deutsche nanoschicht

chemistry meets energy

Produktion supraleitender Drähte für die Energietechnik

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53359 Rheinbach

HTS Drähte und Bänder

„Flexible Supraleiterbänder mit hoher Stromtragfähigkeit für energietechnische und industrielle Anwendungen werden heute kommerziell hergestellt.“

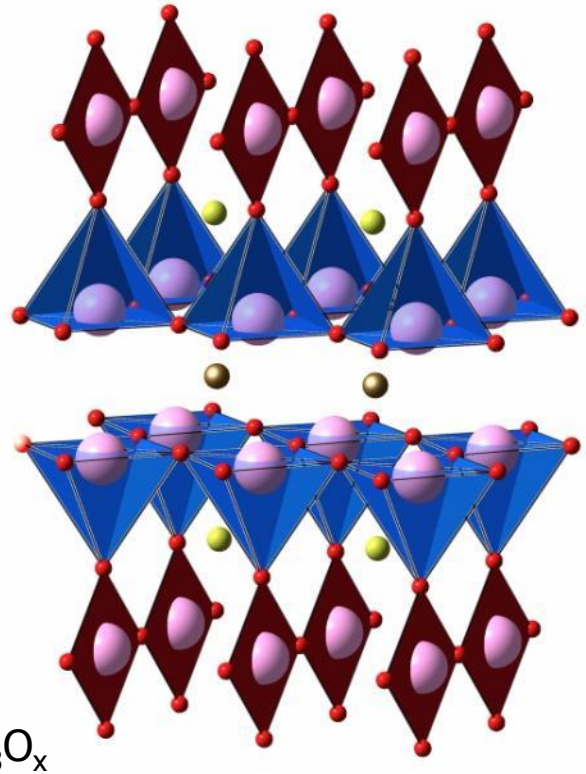
www.ivsupra.de

Inhalt

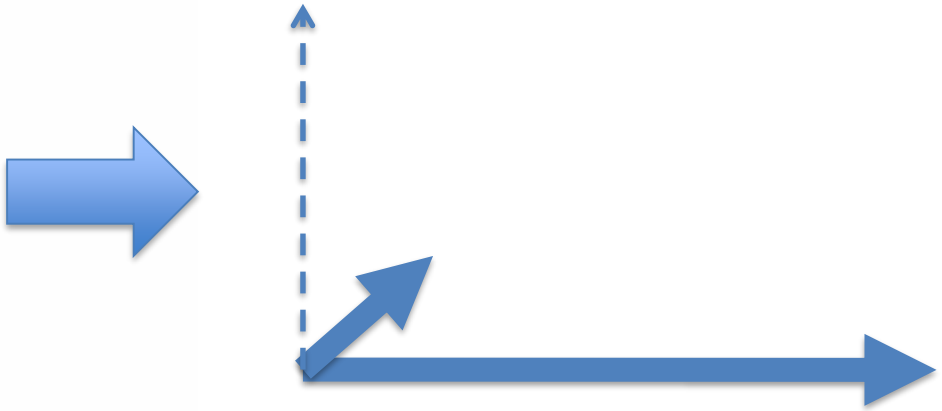
- Hochtemperatur Supraleiter
- HTS Bandleiter
  - Prozesstechnologie
- Hersteller und Kapazitäten
- Zusammenfassung

Hochtemperatur Supraleiter

- Herausforderndes Material (Stromtransport)
  - Komplexe keramische Oxide
  - Kristalline Schichtstruktur
  - Starke Anisotropie



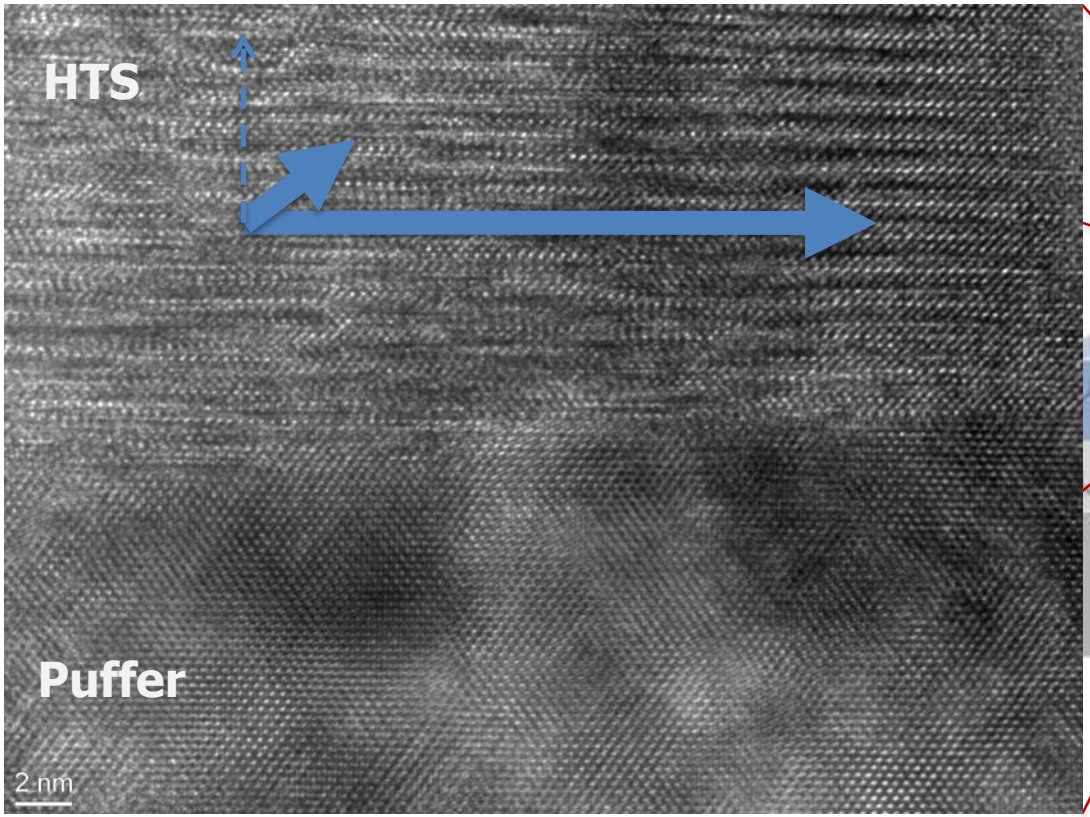
$YBa_2Cu_3O_x$

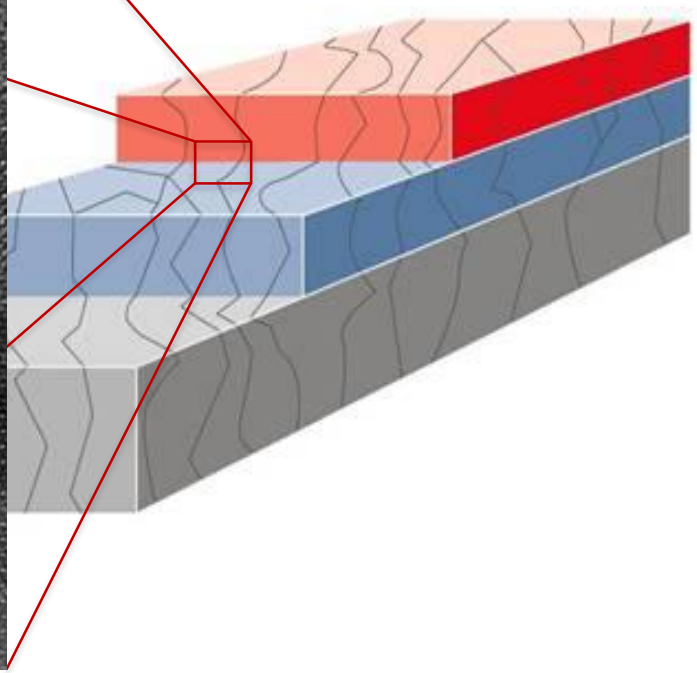


Supraleitender Strom:
parallel CuO-Ebenen >> senkrecht CuO-Ebenen

HTS Bandleiter

- HTS Architektur – dünne flexible Beschichtungen





HTS Bandleiter

- HTS Architecture – orientiertes epitaktisches Kristallwachstum

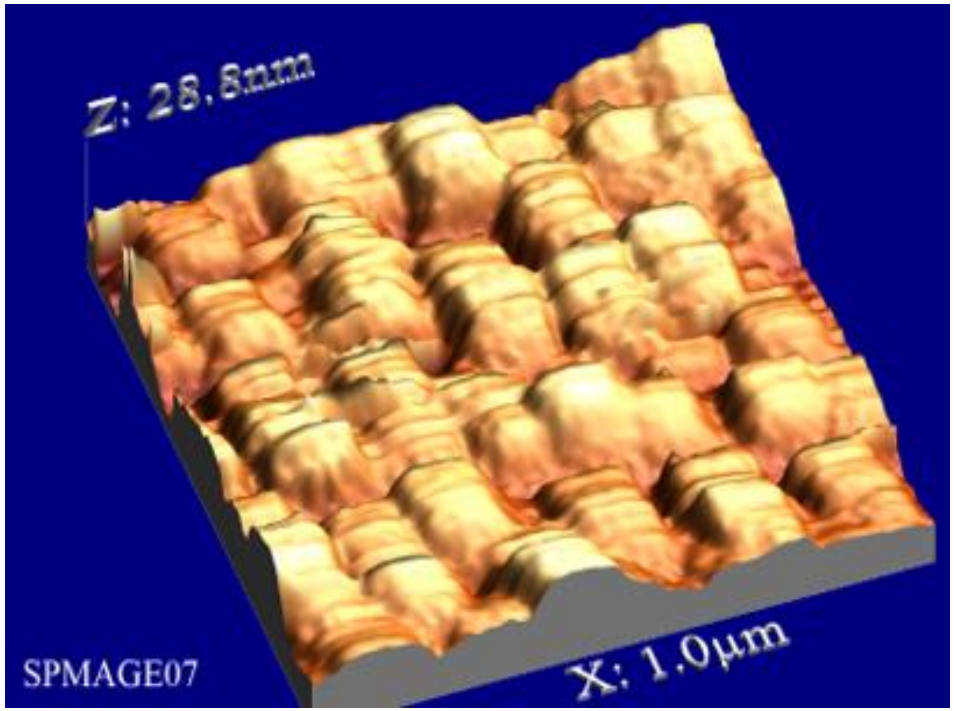
Statistisch orien

Hochorientierte kristalline Schicht

Schablone

HTS Bandleiter

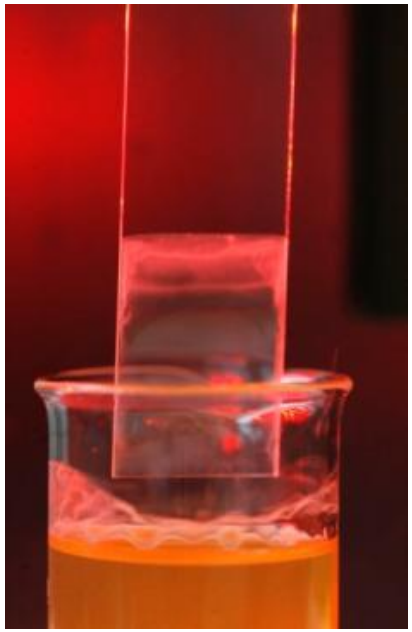
- HTS Architecture – orientiertes epitaktisches Kristallwachstum



AFM–Analyse einer Ceroxid Pufferschicht

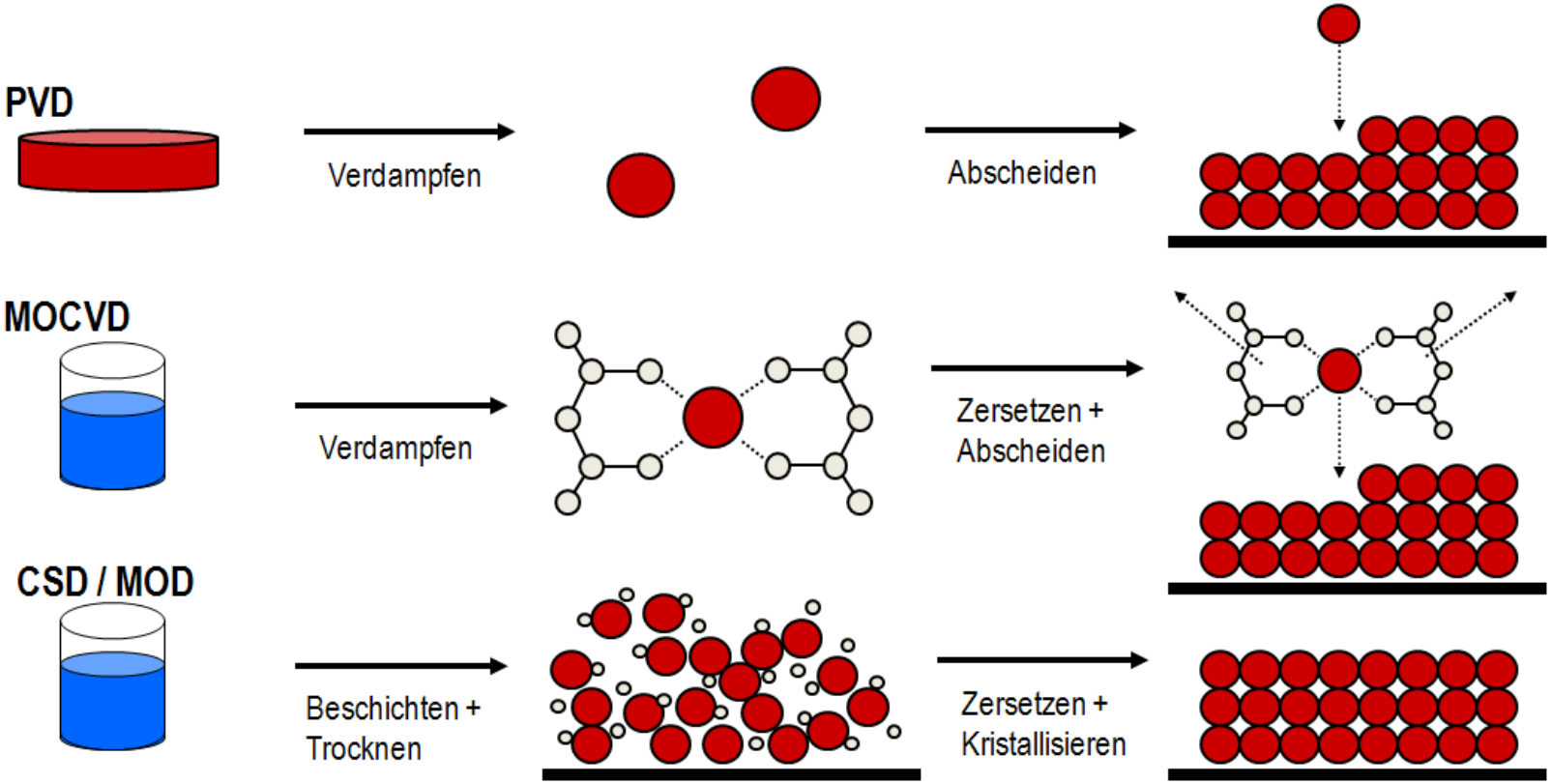
Prozesstechnologie

- Chemical solution deposition (CSD)
- Chemical vapour deposition (CVD)
- Physical vapour deposition (PVD)



Prozesstechnologie

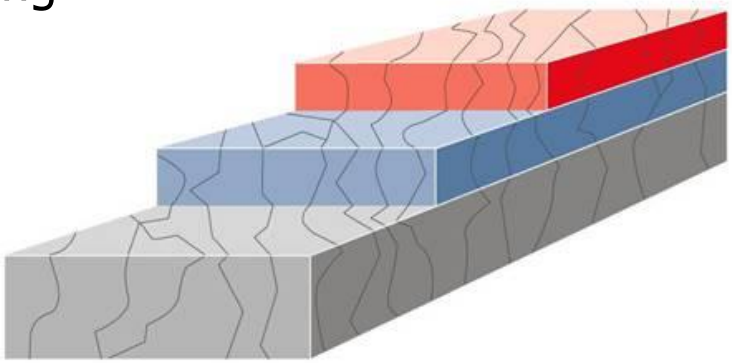
- CSD – CVD - PVD



Prozesstechnologie

- orientiertes epitaktisches Kristallwachstum

Orientierung der
Pufferschicht
während Beschichtung



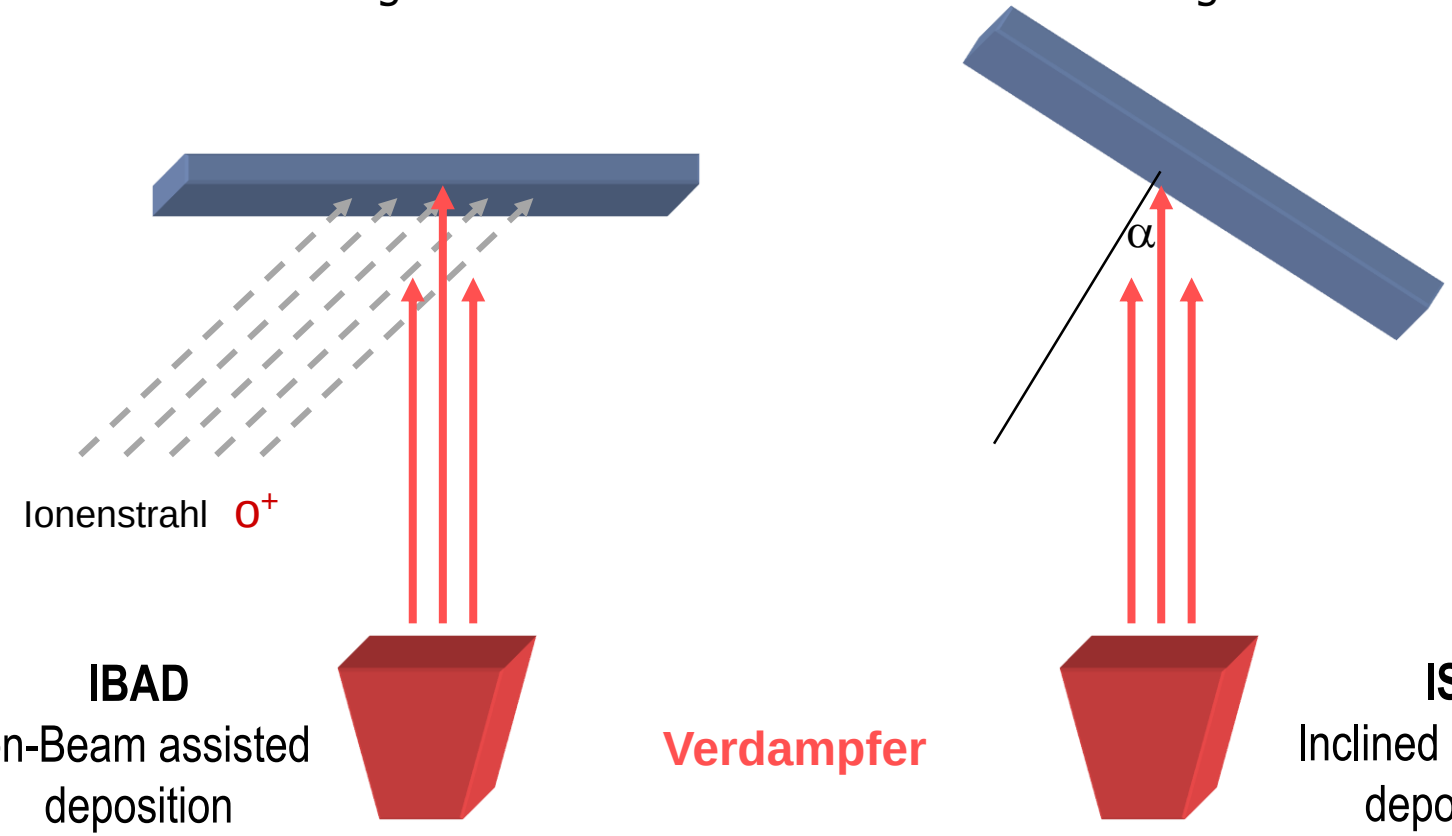
Verwendung von orientiertem
Metallsubstrat

IBAD: Ion-Beam assisted deposition
ISD: Inclined substrate deposition

RABiTS™: Rolling assisted biaxially textured substrate

Prozesstechnologie

- orientiertes epitaktisches Kristallwachstum
  - Orientierung der Pufferschicht während Beschichtung



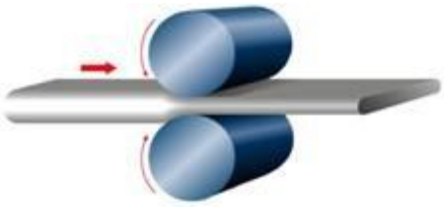
IBAD
Ion-Beam assisted deposition

Verdampfer

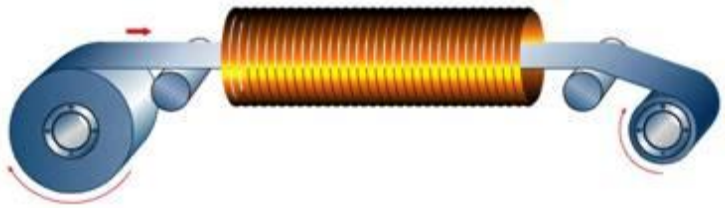
ISD
Inclined substrate deposition

Prozesstechnologie

- orientiertes epitaktisches Kristallwachstum
  - Verwendung von orientiertem Metallsubstrat



Nickel-Wolfram-Legierungen
Kaltverformung >95%

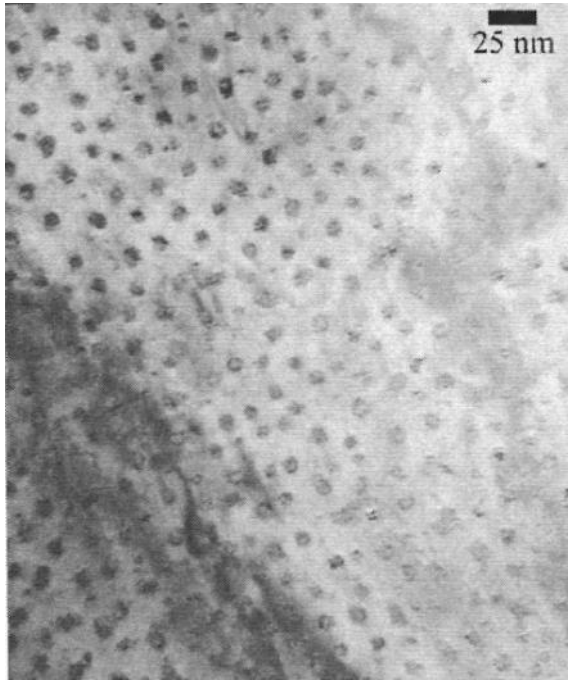


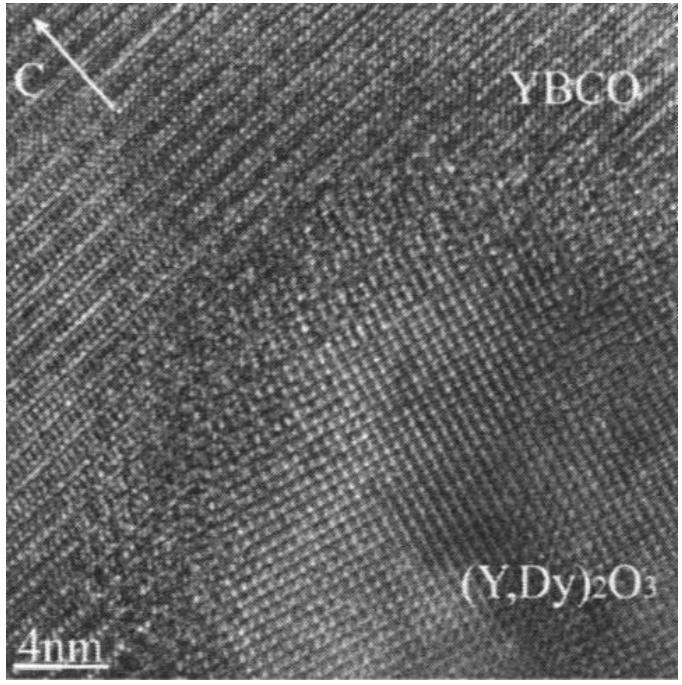
Rekristallisations-Glühung

RABiTS™: Rolling assisted biaxially textured substrate

Prozesstechnologie

- Eigenschaften im Magnetfeld
  - Einbringen von Nanopartikeln in HTS Schichten
  - Möglich mit allen Herstellprozessen

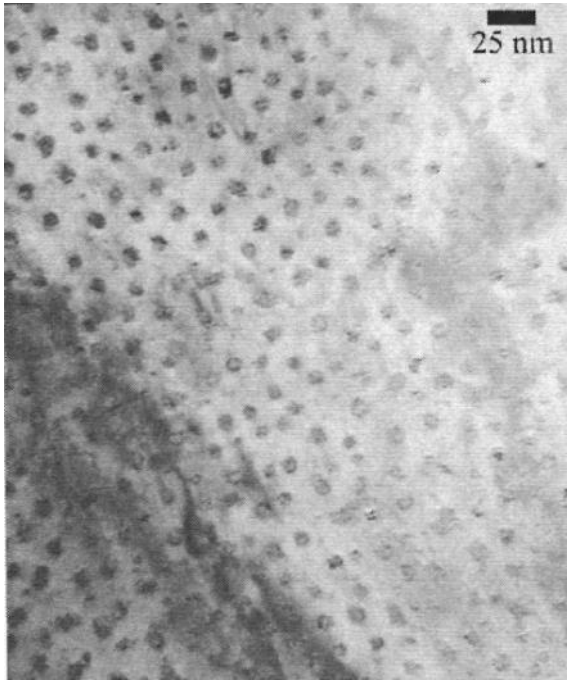


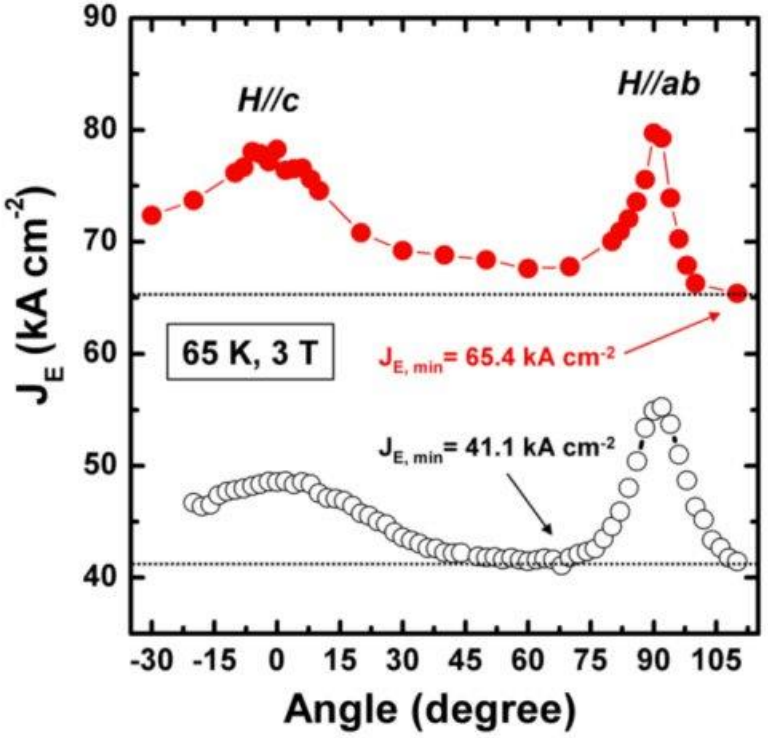


Quelle: ORNL

Prozesstechnologie

- Eigenschaften im Magnetfeld
  - Einbringen von Nanopartikeln in HTS Schichten
  - Möglich mit allen Herstellprozessen





Quelle: ORNL

Hersteller und Kapazitäten

Hersteller und Kapazitäten

Beiträge von:

- **THEVA**
- **Bruker HTS**
- **SUNAM**
- **STI**
- **SWCC**
- **AMSC**
- **Deutsche Nanoschicht**

Für Details wenden Sie sich bitte direkt an die Aussteller

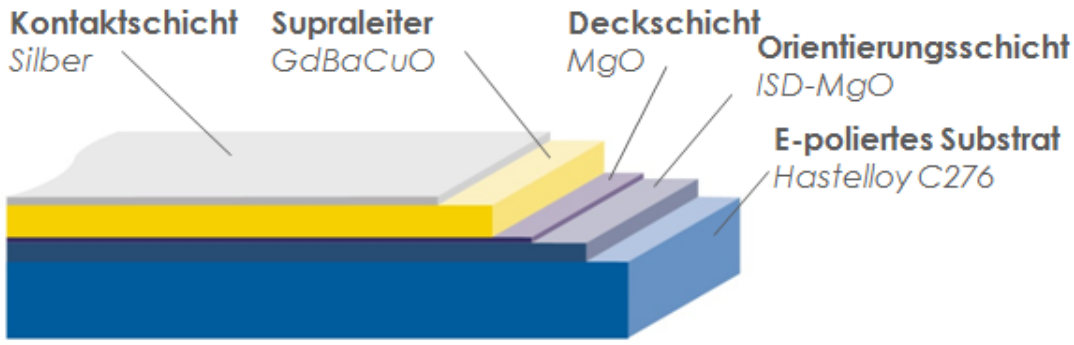
Alle folgenden Folien wurden von den oben genannten Firmen zur Verfügung gestellt. Für den Inhalt sind die Firmen verantwortlich.

Abschätzung: ivSupra

THEVA Pro-Line

Der HTS – Bandleiter von THEVA

- Zuverlässig — striktes Qualitätsmanagement
- Leistungsstark — extrem hohe Stromtragfähigkeit
- Wettbewerbsfähig — Kosteneffiziente, industrielle Fertigungstechnik

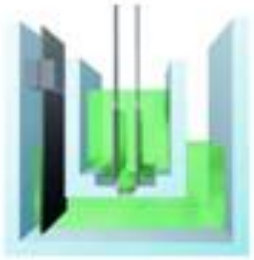


VERFAHRENSTECHNIK

Durchgängige PVD – Abscheidung (e-Strahl-Verdampfen)

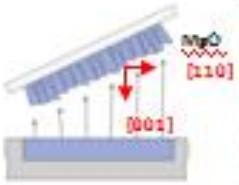
Substrat

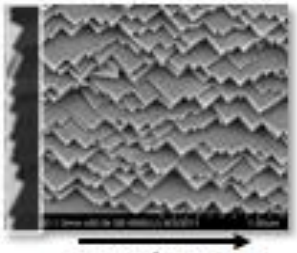
- Hastelloy C276, unmagnetisch
- Hohe Festigkeit > 500 MPa
- Reinigung & Elektropolitur



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

THEVA

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

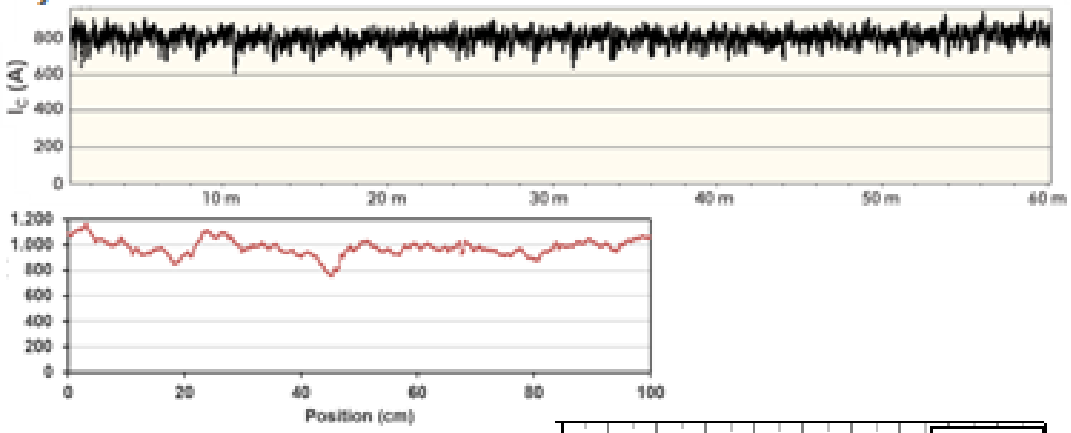
Alle folgenden Ergebnisse aus der Produktion

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 →



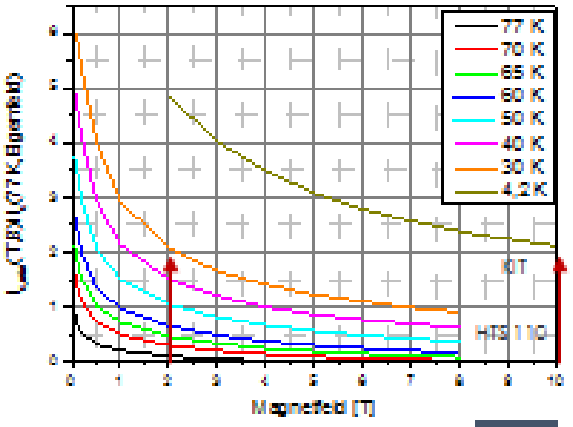
Gute Magnetfeldverträglichkeit

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“



Technische Leiter und Anwendungen

Konfektionierung und Magnetspulen

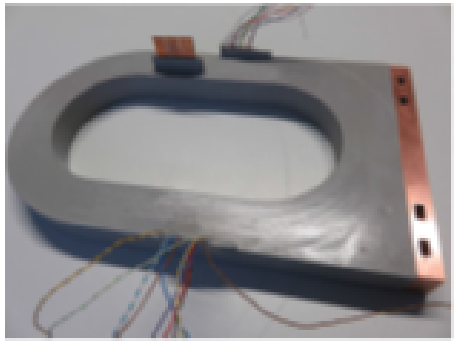
Elektrische Stabilisierung

- Laminierung:

100 µm Cu-Folie einseitig	TPL 12100 CU100	
50 µm Cu-Folie doppelseitig	TPL 13100 CU2x50	
- Galvanik: 10-20 µm Kupfermantel	TPL 12100 CU2x20	

Spulenbau (EcoSwing Windkraft-Generator)

- Industrielle Wickeltechnik
- Niederohmige Kontakte (< 10 nΩ)
- Spulenverguss für robuste Spulen und zur Aufnahme großer Kräfte



EcoSwing 2T-Testspule
mit Sonderabgriffen

BRUKER HTS

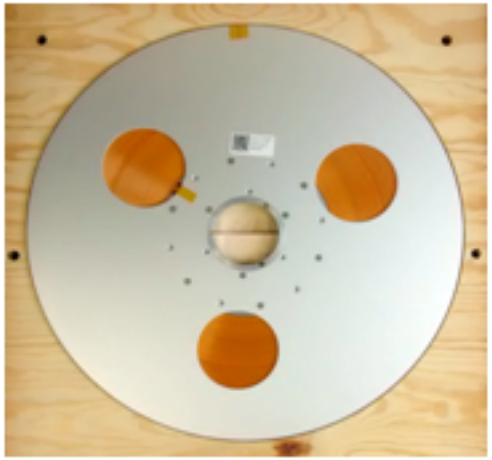
Capabilities of BHTS pilot-lines

- 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



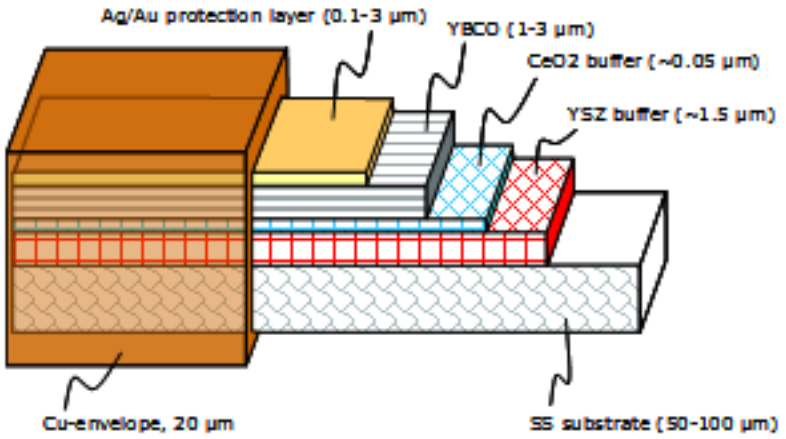
4mm wide HTS tape with insulation on a 20" reel

BRUKER HTS

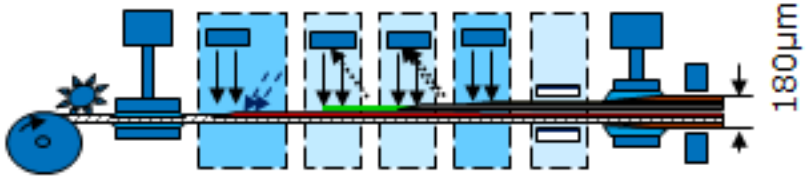
BHTS's process chain

- 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



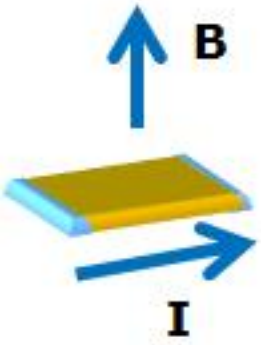
Idealized sketch of the BHTS process chain

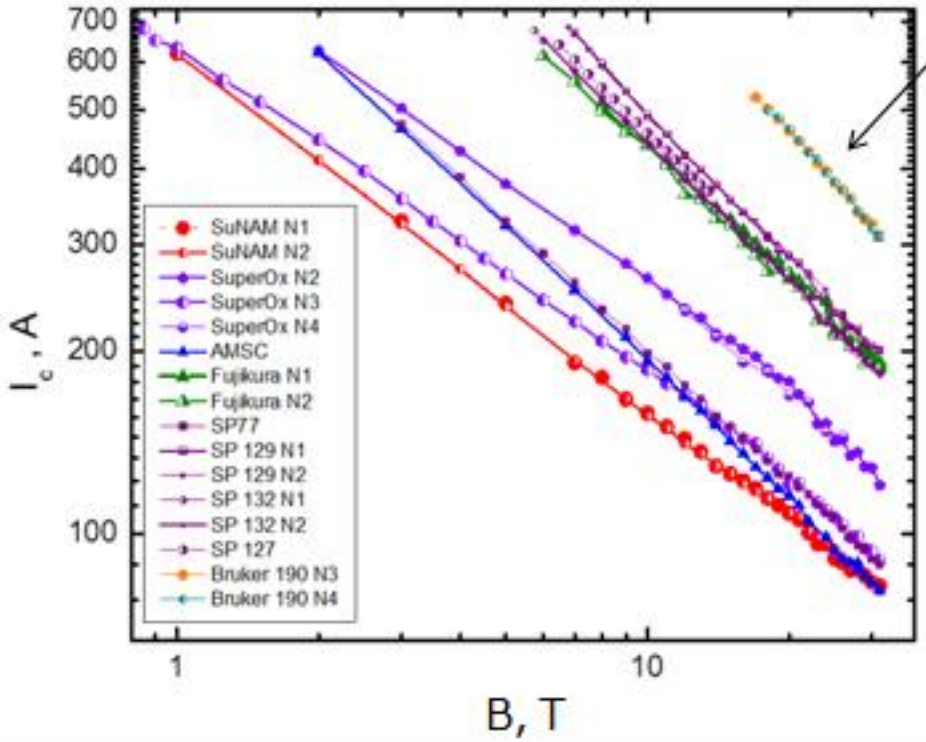


BRUKER HTS

BHTS's core competence

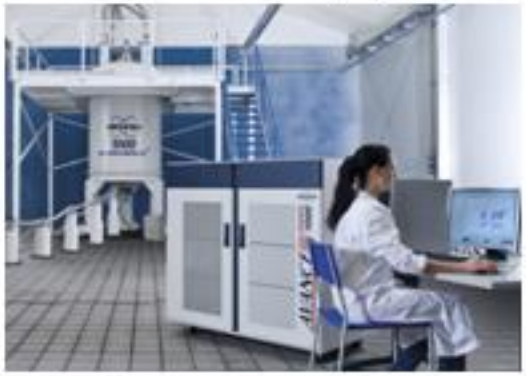
- Ic in-field performance @ (4K, B up to 31T) of coated conductor samples from different manufacturers measured at FSU in November 2014
- An Ic value of 309A at 4K, 31T was obtained for the 4mm wide BHTS tape samples





BHTS tapes ...

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



BRUKER HTS

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

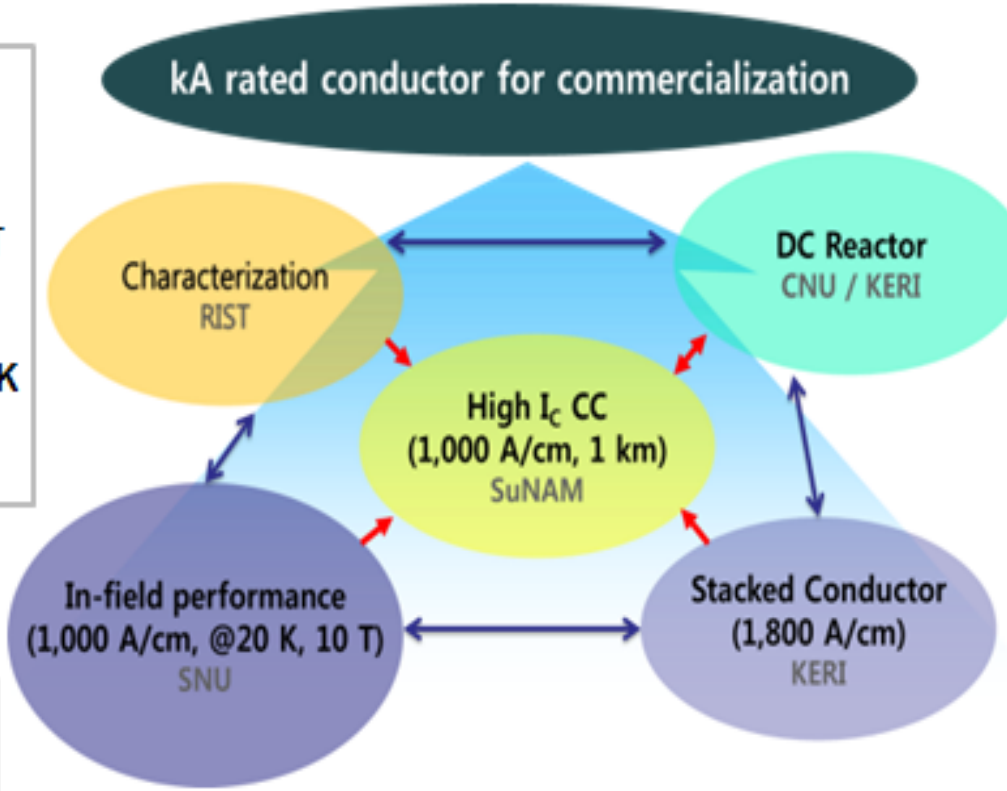
ABAD3
R2R vacuum coater

PLD600
substrate drum

New Gov't Sponsored Coated Conductor Project

Target

- Critical current; I_C > 1,000 A/cm @77 K, s.f. (length > 1 km, uniformity > 96%)
- In-field performance; I_C > 1,000 A/cm @20 K, 10 T
- Stacked conductor; I_C > 1,800 A/cm @77 K, s.f.
- I_C measurement tech.; 0-10 T, > 1,800 A/cm, 20~77 K
- DC reactor demo; 400 mH, 1,500 A



Budget

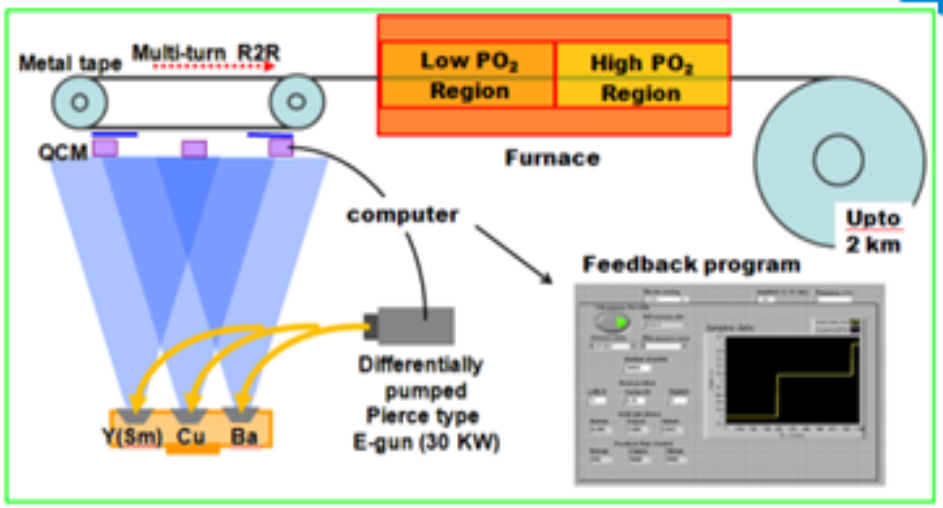
~US$13M; $9M from Gov't, $4M from SuNAM
(June 2013 ~ May 2017, 4 years)

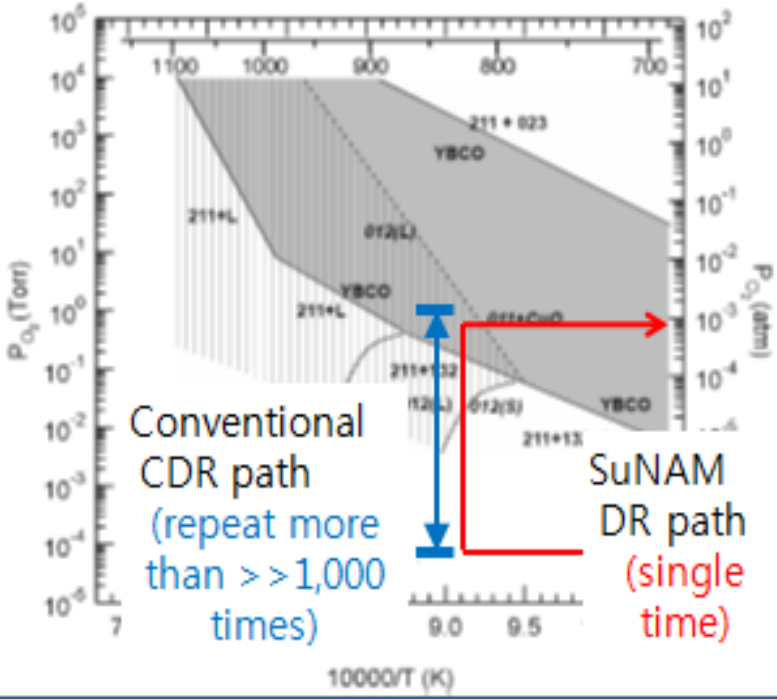
Sponsored by Ministry of Trade, Industry & Energy(MOTIE), through Inst. of Energy Tech. Evaluation and Planning(KETEP)

SuNAM

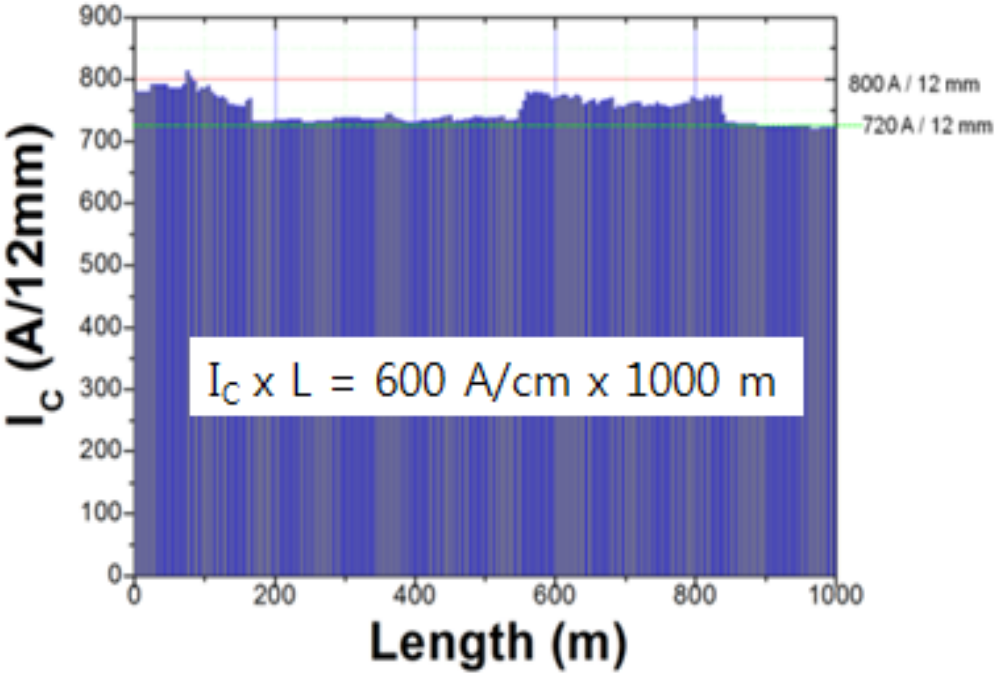
SuNAM RCE-DR process

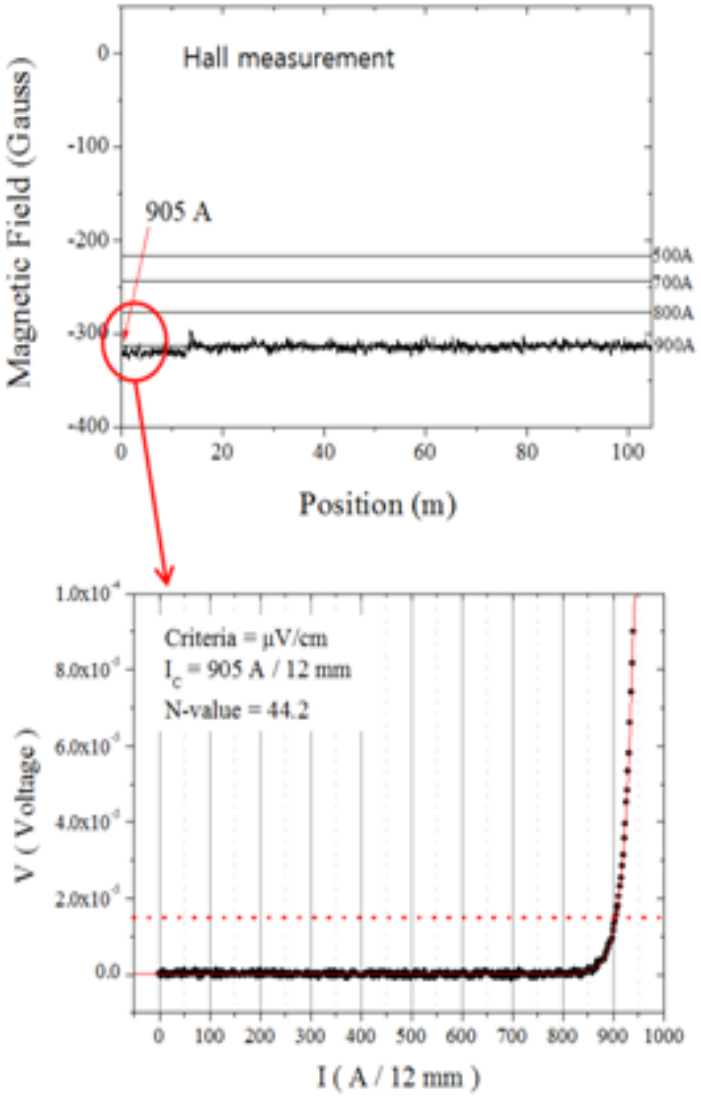
- RCE-DR : Reactive Co-Evaporation by Deposition & Reaction (SuNAM, R2R) : Patent pending(PCT)
- High rate co-evaporation at low temperature & pressure to the target thickness(> 1 μm) at once in deposition zone (6 ~ 10nm/s)
- Fast (<< 30 sec.) conversion from amorphous glassy phase to superconducting phase at high temperature and oxygen pressure in reaction zone
- Simple, higher deposition rate & area, low system cost
- Easy to scale up :single path





RCE-DR Results on Stainless Steel Substrate





(4)-Step Superconducting Wire Manufacturing

SDP

1km x

100 mm

Ceramic Coating

SST / C-276

1

IBAD

1km x 12mm

MgO

Template

2

RCE

1km x 12mm

2G HTS + Ag Cap

3

METALS

(Optional)

Ag / Cu / Other

Varying Thick (µm)

4

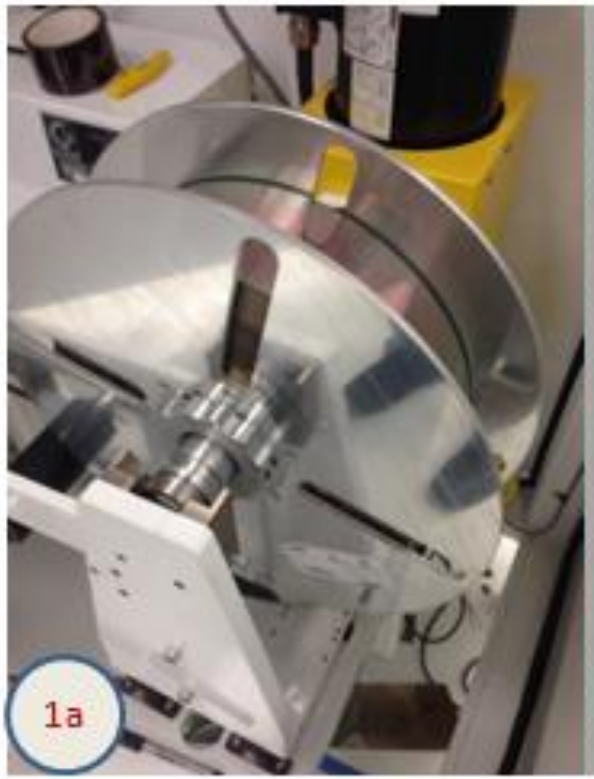
STI

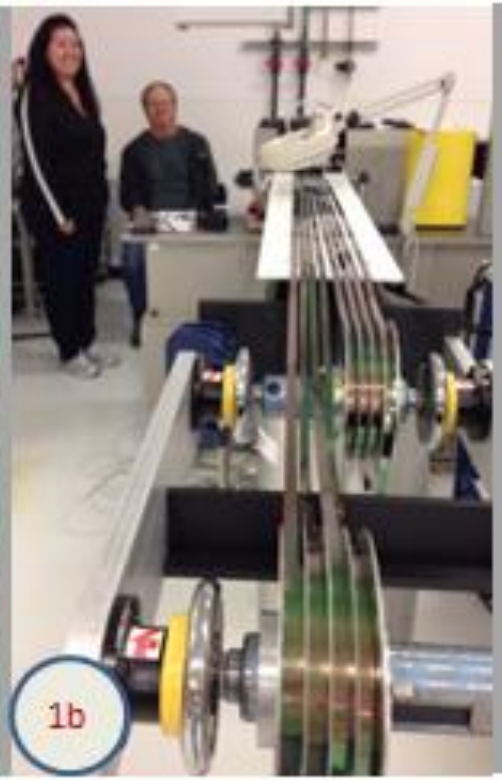
STEP 1 - 1km SDP Planarized Tape

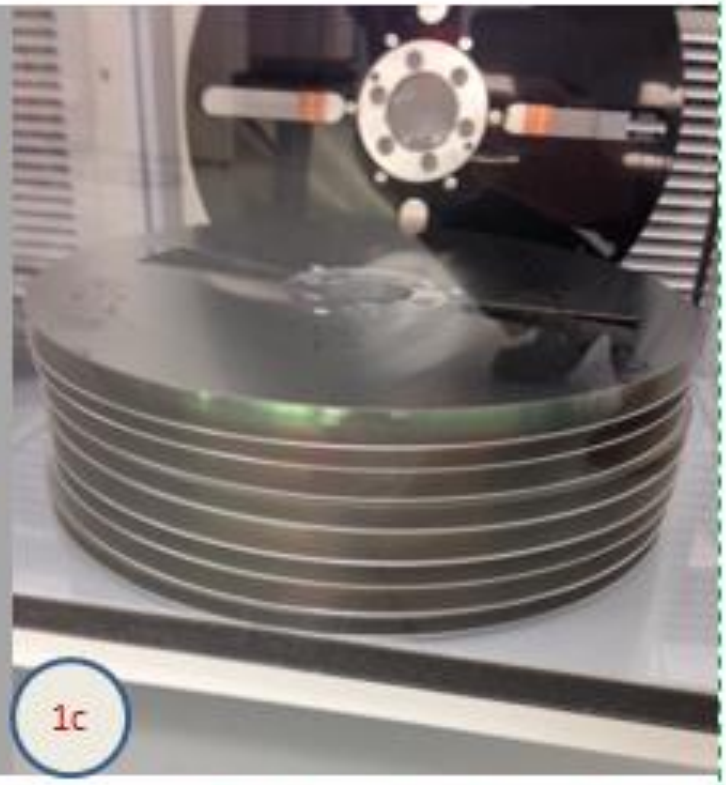
1km x 100mm Wide
Ceramic/SDP
Coated Substrate

EXAMPLE:
Slitting to (8X) 12mm Wide
(Typical Product Dimension)

(8X) 1km length Reels
12mm width Planarized
Coated Substrate







Atmospheric
Reel-to-Reel Process

OPTIONAL Slitting Width – Product Configuration Flexibility

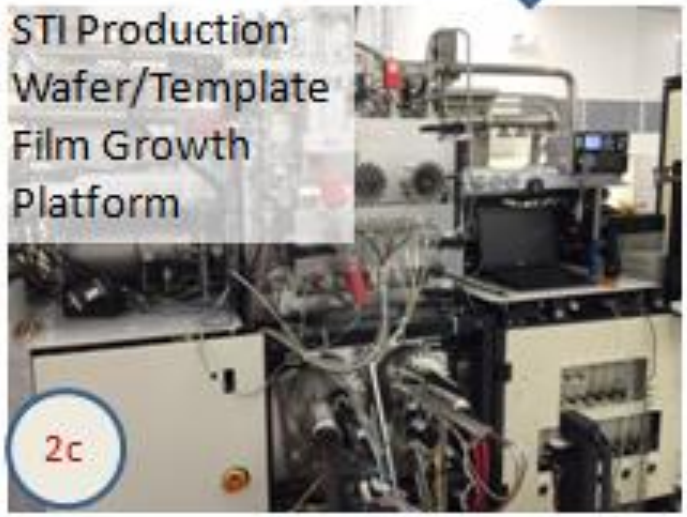
STEP 2 - 1km IBAD Template & Qualification

Vacuum

Reel-to-Reel

Template Quality Control

Load (6x) 20 cm Samples from 1km Reel START & END



Grow Standard 0.7µm Recipe REBCO on (6X) 20 cm tapes

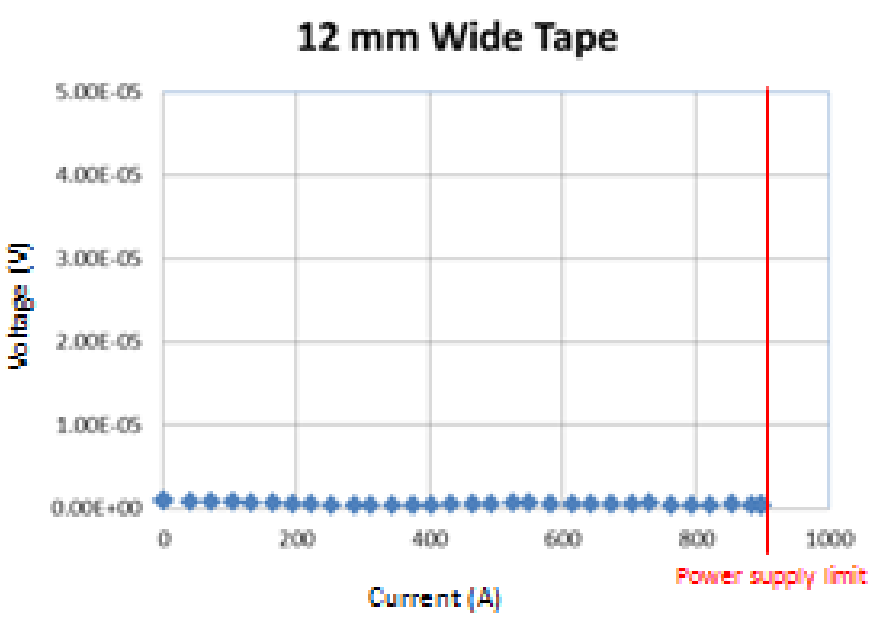
STEP 3 - 2G HTS Tape Completed // Measure

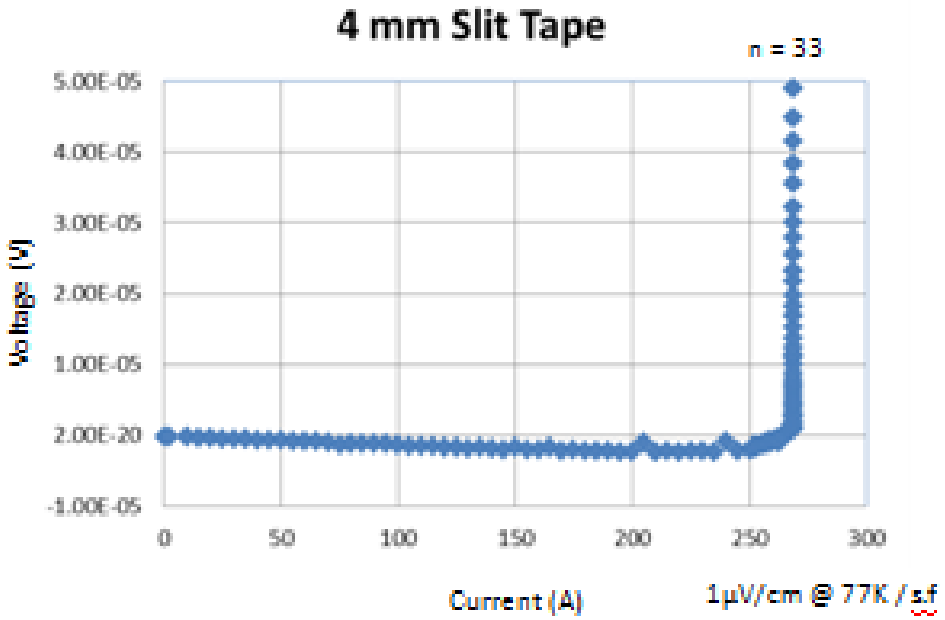
UNLOADING:
12mm x 400 meter length (RE)BCO HTS with Silver cap layer

METROLOGY: TapeStar XL
Atmospheric, Reel-to-Reel

Tape Product Width:	3mm	4mm	10mm	12mm	100mm (tbd)
Batch Size: (meters)	3000	2150	1000	850	100
Capacity: Kilometers/Year/Machine	950	750	300	250	25

Conductus® Ic Measurement



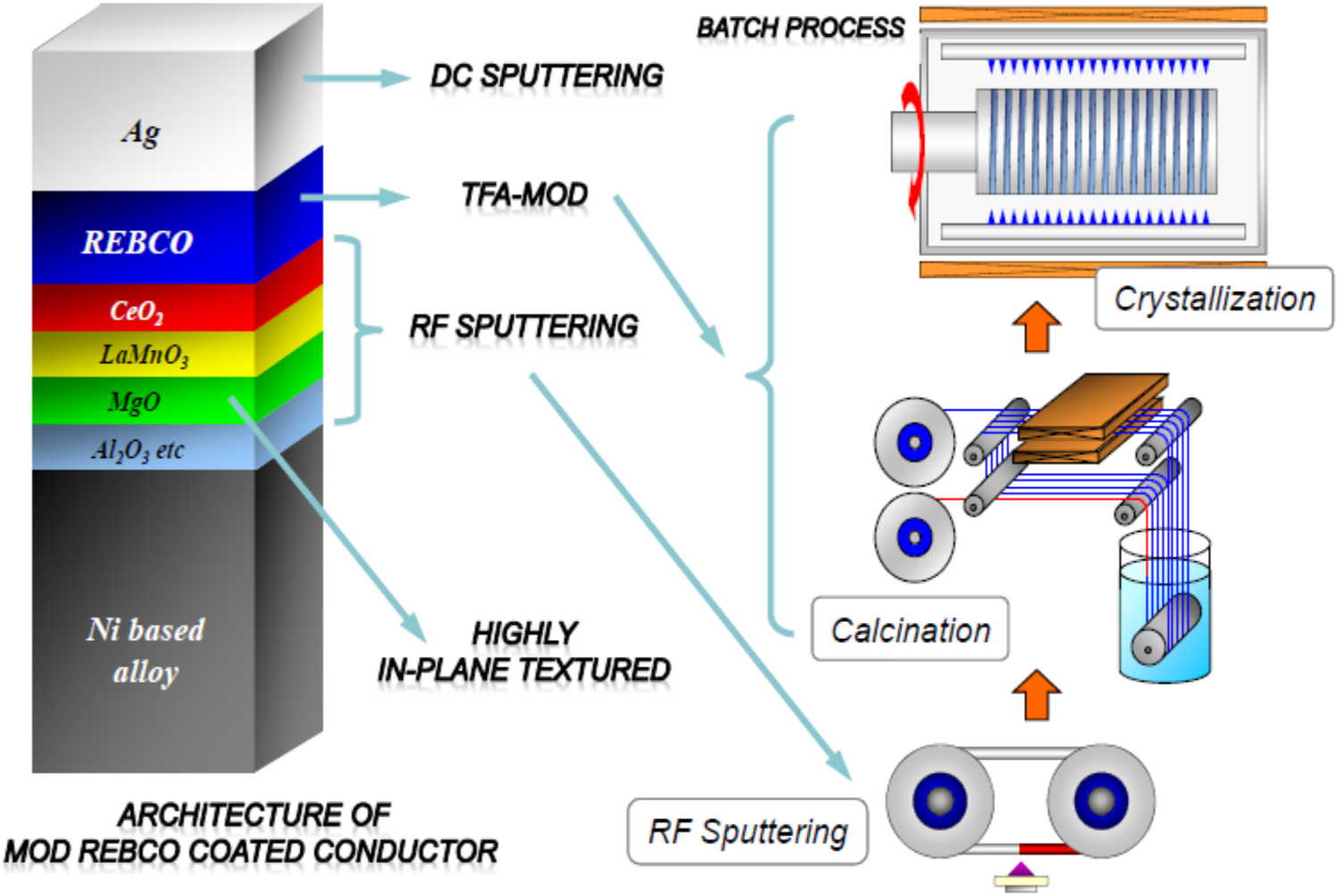


Direct Ic measurement maxed out at 900A for 12 mm tape (power supply limit)

- Slit same tape to 4mm and measured 269A
- This corresponds to 807A – lower than 12 mm due to slitting loss (~10%)
- 4mm tape cut on both edges

MOD REBCO Coated Conductor

Creating for the Future



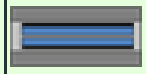
ARCHITECTURE OF MOD REBCO COATED CONDUCTOR

Specifications of HTS cable system

Item	Specifications
Rated voltage	35kV
Nominal voltage (U_o)	21kV
Continues rated current	600A
Critical current (I_c)	1200A
Withstand AC voltage ($2.5U_o$)	53kV
Withstand lightning impulse voltage	200kVp
Short circuit current	25kA 2second

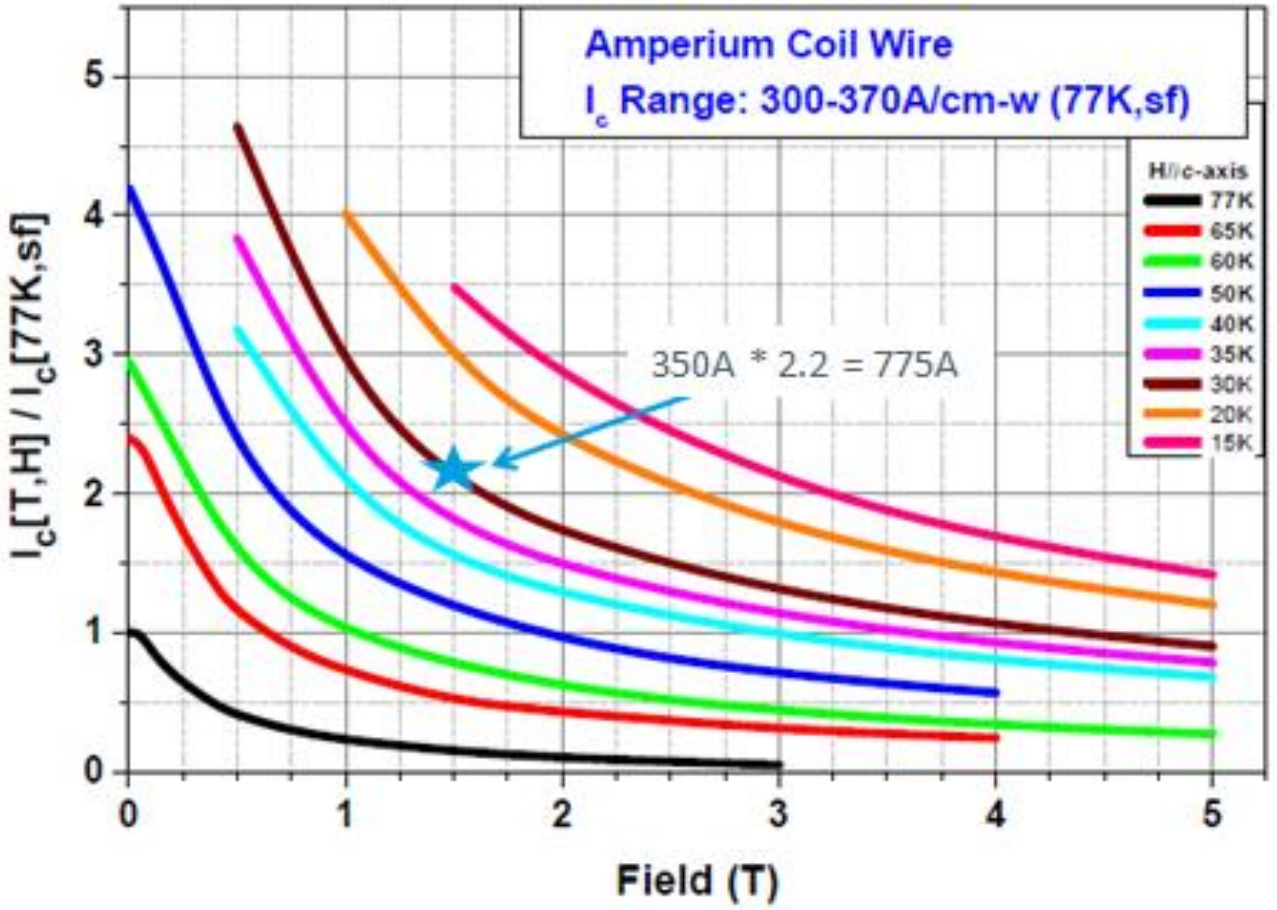
Amperium® Wire Products

Wires addressing a wide range of power applications

Wire Type	Architecture		Minimum I_c 77 K, self-field, 1 µV/cm	Wire Splicing	Applications
Standard Amperium Wires – See www.AMSC.com					
Brass Laminated 4.4 8700		Single HTS, 3-layer, 4.4 mm wide, 150 µm thick brass	*80, 90, 100 A* *140, 150, 160, 170, 180 A* *Cable Formulation*	*Factory spliced to ~1 km long*	Resilient Electric Grid (REG), AC and DC Power Cables, Low Voltage DC Cables
Copper Laminated 4.8 8501		Single HTS, 3-layer, 4.8 mm wide, 50 µm thick copper	*80, 90, 100 A*	*Factory spliced to ~1 km long*	Small Coils, Saturated Core FCLs, Magnets, SMES
Copper Laminated 12 8502		Single HTS, 3-layer, 12 mm wide, 50 µm thick copper	*200, 250 A,* *350 A* *Coil Formulation*	*Factory Spliced to ~500m long*	Large Coils, Generators, Motors, Large SMES
SS Laminated 12 8602		Single HTS, 3-layer, 12 mm wide, 75 µm thick SS	*200, 225, 250 A*	*Splice Free*	Medium and High Voltage Resistive FCLs, Current Leads
SS Laminated 12 Double Insert 8612		Double HTS, 4-layer, 12 mm wide, 75 µm thick SS	*400, 450, 500 A*	*Splice Free*	Medium and High Voltage Resistive FCLs

Amperium Coil Wire: Ic B T, //C

Production Wire, 8502-350, 12mm Copper Stabilized



Process Technology

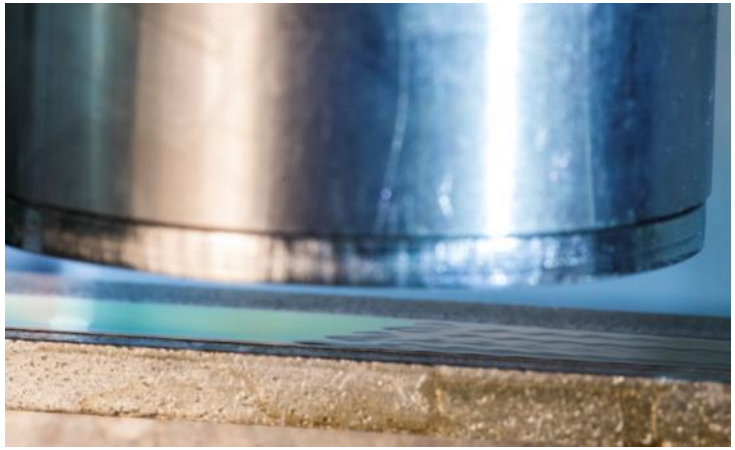
- Challenges for development and production
    - Best price performance ratio (€/kAm)
    - Scalable large volume production
    - Reliable and in-time supply
    - Flexible but mechanically and electrically stable

Process Technology

- Chemical solution deposition

  - Chemical solution deposition (CSD) for all layers is considered to be the „most promising and most challenging process“

  - Unique and protected CSD-multi-layer technology



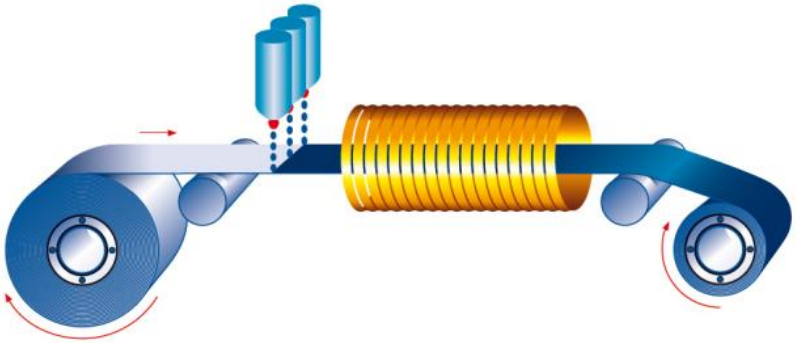
Process Technology

- Chemical solution deposition

Advantages:

- highest throughput (deposition rates)
- lowest investment
- lowest energy consumption
- low raw material costs

⇒ favourable for energy applications

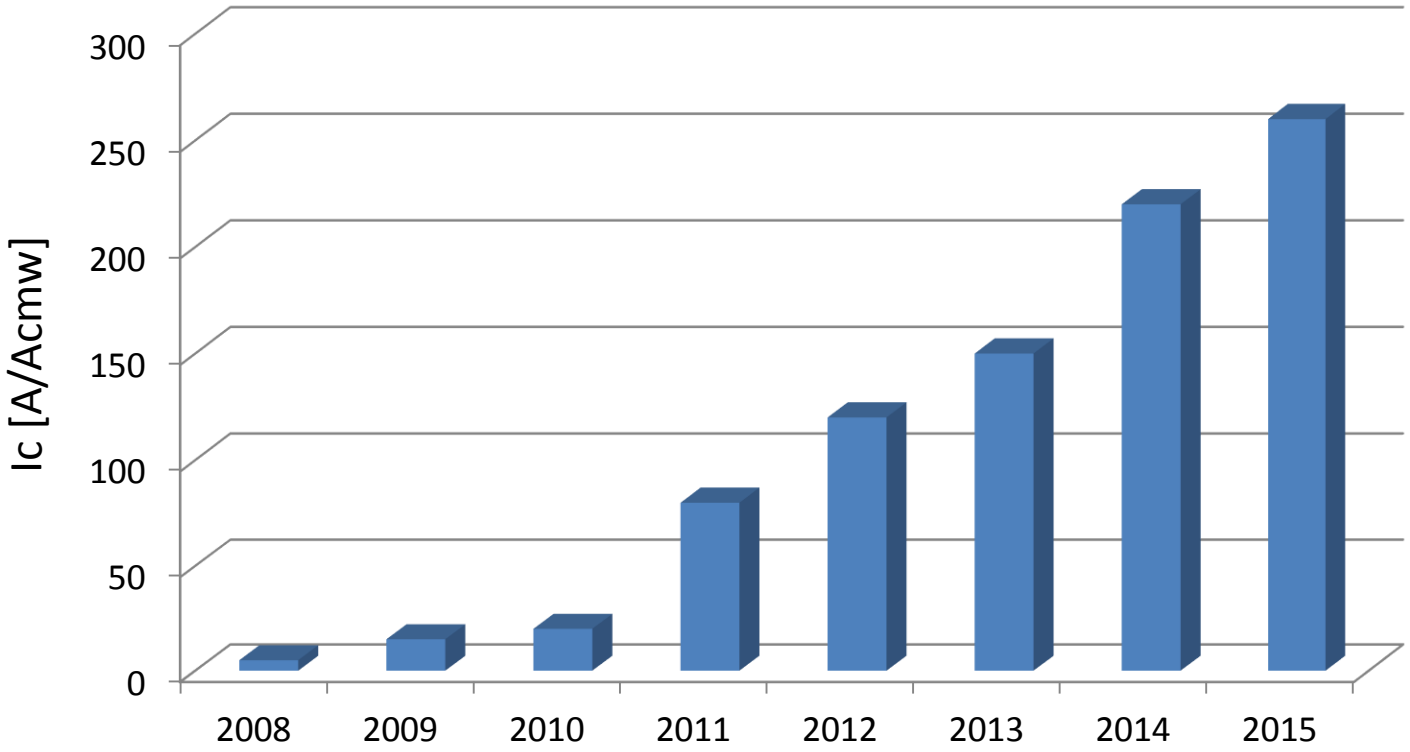


Continuous coating and annealing

Performance

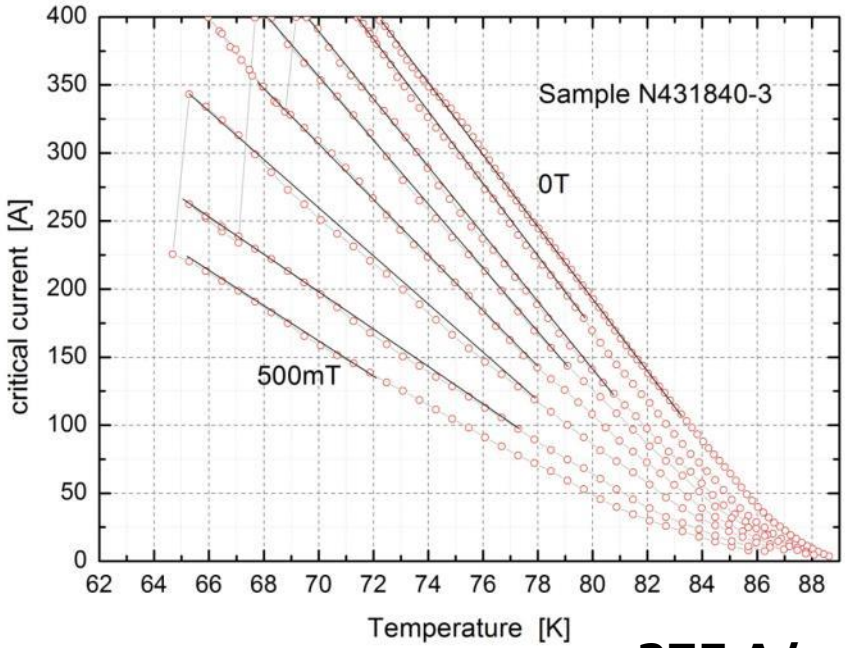
VDM Metals
Honeywell
Heraeus

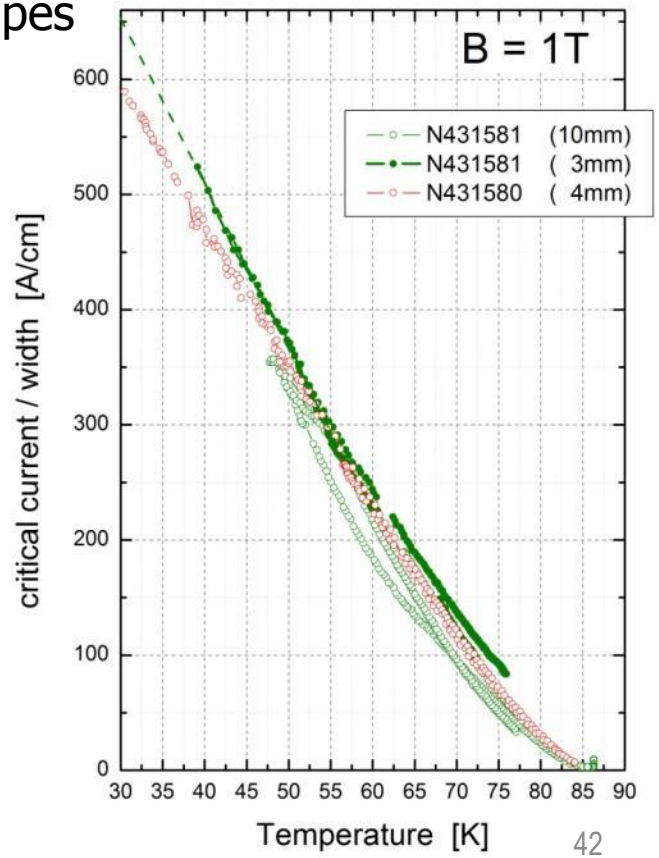
- Development with industrial partners over nearly 10 years
  - Sample lengths increased from 5m (2018) towards >50m (2015)



Performance

- Development with industrial partners over nearly 10 years
  - Short sample measurements of long length tapes





275 A/cmw @ 77K,sf
600 A/cmw @ 30K,1T
(@1000nm HTS layer)

Expanded pilot line

- EPL construction until end 2015
- Planned capacity > 200km technical HTS wire
- Start sampling for projects mid 2016

Lab processing

Expanded Pilot Line

Kooperation BASF (Deutsche Nanoschicht) und AMSC

BASF
We create chemistry

amsc

AMSC and BASF form strategic relationship to develop lower cost superconductor wire

- BASF to license AMSC's second generation high temperature superconductor manufacturing technology
- Parties agree to develop advanced low cost manufacturing process for second generation high temperature superconductor

DEVENS, MASSACHUSETTS, USA and LUDWIGSHAFEN, GERMANY – March 08, 2016 –

Zusammenfassung

„Flexible Supraleiterbänder mit hoher Stromtragfähigkeit für energietechnische und industrielle Anwendungen werden heute kommerziell hergestellt."

www.ivsupra.de

- Ca. 10 Hersteller für HTS Bandleiter weltweit
- >5 Hersteller mit Pilotproduktionen zwischen 100 – 500km/a Kapazität
- Weltweite Kapazitäten ausreichend für Prototypen und Kleinserien
- Auslastung der Kapazitäten essentiell für weitere Aufskalierung und Kostenreduktion

deutsche nanoschicht

chemistry meets energy

Vielen Dank für Ihre Aufmerksamkeit

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Federal Ministry of Economics and Technology

Die Landesregierung Nordrhein-Westfalen

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