Effect of SHI IRRADIATION on CRITICAL CURRENT DENSITY in YBa$_2$Cu$_3$O$_{7-\delta}$ Thick Film with Y$_2$O$_3$ Addition

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Pro
jectile ion

Electronic Energy Loss ($S_e$)

Nucleus

Electron cloud

Implanted Ion

Nuclear Energy Loss ($S_n$)

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Mixed state
\[ B_{c1} < B < B_{c2} \]

The vortices repel each other

A triangular lattice forms

The vortex lattice has the usual defects and interacts with the crystal lattice
Effect of addition at grain boundaries

Modification of the grain boundaries with nanoparticles composites have shown that $J_c$ increases when nanometric particles of NiO, Y$_2$O$_3$, SnO$_2$, SiC, Al$_2$O$_3$, BZO, etc. added to HTSC.


Artificial Pinning Sites

- Heavy ion irradiation
  - Substrate Decoration
  - Antidots (Holes)
  - Magnetic Dots

- Columnar

- Columnar
- Columnar
- Columnar

$Y_2O_3$ has close lattice mismatch with YBCO of about ~ 0.6% thereby allowing low intrinsic strain, which is reported to increase $J_c$.

- Campbell et al. Physica C 423 (2005) 1

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Heavy Ion Irradiation

Irradiating the HTSCs by heavy ions creates extended structural (columnar) defects in the material.

Columnar defects can pin a vortex along its whole length.

Defects are considered to be effective vortex pinning sites (even at high temperatures).

This increase of pinning strength due to the columnar defects is expected to enhance the critical current density.


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The random distribution of defects in HTSC by SHI irradiation act as flux pinning centres for the vortices.

This pinning is optimized when the size of the defects approaches the superconducting coherence length (2-4 nm for YBa$_2$Cu$_3$O$_{7-d}$ at 77 K).

- D. Kanjilal, Vacuum 48 (1997) 979
Critical Current Density

Columnar defects by irradiation increases $J_c$.

Improvements in $J_c$ at various temperature and under the magnetic field are brought about by artificial pinning centers (APCs).

APCs are known to be highly effective for pinning vortices.

Pancake vortices

In the most anisotropic HTS the vortices break between the Cu-O-layers forming pancake vortices

- The pancake vortices move much more easily than normal vortices
- This is one of the main reasons why BSCCO performs poorly in magnetic field

\[ \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \] is currently the best suited high \( T_c \) superconductor for most bulk applications

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Motivation

In this present work we have studied synergetic effect of

Non superconducting inclusion $Y_2O_3$

&

SHI of 200 MeV of silver ions on YBCO thick films.

Magnetic studies are further carried to investigate critical current density.

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Experimental

Sample Preparation

**Thick film by diffusion reaction technique**

**Substrate**  Y211 (green phase)

**Overlayer**  Ba$_3$Cu$_5$O$_8$

\[ \text{Y211} + \text{Ba}_3\text{Cu}_5\text{O}_8 \rightarrow \text{YBCO} \]

\[ \text{Y211} + \text{Ba}_3\text{Cu}_5\text{O}_8 + \text{Y}_2\text{O}_3 \rightarrow \text{YBCO} + \text{Y}_2\text{O}_3 \]

Irradiation of Thick film by 200 MeV Ag ions of Fluence

- $5 \times 10^{10}$ ions/cm$^2$
- $5 \times 10^{11}$ ions/cm$^2$

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Characterization

Structural properties (XRD)

Surface morphology (SEM)

MAGNETIZATION STUDIES (M-H)
RESULTS and DISCUSSION

XRD pattern of YBCO and $Y_2O_3$ doped YBCO thick film irradiated with 200 MeV of Ag ion with varying fluence

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SEM micrographs of 200 MeV silver irradiated samples with fluence of
(a) pure YBCO thick film (b) 10 wt.%Y$_2$O$_3$ doped YBCO pristine
(c) $5 \times 10^{10}$ ions/cm$^2$ (d) $5 \times 10^{11}$ ions/cm$^2$ for YBCO thick films

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SEM micrographs of 200 MeV silver irradiated samples with fluence.
(e) $5 \times 10^{10}$ ions/cm$^2$ (f) $5 \times 10^{11}$ ions/cm$^2$ for Y$_2$O$_3$ doped YBCO.

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Magnetization Loops

M-H loop of YBCO thick film irradiated with 200 MeV silver ions

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Using Bean’s critical state model, \( J_c \) is calculated

\[
J_c = \frac{20 \Delta M}{a(1 - \frac{a}{3b})}
\]

where
- \( a \) thickness of the bar shaped sample
- \( b \) width of the bar shaped sample
- \( \Delta M = M_+ - M_- \) extracted from the magnetization loop.

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Magnetic Field dependence of critical current density for YBCO and YBCO+Y$_2$O$_3$ irradiated with 200 MeV Ag ions at 40 K with varying field
Pinning force, $F_p(H)$ curves for YBCO doped YBCO and YBCO+$Y_2O_3$ irradiated with 200 MeV Ag ions at 40 K with varying field

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Observed values of Critical current density ($J_c$) and maximum pinning force ($F_p$)

<table>
<thead>
<tr>
<th>Sample</th>
<th>$J_c$ (A/cm²x10⁵)</th>
<th>$F_p$(GN/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YBCO</td>
<td>1.06</td>
<td>0.135</td>
</tr>
<tr>
<td>Fluence (5x10¹⁰ ions/cm²)</td>
<td>1.41</td>
<td>0.175</td>
</tr>
<tr>
<td>Fluence (5x10¹¹ ions/cm²)</td>
<td>2.49</td>
<td>0.246</td>
</tr>
<tr>
<td>YBCO+Y₂O₃</td>
<td>1.32</td>
<td>0.161</td>
</tr>
<tr>
<td>Fluence (5x10¹⁰ ions/cm²)</td>
<td>1.28</td>
<td>0.163</td>
</tr>
<tr>
<td>Fluence (5x10¹⁰ ions/cm²)</td>
<td>0.74</td>
<td>0.073</td>
</tr>
</tbody>
</table>

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The structure quality at the grain boundaries varies with silver irradiation.

- Grain size are decreased and the edges become rounded.

YBCO irradiated with silver has greater magnetization width than pure YBCO hence have higher $J_c$.

- Irradiated pure YBCO as well YBCO+$Y_2O_3$ composite have higher $J_c$ as compared to that of unirradiated YBCO.

$J_c$ decreases for YBCO+$Y_2O_3$ composites with increasing irradiation.

- Pinning force at certain low field has the maximum value and then starts decreasing with the increase in field.

Pinning force is maximum for YBCO irradiated with $5 \times 10^{11}$ ions/cm$^2$.

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CONCLUSION

The concentration of $\text{Y}_2\text{O}_3$ may be greater than 10 wt.\% due to Y 211 substrate and composite diffusion reaction.

As the defects (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.