Scaling-up and R&D of 2G-HTS Tapes Fabricated by Ultra-fast PLD Process at Shanghai Superconductors Technology

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Introduction of NEW journal

- Superconducting materials
- Large-scale applications
- Electronics and applications
- Associated technologies/topics for superconducting applications and/or low temperature engineering, such as cryogenics, thermal and electrical insulations, cryogenic electronics, and standardizations.

https://www.journals.elsevier.com/superconductivity
Outlines

• State-of-the-art of 2G-HTS in China
• What we did at Shanghai superconductor technology (SST)
  • Mass product
  • R&D
  • Market
  • Applications
• Conclusion and outlook
State-of-the-art of 2G-HTS (projects) in China

- Fe-based superconductors
- 35 kV Shanghai HTS cable
- 2nd HTS tapes, applications
- World record 32.35 tesla DC all SC magnet
- the World’s first 160kV DC SFCL
- the world’s first MW HTS induction heater

Yangtze River Delta superconducting industry chain alliance
Introduction to SST

**Establishment (2011)**
- Private company funded by strategic investors
- Supported by Shanghai strategic emerging industries

**Industry-Academia Cooperation**
- Research Institute of Superconductivity
- Market/application-aligned R&D

**Current Status**
- Commercialized 2G-HTS conductors since 2015
- 70+ employees
- Ability of design and manufacturing of production facilities
- Two main factory sites: Zhangjiang High-Tech Park for Vacuum deposition, Songjiang Park for other processes
**PLD+IBAD: One of the Most reliable techniques**

- **E-polishing**
- **R2R PVD**
- **R2R IBAD**
- **R2R PVD**
- **R2R PLD**
- **R2R PVD**
- **slitting**
- **E-plating**
- **lamination**

### A reliable method

- High reproducibility
- Fast growth, high yield
- Tunable microstructure

### Necessary QC process and equipment

<table>
<thead>
<tr>
<th>Microstructure</th>
<th>Performance (superconductivity &amp; mechanical)</th>
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</thead>
<tbody>
<tr>
<td>Optical microscopy</td>
<td>XRD</td>
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Invited presentation TC-4 was given at the virtual CCA 2021, October 11-15, 2021.
Strategy at SST: High speed & Customer-friendly

Production \( A \times m \) = \( \text{production time}(s) \times \text{deposition efficiency}(A \times m/s) \)

= \( \text{production time}(s) \times \text{deposition length}(m) \times \text{growth rate}(m/s) \times \text{current density}(A/m^2) \)

<table>
<thead>
<tr>
<th>Production time</th>
<th>Deposition length</th>
<th>Growth rate</th>
<th>Current density</th>
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</thead>
<tbody>
<tr>
<td>Utilization</td>
<td>Deposition area=</td>
<td>Dependent on</td>
<td>Dependent on film</td>
</tr>
<tr>
<td>Effective working length*1cm-w</td>
<td>laser power</td>
<td>quality</td>
<td>pinning centers</td>
</tr>
<tr>
<td>hours of product line</td>
<td>Enlarged by MPMT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>structure</td>
<td></td>
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</tbody>
</table>

Other than more facilities (investments), what else can we do technically?
Strategy at SST: High speed PLD technique

- Radiation assisted conductive heating (RACH) system, leading to high temperature homogeneity under high travelling speed
  - Effective heating technique for high throughput
  - Heating tapes from RT to ~900 °C in 3.5 seconds
  - Temperature variation: ±4 °C
  - Tape speed: >100 m/h

- Unique growth conditions: local overheating → transit liquid phase → enhanced diffusion → quenching


Ultra-high growth rate: > 100 nm/s
High performance GdBCO films with "robust" structure

Annual production for a 300W PLD: >150 km*500 A
i.e., in 2020, 300 + km (10 mm) was produced;

High quality GdBCO film grown under “overgrowth” mechanism
Mixed-landscape pinning centers in "fast grown" EuBCO films

KM-class long EuBCO tapes with high $I_c$ achieved on 30 and 50 μm substrates

- Inclined nano-rods and high density of stacking faults co-exist throughout the film thickness
- Tunable defect landscapes under high growth rates

All the in-filed performance data available at http://htsdb.wimbush.eu/
Competitive performance on the mass produced APC tape

Shanghai-AP-50: 2021 production
Shanghai-AP-30: 2019 production

@ 77 K

4 mm wide tape

Competitive $I_c$ vs $B_{//c}$ at 4.2 K
Continuous improvement of in-field $I_c$
Weak anisotropy

**R&D: Laser Slitting**

- **home-made R2R laser slitting setup**

- **Condition A**: 45 um

- **Condition B**: 35 x 35 um, 90 um

- **Condition C**: 75 um

- **Cross section**
  - **No nodules**
  - **Trade-off between speed and quality**
  - **Appearance of nodules related to the thermal effect**

- **speed**: 120 m/h

- **Appearance of nodules related to the thermal effect**
Strategy at SST: Customization for Robust combined conductor

Lamination techniques for power applications

- Minor $I_c$ degradation after epoxy impregnation
- Automatic lamination equipment
- Wire edge fully covered
- Uniform and robust
- Copper / Brass / Stainless Steel

Double insert or optical fiber coupling
(For China Southern Power Grid SFCL project)

contactless low temperature and rapid cooling package techniques
Case1: Shanghai HTS Cable (three in one type)

- 35m cable $I_c$ test (2019) $I_c$ reached 5769 A @ 77 K

Key Parameters

- **Rated Voltage**: 35kV
- **Rated Current**: 2200A
- **Length**: 1200m

- 170+km, avg. piece length 150m, for conductor layer;

- HTS tape supply completed within 5 months in 2020;

Partly courtesy of Dr. Zong Shanghai Electric cable research Institute & (new company) Shanghai International Superconducting Technology Co., Ltd.
Case2: Shenzhen HTS cable (the tri-axial core type)

- 500 m long HTS cable for Shenzhen Ping An Financial Center (height of 592.5 meters)
- Simplifying the power grid structure: reducing the construction of 110 kV substation, and save area of 500 m²

Project owner: Guangdong Electric Power Design
Designed by: Beijing Jiaotong University
Constructed by: Zhongtian Technology Group
Operated by: Shenzhen Power Supply Bureau
Cooling system by: CSIC Pride Cryogenic Technology Co., Ltd.

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Case 3: MIT-CFS, Tokamak Energy and SST

Compact Fusion/High-field Magnet

- MIT-CFS
- Tokamak Energy

Customers’ feedback:
- Stable product
- Low rejection;
- Ave. $J_e$ exceeding 750 A/mm²
- Comparable lift factor variation as peers

120+ km in total
Complete delivery in 2020

Commonwealth Fusion System (US)
Compact Fusion using 2G-HTS

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2G-HTS Business Chance in China:

- Based on a large demand for electrical power, HTS business is close to commercialization in China.
- Many demonstration projects, including power cable, FCL, high speed maglev train, magnets, are being conducted and planned.
- Commercial 2G-HTS tapes are highly anticipated, to be available at low price and well-customized properties.

Technological developments at SST:

- Large volume production by IBAD + high speed PLD, annual production > 1000 km/4mm ($I_c=150-200A$);
- Low temperature, high field properties improved by advanced APC, composition,…
- Thin tape(high $J_e$): Now 30 μm in thickness available
- New slitting method: laser slitting without damage at the edges
Thank you!

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