All-Chemical-Solution Coated Conductors at Deutsche Nanoschicht GmbH

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Outline

- Deutsche Nanoschicht GmbH
- Process technology
- Expanded pilot line
- Performance
- Technical HTS conductor
- Summary
Deutsche Nanoschicht GmbH

- Since June 2013 part of BASF group
- 63 employees, located in Rheinbach and Heidelberg, Germany
  - High Temperature Superconducting (HTS) wires,
    - chemical solution deposition, ceramic functional layers, ink-jet-printing, epitaxial growth
- Additive manufacturing / 3D-printing
High Temperature Superconductors

- Challenges for development and production

  • Best price performance ratio (€/kAm)
  • Scalable large volume production
  • Reliable and in-time supply
  • Flexible but mechanically and electrically stable
Process Technology

- Chemical solution deposition

  • Chemical solution deposition (CSD) for all layers is considered to be the „most promising and most challenging process“

  • Unique and protected CSD-multi-layer technology
Process Technology

- HTS wire architecture – thin flexible ceramic coatings

Superconductor layer
$\text{YBa}_2\text{Cu}_3\text{O}_x$ (YBCO)

Buffer layer
$\text{La}_2\text{Zr}_2\text{O}_7$ (LZO), $\text{CeO}_2$

Metal alloy substrate
NiW-alloy
Process Technology

- HTS wire architecture – thin flexible ceramic coatings
Expanded pilot line

- Construction of key process devices in house
- In-house built-up of more than 10 devices
Expanded pilot line

- Opening of expanded pilot line in Rheinbach at 10th May 2016
Expanded pilot line

- EPL construction until mid 2016 completed
- EPL capacity ramp-up completed. Increasing the yield is ongoing.
- Theoretical capacity > 200km technical HTS wire
- Started sampling for projects in 2016
Performance

- Development with industrial partners over nearly 10 years
  - Long lengths samples >20m
Performance

- D-nano has produced in 2016 1cm wide 50-100m tapes with $I_c \approx 250 \text{ A/cm}$

Tapestar calibrated against transport $I_c$
Performance

- Recent record value on EPL with length >20m (10mm width uncut)
Performance

- EPL at 6 month after opening: 90 m long / 10 width uncut
Performance

- Typical behavior in magnetic fields
Technical HTS conductor

- Silver coating
  - Unique chemical solution deposition process
  - Fast and vacuum-free processing
  - Thin and dense coating

<table>
<thead>
<tr>
<th>Sample</th>
<th>$T_c$ (K)</th>
<th>$\rho_{\text{contact}}$ ((\mu\Omega\text{cm}^2))</th>
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<td>N433509</td>
<td>89.3</td>
<td>&lt; 0.30</td>
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Technical HTS conductor

- Copper electro-plating
  - Homogeneous coating
  - Variable copper layer thickness
  - Low contact resistance

<table>
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<tr>
<th>Sample</th>
<th>Cu layer thickness</th>
<th>$T_c$ (K)</th>
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</tbody>
</table>
Technical HTS conductor

- Delamination strength
  - c-axis tensile av. 28(6) MPa (bare insert, non-laminated)
  - Architecture suitable for most energy applications

Threshold for cable applications

Specimen geometry: 12.8 x 6.4 mm² (soldered on 10 x 20 mm² sample)
Technical HTS conductor

Temperature Stability

Tested CC with copper coating
- 250 deg C for >1 hour
- 300 deg C for 30 min

Material suitable for welding or soldering

Duration per cycle: 30 minutes @ peak T
Technical HTS conductor

Bending tests (e.g. for CORT geometry)

\[
\frac{I_c}{I_{c,\text{straight}}} \quad [\text{former diameter [mm]}]
\]

- 45 deg, 7 µm Cu Shunt
- 35 deg, 7 µm Cu Shunt
- 30 deg, 7 µm Cu Shunt
- 30 deg, 4.7 µm Cu Shunt

4 mm wide conductor
CORT Cable

- about 9 m long
- 2 layers
- 4 tapes in each layer
- lay angle about 33°
- tension during winding 20 N

Stress test on 4 mm wide tapes.
(Pulling along the axis)
Technical HTS conductor

CORT cable, IEE Bratislava:
- 4mm copper coated tape
- 2 layers, 4 filaments each
- 6.35 mm tube
- 32° lay angle
CORT cable

8 individual 4 mm filaments in 2 layers

Total current in the CORT: >600 A
Technical current density: 18 A/cm²
Process challenges

- Process stabilization
- Large area processing
- High throughput
- Local dropouts
  - Interface defects
  - Handling
  - Raw materials
- Customization

Interface defect: loss of orientation
Summary

- Chemical solution deposition enables economic mass production of high temperature superconducting tapes
- Deutsche Nanoschicht reached significant performance increase over last years and starts pilot production in 2016/17
- HTS conductor successfully customized for applications
- First samples provided to customers

... but challenges remain in product and process development
Thanks for your attention

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