Development of ReBCO coated conductors with improved properties for magnet applications by THEVA

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Introduction

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

Team 45 FTE (mostly technical background + operators)

Products

HTS wire
(coated conductors)

THEVA Pro-Line

HTS coils

Inspection tools

Tapestar™

Ambition

- high performance products
  → I_c, stabilization, mechanics
- Scalable technology

Market

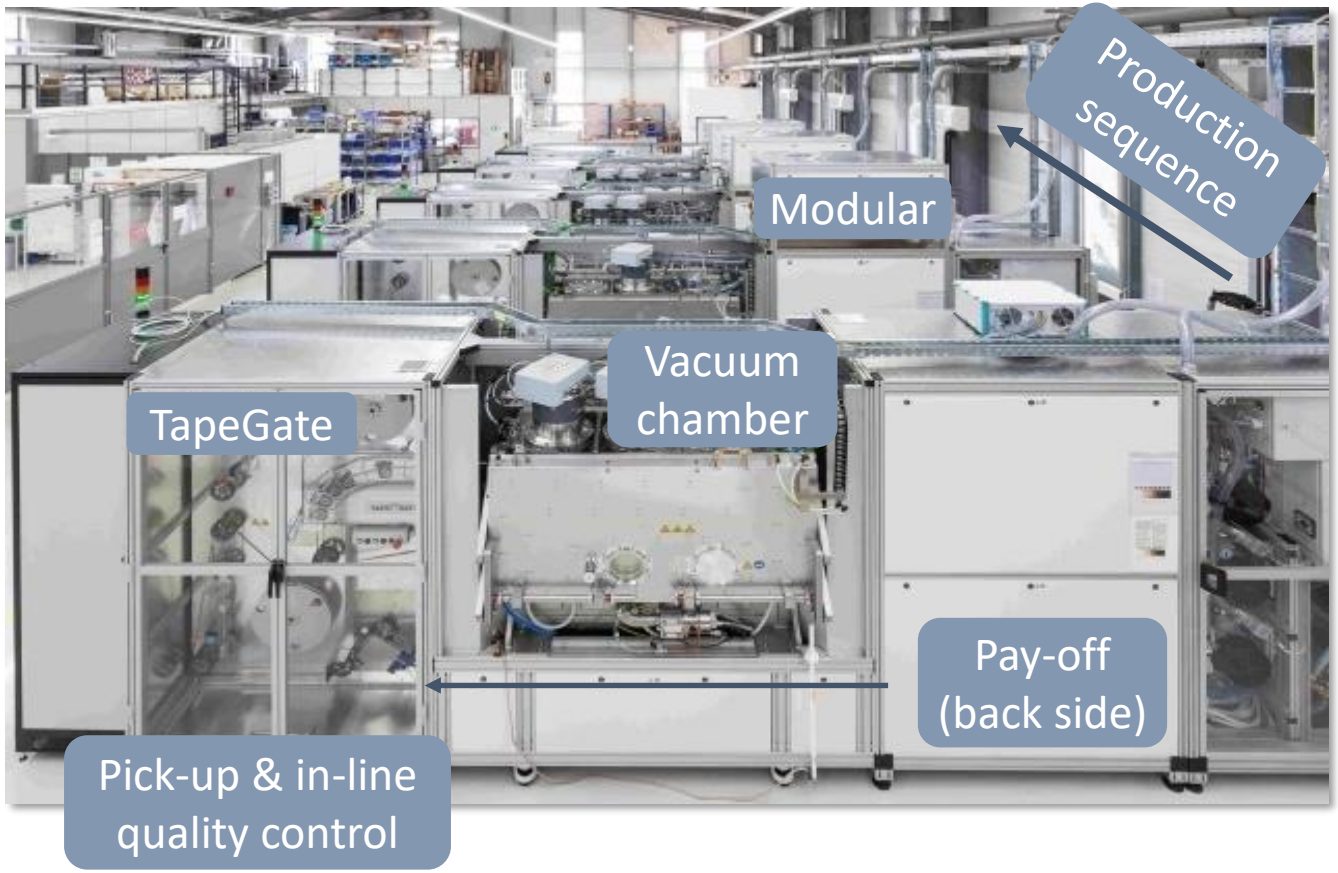
- High power cables and bus bars
- Magnets (fusion, industrial, high field)
- Rotating machines

HTS – Wire Production

Industrial production technology: Scalable, cost efficient

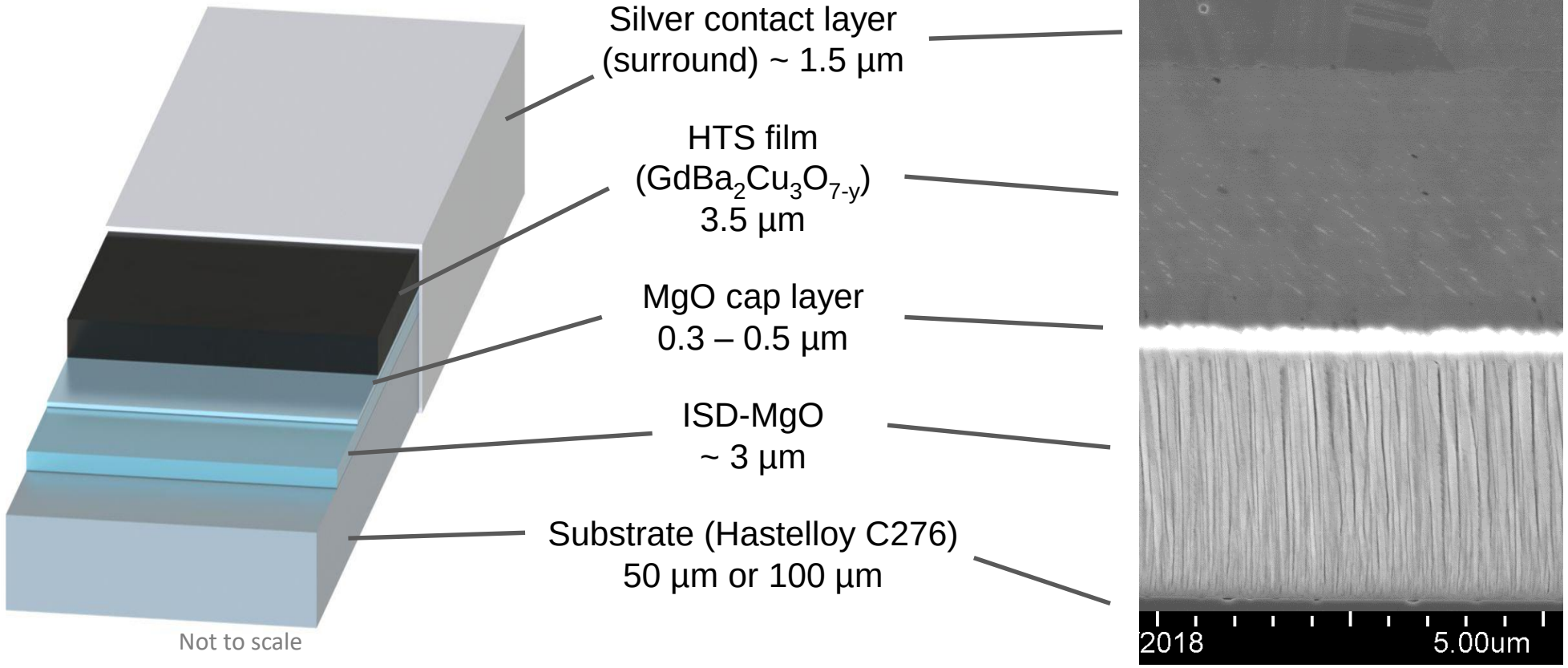
Features of production

- Operational since 2016
- Capacity: 120 km/yr
  @ 12 mm-width
- Production wire length:
  300 m – 400 m (1000 m possible)
- Physical vapor deposition using vacuum systems
- Integrated QC for highest quality



Basic Wire Architecture

THEVA Pro-Line Wire



Not to scale

SEM cross section

A very simple and robust architecture!

I_c-Performance

A steady improvement

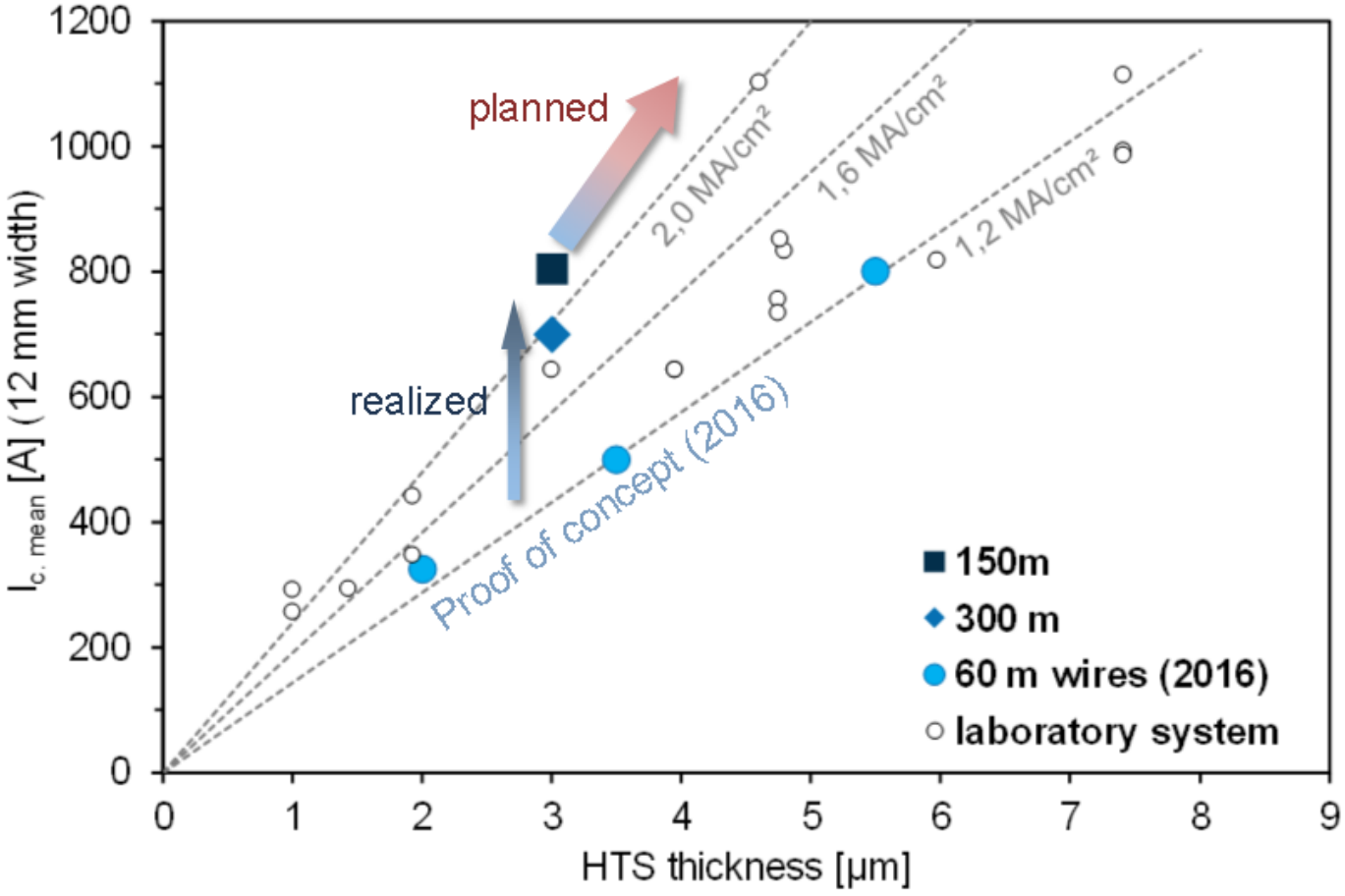
I_c scales with HTS layer thickness

- Demonstrated up to 8 µm
- Production today: 3.5 µm

Continuous optimization success:

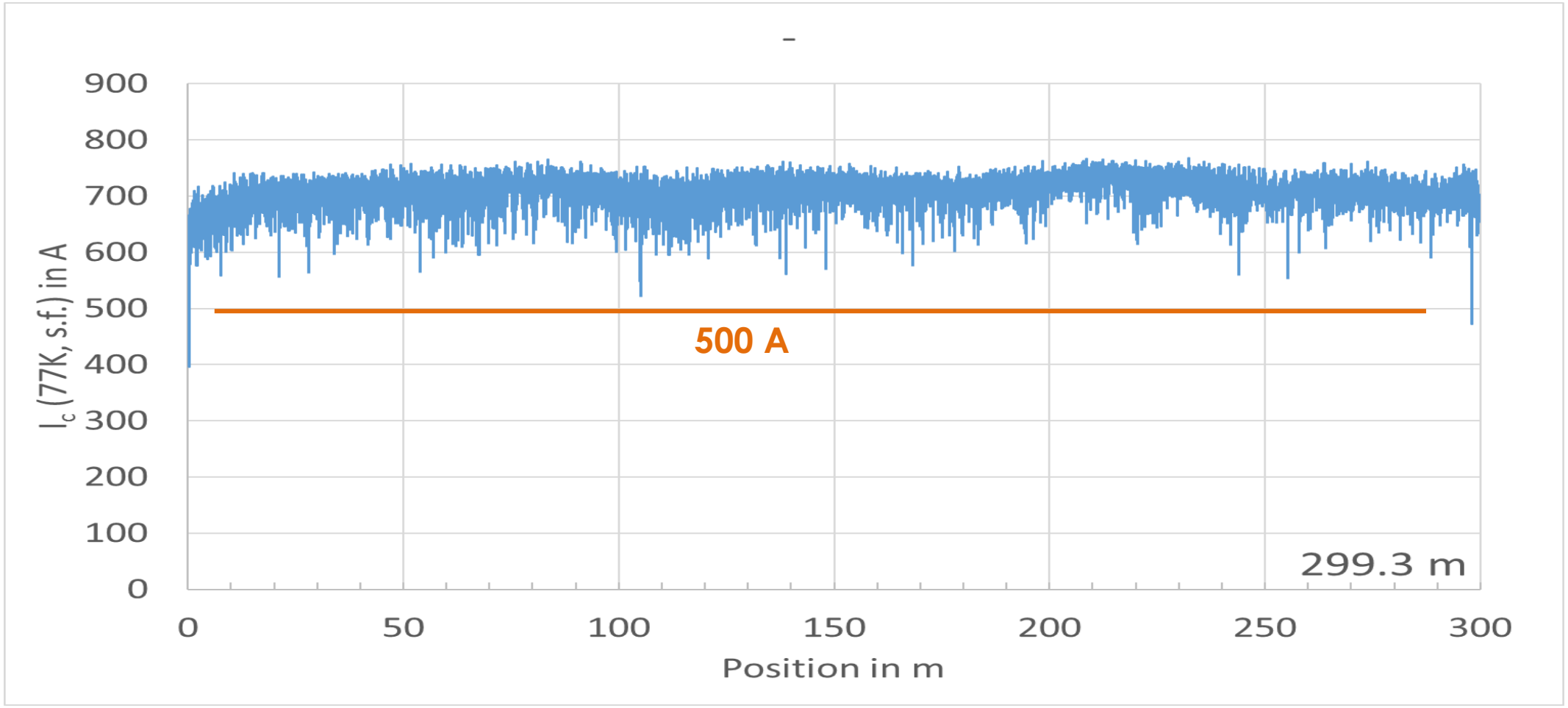
- **100% performance increase since 2016**!
- **$I_c \geq 500$ A in production tapes (12 mm)**

Further increase of I_c by increasing of the HTS thickness is planned!



Performance of HTS-Tapes

High performance on 100 µm substrates



Performance of HTS Tapes

New in production: 50 µm substrates

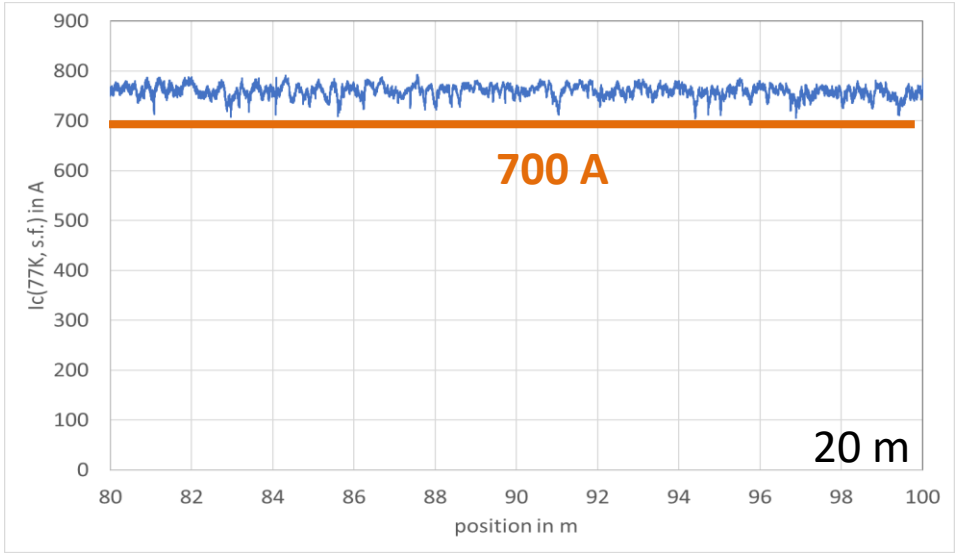
Substrate material: Hastelloy C276

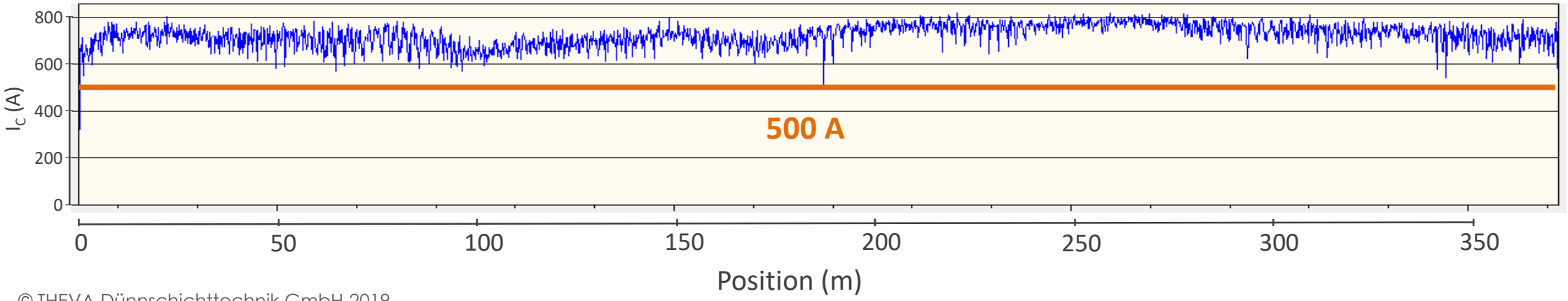
Identical quality on 50 µm and 100 µm

High I_c on regular production tapes

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

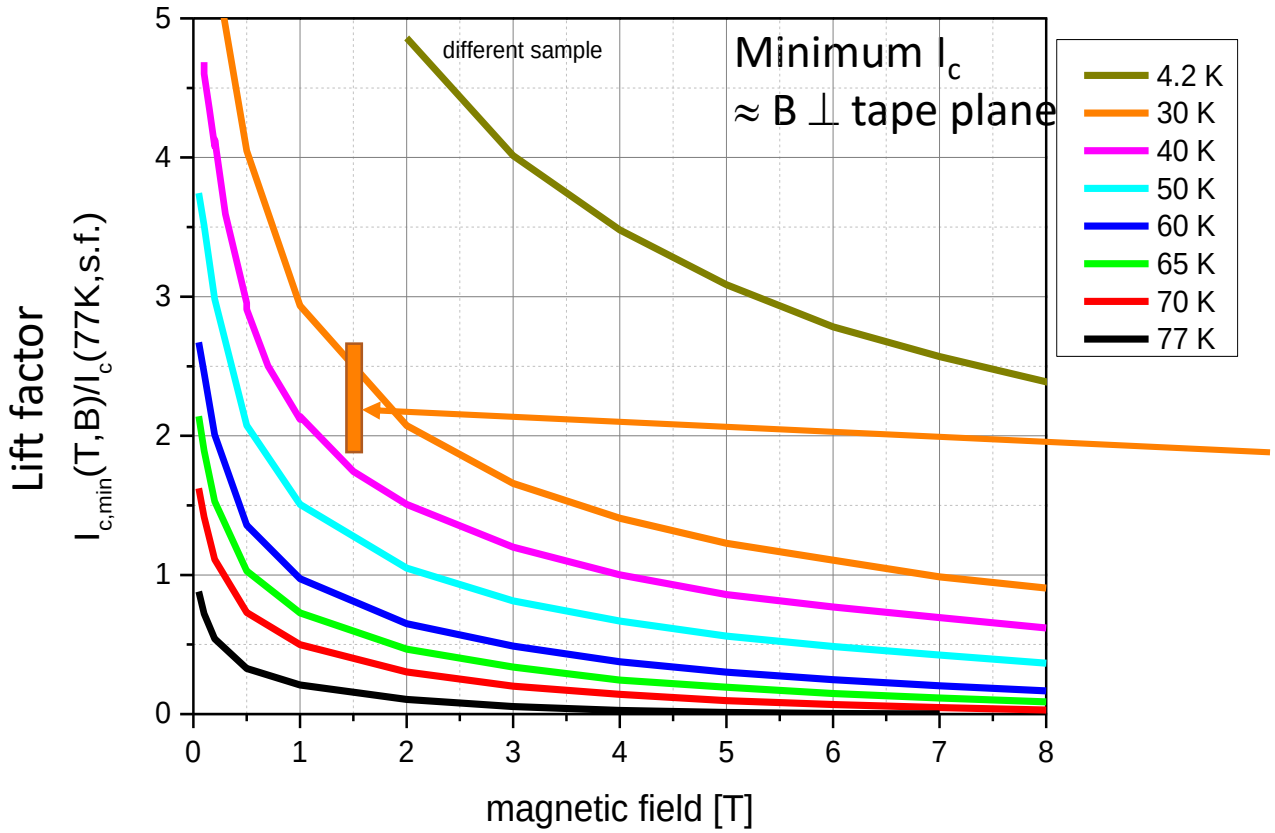
full length limited length





Magnetic Field Performance

Stable performance at intermediate temperatures and B-fields



Lift factor of 15 samples taken out of production during 1 year:

LF(1.5 T, 30K) = 2.2 ± 0.4 (± 18%)

Reliable magnetic field performance!

Magnetic Field Performance

At 4.2 K

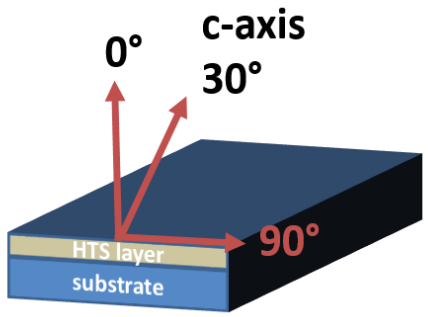
Production sample **without artificial pinning**:

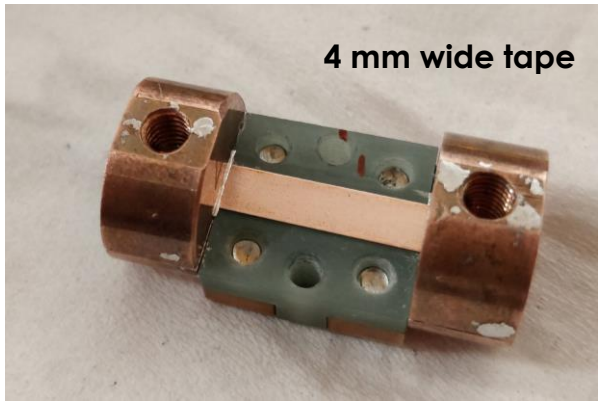
Stable performance:

No difference between 100 µm substrates (2018) and 50 µm substrates (2019)

Current density for B ⊥ tape plane (0°) for 50 µm substrate and 5 µm surround copper coating

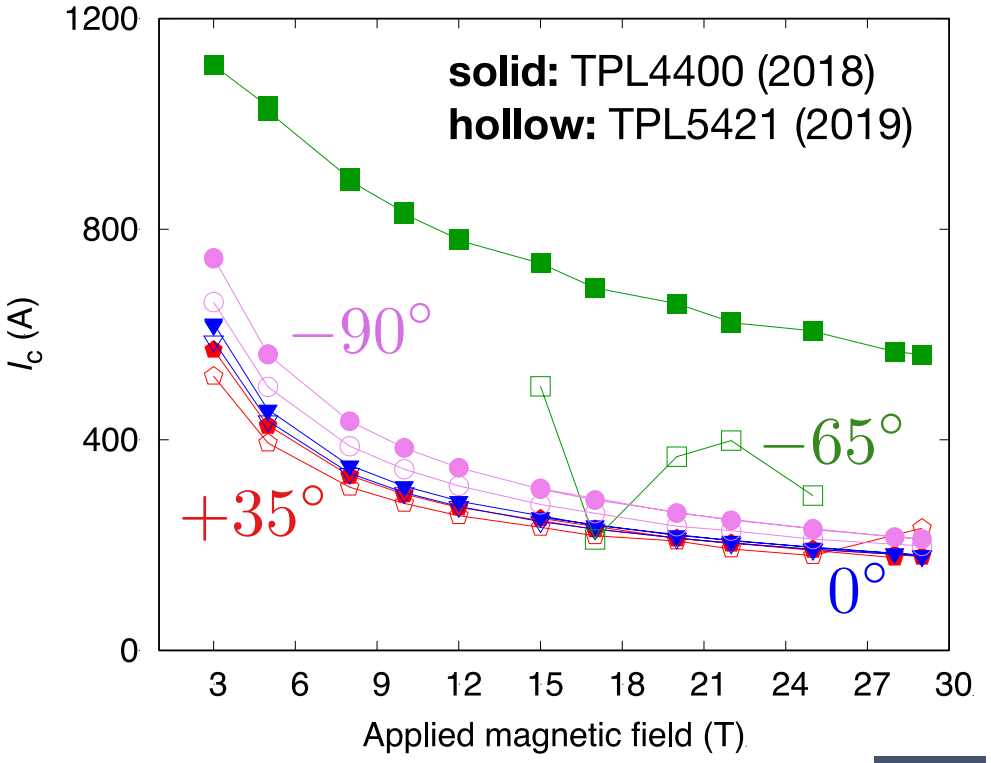
- 10 T: 280 A → 1170 A/mm²
- 20 T: 208 A → 870 A/mm²
- 29 T: 180 A → 750 A/mm²





Measured at LNCMI Grenoble
Mayraluna Lao,
Jens Hänisch, KIT

Details:
Tue-Mo-Po2.10-07



Copper surround coated HTS wire

THEVA

High dimensional accuracy

New product: HTS wire with PVD plated Cu coating

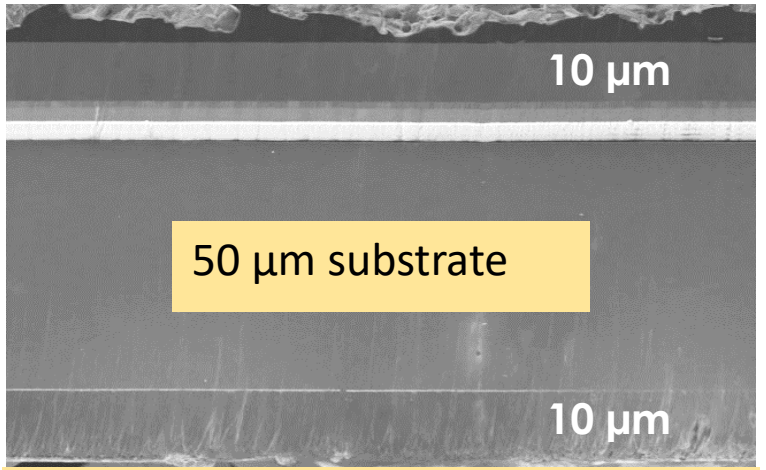
Process and properties

- Copper deposition in vacuum using **P**hysical **V**apor **D**eposition
- Tape passes through deposition zone several times
  - ✓ High homogeneity, exact thickness controll
- Thickness: typical 5 µm to 10 µm
  up to 30 µm demonstrated

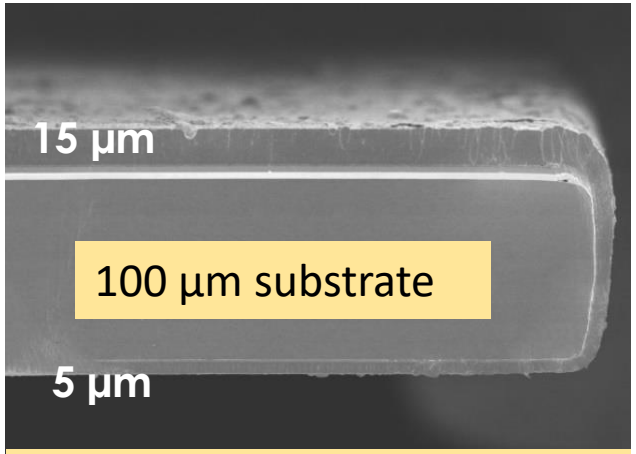
Intrinsically homogeneous thickness, no “dog boning”

Applications

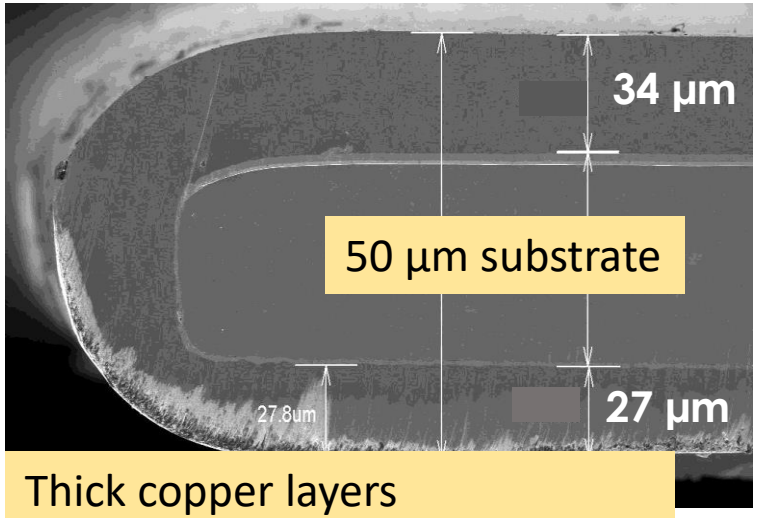
- High J_e magnets
- Stacked conductors



Symmetric copper thickness



Asymmetric Cu thickness

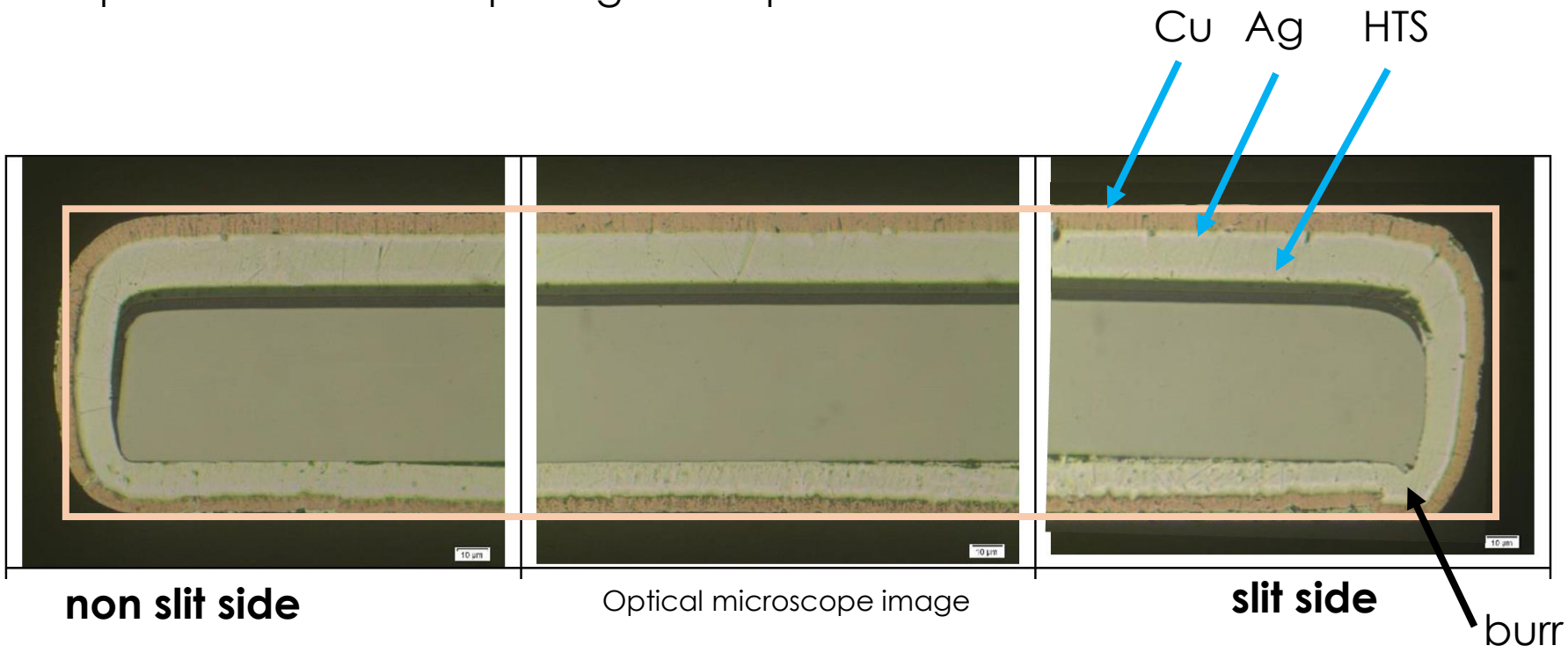


Thick copper layers

PVD plated copper coating

For coils and stacked conductors

4 mm wide tape coated with 10 µm Ag and 3 µm Cu

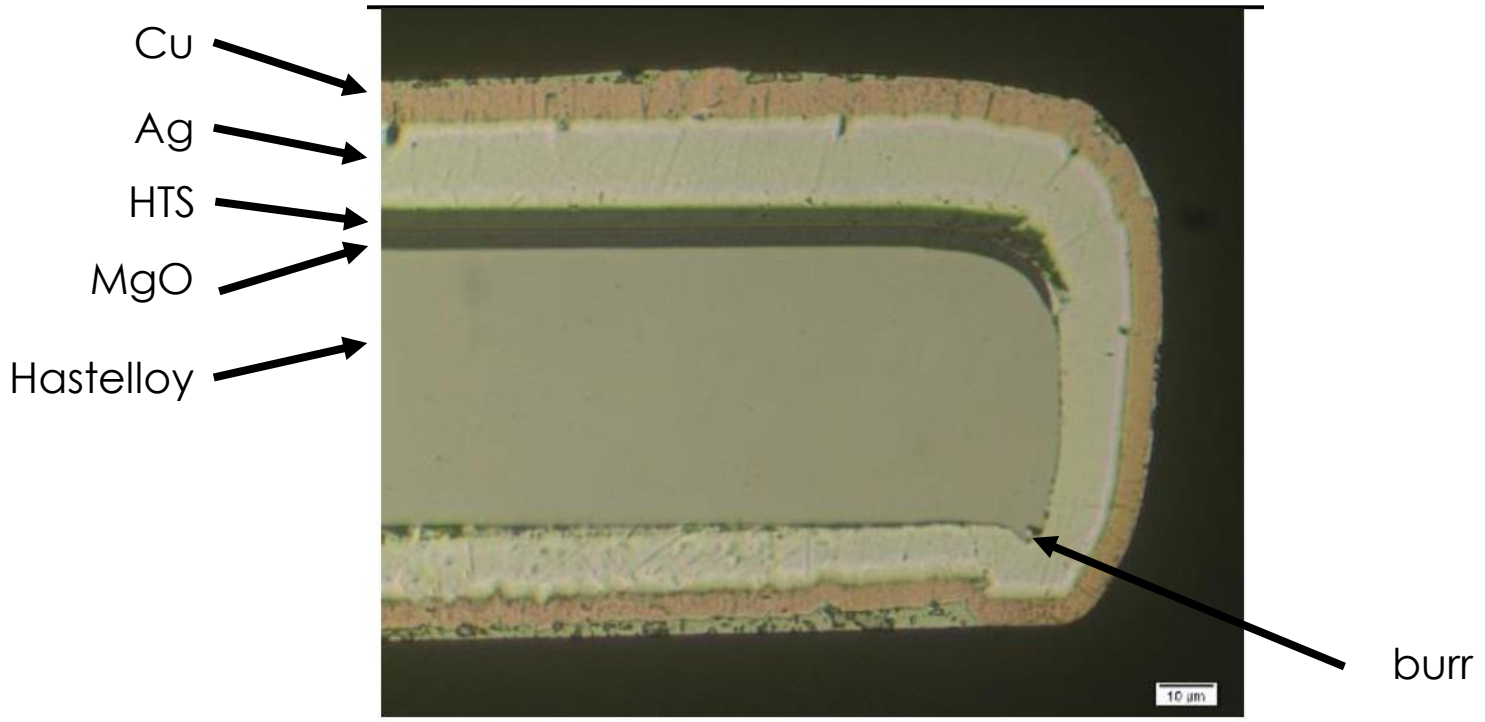


Nearly perfect rectangular cross section

PVD plated copper coating

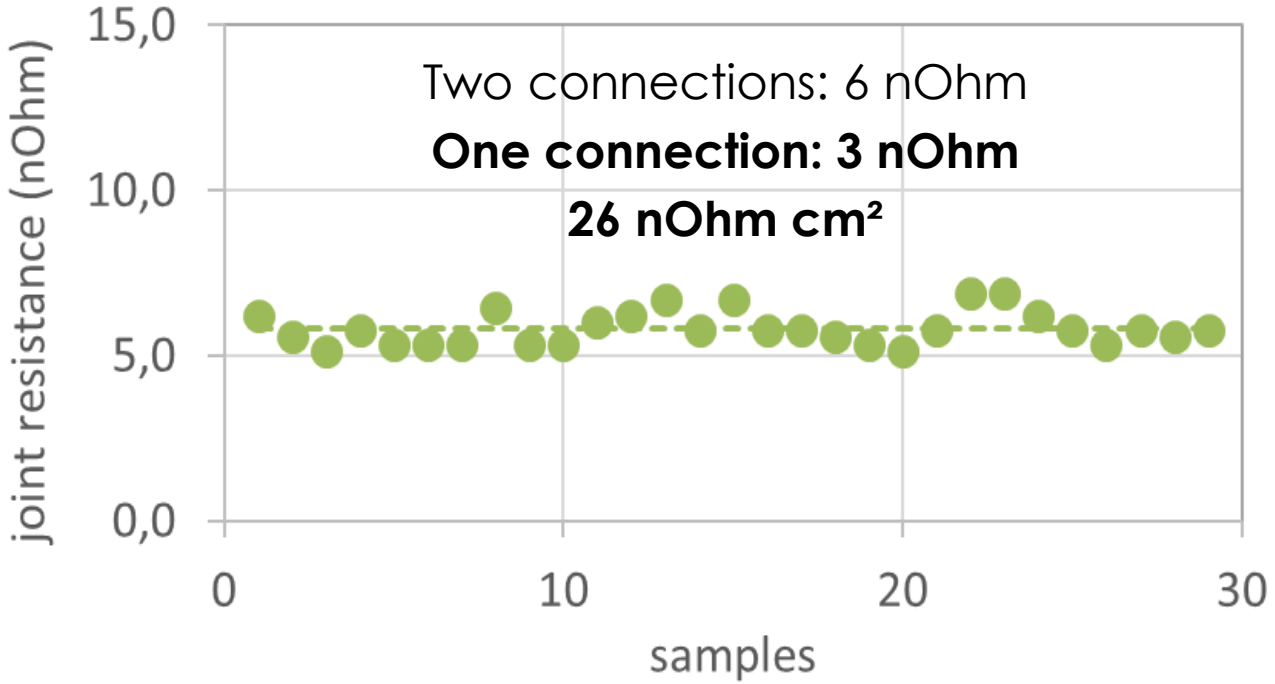
Coverage of slit edges

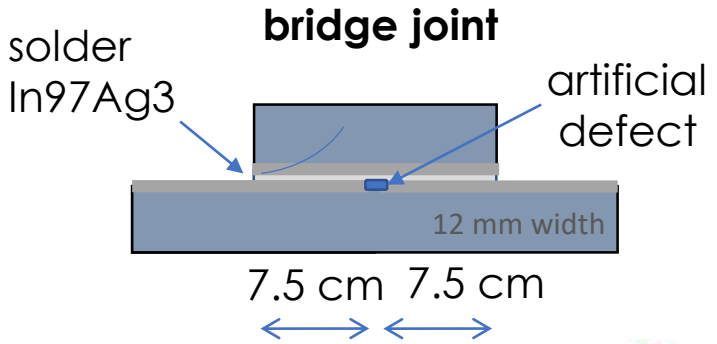
- Burr is unavoidable when tape is slit mechanically
- Coverage of this area is very demanding
- Excellent coverage by PVD plating observed

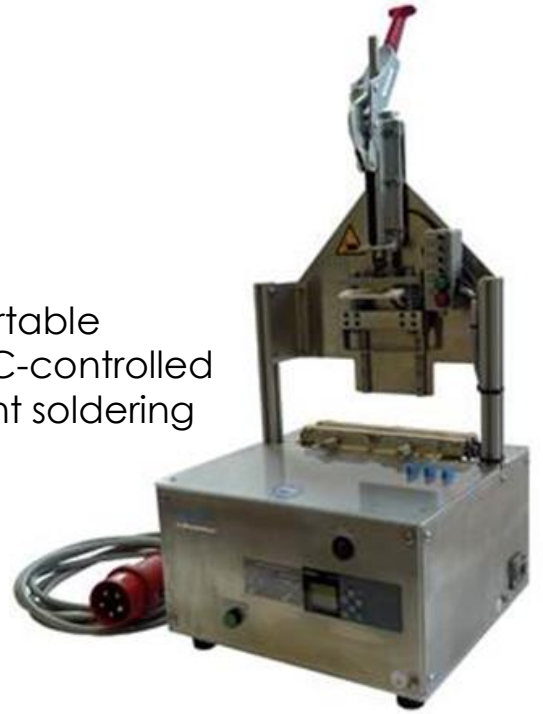


Contact resistance

PVD copper coated tapes







Portable
PLC-controlled
joint soldering

Extremely reproducible + low contact resistance

Reason: clean interfaces due to 100% vacuum processing

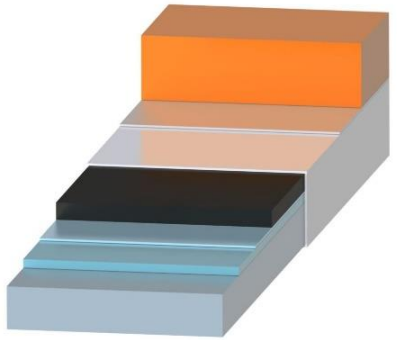
Laminated Copper HTS wire

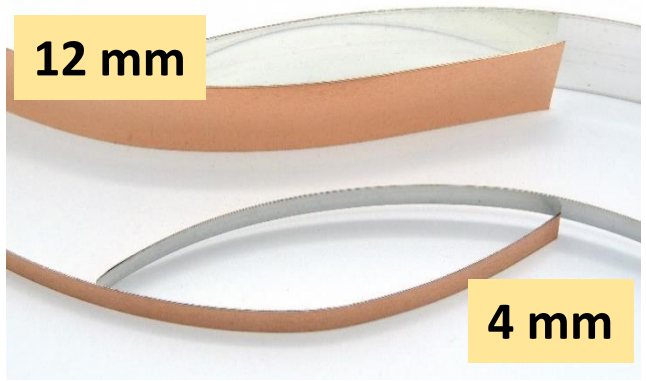
Robust wire: electrically + mechanically

Process and properties

- Single sided soldered laminate
- Optimal for medium to large copper thickness
- RRR of copper = 300
- Low contact resistance: 32 nOhm cm²

Cu foil laminate
50 -100 µm



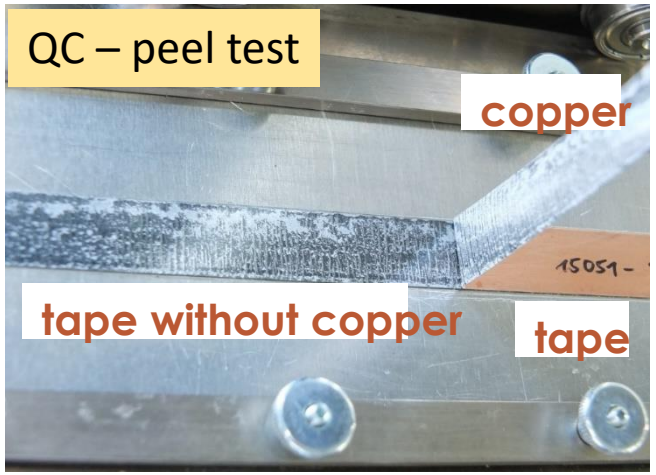


New development: Pb free solder (SAC305)

- RoHS compliant
- Higher melting point 217°C → Full freedom for contact soldering: PbSn solder contacts possible as well as low temperature solders (eg. In-based)

Applications:

- Excitation coils for rotating machines (EcoSwing)
- Industrial Magnets (Induction heaters)
- Cables, bus bars



HTS Coils

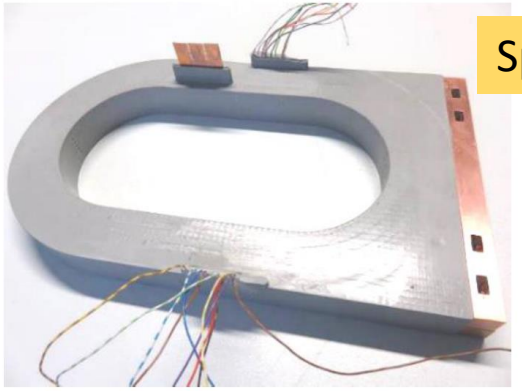
Robust and reliable

Coil winding and casting technology:

- Resin potted
- Single or double pancake coils
- Up to 1.4 m in length
- Shape adaptable (round, square, racetrack….)
- Tested down to 20 K
- Conduction or liquid cooling

HTS tape is well protected → robust coils for industrial applications

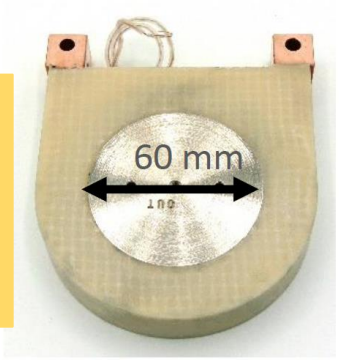
Ideal for conduction cooling because of flat and smooth surfaces



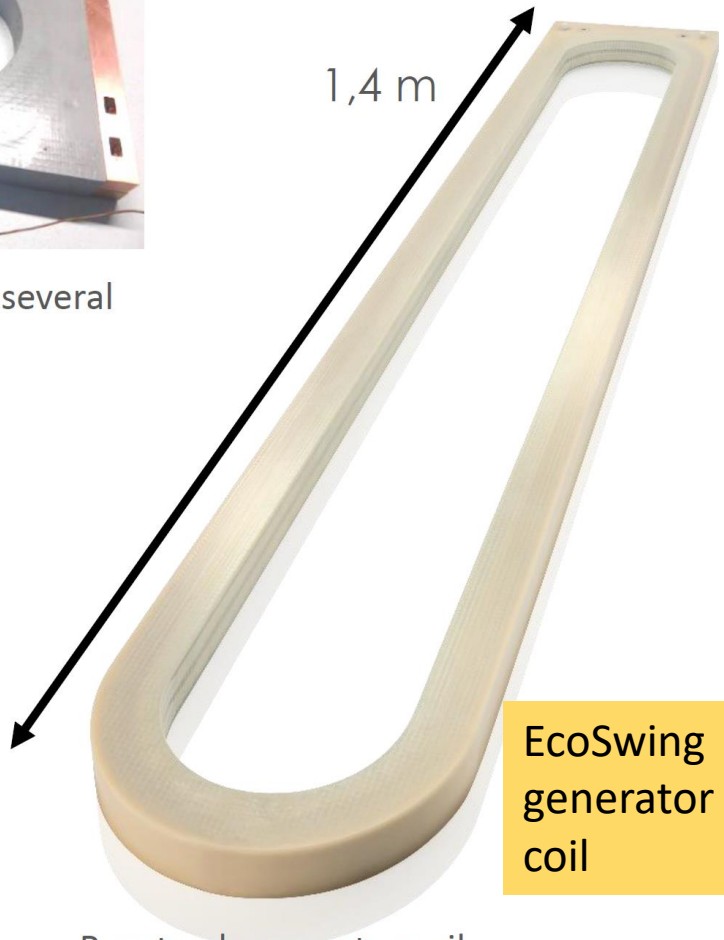
Special version

Experimental coil with several voltage taps

Coil for 1T version of Tapestar



Round double pancake coil with integrated iron core



EcoSwing generator coil

Racetrack generator coil

Summary

Properties and progress of Pro-Line HTS wire

- Industrial and scalable all PVD coating technology for HTS wires
- **New:** substrate thickness of **50 µm**
  - Identical high I_c compared to 100 µm thick substrates: 500 A on +100 m wires (12 mm)
- Field performance of up to 29 T verified also with 50 µm substrate wires:
  - at 20 T/4 K: J_e = 870 A/mm² and 29 T/4 K: J_e = 750 A/mm²
- **New**: CC with **Cu PVD plating**
  - ideal rectangular shape for magnets and stacked conductors
  - Very low and reproducible contact resistance: 26 nOhm cm²
- Available soon: **Lead free laminated HTS wire using high melting point solder** (Tm = 217°C) for high electrical stabilization and unrestricted choice of solder materials for contacts
- Robust and reliable potted HTS coils for conduction cooled applications

Thank you!

and the THEVA team:

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