REBCO coatings for high-energy physics applications under high magnetic fields

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Outline

1 – Superconductivity

2 – High-Temperature superconductors vs Cu: $R_s(H)$ in the GHz range

3 – Coating surfaces with High-Temperature superconductors @ ICMAB

4 – Coated surfaces examples

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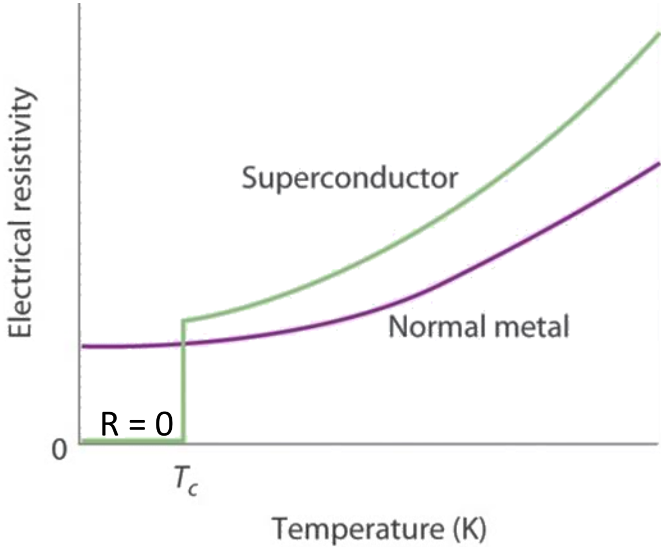
Superconductivity: Phenomenology

Zero (DC) resistivity



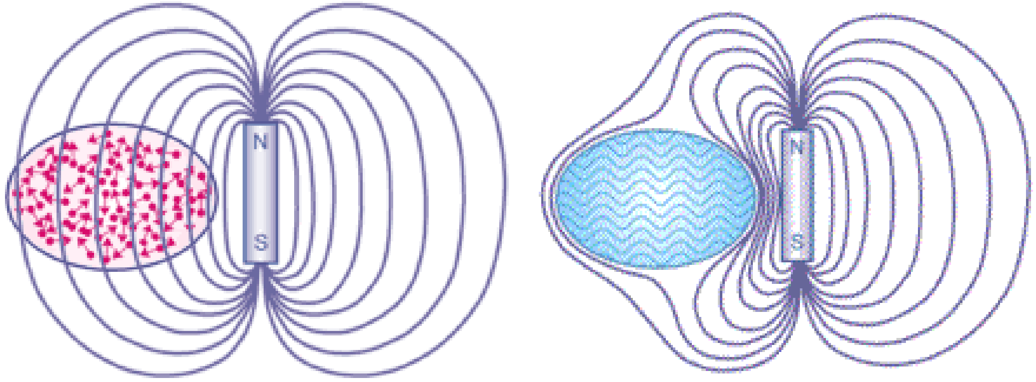
Heike Kamerlingh Onnes

Leiden 1911

Meissner-Ochsenfeld effect

(Perfect diamagnetis)

Walther Meissner and Robert Ochsenfeld in 1933



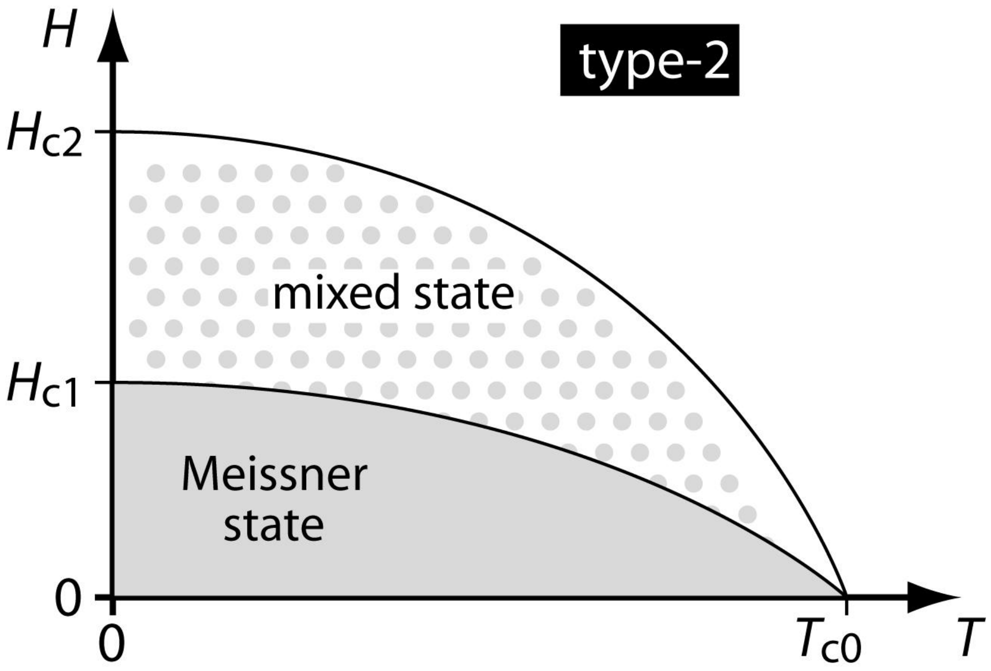
$T > T_c$ Metal *$T < T_c$ Superconductor*

Surface currents expel magnetic field

Superconductors trap magnetic field

H_{c2} ~ 1 - 100 T

H_{c1} ~ 100 Oe

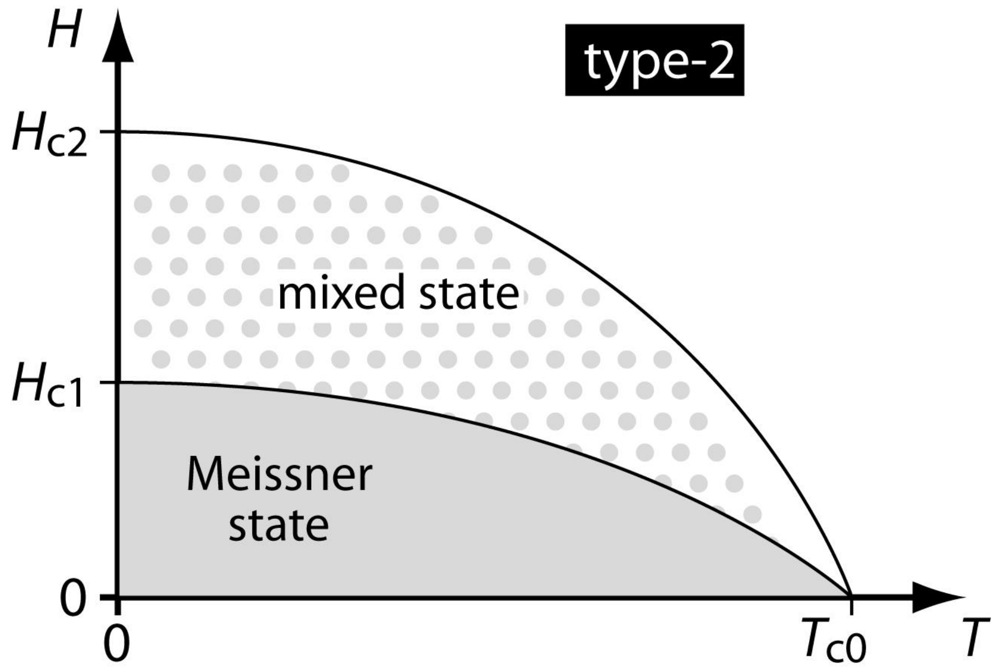


Superconductors trap magnetic field

Inside the SC magnetic field is quantised

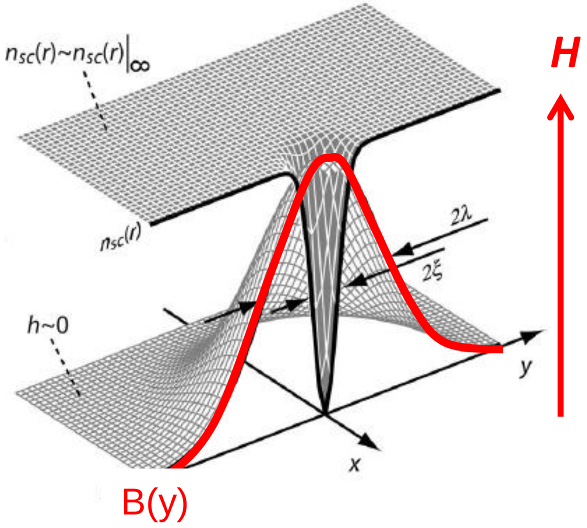
H_{c2} ~ 1 - 100 T

H_{c1} ~ 100 Oe



Vortex

$\Phi_0 = 2.07 \cdot 10^{-15}$Wb



$\xi \sim 1 - 100$ nm

$\lambda \sim 10 - 2000$ nm

Material dependent

Vortex movement → *Energy dissipation*

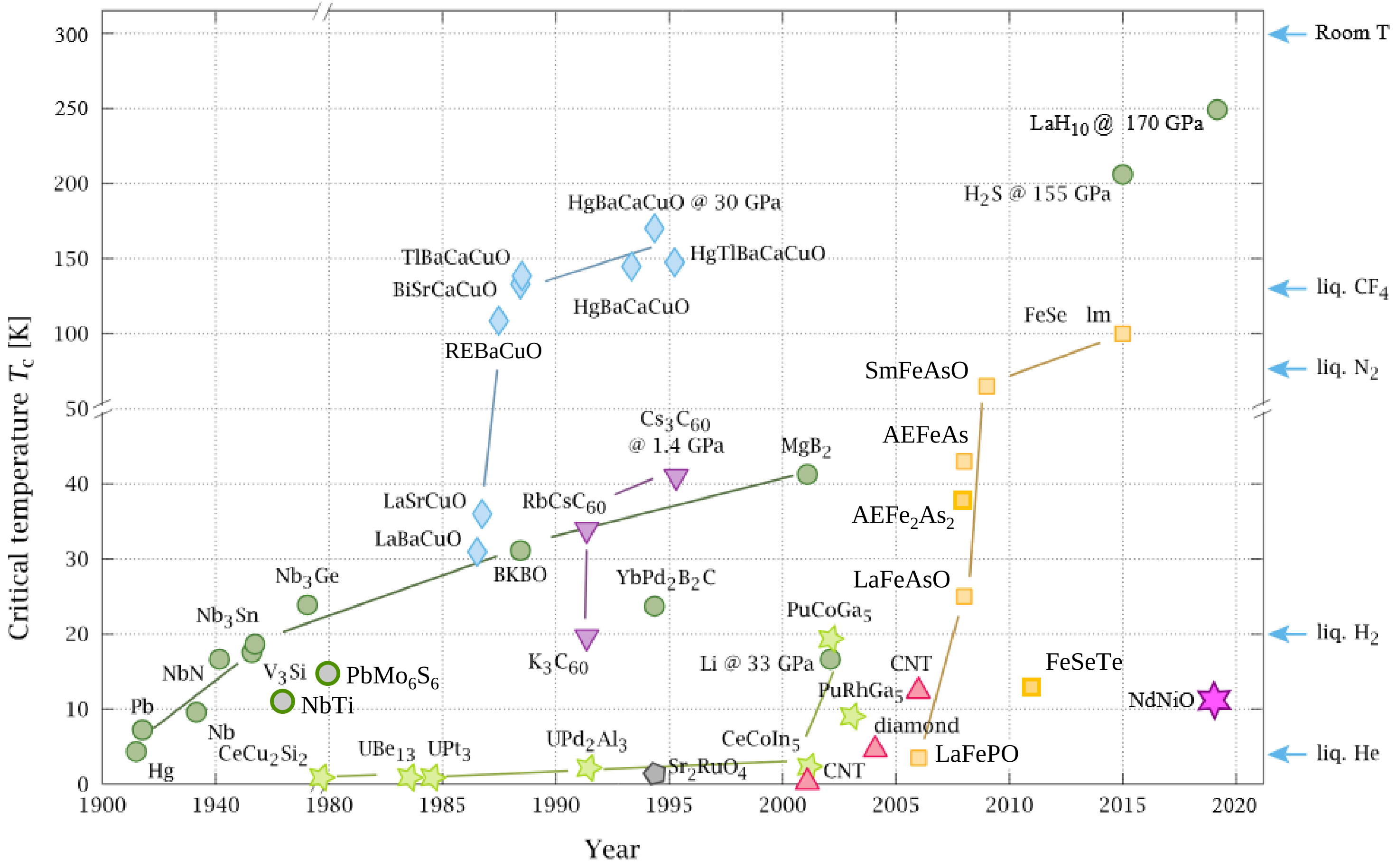
$E_{eff} = v_{fl} \wedge B$

R ≠ 0

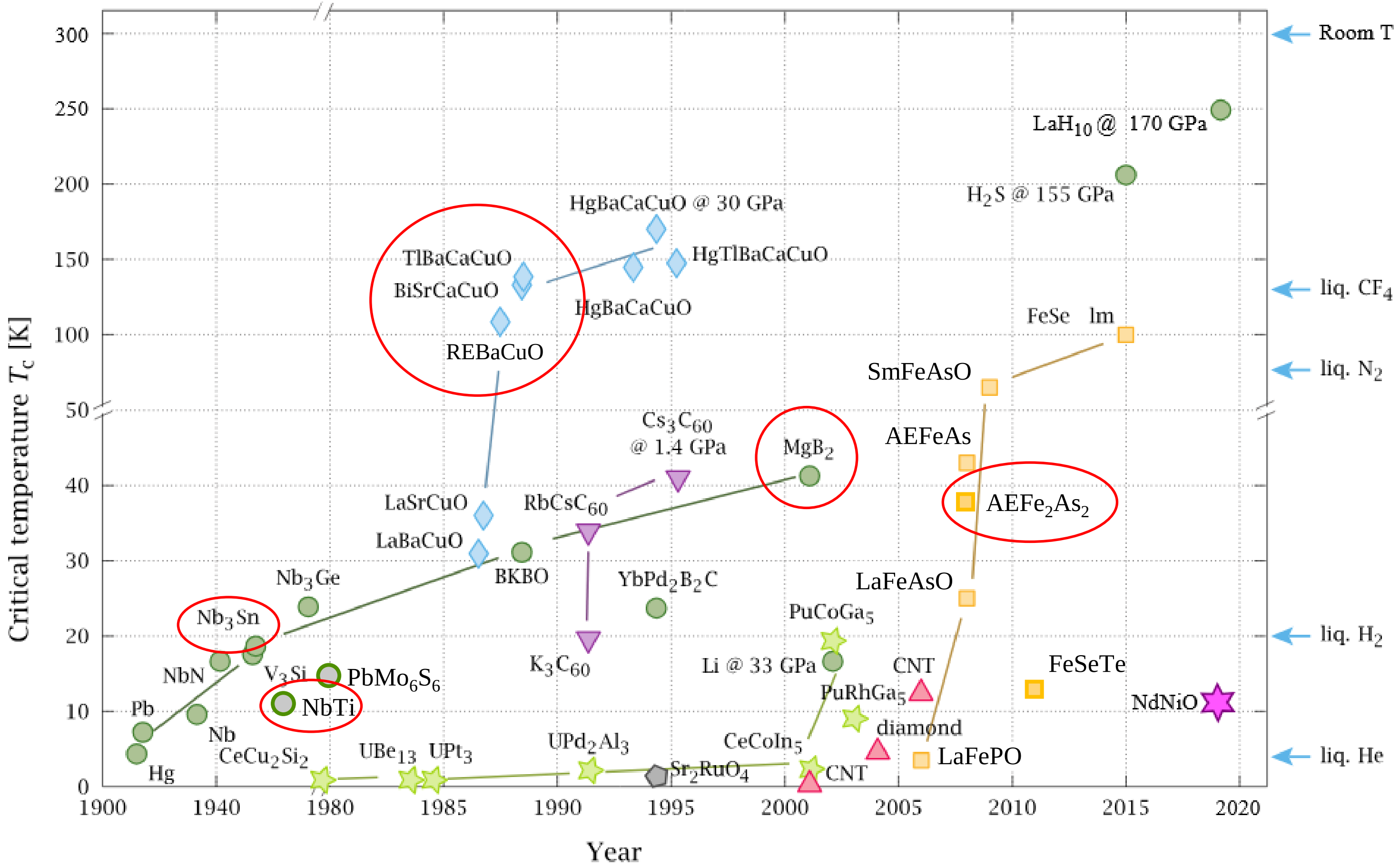
Challenge: Pin vortices

Vortex physics & micro-structure.

Superconductors' time line



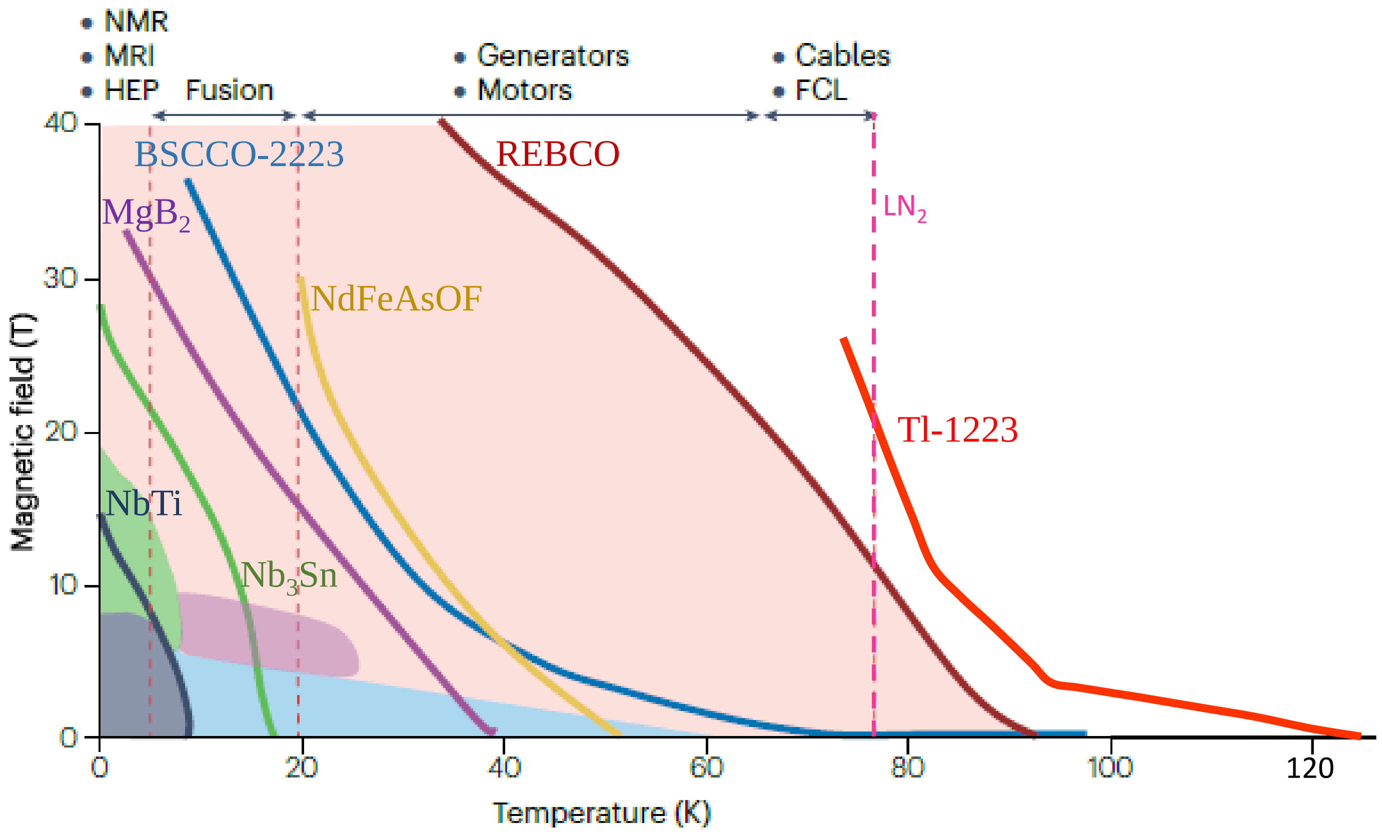
Superconductors’ time line



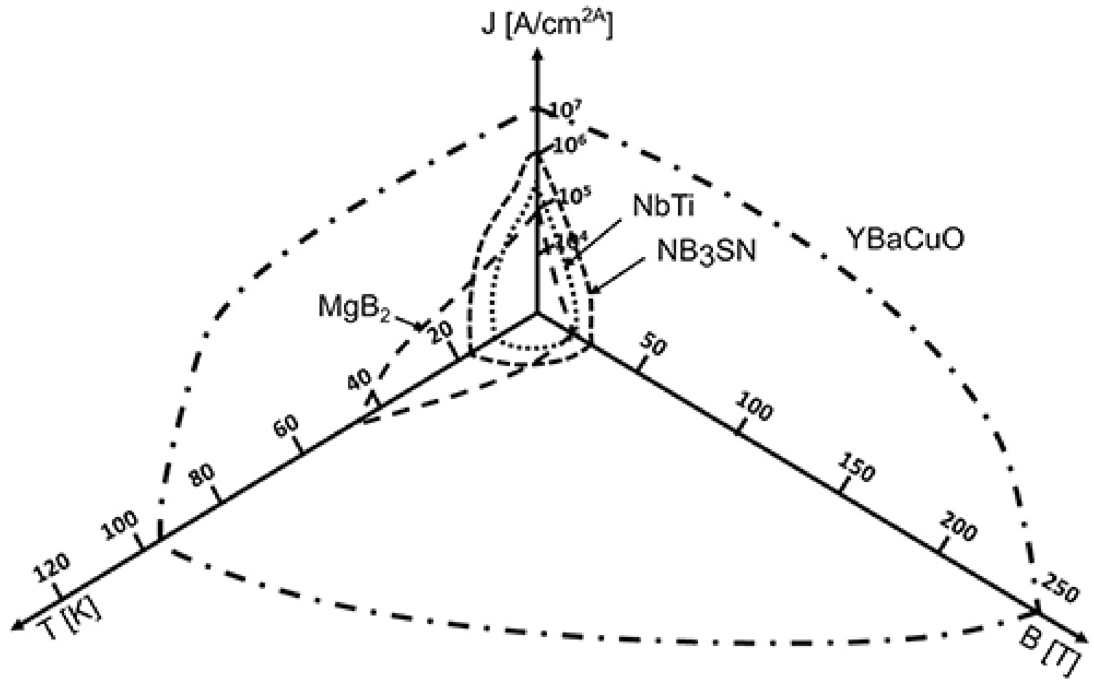
Extra requirements for a practical superconductor:

- *Scalability of growing process*
- *(Wires) Co-processing with metallic materials*
- *(Wires) High currents at long lengths > 100 m*

Why REBCO?

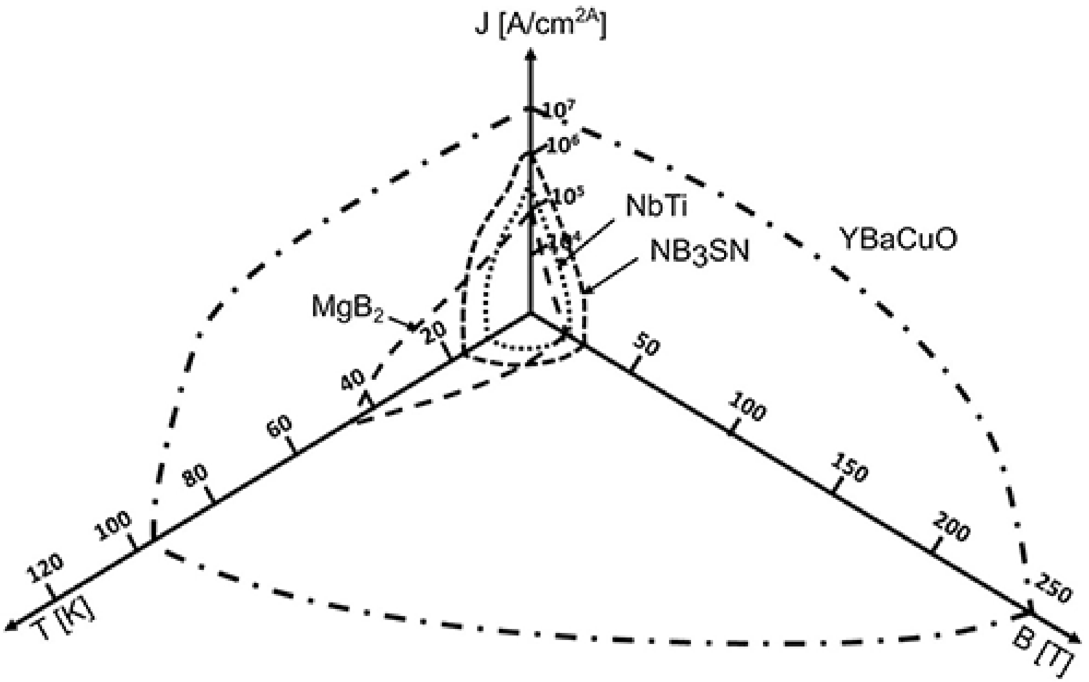


• NMR
• MRI
• HEP
Fusion
• Generators
• Motors
• Cables
• FCL
BSCCO-2223
REBCO
MgB$_2$
NdFeAsOF
LN$_2$
Tl-1223
NbTi
Nb$_3$Sn
Magnetic field (T)
Temperature (K)

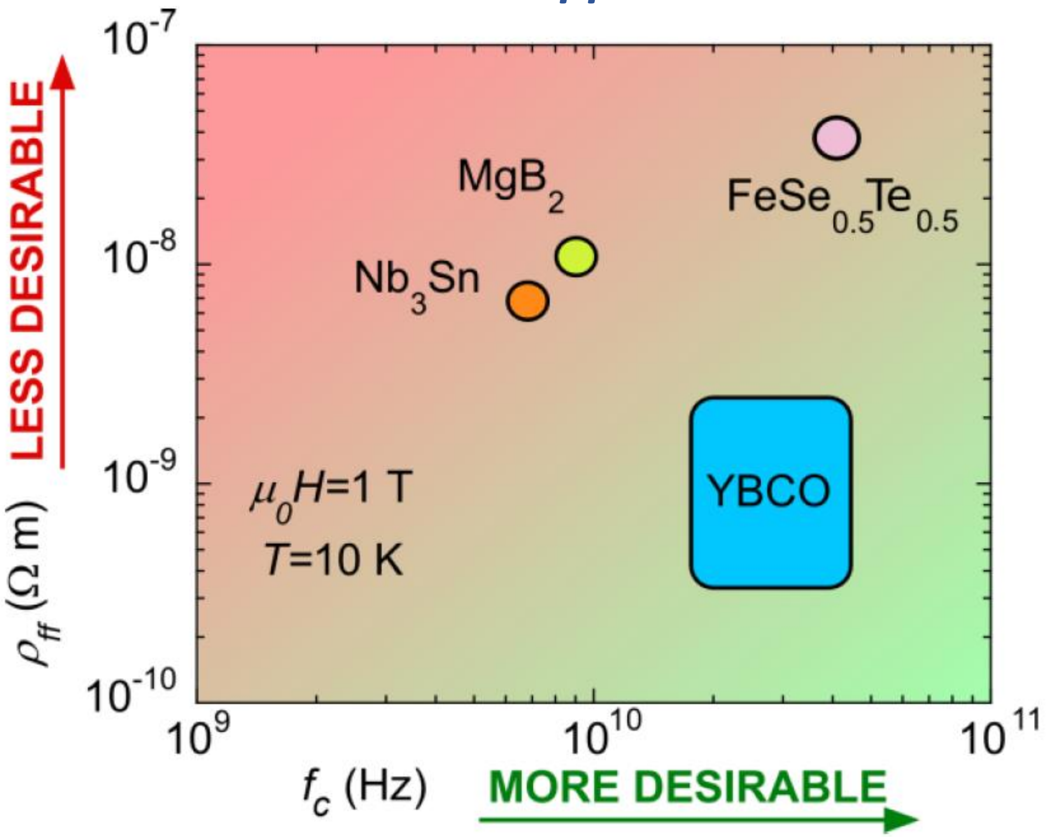


J [A/cm^{2A}]
NbTi
NB3SN
YBaCuO
MgB$_2$
T [K]
B [T]

Why REBCO?



For RF applications



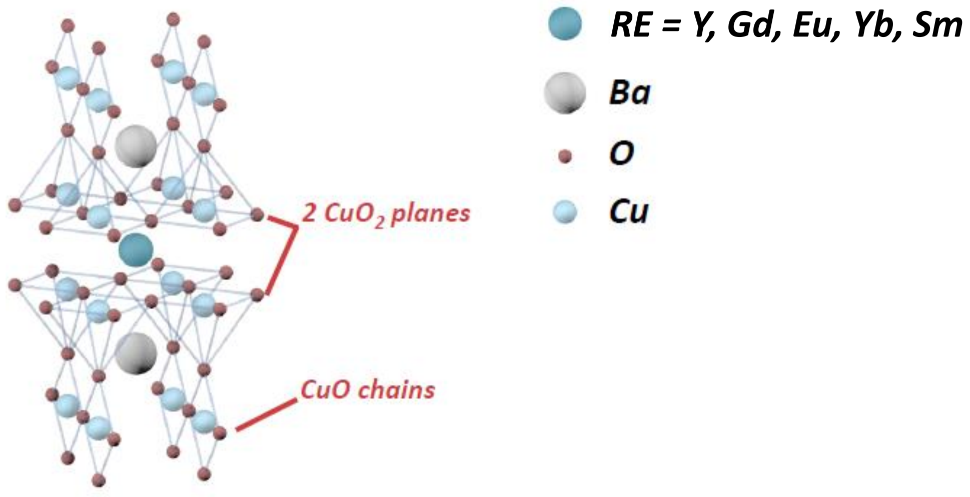
A. Alimenti et al. IEEE Instr. & Meas. Mag. **24** (2021)

***REBCO:** Excellent superconducting properties in a wide H, T, f range*

But….

Cuprates are ceramic d-wave superconductors

In cuprates superconductivity occurs at the CuO_2 planes



RE123

$REBa_2Cu_3O_{7-x}$

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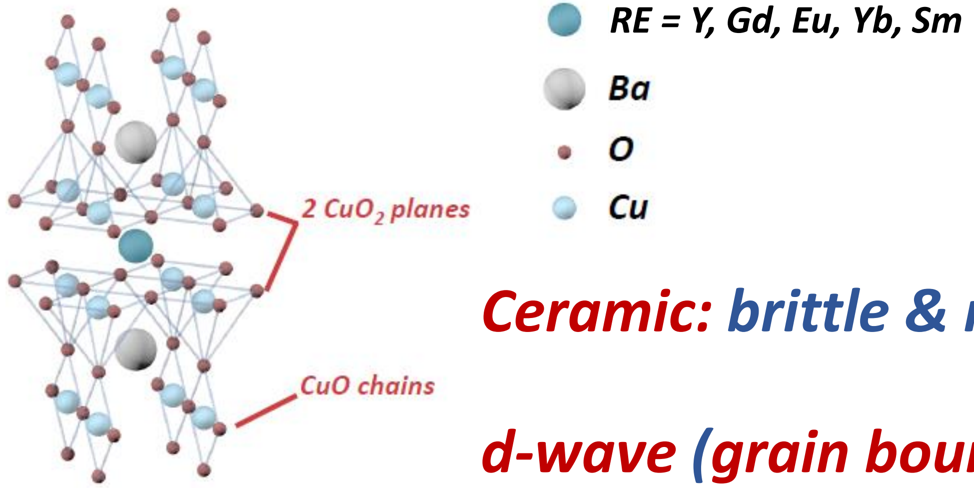
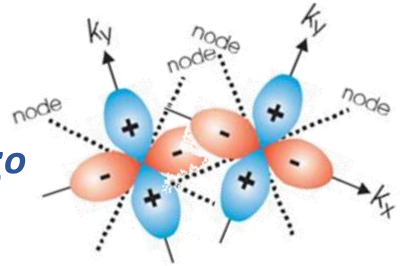


RE123

$REBa_2Cu_3O_{7-x}$

Ceramic: brittle & not flexible

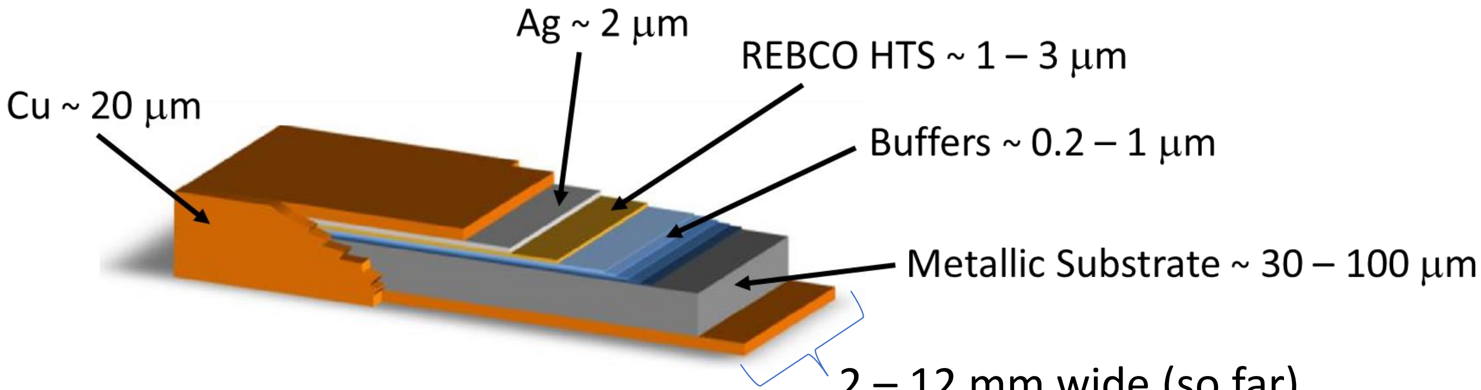
d-wave (grain boundary problem): Superconducting properties greatly degrade with crystal misalignment >5º



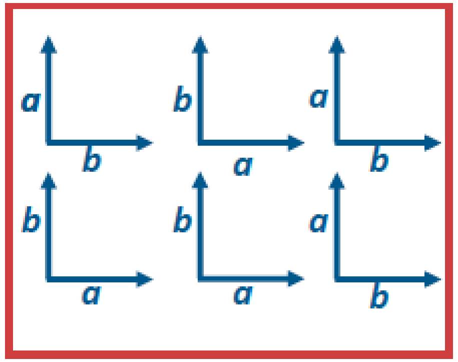
CuO_2 planes: out of plane anisotropy

How do we turn this into a viable technology?

REBCO coated conductors are the solution



Coated Conductor

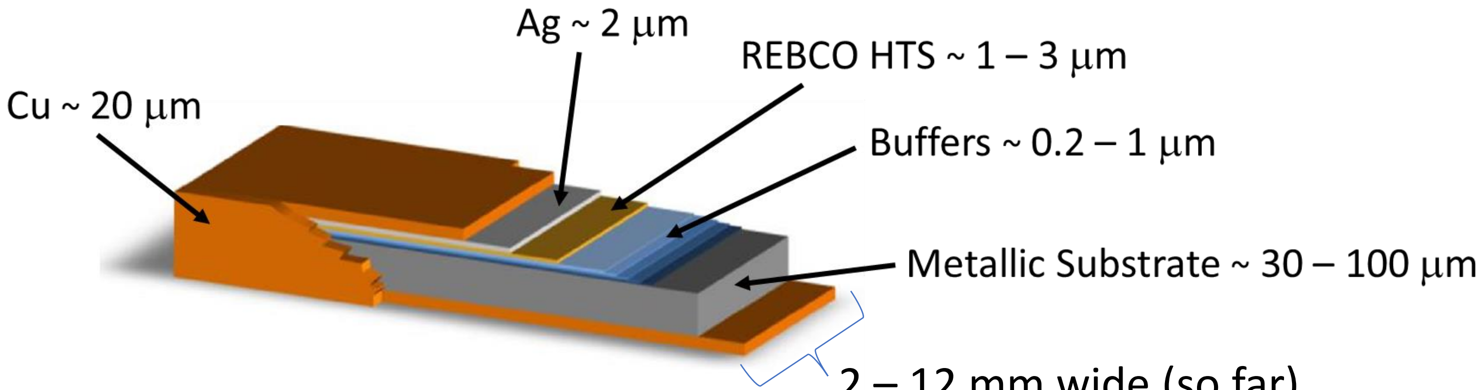


Textured

The template is a metallic substrate coated with a multifunctional oxide barrier

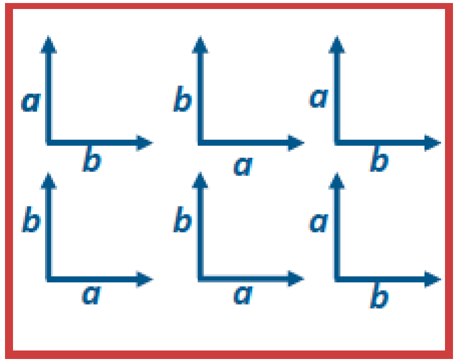
Biaxial texturing – within < 3° – is needed to overcome the grain boundary problem

REBCO coated conductors are the solution



Coated Conductor

30+ years of scientific and technological development



Textured

CCs are

The template is a metallic substrate coated with a multifunctional oxide barrier → *Flexible*

Biaxial texturing – within < 3° – is needed to overcome the grain boundary problem → *Excellent SC properties @Km length*

Produced world wide by 6+ companies

5.000Km production in 2024 (USA, Japan, China & Germany)

50.000Km projected for 2028

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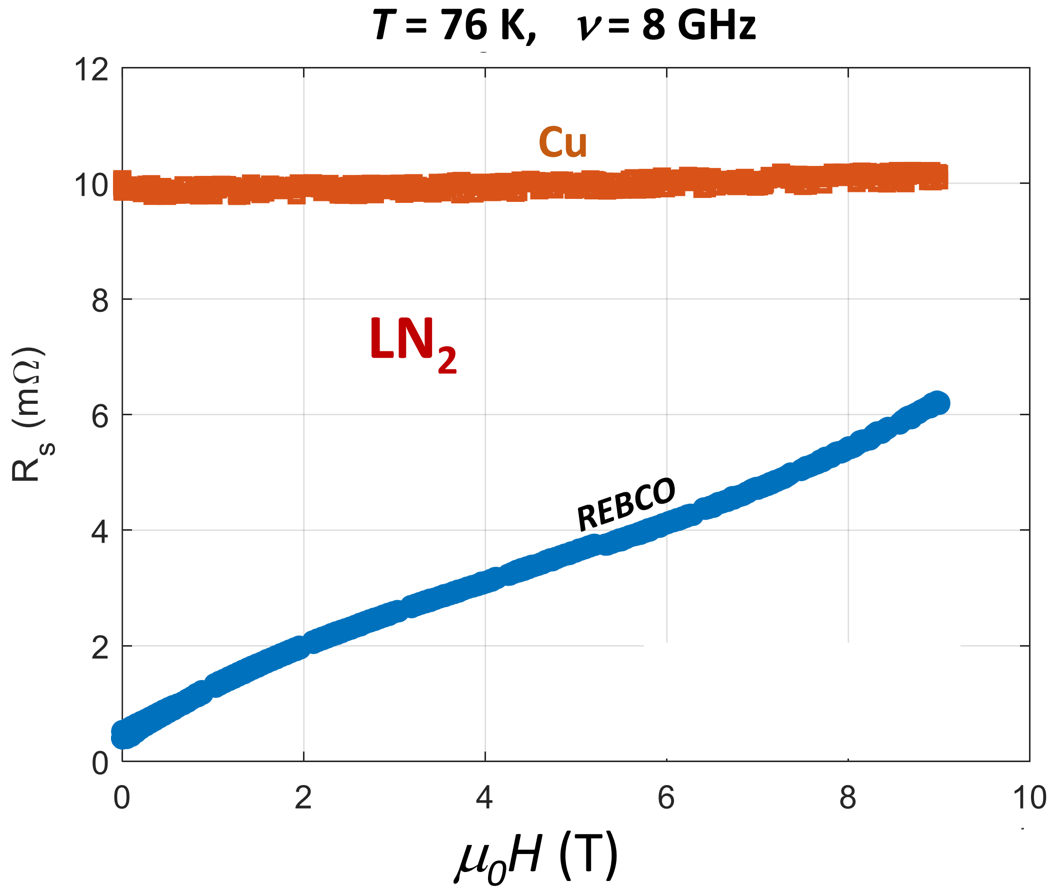
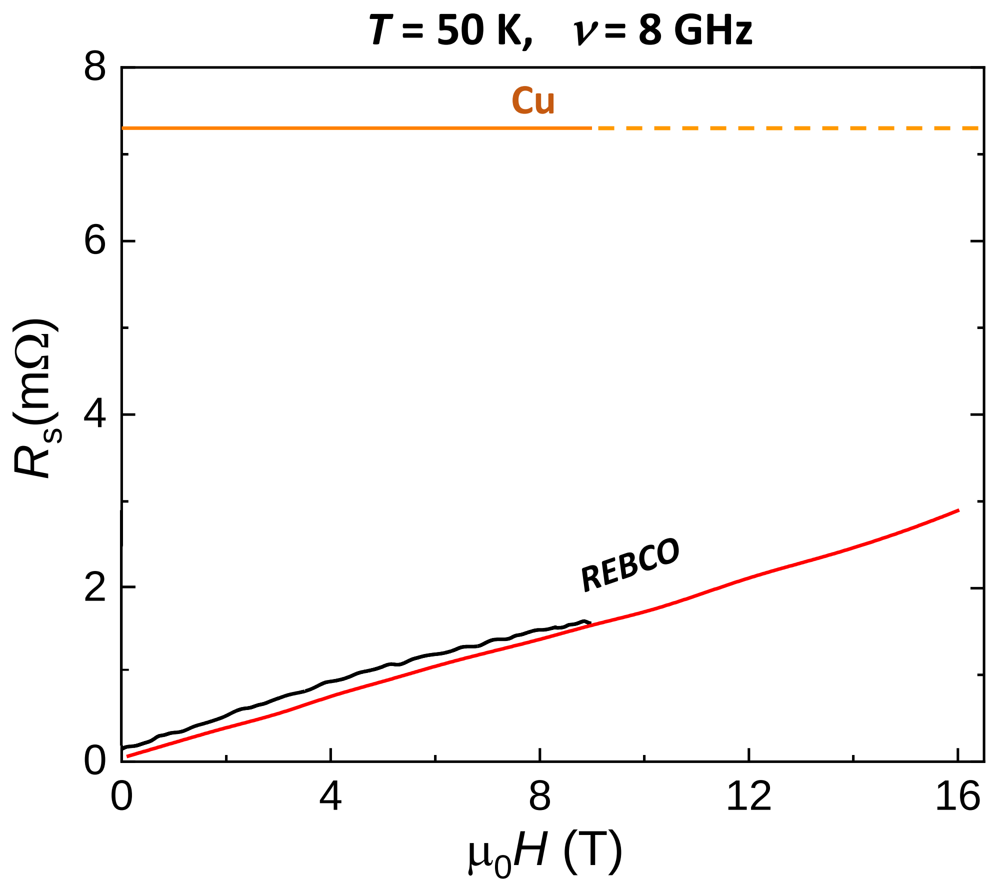
REBCO CCs have lower R_s than Cu → Better RF performance

SCs always dissipate under an AC electromagnetic field

in a wide range of T, H

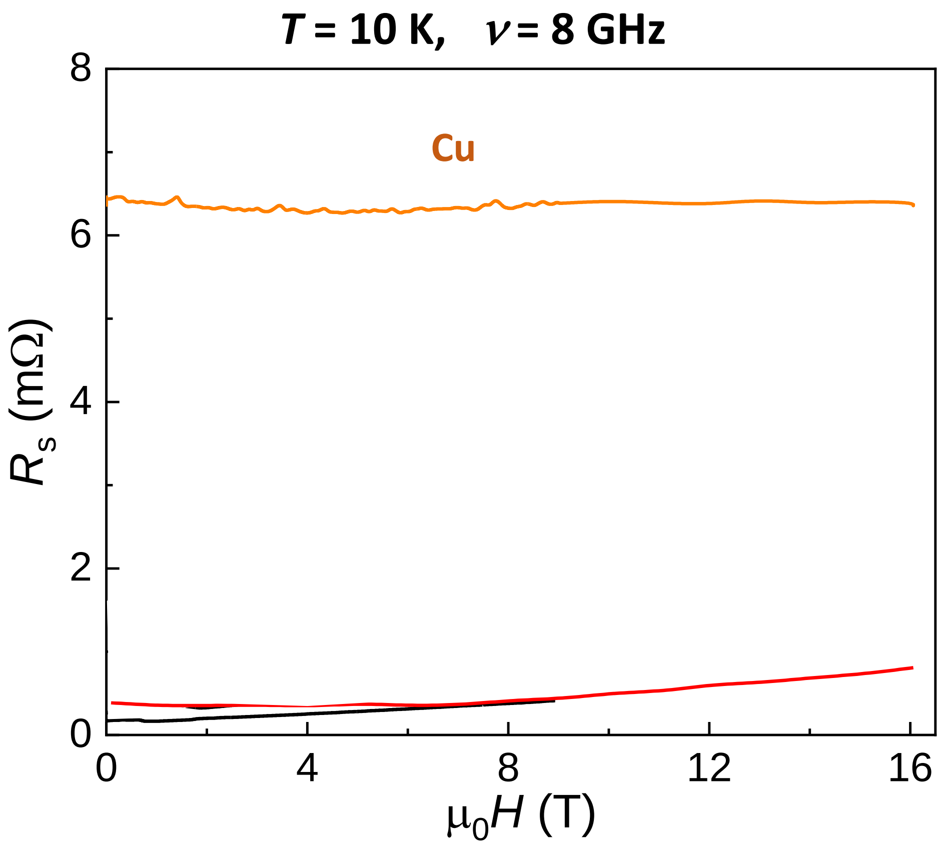


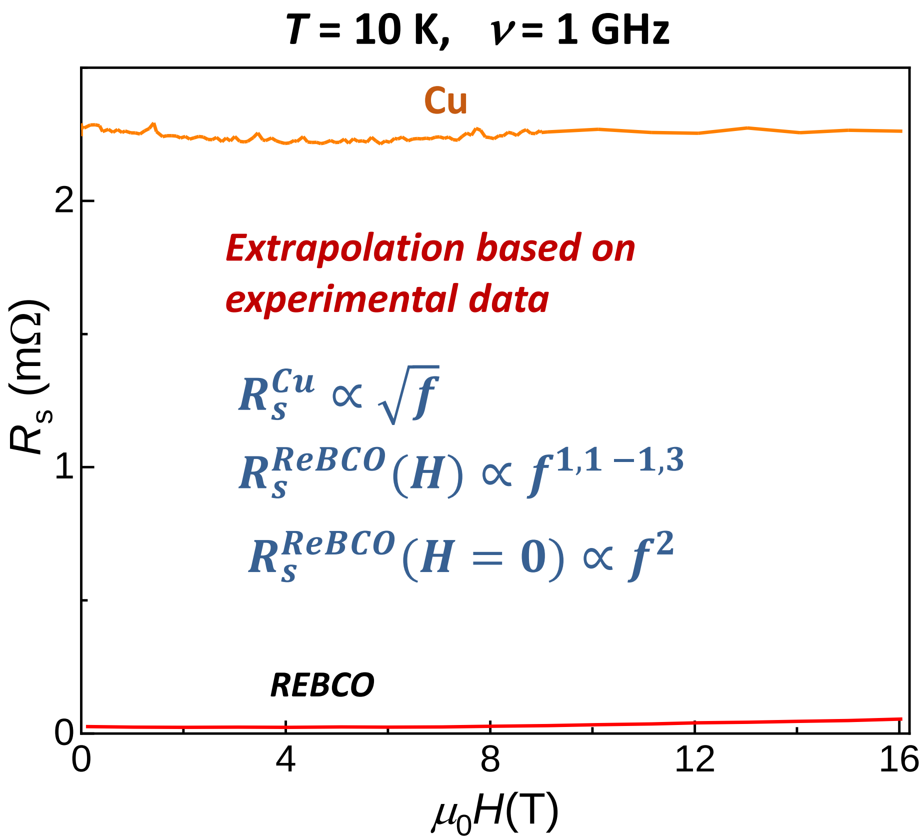


REBCO CCs have lower R_s than Cu → Better RF performance

SCs always dissipate under an AC electromagnetic field

in a wide range of T, H & f



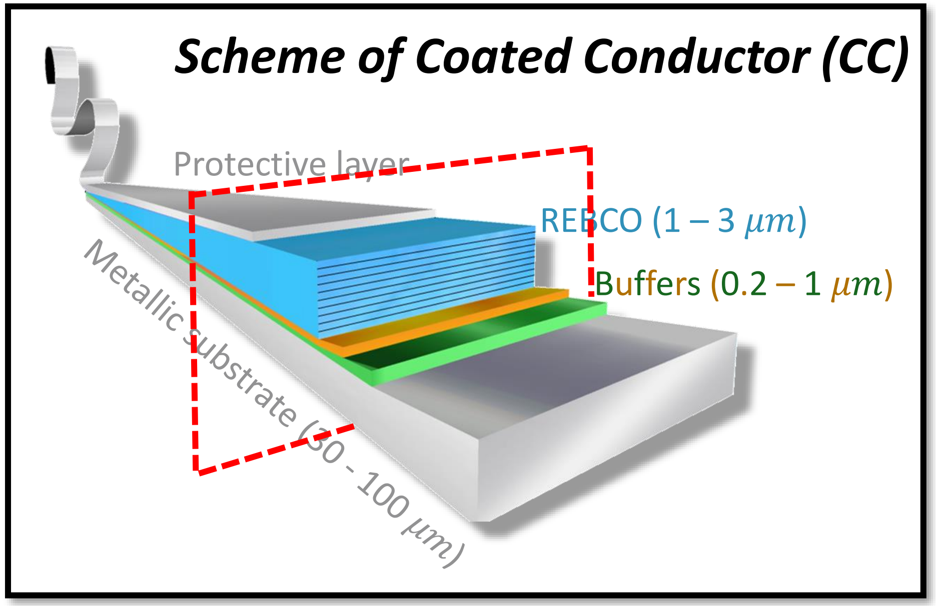


$$Q \propto \frac{1}{R_s}$$

The lower the operating temperature and frequency the larger the benefit from using REBCO

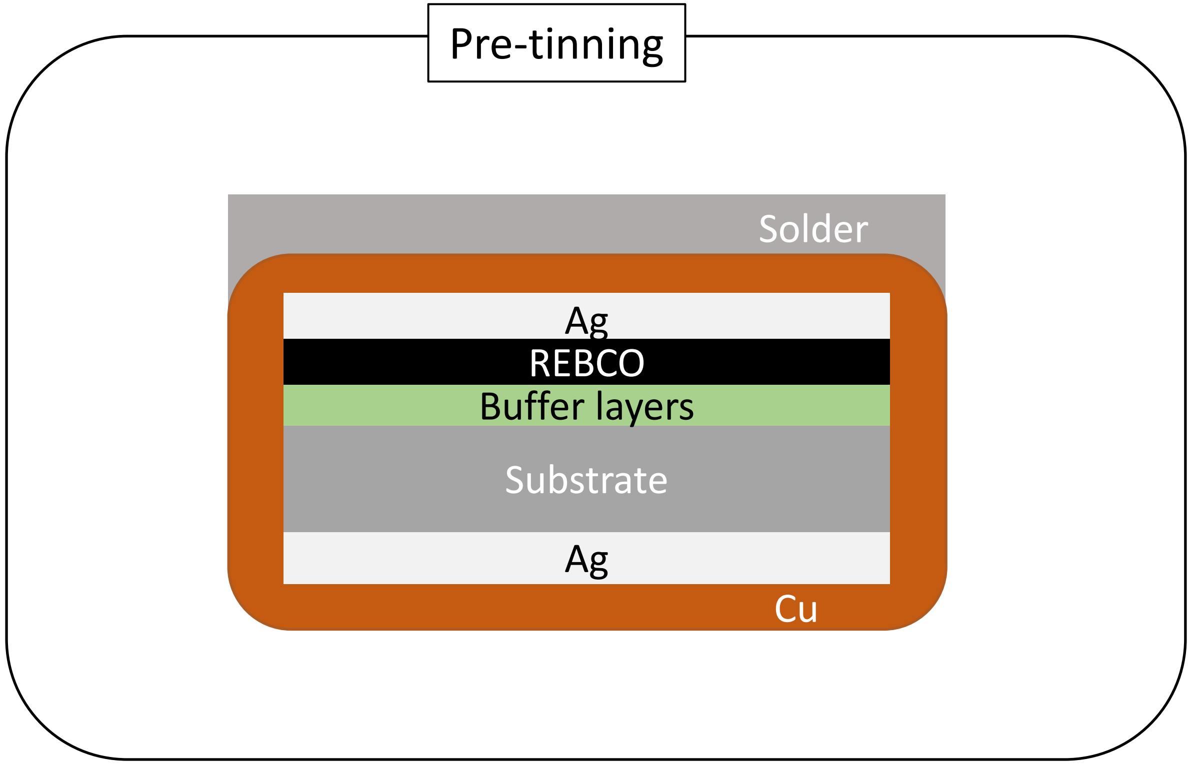
Outline

Coating process in a nutshell:



Coating process in a nutshell:

Thickness & homogeneity of the solder is critical



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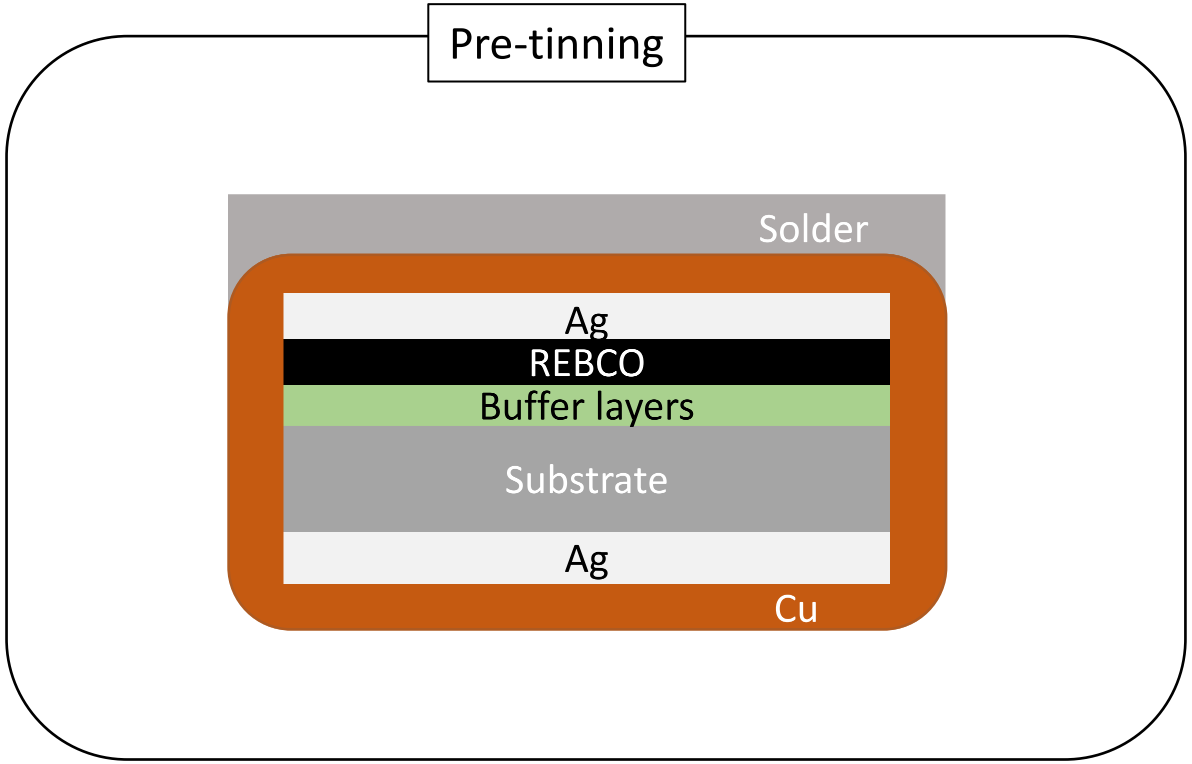
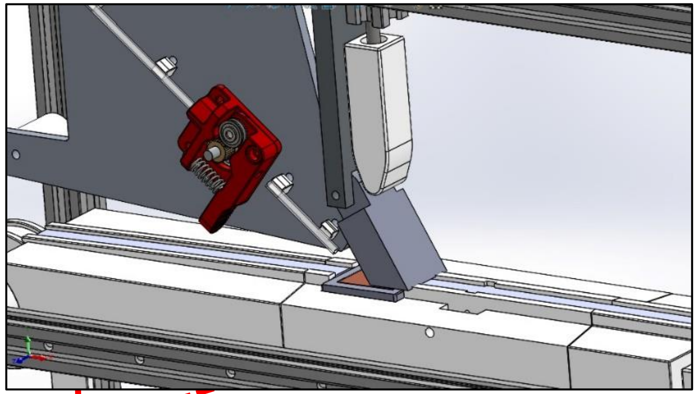
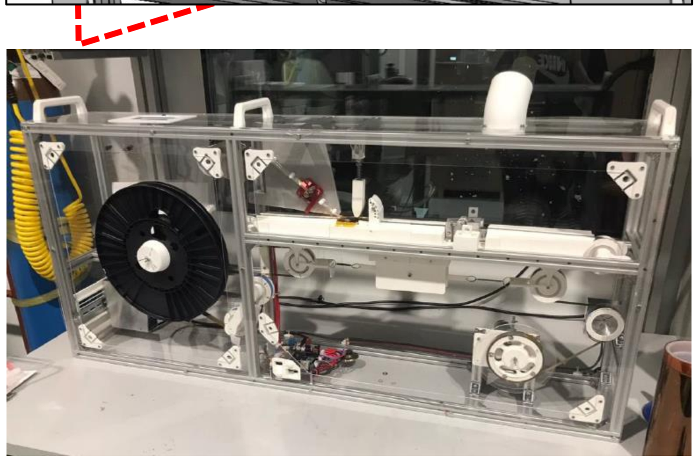




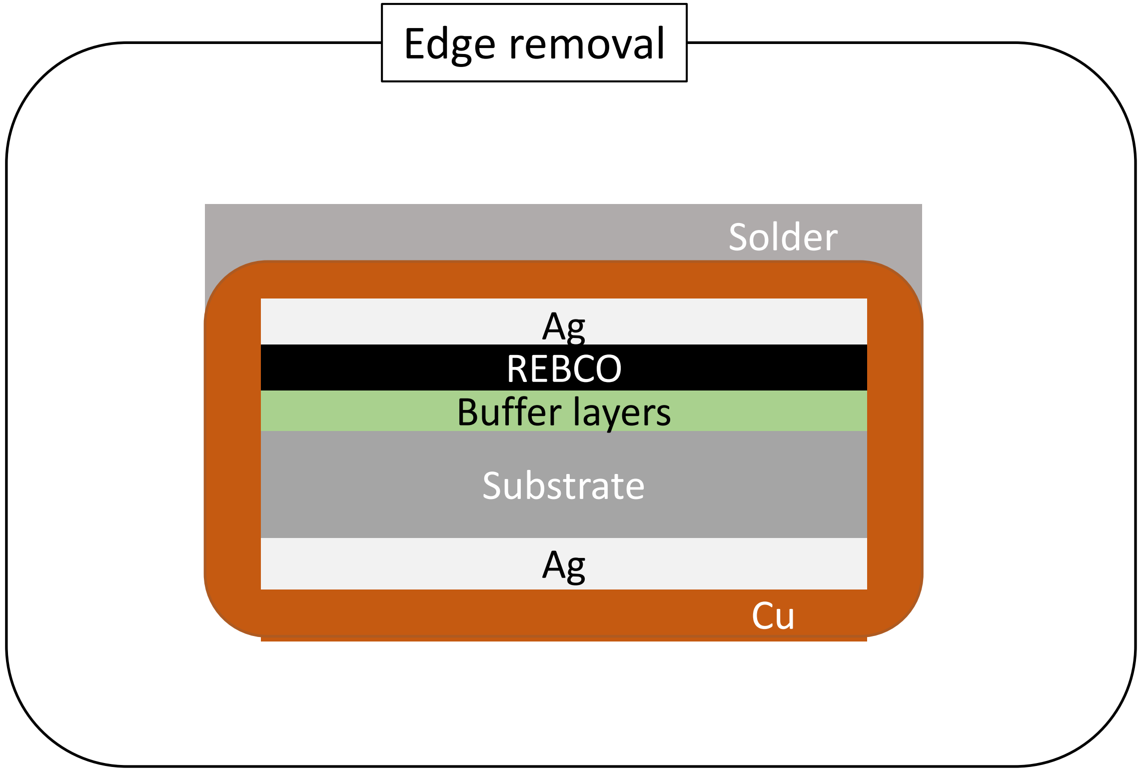


Reel-to-reel pre-tinning machine

Allows for solder thickness control

Coating process in a nutshell

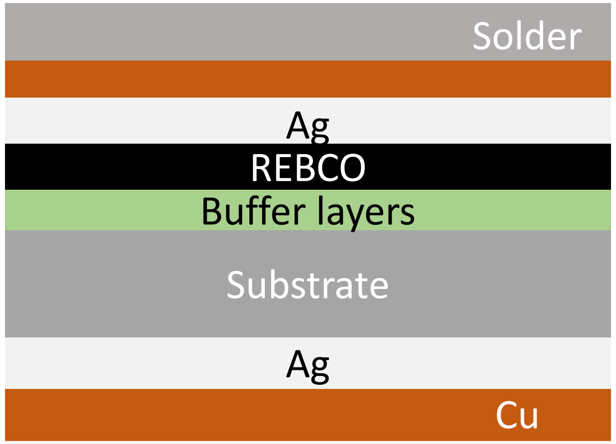
Removing Cu envelope without damaging the REBCO layer

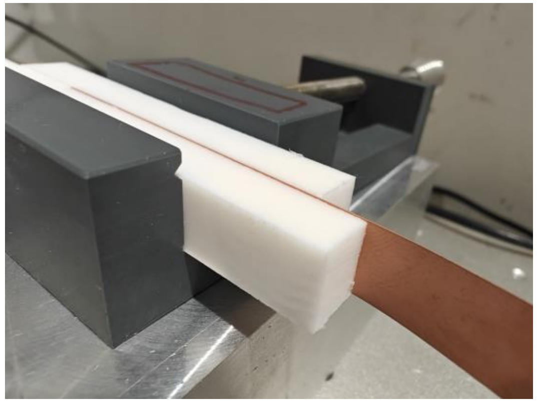


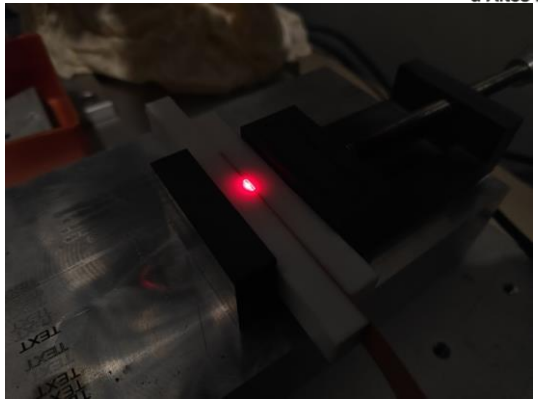
Coating process in a nutshell

Removing Cu envelope without damaging the REBCO layer

Edge removal





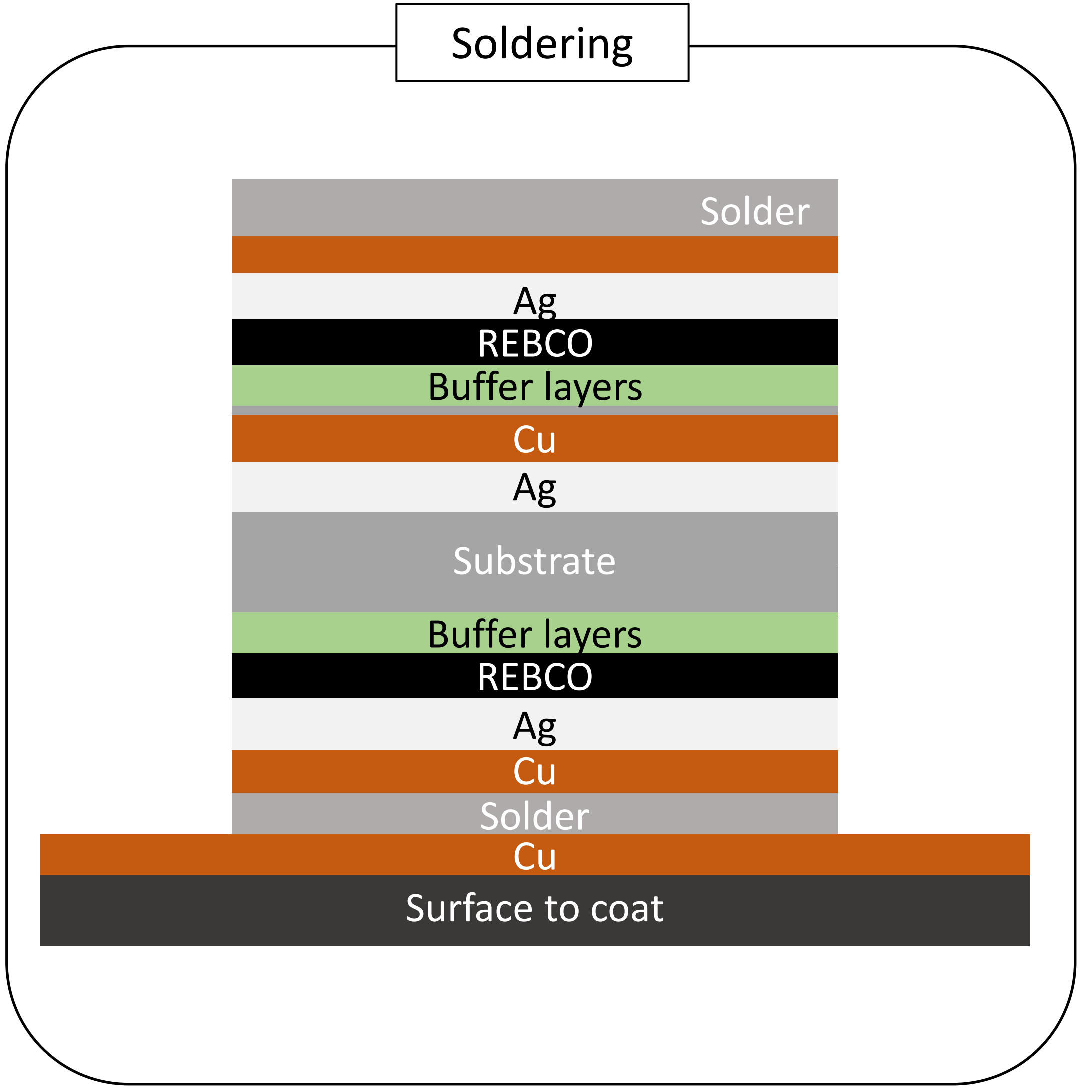


Prototype of a
Reel-to-reel edge-removal machine

Laser allows for fast and clean removal of Cu

Coating process in a nutshell

Homogeneous pressure and temperature are crucial



Coating process in a nutshell

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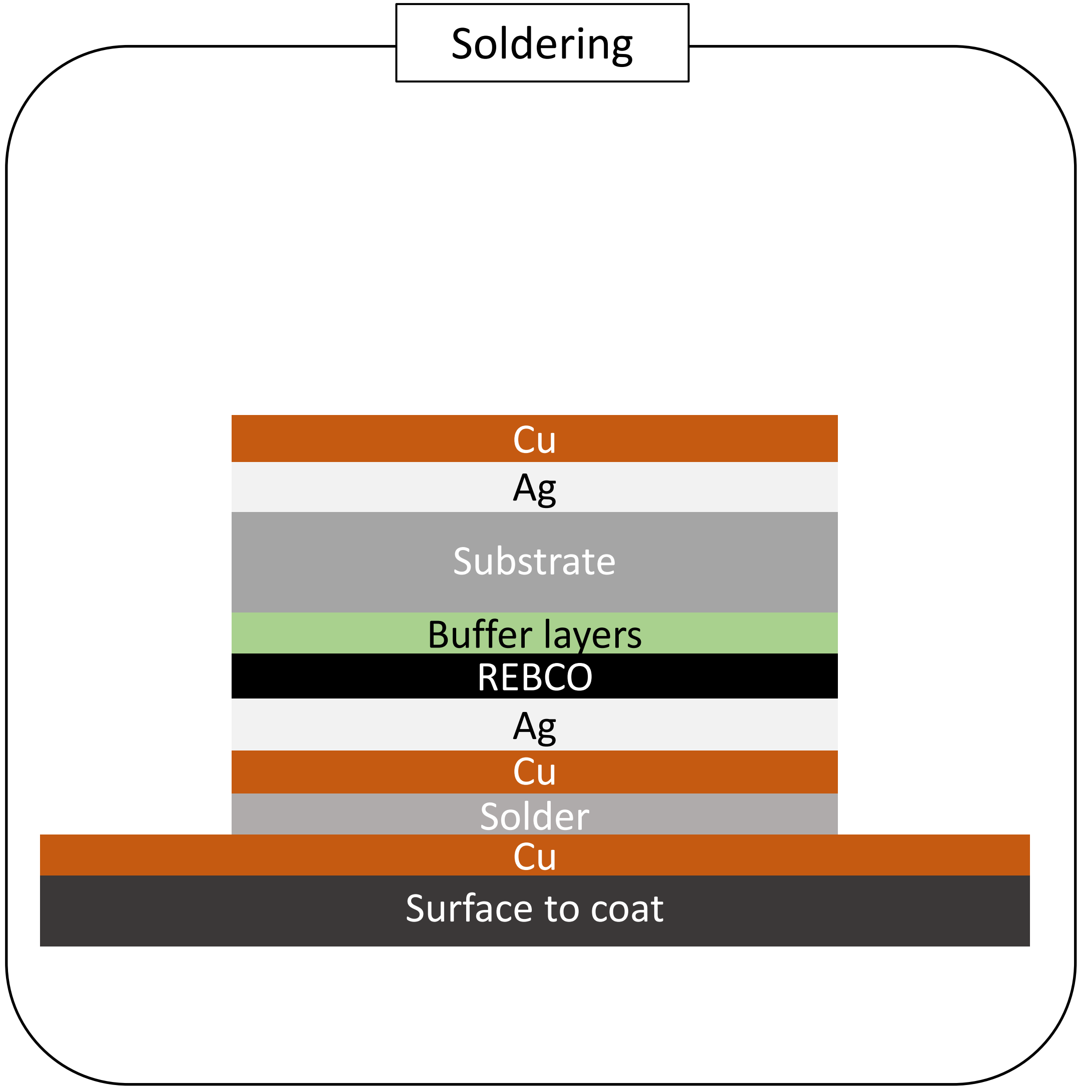
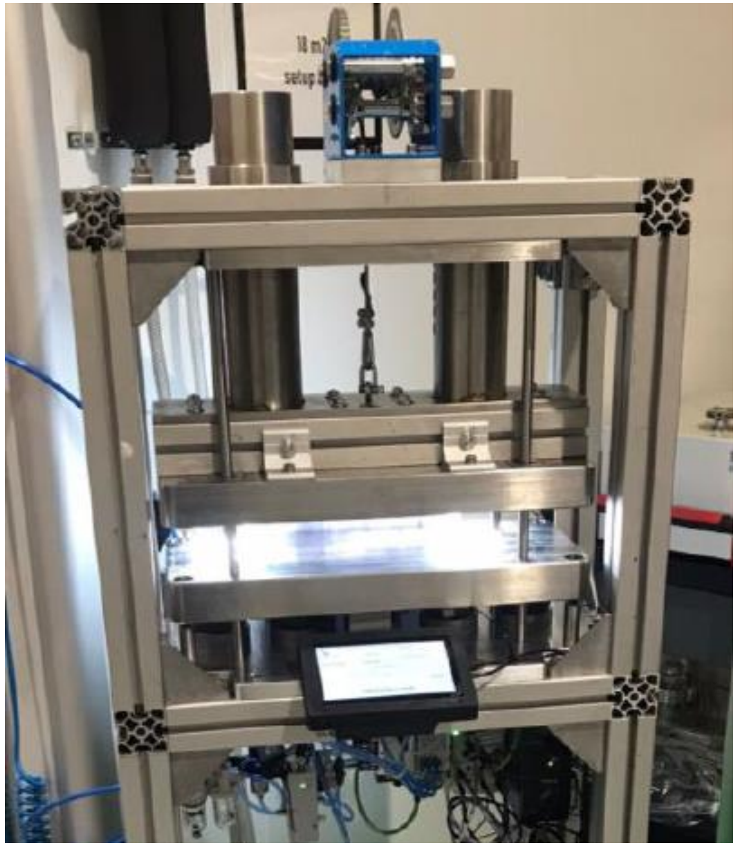


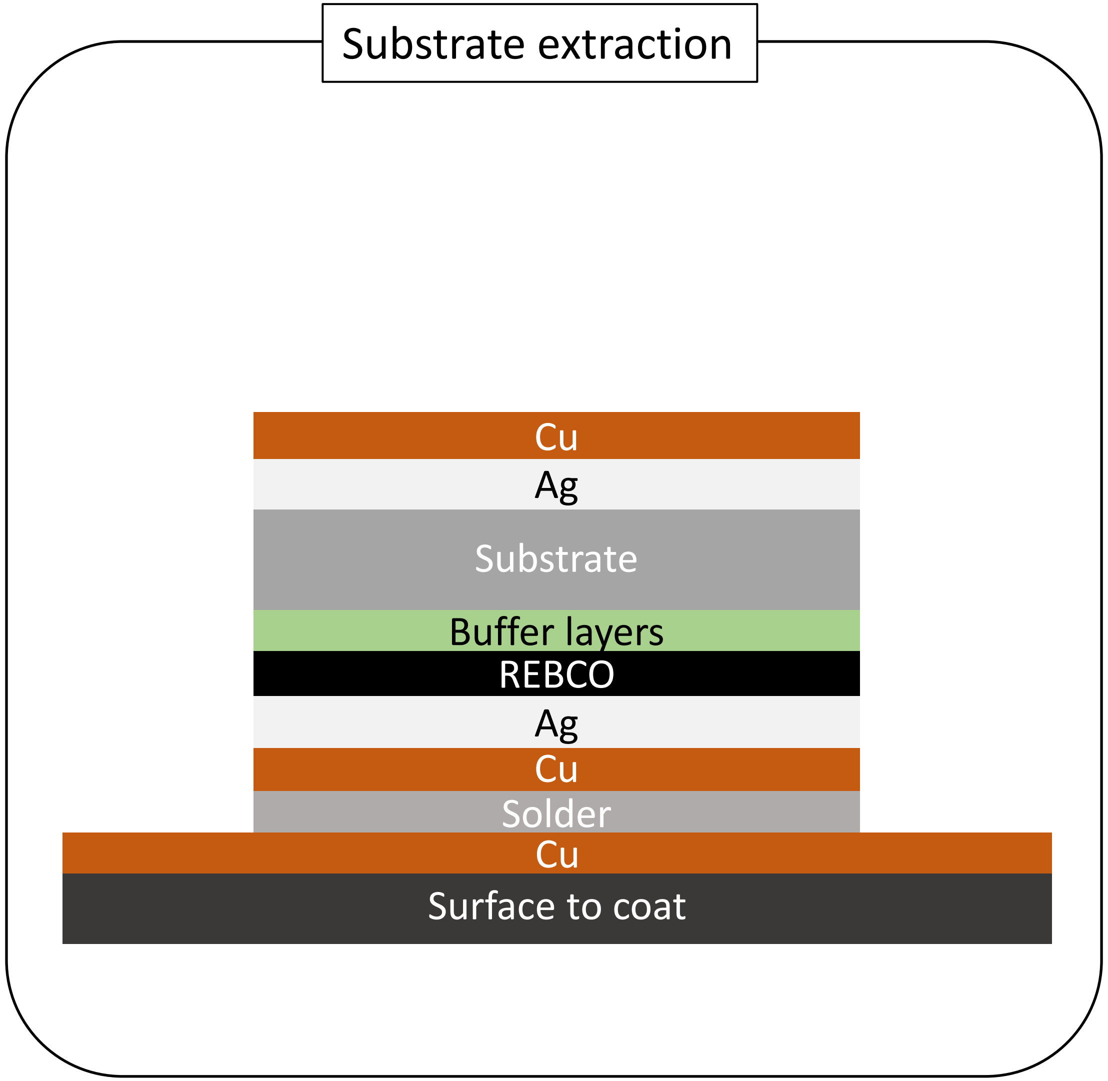


Press machine

Allows for pressure and temperature control during the soldering process

Coating process in a nutshell

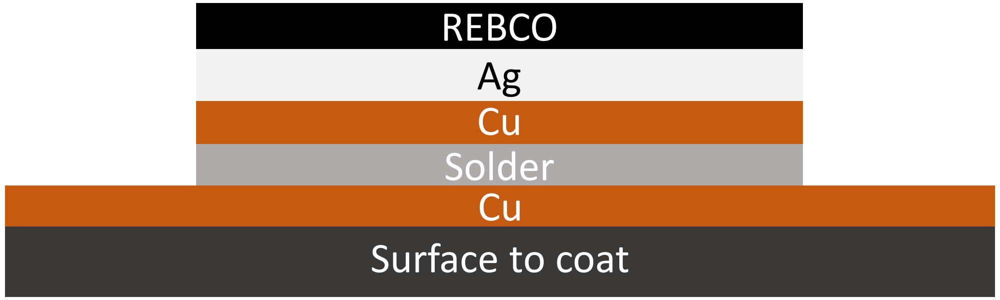
Angle and speed of substrate extraction are crucial

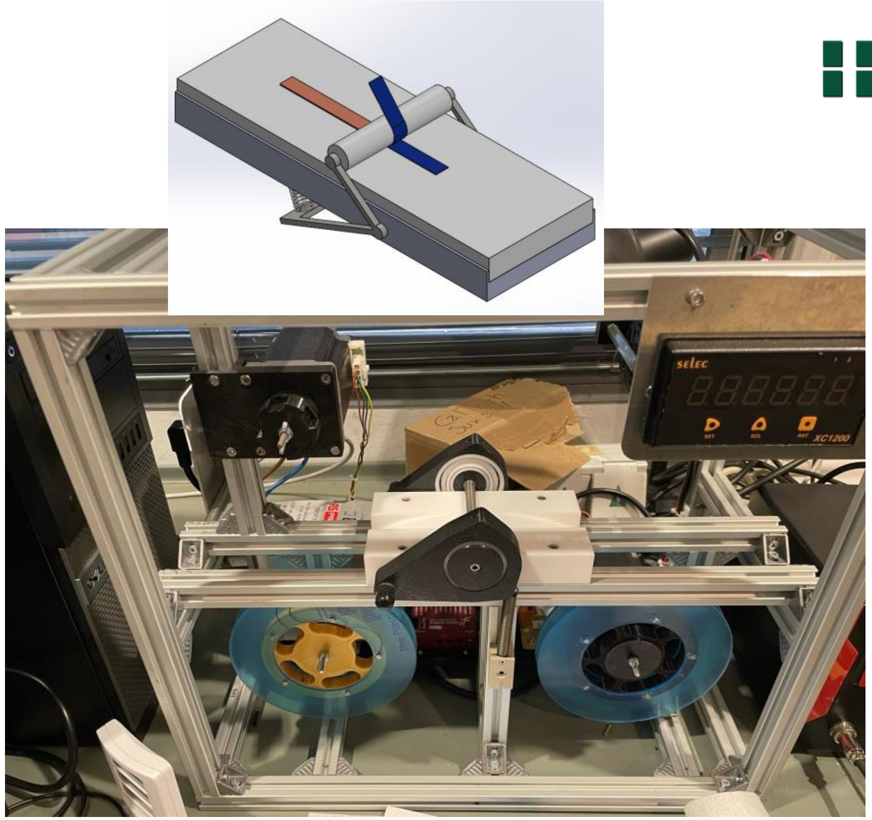


Coating process in a nutshell

Angle and speed of substrate extraction are crucial

Substrate extraction



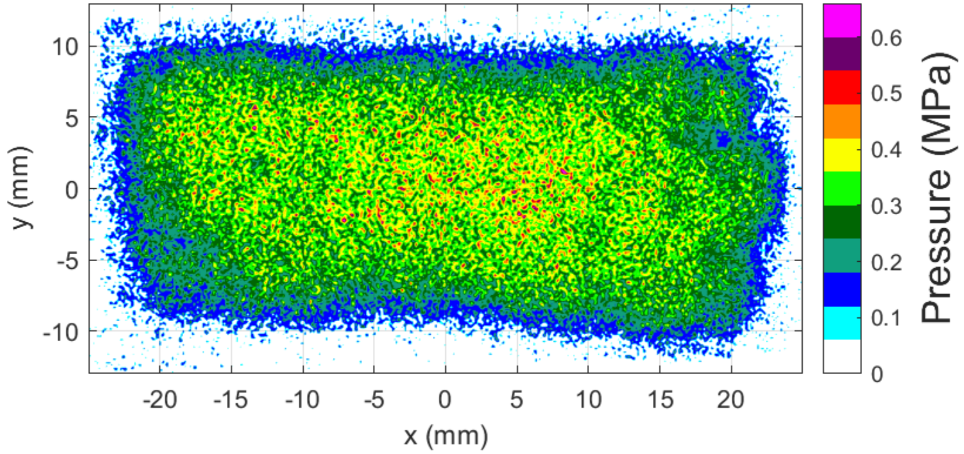


Reel-to-reel delamination machine

Allows for a controlled substrate extraction

Characterization before coating

Pressure must be homogeneous and within 0.2 – 0.3 MPa



1. ***Pressure is measured locally with a pressure sensitive film;***
2. ***Film is scanned with dedicated scanner device***
3. ***Color density is converted into pressure distribution***

Fast characterization of the coatings' SC properties

Optical microscope picture of a delaminated tape

REBCO side

Substrate Side

HSV Colours observed on the substrate correspond to different coating surface compositions determined by EDX.

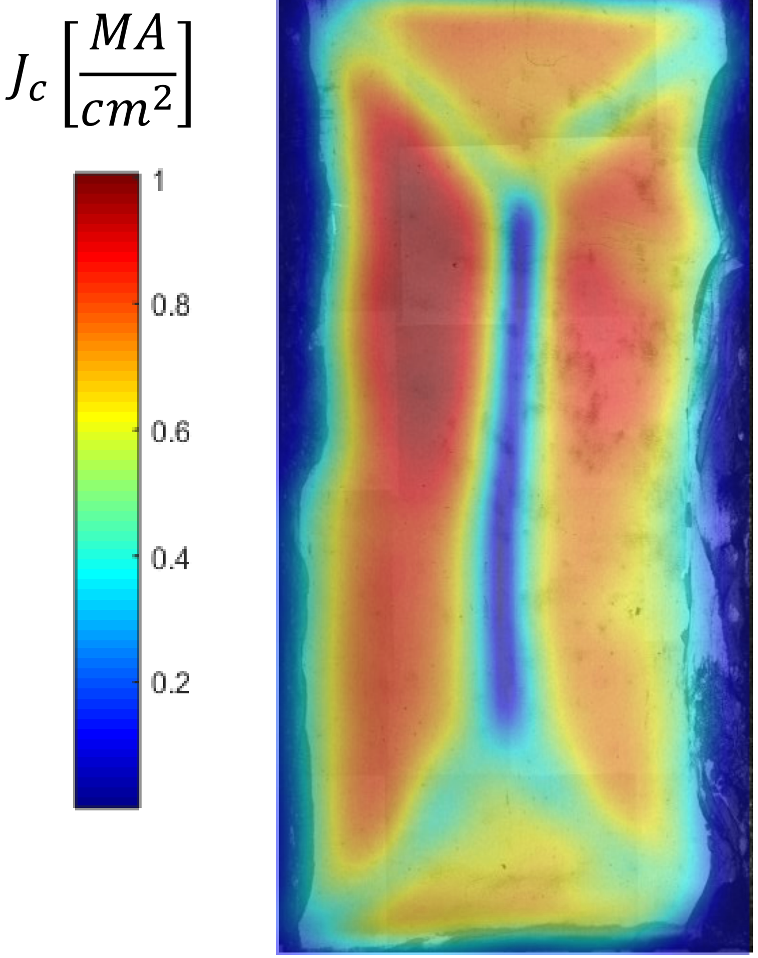
Fast characterization of the coating's SC properties

Optical microscope picture of a delaminated tape

REBCO side

Substrate Side

Correlation between EDX and SHPM

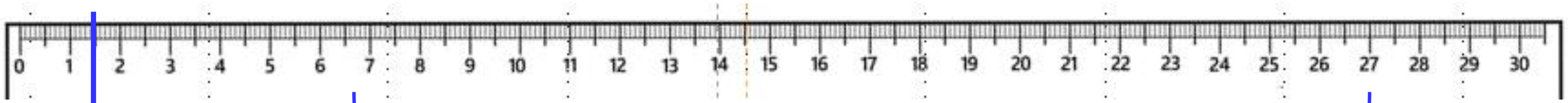


HSV Colours observed on the substrate correspond to different coating surface compositions determined by EDX.

Complete assessment of the sample quality from optical microscopy only

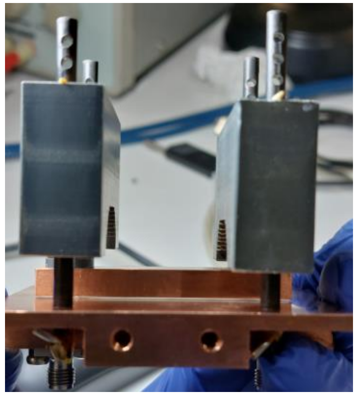
Surface impedance characterization in a wide H, T, f range

Frequency (GHz)

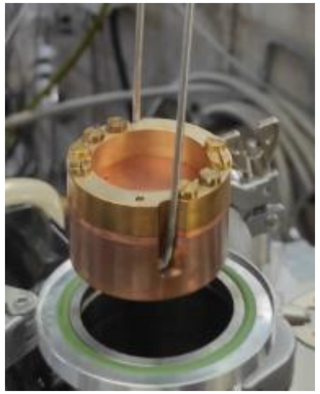


Parallel plate resonators

Under synchrotron radiation

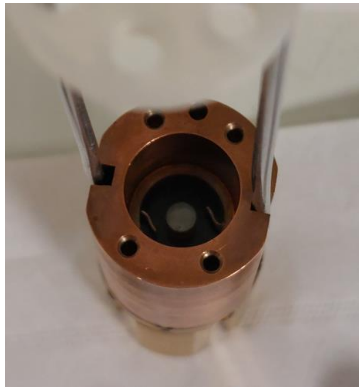


Under B for 16 T system

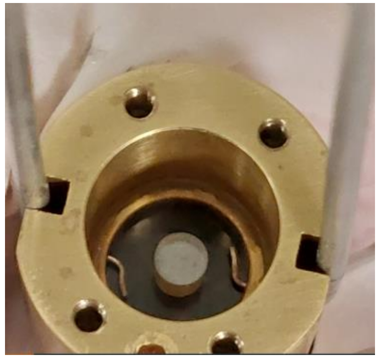


Dielectric resonators

Under B for both 9 T and 16 T system



Multi-mode (6.5, 8, 10 GHz)



16T, 50 mm bore magnet for microwave characterization at cryogenic temperatures

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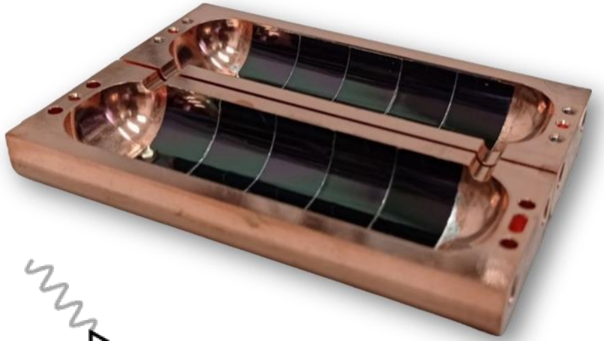
High versatility in coating surface geometries

HTS-Coated RADES Haloscope

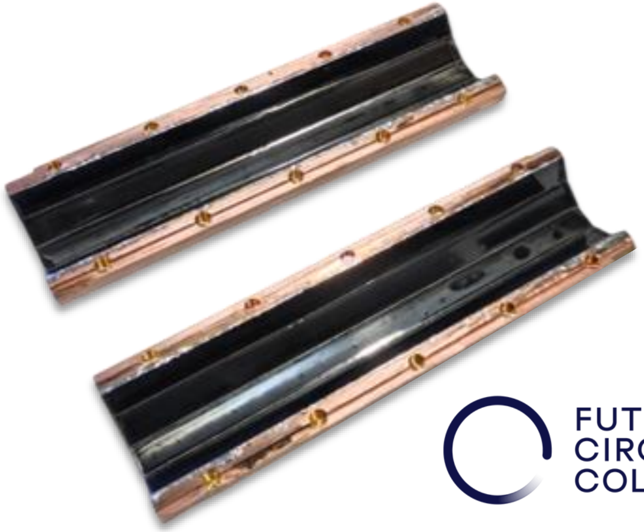


RADES

- 9 cm long
- Half-pipe shaped
- 9 mm bending radius
- High magnetic fields

@5K and 11T
Q-factor = 130.000
(Q-factor Cu = 40.000)

HTS-Coated FCC Beam-screen PSD prototype

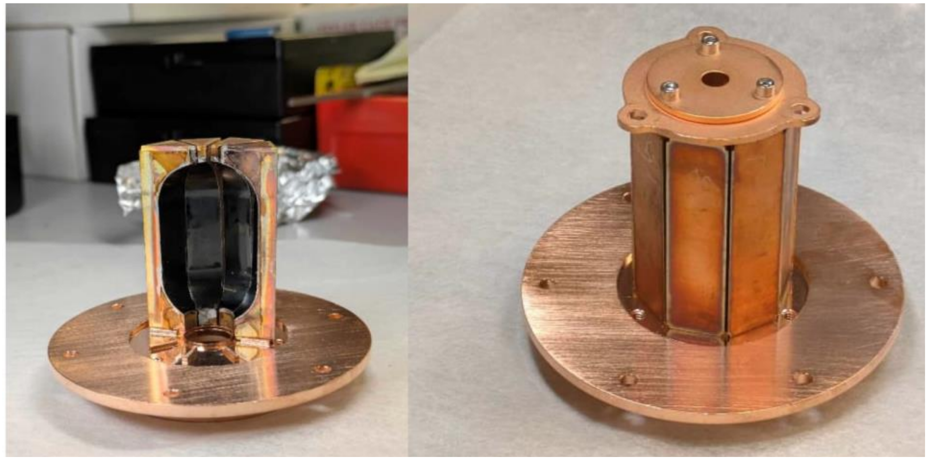


FUTURE CIRCULAR COLLIDER

- 20 cm long
- Decagon shaped
- Flat angled faces
- High vacuum

CERN

HTS-Coated pulse compressor



SLAC NATIONAL ACCELERATOR LABORATORY

iFAST

- 4 cm long
- Polyhedral shaped
- Individual facets
- High vacuum

ICMAB INSTITUT DE CIÈNCIA DE MATERIALS DE BARCELONA EXCELENCIA SEVERO OCHOA
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Conclusions

CCs are very appealing materials for High-energy physics due to their low R_s under high-magnetic fields.

We can coat a wide variety of surface geometries.

We have demonstrated that REBCO coated haloscopes have higher Q-value in the GHz range than Cu haloscopes.

We are in the final steps of automatizing the coating process, which will increase the quality and the yield.