Effects of Element Addition into Cu matrix for IT-Processed Nb$_3$Sn Wires

Nobuya Banno (NIMS),
Y. Miyamoto (Tokai Univ.), Z. Yu (SWJTU, NIMS),
T. Morita (Sophia Univ., NIMS), T. Yagai (Sophia Univ.),
S. Nimori (NIMS), K. Tachikawa (NIMS, Tokai Univ.)
Background

\( J_c \) characteristics of \( \text{Nb}_3\text{Sn} \) : fully optimized?


Potential

Grain morphology?


Compositional gradient (Stoichiometry of \( \text{Nb}_3\text{Sn} \) layer)?


Motivation and objectives

Improvement of stoichiometry of Nb₃Sn layer with a different approach

Internal tin process

New approach: Element X addition

Variety of diffusion reaction

Zn addition: attractive in terms of growth kinetics

Thicker Nb₃Sn layer, smaller residual Sn content

$J_c$ comparison of laboratory-scale samples

![Graph showing $J_c$ vs. Magnetic field (T) for Cu-15wt%Zn matrix and Cu matrix.](image-url)

- **Cu-15wt%Zn matrix**: Higher $J_c$ values are observed compared to Cu matrix.
- **Cu matrix**: Shows lower $J_c$ values across the magnetic field range.

**Notes**:
- **4.2 K**: Temperature at which $J_c$ measurements were conducted.
- **EPMA**: Electron probe microanalysis used for elemental distribution analysis.
Motivation and objectives

Improvement of Nb$_3$Sn layer stoichiometry with a different new approach

Internal tin process

New approach: Element X addition

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Thicker Nb$_3$Sn layer, smaller residual Sn content


*This work: Ge, Ga, Mg and simultaneous addition of Zn and Ge*
Laboratory-scale wires

Single Stack (SS) type
- Cu-5wt%Ge
- Cu-10wt%Ga
- Cu-1wt%Mg
- Gold brass (GB) (Cu-15wt%Zn)
- Cu

Multifilamentary (MF684) type
- Cu-14wt%Zn-5wt%Ge
- Gold brass (GB) (Cu-15wt%Zn)

<table>
<thead>
<tr>
<th>Sample name</th>
<th>SS-5Ge</th>
<th>SS-10Ga</th>
<th>SS-1Mg</th>
<th>MF684-14Zn1Ge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire diameter (mm)</td>
<td>0.6</td>
<td>0.81</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Matrix material</td>
<td>Cu-5wt%Ge</td>
<td>Cu-10wt%Ga</td>
<td>Cu-1wt%Mg</td>
<td>Cu-14wt%Zn-1wt%Ge</td>
</tr>
<tr>
<td>No. of Nb filaments</td>
<td>37</td>
<td>37</td>
<td>37</td>
<td>684 (=19×36)</td>
</tr>
<tr>
<td>Filament diameter (µm)</td>
<td>31.9</td>
<td>43.2</td>
<td>31.9</td>
<td>8.18</td>
</tr>
<tr>
<td>Area fraction in filament region (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matrix</td>
<td>55.6</td>
<td>55.6</td>
<td>55.6</td>
<td></td>
</tr>
<tr>
<td>Nb cores</td>
<td>29.9</td>
<td>29.9</td>
<td>29.9</td>
<td>43.2</td>
</tr>
<tr>
<td>Sn-1.6wt%Ti cores</td>
<td>14.5</td>
<td>14.5</td>
<td>14.5</td>
<td>20.5</td>
</tr>
</tbody>
</table>
5Ge addition

- Sn diffusion rate, Nb$_3$Sn layer growth rate: very slow
- Ge-rich layer: at the outer boundary of Nb$_3$Sn
10Ga addition

EDX Ga & Sn map

- Interesting reaction behavior: Ga diffuse into Nb₃Sn at 650 °C
  pushed out at 700 °C and form Ga-rich layer inside
- On-set $T_c$: improved
1Mg addition

- Grain morphology: finer
  Columnar-like near Nb core
- Layer thickness: a little smaller
- Mg-Sn compound: present in the matrix
$J_c$ for Ge, Ga, Mg addition

Matrix $J_c (A/mm^2)$ vs. Magnetic field (T)

- SS-1Mg-0.6Φ (700°Cx200h)
- SS-Cu-0.6Φ (700°Cx200h)
- SS-5Ge-0.6Φ (750°Cx100h)
- SS-10Ga-0.81Φ (750°Cx100h)
- SS-GB-0.8Φ (700°Cx200h)

4.2 K
14Zn-1Ge addition

EPMA map : 750 °C x 50 h

- Ge-rich layer : No. Ge diffuse across the Nb core.
- Growth rate : good due to Zn addition
- Grain coarsening : suppressed even at 750 °C x 50 h

G. size: 258 nm
G. size: 265 nm
$J_c$ for 14Zn-1Ge addition

Matrix $J_c$ (A/mm$^2$) vs. Magnetic field (T) at 4.2 K

- MF684
- Cu-14Zn-1Ge (750°C x 50 h)
- Cu-15Zn (700°C x 100 h)
## Conclusion

<table>
<thead>
<tr>
<th><strong>Addition</strong></th>
<th><strong>Effect</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Zn</strong></td>
<td>best in terms of growth kinetics.</td>
</tr>
<tr>
<td><strong>Ge</strong></td>
<td>results in the formation of Ge-rich layer, suppression of Nb$_3$Sn grain coarsening</td>
</tr>
<tr>
<td><strong>Ga</strong></td>
<td>easily diffuse into Nb$<em>3$Sn layer. $\rightarrow$ Increase of $T_c$ and $B</em>{c2}$</td>
</tr>
<tr>
<td><strong>Mg</strong></td>
<td>brings about refinement of grain morphology</td>
</tr>
<tr>
<td><strong>Zn + Ge</strong> (a small amount)</td>
<td>Ge-rich layer was not found, a small amount of Ge diffuse into Nb$_3$Sn layer. $J_c$ characteristics of 14Zn+1Ge increased slightly in high fields.</td>
</tr>
</tbody>
</table>

*J*$_c$ characteristics of SS-1Mg : comparable to SS-Cu or relatively good. $\leftrightarrow$ fine grain morphology