Development of 2G HTS wire production at SuperOx
2G HTS wire production: facility expansion

2G HTS wire performance
- Consistent performance without AP
- R&D into AP

HTS device projects
- Roebel cables
- Lightweight cable for aircraft
- Horizon 2020: HTS motor for aircraft
- FCL
2G HTS wire architecture

- **Hastelloy C276**
- **Al$_2$O$_3$**
- **Y$_2$O$_3$**
- **IBAD - MgO**
- **LaMnO$_3$**
- **CeO$_2$(Gd$_2$O$_3$)**
- **GdBCO**
- **Ag**
- **Finish**

**Technology Details**

- Sputtering (custom thickness)
- PLD (1-3 microns)
- PLD (100-200 nm)
- 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 (60 or 100 microns)
- Customised finish tailored to application

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<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moscow</td>
<td><strong>Substrate</strong></td>
<td><strong>Buffer</strong></td>
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<tr>
<td></td>
<td></td>
<td><strong>HTS</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Ag</strong></td>
<td><strong>Cu</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Finish</strong></td>
<td><strong>Finish</strong></td>
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<tr>
<td>Tokyo</td>
<td><strong>Buffer</strong></td>
<td><strong>HTS</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Ag</strong></td>
<td><strong>Cu</strong></td>
</tr>
</tbody>
</table>

Decisions to increase throughput are driven by demand
SuperOx Japan LLC: in operation since Nov 2011

Multiprocess one-chamber sputtering/IBAD system
Dual-chamber PLD-HTS system for CeO$_2$ and GdBCO

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e-Polished Hastelloy substrate in Ready buffered tape with LaMnO$_3$ on top out
Moscow buffer layer line commissioned Jan 2016

Good IBAD-MgO RHEED patterns

$\Delta \phi$ (110) LMO < 7°

High $I_c$ by PLD-HTS on Moscow buffer

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Moscow PLD-HTS line commissioned Dec 2016

SuperOx production capacity doubled
## 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>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In-line</strong></td>
<td>Optical</td>
<td>RHEED</td>
<td>Optical</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Off-line, full length</strong></td>
<td></td>
<td></td>
<td></td>
<td>Non-contact $I_c$</td>
<td>Non-contact $I_c$</td>
<td>Non-contact $I_c$</td>
</tr>
<tr>
<td><strong>Off-line, segments</strong></td>
<td>AFM</td>
<td>XRD</td>
<td>XRD  SEM</td>
<td>Transport $I_c$</td>
<td>Transport $I_c$</td>
<td>Specific tests</td>
</tr>
</tbody>
</table>
2G HTS wire: high $I_c$ over long length

12 mm

77 K

4 mm

$I_c$ (A)

Position (m)

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2G HTS wire: consistent performance


- Low angular anisotropy
- Reproducible lift factors
- NO artificial pinning centres, only intrinsic Gd$_2$O$_3$ nanoparticles due to excess Gd

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Production rate PLD. Classic nanocolumns of perovskite AP centres.
Less anisotropy and higher min. $I_c$ in field with pinning
2G HTS wire: artificial pinning in high rate PLD
first R&D results

Critical current density (MA/cm²) vs. Applied Field (T)

- **AP**
- **No AP**

- **4.2 K**
- **B//c**

- **α = 0.59**
- **α = 0.63**

Higher $J_c/I_c$ in liquid helium

Next steps:
- Optimise for specific T, B
- Verify reproducibility in production wires

Talk M3OrC

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# 2G HTS wire: customisation

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Silver</th>
<th>Copper plating</th>
<th>Lamination</th>
<th>Surround polyimide</th>
<th>Polyimide wrapping</th>
<th>Solder plating</th>
<th>Tape stacks</th>
<th>Filaments</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMSC</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<td>●</td>
<td>●</td>
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<tr>
<td>Fujikura</td>
<td>●</td>
<td>●</td>
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<td>●</td>
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<tr>
<td>SuNAM</td>
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<td>SuperOx</td>
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<td>●</td>
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<tr>
<td>SuperPower</td>
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</tr>
</tbody>
</table>

*Polyimide deposition*

*Custom copper plating*

*Custom solder plating*

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## 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>Tape width</td>
<td>4 mm</td>
</tr>
<tr>
<td></td>
<td>6 mm</td>
</tr>
<tr>
<td></td>
<td>12 mm</td>
</tr>
<tr>
<td>Critical Current @ 77K, s.f.</td>
<td>80-150 A</td>
</tr>
<tr>
<td></td>
<td>120-200 A</td>
</tr>
<tr>
<td></td>
<td>250-500 A</td>
</tr>
<tr>
<td>$J_e$ at 4.2 K, 20 T</td>
<td>$&gt; 400$ A/mm$^2$</td>
</tr>
<tr>
<td></td>
<td>$&gt; 400$ A/mm$^2$</td>
</tr>
<tr>
<td></td>
<td>$&gt; 400$ A/mm$^2$</td>
</tr>
<tr>
<td>Current Uniformity</td>
<td>±10%</td>
</tr>
<tr>
<td></td>
<td>±10%</td>
</tr>
<tr>
<td></td>
<td>±10%</td>
</tr>
</tbody>
</table>

**Customisation:**

- + Variable silver thickness
- + Variable copper thickness
- + Lamination
- + Insulation
- + Solder plating
- + Low resistance splices
- + Filaments
- + … just ask

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Punch-and-Coat: perfect degradation/delamination stability

Coat-and-Punch: delamination on cycling occurs

S. Otten et al., SUST 28 (2015) 065014

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Poster M1PoB
2G HTS Roebel cables

TapeStar data on individual strand

4.2 K

J. Fleiter et al. CERN Internal Note 2017_15, EDMS: 1757653

35 m cable now in Feather 2 coil at CERN

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Poster M1PoB
In this area, losses in HTS cable are lower than in Al or Cu.
HTS motor for aircraft. Horizon 2020 consortium

Advanced Superconducting Motor Experimental Demonstrator

Source: Airbus Group Innovations
3.3 kV DC FCL for railway grid

- Medium-voltage DC
- Retrofitted into a standard switchbox
- Joint project with «NIIEFA-ENERGO», LLC (St.Petersburg)

<table>
<thead>
<tr>
<th>Specification</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>3.3 kV</td>
</tr>
<tr>
<td>Rated current</td>
<td>Up to 5 kA</td>
</tr>
<tr>
<td>Limitation speed</td>
<td>100 ms</td>
</tr>
<tr>
<td>Resistance w/o fault</td>
<td>0.001 Ohm</td>
</tr>
<tr>
<td>Resistance during fault</td>
<td>1 Ohm</td>
</tr>
<tr>
<td>Power consumption</td>
<td>&lt; 6 kW</td>
</tr>
<tr>
<td>Cryo-system</td>
<td>Closed type, cryocooler</td>
</tr>
<tr>
<td>Dimensions (mm)</td>
<td>800 x 1740 x 2100</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>700</td>
</tr>
</tbody>
</table>
220 kV FCL for Moscow City grid

- SuperOx runs a contract for Moscow City-owned grid company UNECO, for the first high-voltage FCL in Russia
- Huge long-term benefits for the Moscow city grid from FCL use

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Outline

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THANK YOU FOR YOUR ATTENTION

www.superox.ru