High Performance 2G Wire: From R&D to Pilot-scale Manufacturing


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Applied Superconductivity Conference, Chicago, August 17 - 22, 2008
# Other SuperPower Presentations

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<td>Coated Conductor XI - Substrates and Buffers</td>
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<td>Juan Carlos Llambes</td>
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SuperPower’s 2G wire is based on high throughput processes & superior substrate

- High throughput is critical for low cost 2G wire and to minimize capital investment
- SuperPower’s 2G wire is based on high throughput IBAD MgO and MOCVD processes
- Use of IBAD as buffer template provides the choice of any substrate
- Advantages of IBAD are high strength, low ac loss (non-magnetic, high resistive substrates) and high engineering current density (ultra-thin substrates)
SuperPower’s 2G pilot manufacturing facility has been operational since 2006

- Majority of investment already made for 1000 km/year capability
In 2007, 30 m cable was manufactured by Sumitomo Electric with ~10,000 m of SuperPower 2G HTS wire.
2G cable was installed, connected to 1G cable section and fully tested by end of 2007

Installation at Albany Cable site (Aug. 5, 2007)

Joint made between 320 m 1G cable & 30 m 2G cable

Complete 350 m cable tested $I_c = \text{at 2300 A, same as factory test performance of 2G cable section}$

$\text{SUMITOMO ELECTRIC}$
Demonstration of the world’s first device with 2G HTS wire in a live power grid

Cable made with 2G HTS wire was energized in the grid in January 2008 & performed without any issues
Our main objective in 2008 was to meet market requirements for 2G wire

- **Replace 1G wire in large HTS device demonstration projects in the U.S. and around the world**
  - **Key requirements:** Long length, availability, Ic, price

- **Supply large volumes of 2G wire to customers who have been waiting to take advantage of the superior performance of 2G**
  - **Key requirements:** Long length, Ic, additional performance metrics such as in-field Ic, ac losses, joints, insulation, FCL metrics …

- **Advance towards medium-term goal of replacing copper wire in commercial HTS projects and challenge LTS wire in high-field applications**
  - **Key requirements:** Long length, availability, Ic, price, in-field performance and other additional performance metrics
High current metric: Capability of ~ 1000 A in 12 mm widths achieved!

Over 1.2 m length,
Ic = 964 A = 803 A/cm

3.5 μm film made in 10 passes: Ic = 964 A = 803 A/cm (Jc = 2.06 MA/cm²)
2.1 μm film made in 6 passes: Ic = 929 A = 774 A/cm (Jc = 3.68 MA/cm²)

All achievements using production buffer tapes

Ic measurement using continuous dc current (no pulsed current) across entire tape width of 12 mm. No patterning
High current wire processing is repeatable!

- **Over 1 m length,**
  \( I_c = 976 \text{ A} = 813 \text{ A/cm}, \)
  \( 3.33 \mu\text{m}, \ J_c = 2.44 \text{ MA/cm}^2 \)

*End-to-end I-V curve over 1 m*

*\( I_c \) measurement using continuous dc current (no pulsed current) across entire tape width of 12 mm. No patterning*

*All achievements using production buffer tapes*
In-field performance metric: dramatic improvements achieved by Zr doping

BZO additions have been very effective in improving in-field performance of PLD films, but was yet to be demonstrated with MOCVD.

Gd substitution results in strong pinning parallel to the tape.

Zr doping strongly enhances pinning perpendicular to tape & in intermediate fields.

2 to 2.5x improvement in $I_c$ by Zr doping

Data from Y. Zhang, M. Paranthaman, A. Goyal, ORNL
In-field performance enhancement by Zr doping maintained even in 3 micron thick films

Data from Y. Zhang, M. Paranthaman, A. Goyal, ORNL

2 to 2.5 x improvement in $I_c$ by Zr doping

<table>
<thead>
<tr>
<th>$I_c$ (77 K, 1 T)</th>
<th>2008 Zr-doped (Gd,Y)BCO</th>
<th>2007 (Gd,Y)BCO</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>B perp. to tape</td>
<td>229 A/cm</td>
<td>116 A/cm</td>
<td>97%</td>
</tr>
<tr>
<td>Minimum $I_c$</td>
<td>186 A/cm</td>
<td>101 A/cm</td>
<td>85%</td>
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</table>
Excellent in-field performance at 65 K, 3 T

- Title III Phase 3 program goal is $J_e$ without stabilizer of 15,000 A/cm² at 65 K, 3 T
- Minimum $I_c = 267$ A/cm corresponds to $J_e$ of 41,000 A/cm² at 65 K, 3 T
- $I_c$ perpendicular to tape = 340 A/cm corresponds to $J_e$ of 52,300 A/cm²

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<th>Improvement</th>
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</thead>
<tbody>
<tr>
<td>$B \parallel c$</td>
<td>340 A/cm</td>
<td>181 A/cm</td>
<td>88%</td>
</tr>
<tr>
<td>Minimum $I_c$</td>
<td>267 A/cm</td>
<td>160 A/cm</td>
<td>67%</td>
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Data from Y. Zhang, M. Paranthaman, A. Goyal, ORNL
Abundant columnar defects seen in Zr-doped wire

Columnar defects introduced parallel to c-axis by Zr-doping, while maintaining the RE-rich precipitates perpendicular to c-axis, thereby providing excellent pinning over a wide angular range.

TEM by A. Goyal, ORNL
Nano-defect sources for bi-directional pinning

HREM of nanorod

Horizontal (Gd,Y)\(_2\)O\(_3\) nano cluster

Vertical BZO Nanorod

TEM by F. Kametani (TEM) and D. Larbalestier, FSU
Zr-doped chemistry has been successfully transferred from Research system to Pilot MOCVD.

Long-length wires are now being produced with Zr-doped chemistry.

Data from Y. Zhang, M. Paranthaman, A. Goyal, ORNL
In 2007, we demonstrated world record high-field magnet

SuperPower coil tested in NHMFL’s unique, 19-tesla, 20-centimeter wide-bore, 20-megawatt Bitter magnet

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Coil ID</td>
<td>9.5 mm (clear)</td>
</tr>
<tr>
<td>Winding ID</td>
<td>19.1 mm</td>
</tr>
<tr>
<td>Winding OD</td>
<td>~ 87 mm</td>
</tr>
<tr>
<td># of Pancakes</td>
<td>12 (6 x double)</td>
</tr>
<tr>
<td>2G wire used</td>
<td>~ 462 m</td>
</tr>
<tr>
<td>Average Ic of wires in coil</td>
<td>78 A in 4 mm width (77 K, self field)</td>
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SuperPower coil tested by H. Weiiers, D. Markewicz, & D. Larbalestier, NHMFL, FSU