25 YEARS

THEVA

# Latest Developments in Coated Conductors will Revolutionize Magnet Technology

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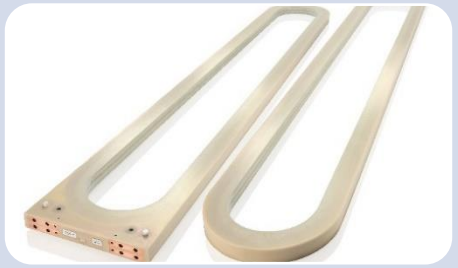
# THEVA AT A GLANCE

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™-XL


## Value proposition

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

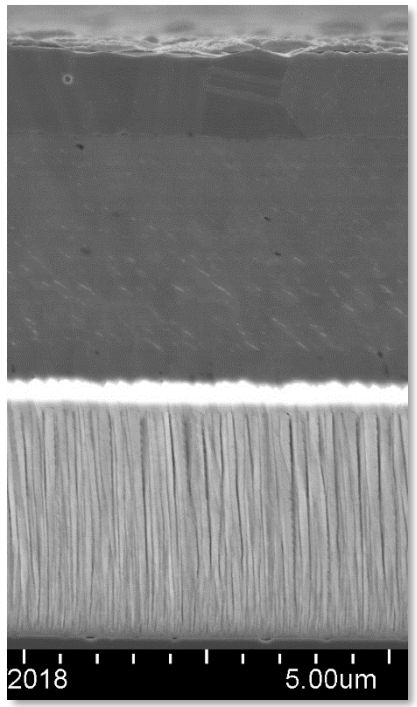
## Main applications

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

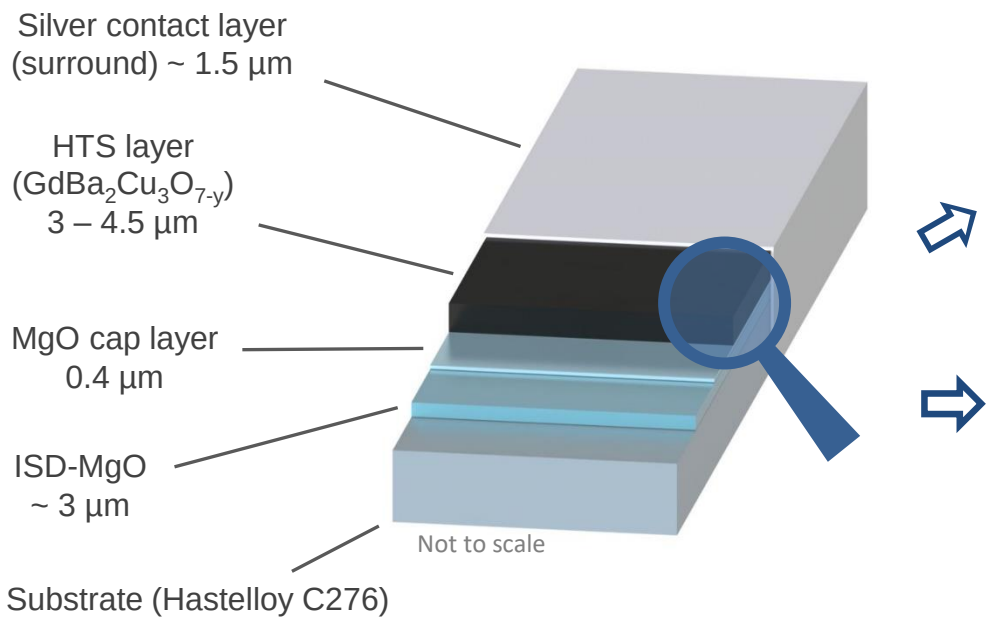
# HTS Wire: Production & Properties

# 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

# High - Performance HTS Wire

## Regular production wire

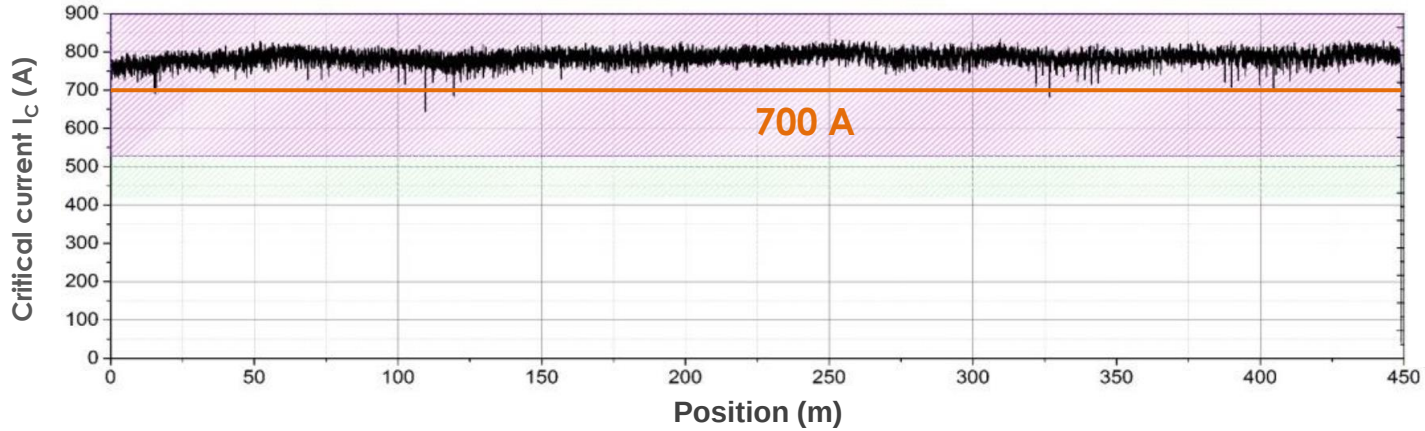
Width: 12 mm

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

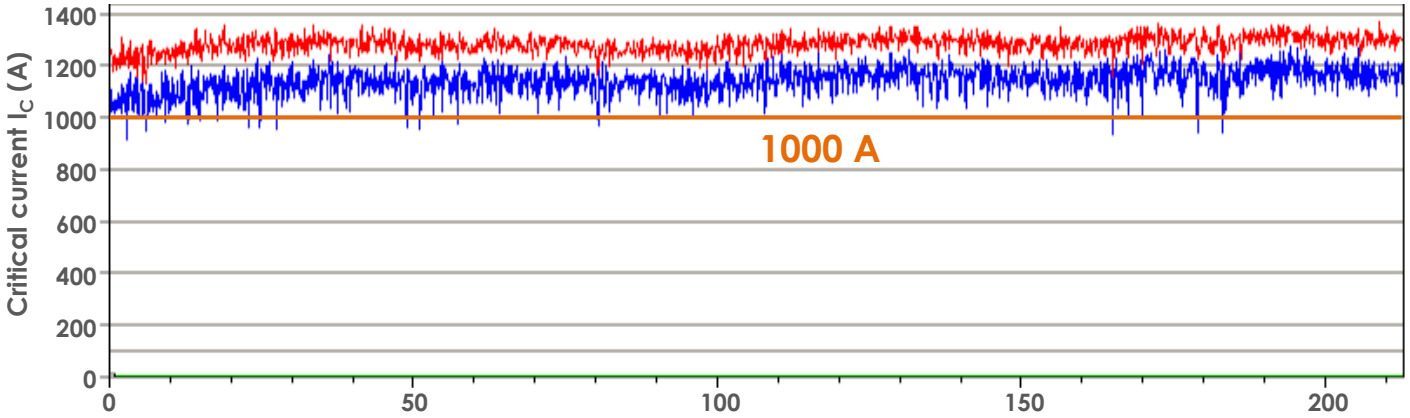



## High performance wire

Enhanced HTS thickness (4.5 µm)

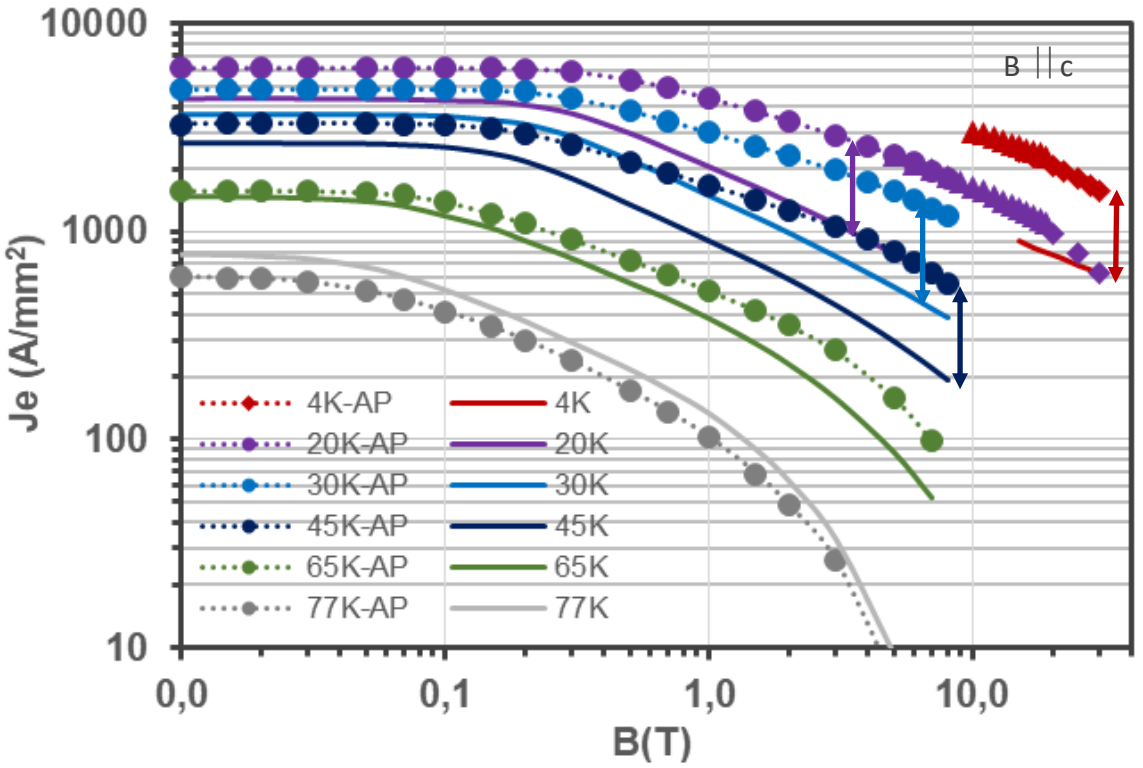
$I_{C,min}$ (77K, s.f.) = 750 A – 1000 A

Piece length: 50 m – 200 m



# 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

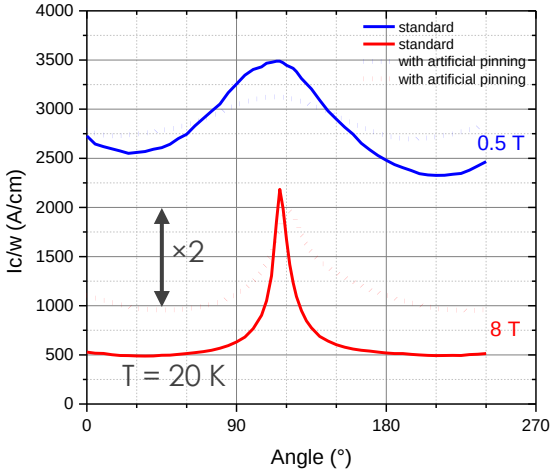
Current density for B || c of total 60 µm thick tape (40 µm substrate and 5 µm surround Cu coating)

- 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

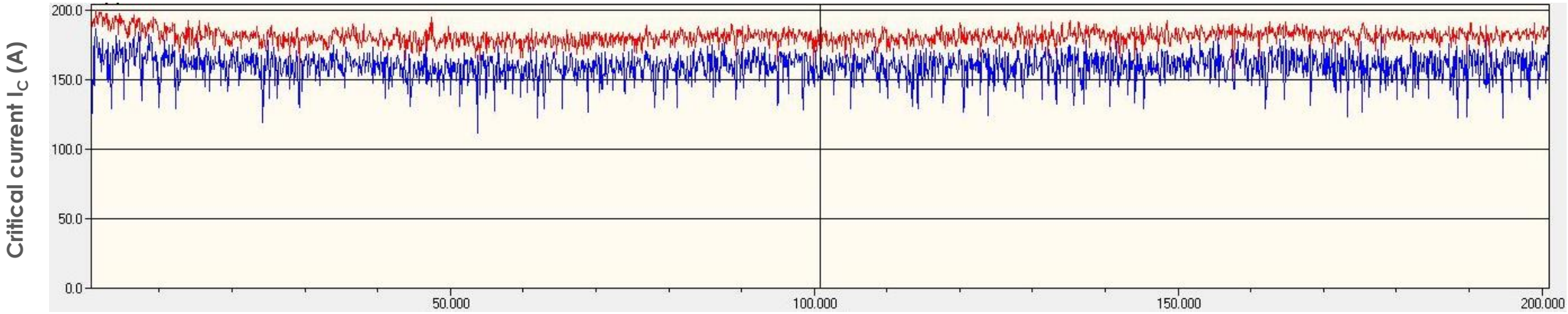
- AP randomly dispersed
- no columnar growth






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

# SERIES PRODUCTION OF AP-REBCO WIRE




**Stable Ic over length > 200 m (4 mm width, after copper coating)**

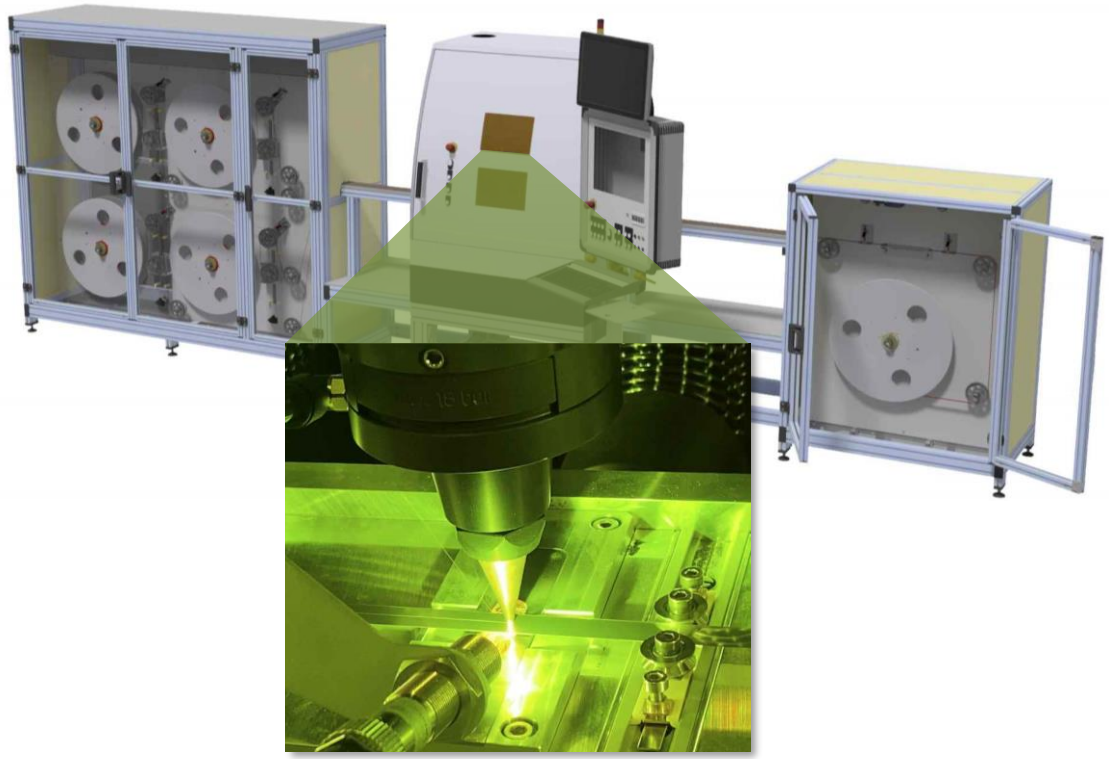
Full length high resolution Tapestar scan of Ic @ 77 K, s.f. as a quality indicator

→ with our Tapestar XL-HF, full length scan @ 77K, 1 T possible (down to 68 K with subcooling option)

# LASER-SLITTING

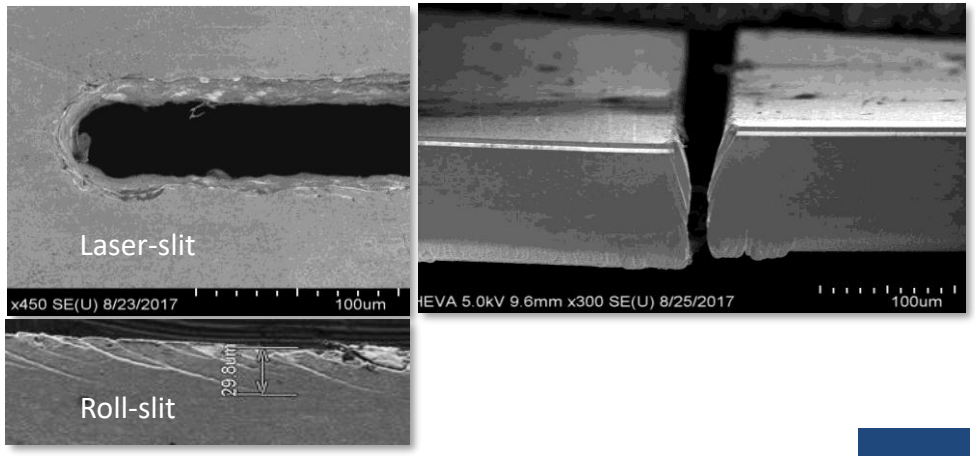
- **Cost aspect**: slitting can destroy substantial value
- **Edge defects** are critical for high field applications

### High yield Laser tape slitting



### Laser Slitting benefits

- 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
- Narrow tapes essential to lower AC losses



# QUALITY CONTROL: TAPESTAR™ - ENHANCED FUNCTIONALITY

## Enhanced operating range


**In-field measurement**

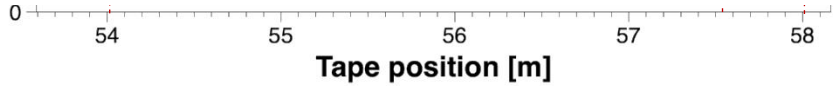
**HTS field coil up to 1 Tesla in LN**

**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

# High Field Magnet Applications

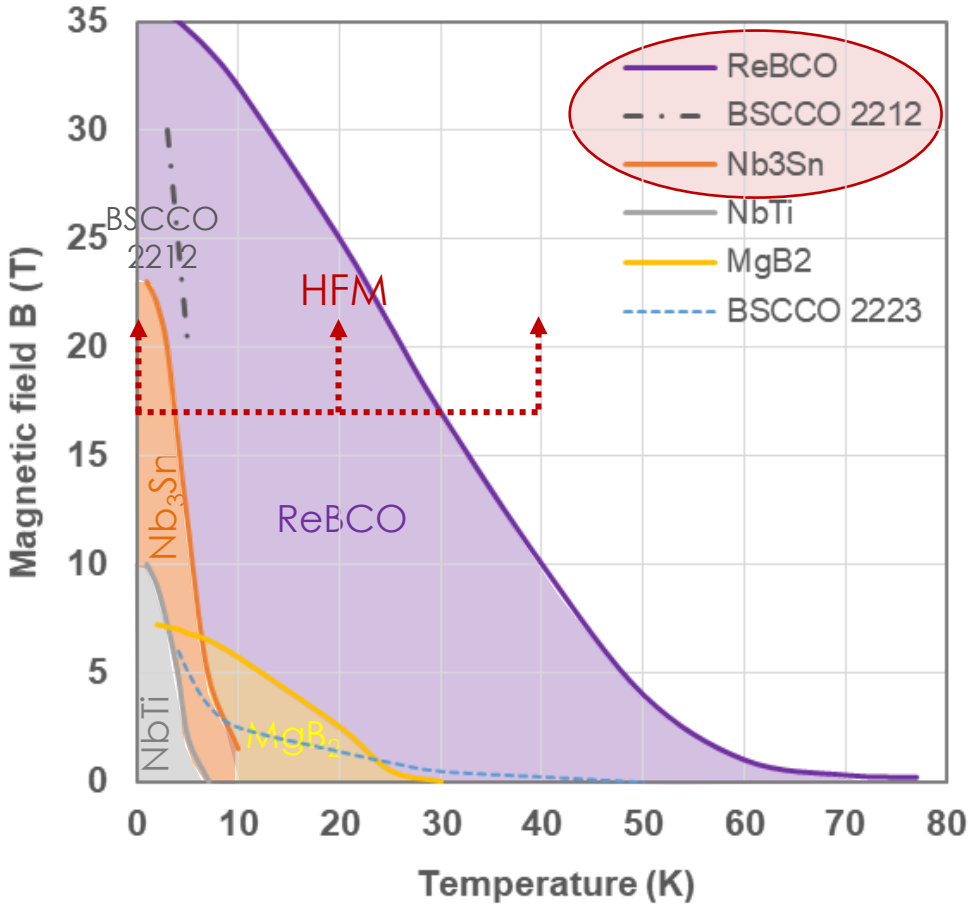
# Superconducting Wire Materials – a Comparison

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 |

# 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

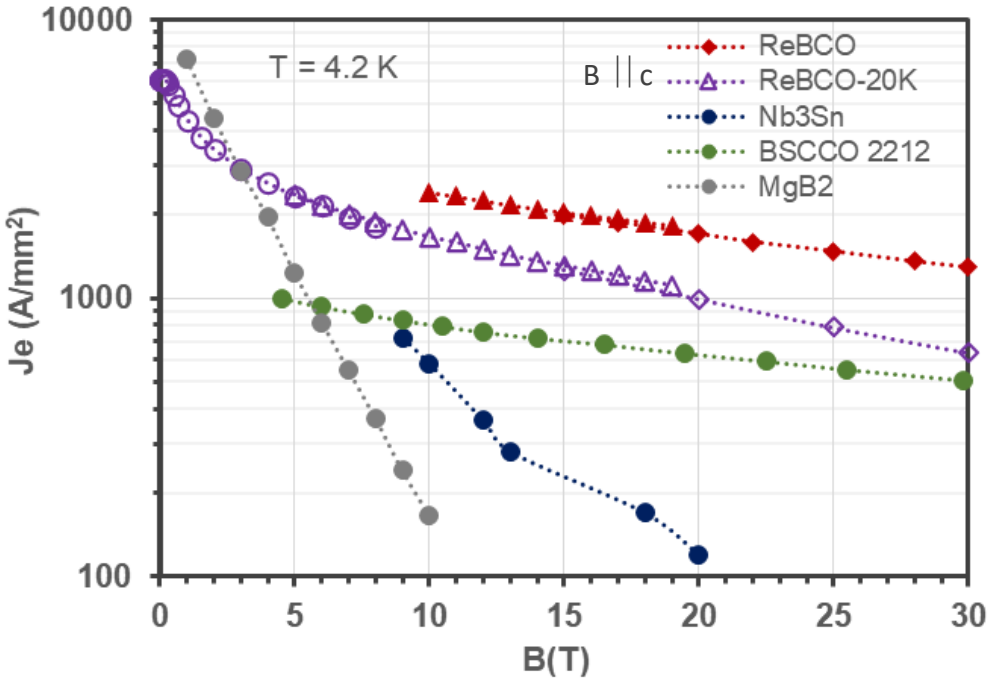
    Perspective: commodity product, cost decline
  - RE/NM-content negligible – not a cost factor

W&R = wind & react material

RE = rare earth, NM = noble metal

# 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

# 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**
  - HTS systems at 20 K are more benign compared to 4 K LTS systems (e.g. heat capacity)
  - extremely high pinning forces
  - large operation window
  - quench-resilient → stable operation
- **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**

# Thank you!

**… and the THEVA - team**

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