Superconducting Materials: 2nd HTS Generation, Status and Outlook

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Agenda for today

1. Bruker:
   Bruker Advanced Supercon :
       Bruker HTS

2. 1G and 2G HTS tapes

3. Coated Conductors: Technological status and outlook

4. Performance: Currents in field, mechanical properties, etc.

5. Realistic Applications

7. Short Summary
Bruker's major worldwide sites

- Billerica, MA, USA
- Freemont, CA, USA
- Madison, WI, USA
- Rheinstetten, Germany
- Fällanden, Switzerland
- Wissembourg, France
- Tsukuba, Japan

- R&D
- Manufacturing
- Service
- Sales
The product range **BEAS** and **BHTS**

**NbTi**

**NbSn**

**Bi-2223**

**YBCO**
Bruker HTS GmbH

Bruker HTS is the High Temperature Superconductor division of Bruker Advanced Supercon

Company headquarters is located in Hanau, while all research and production activities are located at advanced facilities in Alzenau.

The research and development teams consists of more than 30 people developing Bismuth (Bi) and Yttrium (Y)-based high temperature superconducting technologies and devices.

Bruker HTS provides industrial superconductors and application solutions to a wide range of customers.
Bruker HTS

- EHTS facility in Alzenau, Germany
- High Temperature Superconductors:
  - 1st generation - Bi-conductors,
  - 2nd generation - YBCO coated conductors
BiSCCO & YBCO CC wire designs

HTS: Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_{12}$

Polycrystalline material with uniaxial texture by thermo-mechanical treatment

Textured Bi-2223-Filaments in Silveralloy matrix
Typical dimensions:
4 mm x 0.22 mm

HTS: Y$_1$Ba$_2$Cu$_3$O$_{7-\delta}$

Textured YBCO thin film with shunt-layer on bi-axially oriented oxide-buffer-layer grown on polycrystalline stainless steel tape
Typical cross-section:
4 mm x 0.1 mm
BHTS processing route

- deep polishing
- US cleaning
- ABAD YSZ buffer
- HR-PLD CeO2
- HR-PLD YBCO
- PVD Ag or Au
- Annealing
- Cu plating

Vacuum, mbar: 10^{-5} 10^{-1} 10^{-1} 10^{-5}

Bruker HTS A.Usoskin/ CIRED 2009, Prague June 9, 2009
YBCO Coated Conductors: production route

- YBCO (~1 µm)
- YSZ Buffer (~1.5 µm)
- SS-Substrate (100 µm), non-magnetic
- CeO₂ Buffer (~0.05 µm)
- Au
  - Protective/stabilizing layer (~0.2 µm)
- Cu
  - Shunt layer (~20 µm)
HRPLD: 100m tape coated with YBCO

Steps of length up-scaling:
- 12m CC tape – before 2005
- 40m CC tape – June 2006
- 100m CC tape – Dec 2007
- 2000m CC tape – 2009
HR-PLD up-scaling
Cu Plating

1S
2SA
2SQS

Cu plating

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CC tapes delivered for cable project SUPER3C (Lamination provided by Nexans)

More than 3km of ABAD tape was produced to deliver CC tapes for this project.
Outlook: up-scaling goals

- New 6-zones HRPLD machine
  Processing speed: 70-75 m/h
  Unit length of CC: 2300 m
  Status: developed, installation in progress

- New ABAD machine
  Processing speed: 35 m/h
  Unit length of CC: >2000 m
  Status: development to be finished in 2009
YBCO Coated Conductors

Current density: 2-3 MA/cm²

Critical currents: from 250 to 500 A/cm-w (77K, SF)
e.g. 200 A in 4mm wide CC

Axial stress: 650 MPa

Bending radius: 6mm in each direction
CC tapes plated with Cu: Mechanical Properties

Axial stress: 500-650 MPa
Bending radius: 6mm
High edge bending: R=0.5m
Torsion: 30°/cm at 40N load in 4mm wide CC
CC tapes: bending tests at NIST

4mm wide CC, Cu plated; $I_c$ (strain) dependence exhibited a maximum at tensile strain of 0.4 %.

Critical current is about 240 A/cm-w in this maximum. This effect is caused by a pre-stress determined by a substrate form during film deposition.

4mm wide CC-s; 2 different samples of similar quality were measured.

(NIST & ZFW, Aug 2007)
Comparison with worldwide status

A. Xu, Y. Viouchkov, C. Tarantini, V. Griffin, Jun Lu, J. Jaroszynski, D. Larbaestier, NMFL Tallahassee
AC losses

AC losses:
4 mW/m at I=50 A without filamentization!
Coated conductors: Worldwide status

Cost evaluation for IBAD/PLD process

- Initial installation and maintenance cost

\[ \text{Throughput (m/h)} \quad 1.2 \text{ yen/Am} \sim 10 \text{ dollars/kAm} \]

Throughput of over 20m/h is needed.
Comparison of metallic substrates

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Axial Stress (MPa)</th>
<th>Ferromagn.</th>
<th>Production Costs, a.u.</th>
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</thead>
<tbody>
<tr>
<td>RABiTS tape</td>
<td>130</td>
<td>yes</td>
<td>highest</td>
</tr>
<tr>
<td>Hastelloy</td>
<td>&gt;700</td>
<td>no</td>
<td>&gt;20 Euro/kAm</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>650-700</td>
<td>no</td>
<td>~0.5 Euro/kAm</td>
</tr>
</tbody>
</table>
HTS Application - NMR

Nuclear Magnetic Resonance (NMR)

HTS enable NMR systems to blast the technical limits in resolution of today’s NMR systems. By using HTS insert coils the magnetic field range and therefore the resolution of NMR systems can be expanded.
SUPERC3C Cable based on BRUKER-HTS Coated Conductors

Assembled by Nexans

benefits:
- smaller volume/
- higher energy,
- voltage,
- volume density
- lower loss
- longer transmission lengths possible
- no external fields
- no cooling oil
Inductive shielded and resistive SFCL

SUPERPOLI FCL-5.5-50 module based on YBCO-coated stainless steel tubes and Au shunt layer.

Nominal (non-limited) current 2 500 A (ampl.)
Nominal power losses ~ 0.1 W
Fault current, max. 50 000 A (ampl.)
Peak power at fault current: 150 000 W
HTS Application - SFCL

benefits:

- Over 100 times faster response than conventional technology
- 10 to 20 times shorter recovery time
- Time adjustable response functions
- non-destructing switching, self recovery
- easy to bundle
- tailorable to fit your requirements
- low loss at nominal current
- allow downsizing of overload capability of the grid
YBCO Coated Conductors: Short Summary

- Technology of HTS Coated Conductors is available in Europe;
- First European HTS cable, SUPER3C, Nexans, is based on these tapes; Up-scaling of manufacturing line is in progress
- First product utilizing Bruker HTS 2G tapes seems to be superconducting fault current limiter
Supporting Foils
Kinetics of quench and recovery: inductive SFC
Kinetics of quench and recovery: inductive SFC

Kinetics of quench and recovery in SFCL with a shielding module exhibiting 0.9 kA critical current.

Current versus time at quench event with duration of 31 ms. Prospective current of 30 kA (peak value) is limited to 1.2 kA (second peak).