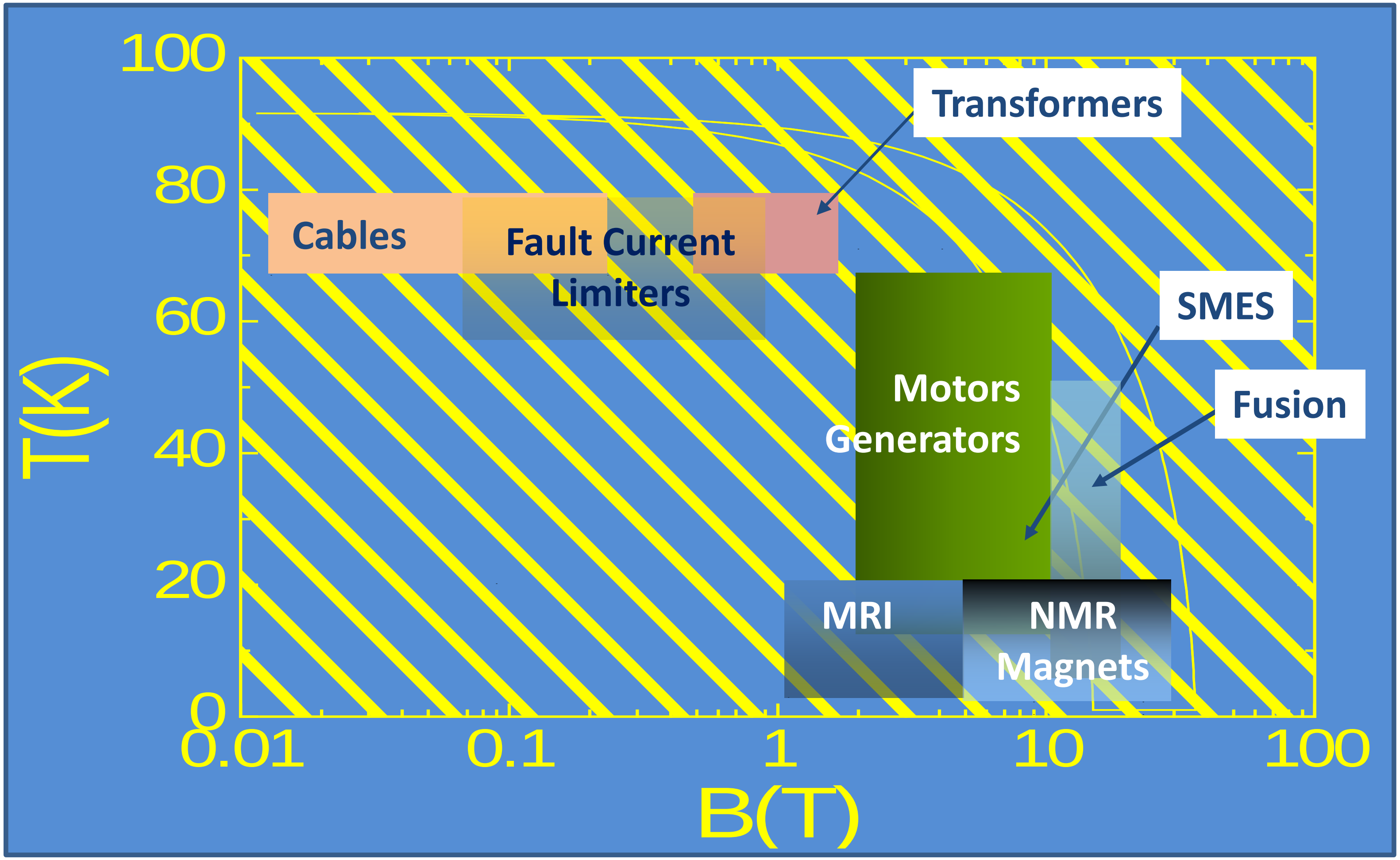


Courtesy of T. Izumi

HTS: Enabling Power Applications

ICMAB CSIC

26 years after the discovery of HTS ….we are ready !



$YBa_2Cu_3O_{7-x}$ is able to push all the power applications up to the present limits
Lenght, allowed cost and required performances strongly differ (~1 km to 300 km)

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Coated Conductor research in Europe

Xavier Obradors

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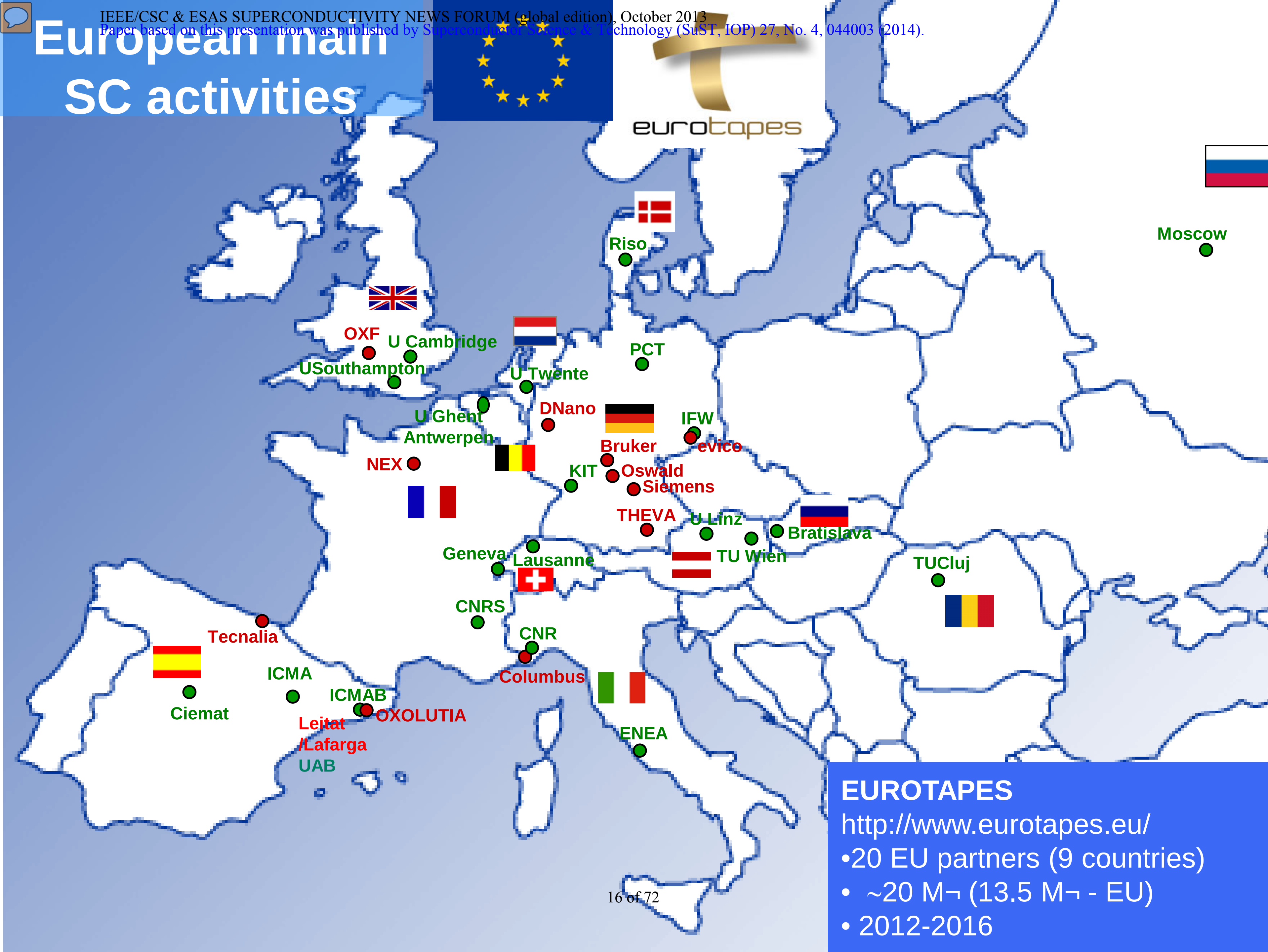
EUROTAPES: European development of Superconducting Tapes: integrating novel materials and architectures into cost effective processes for power applications and magnets (2012-2016)

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

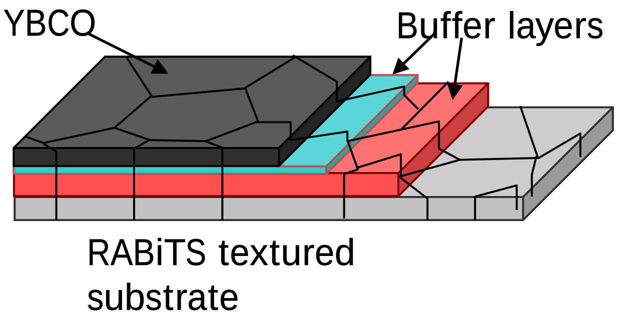
European main SC activities

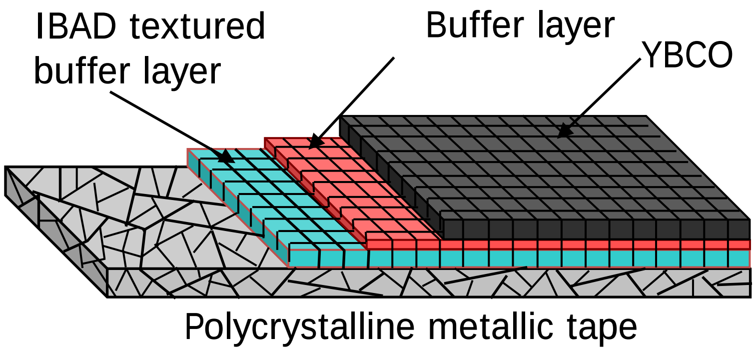


EUROTAPES
http://www.eurotapes.eu/
- 20 EU partners (9 countries)
- ~20 M¬ (13.5 M¬ - EU)
- 2012-2016

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

YBCO COATED CONDUCTORS: EPITAXIAL ARCHITECTURE





Nanostructure control on km length materials: very close to real power applications

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2013
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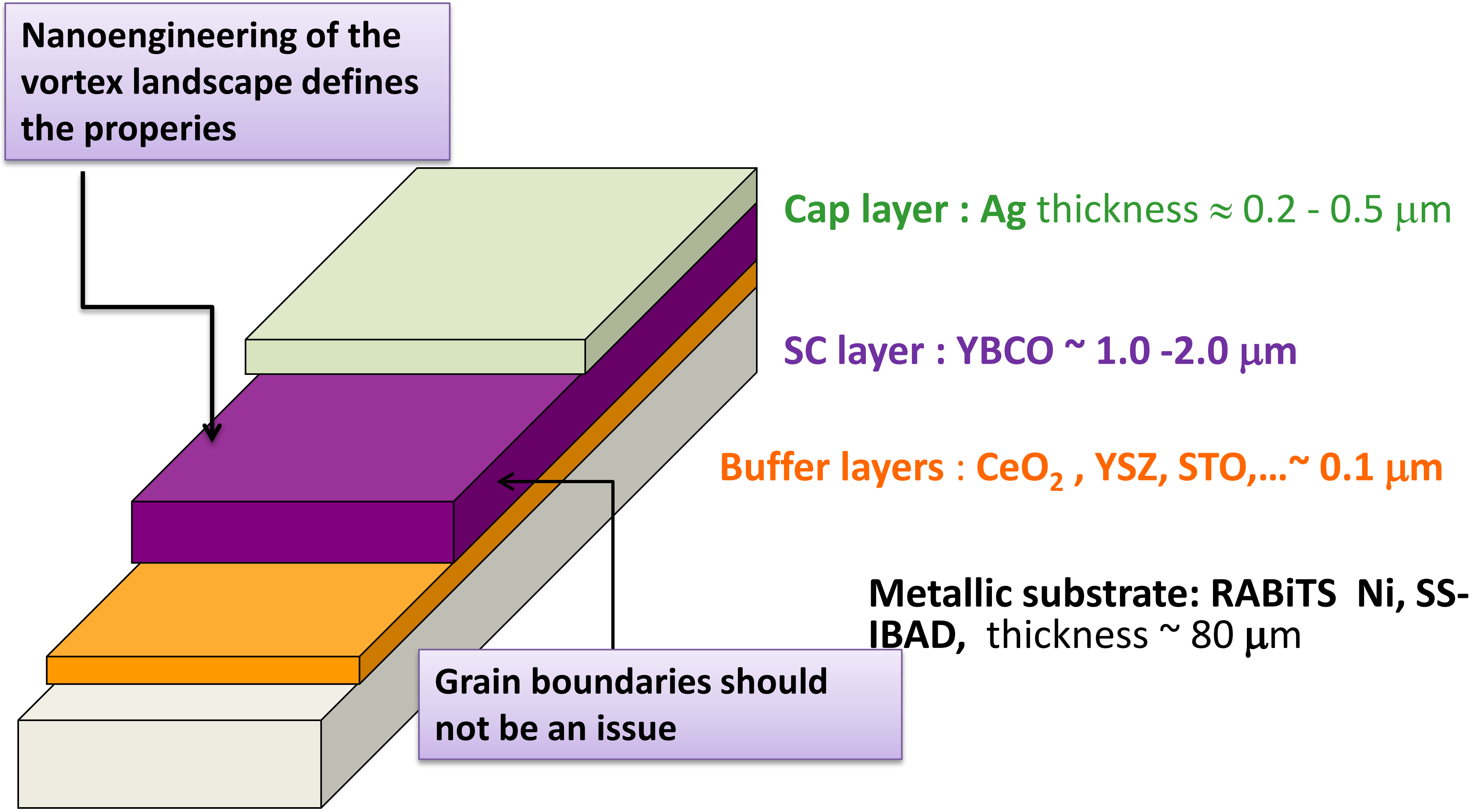
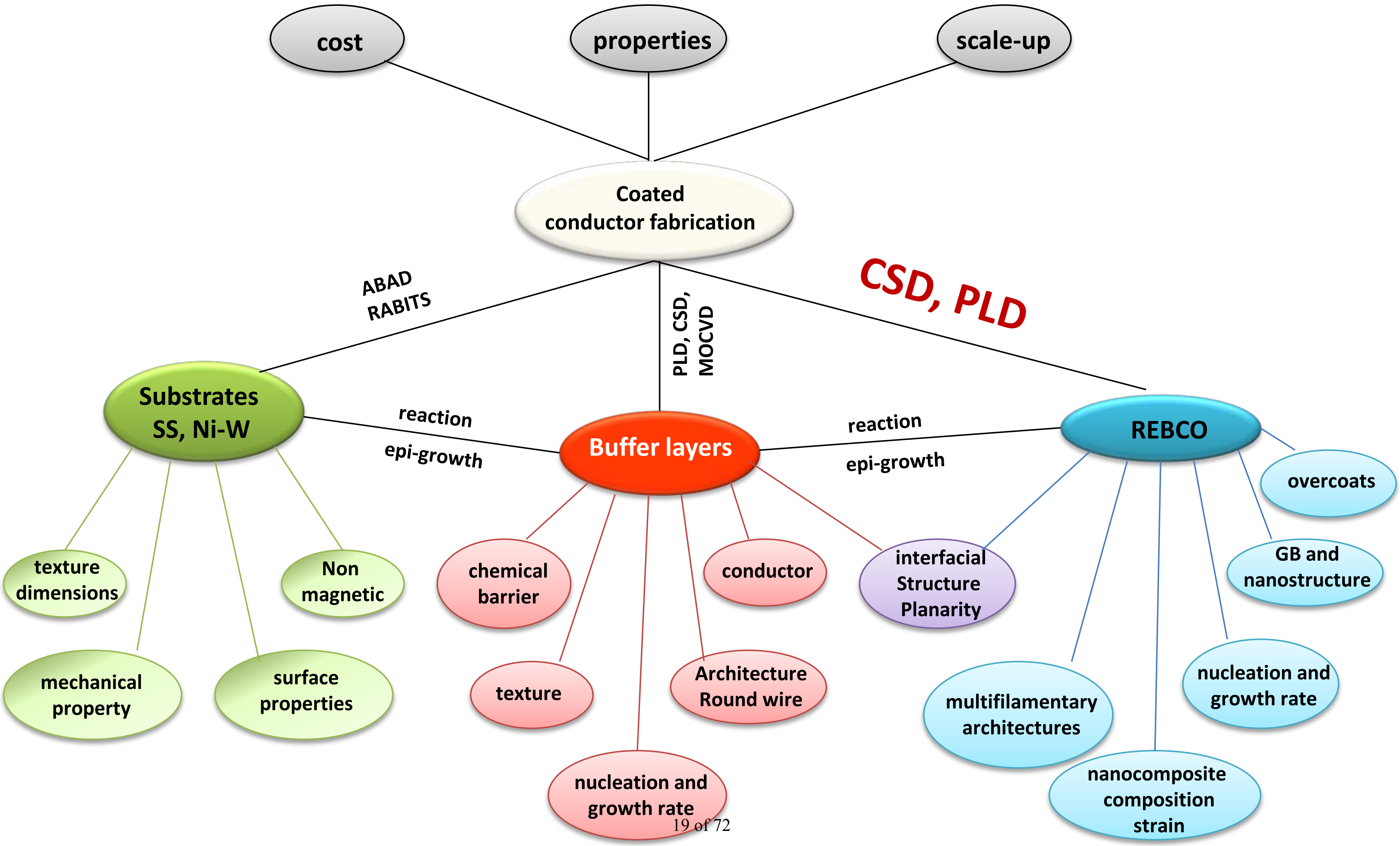
YBCO COATED CONDUCTORS: EPITAXIAL ARCHITECTURE



Nanostructure control on km length materials: very close to real power applications

CC's: multiparameter integration



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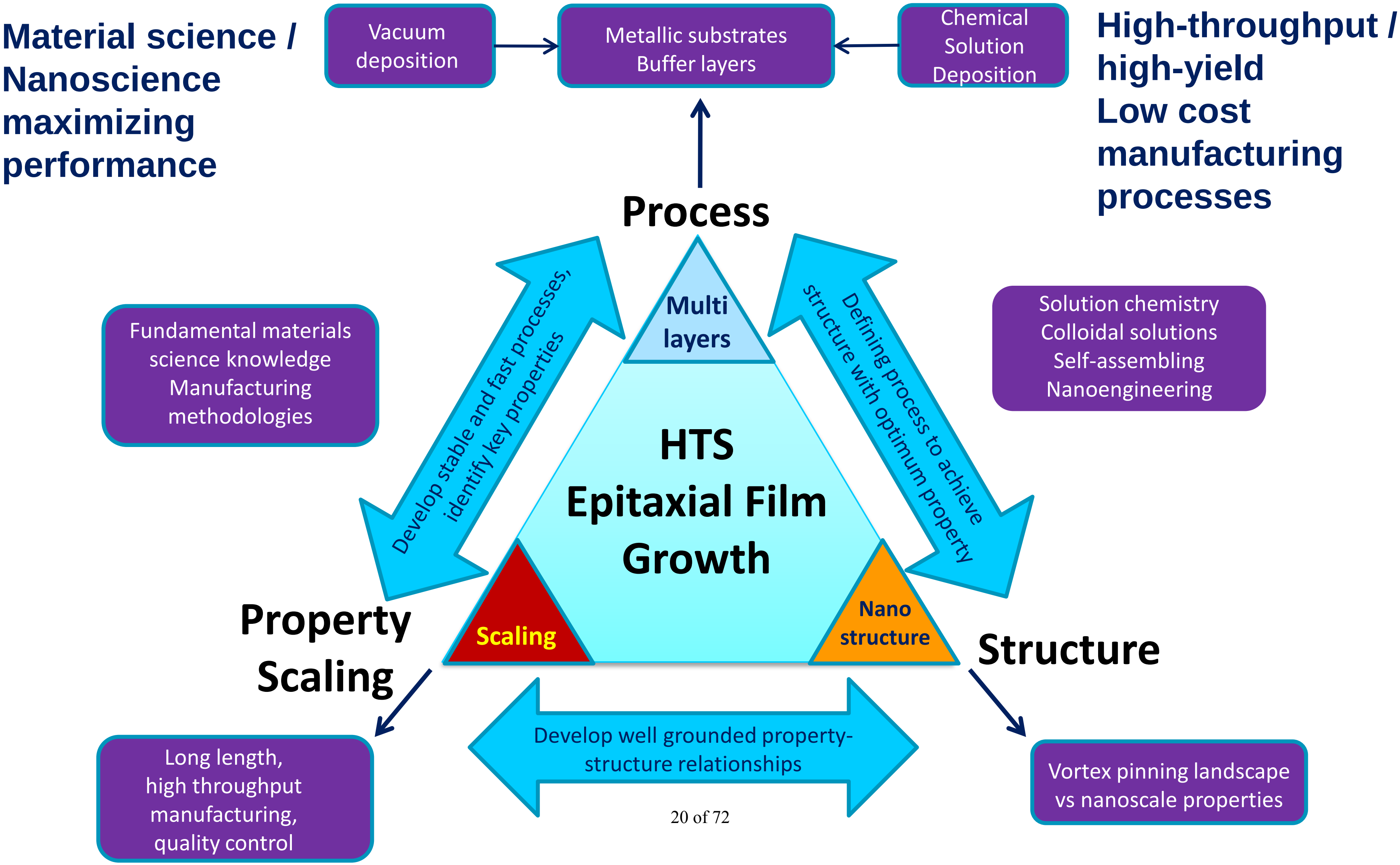
CC's: A tough S&T issue ! Interdisciplinary know-how required !



Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Plenty of room for improvement: self-field $J_c(T)$

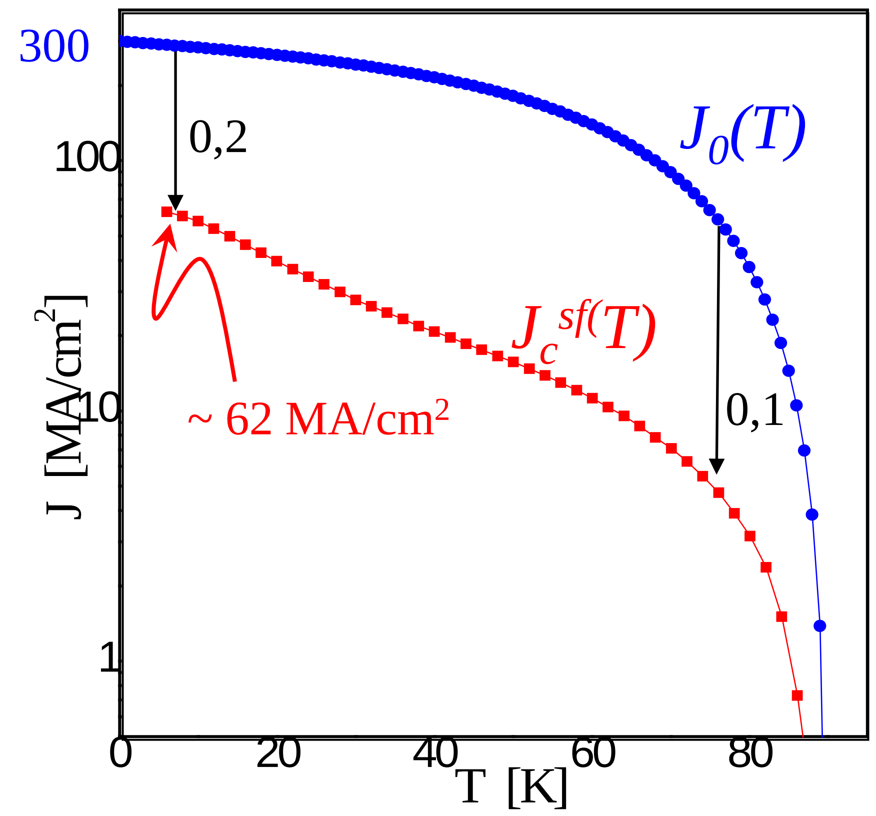
Self – field J_c

For $T \rightarrow 0$, $J_c^{sf}/J_0 \sim 0.2$

At 77 K, $J_c^{sf}/J_0 \sim 0.1$

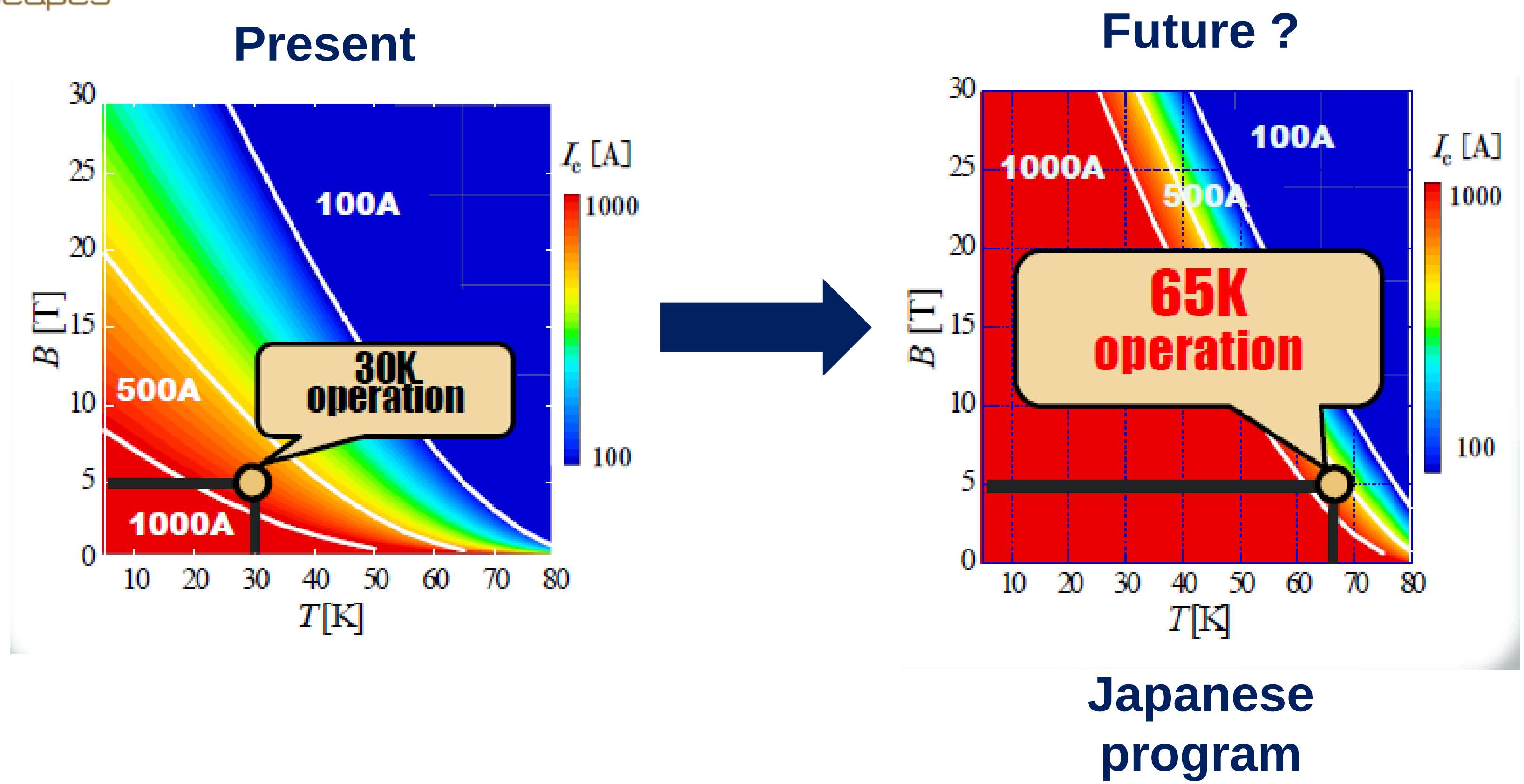
J_c^{sf}(77K)<6-7 MA/cm^2

J_o(77K)~70 MA/cm^2



- Theoretical limit for self-field J_c: depairing current density
- Can we multiply by 5 the self-field J_c (77K)?

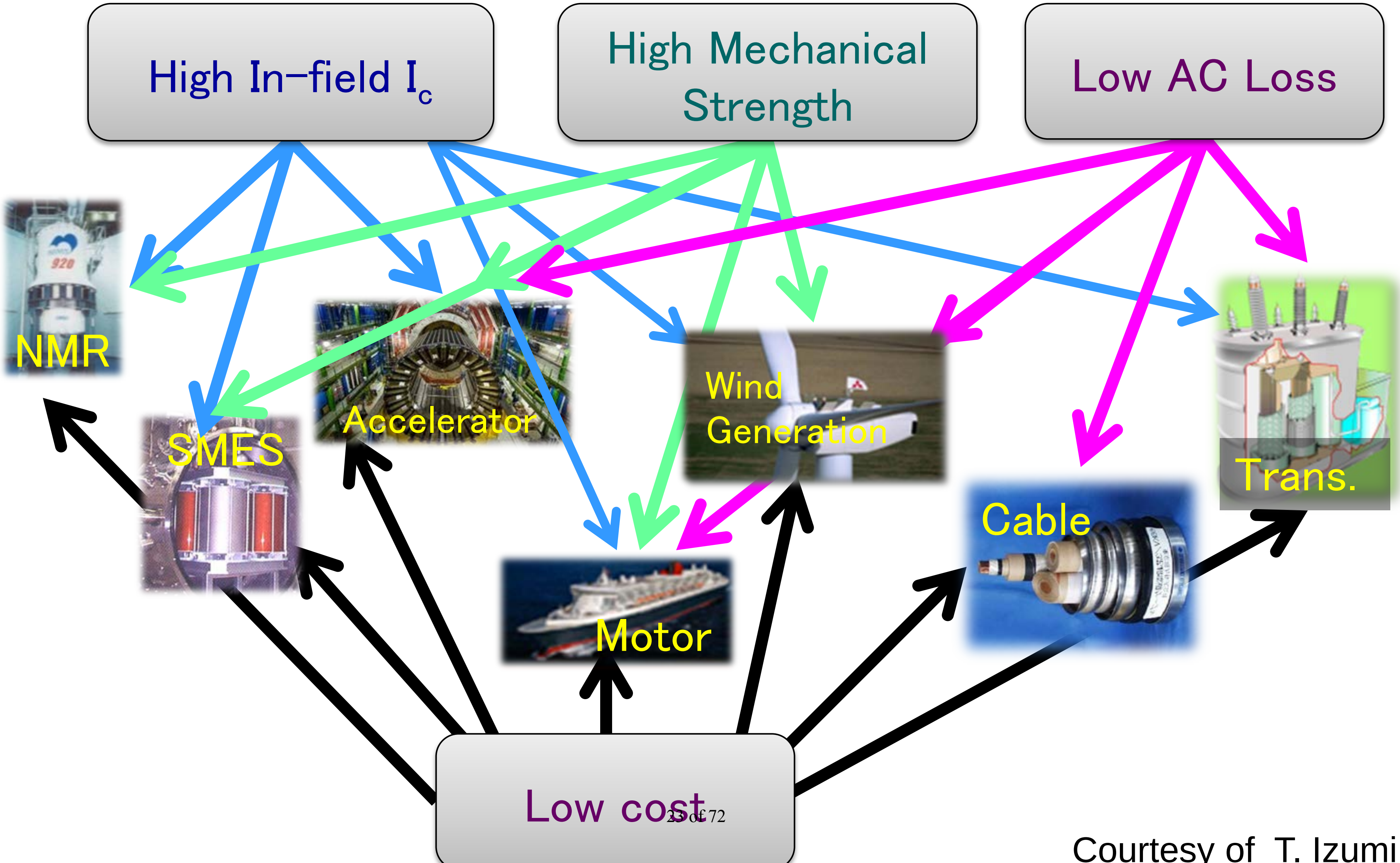
Plenty of room for improvement: $I_c(T,B)$



- Increase of I_c through J_c and thickness enhancement
- Reduce the magnetic field dependence J_c(H): vortex pinning
- Practical processes to achieve high I_c(H) values

Courtesy of T. Izumi

Specifications and cost for applications

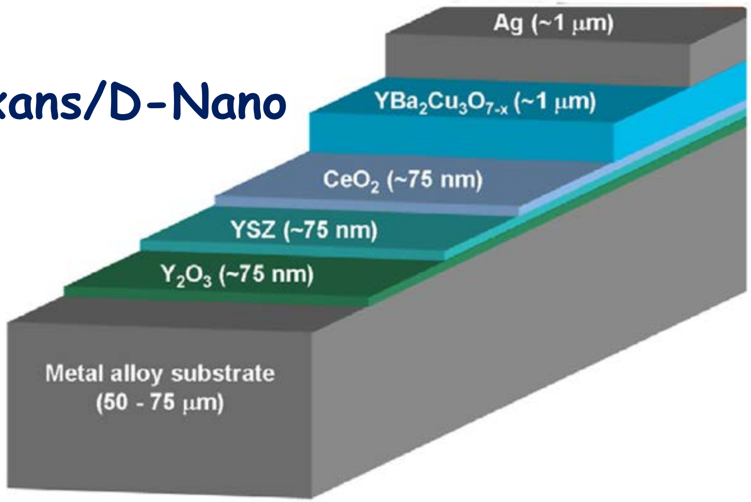


Courtesy of T. Izumi

Search for breakthroughs

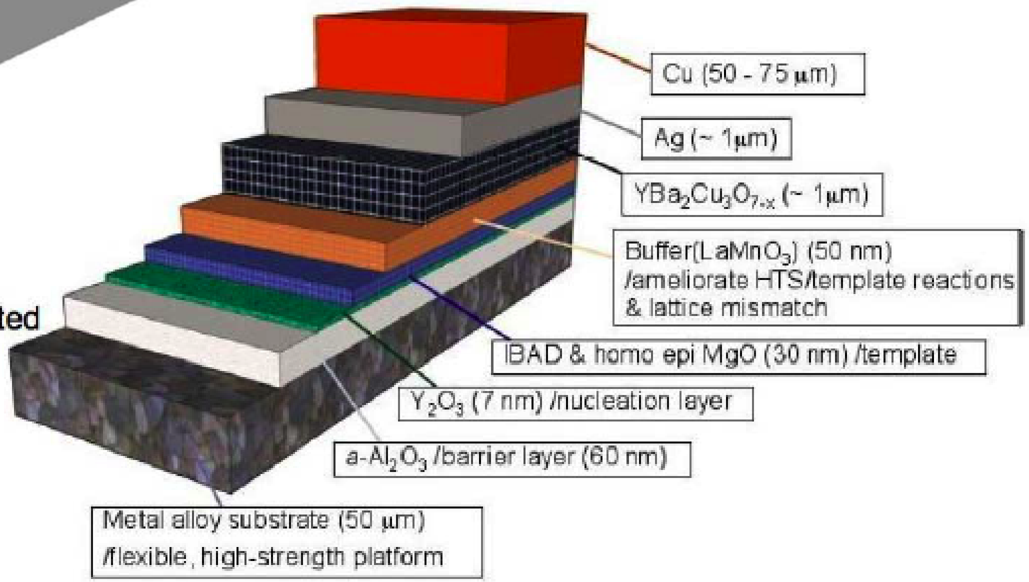
Simplified architectures ? / All chemical ? / Large thickness

- AMSC
- Evico/Nexans/D-Nano



Rolling Assisted Biaxial Texturing (RABiT)

- Superpower
- Fujikura
- Bruker / Oxolutia
- SuNAM

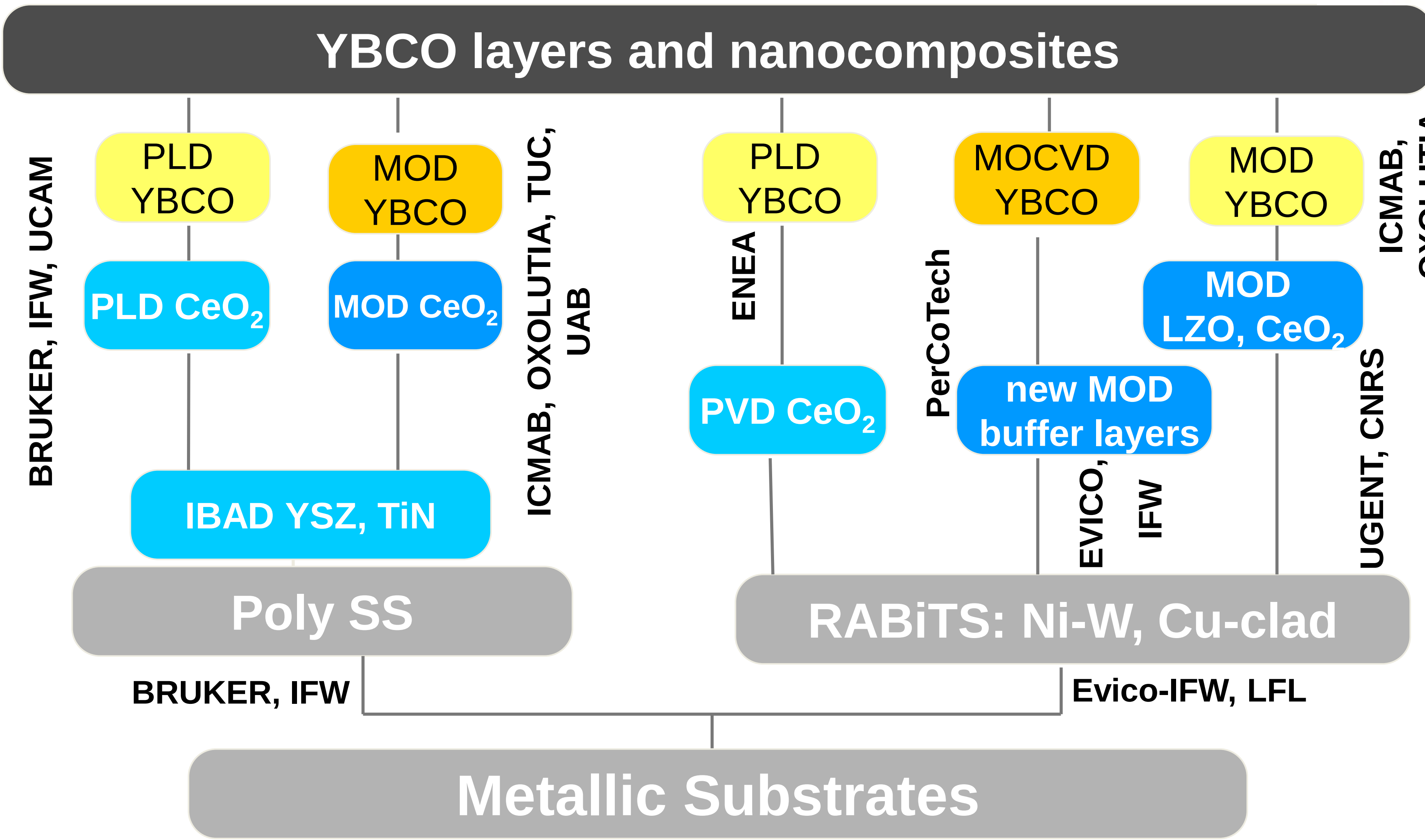


Ion Beam Assisted Deposition (IBAD)

- **Urgent need for simplified conductors and reduced cost/performance ratio (similar needs in photovoltaic industry)**

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2013
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

EUROTAPES project



Advanced characterization and in-situ monitoring: TUWien, UAntwerpen, THEVA
Striations, ac losses, round wire : UCAM, Bratislava, NEXANS

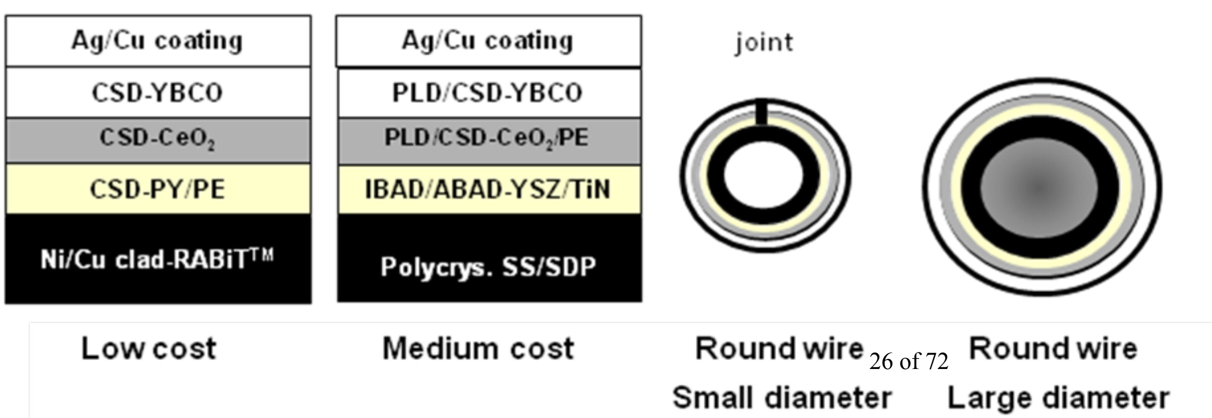
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

eurotapes

EUROTAPES objectives

ICMAB

- Metallic substrates with reduced ac –losses and lower cost ABAD templates
- Simplified architectures and cost effective CC
- Engineered nanocomposite CC (CSD, PLD) for high fields (3-10T, 60K) and ultrahigh fields (>20T, 5K).
- Eco-friendly chemical and colloidal solutions for nanocomposite CC's
- New round wire low cost and low ac losses
- Multifilamentary striated conductors at low cost and low ac losses
- High throughput processing with high yield and performance
- Development of in-situ monitoring tools for process scalability
- Demonstrate (+500 m) manufacturing



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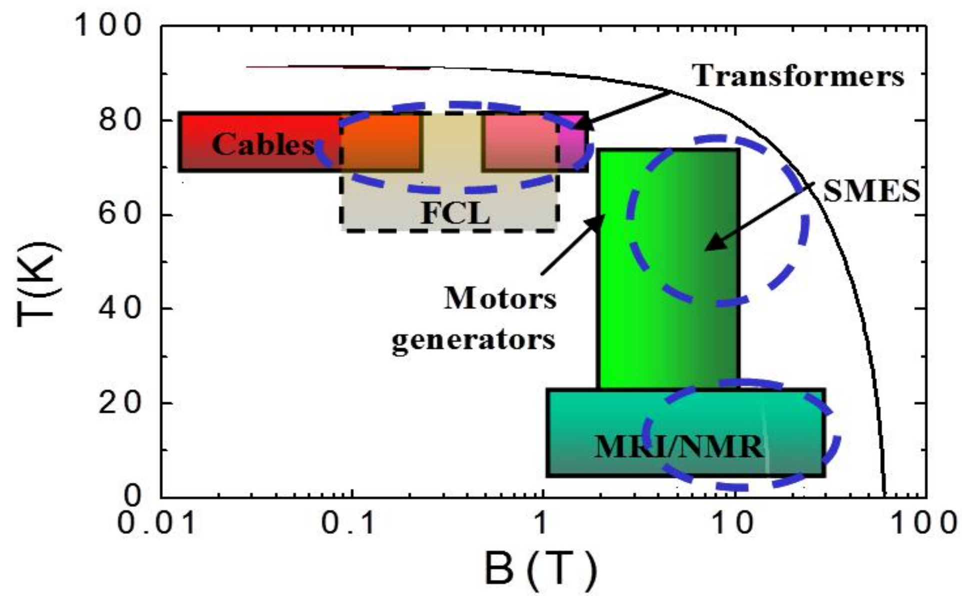
eurotapes

EUROTAPES objectives

ICMAB



TARGETS:

•**Pre-comercial cost**: ~100 ¬/kAm

• **Length** :+500 m

•**Performance:**

•For low fields (B< 1 T):

I_c (77K, sf) > 400 A/cm-w

•For ultrahigh fields (B > 15 T):

I_c(5K, 15 T) > 1000 A/cm-w

•For high fields (B ~3-5 T):

F_p(60 K) > 100 GN/m^3

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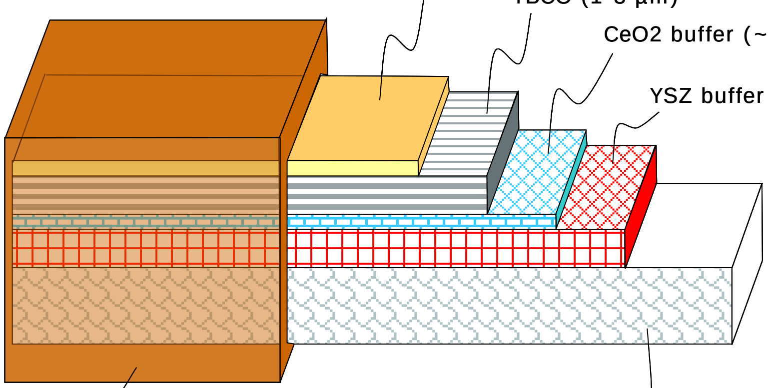
ABAD metallic substrates

ABAD 40mm, YSZ/SS
(4mm/12mm also available)



Targets:

Substrate polishing 8 => 150 m/hour

ABAD 4 => 35 m/hour
width 12 => 40 mm
length 100 => 500 m

OXOLUTIA ICMAB

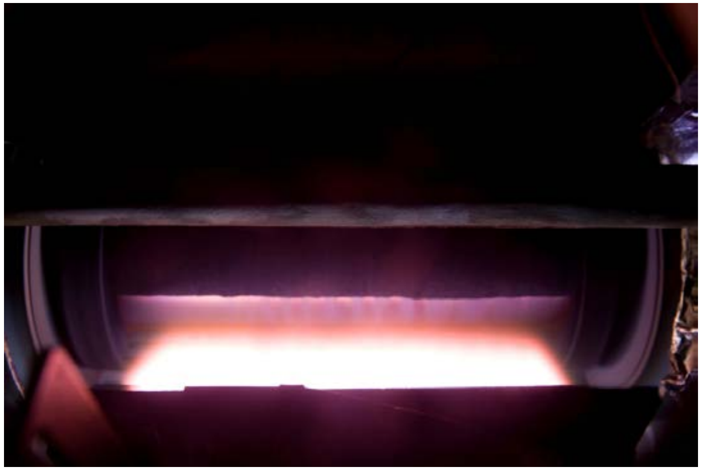
Towards cost reduction :
Solution Deposition Planarization (SDP) process to substitute mechanical polishing

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

All PLD approach: longest CC's in Europe (~280 m)

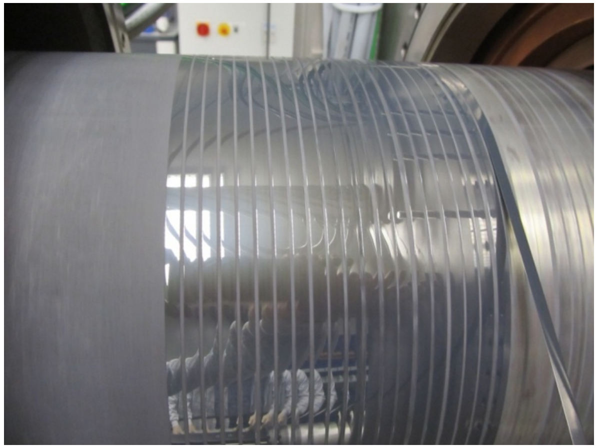
6B-PLD machine with deposition area of 0.13m^2

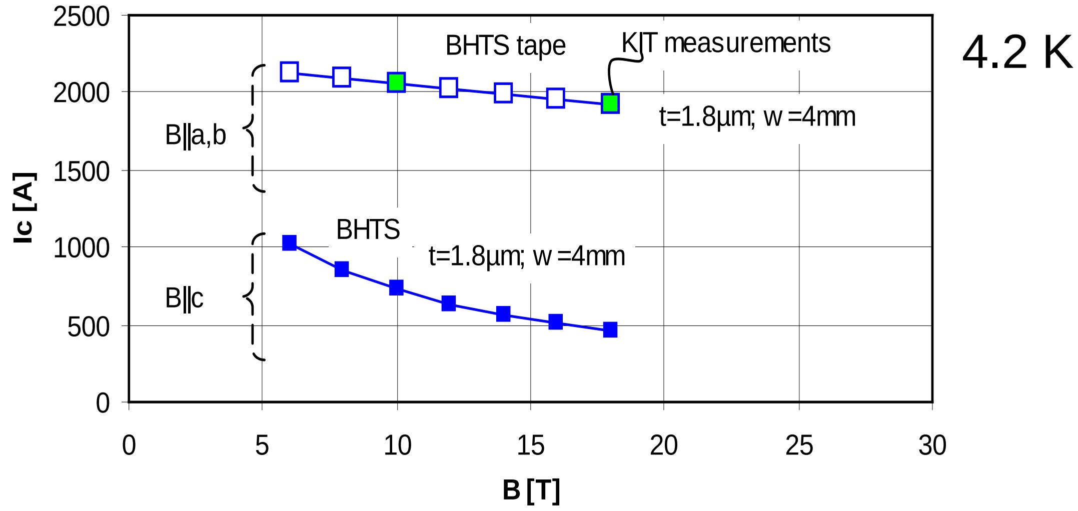
Multi plume HR-PLD for Large area HTS coated conductors



- Efficiency of material transfer is about 2 times higher as was expected
- Pulse energy of 600mJ is sufficient for 8 beams
- This indicates further increase cost efficiency and throughput

45m long, 4mm wide tape





Highest I_c achieved in 6 m long tape: 500 A/cm-w at 77K, SF

Well-reproducible I_c(~ 200 m): 250 A/cm-w at 77K, SF

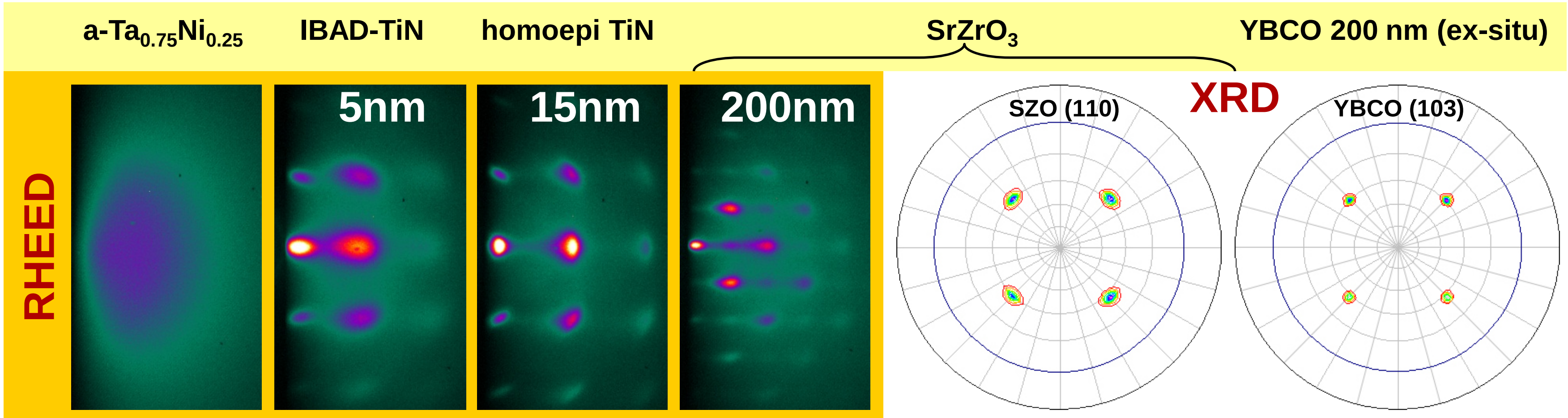
WR (Fujikura) 572 A/ 816 m

Bruker HTS

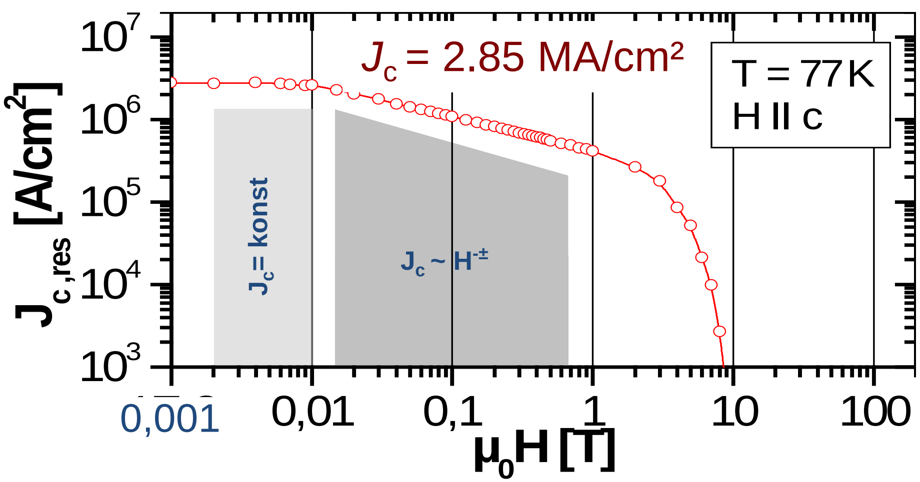
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

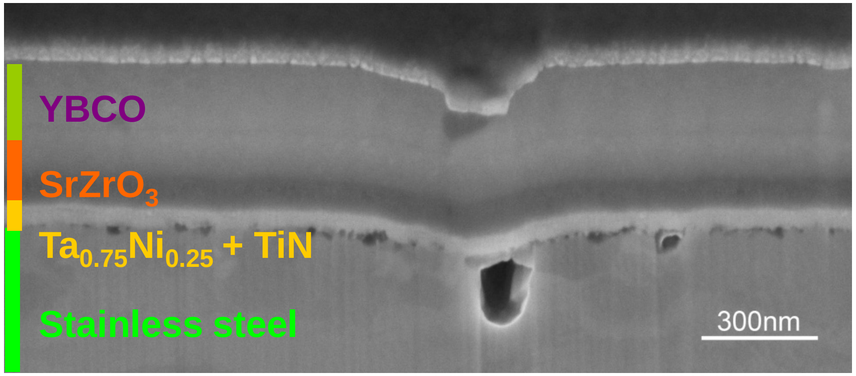
IBAD alternative: TiN based CC's

Application of IBAD-TiN on stainless steel: faster alternative to YSZ-ABAD?



In-plane FWHM: ~6˚





FIB cross section

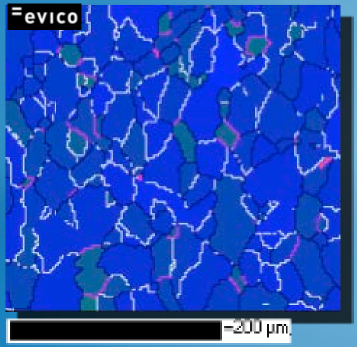
R. Gärtner et al., IEEE Trans. Appl. Supercond. 21 (2011) 2920

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014)

RABiTS NiW substrate: a commercial product

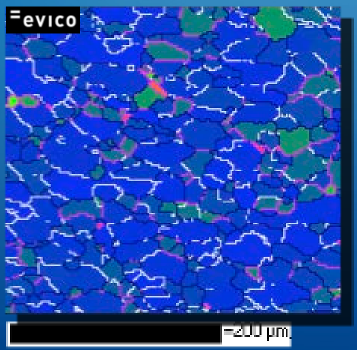
Available products:

Ni5at%W - evico STANDARD



- > 98% cube texture fraction
- < 5 nm surface roughness
- high quality, stable process
- 80 µm thickness, 10 mm width, 10 -250 m length

Ni7.5at%W - evico LOW AC LOSS



- > 96% cube texture fraction
- status: available, pilot production
- 80 µm thickness, 10 mm width, 1 -100 m length

- **customized dimensions on request**
- **Ni9at%W - Research**
  not available yet
  > 94 % cube texture fraction
  Status: transfer to production soon

Spin-off from IFW- Dresden

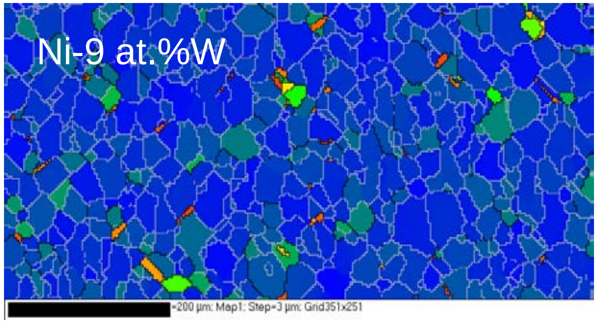
The leading manufacturer of Ni-based RABiT in Europe

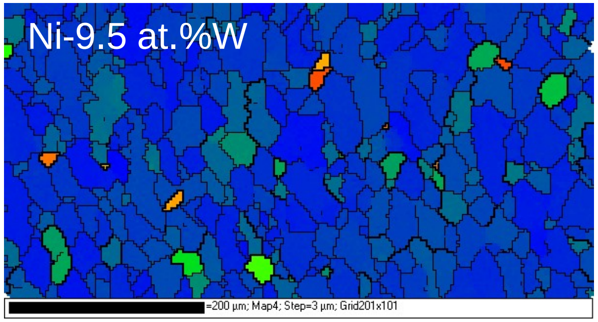
evico

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Non-magnetic RABiT Ni-W tapes

Development of highly textured non-magnetic RABiTS tapes



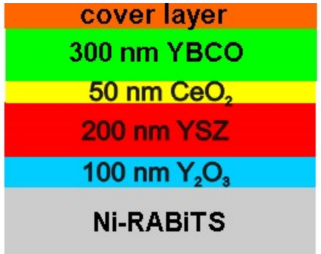


Fraction of cube texture: >95%

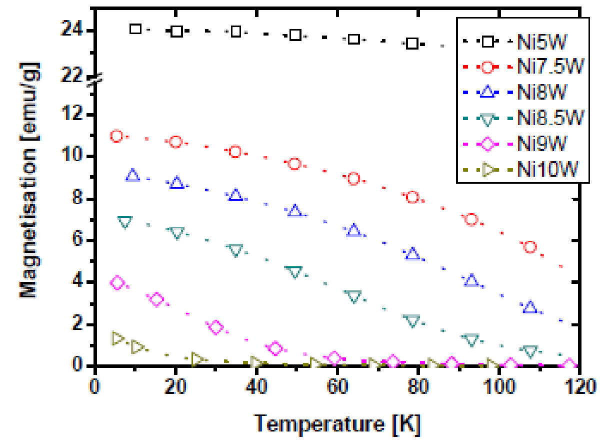
Deviation from (001)[100] cube texture:

0° 62°

YBCO coated conductor architecture validated by pulsed laser deposition

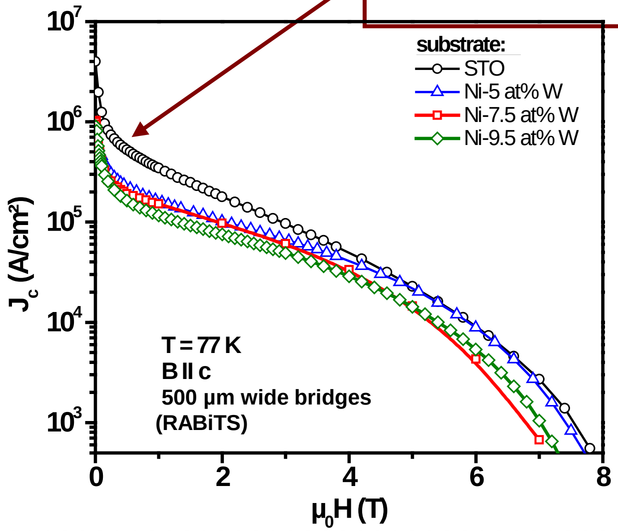


R. Hühne et al., Supercond. Sci. Technol. 23 (2010) 034015



U. Gaitzsch et al., Scripta Mater. 62 (2010) 512

Typical J_c-values: 1.6 … 1.8 MA/cm²

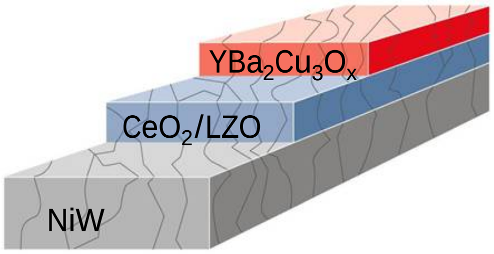


Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

All-chemical CC's: CSD buffer on NiW

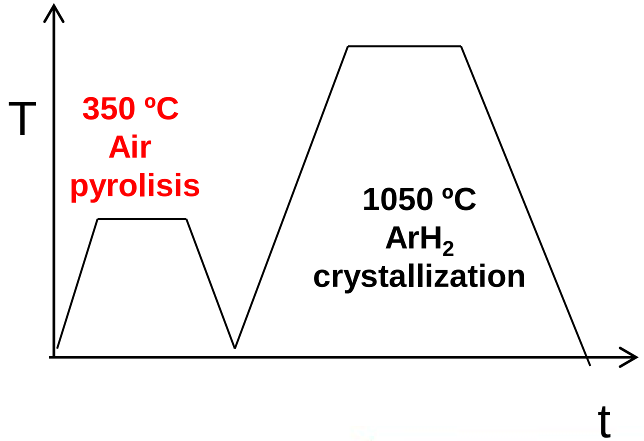
100 nm $La_2Zr_2O_7$ are effective as metal difusion barrier

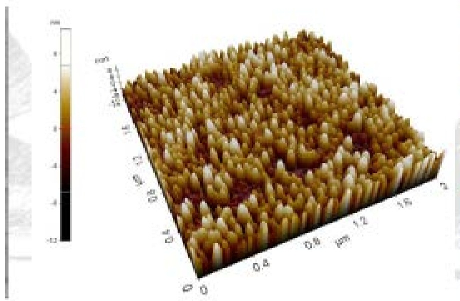
All chemical CC architecture

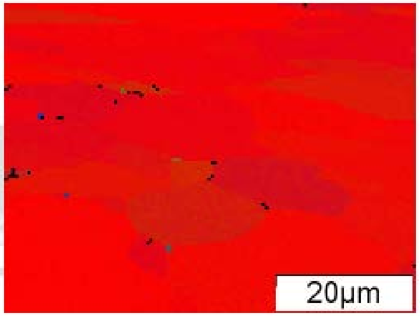


Pyrolysis atmosphere

Full elimination of organic components with an air pyrolysis in a single coat of 100 nm







Roughness R_{rms} = 3.5 nm (2x2µm)
(6.5 with standard annealing)

Good texture

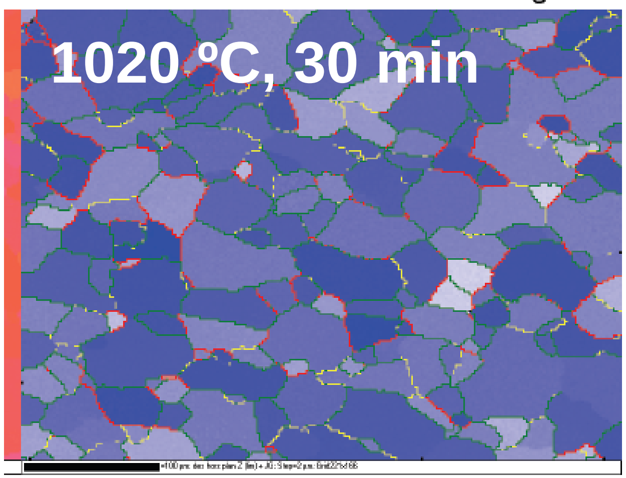
IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2013
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

All-chemical CC's: CSD buffer on NiW

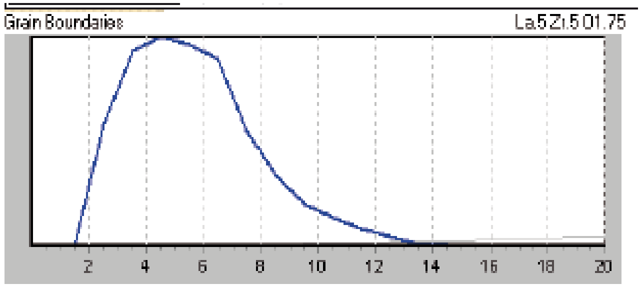
100 nm $La_2Zr_2O_7$ are effective as metal difusion barrier

Effect of annealing temperature (980ºC-1060ºC)- optimum for 1020 ºC

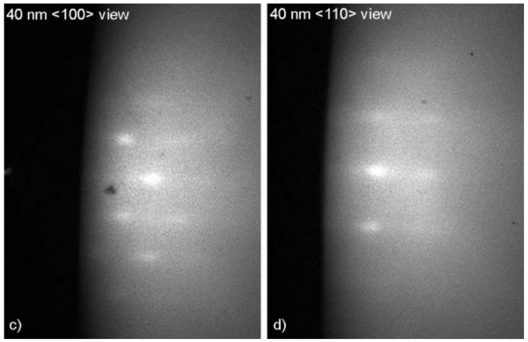
320x400 microns EBSD image



For 1020°C: 99% of the scan points are indexed as LZO; No defects.
The joints between crystals are all below 7°.



New buffer layer: $YBiO_3$

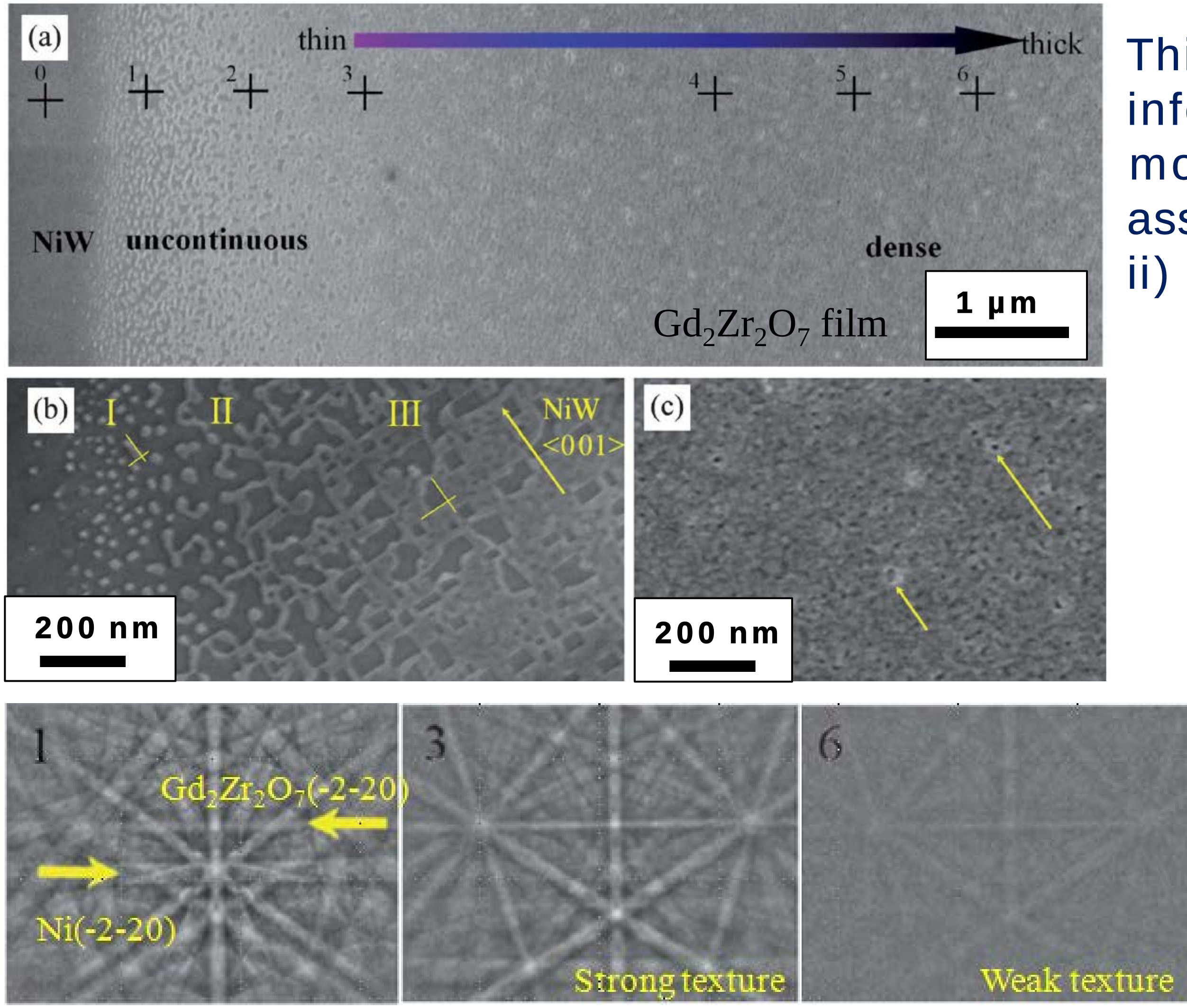


- **YBCO deposition by PLD yields 3.6 MA/cm² on YBO-buffered single crystals**

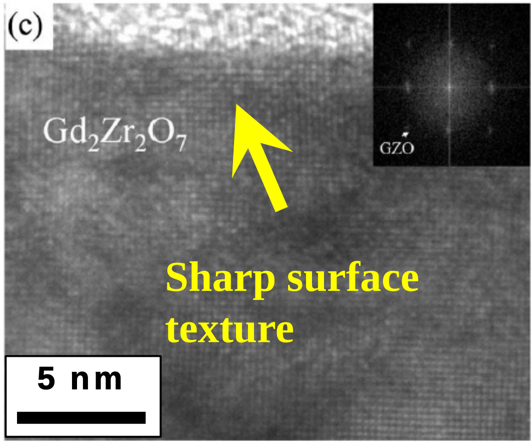
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Understanding the thickness dependence of the CSD films

Buffer layers by CSD: $Gd_2Zr_2O_7$



Thickness gradient is very informative to study: i) morphology change associated with growth mode ii) surface texture evolution



CrystEngComm, 2012, 14, 3089

a multi-step annealing process

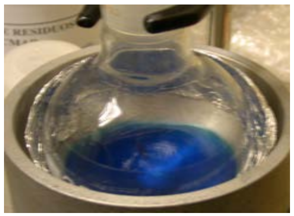
eurotapes

ICMAB CSIC

TFA based CSD: Low cost YBCO and nanocomposites

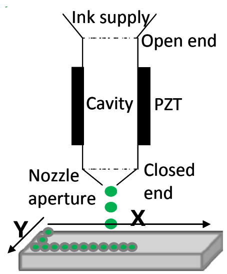
Precursor solution synthesis

Y, Ba,Cu metal-organic precursors



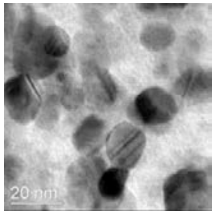
Solution deposition

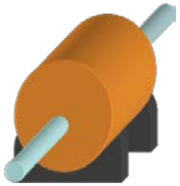
Ink-jet Printing



Pyrolysis

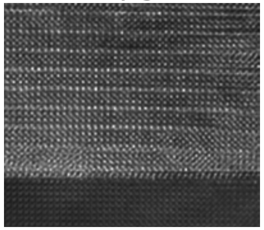
Removal organic precursors





Ex-situ Growth

Nucleation, crystallization and oxygenation



X. Obradors, et al, SUST (2012)

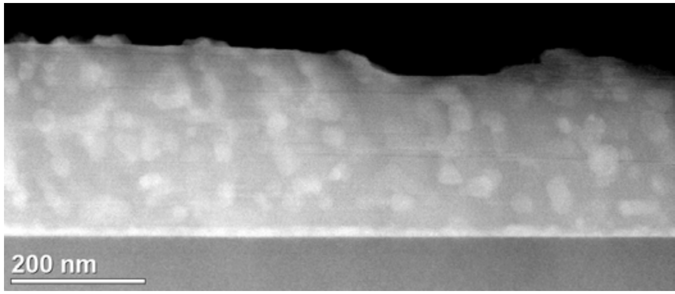
For Nanocomposites: In-situ

Addition of metal-organic salts (Zr, Ce, Ta, …) in the TFA precursor solution: Spontaneous Np segregation within the epitaxial $YBa_2Cu_3O_7$ matrix : **Y_2O_3, $BaZrO_3$, Ba_2YTaO_6, $BaCeO_3$**, …

Nature Materials (2007); Nature Materials (2012)

For Nanocomposites: Ex-situ

TFA colloidal precursor solutions: **MFe_2O_4 (M=Co, Mn), CeO_2 ($BaCeO_3$), …**



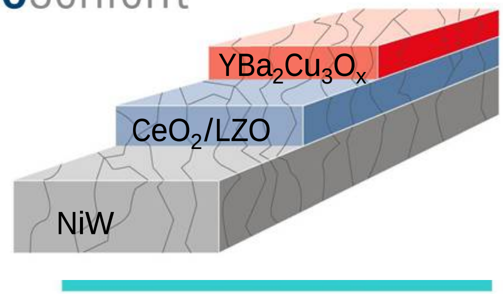
J. Nanoparticle Res. (2012); Mat. Res. Bull. (2013)

ICMAB

CC strategy based on CSD

eurotapes

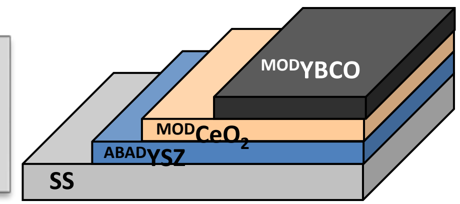
deutsche nanoschicht



YBCO films multilayers

OXOLUTIA

BRUKER



CSD
Ink Jet Printing

ABAD / RABIT
CSD
Buffer layers

TFA precursors (BaF_2 process)

- In-situ nanocomposites
  - Nucleation and growth control
- Ex-situ nanocomposites
  - Nanoparticles
  - Stabilize solutions

Low F precursors (BaF_2 process)

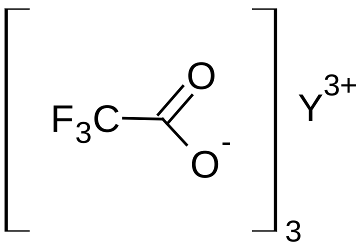
- Robustness, R2R, large I_c, throughput, length

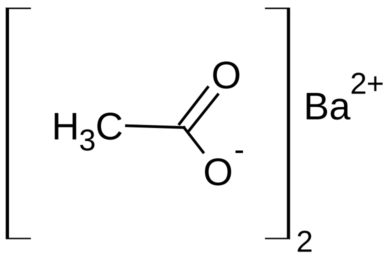
Non F precursors (Non BaF_2 process)

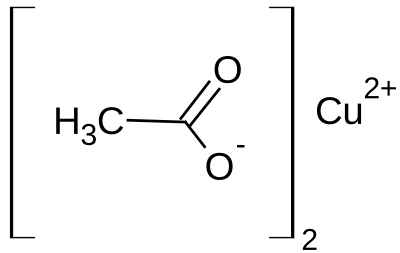
- Explore capabilities

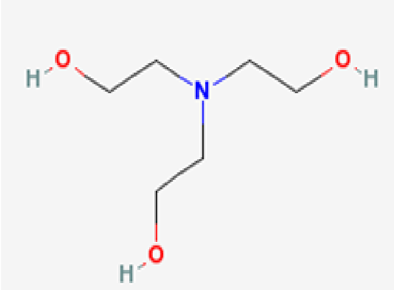
Low flourine / non-fluorine precursor solutions

Carboxylate salts	+Solvent	+ Chelating Agent
Acetate	Methanol	Triethanolamine (TEA)
Propionate	Propionic acid	
Ethylhexanoate	Acetic acid	~50-80% less fluorine



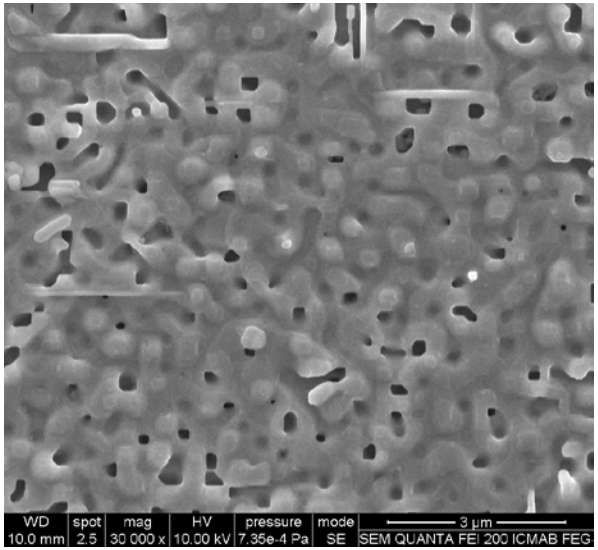






- 80 % F

J_c (77K, sf) = 3-4 MA/cm^2



- **More environementally friendly (-80 % F or non-F)**
- **Stable solutions adapted to IJP: less sensitive to humidity (chelating agents)**
- **Large thickness with one coat (~1000 nm)**
- **Pyrolysis can be undertaken at faster ramps**
- **Similar growth process that TFA-based solutions**
- **Good progress towards F-free CC's**

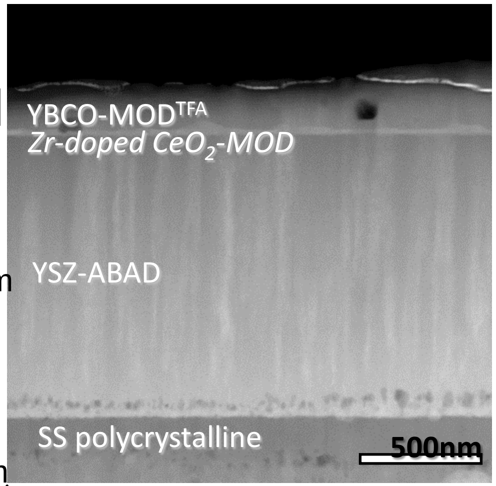
X. Palmer et al,, to be published
L. Soler et al, to be published

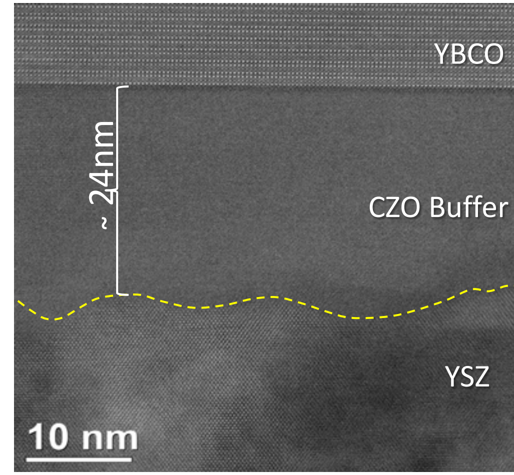
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

CSD CC's on ABAD-YSZ

All chemical IJP: YBCO / CeO_2 / ^{ABAD}YSZ /SS

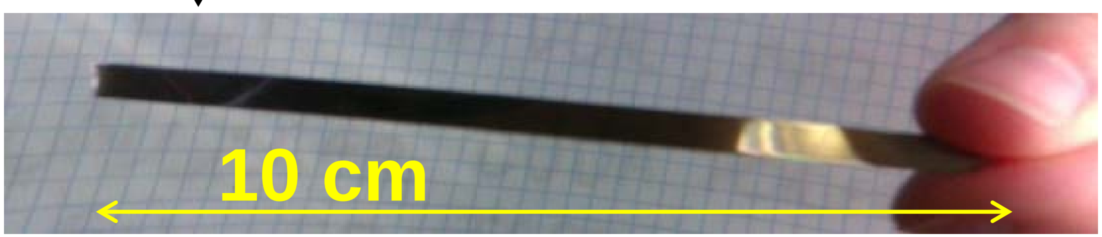
- CZO^{MOD} epitaxial with good texture quality.
- Enhanced surface planarity, small grain size

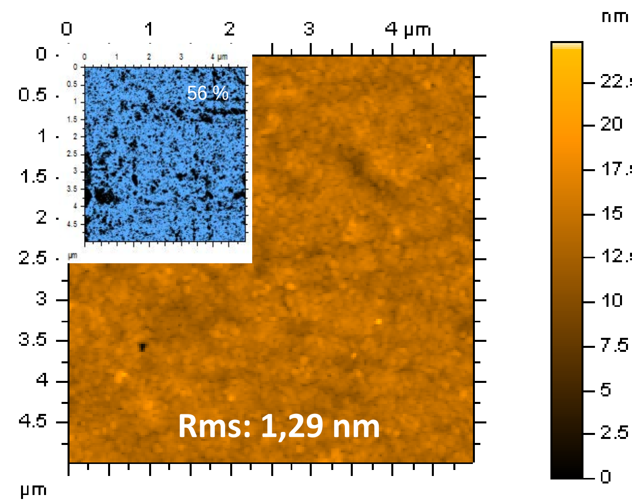




J_c(sf,77K)=2 MA/cm^2 I_c=108 A/cm-w

E. Bartolomé et al, SUST (in press)





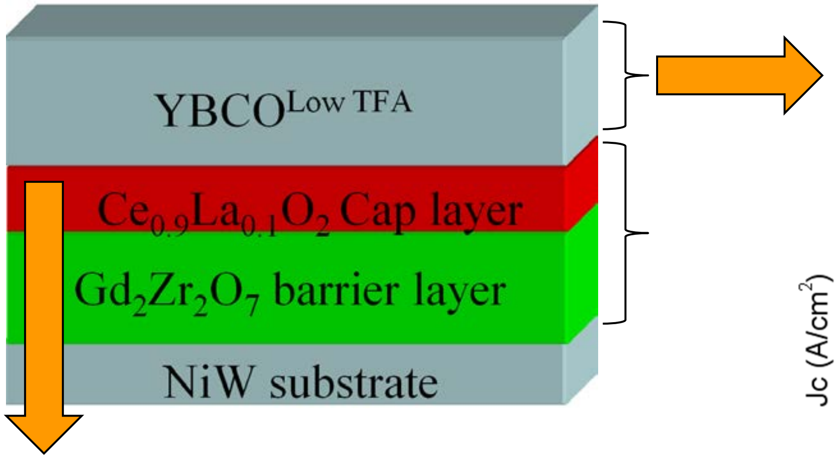
- No coherence between buffer layer and YBCO grains
- Current percolation different than RABiT CC's

Goals: Low-F - 200 A/cm-w - 1 nm/s - 10 m

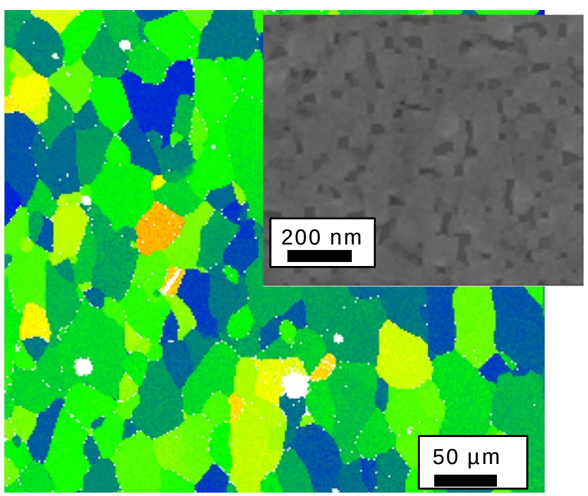
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

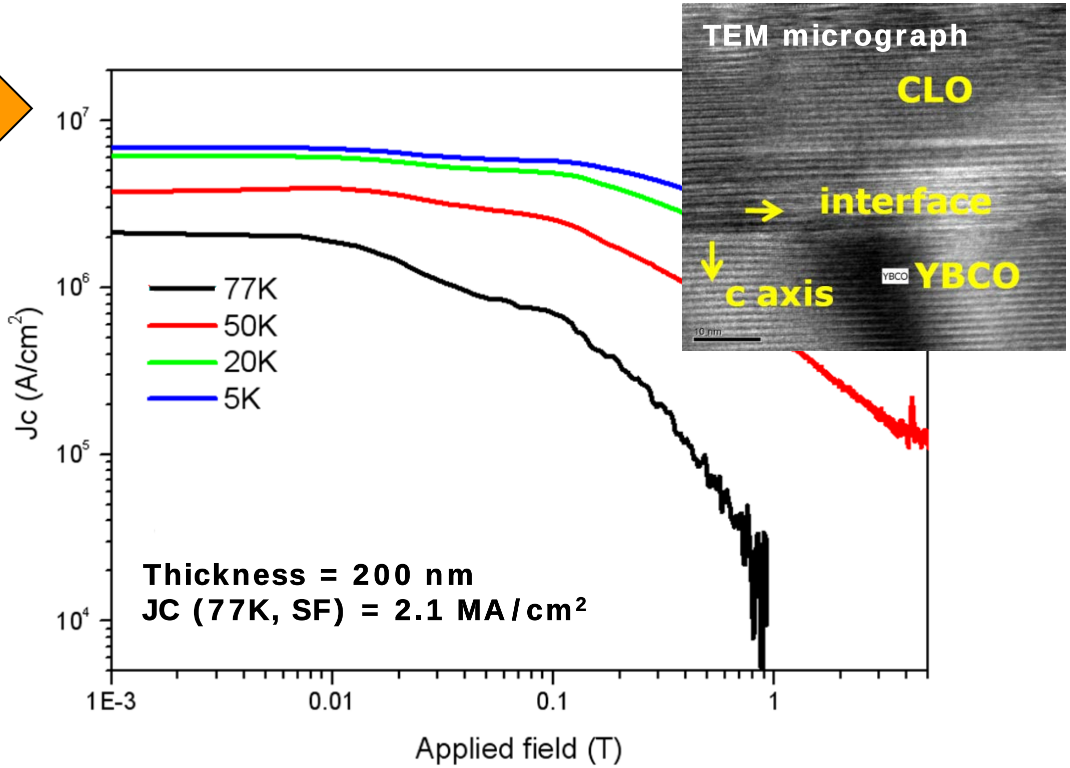
Development of RABiT CC's by ALL-CSD processes

Superconducting layer by Low F TFA process



High quality buffer layer stack *Supercond. Sci. Technol. 25 (2012)*





• **A <u>strong surface texture</u>** and a **<u>superior morphology</u>** on the cap layer ensure the high performance of the YBCO layer

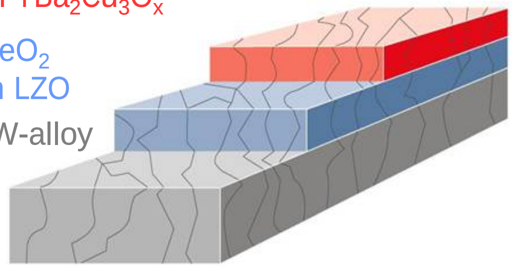
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Ink-Jet Printed RABiT CC's

deutsche nanoschicht

BASF GmbH owner

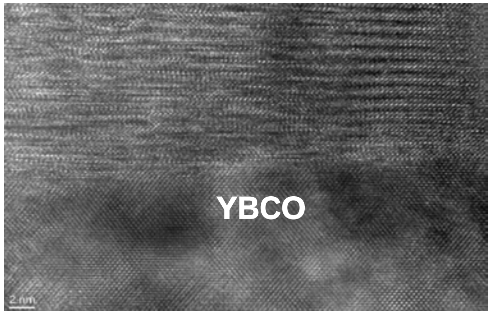
200-800nm silver, 10-100µm copper
0.5-1.2µm $YBa_2Cu_3O_x$
10-30nm CeO_2
200-350nm LZO
50-80µm NiW-alloy



Ink-jet printing in continuous processing

- **CSD for all layers is considered to be the "most promising and most challenging process**
- **Unique and protected CSD-multi-layer technology, IJP.**
- **Established industrial cooperations on metallic substrates (Thyssen Krupp), coating solutions (Honeywell) and insulation (Elektrisola)**

universitätbonn



✓ **All samples continuously processed in minimum 10 m lengths**

✓ J_c (77K, sf) = 1.2 -1.8 MA/cm^2 for 1 µm HTS

✓ 7mm wide slitted and stabilized sample, I_c /cm-w > 160A

✓ 100 m wound to coil with overall J_c =1.4 MAcm^2

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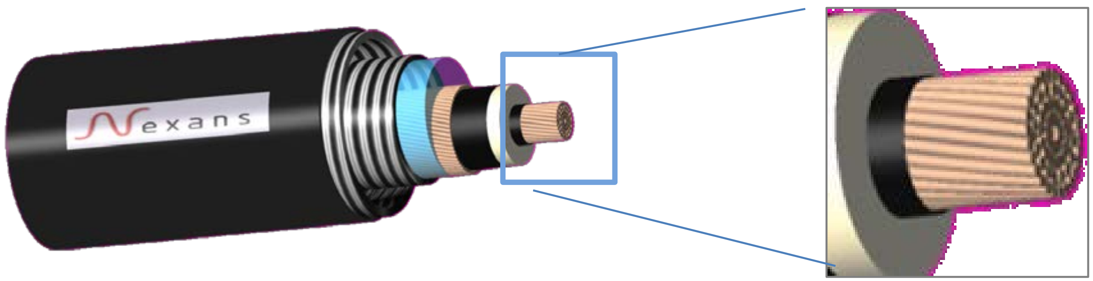
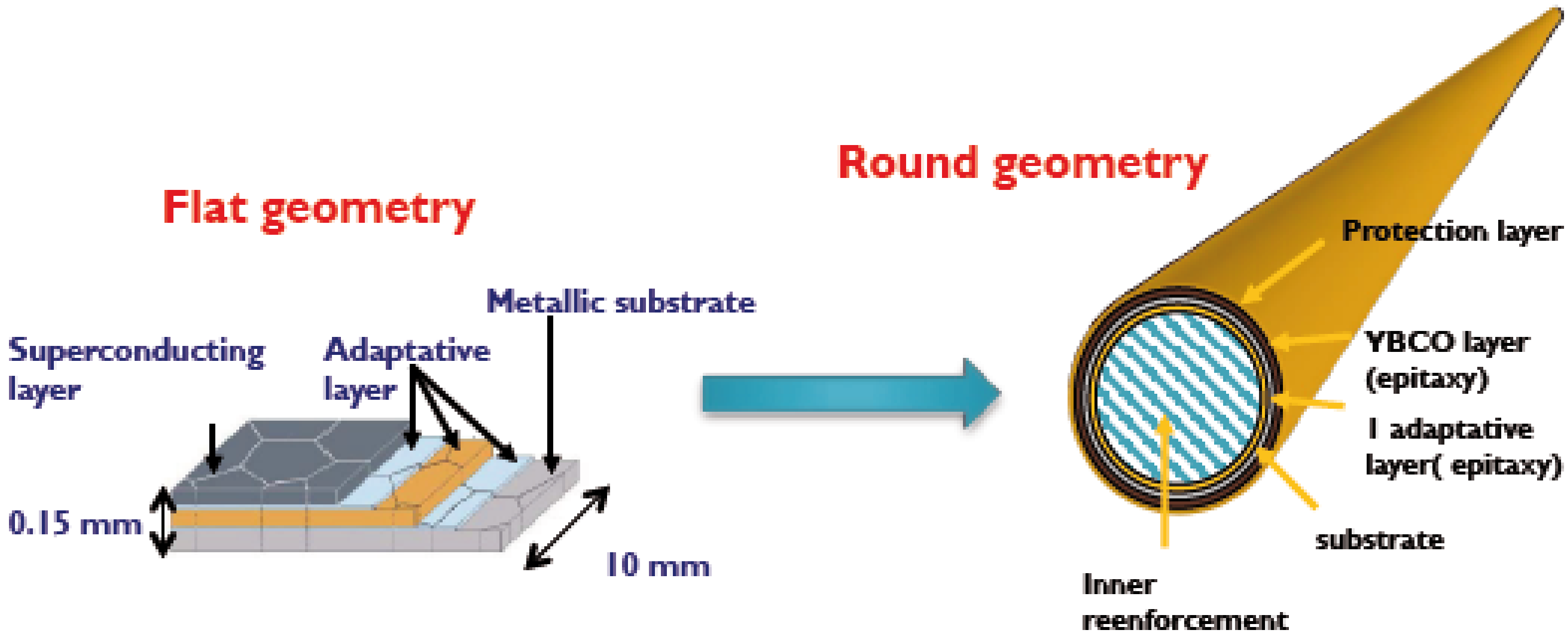
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Round wire objective: more compact and low cost cables



Core made of superconductive wires

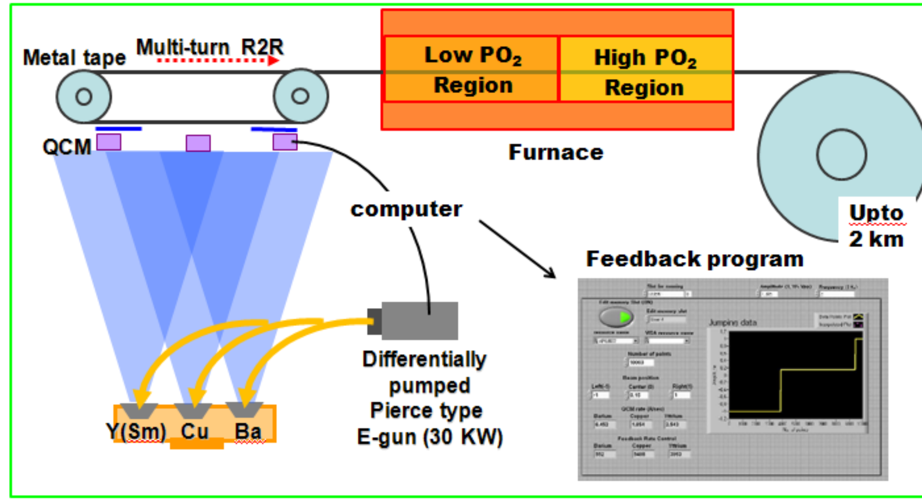


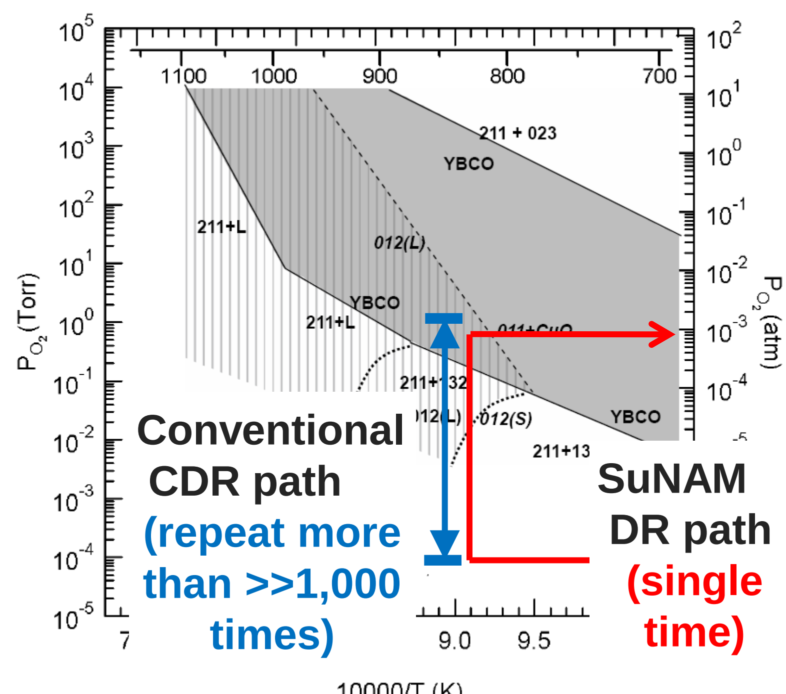
Welding technology already developed by Nexans

Nexans patent

Korean approach: high growth rate CC's

- RCE-DR : Reactive Co-Evaporation by Deposition & Reaction
- High rate co-evaporation to the target thickness (> 1 μm) (6 ~ 10nm/s)
- Fast (<< 30 sec.) conversion from amorphous glassy phase to superconducting phase (~ 100 nm/s)
- Simple, higher deposition rate & area, low system cost
- Easy to scale up :single path





SUNAM

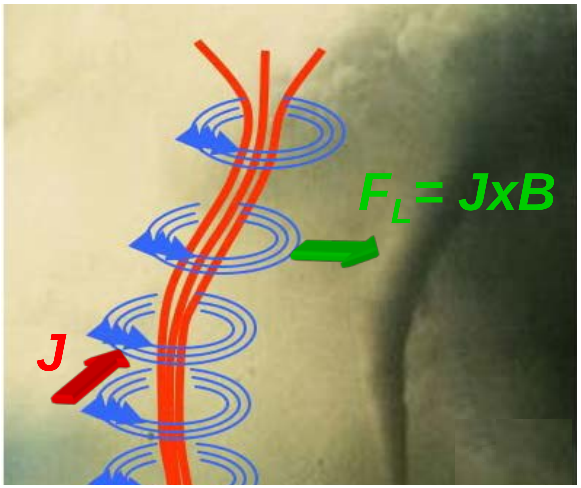
IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2013
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

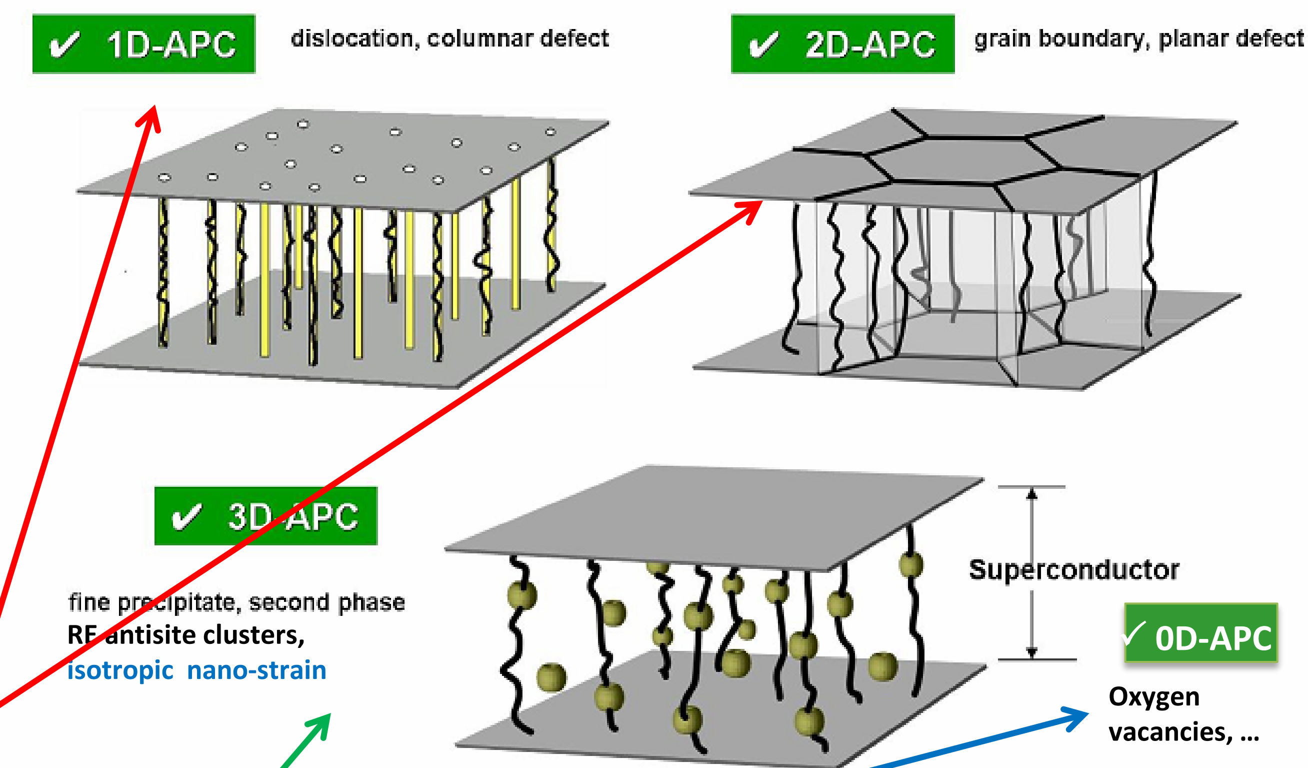
ICMAB

Vortex pinning in YBCO Nanocomposites

CSIC

Nanoengineering is the path towards control of vortex pinning and enhace performances





Courtesy M. Matsumoto (adapted)

Anisotropic and strong defects

Isotropic and strong defects

Isotropic and weak defects

The role of interfaces in nanocomposites are the key issue

… but there always exits superposition of different contributions in a single material

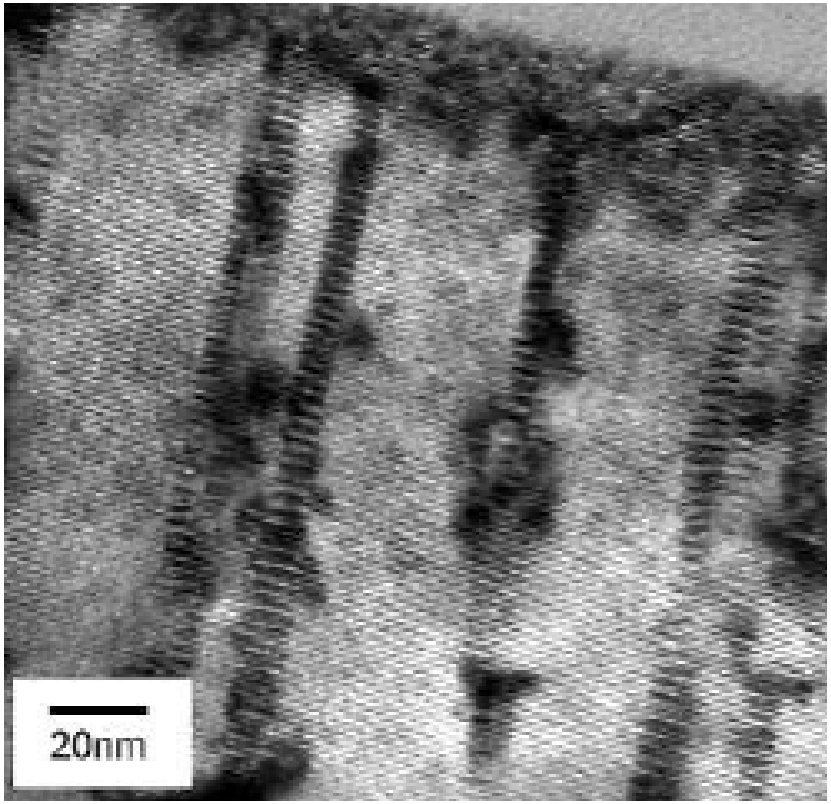
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

PLD YBCO nanocomposites

Interfaces and associated strains, defects, … can be tuned and maximized and vortex pinning properties enhanced

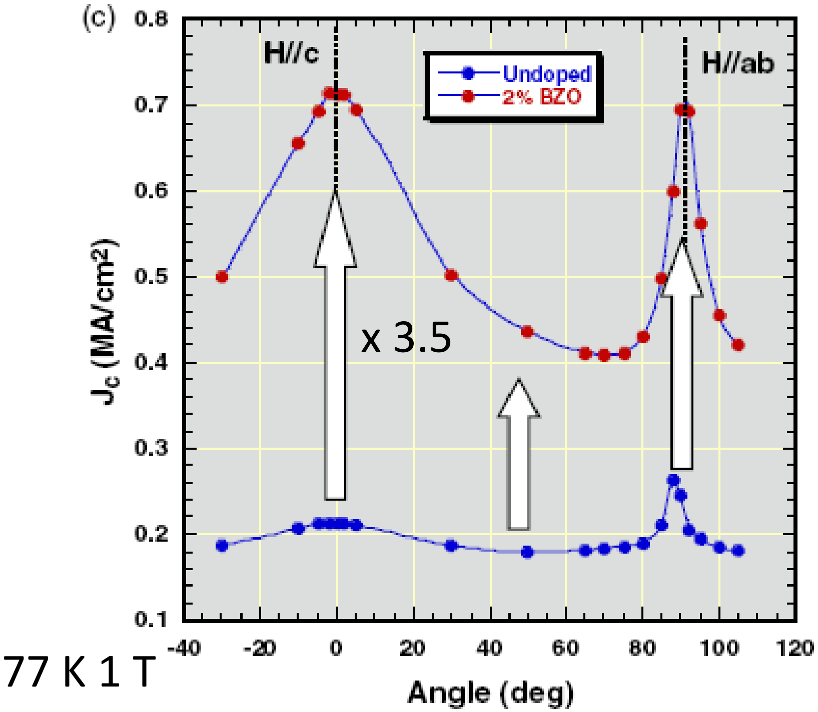
$YBa_2Cu_3O_{7-x}$ – $BaZrO_3$ nanocomposite by PLD/MOCVD

Epitaxial YBCO-BZO interfaces



J. McManus-Driscoll, Nat. Mat. 3, 439(2004)

Self-organized $BaZrO_3$ nanorods



Anisotropic increase of performances

Y. Yamada, APL 87(2005) B. Maiorov, Nat Mat 8 (2009)

S. Kang, Science 311 (2006)

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

PLD: YBCO co-doping with Nb and Ta

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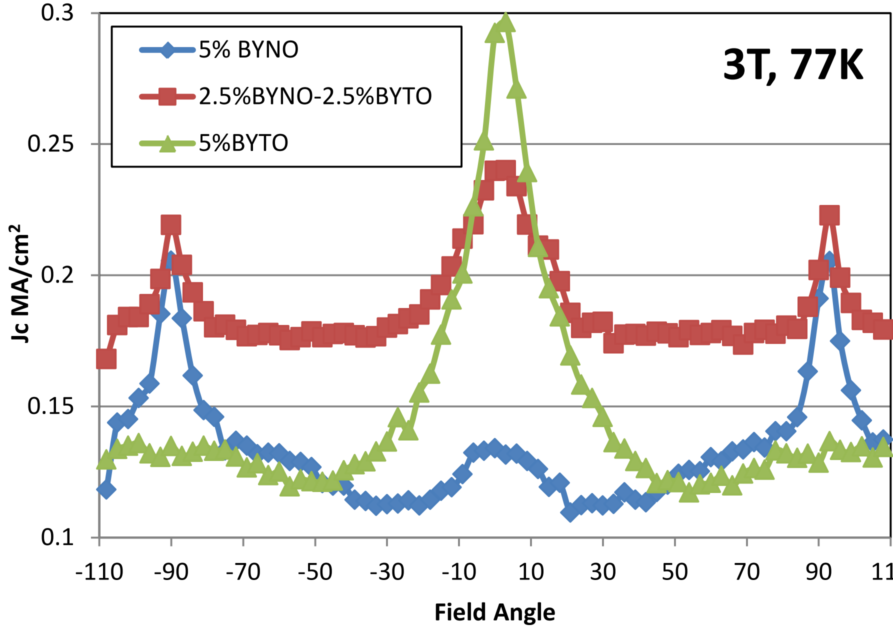
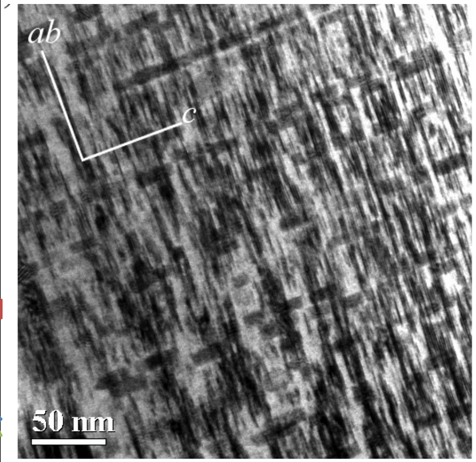
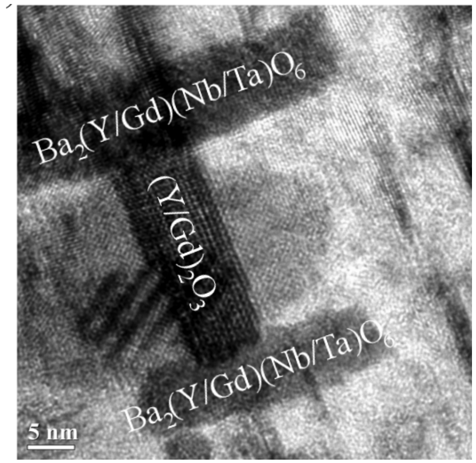
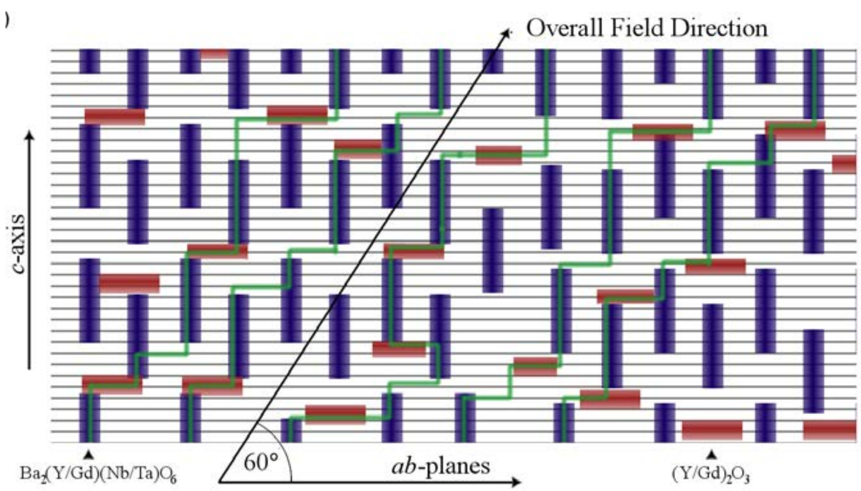
Nanorods / nanoplatelets

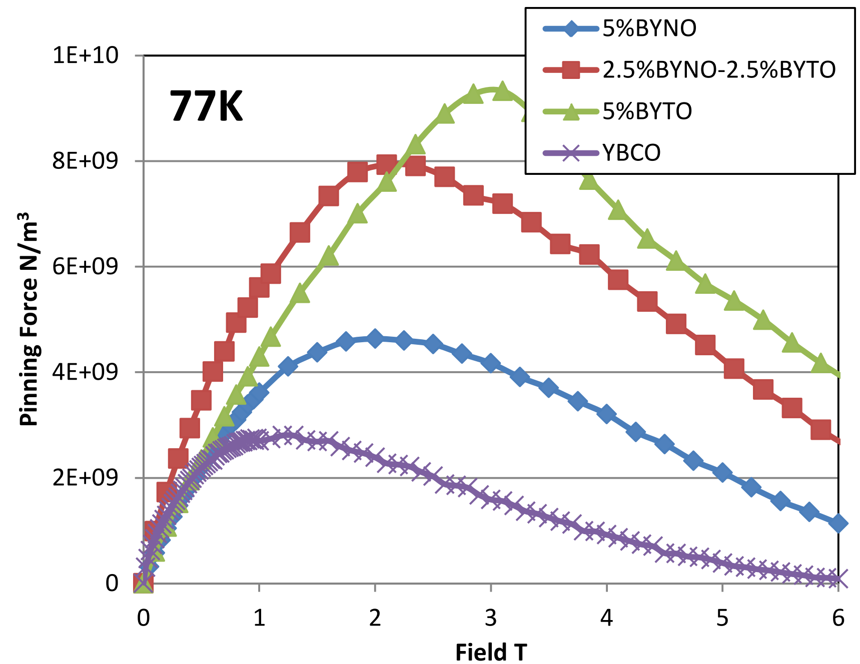






- Superior, but complex, angular properties
- Excellent and easy tunability





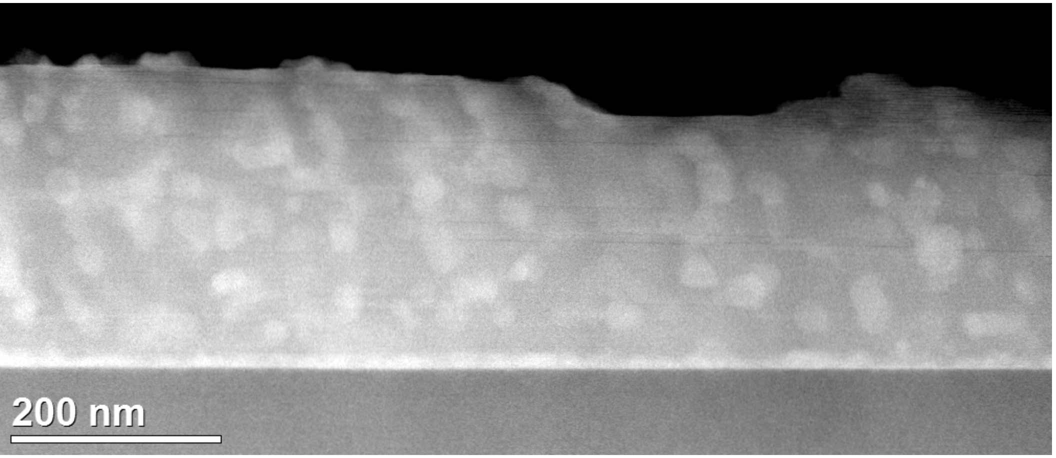
M.Bianchetti, G.Ercolano, A.Kursumovic , J.L. Macmanus-Driscoll (unpublished)

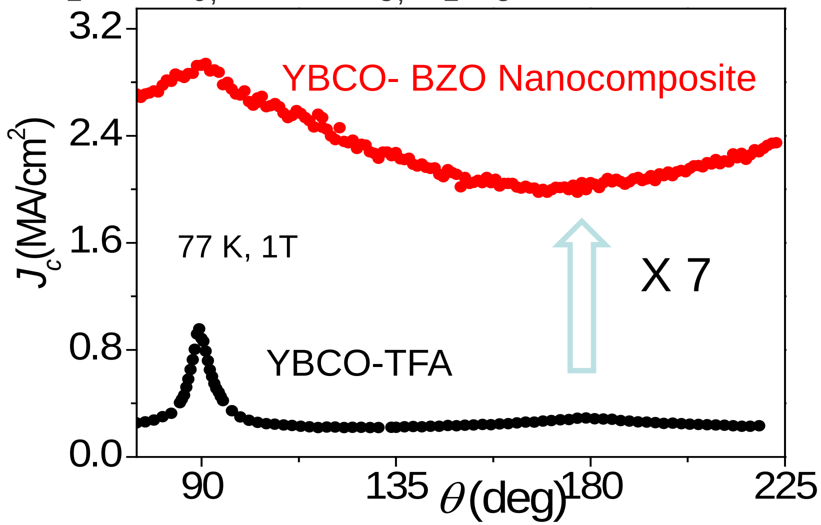
B. Maiorov, Nat Mat 8 (2009)

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

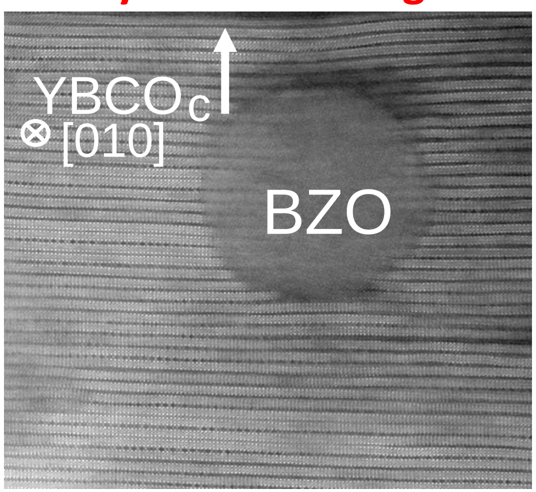
Solution derived- YBCO nanocomposites

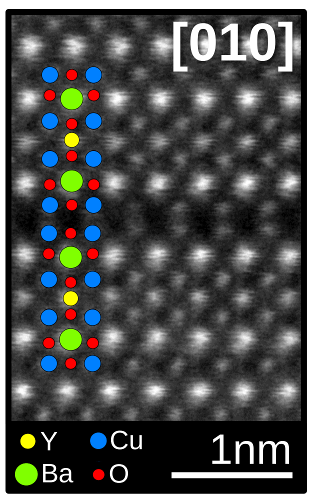
Addition of metal-organic salts in the TFA precursor solution : Spontaneous nanoparticle segregation within $YBa_2Cu_3O_7$ matrix : $BaZrO_3$, Ba_2YTaO_6, $BaCeO_3$, Y_2O_3

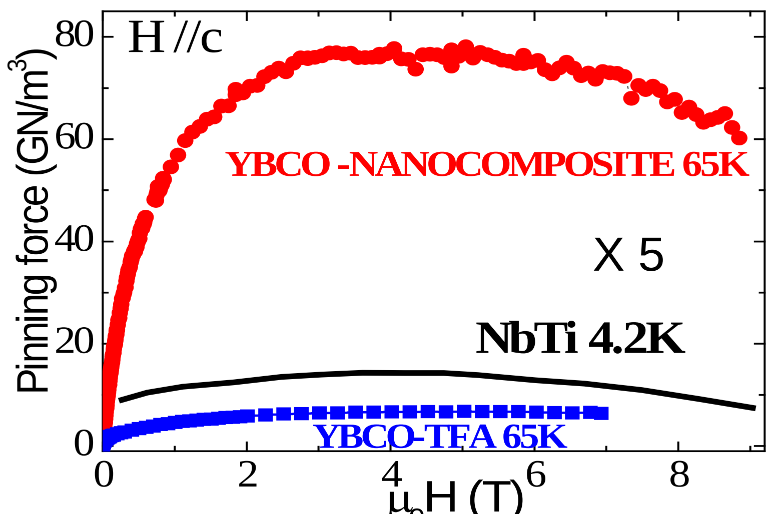




Incoherent YBCO-BZO interfaces give rise to high density of Y248 intergrowths







The highest isotropic performance ever found in any superconducting material

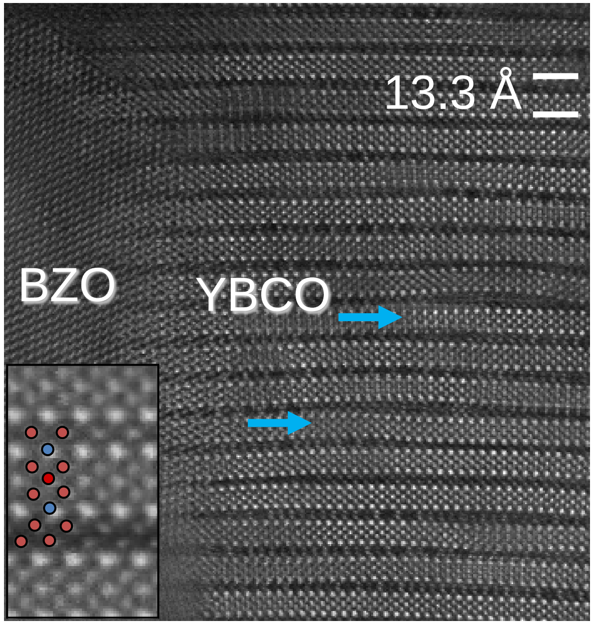
A. Llordés, et al. Nat. Mater , 11, 329 (2012)
J. Gutierrez et al, Nat. Mater. 6, 367 (2007)

New vortex pinning mechanims in CSD YBCO nanocomp.

ICMAB

eurotapes

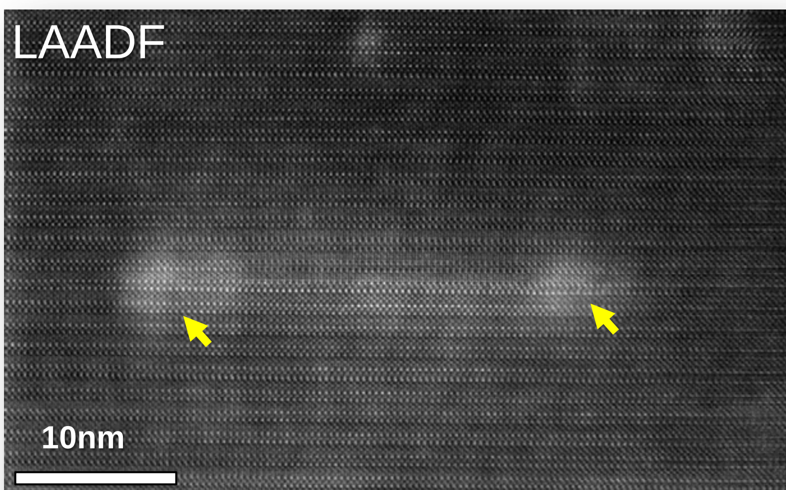
Addition of metal-organic salts for TFA nanocomposites with Y_2O_3, $BaZrO_3$, Ba_2YTaO_6, $BaCeO_3$ nanoparticles

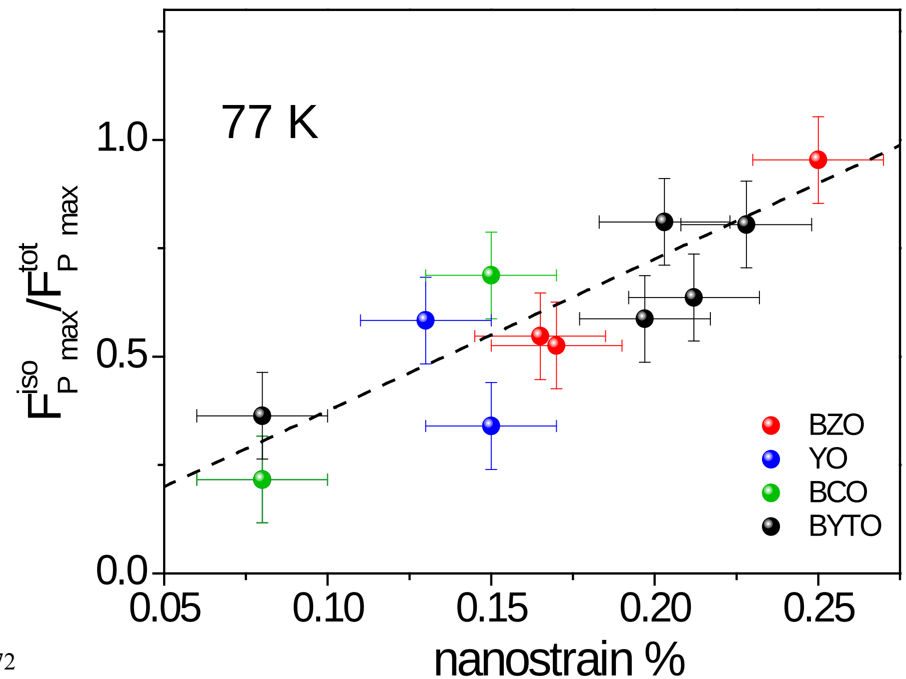


Nanostrain is the key issue for the performances achieved

- *Local lattice strains generated by CuO intergrowth*
- *XRD: nanostrain determination*

A. Llordés, et al. Nat. Mater , 11, 329 (2012)
J. Gutierrez et al, Nat. Mater. 6, 367 (2007)
M. Coll et al., SUST 26, 015001 (2013)

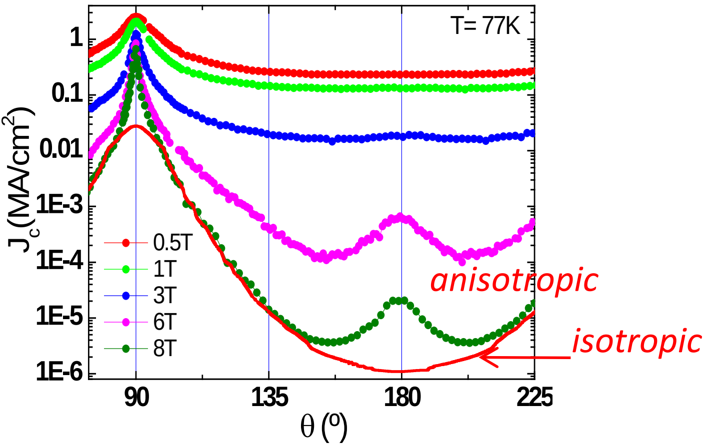




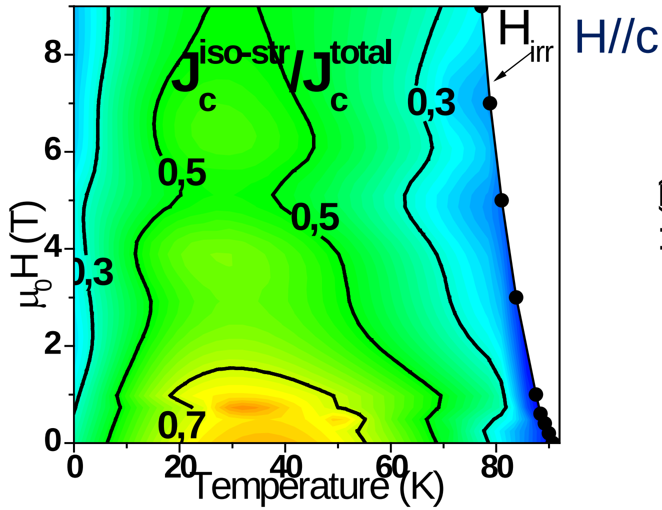
YBCO CSD nanocomposites: isotropic pinning landscape

ICMAB

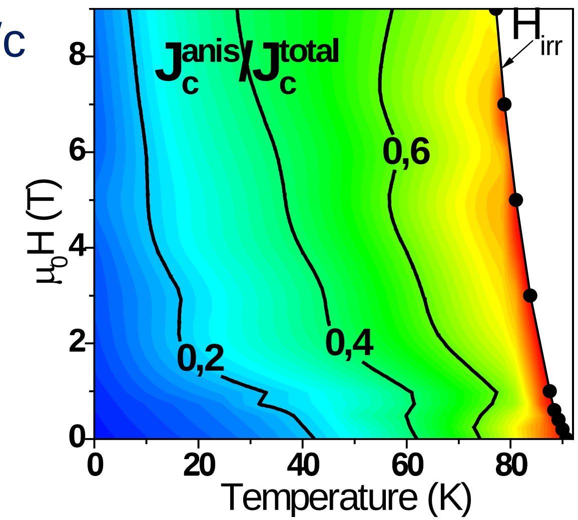
YBCO



Isotropic J_c(H)

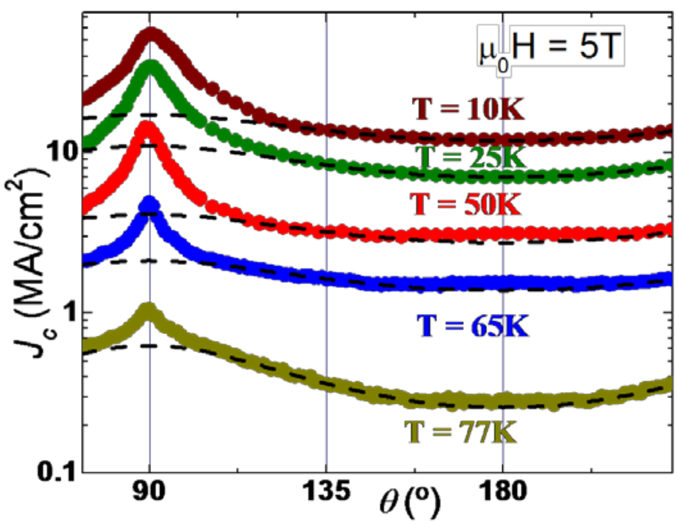


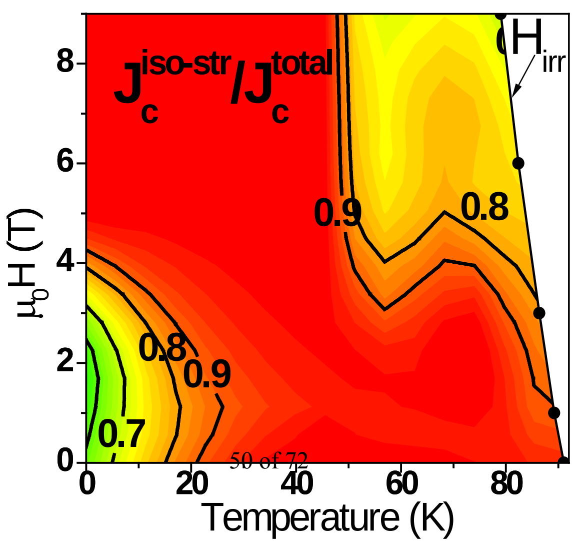
Anisotropic J_c(H)

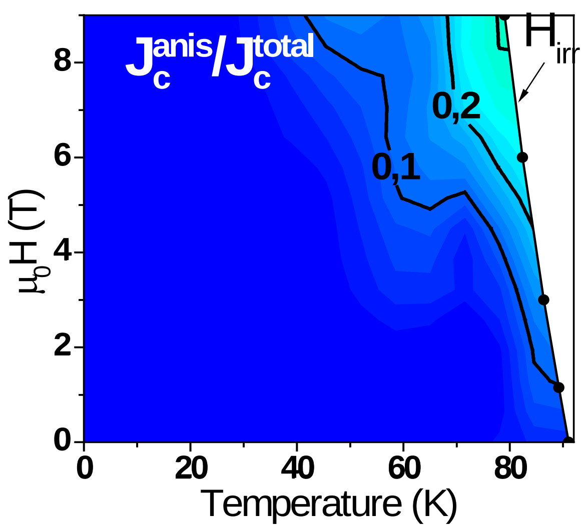


YBCO – BZO nanocomposite

*T.Puig et al., SUST **21,** 034008 (2008); J. Plain et al, PRB 65, 104526 (2002); J.Gutierrez et al., Appl. Phys. Lett. 90 (2007)*





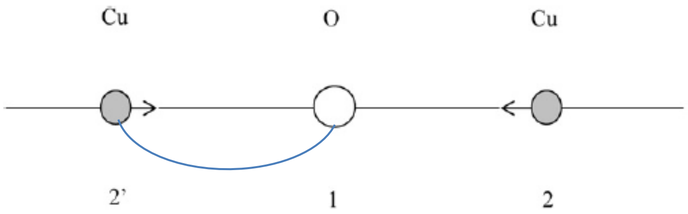


Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

New vortex pinning proposal: Bond contraction pairing model

Coupling lattice strains with Cooper pair supression

BCP :

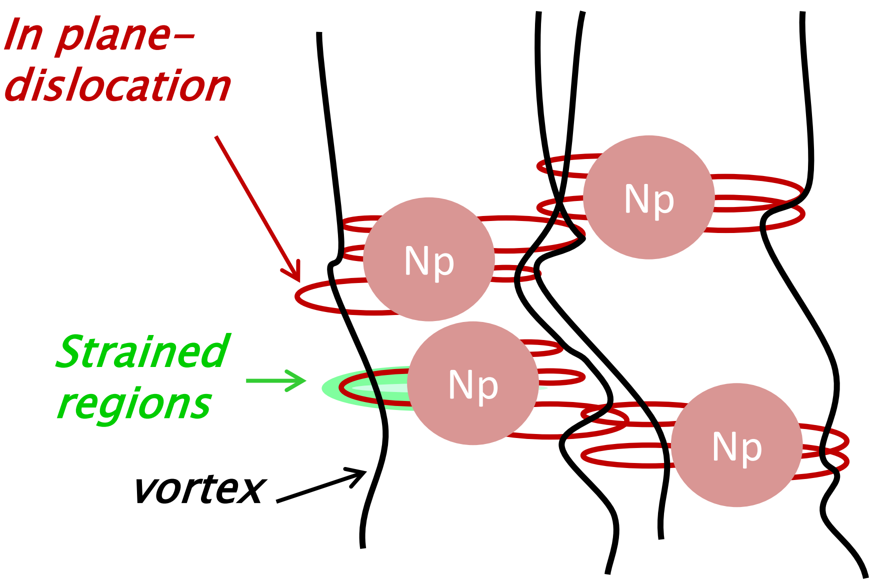


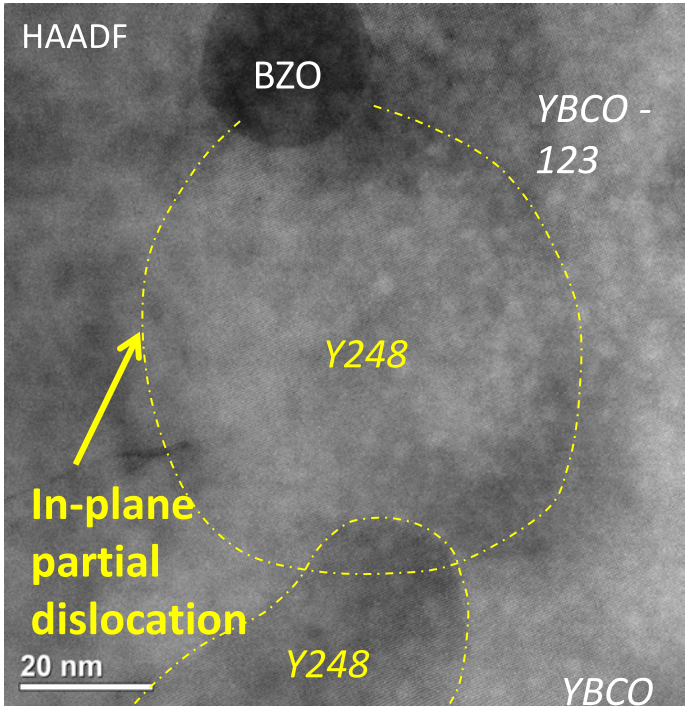
Pair breaking energy:

$$2\Delta = 4\frac{(t_{CuO})^2}{U} - 8t_0$$

t_{CuO} ($\propto 1/d_{CuO}^5$)

- Δ : pseudogap
- t_{CuO} : transfer integral between Cu *d* and O *p* orbitals
- *U* : on-site Coulomb repulsion
- t_0 : half bandwidth

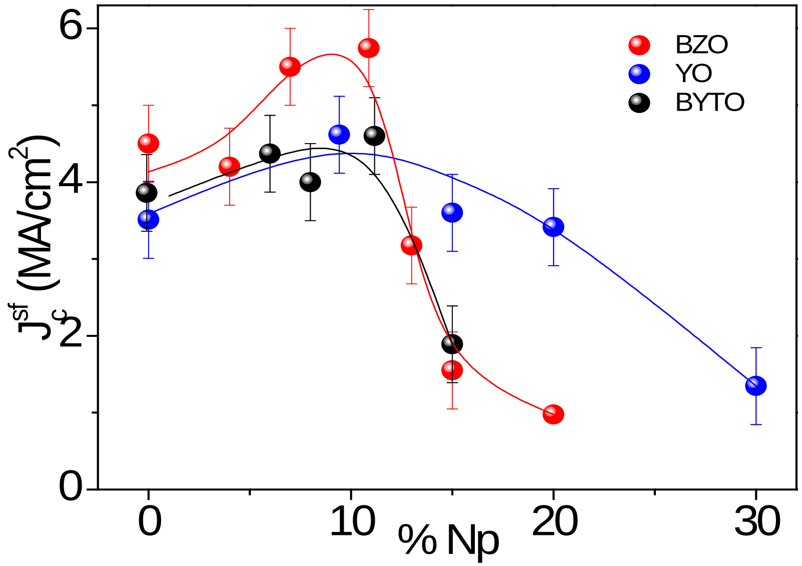




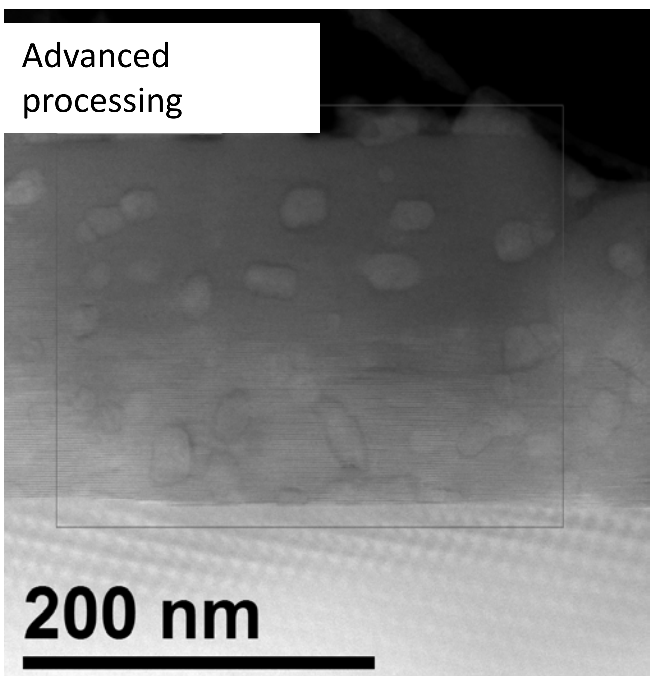
Huge dislocation density ~1-5 x10^{12} cm^{-2}

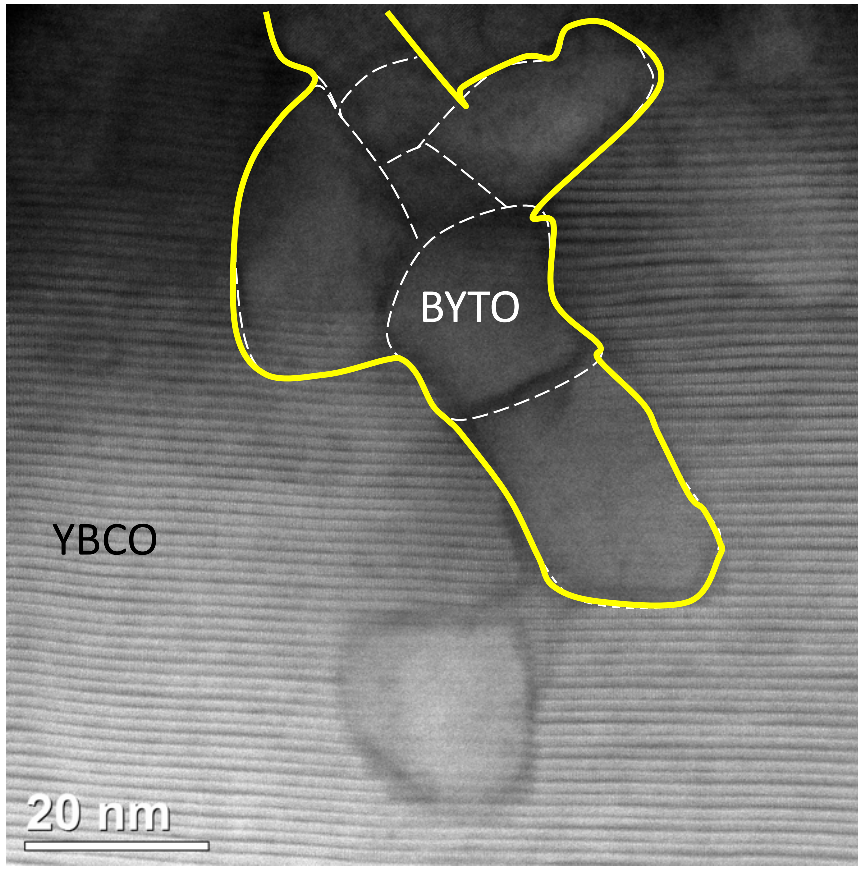
G. Deutscher, P.G. de Gennes, CRAS (2007) / G. Deutscher, APL (2010); / A. Llordes et al., Nat. Mater 11, 329 (2012)

Can we further improve J_c^{sf} and F_p ?



***J_c^{sf}*: Blocking effects of nanodots on percolating current should be reduced**



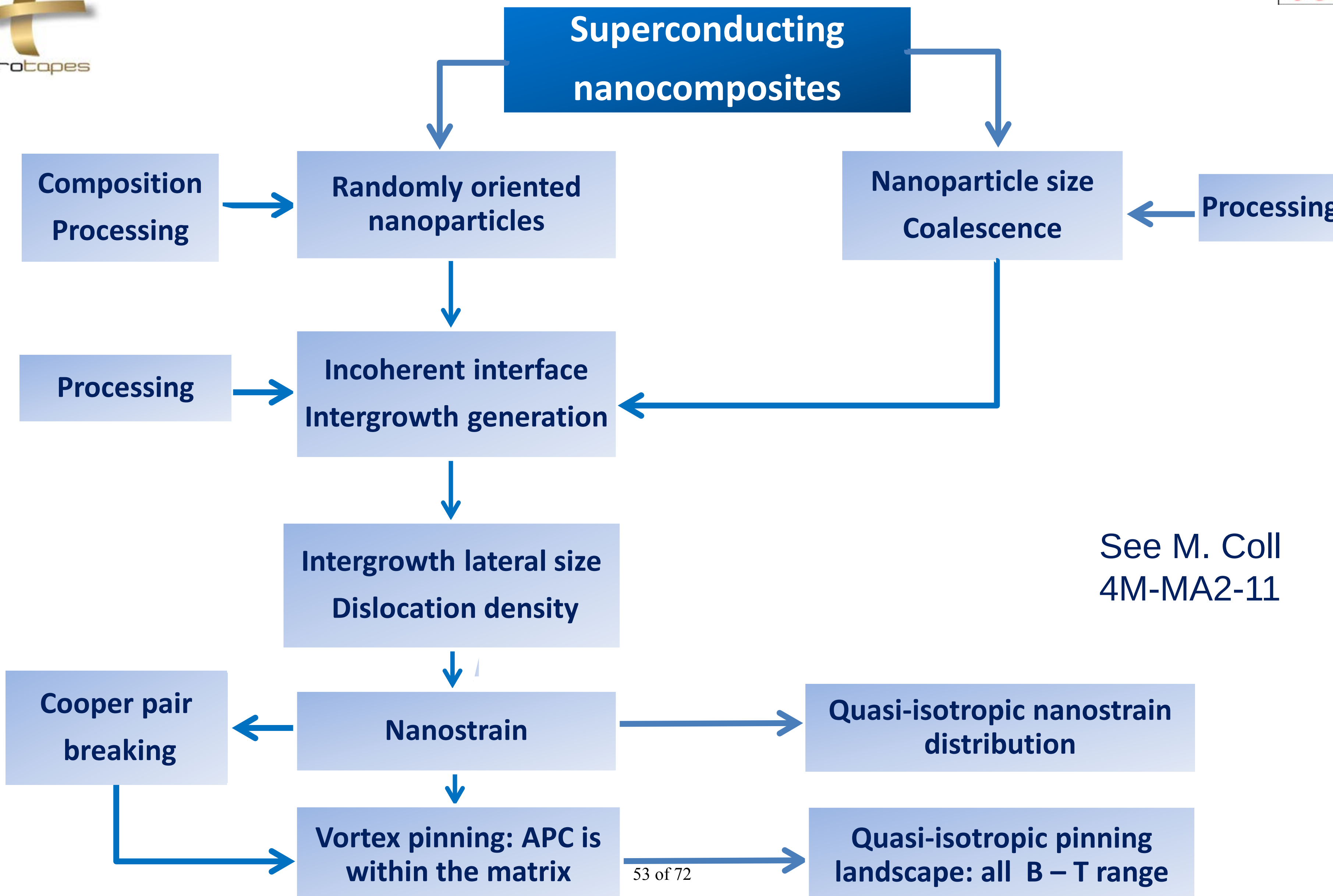


J_c(H): Enhanced nanostrain avoiding np coalescence

See M. Coll 4M-MA2-11

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2013
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

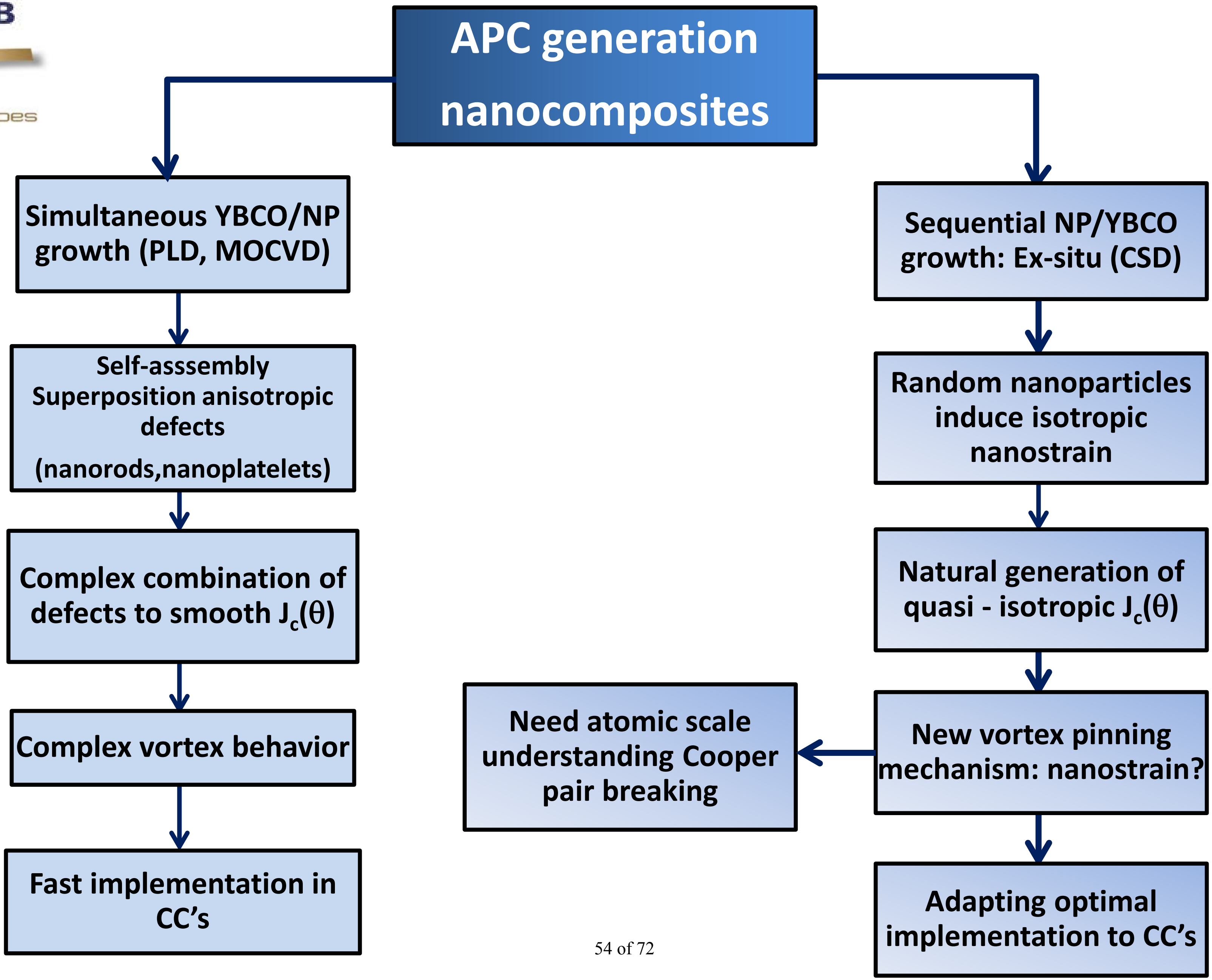
CSD: novel vortex pinning approach



See M. Coll
4M-MA2-11

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Vortex pinning issues in YBCO nanocomposites



Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014)

What's next?: engineered nanocomposites from colloidal solutions

Thermal (2h) and MW (10 min) synthesis

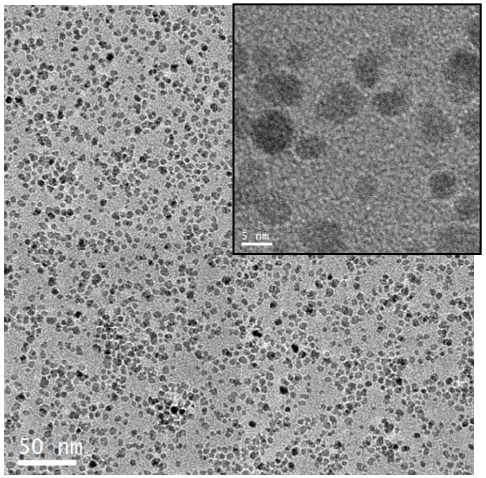
Highly dispersed and crystalline nanoparticles (~90 mM)

- MFe_2O_4 NPs (M = Mn, Fe, Co, Ni and Zn)
- CeO_2, YSZ, Ru, …

E. Solano et al., J Nanopart Res (2012) 14:1034

$MnFe_2O_4$

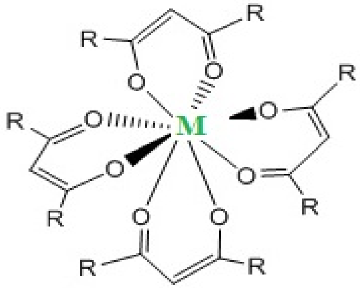
Np size: 5 ±2 nm



- **Stable solutions in alcoholic media**

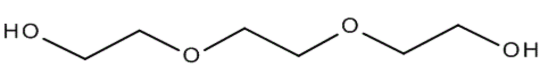
TFA colloidal solutions are stable !

NPs precursor



+

Triethylene glycol (TREG)



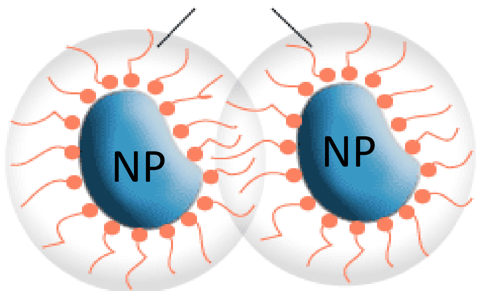
M= Ce, Mn, Fe, Ru, …

R= CH_3, Ph, CF_3, …

Np size:

2±0.4 nm

Stabilizing compound



A. Garzón et al., (to be published)

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

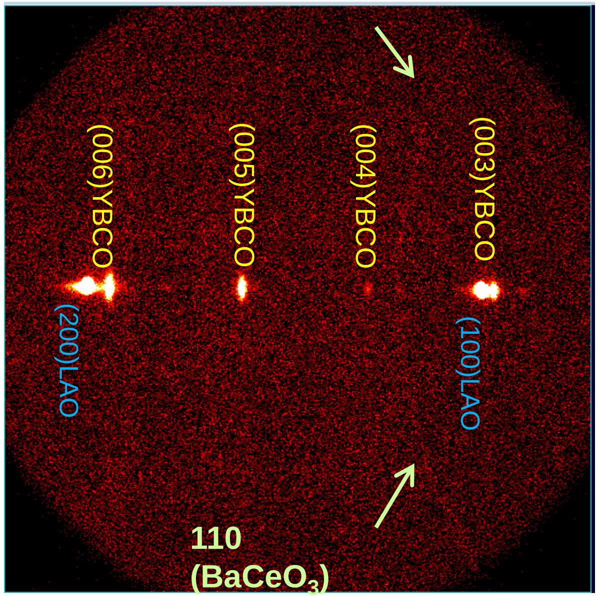
Growth of nanocomposites: $YBa_2Cu_3O_7$ + NP

ICMAB

eurotapes

CSIC

CeO_2 NP size: 2-4 nm

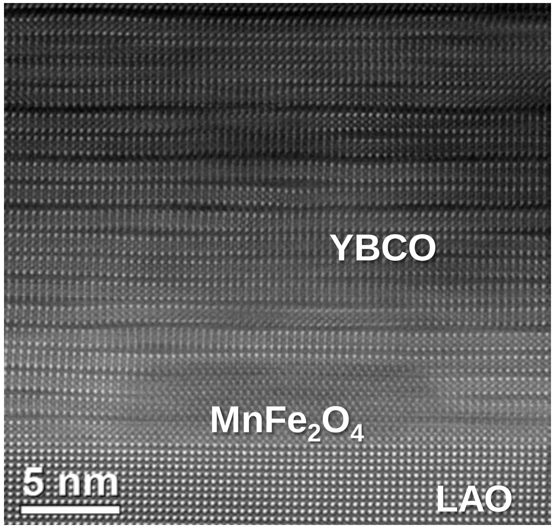


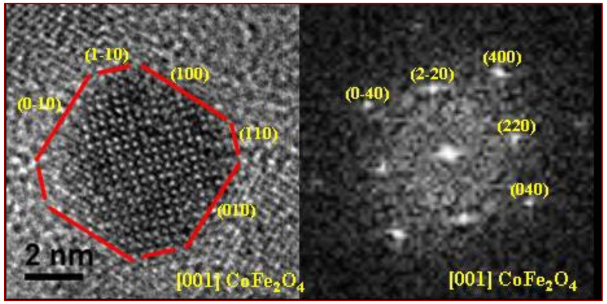
Challenges

- Keep nanoscale dispersion of NP's
- Control chemical reactivity NP's with YBCO precursors
- Avoid coarsening of NP's
- Minimize impurity diffusion into YBCO (keep high T_c)

CeO_2 NPs react with Ba: $BaCeO_3$ NP's are formed
Some NP coarsening occurs (~20 nm)
T_c~ 90 K, J_c= 3-3.5 MA/cm^2

T_c=85.6 K



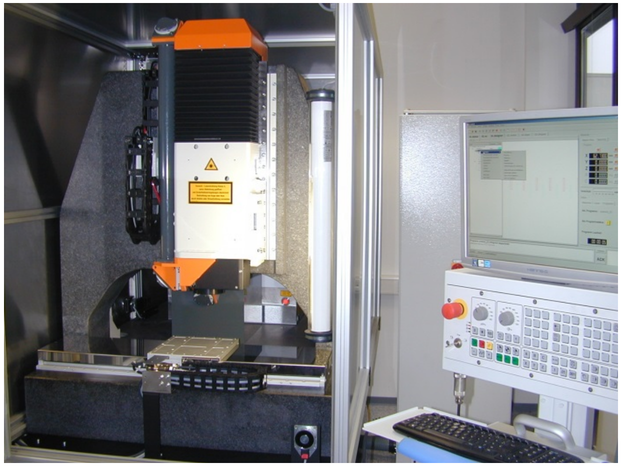


Concentrations of spinel NPs in YBCO: ~ 10 % mole
Some decrease in T_c: Fe diffusion into YBCO lattice?

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

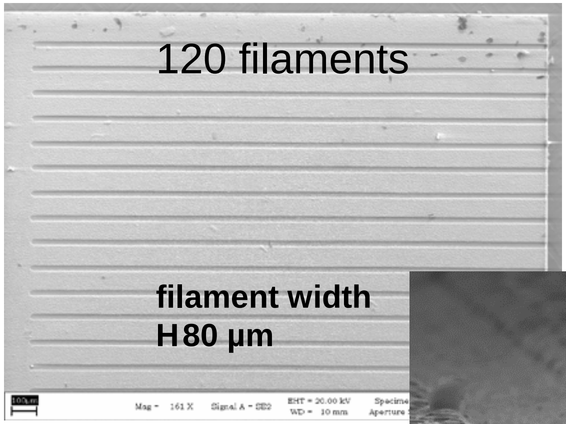
Laser structuring of CC (IR Pico-second laser) at KIT

Karlsruhe Institute of Technology

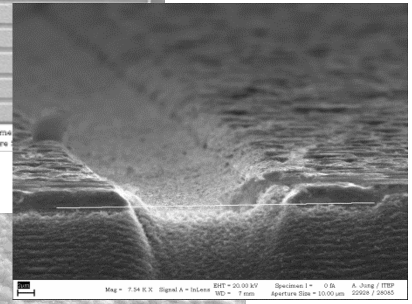


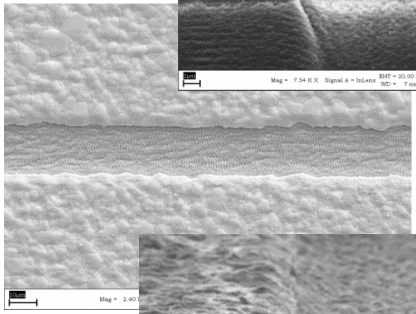
- **KIT Picosec-pulse-laser generates nearly no heat**
- **negligible melting effects at the edges of the groves**

See: EUCAS 3P-WTR-12

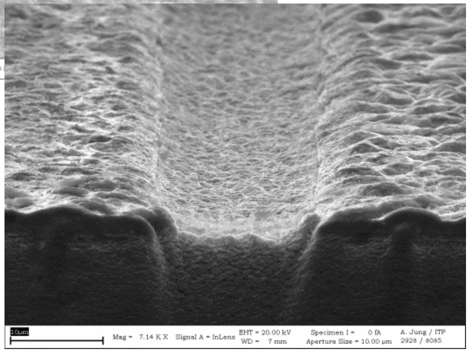


Up to 120 filaments shown (100 / cm-w.)

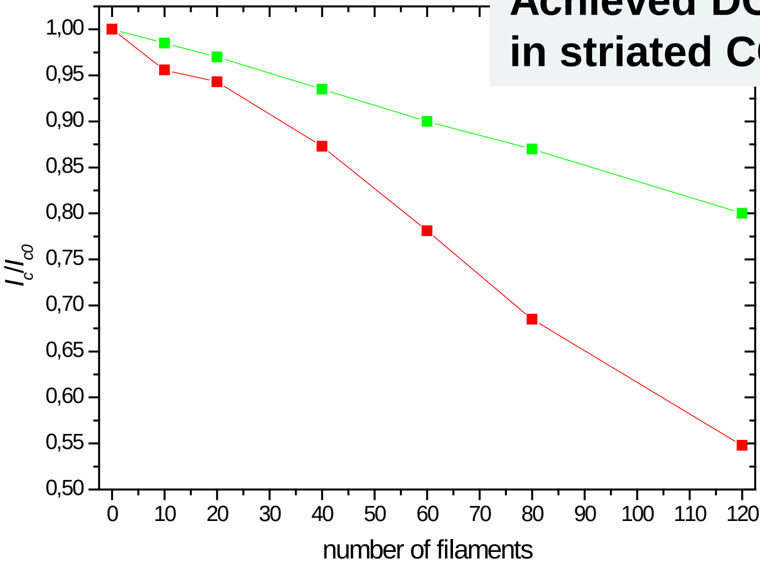




Width
20 micron



Achieved DC Currents in striated CC



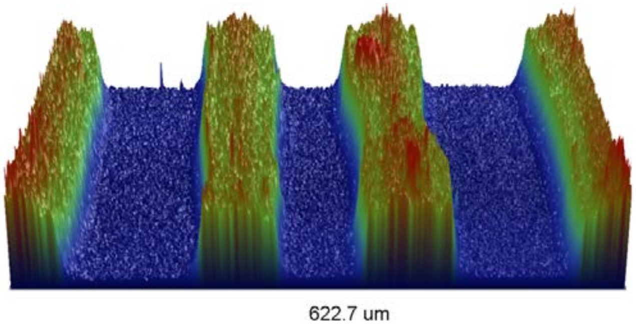
Green curve: expected I_c due to loss of superconducting material in the grove

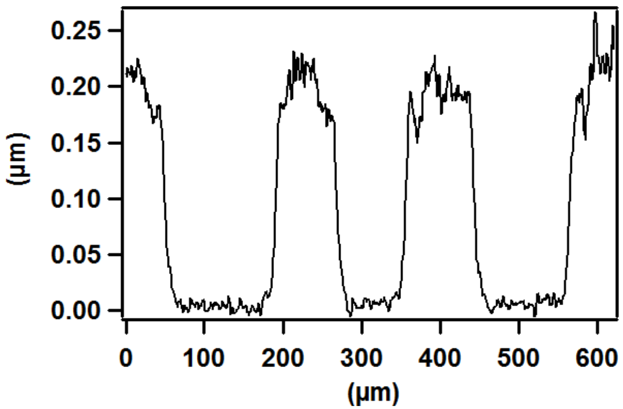
Red curve: measured I_c additional degradation occurs from statistically distributed inhomogeneities

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2013
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

YBCO Patterning by inkjet printing

Water based solutions

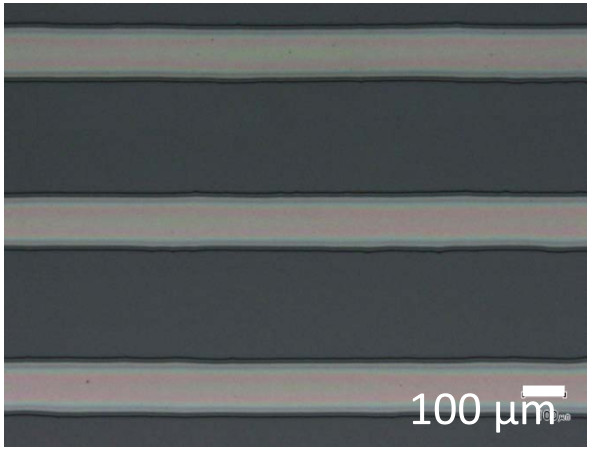


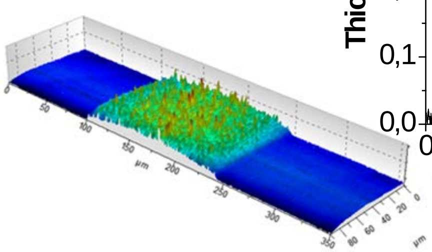


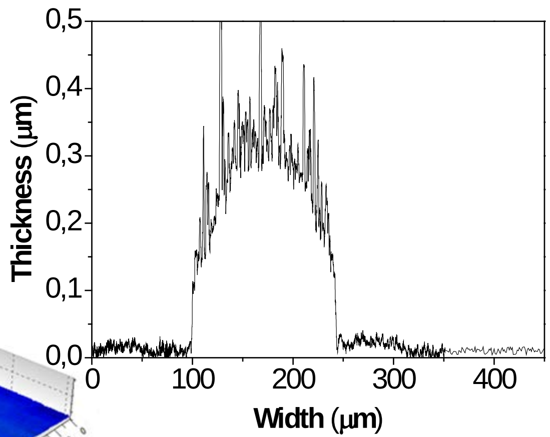
YBCO pattern after a 5 x fold printing sequence, without an intermediate drying step.

The homogeneous lines with average **thickness of 200 nm** at a **width of 200 µm**.

MOD based solutions





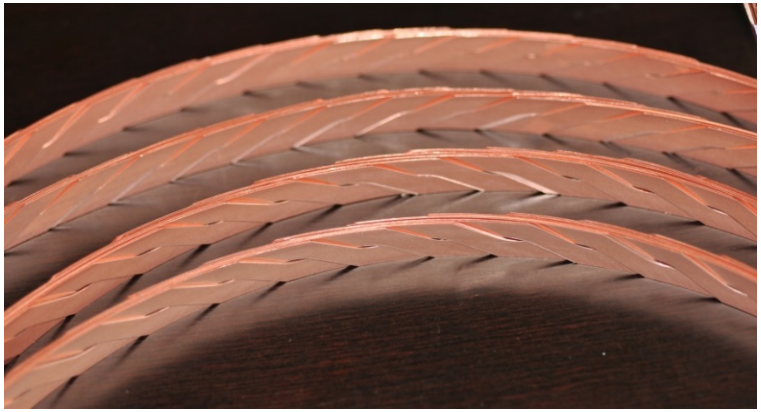


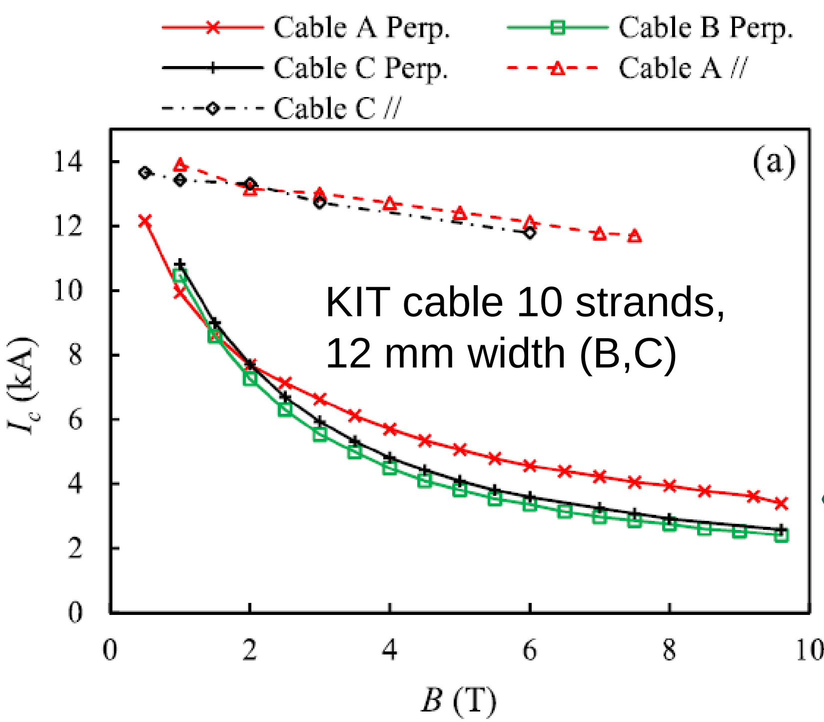
High homogeneity and uniformity along all track length. Tracks are **150 µm x 300 nm**. Similar J_c in all filaments

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Low Temperature performance of KIT Roebel cables

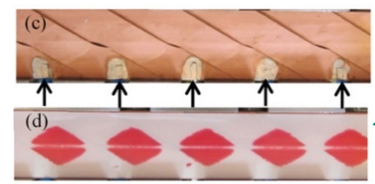
Karlsruhe Institute of Technology





- **> 5 m long produced at KIT**
- **2 m tested at CERN (FRESCA) at 4.2 K and B < 10 T (sample B, C)**
- **I_c = 1 100 A @ 77 K s.f.**
- **I_c = 14 000 A @ 4.2 K s.f.**

Modified cable design will allow > 5 x current enhancement for Fusion magnets, LHC dipoles



Strain sensitive paper

Cable withstands up to 160 MPa transverse stress

Supercond. Sci. Technol. 26 (2013) 065014 (5pp) doi:10.1088/0953-2048/

Electrical characterization of REBCO Roebel cables

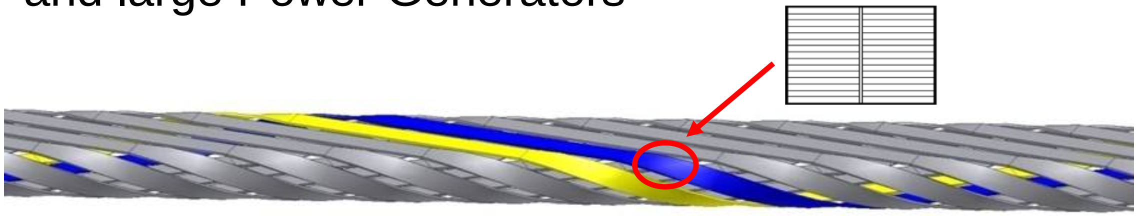
J Fleiter[1,2], A Ballarino[1], L Bottura[1] and P Tixador[3]

[1] CERN, Geneva 23, CH-1211, Switzerland
[2] University of Grenoble, 271 rue de la Houille Blanche, Saint Martin d'Hères, F-38402, France
[3] Grenoble-INP, 46 avenue Félix Viallet, Grenoble, F-38031, France

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

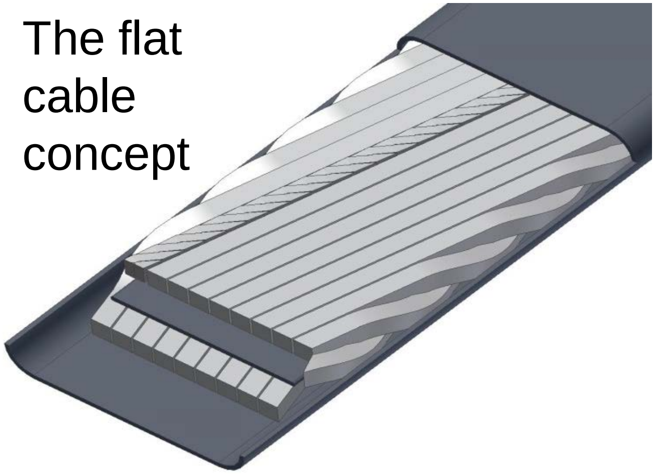
Rutherford Cable with CC Roebel strands

Concept for >20 kA for HTS Fusion Magnets (12T, 50K) and large Power Generators

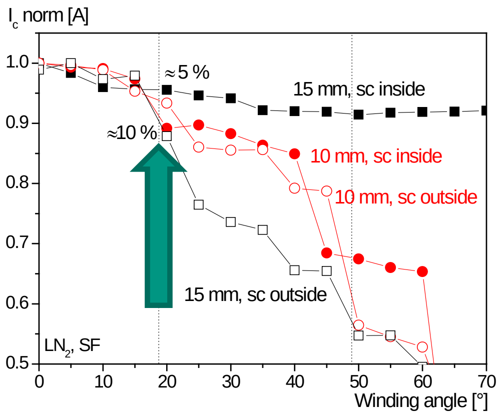


Several strands investigated on the RF-former

The flat cable concept

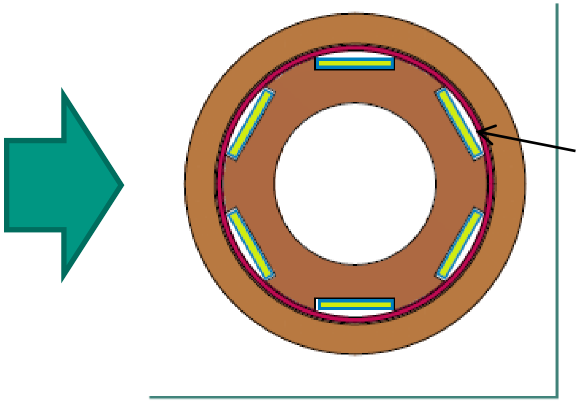


The new and alternative round concept



The edge bending was too strong for crack free Roebel strand application

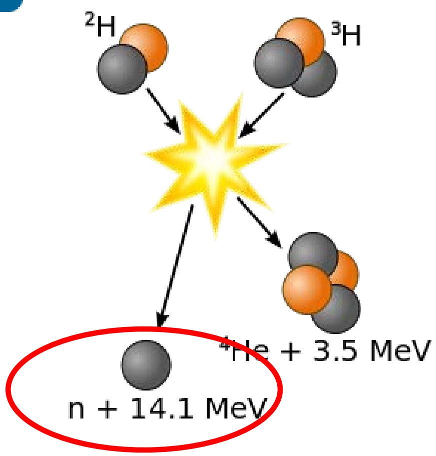
Longer transposition needed



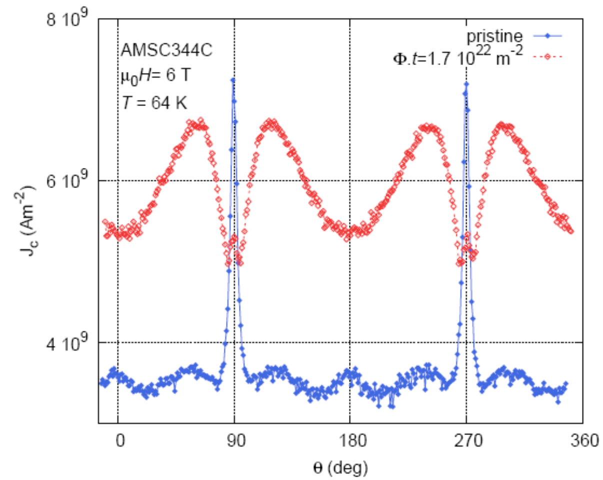
Roebel strands

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

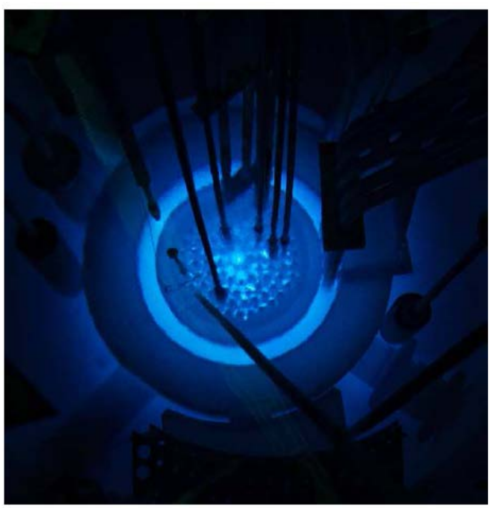
Coated conductors for fusion magnets



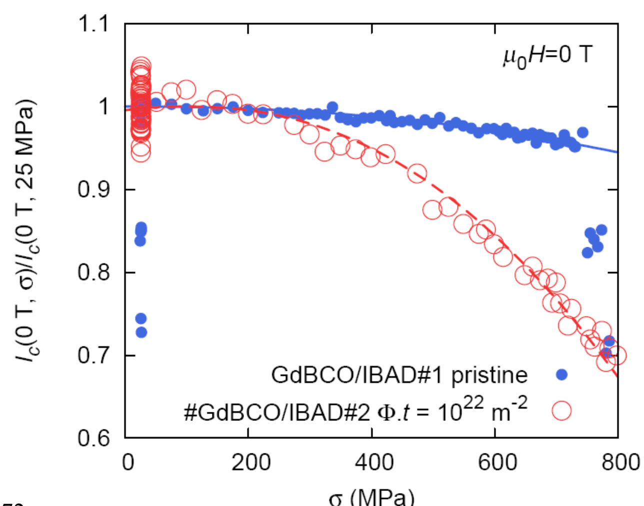
Neutron irradiation changes J_c-anisotropy:



Damage in fusion reactor can be simulated by irradiation in the TRIGA MARK II Reactor



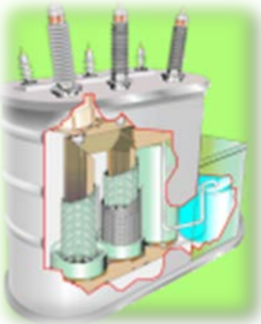
and stress sensitivity:



Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Lower cost and higher performance of conductors is key for propagation!

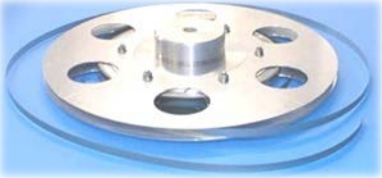
Propagation



Marketable

Applicable

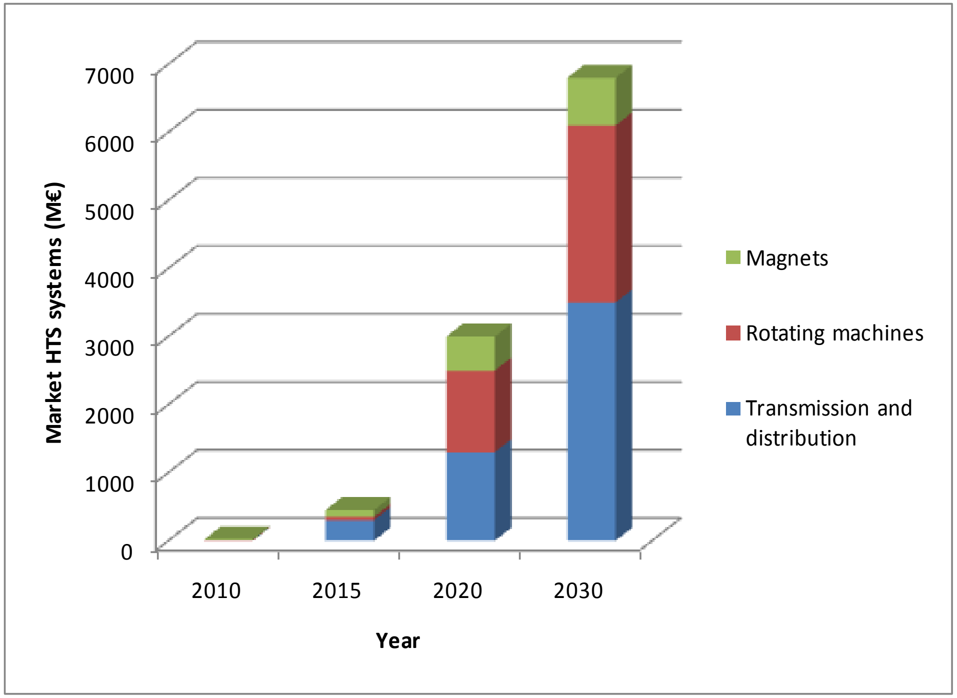
Capable



Courtesy of T. Izumi

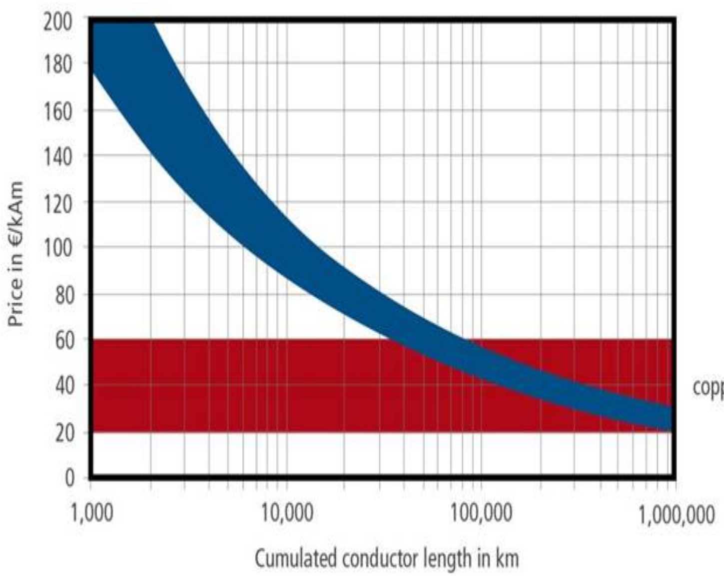
eurotapes

CC's: expected market growth and cost decrease



Estimated world market evolution of SC systems

Throughput and performance are key to reduce cost/kAm: capital investment depreciation and total current



Estimated cost decrease of CC's with cumulated production: operating condition is the real metric

~ 6.5 bn € by 2030 (1.3 bn € in wires)

~ 1.500.000 km/year by 2030 (x 1000 present production)

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Contributions to Power Applications at Applied Superconductivity Conference 2012 in Portland

	Cables	Fault Current Limiters	Rotating Machines	Trans-formers	SMES	Total
Korea	14	42	10	-	14	**80**
China	13	19	11	-	13	**56**
Japan	10	5	7	1	8	**31**
Europe	6	21	14	5	4	**50**
US	7	4	5	-	3	**19**
Others	2	8	3	1	2	**16**
Total	**52**	**99**	**50**	**7**	**44**	**252**

Percentage contributions

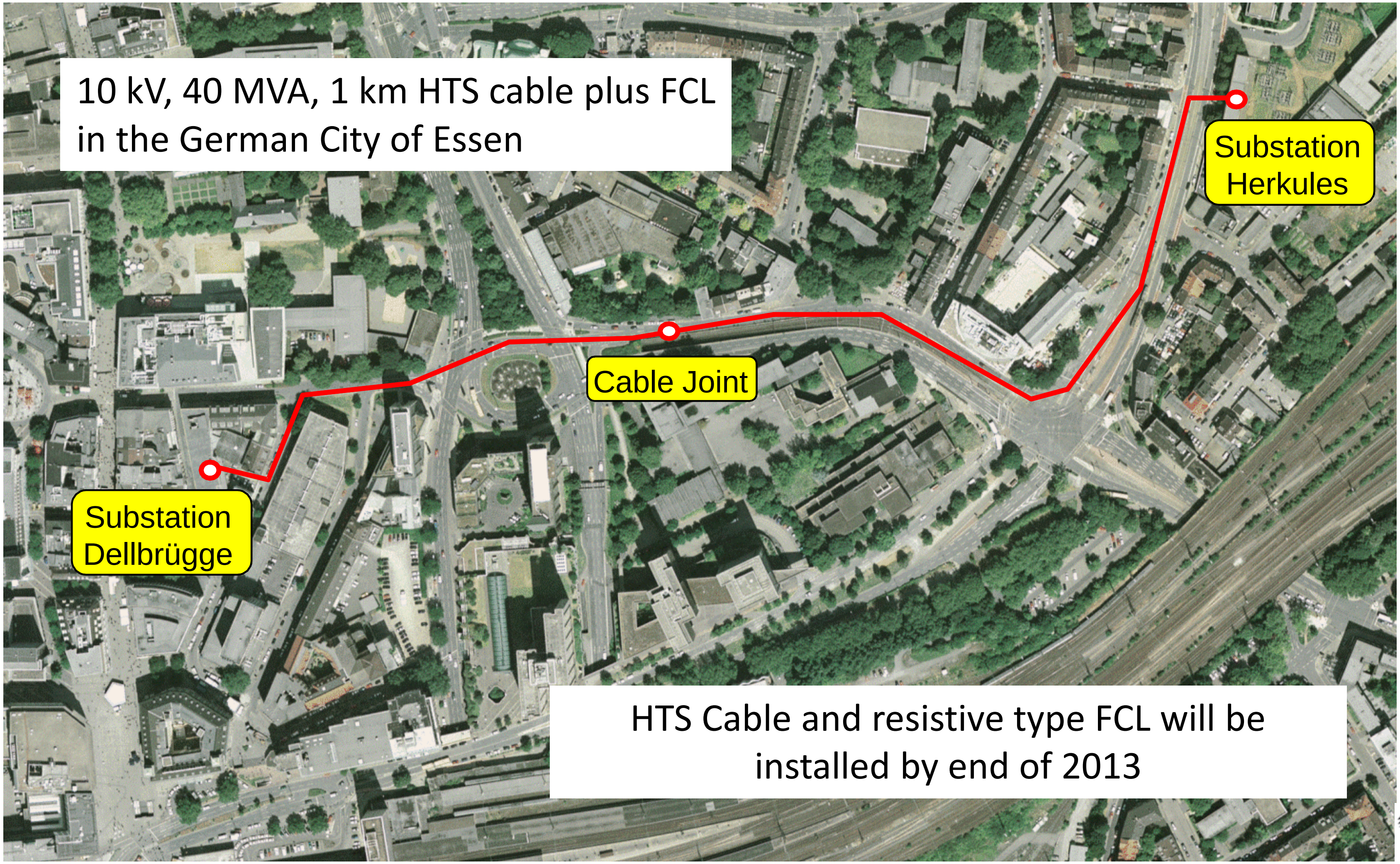
- 66% Asia
- 20 % Europe
- 7 % USA

Asia is taken a leading role in Power Applications of Superconductivity
Significant effort EU and USA. Leadership towards a new electrical paradigm?

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Superconducting Cables
Ampacity Project 09/2011-2/2016

AMPACITY
Smart grids for the city



Luftbild: "Darstellung aus HK Luftbilder / Karten Lizenz Nr. 197 / 2012 mit Genehmigung vom Amt für Geoinformation, Vermessungund Kataster der Stadt Essen vom 13.02.2012"

Source: M. Stemmle et. al. „40 MVA HTS Cable and Fault Current Limiter Installation", ASC Conference 2012, Portland USA

Federal Ministry of Economics and Technology

VORWEG GEHEN nexans KIT Karlsruhe Institute of Technology

PtJ Projektträger Jülich Forschungszentrum Jülich

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

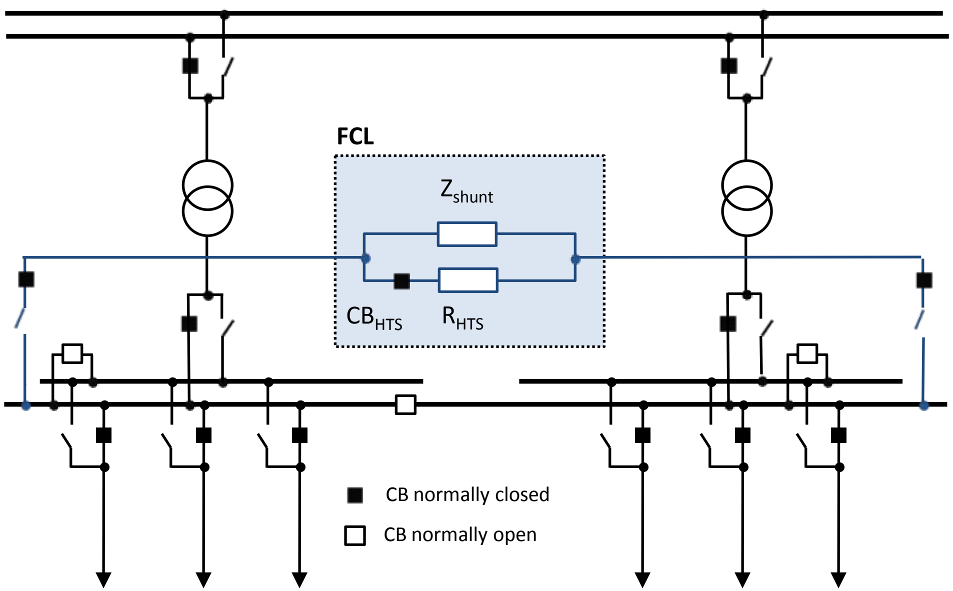
EU FP7 ECCOFLOW Superconducting FCL

2010-2014

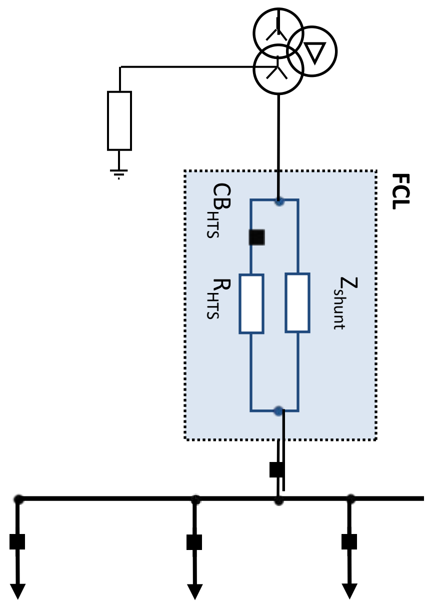
Resistive FCL 1 kA, 24kV, YBCO

One resistive SCFCL design fits two different applications

Busbar Coupling



Transformer Feeder



Endesa Grid in Mallorca, Spain (6 months 2013)

Slovakia, permanent installation

Other FCL:

Bruker (10 kV, 800 A inductive), Italy (9 kV, 3.4 MVA Resistive) , Russia (3.5 kV, 650 A Resistive)

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

Rotating Machines : Synchronous Machines at Siemens

4 MW HTS II – Long term field test at Siemens motor factory in Nuremberg

Test results:

- Loss reduced by 50 %
- Full capacitive power
- High overload stability
- Low voltage drop
- Low total harmonic distortion
- More than 7500 operating hours
- Safe operation

Figure: Siemens

None of the shutdowns caused by HTS winding or cooling!
All operating states and shutdowns tolerated by the system!

Source: Tabea Arndt. „Experience, status and prospects of HTS rotating machines with 1G and 2G HTS at Siemens “, ASC Conference 2012, Portland USA

Other Rotating Machines: Wind generator projects (USA, Korea, Japan)

Russia (Synchronous generator, 10 MVA), Oswald (Torque motor 26000 Nm ,156 kW, 57 rpm)

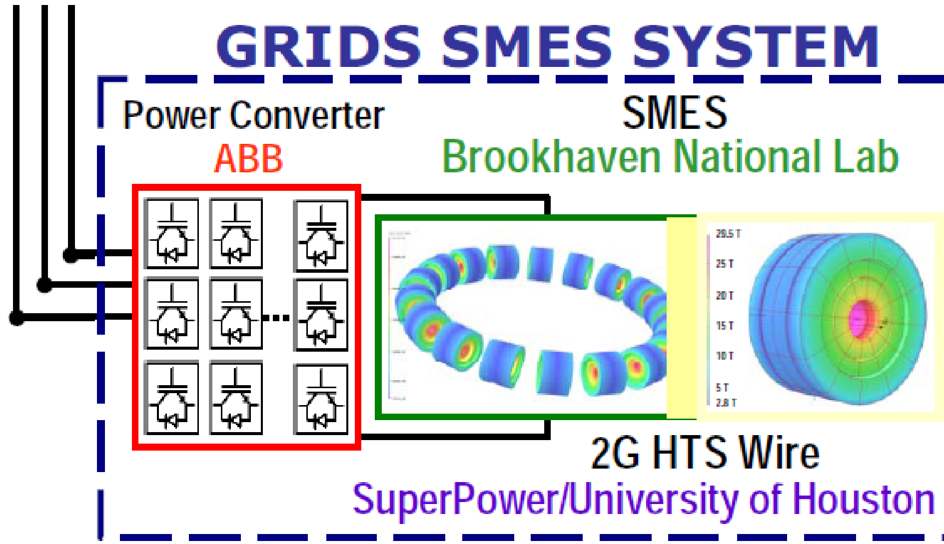
IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2013
Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

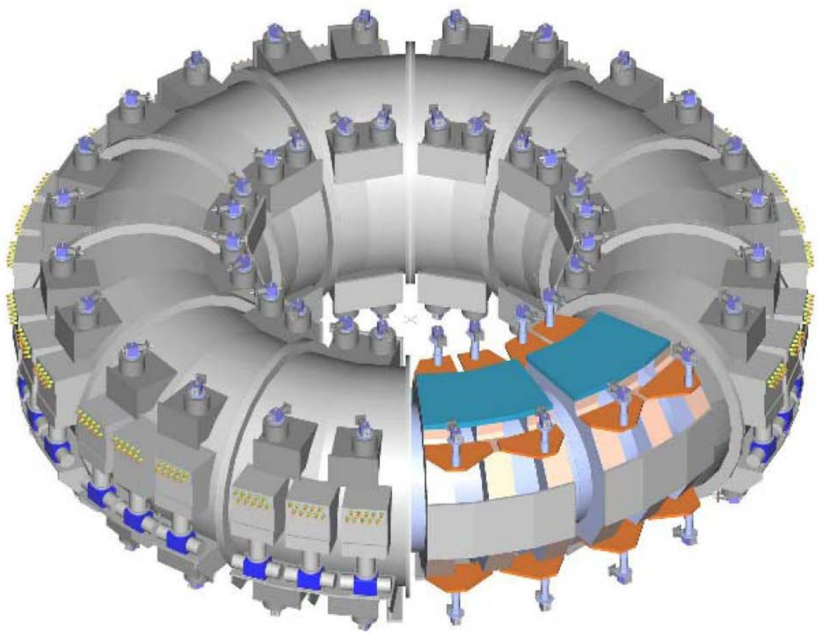
HTS SMES
(Superconducting Magnetic Energy Storage)

USA

25 T, 20 kW, 3 MJ HTS prototype

HTS - SMES for integrating renewables





10 m

2 GJ, 100 MW for load compensation

JAPAN

High power density and low discharge time energy storage for smart grids

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

New National Projects in JAPAN

"Development of HTS Coiling Technology"

(2013~2017 $9M/year) *Awarded !*

Realization of He-less Medical Magnet

1. HTS Coils for MRI

- 10ppm in 40cmΦ with 1 ppm/h @ 3, 10T

2. HTS Coils for Medical Accelerator

- 100ppm in 10cmΦ under Pattern Excitation to 3T

3. Common Technologies for HTS Coils

- "Coil operated in Liq. N_2" and "Low Loss Coil"
- **"Long CC with High Ic(B)" and "Ultra-low Loss CC"**

Paper based on this presentation was published by Superconductor Science & Technology (SuST, IOP) 27, No. 4, 044003 (2014).

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Conclusions

- After 100 years of superconductivity, materials are ready to transform electrical engineering: contribution to a new energy paradigm

- The input of nanoscience has been essential to meet the challenges faced for high performance coated conductors

- Progress in "all chemical conductors": very promising low cost approach. It requires a solid understanding and control of the whole growth process. Cost reduction is progressing in all CC's.

- Nanocomposites very useful to enhance vortex pinning in HTS. Further understanding of nanostructure versus pinning required: room for improvement

- Power systems based on HTS are being spread all around the world

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