Effect of SHI IRRADIATION on CRITICAL CURRENT DENSITY in $Y_{1-x}Ca_xBa_2Cu_3O_{7-\delta}$ Thick Film with $Y_2O_3$ Addition

Abstract

$Y_{1-x}Ca_xBa_2Cu_3O_{7-\delta}$ (x = 0.1) + $Y_2O_3$ (10 wt.%) composite thick film has been prepared by diffusion reaction technique. The samples are irradiated with 200 Mev Ag ions. X-ray diffraction, SEM reveals the micro structural changes on the irradiated samples. Using Beans critical state model critical current density was estimated from the width of magnetization loops. The enhancement of $J_c$ from $1.4 \times 10^4$ Acm$^{-2}$ to $6.7 \times 10^4$ Acm$^{-2}$ with irradiation upto fluence $5 \times 10^{11}$ ion-cm$^{-2}$ in YCaBCO samples is observed indicating that flux pinning increases due to the creation of columnar defects induced by irradiation. Addition of $Y_2O_3$ increases the $J_c$ in the pristine sample to $8.3 \times 10^4$ Acm$^{-2}$ but decreases with increasing fluence. Like the columnar tracks, the insulating inclusions $Y_2O_3$ causes $J_c$ increase by the same process of flux pinning. Either increasing the volume fraction of the inclusions or irradiating the composites might degrade the superconducting volume fraction and cause $J_c$ decrease. Degradation of the superconducting volume fraction has been observed as $T_c$ is lowered in the composite. As the defects (linear defects with columnar defects due to irradiation) are more, the interaction energy between vortex and defects dominate over the pinning energy. Hence the pinning sites are not used effectively. Thus $J_c$ starts to decrease with irradiation.
**Efficient Pinning Centers**

- Non Superconducting Phase
- IRRADIATION
- Crystalline Defects

- Ca, Y$_2$O$_3$, Y211, CeO$_2$, BaMO$_3$, (Zr, Ir, Hf, Sn), REBCO (RE= Er, Nd, Gd, Sm)

- Creating columnar defect
- Track size ~ 6-7 nm
- Vortex pinning
- Increases $J_c$

- Why Ca
  - Replacing Y$^{+3}$ with Ca$^{+2}$
  - Increases holes concentration
  - Improves superconductor coupling between grains
  - $J_c$ Increment

- Why Y$_2$O$_3$
  - Close lattice mismatch with YBCO of about ~ 0.6%
  - Low intrinsic strain
  - 10% will show maximum levitation
  - Increases $J_c$

Ref: 1-8
Sample Preparation

Thick film by
Diffusion Reaction method

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Y211 + Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overlayer</td>
<td>Ba₃Cu₅O₈</td>
</tr>
</tbody>
</table>

Y₂₁₁ + Ca + Ba₃Cu₅O₈ \rightarrow YCaBCO

Y₂₁₁ + Ca + Ba₃Cu₅O₈ + Y₂O₃ \rightarrow YCaBCO + Y₂O₃

Irradiation of Thick film by 200 MeV Ag ions of Fluence
- 5 \times 10^{10} \text{ ions/cm}^2
- 5 \times 10^{11} \text{ ions/cm}^2
XRD

Intensity (a.u.)

2θ (Deg)

YCaBCO+Y₂O₃ $5\times 10^{11}$

YCaBCO+Y₂O₃ $5\times 10^{10}$

YCaBCO $5\times 10^{11}$

YCaBCO $5\times 10^{10}$

(003) (110) (005) (113) (006) (200) (007) (116, 123) (108)

Ref: 9-10
<table>
<thead>
<tr>
<th>Samples</th>
<th>Fluence (ions/cm²)</th>
<th>a (Å)</th>
<th>b (Å)</th>
<th>c (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YCaBCO Un irradiated</td>
<td></td>
<td>3.8377</td>
<td>3.8766</td>
<td>11.6973</td>
</tr>
<tr>
<td>YCaBCO</td>
<td>5x10¹⁰</td>
<td>3.8244</td>
<td>3.8748</td>
<td>11.7028</td>
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<tr>
<td>YCaBCO</td>
<td>5x10¹¹</td>
<td>3.8241</td>
<td>3.8667</td>
<td>11.7110</td>
</tr>
<tr>
<td>YCaBCO + Y₂O₃ Un irradiated</td>
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<td>3.8373</td>
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<tr>
<td>YCaBCO+Y₂O₃</td>
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<td>3.8370</td>
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<td>11.6885</td>
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<tr>
<td>YCaBCO + Y₂O₃</td>
<td>5x10¹¹</td>
<td>3.8279</td>
<td>3.87480</td>
<td>11.6973</td>
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</tbody>
</table>
SEM images of (a) Pure YCaBCO thick film (b) 10%Y$_2$O$_3$ doped YCaBCO pristine (c) $5 \times 10^{10}$ (d) $5 \times 10^{11}$ for YCaBCO thick films (e) $5 \times 10^{10}$ (f) $5 \times 10^{11}$ for Y$_2$O$_3$ doped YCaBCO

Ref: 11
Magnetization Loops

Magnetization as function of applied field in loop of YCaBCO thick film irradiated with 200 MeV silver ions.
Magnetization as function of applied field in YCaBCO +10% $Y_2O_3$ thick films irradiated with 200 MeV silver ions measured at 40K
Comparison of magnetization loop at 40K of $Y_{1-x}Ca_xBa_2Cu_3O_{7-\delta}$ and $Y_{1-x}Ca_xBa_2Cu_3O_{7-\delta}+Y_2O_3$ thick film irradiated with 200 MeV Ag ions.

- The width of loops increases with irradiation doses in YCaBCO.
- Magnetization width decreases with irradiation doses in composites.
- Unirradiated YCaBCO doped with 10%$Y_2O_3$ has the biggest width.
- Highest fluence $5\times10^{11}$ ions/cm$^2$ has smallest width.
Magnetic Field dependence of critical current density for YCaBCO and YCaBCO+10%Y$_2$O$_3$ irradiated with 200 MeV Ag ions at 40K with varying field.
Pinning force, $F_p(H)$ curves for YCaBCO and YCaBCO+10%Y$_2$O$_3$ irradiated with 200 MeV Ag ions with different fluences at 40K with varying field.
## Maximum values of $J_c$ and $F_p$

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fluence (ions/cm$^2$)</th>
<th>$J_c$ (A/cm$^2 \times 10^4$)</th>
<th>$F_p$ (GN/m$^3$)</th>
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</thead>
<tbody>
<tr>
<td>YCaBCO Un irradiated</td>
<td></td>
<td>1.477</td>
<td>0.0166</td>
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<tr>
<td></td>
<td>$5 \times 10^{10}$</td>
<td>2.902</td>
<td>0.0368</td>
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<td></td>
<td>$5 \times 10^{11}$</td>
<td>6.736</td>
<td>0.0886</td>
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<tr>
<td>YCaBCO +10%Y$_2$O$_3$ Un irradiated</td>
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<td>8.327</td>
<td>0.0939</td>
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<td></td>
<td>$5 \times 10^{10}$</td>
<td>7.077</td>
<td>0.0791</td>
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<td></td>
<td>$5 \times 10^{11}$</td>
<td>1.432</td>
<td>0.0128</td>
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</table>
Temperature dependence of magnetization for YCaBCO irradiated with silver ions with fluence of $5 \times 10^{11}$ ions/cm$^2$.
CONCLUSION

Granular nature of the samples is improved after irradiation and has significant effect on the grain boundaries. Weak link effect is reduced greatly.

The radial stresses causes contraction of a and b-axis and an extension along c-axis of the surrounding crystalline YCaBCO structure.

YCaBCO irradiated with silver has greater magnetization width hence will have higher $J_c$ due to columnar defect.
Unirradiated YCaBCO+10%Y₂O₃ has highest Jc with value 8.3×10⁴(A/cm²). Due to synergetic effect of ions and inclusions more number of defects is introduced due to which J_c is lowest for YCaBCO+10%Y₂O₃ irradiated with fluence 5×10¹¹ ions/cm² so we observe decline in J_c.

Pinning force is maximum for YCaBCO unirradiated the interaction energy between vortex and defects dominate over the pinning energy.

Synergetic effect of Y₂O₃ creating defects and SHI producing columnar defect have resulted in degradation of superconducting volume fraction.
REFERENCES