Development of 2G HTS wire production at SuperOx
2G HTS wire production
  - Facility expansion
  - Quality control

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

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

- **Finish**: Customised finish tailored to application
  - 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)

Diagram:
- Hastelloy C276
- Al₂O₃
- Y₂O₃
- IBAD - MgO
- LaMnO₃
- CeO₂(Gd₂O₃)
- GdBCO
- Ag
- Finish
**Production status and development**

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Moscow</th>
<th>Tokyo</th>
</tr>
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<tbody>
<tr>
<td>Originally: 2011-2015</td>
<td>Substrate</td>
<td>Buffer</td>
</tr>
<tr>
<td>Moscow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tokyo</td>
<td>Buffer</td>
<td>HTS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Moscow</th>
<th>Tokyo</th>
</tr>
</thead>
<tbody>
<tr>
<td>At present: 2017</td>
<td>Substrate</td>
<td>Buffer</td>
</tr>
<tr>
<td>Moscow</td>
<td>Buffer</td>
<td>HTS</td>
</tr>
<tr>
<td>Tokyo</td>
<td>Buffer</td>
<td>HTS</td>
</tr>
</tbody>
</table>

Decisions to increase throughput are driven by demand
Multiprocess one-chamber sputtering/IBAD system
Dual-chamber PLD-HTS system for CeO$_2$ and GdBCO

19 September 2017
e-Polished Hastelloy substrate in Ready buffered tape with LaMnO$_3$ on top out

19 September 2017
Moscow buffer layer line commissioned Jan 2016

Good IBAD-MgO RHEED patterns

$\Delta \phi \ (110) \ LMO \ < \ 7^\circ$

High $I_c$ by PLD-HTS on Moscow buffer

19 September 2017
Moscow PLD-HTS line commissioned Dec 2016

SuperOx production capacity doubled

Wire produced at SuperOx in Moscow and at SuperOx Japan is of identical high quality
## 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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<tbody>
<tr>
<td><strong>In-line</strong></td>
<td>Optical</td>
<td>RHEED</td>
<td>Optical</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</td>
<td>Transport $I_c$</td>
<td>Transport $I_c$</td>
<td>Specific tests</td>
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<td></td>
<td>SEM</td>
<td></td>
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<td>EDX</td>
<td></td>
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</tbody>
</table>
In-line QC in textured template production

- RGB Scan: software for optical detection of various 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

In-line R2R surface QC during substrate electropolishing

19 September 2017

Poster on Thursday: 4MP7-14
In-line QC in textured template production

- GreenScan: software for digital analysis of RHEED patterns
  - Texture quality is described by a single parameter
  - Closed-loop texture quality control is implemented

In-line R2R
IBAD-MgO texture QC

Correlation between $I_c$ and MgO-IBAD texture
19 September 2017
Poster on Thursday: 4MP7-14
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19 September 2017
2G HTS wire: high $I_c$ over long length

![Graph showing $I_c$ vs. Position (m) for 12 mm and 4 mm samples at 77 K.](image-url)
2G HTS wire: consistent performance


19 September 2017
Production rate PLD. Classic nanocolumns of perovskite AP centres.
2G HTS wire: artificial pinning in high rate PLD

65 K, 1 T

Reference sample
6% BSO, 750 nm/min
6% BSO, 560 nm/min
6% BSO, 375 nm/min
12% BSO, 750 nm/min
18% BSO, 750 nm/min
6% BZO, 750 nm/min

Field angle (deg.) 0° = B//ab, 90° = B//c

I_c (A/12 mm)

Less anisotropy and higher min. I_c in field with pinning

V. Chepikov et al., submitted to SuST special issue
2G HTS wire: artificial pinning in high rate PLD

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

V. Chepikov et al., submitted to SuST special issue

19 September 2017
# 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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</tr>
</tbody>
</table>

**Polyimide deposition**

**Custom copper plating**

**Custom solder plating**

19 September 2017
# 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, 6 mm, 12 mm</td>
</tr>
<tr>
<td>Critical Current @ 77K, s.f.</td>
<td>80-150 A, 120-200 A, 250-500 A</td>
</tr>
<tr>
<td>$J_e$ at 4.2 K, 20 T</td>
<td>&gt; 400 A/mm$^2$, &gt; 400 A/mm$^2$, &gt; 400 A/mm$^2$</td>
</tr>
<tr>
<td>Current Uniformity</td>
<td>±10%, ±10%, ±10%</td>
</tr>
</tbody>
</table>

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

19 September 2017
Outline

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19 September 2017
220 kV FCL for Moscow City grid

Scope

• First SFCL in Russian Power Grid
• 220 kV – class
• In operation in 2018
• SuperOx manages full project

1. Superconductor manufacturing

2. Engineering and production

3. Onsite construction
3.3 kV DC FCL for railway grid

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

### Specification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</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>
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<tr>
<td>Power consumption</td>
<td>&lt; 6 kW</td>
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<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>

19 September 2017
HTS cable system for Airbus

- Total power: 0...12 MW
- Length: 30...40 m
- Voltage level: 5...5000 V
- Frequency: 0...400 Hz

Current (kA)

In this area, losses in HTS cable are lower than in Al or Cu

19 September 2017
Advanced Superconducting Motor Experimental Demonstrator

Source: Airbus Group Innovations
Punch-and-Coat: perfect degradation/delamination stability

Coat-and-Punch: delamination on cycling occurs

S. Otten et al., SUST 28 (2015) 065014
2G HTS Roebel cables

TapeStar data on individual strand

35 m cable now in Feather 2 coil at CERN

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THANK YOU FOR YOUR ATTENTION

www.superox.ru