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2G HTS Wire Development at SuperPower

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2G HTS wire production at SuperPower

**IBAD-MOCVD based REBCO wire on Hastelloy substrate**

- **REBCO formulation:**
  - **AP** (Advanced Pinning) – with enhanced in-field performance for B//c, targeting at coil applications such as high-field magnets, SMES, motors/generators
  - **CF** (Cable Formulation) – for cables, transformers, FCL

- **$I_c(77\text{K}, \text{s.f.})/12\text{mm} = 400-600\text{A}$**, **piece length = up to 500m.**
- Variations in width (2-12mm), substrate thickness (30, 50 or 100μm), Ag thickness (1-5μm), Cu thickness (10-115μm), and insulation
- Bonding conductors: 2x2mm, 2x4mm, 2x12mm (face to face / back to back)
- Product lineup is expanding
Demanding applications and conductor requirements

- Our wires are being utilized for device/equipment development for many applications, including high-field magnets, accelerator magnets, fusion magnets, SMES, motors/generators, Maglev, medical applications, SFCL, etc.

- Conductor requirements
  - High $I_c(B,T,\theta)$ performance
  - Uniformity along length/across width
  - Robustness
  - Long piece length
  - Thinner substrate, Thicker substrate
  - Lower ac losses

- Continuous development and improvement driven by customers
  - Innovative conductor design
  - Processing optimization and control
  - In-line inspections
  - Property and quality measurements

- Higher performance + higher yield $\rightarrow$ lower cost/price
Conductor development areas

• Manufacturing improvements are a current focus area
  – Longer uniform piece lengths
  – Run-to-run repeatability
  – Tightening process windows
  – Improving process hardware

• Enhancing understanding of pinning optimization for operating conditions (4K/high field, 20-50K/2-5 T, 65K, lower fields)
  – Artificial pinning centers (BZO, others)
  – Process control

• Maximizing Je
  – Thinner substrates
  – Thicker films
Ic performance of Enhanced A.P wire at 77K/s.f

- Magnetic, non-contact measurement
- High special resolution, high speed, reel-to-reel
- Monitoring $I_c$ at multiple production points after MOCVD
- Capable of quantitative 2D uniformity inspection
Ic performance of Enhanced A.P wire at 77K/s.f

- Transport measurement by every 5m, with 40µm copper.
- Extend the piece length up to 500m

![Graph showing Ic performance at 500m/4mmW with a 1 µV/cm noise level.](image-url)
Performance of Enhanced A.P wire (7.5% Zr)

- Enhanced A.P wire shows high in-field performance

$\text{I}_c = 190.9 \text{A at 77K}$

Measured by Tohoku university
IcBT typical data – enhanced AP

M4-292-9S 2mm

-30 -10 10 30 50 70 90 110

0 100 200 300 400 500 600

Ic [A]

Angle [deg]

- 77K/1.5T
- 65K/1.5T
- 50K/1.5T
- 40K/1.5T
- 30K/1.5T
- 20K/1.5T
Electromechanical property - $I_c$ under tension at 77K

- **Enhanced A.P**
- $I_c/I_c(0)=0.95$
- SCS12050 with 40μm copper
Development progress of 30µm substrate

- Base performance of 30µm substrates are comparable to 50µm.
Electropolishing parameters of 30 µm Hastelloy C276 substrate developed

AFM 5 x 5 um scan obtained from 30 um thick electropolished Hastelloy C-276.
Buffer stack deposition parameters of 30 µm tapes developed

(a) In-plane texture and (b) (110) pole figure of LMO buffered IBAD MgO template on 30 um substrate.
MOCVD deposition parameters for 30 µm tapes established

(103) Pole figure of REBCO film with 7.5% Zr deposited on IBAD MgO template on 30 µm substrate.
Improved $J_e$ demonstrated with 30 $\mu$m tapes

Engineering current density at 4.2 K vs. applied field for 30 um and 50 um ReBCO tapes with 7.5% Zr

Measured at NHMFL
**CORC® wires using SuperPower tapes**

16 superpower tapes wound helically
- Copper core: 2.2 mm diameter
- 2 mm wide tapes with 30 µm substrate
- 6 mm twist pitch with partially transposed tapes for low AC loss
- Wire outer diameter: 3 mm
- Terminal diameter: 6.35 mm
- Nominal wire $I_c$: > 1,000 A (77 K)

**Applications**
- High field magnets
- Accelerator magnets
- Fusion magnets
- High power density transmission

High magnetic field critical current density obtainable by increasing wire diameter and decreasing substrate thickness

Value desired for accelerator magnets such as CCT dipoles
Value desired for high-field research magnets
Bonding line developed for clad conductors

<table>
<thead>
<tr>
<th>Feed Reel</th>
<th>Stand</th>
<th>Superconductor</th>
<th>Laminate</th>
<th>Main controller</th>
<th>Tension and heater</th>
<th>Pre-Clean</th>
<th>Pre-heat, Bond, edge &amp; cool</th>
<th>Hot wire deburr</th>
<th>Post clean</th>
<th>Quality: X-ray for voids</th>
<th>Laser check for burrs</th>
<th>voids, dimensions</th>
<th>Drive system</th>
<th>Take up reel stand</th>
</tr>
</thead>
</table>

Each component of the line has been developed, tested, validated and run production quantities of product.

6 layers of “PPLP” insulation

1 mm x 14 mm C715 CuNi substrate

Solder interface layer

Modified SF12050 conductor - Ag alloy vs. Ag w/ bonding interface layer on back of conductor
Prototype HV windings fabricated

- Winding AC loss / FCL test coil
- Scaled version of HV coil module-using transformer winding technique
FCL functionality confirmed

FCL transformer module testing at CAPS(FSU)

Red trace is calculated prospective current, based on empirical device impedance before current limiting effect
Alternative bonded conductors under evaluation

- Bonding conductor: Face to Face, 2 x 4mm, total thickness ~200μm
- No degradation after 10 times thermal cycles
Low heat leak 2G HTS tapes available for current lead application

- 2G HTS offers low heat leak options for current lead applications
- Standard 2G HTS tapes offer better performance than 1G HTS based leads
- Alloyed Ag w/ 2G HTS leads offers best low heat leak option
Summary

• Focus on processing to improve uniformity, repeatability, piece lengths and yield.
• Maximize current capacity while developing next generation equipment
  – When is the time to pull the trigger?
• Enhance performance parameters for developing operating spaces
  – Thinner substrates
  – Thicker films
  – Optimized pinning
• Continue to improve mechanical properties
  – Delamination mitigation
  – $I_c (\varepsilon)$
Thank you for your attention

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