REBa$_2$Cu$_3$O$_7$ coated conductors as a beam screen coating: Linking surface resistance to microstructure

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Outline

1. REBCO CCs for beam screen coating
2. Linking CC’s surface resistance to microstructure
3. Evaluation of secondary electron yield
1. **Motivation:** *REBCO CCs for beam screen coating*

Synchrotron radiation in FCC much higher:
- $P_{beam}^{LHC} \approx 0.2 \text{ W/m}$
- $P_{beam}^{FCC} \approx 35.4 \text{ W/m}$

Limit the cryogenic load to 100 MW

$\Delta T_{FCC} = 40 - 60K$

Superconductors belong to only material class where $R_{S}^{SC} < R_{S}^{Cu}$

*Cu may not provide low enough surface impedance at 40-60K*

26.06.2019
1. Motivation: **REBCO CCs for beam screen coating**

REBCO coated conductors are layered structures consisting of:

- **Multifunctional oxides**
  - HTS REBa$_2$Cu$_3$O$_{7-x}$
  - Buffers that allow epitaxial growth

- **Flexible, metallic substrate**

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**Superconductive at FCC conditions:**

\[ T_c \approx 93K \quad B_{c2}(50K) \approx 80T \quad I_c(50K, 16T) > 25A \]

**Commerially available in km length (≈5000 km/a).**

Participating manufacturers in FCC study:

- **Rare earth**
  - Y
  - Gd
  - Eu
  - Dy
  - ...  

**Intrinsic PC**

- Grain boundaries
- Secondary phases
- Stacking faults
- Point defects
- ...

**Artificial PC**

- BaZrO$_3$
- BaHaO$_3$
- ...

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Outline

1. REBCO CCs for beam screen coating
2. Linking CC’s surface resistance to microstructure
3. Evaluation of secondary electron yield
2. Linking $R_S$ to microstructure

- Within the consortium, ALBA and UPC developed 8 GHz cavity dielectric resonator
- compatible with 25mm bore 9 T magnet at ICMAB

State of the art REBCO CCs outperform Cu at 50K, 8 GHz and up to 9T
2. Linking $R_s$ to microstructure

State of the art REBCO CCs outperform Cu at 50K, 8 GHz and up to 9T

$R_s$ is microstructure dependent

$T = 50K, \nu \approx 8GHz$

FCC Cu (300µm on st.st.)

Microstructure of YBCO with BZO nanorods


T. Puig et al. (SUST accepted)
2. Linking $R_s$ to microstructure

**Classical rigid-fluxon model**

S. Calatroni and R. Vaglio, IEEE Transactions on Applied Superconductivity 27, 2017

Assumptions:
1. Fluxon shape cannot be deformed
2. Rigid flux tube lattice

Equation of motion for fluxons:

$$m\ddot{x} + \eta \dot{x} + kx = J_{rf} \Phi_0$$

**Surface resistance:**

$$R_{fl}(T, H, \nu) = R_n \sqrt{a^2(J_c, \rho, B_{c2}) + b^2(J_c, \rho, B_{c2}) - b(J_c, \rho, B_{c2})}$$

**Depinning frequency:**

$$\nu_0 = \rho_n \frac{J_c}{B_{c2}} \sqrt{\frac{H}{\phi_0}}$$
2. Linking $R_S$ to microstructure

Overestimation of $R_S$ with rigid-fluxon model:

$$R_{fl}(T, H, \nu) = R_n \sqrt{a^2(J_c, \rho, B_{c2}) + b^2(J_c, \rho, B_{c2}) - b(J_c, \rho, B_{c2})}$$

Introduction of correction factor $r$:

$$R_{fl}(T, H, \nu) / r$$

$T = 50K$, $\nu \approx 8GHz$

Correction factor $r = 8.0$

Calculated from transport values

Measured with resonator
2. Linking $R_s$ to microstructure

Correction factor $r$ depends on the microstructure of CC

$T = 50K, \nu \approx 8GHz$

- $r_{SuNAM} = 5.4$
- $r_{Super0x} = 7.7$
- $r_{Bruker} = 8$
- $r_{Theva} = 24$
- $r_{Fujikura} = 10$
- $r_{SuperPower} = 11.5$
- $r_{Fujikura\ NP} = 30$
2. Linking $R_s$ to microstructure

Underestimation of $\nu_0$ compared to literature $\nu_0^{lit}(50K) \geq 15GHz$. 

2. Linking $R_s$ to microstructure

Ignore the depinning frequency derived from rigid-fluxon model:

$$\nu_0 = \frac{\rho n J_c B_{c2}}{\phi_0}$$

→ Use $\nu_0$ as fitting parameter.

Fitted value $\nu_0 \approx 29 \text{ GHz}$:

1. No correction factor needed
2. Matches better with literature
2. Linking $R_s$ to microstructure

$T = 50K, \nu \approx 8GHz$

$\nu_0^{\text{rigid-fluxon}} = \rho_n \frac{J_c}{Bc2} \sqrt{\frac{H}{\phi_0}}$ identified as weakness of model $\rightarrow$ Gives potential to adjust model.

<table>
<thead>
<tr>
<th>Provider</th>
<th>$\nu_0^{\text{rigid-fluxon}}$ (9T) in GHz</th>
<th>$\nu_0^{\text{fit rigid-fluxon}}$ in GHz</th>
<th>$\nu_0^{\text{CoffeyClem}}$ in GHz</th>
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<tr>
<td>Bruker</td>
<td>3.0</td>
<td>29.3</td>
<td>30.0</td>
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<tr>
<td>Fujikura NP</td>
<td>1.3</td>
<td>67.8</td>
<td>71.0</td>
</tr>
</tbody>
</table>
2. Linking $R_s$ to microstructure

*Extrapolation of $R_s$ using rigid-fluxon model with $v_0^{\text{fit rigid-fluxon}}$ to 1GHz and 16T:*

$T = 50K, \nu = 1 \text{ GHz}$

FCC Cu (300μm on st.st.)

Predicted by rigid-fluxon model: Out performance of Cu by HTS CC at FCC conditions even more pronounced!
Outline

1. REBCO CCs for beam screen coating

2. Linking CC’s surface resistance to microstructure

3. Evaluation of secondary electron yield
3. Beam instability: Secondary electron yield

- In untreated form not suitable for use in particle accelerators
- Conditioning treatment not sufficient
- Roughness of a-C decreases SEY under desired limit
- Ti as adhesion and protection layer

Thin layers of a-C and Ti decrease the SEY below threshold value 1.3.
3. Beam instability: Secondary electron yield

Increase of $R_s$ for 150 nm Ti + 100 nm a-C not detrimental.
Conclusions

- State of the art REBCO CCs outperform Cu at 50K, 8 GHz and up to 9T

- Extraction of $\nu_0$ as for all CCs by means of ridig-fluxon model

- Extrapolation of surface resistance to FCC conditions 1 GHz, 16 T, 50K $\rightarrow$ outperformance of Cu by CCs by two order of magnitude expected at FCC conditions

- a-C (50-100 nm) and Ti (100-150 nm) capping to reduce the secondary electron yield below required limit $\delta_{\text{lim}} \approx 1.3$

- Increase in $R_s$ due to capping is not significant at 50K, 8GHz, up to 9T
Outlook: REBa$_2$Cu$_3$O$_7$ coated conductors for beam screen coating

1. Characterization of CCs up to 16T:

- Cylindrical dielectric resonator $\nu \approx 8$ GHz
- Resonator configuration with $\nu \approx 1$GHz (currently in development at UPC/ALBA)

Surface impedance $Z_s$ measurable at FCC conditions.
- $\nu = 1$ GHz, 8GHz
- Wide Temp. range
- Up to 16 T

$\rightarrow$ Understanding the influence of magnetic field on vortex dynamics up to 16T.

2. Evaluation of persistent currents

- Analyzing persistent currents will define the required aspect ratio of Cu and REBCO CC in beam screen
- Construction of proof-of-concept device based on generated knowledge

3. Welding solutions of aC/REBCO/Steel stacks

- Soldering of REBCO CCs to st. st. with delamination of superconducting layer possible in large scales
- Delaminated bottom layer shows no degradation in $R_s$ performance
- Superconducting performance of delaminated layers still to be investigated

4. Mechanical tests of aC/REBCO/Steel stacks

- Experimental system to assess 2D /3D stress maps based in optical image correlation with in situ monitoring the $I_c$ has been finished and will be taken into operation in Q3/Q4 2019
- Full evaluation of stresses associated to new welding solution targeted
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Thank you for your attention!