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25 YEARS

THEVA

LATEST DEVELOPMENTS IN COATED CONDUCTORS WILL REVOLUTIONIZE MAGNET TECHNOLOGY

Werner Prusseit, Veit Grosse, Markus Bendele, Oleksiy Troshyn
THEVA Dünnschichttechnik GmbH

Virtual CCA 2021
14.10.2021

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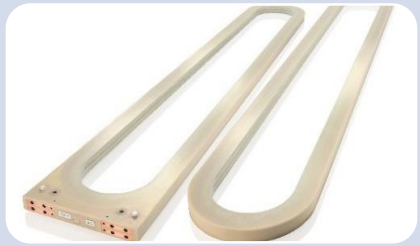
THEVA AT A GLANCE

Company: THEVA GmbH, HQ in Ismaning, Germany, established 1996

Team: 50 FTE (mainly R&D engineers and production team)

Product portfolio

HTS wire
THEVA Pro-Line



HTS coils

Inspection tools
Tapestar™

Value proposition

- Robust, high performance products
- Reliable wire supply
- Expertise and engineering support

Main applications

- HTS cables and bus bars for high current
- Current leads (with low heat input)
- Magnets: high field, fusion, industry

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HTS Wire: Production & Properties

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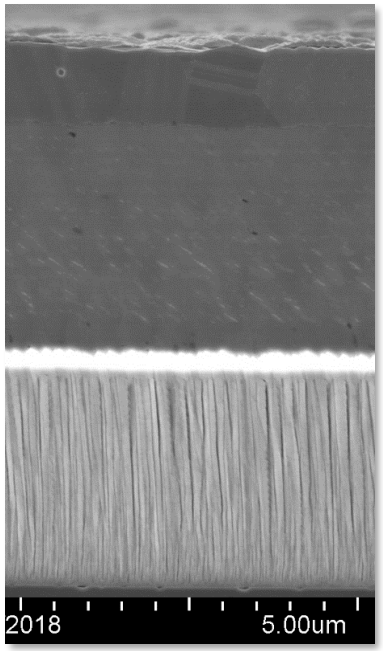
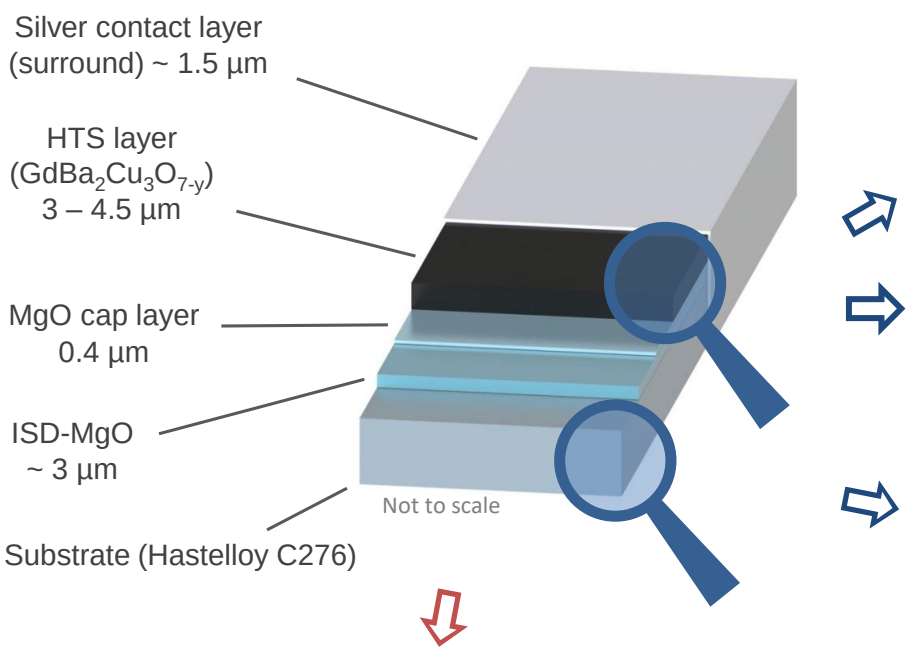
THEVA PRO-LINE HTS WIRE AND LATEST IMPROVEMENTS

Basic wire architecture



SEM cross section



Low heat conductivity
for current leads (1.5 mW/100A)

Performance improvements

High performance (HP) wire
Increased HTS thickness
3 µm → 4.5 µm
I_C (77K,sf) 700 A → 900+ A

Artificial pinning (AP) formula
$BaHfO_3$ nano-particles
Randomly dispersed – no columns
I_C (20K,20T) > 500 A/cm

Reduced substrate thickness
50 µm → 40 µm
Higher engineering current density
AP-wire: j_e(20K, 20T) > 800 A/mm^2

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HIGH - PERFORMANCE HTS WIRE

Regular production wire

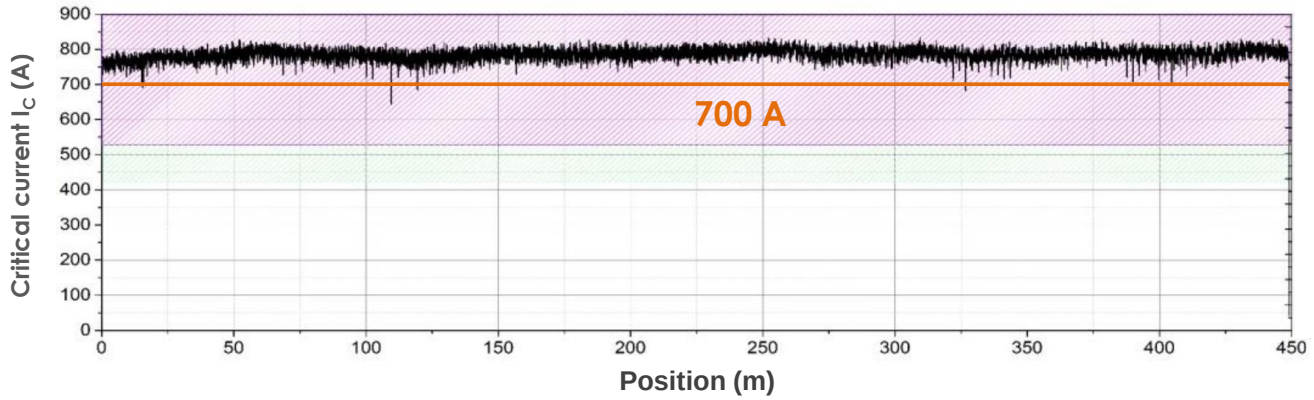
Width: 12 mm

3, 4, 6 mm available by Laser slitting

$I_{C,min}$ (77K, s.f.) = 500 A – 700 A

Piece length: 100 m – 200 m

also with AP-formula

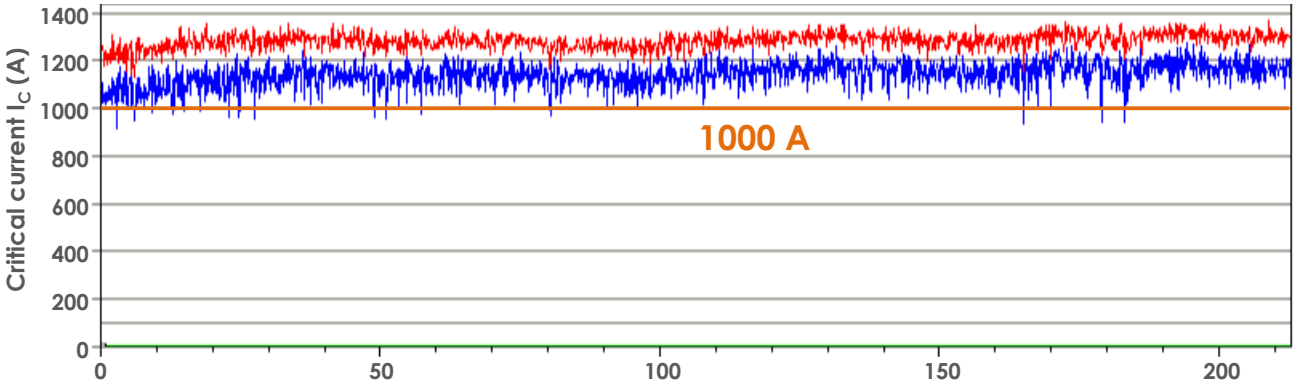


High performance wire

Enhanced HTS thickness (4.5 µm)

$I_{C,min}$ (77K, s.f.) = 750 A – 1000 A

Piece length: 50 m – 200 m



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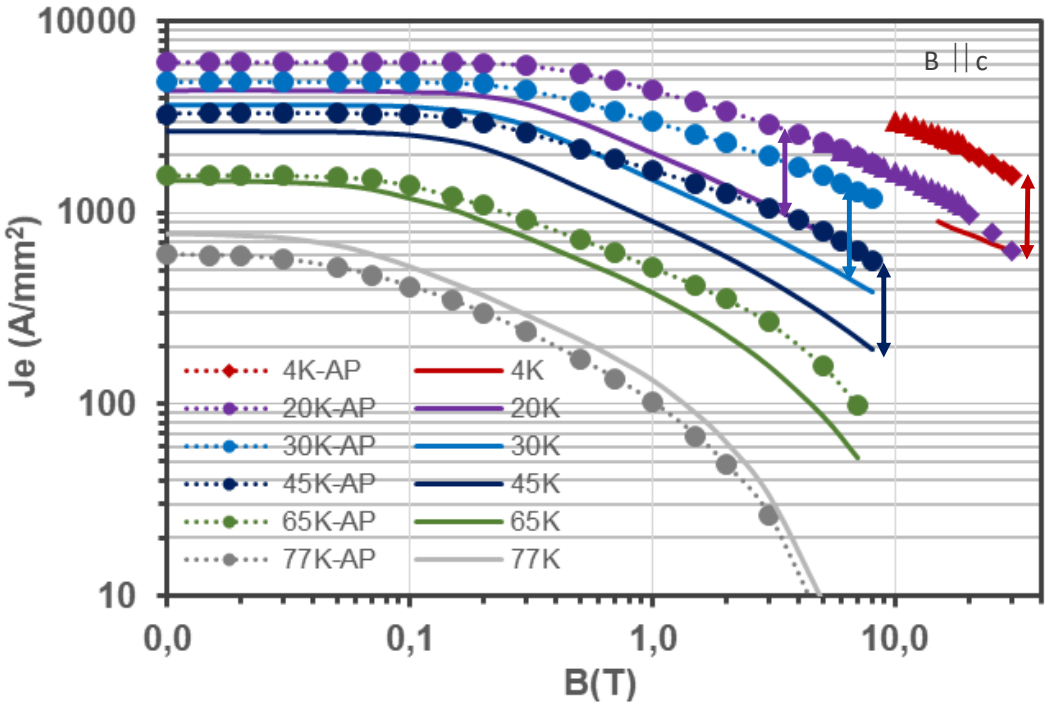
MAGNETIC FIELD PERFORMANCE OF AP-REBCO WIRE

Field dependence of ReBCO-wire (+ $BaHfO_3$)



Below 50 K: **I_C(B) improvement by factor 2.5**

THEVA Pro-Line AP wire performance

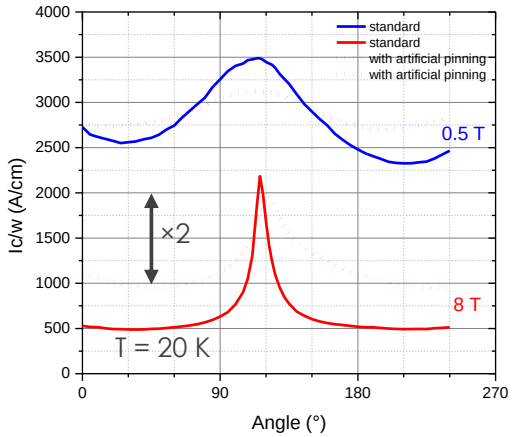
Current density for B || c of total 60 µm thick tape (40 µm substrate and 5 µm surround Cu coating)

- 10 T: 3000 A/mm²
- 20 T: 2000 A/mm² **@ 4.2 K**
- 30 T: 1550 A/mm²

@ 20 K, 20 T: 800 - 900 A/mm²

Reduced anisotropy

- AP randomly dispersed
- no columnar growth



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HF data from LNCMI Grenoble, Univ. Geneva, RRI Wellington

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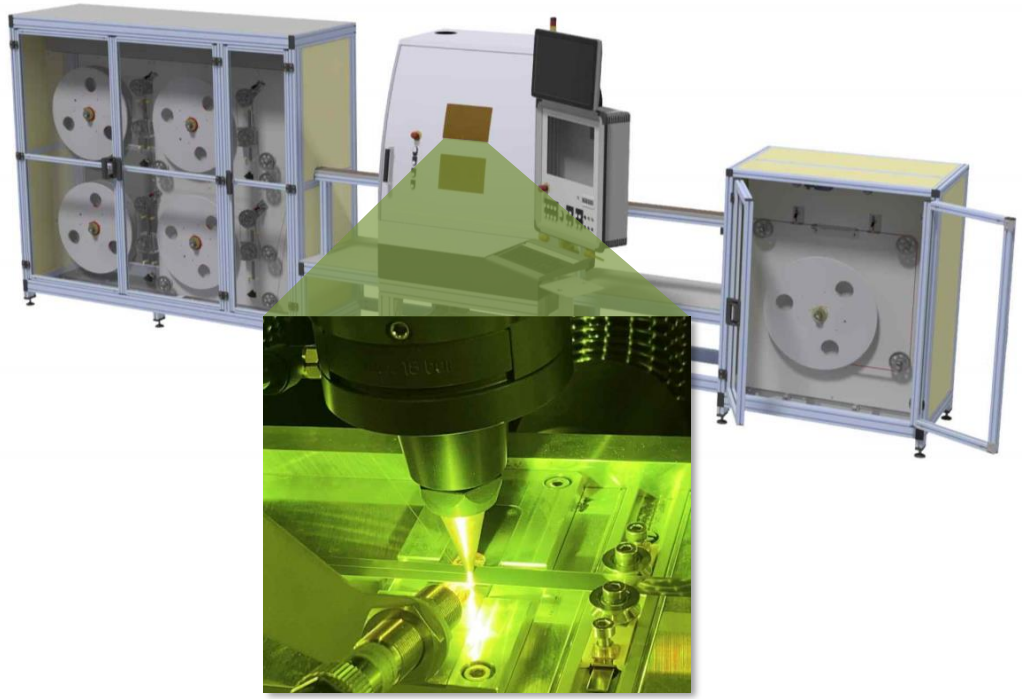
LASER-SLITTING

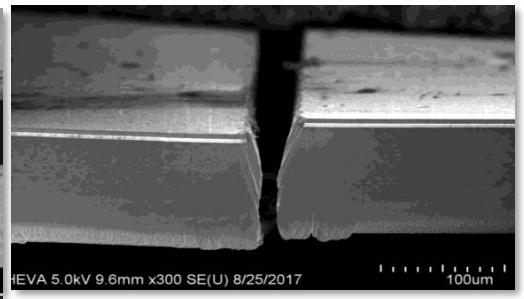
- **Cost aspect**: slitting can destroy substantial value
- **Edge defects** are critical for high field applications

High yield Laser tape slitting



Technical characteristics

- High speed 1000 m/h (for 100 µm HC276)
- High accuracy, narrow tolerances
- No waste material
- No I_C – reduction ($I_{C\text{-}12mm} = 4 \times I_{C\text{-}3mm}$)
- No cracks or defects induced
- Clean, straight edge – no burr



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QUALIY CONTROL: TAPESTAR™ - ENHANCED FUNCTIONALITY

Enhanced operating range

In-field measurement

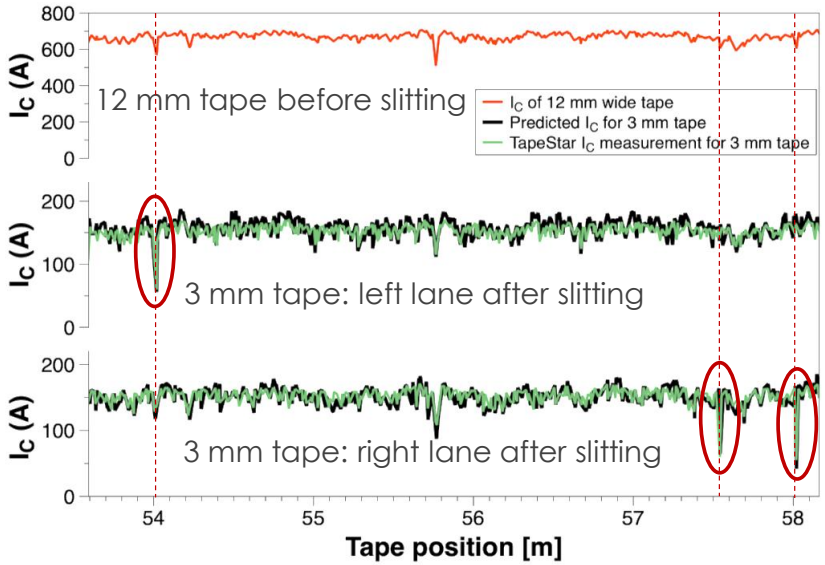
HTS field coil up to 1 Tesla in LN

Low temperature option

Subcooling LN down to 68 K

Yield forecast for (Laser) slitting

Algorithm using full 2D Tapestar data of wide tape analyzing existing defects and predicting slitting yield



- black: I_C -simulation for 3 mm slitting
- green: measured I_C after 3 mm slitting

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High Field Magnet Applications

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SUPERCONDUCTING WIRE MATERIALS – A COMPARISON

How does ReBCO compare to classical superconductor wire ?

	Pros & Cons
➢ **LTS, MgB_2 or BSCCO** produced by classical, metallurgical PIT – route	Modifications tricky
▪ Round, filamentary wire, easy twisting and flexible handling and packaging	Design freedom
▪ Some materials (Nb_3Sn, BSCCO 2212) require "wind and react" processing	Adversity, risk
➢ **ReBCO "wires"** are coated tapes (coated conductors)	
▪ **Additive fabrication**: coatings are applied layer by layer by PVD	
▪ Growth can be controlled and manipulated (e.g. adding artificial pinning)	Easy modification
▪ 12 mm production width – Laser-slit to custom-width (3 – 12 mm)	Flexible adaptation
▪ Customized electrical stabilization applied afterwards	Flexible adaptation
▪ Tape geometry, no filaments, only stacking possible	Limited freedom
▪ Mechanical strength determined by substrate choice (mostly HC276)	Strength adjustable

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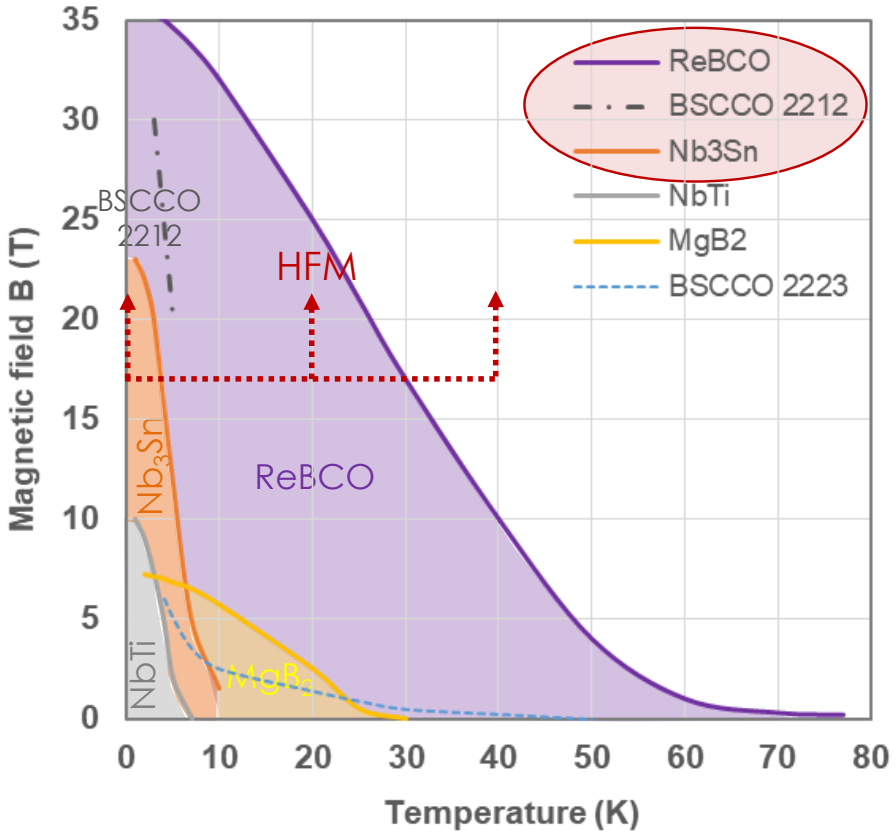
Material Choice for High Field Magnets (HFM)

Practical operation range of superconductors



For HFM the choice has considerably increased

- Classical, well-established Nb_3Sn (OST/BEST), W&R
- BSCCO 2212 – experimental material, high pressure processing, W&R, single source, cost ?
- **ReBCO (2G HTS)**
  - Extremely wide operation range (B & T)
  - High pinning forces & H_{irr}
  - Sprouting industrial (volume) production

    Perspective: commodity product, cost decline
  - RE/NM-content negligible – not a cost factor

W&R = wind & react material
RE = rare earth, NM = noble metal

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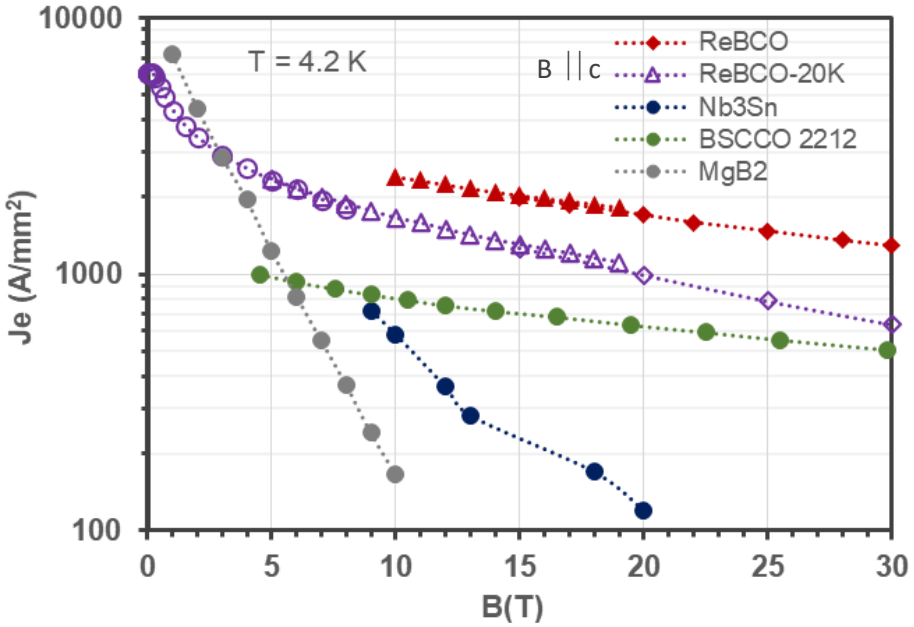
SUPERCONDUCTORS FOR EXTREMELY HIGH FIELD MAGNETS

Commercial superconductor wire



MgB_2: M. Tomsic, Hypertech 2015
BSCCO: Z. Melhem, OST @ ASC 2020
Nb_3Sn: Supercon 2020

Artificial pinning (AP) ReBCO wire

- Giant progress made in ReBCO wire recently
- All suppliers offer special AP-material
- **Extremely high pinning forces**

  1.2 TN/m³ @ 4 K, 18 T *
- **Broad HF operating range (up to 20 K)**
- **Quench – resilient**

Beyond 18 T the future belongs to ReBCO wire

* T. Yoshida et al., Fujikura Technical Review 2017

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QUENCH BEHAVIOR OF HTS MAGNETS

Comparing LTS (4K) to HTS (20K) operation

Trigger event
Flux jumps
$F_L > F_P$

Pinning forces (GN/m^3)
$F_P(HTS) >> F_P(LTS)$
1200 3 - 20

⇒ Dissipation Q_{in}

Reservoir
$c_p(T) \cdot \Delta T$
$c_p(20K) \approx 20 \cdot c_p(4K)$

⇒ Heat sink
$Q_{out} \propto \lambda(T) \cdot \Delta T$
$\lambda(20K) \approx 2\text{-}3 \cdot \lambda(4K)$

$Q_{out} < Q_{in}$ → **Quench**

Shunt $\propto \rho_{Cu} \cdot \Delta I^2$

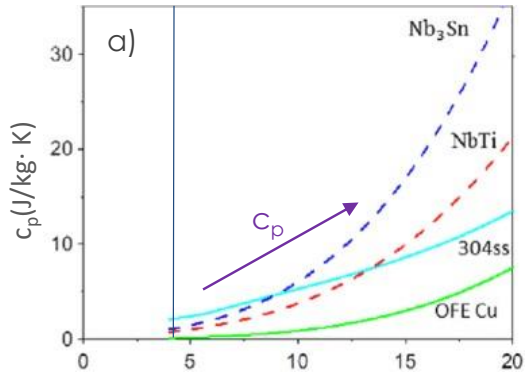
Sensitivity $\frac{\partial I_c}{\partial T} \propto -\frac{1}{T_c}$

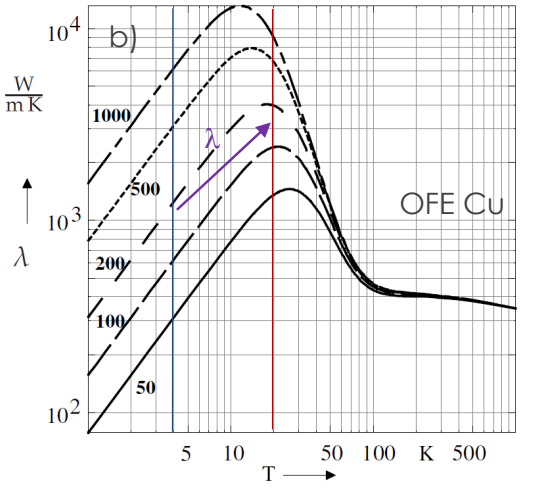
$T_c(HTS) \approx 5\text{-}10 \cdot T_c(LTS)$

$Q_{out} \geq Q_{in}$

$I = I_{C,min} + \Delta I > I_{C,min}$

$I < I_{C,min}$ → **Stable operation**





- HTS material: quench – resilient, lots of safety margin
- Benign behavior (phys. properties) at higher temperature
- No LHe inventory – no He gas burst

HTS magnets are much more stable to operate

[a] T. Tabin, et al. Int. J. of Solids and Struct. 202.10.1016/j.ijsolstr. 2020.05.033 (2020)
[b] S. Russenschuck, 2011; https://doi.org/10.1002/9783527635467.app1

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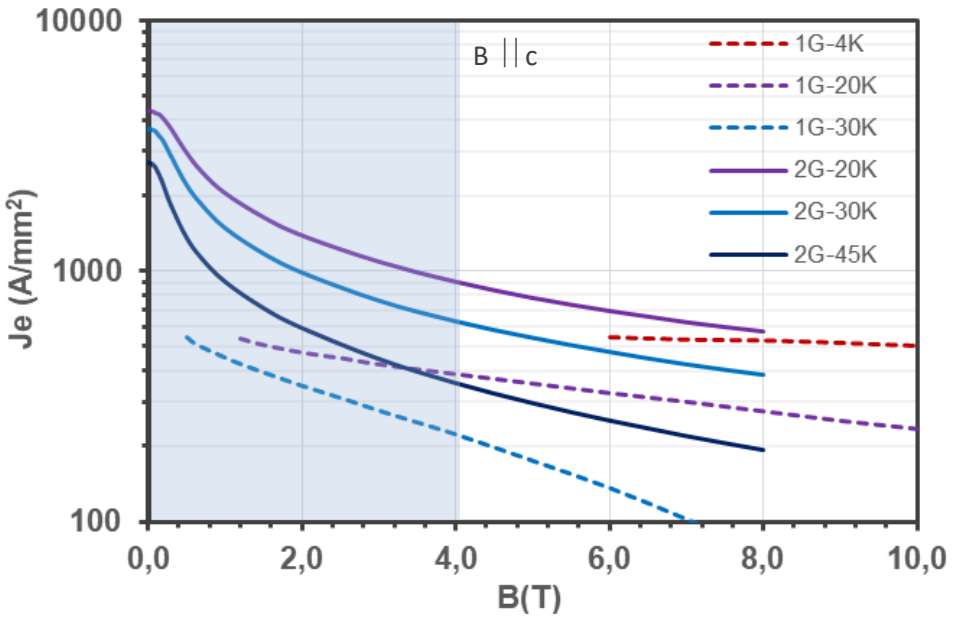
COMPARISON 1G VS. 2G -WIRE IN MODERATE FIELD APPLICATIONS

Comparison of commercial 1G and 2G wires



1G DI-BSCCO 2223 data from SEI datasheet SCT02-2020-041

Standard ProLine ReBCO without AP

- @ 2 T, same temperature 2G performs 3× better
- Up to 3 T 2G-wire @ 45K better than 1G @ 20K
- **For moderate field applications 1- 5 T standard 2G-wire outperforms 1G by factor of 3**
- THEVA's 2G-AP wire even 6 - 8 times superior
- **2G-wire has a clear cost advantage in motor- and MRI applications**

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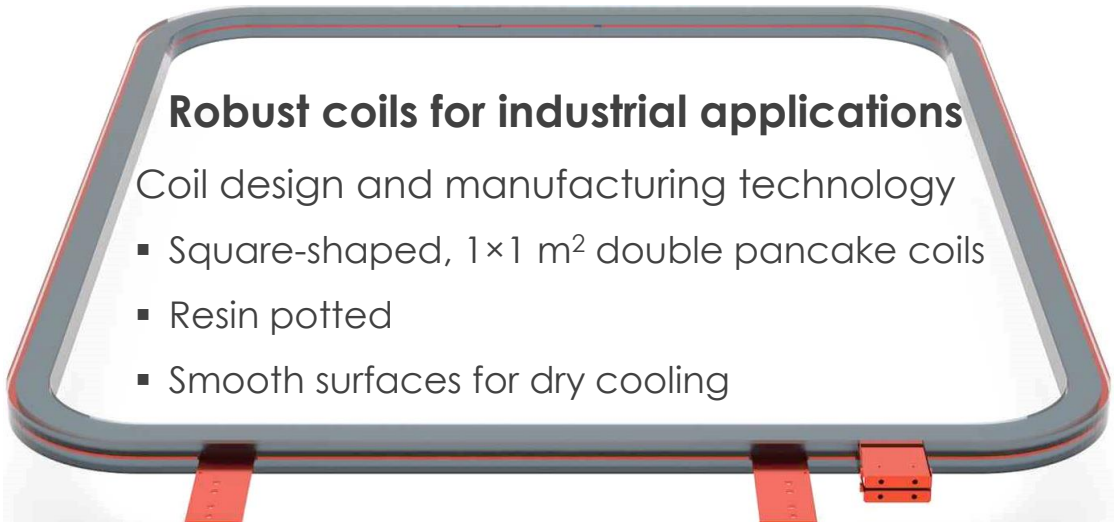
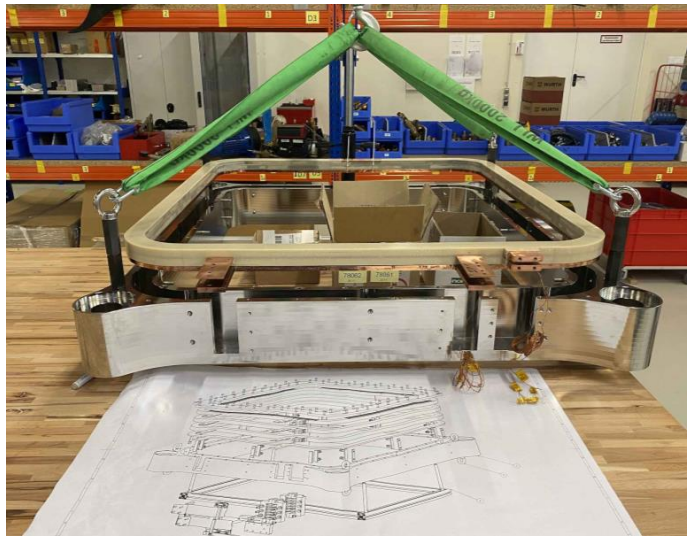
RoWaMag: HTS Magnet System for Aluminum Billet Heater

FEM design and manufacturing of HTS magnet system





Status

- All coils successfully tested in LN
- Magnet system assembled
- Induction heater assembly ahead

Partners

KIT Karlsruhe Institute of Technology — Cryogenic system

Bültmann Partners in know-how — OEM induction heater

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SUMMARY

ReBCO – wire is …

- **a novel product that differs in many ways from classical superconductors**
- **offering new perspectives for robust magnets even at extremely high fields**
  - extremely high pinning forces
  - large operation window
  - quench-resilient
- **Ready to use material (no W&R) with high resolution inspection data available**
- **Attractive cost perspective**
  - Raw material < 20% of product cost
  - HTS content of wire < 5%
  - Production cost scale with volume: 10× production volume ⇨ ½× cost

2G HTS wire will revolutionize high field magnet design

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Thank you!

… and the THEVA - team

V. Grosse, M. Bendele, O. Troshyn, S. Furtner, C. Hintze, A. Smara, L. Eisenhofer

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