Critical Current Properties of Precisely Cation Composition Controlled RE123 Melt-Solidified Bulks

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Background

Generic Concept of Cuprate Superconductors with High J_c

Strong pinning centers with moderate density in **strong superconducting matrix = large condensation energy**

numerous studies for introduction of pinning sites to improve J_c-B characteristics and H_{irr}

- atomic defects
- twins
- dislocations
- fine non-superconducting precipitates
- locally weak superconducting regions by element substitutions or nonstoichiometric cation composition
- irradiation damages

numerous studies for improving grain alignment

J_c (77 K, s.f.)

c-axis alignment --- < 10^5 Acm^{-2}

bi-axial alignment --- > 10^6 Acm^{-2}

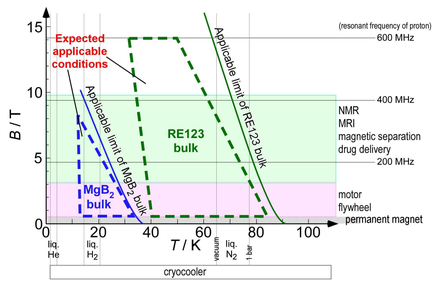
decreasing anisotropy

improving conductivity at blocking layer by carrier overdoping and/or cation substitutions

Few studies on precise control of nonstoichiometric cation compositions (unintentional)

Very low level site exchange between cations in whole materials are desirable.

Expected Application for Superconducting Bulks

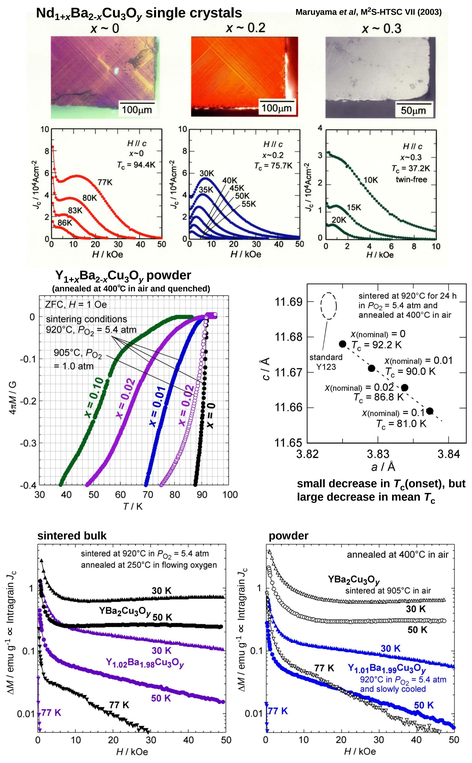


Ideal characteristics of superconducting bulks
- High $J_c(B)$
- High homogeneity
- High mechanical strength

High $J_c(B)$ characteristics for melt-solidified RE123 bulks ;
- High crystallinity with moderately dispersed fine RE211 precipitates
- RE123 matrix with precisely controlled cation and oxygen compositions

RE substitution for Ba → excess oxygen at CuO chain
→ local lattice deformation & ineffective carrier doping
→ Effective pinning site (low level substitution)
while poor superconductivity (high level substitution > 0.5% for Ba-site)

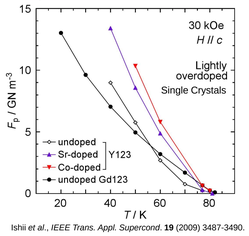
Serious Degradation of Superconducting Properties by RE Substitution for Ba in RE123 Materials



Substituted Y ions at Ba-site kill superconductivity around them. J_c is strongly influenced by cation composition even for samples with very low RE substitution levels less than 1% for Ba.

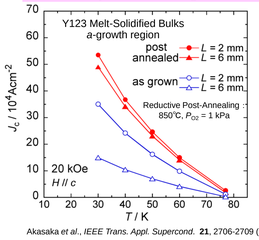
Hint, Motivation, Strategy

F_p at low temp : Y123 > Gd123



Ishii et al., IEEE Trans. Appl. Supercond. 19 (2009) 3487-3490.

Reductive post-annealing for Y123



Akasaka et al., IEEE Trans. Appl. Supercond. 21, 2706-2709 (2011)

Control of oxygen content is relatively easy.
Establishment of effective methods to control RE substitution level for Ba within 0.5% is essential to develop high performance RE123 bulk materials.

Our strategies

- RE mixing
- starting from Ba-rich compositions

To understand the effect of cation composition, high energy electron irradiation (35 MeV) effect on flux pinning properties were studied.

Experimental

Synthesis procedures of RE123 melt-solidified bulks

RE-mixed RE123

RE'123 : RE"211 = 7 : 3

Ba-rich Gd123

Gd : Ba : Cu = 1.3 : 3.4+2x : 4.8
Gd123 : Gd211 ~ 7 : 3

Pressed into pellets

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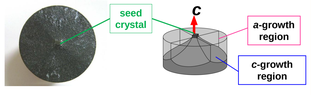
Melt-solidification (in air, cold-seeding using Nd123 single crystal)



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Post annealing

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Electron irradiation (35 MeV)

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Characterization

Superconducting properties : SQUID magnetometer (QD- MPMS)
Phases, Lattice constants : Powder X-ray diffraction
Microstructure, Local composition : SEM-EDX, EPMA

Definition of orthorhombicity of RE123 crystal

$$\gamma_O = \frac{1000(b-a)}{b+a}$$

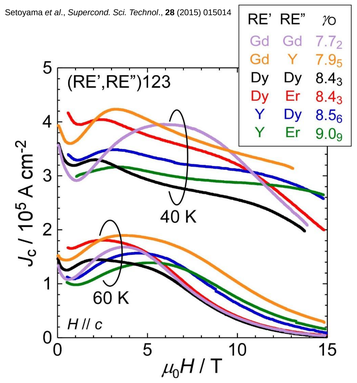
a, b : a, b-axis length [Å] ($b > a$)

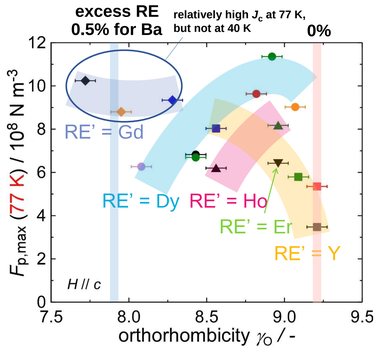
large γ_O = low RE substitution level for Ba

Results and Discussions

RE-mixed RE123 bulks

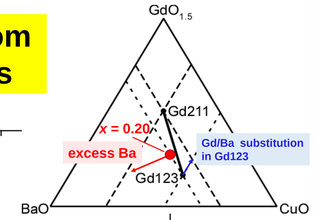
Setoyama et al., Supercond. Sci. Technol., 28 (2015) 015014



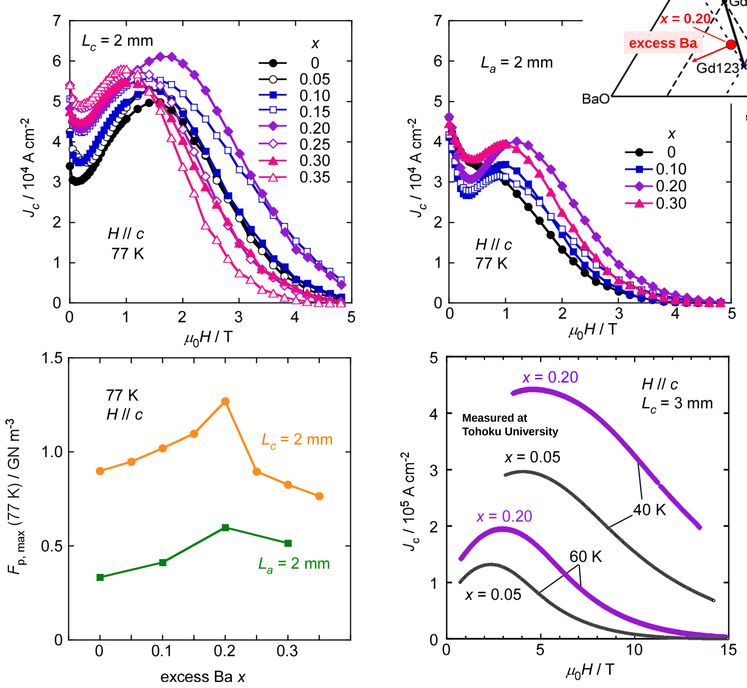


To achieve high J_c at ~ 40 K up to high field, RE-mixing using RE'123 with small RE' ions is recommended.

Gd123 bulks grown from Ba-rich compositions



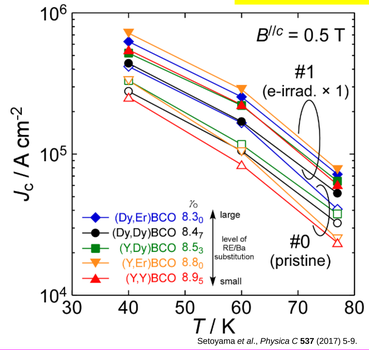
Matsumaru et al., in preparation



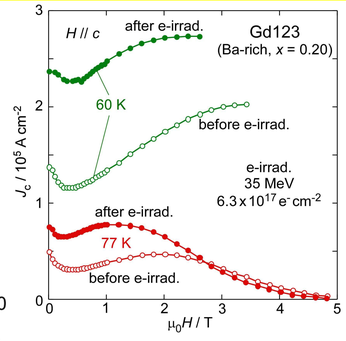
To suppress unintentional Gd substitution for Ba, staring from Ba-rich composition is substantially effective. This result is consistent with addition of BaO_2 before melt-solidification*.

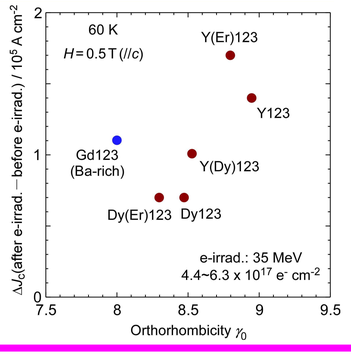
*Hu et al., Supercond. Sci. Technol. 17 (2004) 545.

Electron irradiation effect on critical current properties



Setoyama et al., Physica C 537 (2017) 5-9.





Atomic scale defects produced by electron irradiation act as more effective pinning centers in RE123 bulks with high γ_O.

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Condensation energy is larger in RE123 bulks with high γ_O.

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Control of γ_O being ~8.5 is a guiding principle to produce RE123 bulks generating high magnetic fields at low temperatures < 60 K.

Conclusions

Precise control of RE substitution level at Ba-site by RE-mixing with appropriate combinations or starting from Ba-rich composition is effective to enhance critical current properties of RE123 melt-solidified bulks in particular at low temperatures where various applications as strong magnets, such as NMR, are considered.

How to derive such high potential of J_c in whole part of bulks is the substantial subject in future.