Progress in SuNAM’s Coated Conductor Manufacturing

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SuNAM’s coated conductor; architecture, characteristic, process, quality control

Thicker S.C. layer; 1.6 μm, I_c>800 A/cm

Substrate removal (exfoliation) to enhance J_e

18 T magnet for Axion detection

Summary
Typical $I_c \sim > 700A/12\text{mmW}$ at 77K Self-field ($J_c \sim > 5 \text{ MA/cm}^2$)
**Production Facilities**

- Site area: 5,500 m$^2$
- Building area: 1,750 m$^2$
- Gross floor area: 3,050 m$^2$
- Class < 10,000 clean room area: 1,000 m$^2$
- Production capacity ~ 60 km/month (4 mm width) considering the yield (~70%)
SuNAM RCE-DR process

- **RCE-DR**: Reactive Co-Evaporation by Deposition & Reaction (SuNAM, R2R): Patented
- High rate co-evaporation at low temperature & pressure to the target thickness (> 1 μm) at once in deposition zone (6 ~ 10nm/s)
- Fast (<< 30 sec.) conversion from amorphous glassy phase to superconducting phase at high temperature and oxygen pressure in reaction zone
- Simple, higher deposition rate & area, low system cost
- Easy to scale up: single path
Growth mechanism of the GdBCO film by RCE-DR

- Very low $PO_2$ zone ($\sim 10^{-5}$ Torr): **Amorphous Film**
- Lower $PO_2$ zone ($\sim 30$ mTorr): $Gd_2O_3$ + Liquid ($< 5$ sec)
- Higher $PO_2$ zone ($\sim 100$ mTorr): GdBCO Film ($< 20$ sec)

GdBCO growth mechanism: a seeded melt-textured growth!!!
Quality Control: RHEED Vision System

- An appropriate feedback algorithm can keep the shape of the RHEED spot in the specific range, while QCM monitoring to adjust the e-gun power.
Feedback route based on RHEED spot analysis

- Because of different evolution of $\Delta \phi$ & $\Delta \omega$, optimization is very important for high quality 2G wire.
- Intensity & tilt angle of MgO (110) spot is one of the most important parameter.
Quality Control: RCE Vision Inspection System

Based on color dependence of composition DB, optimum composition level is automatically controlled by PC. (Slow feedback)
RCE Vision System will be introduced for increasing the uniformity of composition in RCE-DR process. The control computer takes (RGB) values in three-dimensional vector space which is transformed from the color of the tape surface.
HTS 2G wire performances (daily production)

<table>
<thead>
<tr>
<th>Length (m)</th>
<th>Ic</th>
<th>Ic,max</th>
<th>Ic,min</th>
<th>1 sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>739</td>
<td>820</td>
<td>857</td>
<td>761</td>
<td>1.7</td>
</tr>
<tr>
<td>743</td>
<td>803</td>
<td>840</td>
<td>651</td>
<td>1.8</td>
</tr>
<tr>
<td>682</td>
<td>801</td>
<td>865</td>
<td>615</td>
<td>3.4</td>
</tr>
<tr>
<td>718</td>
<td>800</td>
<td>869</td>
<td>707</td>
<td>3.6</td>
</tr>
<tr>
<td>710</td>
<td>804</td>
<td>859</td>
<td>716</td>
<td>2.5</td>
</tr>
</tbody>
</table>

( ~ 6 hrs deposition time (120 m/hr))
# SuNAM’s 2G HTS Wire

## [ Specification Table ]

<table>
<thead>
<tr>
<th>Model</th>
<th>AN</th>
<th>CN</th>
<th>LB/LS/LC</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Silver(+Cu…) Dry coating</td>
<td>Copper Wet Coating</td>
<td>Brass/STS/Copper Lamination</td>
<td>Polyimide tape(+) Insulation</td>
</tr>
<tr>
<td>Special offer STS metal cladding / Tin coating / Single side lamination</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substrate</td>
<td>Hastelloy C-276 or Non-magnetic Stainless Steel STS310S</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width [ mm ]</td>
<td>Commercial: 4 mm, 12 mm. Special Order: 2 ~ 10 mm multi width is available</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness [ mm ]</td>
<td>HAS: 0.06<del>0.07 STS: 0.11</del>0.12</td>
<td>HAS: 0.09<del>0.11 STS: 0.14</del>0.16</td>
<td>Customized</td>
<td>+ 0.1</td>
</tr>
<tr>
<td>Final Process</td>
<td>Sputtering</td>
<td>Electro Plating</td>
<td>Lamination</td>
<td>Wrapping</td>
</tr>
<tr>
<td>Piece Length</td>
<td>Above 100 m, 200 m, 300 m + without Splice</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. Ic @ 77 K S.F.</td>
<td>&gt; 150 / 200 / 250 A + @ 4 mm</td>
<td>&gt; 500 / 600 / 700 / 800 A + @ 12 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**SuNAM’s 2G HTS Wire**

**Stabilizer [Cu, Brass, STS]**

**Non-magnetic substrate**

**1μm GdBCO-HTS(esitaxial)**

**LMO(esitaxial)**

**MgO(esitaxial)**

**IBAD / MgO**

**Y₂O₃**

**Al₂O₃**
I<sub>C</sub> enhancement by thicker SC layer

- It is needed to increase layer thickness without compromising high J<sub>C</sub>

- We ‘squeezed’ 2 more turns into the same deposition area, while keeping evaporation rates of metal sources roughly the same.

- Achieved 800 A/cm in 1.6 μm film; plan to reach 1,000 A/cm with 2 μm film by the end of the year
$I_C$ enhancement by thicker SC layer

@ 77 K, self-field

1,050A/12mm-w

(→ 875A/cm-w)

1.6 μm-thick
5.5 MA/cm$^2$

$\mu$m-thick SC layer

$IC$ enhancement by thicker SC layer

500 nm

0.5 μm

500 nm

STS

Pt

Amorphous film

0.5 μm

1.6 μm

@ 77 K, self-field
Effort to enhance $J_e$ by removing substrate

- Thinner substrate $\rightarrow$ higher $J_e$, but cause problem in multi-turn system
- Remove substrate $\rightarrow$ thin laminated metal acts as a substrate

![Substrate remove machine]
Effort to enhance $J_c$ by removing substrate

- $I_c$ only slightly degraded
- Very good crystallinity
- Mechanical strength to be verified with STS lamination
26.4 T all 2G wire one-body(non-nested) magnet

No-insulation, multi-width, and compact!

- Multi-width Double Pancake Coils
- Stacked Double Pancake Coils
- Fully assembled

- Immersed in liquid Helium

- Designed by Dr. S. Hahn
Another all HTS magnet system by SuNAM

✓ Delivered to Center for Axion and Precision Physics Research, IBS(Institute for Basic Science) in Korea; Aug. 2017.

✓ 18.7 T at 4.2 K, 70 mm clear bore.

✓ Compared to 26 T magnet twice larger I.D.(2.1X), slightly smaller O.D.(0.9X), ~1.5 times taller, roughly the same stored energy about 20% more tape used

✓ LHe boil rate < 2 liters/hr
Ramp rate: 0.02 A/s (under 180 A), 0.01 A/s (Over 180 A)
SuNAM has been producing high $I_c$ coated conductors consistently

- With thicker S.C. layer, we achieved $>800$ A/cm

- Substrate removal (exfoliation) tried to enhance $J_e$

- We delivered 18 T all-HTS magnet for physical science
Thanks for Attention!

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