Bi-based high-$T_c$ oxide and MgB$_2$ tapes and wires promising for CO$_2$ emissions reduction

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Outline

1. MgB$_2$ wires (ALCA project)
2. BSCCO (Bi-2223 and Bi-2212) tapes and wires
3. Summary
$B_{c2}$ of PIT processed MgB$_2$ wire

High quality MgB$_2$ single crystal

$H_{c2}(T)$ vs $T$ (K)

- 10%-SiC-doped MgB$_2$ wire
- $H//c$-axis (MgB$_2$ thin film)
- $H//a$-$b$ plane (MgB$_2$ thin film)
- Nb$_3$Sn
- MgB$_2$ wire w/o SiC doping


Nb-Ti wire (4.2K operation)
MgB$_2$ wire (20K operation with LH$_2$ or cryocooler)
Fabrication of MgB$_2$ wire and tape
Powder-In-Tube (PIT) method

Mg+B+(SiC) powder → drawing → Metal tube → Multi-filament wire → Multi-filament tape → Heat treatment

No grain orientation is required!

Examples of MgB$_2$ wires and tapes
Typical $J_c$-$B$ curves of PIT processed MgB$_2$ tape

![Graph showing typical $J_c$-$B$ curves for PIT processed MgB$_2$ tape.](image)

- **MgB$_2$/α-Al$_2$O$_3$ thin film (PLD method)**
- **tape(PIT)**
- **Nb$_3$Sn**

The density of MgB$_2$: ~50%

Shrinkage of volume during heat treatment:

$$
\text{Mg} + \text{B} \rightarrow \text{MgB}_2
$$

- **B**: 2.34 g/cm$^3$
- **Mg**: 1.7
- **MgB$_2$**: 2.6

One big problem of PIT is the low packing density (large porosity) of MgB$_2$ core.
Comparison of IMD and PIT

Internal Mg diffusion (IMD) process
- Metal Tube
- Mg rod
- B Powder

Packing density: ~80%

PIT process
- Metal Tube
- Mg+B Powder

Packing density: ~50%
Internal Mg Diffusion (IMD) Process

- PIT method
  - B+Mg(+SiC) powder

- Mg diffusion method
  - B(+SiC) powder
  - Diffusion
  - Mg

Mono core wire

Cu-Ni, Ta, B+SiC, Mg

200µm

7-filament wire

19-filament wire

Heat treatment

Pure Mg Rod (φ2.0mm)
Fe, Ta, Nb Tube
Outer diameter: 6mm
Inner diameter: 4mm

B Powder (+nano SiC)
5mol%SiC
10mol%SiC

Groove Rolling

Short Sample
Longitudinal cross sections of IMD processed MgB$_2$ wires (uniformity in longitudinal direction)
$J_c$ and $J_e$ comparisons of IMD and PIT processed wires

Critical current density $J_c$ (A/cm$^2$) vs. Magnetic field $H$(T)

Engineering $J(J_e)$ A/cm$^2$ vs. Magnetic field $H$(T)
The diffusion distance by Mg liquid infiltration is limited to <50μm!

The reduction of filament size is essential to complete the reaction with short heat treatment time!
Local $I_c$ distribution of SiC added IMD wire
(Analysis by scanning hole probe microscope)

$J_c$ (A/cm$^2$) @10 K, 0 T

Measured magnetic field $B_z$ (mT)

$Lift-off: 200 \mu m$

$J = 1$ MA/cm$^2$ per $B_{peak} = 80$ mT

Locally low property $\Leftarrow$ Localized Mg$_2$Si

LT-SHPM, Kiss Lab. Kyushu Univ.
Comparison of $J_c$ values obtained by the resistive method and SHPM

About 3 times higher $J_c$ is expected by the improvement of the homogeneity.

Comparison of $C_{24}H_{12}$ and SiC addition (IMD processed MgB$_2$ wires)

**Coronene ($C_{24}H_{12}$)**

Decomposition temperature: ~600°C

**TEM image**

![TEM image](image-url)
Present status of MgB$_2$ wires
Stress effect of PIT and IMD mono-filamentary MgB$_2$ wires (at 10 T, 4.2 K)

**Table:**

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_{\text{irr}}$</th>
<th>$d(I_c/I_{c0})/d\varepsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMD</td>
<td>0.67%</td>
<td>0.143</td>
</tr>
<tr>
<td>PIT</td>
<td>0.54%</td>
<td>0.213</td>
</tr>
</tbody>
</table>

**Graph:**

- **IMD-MgB$_2$ wire shows larger $\varepsilon_{\text{irr}}$ and smaller strain sensitivity**

- Voids at the center of IMD wires seem to have no negative effect on strain sensitivity of $J_c$. 
Superconducting joint of IMD processed \( \text{MgB}_2 \) wire

- Fe sheath
- B layer
- \( \text{C}_{24}\text{H}_{12} \) added \( \text{MgB}_2 \) wire
- Mg core
- Pressing (one end)

Examples of joints

Pressing

Heat treatment (under the same condition as the wire)

Metal tube

Fe or SS tube
$I_c$-$B$ curves of superconducting joints (IMD MgB$_2$ wire)

Critical current $I_c$ (A) vs. Magnetic field $B$ (T)

- Fe tube
- S.S. tube
- Wire

4.2K
Crystal structure of Bi-based oxide superconductors

$\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ (Bi-2212)

$\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10+\delta}$ (Bi-2223)

$T_c \sim 90K$

$T_c \sim 110K$

$\text{Bi-2212 (n = 1)}$

$\text{Bi-2223 (n = 2)}$
Bi-based oxide wire and tape fabrication by a powder-in-tube (PIT) method

Calcination

Powder Bi$_2$O$_3$, SrCO$_3$, CaCO$_3$, CuO

Metal tube (Ag)

drawing

Multi-filamentary wire

Heat treatment

Multi-filamentary tape

Grain orientation of Bi-oxide is essential to obtain large current transfer.

結晶粒の配向化が必須
Microstructure of Bi-2212 tape

Heat treatment schedule of Bi-2212 tape

C-axis grain orientation is obtained by the Slow cooling from partially melting state.
### Examples of Bi-2212 wires

**Bi-2212 wire configurations for different operating current demands**

<table>
<thead>
<tr>
<th>Wire configuration (filament number in sub x number of sub bundle)</th>
<th>Fill factor (%)</th>
<th>Optimized wire diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 x 36</td>
<td>24.0</td>
<td>0.8</td>
</tr>
<tr>
<td>37 x 18</td>
<td>24.8</td>
<td>0.8</td>
</tr>
<tr>
<td>55x18</td>
<td>24.9</td>
<td>1</td>
</tr>
<tr>
<td>85 x 18</td>
<td>25.2</td>
<td>1.2</td>
</tr>
<tr>
<td>121 x 18</td>
<td>25.4</td>
<td>1.5</td>
</tr>
</tbody>
</table>

- Various wire configurations to fit different application requirements- cable (0.8-1.0 mm) and insert coil (1.0-1.5 mm)
Core densification by over pressure HT

Over Pressure Heat Treatment (10 bar HT by ASC/FSU)

- Highly reproducible Bi-2212 wires with good $J_e$ performance
- Maximum length of Bi-2212 wire: ~1000m
Fabrication of Bi-2223 tapes by Powder-In-Tube (PIT) method

Formation of Bi-2223 phase
Bi-2212 + Ca₂PbO₄ + Ca₂CuO₃ + ? → Bi-2223

Cross section of typical Bi-2223 tape

Centre | Edge

Multi-filamentary wire
Multi-filamentary tape
Heat treatment
C-axis grain oriented microstructure of Bi-based superconducting tapes

Bi-2212 tape
Grain orientation by the slow solidification from melting state.

Bi-2223 tape:
Grain orientation is obtained by the combination of cold rolling and heat treatment. (Y. Yamada, et al.)
Recent progress of Bi-2223/Ag tape conductors

Cross section of typical Bi-2223 tape (4.2mm$^w$x0.22mm$^t$)

$J_e \sim 20,000$A/cm$^2$
(77K, self-field)
(4.2mm$^w$x0.22mm$^t$)

km-class Bi2223/Ag tape