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

- Substrate (Hastelloy C276) 50 µm or 100 µm
- ISD-MgO ~ 3 µm
- MgO cap layer 0.3 – 0.5 µm
- HTS film (GdBa$_2$Cu$_3$O$_{7-y}$) 3.5 µm
- Silver contact layer (surround) ~ 1.5 µm

A very simple and robust architecture!

SEM cross section

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**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

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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

\[ I_{c,\text{min}} \, (77K, \text{ s.f.}) = \begin{cases} 500 \, \text{A} & \text{full length} \\ 700 \, \text{A} & \text{limited length} \end{cases} \]

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Magnetic Field Performance
Stable performance at intermediate temperatures and B-fields

Minimum $I_c \approx B \perp$ tape plane

Lift factor of 15 samples taken out of production during 1 year:
$\text{LF}(1.5 \text{T}, 30\text{K}) = 2.2 \pm 0.4 (\pm 18\%)$
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 $B \perp$ tape plane ($0^\circ$) 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

High dimensional accuracy

New product: HTS wire with PVD plated Cu coating

Process and properties

• Copper deposition in vacuum using Physical Vapor Deposition
• Tape passes through deposition zone several times
  ✓ High homogeneity, exact thickness control
• Thickness: typical 5 µm to 10 µm
  up to 30 µm demonstrated

Intrinsically homogeneous thickness, no “dog boning”

Applications

• High J_\text{e} magnets
• Stacked conductors

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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

Cu
Ag
HTS
MgO
Hastelloy

burr
slit side
Contact resistance
PVD copper coated tapes

Extremely reproducible + low contact resistance
Reason: clean interfaces due to 100% vacuum processing

Two connections:  6 nOhm
One connection:  3 nOhm
26 nOhm cm²

Portable PLC-controlled joint soldering

solder In97Ag3
artificial defect

bridge joint

12 mm width
7.5 cm 7.5 cm

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

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

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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
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
  o 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:
  o at 20 T/4 K: $J_e = 870$ A/mm$^2$ and 29 T/4 K: $J_e = 750$ A/mm$^2$
• **New:** CC with **Cu PVD plating**
  o ideal rectangular shape for magnets and stacked conductors
  o Very low and reproducible contact resistance: 26 nOhm cm$^2$
• Available soon: **Lead free laminated HTS wire using high melting point solder** ($T_m = 217^\circ$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!
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