Status of 2G HTS wire production at SuperOx
Outline

• Wire production facility development
• Quality management
• 2G HTS wire performance
• Yield assessment
• Product development
• Examples of active large projects with SuperOx wire
• 2018 wire opportunity
SuperOx 2G HTS wire architecture

Customised finish tailored to application

Sputtering (custom thickness)

PLD (1-2 microns)

Sputtering (30-50 nm)

e-beam IBAD (5-7 nm) + epi (50-150 nm)

Sputtering (5-10 nm)

Sputtering (30-50 nm)

Cold rolled & electro polished (40 or 60 or 100 microns)
• Wire production facility development
  • Quality management
  • 2G HTS wire performance
  • Yield assessment
  • Product development
  • Examples of active large projects with SuperOx wire
  • 2018 wire opportunity
### Production facility development

<table>
<thead>
<tr>
<th>Originally: 2011-2015</th>
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<tbody>
<tr>
<td><strong>Moscow</strong></td>
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<tr>
<td><strong>Tokyo</strong></td>
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<table>
<thead>
<tr>
<th>2016 onwards</th>
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<tr>
<td><strong>Moscow</strong></td>
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Decisions to increase throughput are driven by demand.
Multiprocess one-chamber sputtering/IBAD (buffer R&D and production back-up)
Dual-chamber PLD-HTS system for CeO$_2$ and GdBCO

50 km wire in 2018
Moscow buffer layer line commissioned Jan 2016

e-Polished Hastelloy substrate in
Ready buffered tape with LaMnO$_3$ on top out

Extra capacity: Textured template offered for sale

100+ km buffer tape in 2018
Moscow PLD-HTS line commissioned Dec 2016

SuperOx production capacity doubled: 2 x 50 km/year (12 mm width). Operate at full capacity!

Wire made at SuperOx in Moscow and SuperOx Japan is of identical high quality.
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  • 2018 wire opportunity
## Quality control

<table>
<thead>
<tr>
<th></th>
<th>Substrate</th>
<th>Buffer</th>
<th>HTS</th>
<th>Ag</th>
<th>Cu</th>
<th>Finish</th>
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<tr>
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<td>Optical</td>
<td>RHEED Optical</td>
<td>Optical</td>
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<tr>
<td>Off-line, full length</td>
<td></td>
<td></td>
<td></td>
<td>Non-contact I&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Non-contact I&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Non-contact I&lt;sub&gt;c&lt;/sub&gt;</td>
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<tr>
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<td>XRD</td>
<td>XRD SEM EDX</td>
<td>Transport I&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Transport I&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Specific tests</td>
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</table>

- Rejection of defective material at early processing stages for cost optimisation
- Real time closed-loop control for high yield
**In-line QC in textured template production:**

**substrate electropolishing**

**RGB-Scan:** software for optical detection of surface defects
- The software collects images from a camera and performs digital analysis of the tape surface quality
- Several quality parameters are derived from each image
- Rejection of defective tapes at early processing stages for cost optimisation

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**Serial production tape: no defects**

A. Mankevich et al., IEEE TASC, 28(4) 2018, 6602005
In-line QC in textured template production: IBAD-MgO

**Green-Scan**: software for digital analysis of RHEED patterns
- One number derived from a RHEED image describes texture quality
- Closed-loop texture quality control is implemented resulting in high yield

RHEED data on IBAD-MgO texture correlate with the LMO layer texture measured by XRD

A. Mankevich et al., IEEE TASC, 28(4) 2018, 6602005
In-line QC in textured template production: IBAD-MgO

**Green-Scan**: software for digital analysis of RHEED patterns
- One number derived from a RHEED image describes texture quality
- Closed-loop texture quality control is implemented resulting in high yield

![Graph showing manual and auto control of texture quality](image)
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  • 2018 wire opportunity
2G HTS wire: long length, high current, good uniformity

SuperOx representative production wires. TapeStar XL data.
# 2G HTS wire: consistent performance at 77 K


<table>
<thead>
<tr>
<th>B//c (Tesla)</th>
<th>Sample Width (mm)</th>
<th>Ic at 77 K, s.f. (A)</th>
<th>Measured at</th>
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<th>NHMFL</th>
<th>LPI</th>
<th>INEA CR Frascati</th>
<th>PSI-CRPP</th>
<th>PSI-CRPP</th>
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<th>PSI-CRPP</th>
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</tbody>
</table>

2G HTS wire: consistent performance at 77 K

Reproducible lift factors

NO artificial pinning centres, only intrinsic \( \text{Gd}_2\text{O}_3 \) nanoparticles due to excess Gd

2G HTS wire: consistent performance at 77 K

Angular dependence of Lift-factor at 77 K, 1 T
(min. 3 independent measurements per point)

Reproducible lift factors

NO artificial pinning centres, only intrinsic Gd\textsubscript{2}O\textsubscript{3} nanoparticles due to excess Gd

Data updated regularly, available for download at
2G HTS wire: consistent performance at 4.2 K


Reproducible lift factors

NO artificial pinning centres, only intrinsic Gd$_2$O$_3$ nanoparticles due to excess Gd
# 2G HTS wire: specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate thickness</td>
<td>60 or 100 μm</td>
</tr>
<tr>
<td>Tensile strength (95% $I_c$ retention)</td>
<td>&gt; 500 MPa / 0.55% deformation</td>
</tr>
<tr>
<td>Critical bend diameter</td>
<td>22 mm</td>
</tr>
<tr>
<td>Wire width</td>
<td>4 mm / 6 mm / 12 mm</td>
</tr>
<tr>
<td>Min. critical current @ 77K, s.f.</td>
<td>80-150 A / 120-250 A / 300-600 A</td>
</tr>
<tr>
<td>Critical current uniformity</td>
<td>$I_c$ Standard deviation ≤ 2%</td>
</tr>
</tbody>
</table>

**Customisation:**
- Variable silver thickness
- Variable copper thickness
- Lamination
- Insulation: 10-20 micron thin polyimide varnish
- Solder plating
- Low resistance splices
- ... just ask
Outline

- Wire production facility development
- Quality management
- 2G HTS wire performance

**Yield assessment**

- Product development
- Examples of active large projects with SuperOx wire
- 2018 wire opportunity
Integral yield: tool for quality management and economic analysis

TapeStar XL data for an individual wire

Integral yield (%) map
Integral yield: tool for quality management and economic analysis

- Compare time periods
- Know your stock
- Manage new orders

Integral yield (%) for a group of wires
Cost ($/kAm) assuming $50/m for 100% yield
Outline

• Wire production facility development
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• Yield assessment

• Product development
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Product development:
40 micron substrate, 3 mm wide wire

Thin substrate

Narrow wire

SuperOx wire on 40 micron thick substrate. TapeStar XL data.

SuperOx 3 mm wide wire. TapeStar XL data.
Product development: pinning enhancement

Varied parameters:
- APC composition: BaSnO$_3$/BaZrO$_3$
- APC content: 0, 6, 12, 18% (molar) in HTS
- PLD GdBCO growth rate: 375, 560, 750 nm/min

VSM measurements

V Chepikov et al 2017 Supercond. Sci. Technol. 30 124001

Phase I results: up to 80% improvement in LHe
Future direction:
• Optimise for APC content and PLD-HTS growth rate
• Explore within the GdBCO composition triangle with and without APC
• **Check reproducibility thoroughly**
Outline

• Wire production facility development
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Examples of running large projects with SuperOx wire:
SuperOx: 220kV / 450 MW SFCL for Moscow city grid

1. Superconductor manufacturing
2. Engineering and production
3. Onsite construction
Examples of running large projects with SuperOx wire:
Kinelectrica/SuperOx: HTS cable system for Airbus

<table>
<thead>
<tr>
<th>Total power</th>
<th>0...12 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>30...40 m</td>
</tr>
<tr>
<td>Voltage level</td>
<td>5...5000 V</td>
</tr>
<tr>
<td>Frequency</td>
<td>0...400 Hz</td>
</tr>
</tbody>
</table>

In this area, losses in HTS cable are lower than in Al or Cu.
Examples of running large projects with SuperOx wire:
HTS motor for aircraft. Horizon 2020 consortium

Advanced Superconducting Motor Experimental Demonstrator

Source: Airbus Group Innovations
Examples of running large projects with SuperOx wire: CNRS, Grenoble/BOSSE: 1 MJ, 10+ T SMES and dipole launcher

Fig. 7. View of a prototype pancake. The mandrel, the internal contact, the winding, the external contact and a flange are visible.

Fig. 8. Cross section view of the solenoid. As the tapes are wider, the current density is lower at solenoid extremities. $R = 135\, \text{mm}$, $TH = 29\, \text{mm}$, $H = 384\, \text{mm}$.

Fig. 12. CAO plan of the SIEL launcher (courtesy R. Pasquet, SigmaPhi).

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Feb 2018: We expect to build temporary stock of few tens of km of wire by the end of 2018. Now is good time to order.

Jun 2018: ~20 km of wire in stock.

Sep 2018: Stock almost gone.

Sep 2018: We keep making 2 km wire in a week. It is still good time to order.
Thank you for your attention
Product development: pinning enhancement

Possible scenarios of the pinning enhancement programme

- **Baseline**
  - Critical current at 4.2 K (A/4 mm)
  - Perpendicular field (T)

- **Unacceptable**
  - Critical current at 4.2 K (A/4 mm)
  - Perpendicular field (T)
  - ± 30%
  - ± 100%

- **Acceptable**
  - Critical current at 4.2 K (A/4 mm)
  - Perpendicular field (T)
  - ± 30%