Fabrication of grain aligned Bi2223 thick films with high critical current properties

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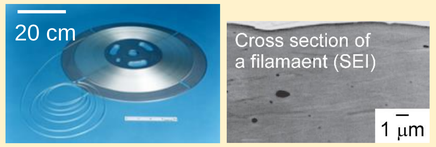
Introduction

Ag-sheathed Bi2223 tapes

- Sintered by CT-OP method (ConTrolled-Over-Pressure)
- Dense & *c*-axis oriented
- Used for practical applications
- **J_c ~6×10^4 A cm^{-2}** @77 K



Sumitomo Electric Industries, Ltd.

Single crystal film: J_c ~3×10^6 A cm^{-2} @77 K Y. Hakuraku *et al., J. Appl. Phys.* (1993).

J_c is mainly limited by weak grain coupling.
- Short coherence length
- Large anisotropy
- Porous microstructure

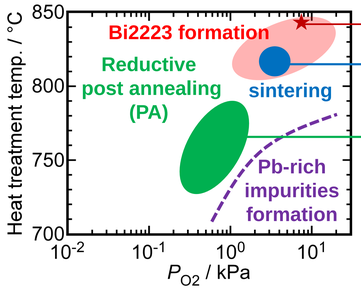
To improve grain coupling of polycrystalline materials

✓ **c-axis oriented microstructure as filaments in the tapes**

- **Prepared by mechanical pressing or rolling**
- **Well aligned Bi2223 grains near the Ag surface** L. Zhang *et al., Physica C* (2000).

➡ **Grain aligned microstructure can be easily formed in Bi2223/Ag thick films by pressing & sintering**

✓ **Heat-treatment under low P_{O2}**



Fabrication of the tapes (~100 h)
Large grain size

Fast phase formation (<10 h)
→ Forming fine grains

Controlling nonstoichiometric cation compositions [(Bi,Pb): Sr: Ca: Cu ~2: 2: 2: 3]
→ Increase in condensation energy
→ Improving Superconducting properties

Y. Takeda *et al., Physica C* (2017).

✓ **Carrier over doping state by oxygen annealing at low temp.**

Motivation and Strategy

Fabrication of Bi2223 thick films with high critical current properties ➡ **Establishment of guiding principles for higher J_c**

✓ **Optimization of fabricating conditions**
- Heat treatment conditions
- Constituent phases of precursor powders

✓ **Increase in film thickness for higher I_c properties**

Experimental

Bi2223 calcined powder (Main phase: Bi2212)
- Pelletizing & sintering (820°C, 12 h, P_{O2} = 3 kPa)
- Grinding

Sintered powder (Main phase: Bi2223)

***$w_{(A)}$: Mass of *A* powder**

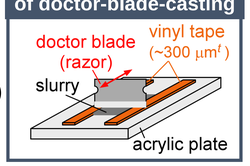
- Mixing $w_{(calcined)} : w_{(sintered)} = X : 1 - X$ (X = 0 - 1)
- Ball milling (~50 h)

Reagents for preparing slurry
- Solvent: EtOH/BuOH
- Dispersant: Polyethylenimine
- Binder: Polyvinyl butyral
- Plasticizer: dibutyl phthalate

Slurry (Bi2212・Bi2223 powder)
- Doctor-blade-casting
- Cutting & calcination in air (500°C)

Green tape on Ag foil
- Ar annealing (600°C, 12 h)
- Sealed in Ag foil
- Pressing (~1 GPa) & sintering (P_{O2} = 3 kPa)

Schematic illustration of doctor-blade-casting



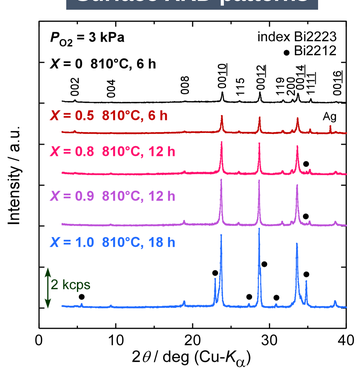
Bi2223 thick film
- Reductive post annealing **[PA]**
- Oxygen annealing **[OA]**

Characterization (XRD, FE-SEM, SQUID, ρ-T measurement)
- $J_{c\ (intergrain)}$ was examined by remanent magnetization measurements.
- Magnetic fields were applied vertical to the film surface.

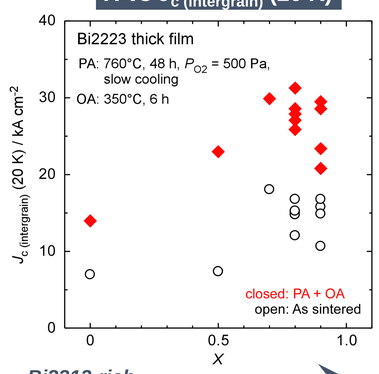
Results & Discussion

Optimization of fabricating conditions

Surface XRD patterns

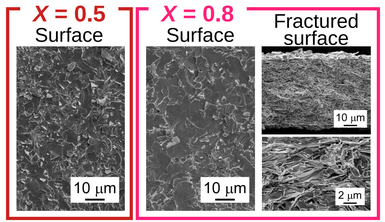


X vs $J_{c\ (intergrain)}$ (20 K)



Bi2212-rich precursor powders ➡

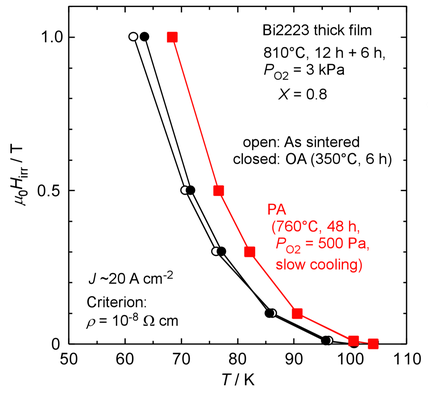
SEI (810°C, 12 h + 6 h)



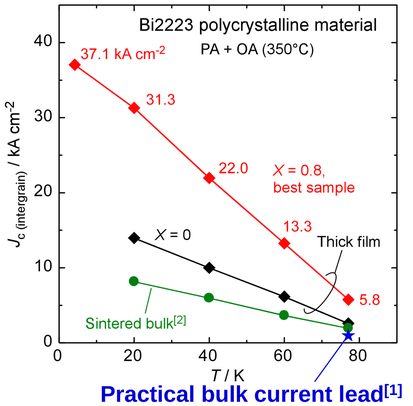
Employing Bi2212-rich precursor powders [Larger *X*]
- ***c*-axis oriented microstructure**
- **Higher intergrain-J_c**

➡ **High quality films**

Temp. dependence of $\mu_0 H_{irr}$



Temp. dependence of $J_{c\ (intergrain)}$



Practical bulk current lead[1]

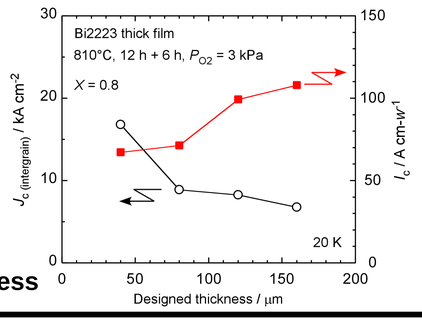
[1] M. Ishizuka *et al., Physica C* (2006). [2] Y. Takeda *et al., Physica C* (2017).

- **Annealing process largely improved superconducting properties.**
- **The sample with X = 0.8 showed the highest J_c ~5.8 kA cm^{-2} @77 K. (Highly grain aligned & strong grain coupling)**

Increase in film thickness

Intergrain-J_c declined with an increase in thickness, while estimated I_c was enhanced to ~100 A cm-w^{-1} @20 K.

Thickness dependence of J_c & I_c



Further improvement in I_c is expected by additional annealing process.

***I_c = $J_{c\ (intergrain)}$ × Designed thickness**

Conclusions

Attempts to fabricate high quality Bi2223 thick films

- **Bi2223 single phase & *c*-axis oriented microstructure**
- **High quality films with Bi2212-rich slurry**
- **Intergrain-J_c ~5.8 kA cm^{-2} @77 K (the best sample)**
- **Higher I_c observed in thicker films**

➡ **Thick film materials could be applicable for current leads or magnetic shielding**

Future Plans

- **Densification by sintering under high gas pressure**
- **More precise control of cation compositions**

➡ **Strong grain coupling & J_c >10^4 A cm^{-2} @ 77 K**