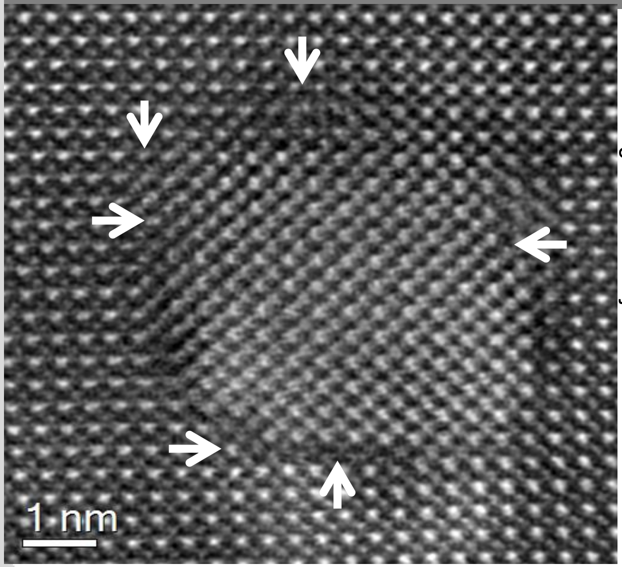
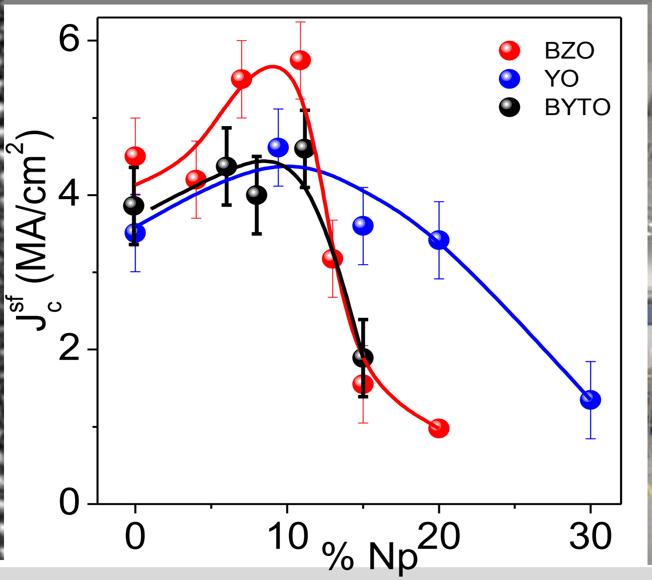
Fortschritte bei der Entwicklung und Produktion von HTS Bandleitern

Bernhard Holzapfel, Institute for Technical Physics, Karlsruhe Institute for Technology,
materials valley workshop, 10^{th} March 2016

Institute for Technical Physics





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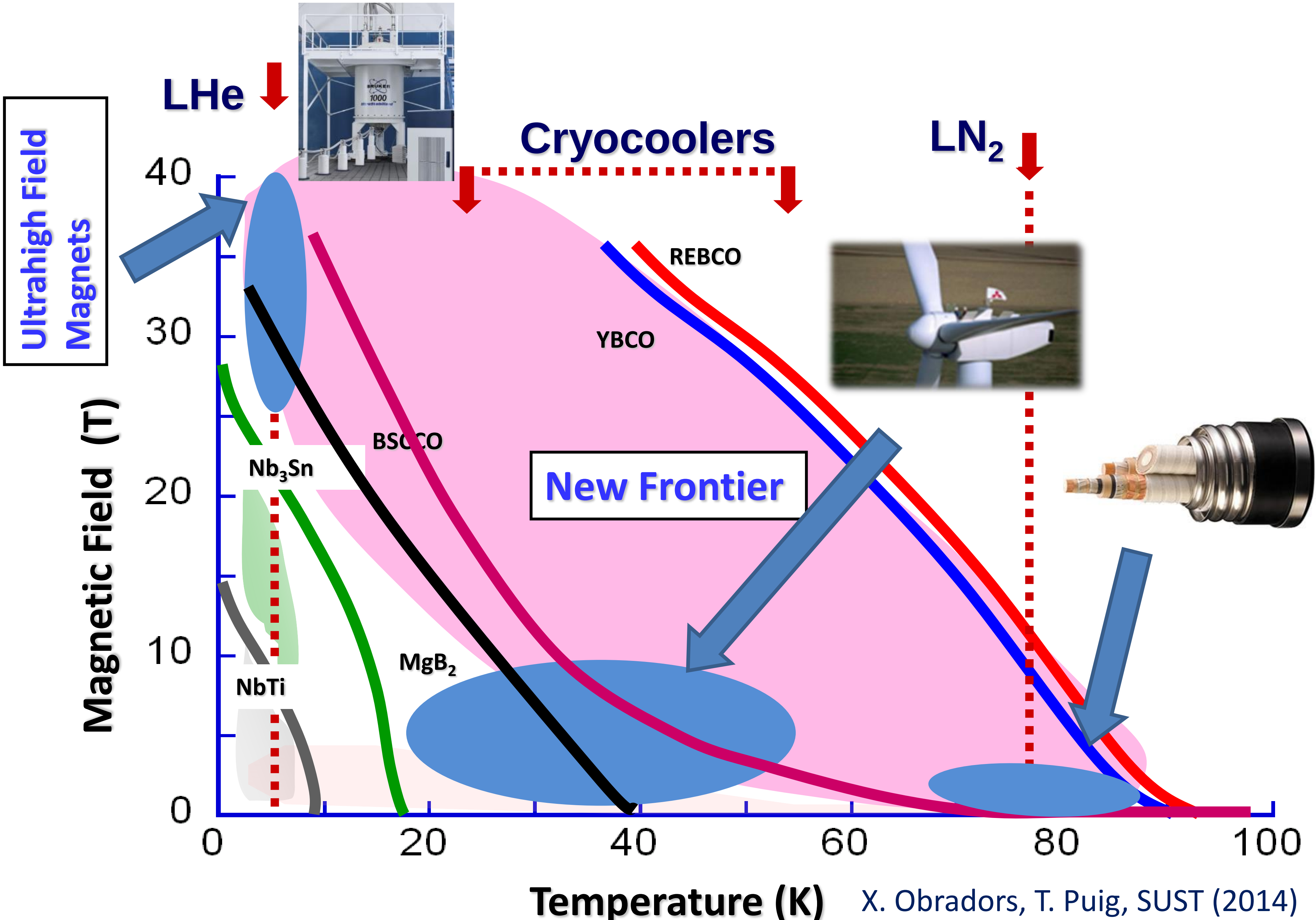
YBaCuO basierte HTS Bandleiter

- RABiTS vs. IBAD basierte Bandleiter
- $J_c(B,T)$ Steigerung mittels Nanoengineering

Entwicklung der HTS Bandleiterproduktion in Deutschland

- Deutsche Nanoschicht
- THEVA
- Bruker

New frontiers for HTS applications



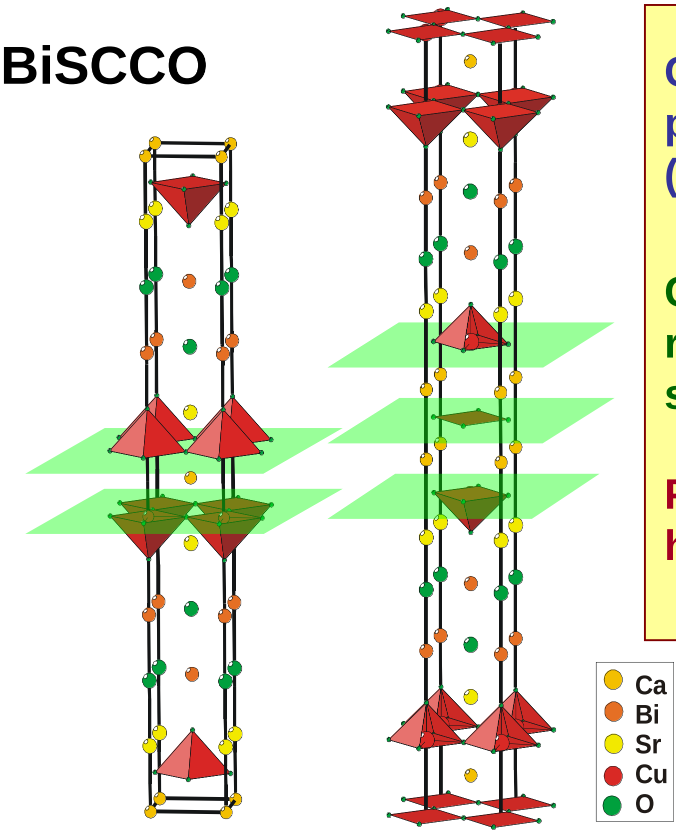
X. Obradors, T. Puig, SUST (2014)

High temperature superconductors

Bi(Pb)-2212 Bi(Pb)-2223

2212 ≈ $(Bi,Pb)_2Sr_2CaCu_2O_x$ (x ≈ 8)
2223 ≈ $(Bi,Pb)_2Sr_2Ca_2Cu_3O_x$ (x ≈ 10)

BiSCCO



T_C = 85K T_C = 110 K

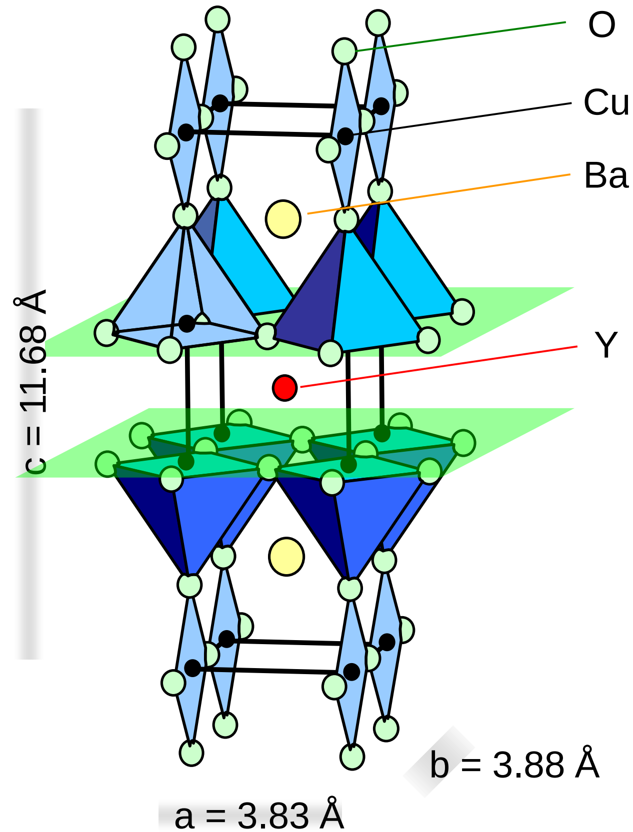
Ceramics: layered perovskite material (2-dimensionality)

CuO_2-planes responsible for superconductivity

Properties show high anisotropy

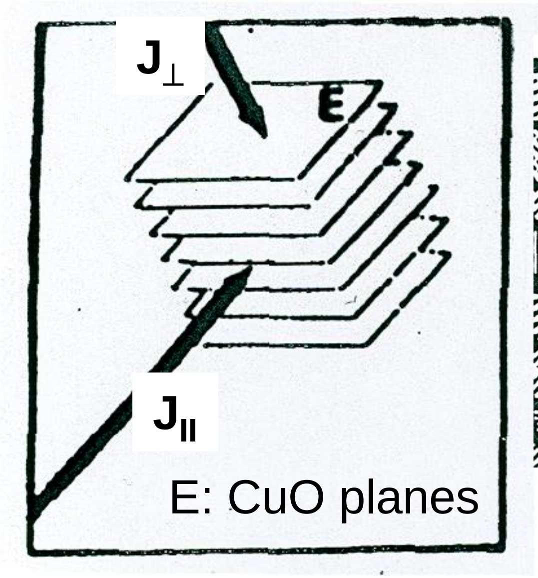
REBCO

$REBa_2Cu_3O_{7-x}$
RE: Y, Nd, Er, Gd, Eu…

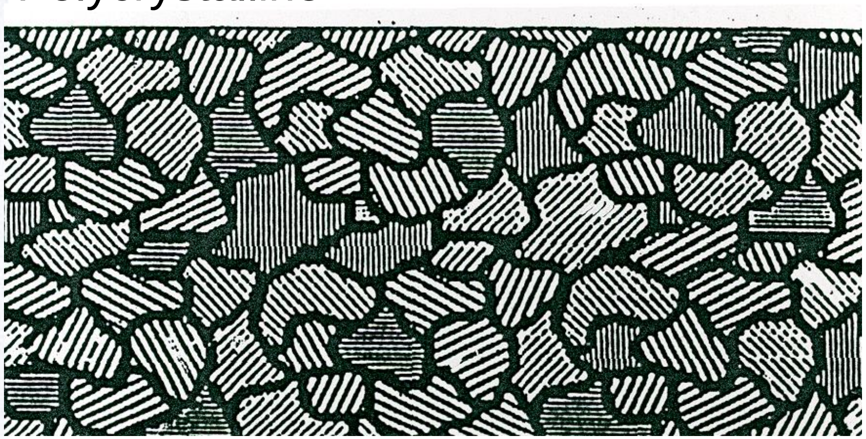


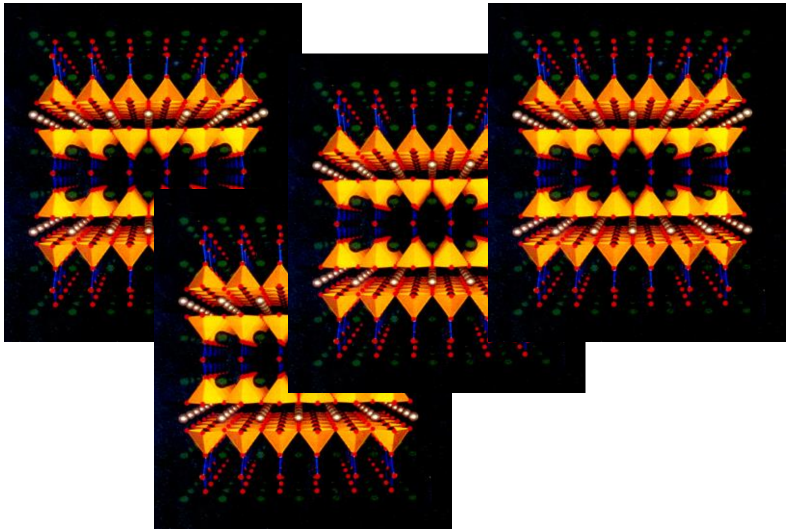
T_C = 92 K

Requirements for High Critical Currents



Polycrystalline



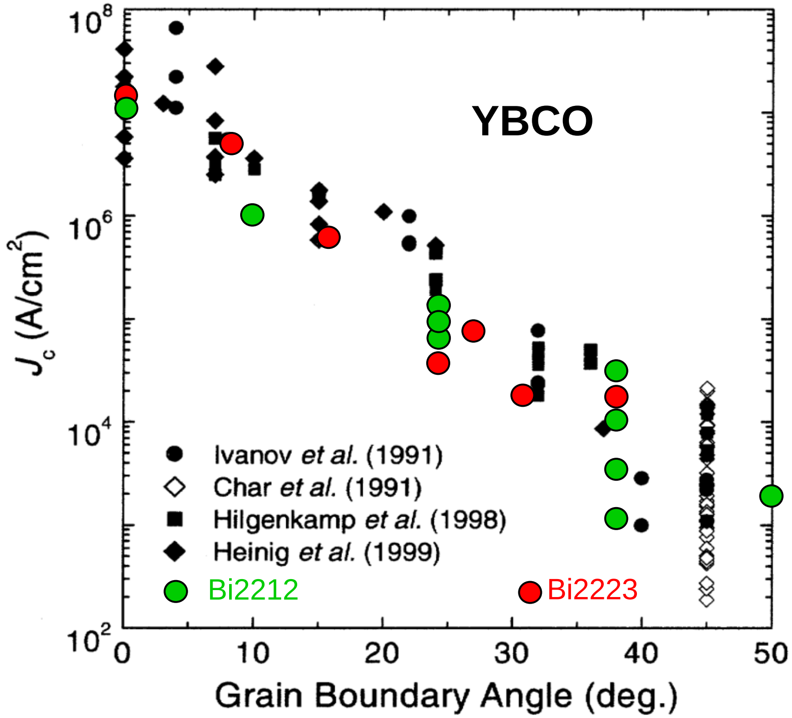


J_{II}: current parallel to CuO plane
$J_\perp$: current perpendicular to CuO plane

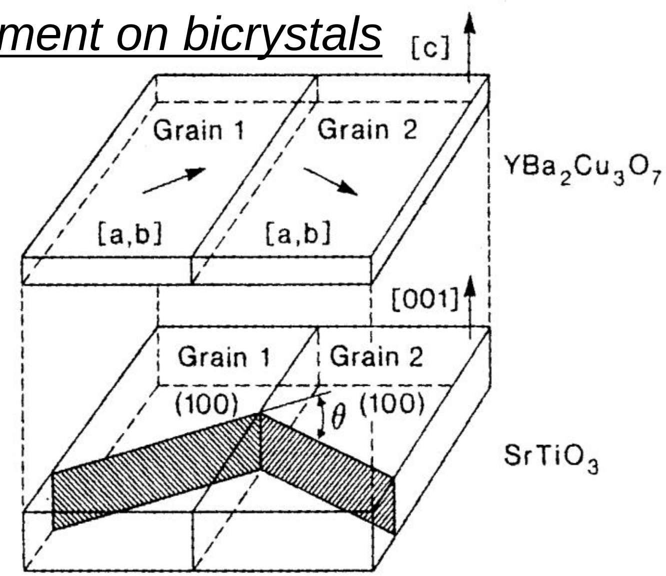
$$J_{II} >> J_\perp$$

Parallel alignment of CuO planes necessary for high J_c

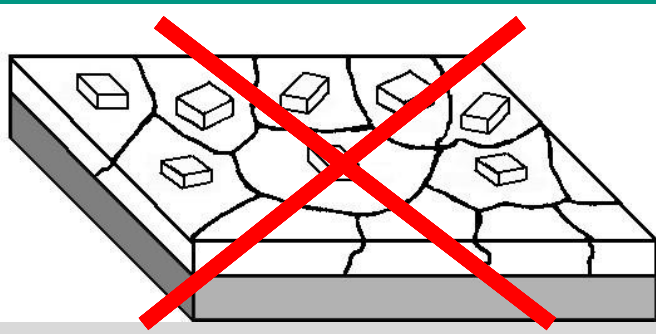
HTSC grain boundary challenge

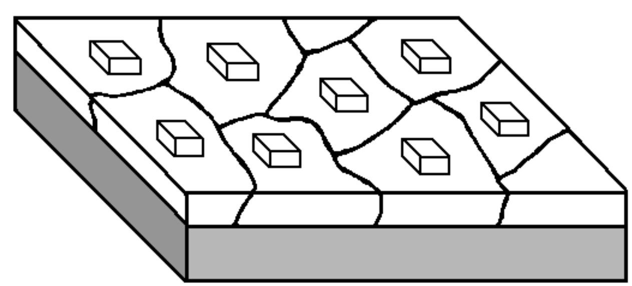


Measurement on bicrystals



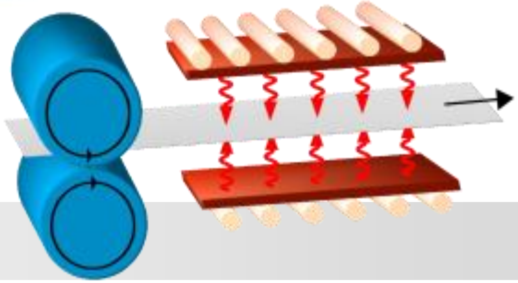
High J_c in polycrystalline materials requires strong biaxial texture

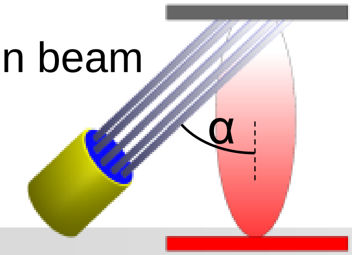


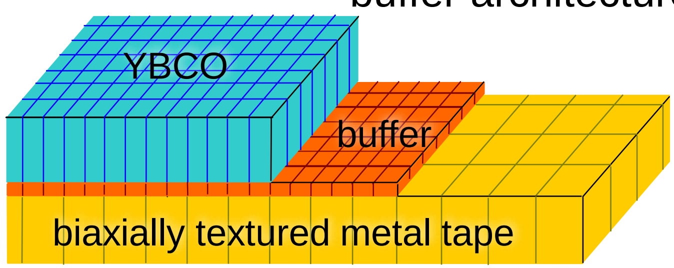


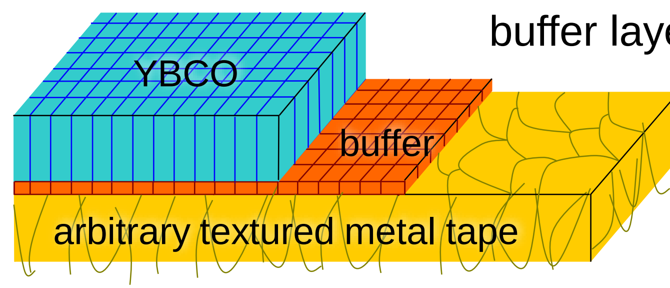
Coated Conductor

Rolling Assisted Biaxially Textured Substrates (RABiTS)	Ion Beam Assisted Deposition (IBAD/ABAD)









Biaxial texturierte Substrate

Biaxial texturierte Pufferschichten

Synthesis Variants Coated Conductor

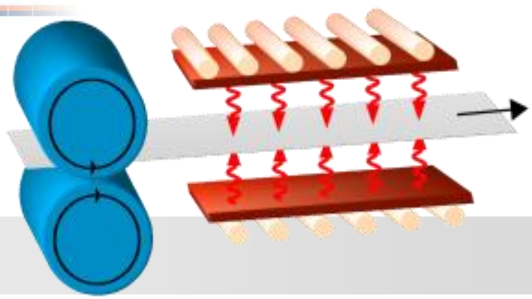
KIT Karlsruhe Institute of Technology

Rolling Assisted Biaxially Textured Substrates (RABiTS)	Inclined Substrate Deposition (ISD)

deutsche nanoschicht

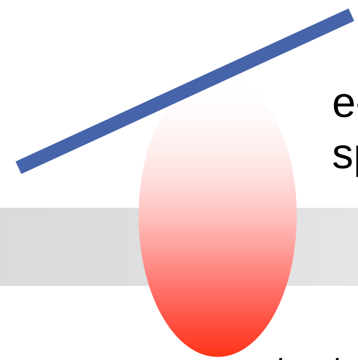
rolling annealing

Ni or Cu alloys



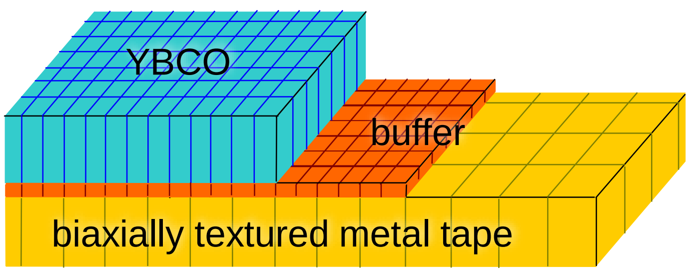
substrate

THEVA

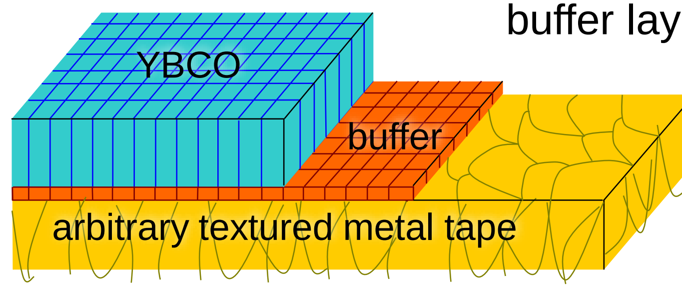


e-beam, sputtering

epitaxial deposition of buffer architecture



texture evolves in buffer layer



Biaxial texturierte Substrate

Biaxial texturierte Pufferschichten

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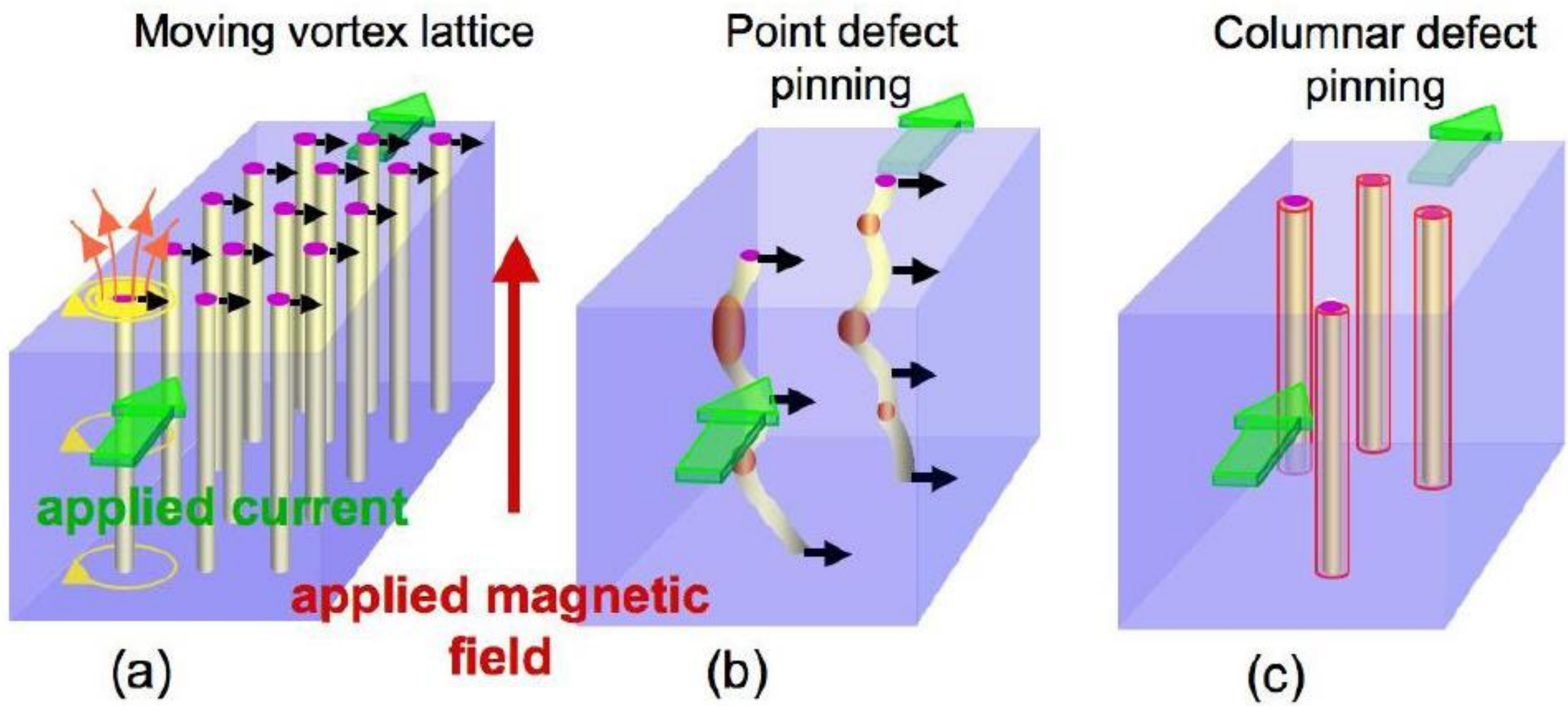
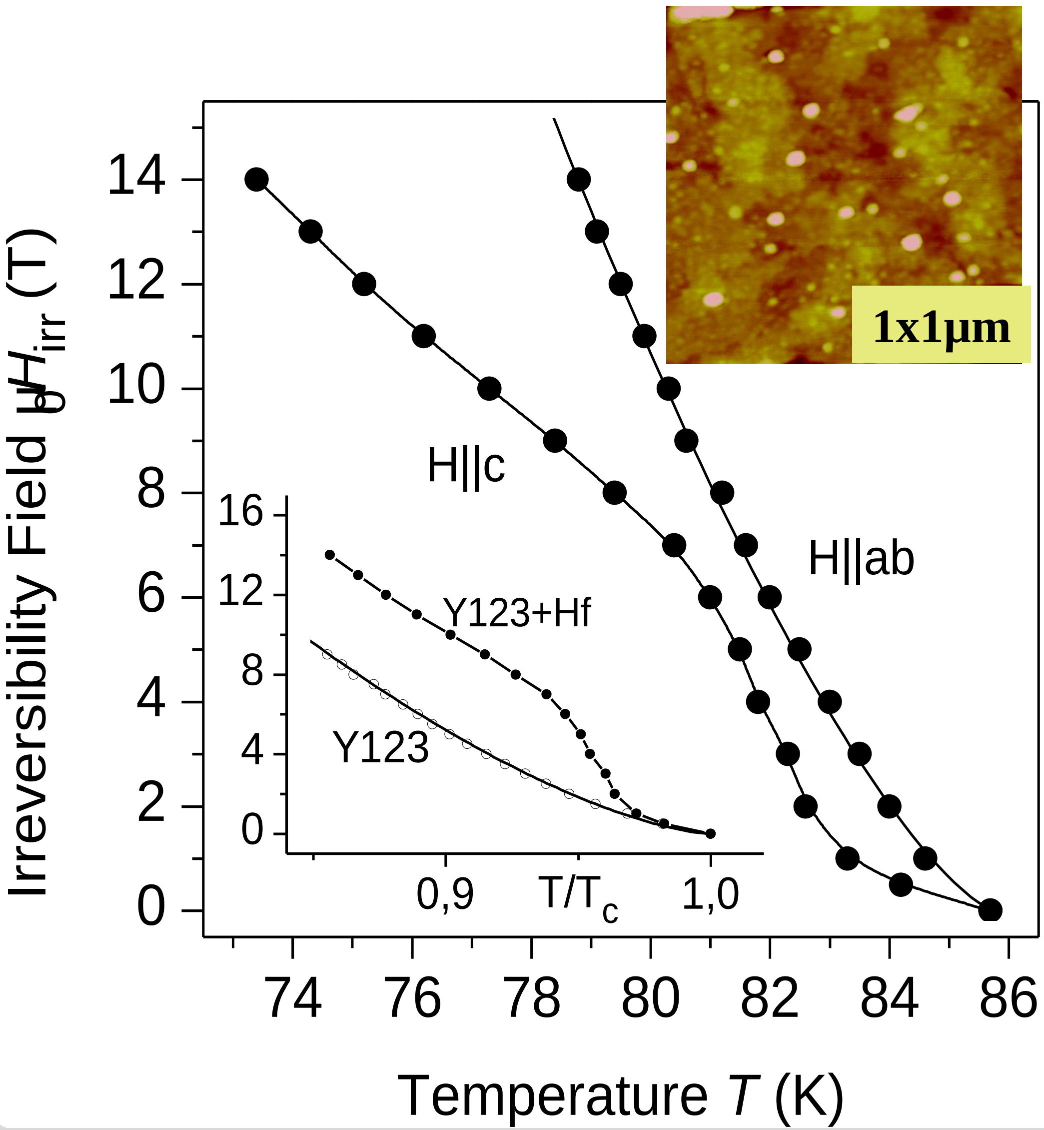
Pinning by (artificial) defects



- Random 0D defects: e.g. Point defects
- Columnar 1D defects: e.g. Dislocations
- Planar 2D defects: e.g. Stacking faults
- 3D defects : e.g. Non superconducting nanodots

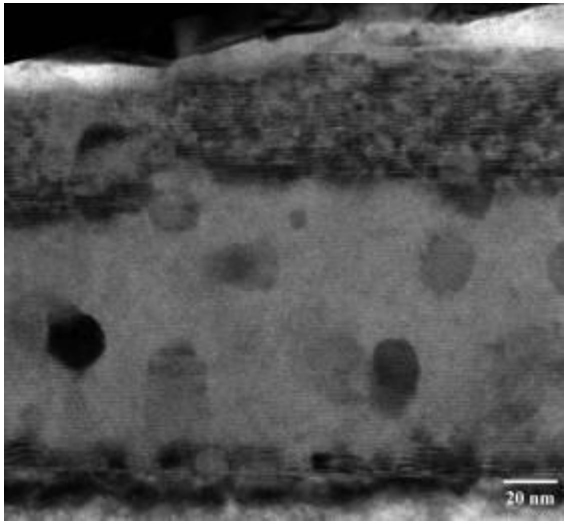
Nanoengineering of HTS Materials

Karlsruhe Institute of Technology



Nanoscale defects (pinning centres) enhance H_{irr} and J_c

$BaHfO_3$-Ausscheidungen in YBCO

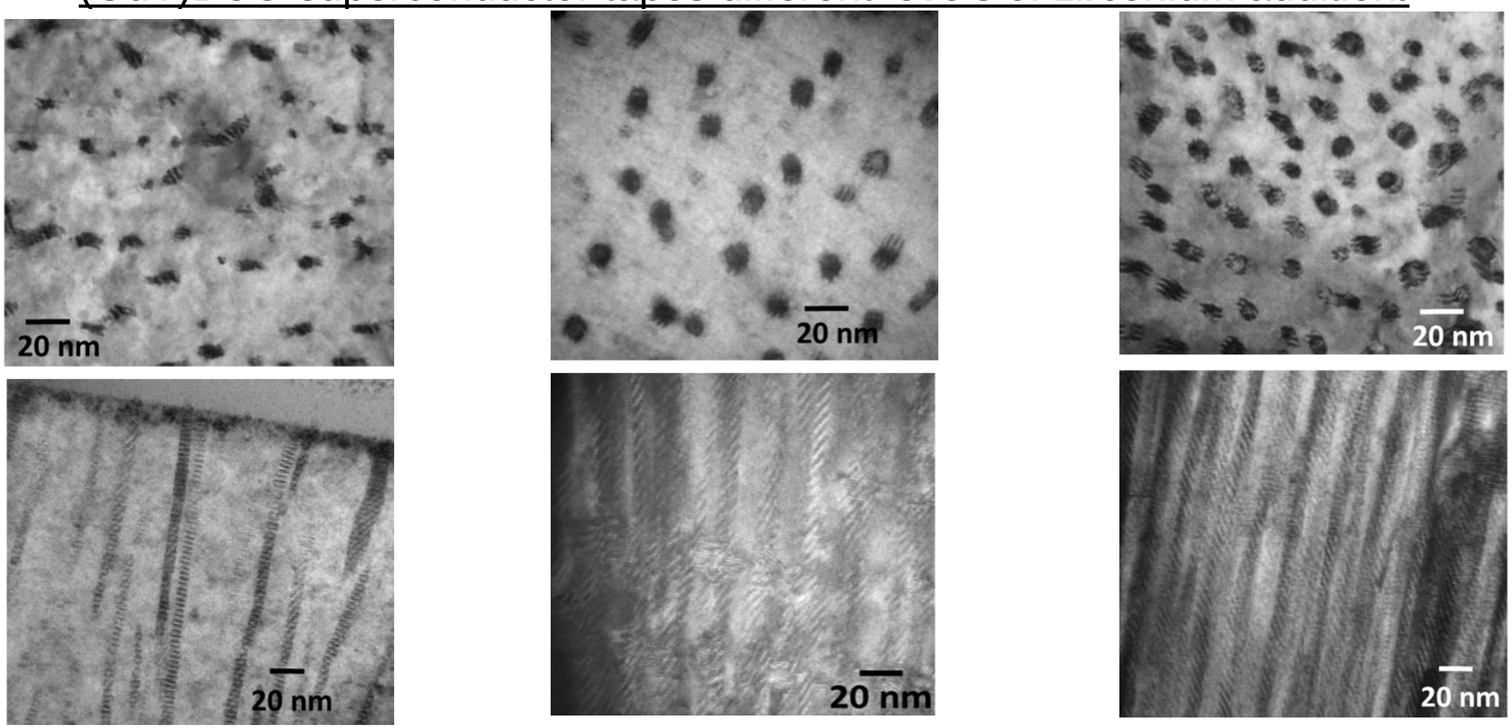


J. Hänisch et al. APL 86, 122508 (2005), SUST (2006)
S. Engel et al. APL 90, 102505 (2007)

Improving performance of REBCO tapes with heavy doping with Zr

- Zr doping results in $BaZrO_3$ nanoscale defects aligned along thickness of the superconductor film

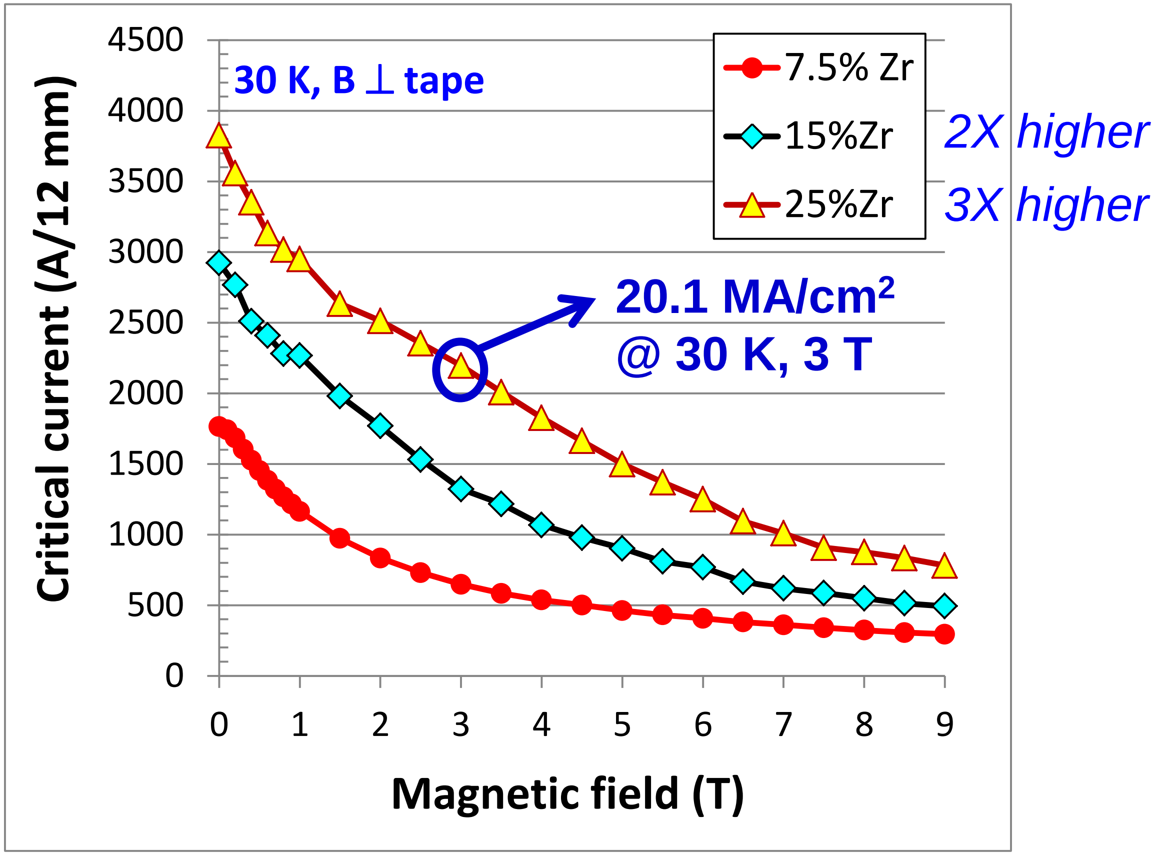
Plan view (top row) and Cross section view (bottom row) microstructures of (GdY)BCO superconductor tapes different levels of zirconium addition.



7.5% Zr | 15% Zr | 25% Zr

The density of nanoscale defects in the superconductor film increases with increasing zirconium addition.

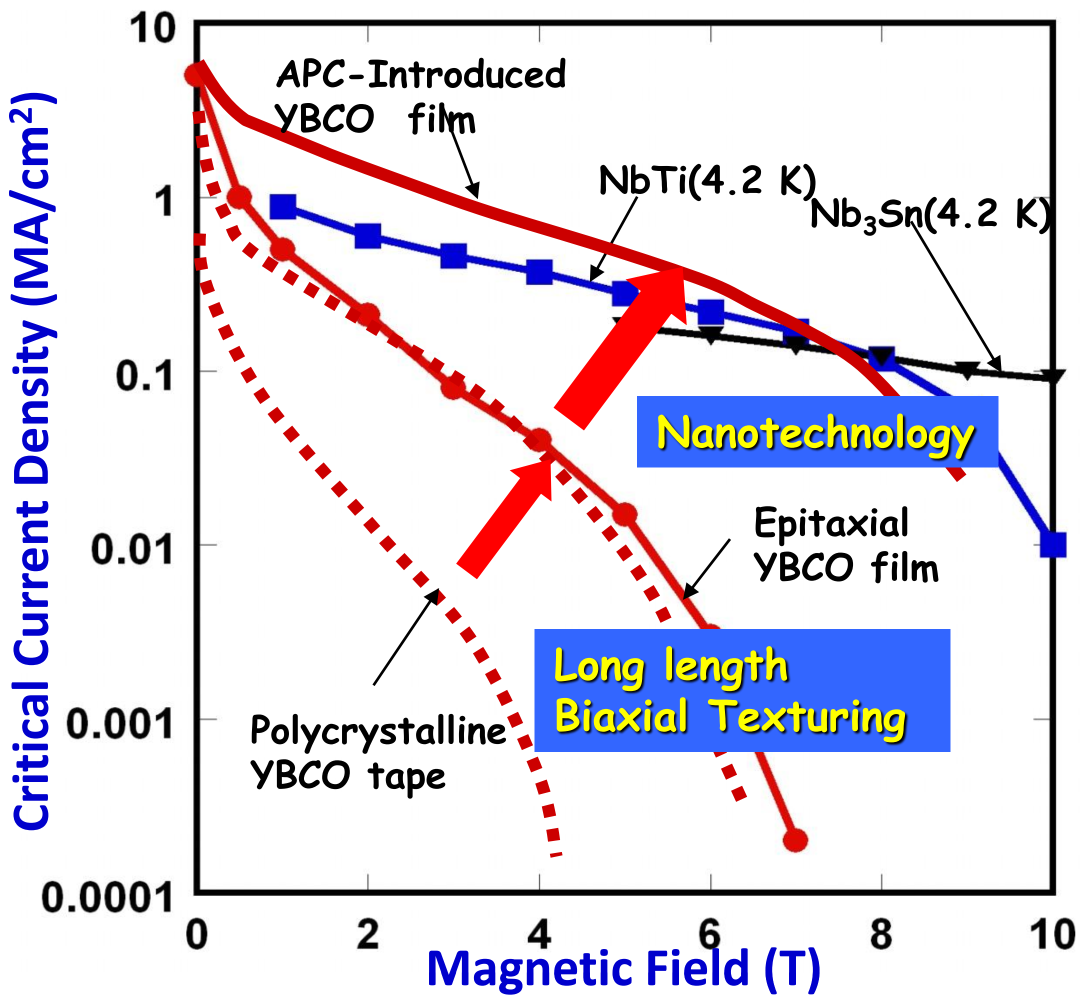
3X improvement in in-field performance of REBCO tapes in the last 2 years



- *Critical current of 25% Zr-added tape at 30 K, 3 T, B||c* ***~ 2172 A/12 mm*** ***J_c = 20.1 MA/cm², Pinning force = 603 GN/m³***
- *Lift factor at 30K, 3 T, B||c* ***~ 6.4 (200% improvement!)***

- Enabled by engineering a high density of nanoscale defects while maintaining high crystalline quality of the superconductor films

Coated Conductors:
The HTS materials for power applications



77 K

Courtesy M. Matsumoto

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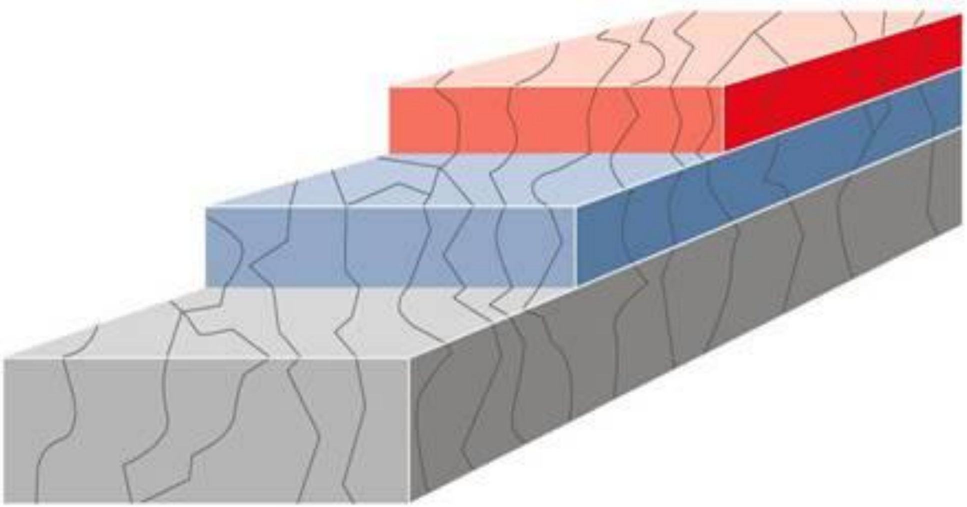
Prozesstechnologie

- HTS Drahtarchitektur – dünne, flexible, keramische Beschichtungen

Supraleiterschicht
$YBa_2Cu_3O_x$ (YBCO)

Pufferschicht
$La_2Zr_2O_7$ (LZO), CeO_2

Metallsubstrat
NiW-alloy



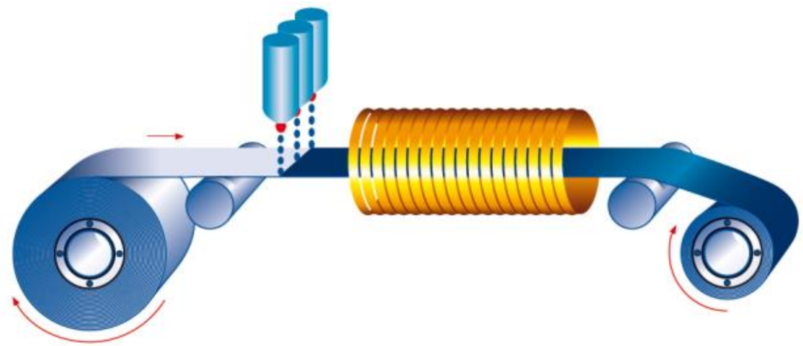
Prozesstechnologie

- Chemische Beschichtungstechnologie

Vorteile:

- Höchster Durchsatz (Abscheideraten)
- Niedrigstes Investment
- Niedrigster Energieverbrauch
- Niedrige Rohmaterialkosten

⇒ bestens geeignet für energietechnische Anwendungen



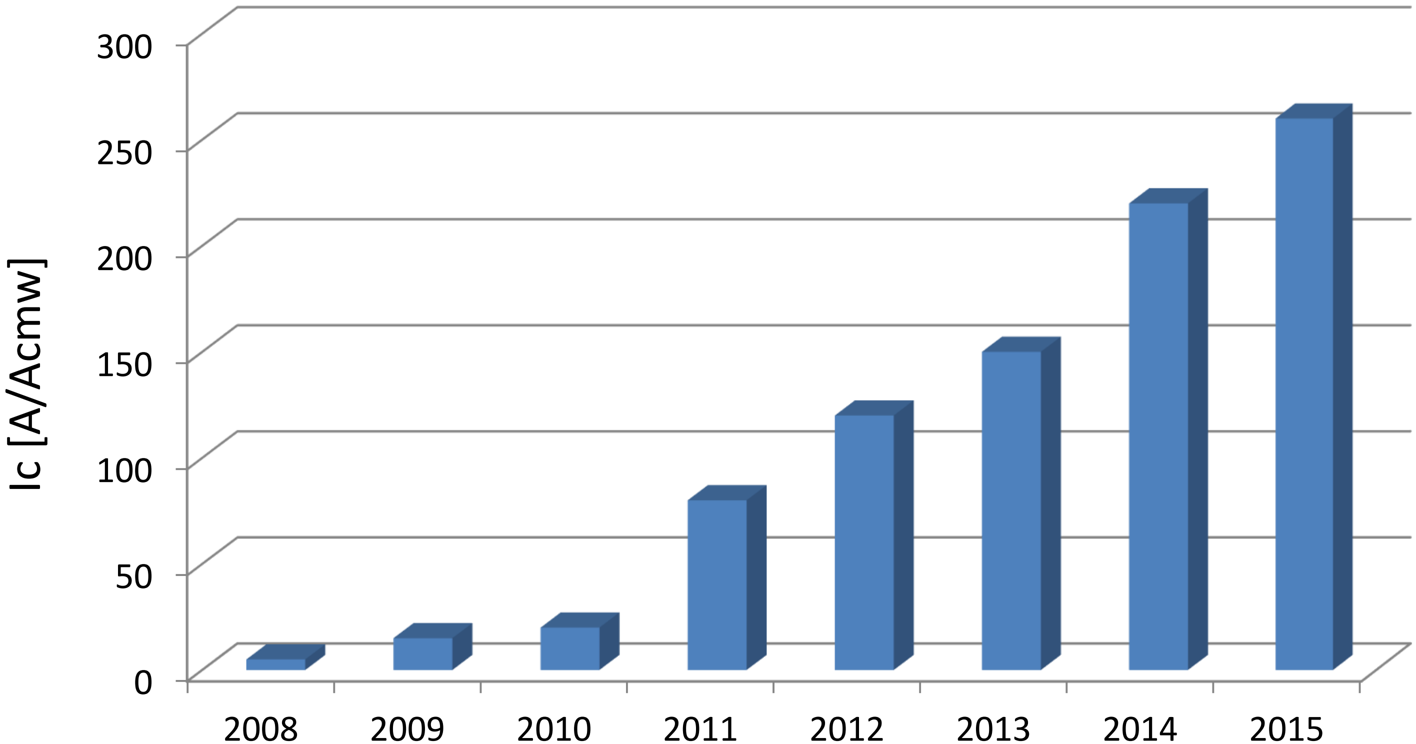
Kontinuierliche Beschichtung und Glühung

deutsche nanoschicht

Eigenschaften

VDM Metals
Honeywell
Heraeus

- Entwicklung mit industriellen Partnern über mehr als 10 Jahre
  - Eigenschaften von Proben >20m



Pilotproduktion

- Technische Fertigstellung der Pilotproduktionsanlage bis Ende 2015
- Geplante Kapazität > 200km technischer HTS Draht
- Bemusterung für Kundenprojekte ab Mitte 2016

Laborfertigung

Pilotfertigung

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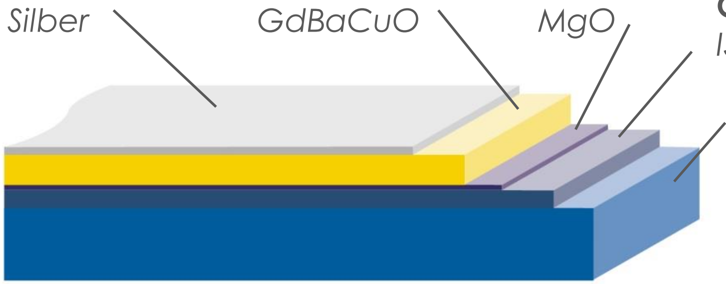
VERFAHRENSTECHNIK

Durchgängige PVD – Abscheidung (e-Strahl-Verdampfen)

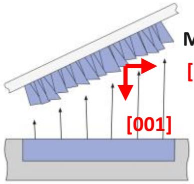
Substrat

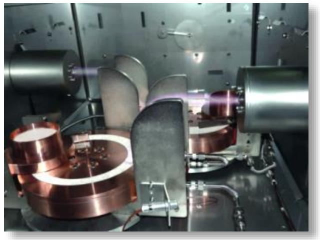
- Hastelloy C276, unmagnetisch
- Hohe Festigkeit > 500 MPa
- Reinigung & Elektropolitur

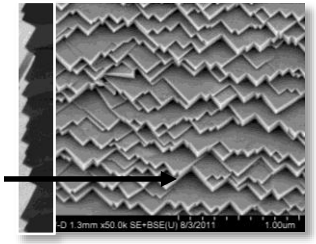


MgO-Pufferschicht

- Schrägbedampfen (ISD)
- biaxiale Orientierung, FWHM < 10°
- 25° Verkippung, gestufte Oberfläche



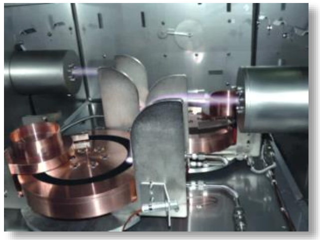




Bandrichtung

$GdBa_2Cu_3O_7$-Schicht

- Kontinuierliche E-Strahlverdampfung
- Hohe Abscheiderate
- Stoichiometrie fest vorgegeben durch Pulver

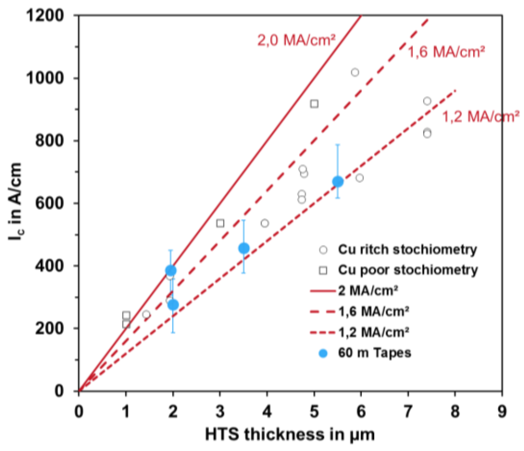


Ergebnisse

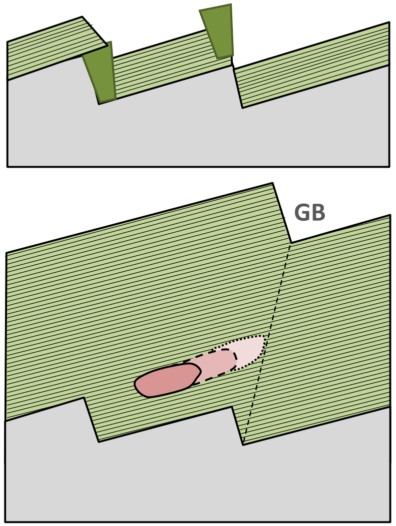
Hohe Stromtragfähigkeit durch dicke HTS - Schichten

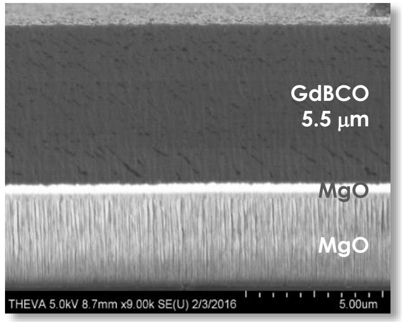
Einzigartiger Vorteil

- Gestufte Oberfläche erlaubt Wachstum dicker HTS - Schichten > 5 µm
- Größe von Defekten limitiert durch Terrassenbreite
- Defekte werden von höherer Terrasse aus lateral überwachsen und gestoppt



Vergleich alter Laborergebnisse (offene Symbole) mit 60 m Bandleitern aus Produktion (blau)





HTS - Bandleiterfertigung

Modernste Produktionstechnik

Merkmale der Pilotfertigung

- Modulare, vollautomatische Anlagen
- Kontinuierliche Ein- und Ausschleusung
- Inline Qualitätskontrolle
- Geschwindigkeit aktuell: >30 m/h @ 12 mm Breite
- Leiterlänge: 60m (aktuell) – 600m (bis Ende 2016)
- Ausbeute: > 70% (Kriterium: I_C>360A, L > 25m)

Zielsetzung

- Hohe Kosteneffizienz in der Produktion
- Robuste Prozesse mit hoher Ausbeute
- Implementierung industrieller Standards
- Durchgängige Qualitätssicherung

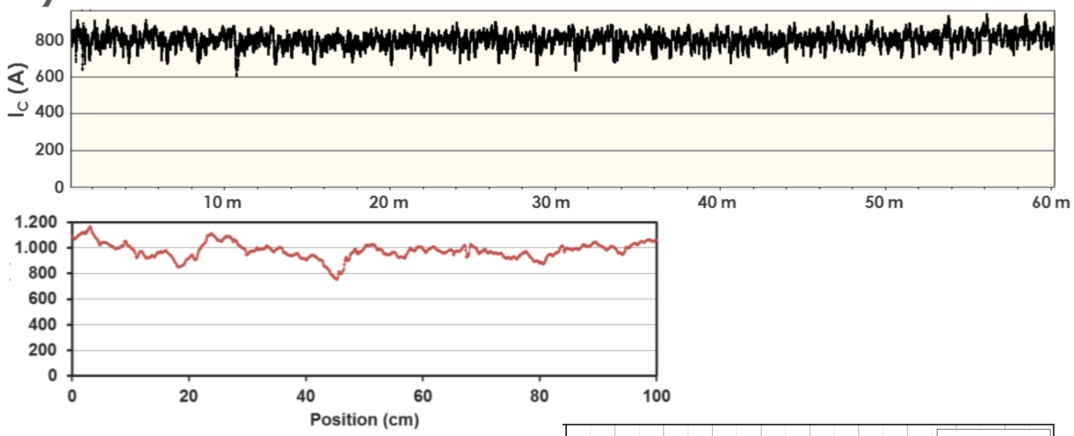
Alle folgenden Ergebnisse aus der Produktion

Ergebnisse

Leistungsfähigkeit – 60 m Prozesslänge

Stromtragfähigkeit (@ 12 mm)

- $I_{C,min}$ bis zu 600 A
- $I_{C,avg.}$ bis zu 800 A
- $I_{C,max.}$ bis zu 1200 A



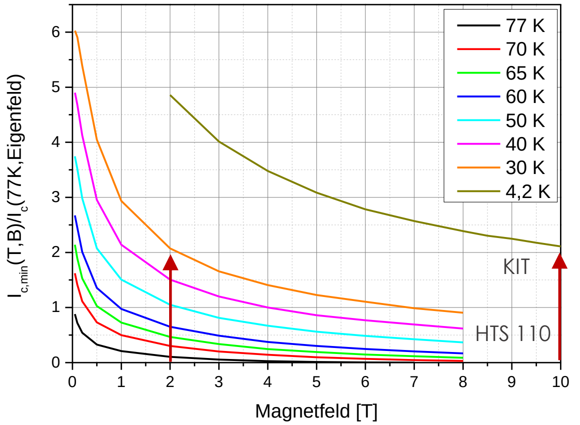
Gute Magnetfeldverträglichkeit

Lift-Faktoren:

$I_C(30K, 2T)/I_C(77K, s.f.) = 2$

$I_C(4,2K,10T)/I_C(77K, s.f.) = 2$

vergleichbar zu AMSC „enhanced pinning“



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BRUKER HTS

BHTS's process chain

- The standard processing route for the BHTS coated conductors consists of …

  … stainless steel substrate polishing and cleaning

  … YSZ buffer layer coating by vacuum deposition (ABAD)

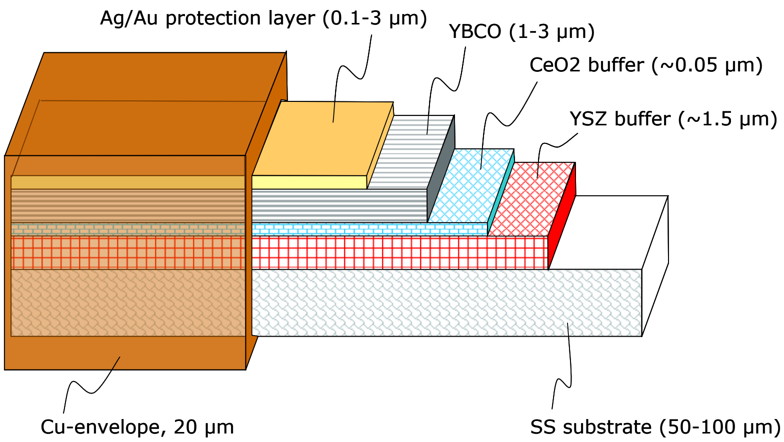
  … Ceria and YBCO layer coating by vacuum deposition (PLD)

  … Ag shunt layer coating by vacuum deposition (evaporation) and Ag layer annealing in O2 atmosphere

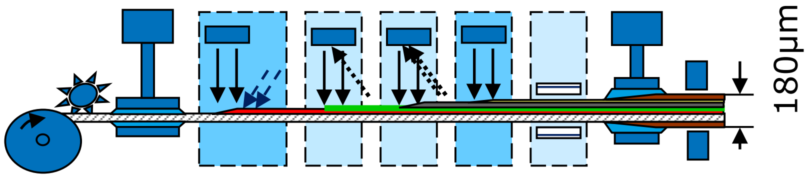
  … Cu encapsulation by plating

  … final inspection and quality check of the HTS tapes

Typical HTS layer stack



Idealized sketch of the BHTS process chain



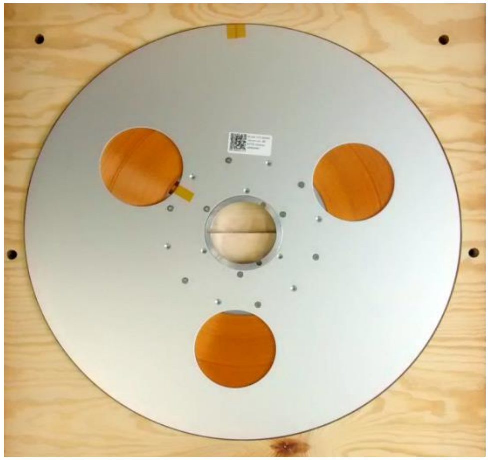
Capabilities of BHTS pilot-lines

- BHTS main mission:
  manufacturing of 2G HTS coated conductors
- Two production lines in Alzenau:
  - Pilot-line for 4mm wide HTS tapes with the capability to process a max. single piece tape length of **600m**

    IN OPERATION
  - Pilot-line for 12mm wide HTS tapes with the capability to process a max. single piece tape length of **100m**

    RAMP-UP IN PROGRESS
- Comprehensive testing devices for process and quality control of coated conductors

4mm wide HTS tape without insulation

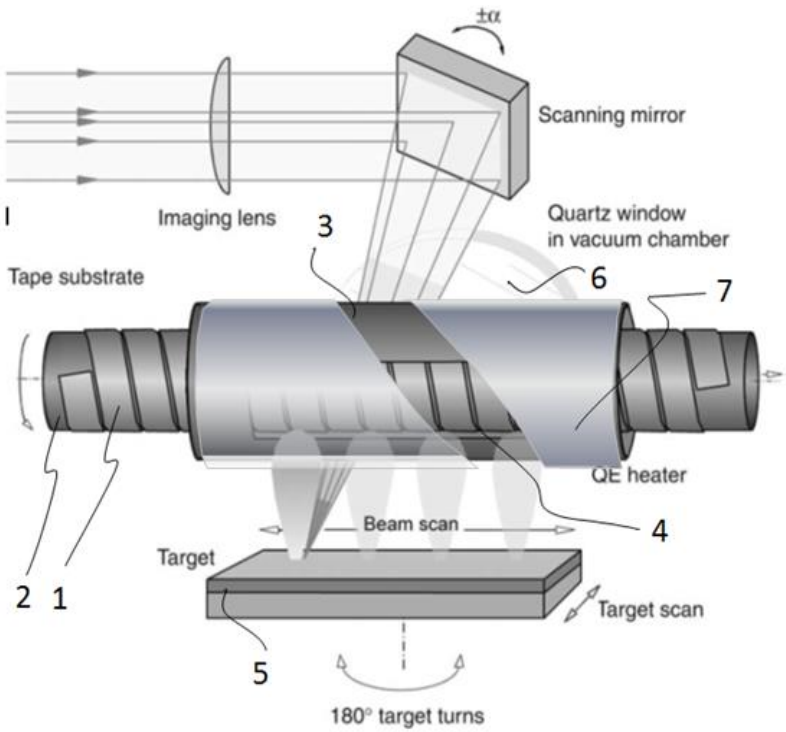


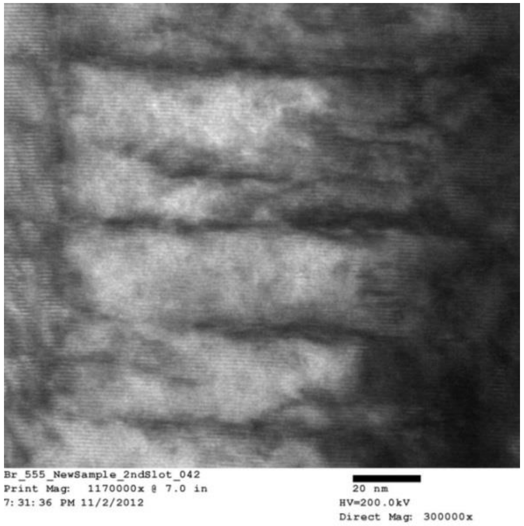
4mm wide HTS tape with insulation on a 20" reel

BRUKER HTS

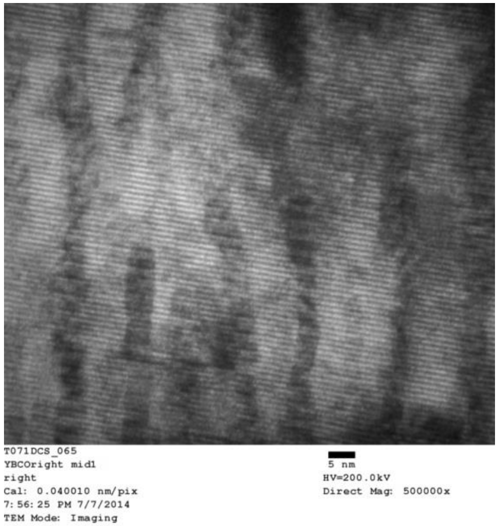
BHTS’s core competence

- Manufacturing of coated conductors (HTS 2G) tailored for it’s application in high magnetic fields
- Structural design of the YBCO superconducting thin films on a nano-scale by pulsed laser deposition PLD





INTRINSIC stoichio-metric deviations in the YBCO film

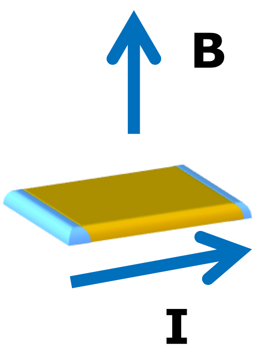


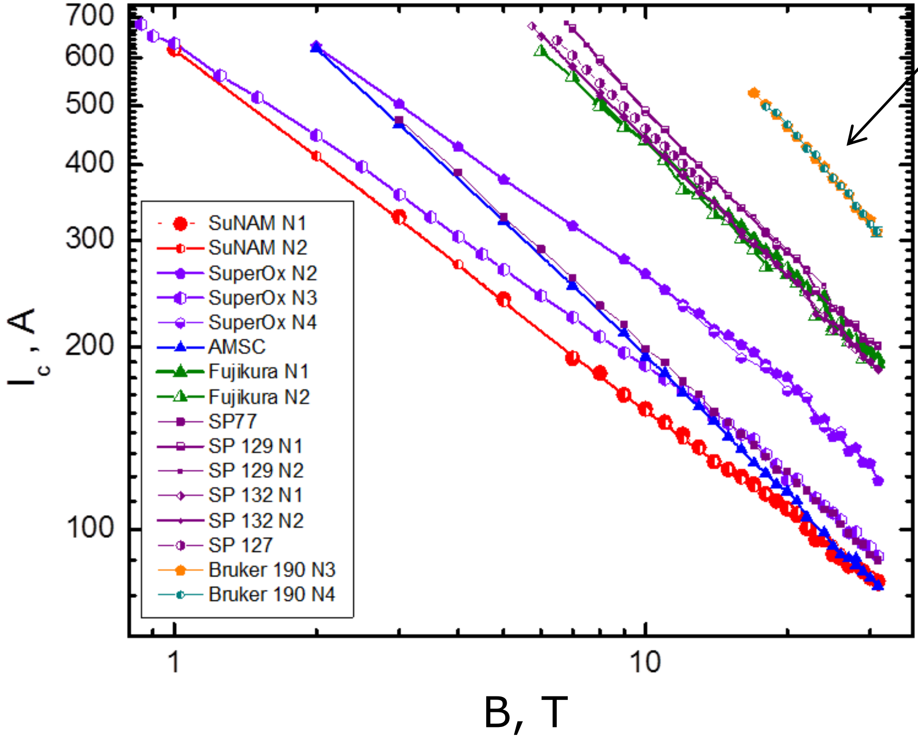
EXTRINSIC second phase nano-structures in the YBCO film

BRUKER HTS

BHTS’s core competence

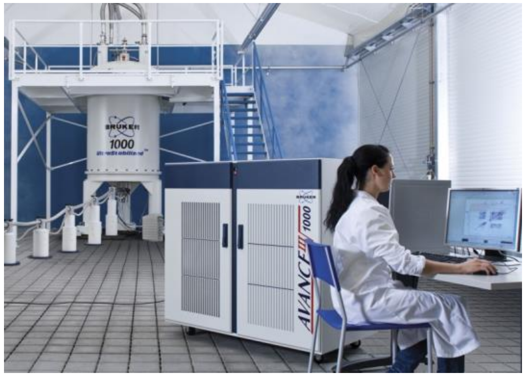
- Ic in-field performance @ (4K, B up to 31T) of coated conductor samples from different manufacturers measured at FSU in November 2014
- An Ic value of 309A at 4K, 31T was obtained for the 4mm wide BHTS tape samples





BHTS tapes …

… which fulfills the Ic requirements for the next generation of BRUKER BIOSPIN persistent super-conducting magnet for NMR spectroscopy



BRUKER HTS

BHTS at the new site

- Successful relocation of the operation BHTS in Q3 2015
- Since August 2015:
  BHTS at the new site in the Röntgenstr. 9 in Alzenau
- More than 2000sqm operation area available
- Excellent infrastructure and media supply for vaccum coating fab lines

BRUKER HTS GmbH
Industriepark Nord
Röntgenstr. 9
63755 Alzenau
Germany

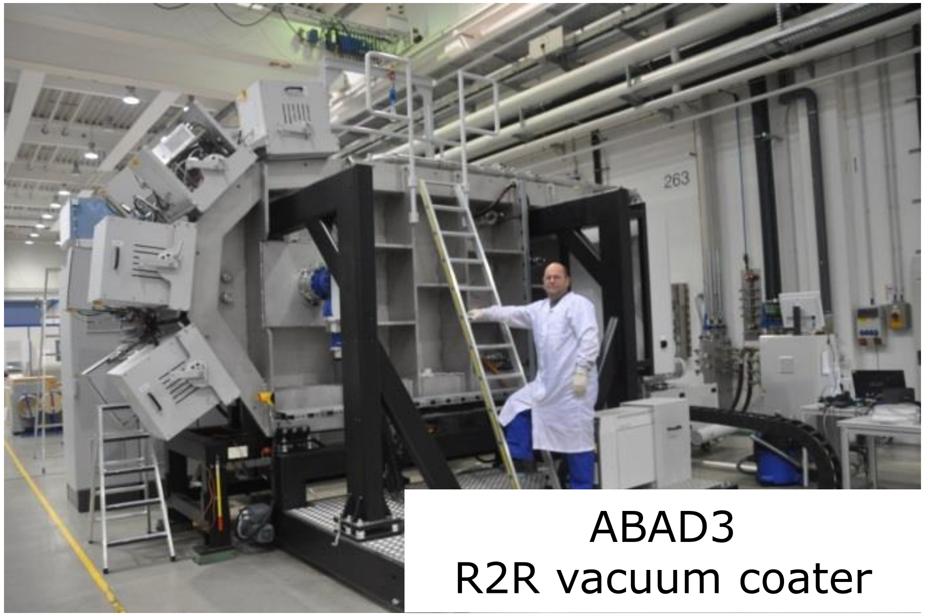
BRUKER HTS

Pilot-line equipment

- Tape processing equipment with different substrate handling concepts (batch and reel-to-reel R2R processes)

PLD600
Batch vacuum coating

EPOL3
R2R electropolishing



ABAD3
R2R vacuum coater

PLD600
substrate drum

Summary

- **Highly textured HTS based Coated Conductor enable high critical current densities over long length**
- **Controlled Nanoengineering improves strongly critical current in magnetic fields**
- **Industrial upscaling under way with strong German contributions**
- **Further industrial production improvements necessary to transfer HTS tapes into “industrial commodities”**

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