Study of Tl(1223) superconducting coatings for beam impedance mitigation in the Future Circular Collider

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High synchrotron radiation load (SR) of protons @ 100 TeV:

~30 W/m/beam (@16 T)

→ 5 MW total in arcs (LHC <0.2W/m)

New type of ante-chamber
- absorption of synchrotron radiation
- avoids photo-electrons, helps vacuum
- Optimum $T_{\text{screen}} \sim 50$ K


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Superconducting coating for beam impedance mitigation
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10^{11} protons will circulate in bunches in the ring at v≈c
Proton are charged -> it will produce an EM field
The EM Field will produce an image current in the screen
The image current will dissipate
Due to the delay, it will affect back the beam causing instabilities.
The surface resistance of copper at 50 K may not be sufficiently low to guarantee a safe operational margin for the FCC-hh beams, in particular at injection energy.

Introduction of a HTSC coatings to mitigate the beam impedance

Joint project to study this possibility
HTS films requirements for beam screen

Bunches of $10^{11}$ protons, 8 cm long

Beam screen of 30mm diameter.

Assuming a film thickness / skin depth of 1 µm the HTS material should have a critical current density $J_c$ of about 25 kA/cm$^2$ ($2.5 \times 10^8$ A/m$^2$) at 50 K and 16T 1GHz

At present NO superconductors have these performance!
HTS films requirements for beam screen

- T=50 K Very high operation temperature
- B=16 T Very High magnetic field
- ω=1GHz Very high frequency
- High synchrotron radiation intensity
- Boundary materials with 100 TeV particles (only supernova burst can exceed this energy)
Surface resistance: general definition

\[ R_s(H_{rf}, T, B) = R_{BCS}(H_{rf}, T, 0) + R_{res}(H_{rf}, 0, 0) + R_{fl}(H_{rf}, T, B) \]

Flux flow depends on pinning strength and frequency

\[ Z_{sf} \equiv Z_f = Z_n \sqrt{\frac{B_o}{B_{c2}}} \]

Gittleman and Rosenblum: Journal of Applied Physics 39, 2617 (1968)

\[ R_{sf} \equiv R_f = \frac{R_n}{\sqrt{2}} \sqrt{\frac{B_o}{B_{c2}}} \left( \frac{\nu}{\nu_0} \right)^{3/2} \]

\[ X_{sf} \equiv X_f = R_n \sqrt{2} \sqrt{\frac{B_o}{B_{c2}}} \left( \frac{\nu}{\nu_0} \right)^{1/2} \]

for \( \nu \gg \nu_0 \)

for \( \nu \ll \nu_0 \)

Flux flow regime

No flux flow

Surface Resistance of Superconductors in the Presence of a DC Magnetic Field: Frequency and Field Intensity Limits

Superconducting materials phase diagram

\[ R_{fl} \approx \frac{B}{B_{c2}} \]

\[ \frac{H}{H_{c2}} = \sqrt{\frac{16T}{80T}} = 0.45 \]

\[ \frac{H}{H_{c2}} = \sqrt{\frac{16T}{140T}} = 0.33 \]

See J. Gutierrez et al. tomorrow 4LP5-21

\( H_{c2} \) and \( H_{irr} \)

Beam screen working point
1.06 T Injection

16 T Maximum energy

\( \nu_0(B_0) = \frac{\rho_n \sqrt{B_0 J_c(B_0)}}{\Phi_0 B_{c2}} \)

Depinning frequency

\( Z_{sf} = Z_f = Z_n \sqrt{\frac{B_0}{B_{c2}}} \quad \text{for} \quad \nu \gg \nu_0, \)

\( R_{sf} = R_f = \frac{R_n}{\sqrt{2}} \sqrt{\frac{B_0}{B_{c2}} \left( \frac{\nu}{\nu_0} \right)^{3/2}} , \quad R_n = \sqrt{\frac{\mu_0 \rho_n}{\pi \nu}} \)

\( X_{sf} = X_f = R_n \sqrt{2} \sqrt{\frac{B_0}{B_{c2}} \left( \frac{\nu}{\nu_0} \right)^{1/2}} \quad \text{for} \quad \nu \ll \nu_0. \)

Assuming:

- (conservative estimate)
  - \( \rho_n = 40 \ \mu \Omega \ \text{cm} \)
  - \( B_{c2} (50K) = 70T. \)
  - \( J_c \div 10^8 \ \text{to} \ 10^9 \ \text{A/m}^2 \)

At low frequencies, where the most unstable modes are predicted for a copper beam screen, a substantial gain of several orders of magnitude is clearly apparent.
Superconducting coating for beam impedance mitigation

Electrodeposition

The Ag\{110\}:

- Initial Ag
- Cold Rolling: 20% reduction at each pass
- Bridgman technique
- Orienting by X-ray Laue method
- Recrystallization: Vacuum 800 °C
- \{110\} textured ribbons
- \{110\} Single crystal
- cutting (electroerosion), polishing and chemical etching

Lattice parameter matching of TI(1223) and silver

Electron Back Scattered Diffraction map (EBSD)
Superconducting coating for beam impedance mitigation

Solution:
- Ag standard foils
- Ag textured tapes
- Ag single crystal
- SrTiO₃ single crystal

Vacuum annealing at 900 °C

Chemical electrodeposition
1-10 min, -3 V (continuous)
1-20 min, -3V, 10 s; -1 V, 5 s (pulsed)

Oxidation reaction
- High isostatic pressure (50 bar He/1 bar O₂)
- 870-930 °C 20-60 min

Substrates:
- Ti, Bi, Pb, Sr, Ba, Ca, Cu nitrates dissolved in DMSO
As rolled Ag ribbon

c axis texture
on Ag grain local epitaxy

TL-1223 rocking curve 00l

FHWM = 6.5°

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Superconducting coating for beam impedance mitigation
For first preliminary superconducting characterization see 4MP5-16 S. Holleis et al. tomorrow morning.
Conclusions

- An HTSC coating have been proposed to mitigate the beam impedance in FCC
- Working condition are «Extreme»
- Models validate the feasibility with Tl(1223) and Re-123 (large gain at low frequency)
- A scalable deposition method for Tl(1223) based on electroplating was developed
- First S/C have been produced with local biaxial texture

To be done:

- Investigation of grain boundaries requirements
- Silver substrate optimization
- High-frequency, high field surface-resistance measurements (model validation)
- Secondary electron emission
THANK YOU FOR YOUR ATTENTION
Electrodeposition on:

110 Textured Ag ribbon

110 oriented Ag singlecrystal

TI-superconductors grow epitaxially on the Ag: local biaxial texture.

The different Ag grains are rotated in the plane.

No macroscopic texture is present.

The biaxial alignment is observed in large region (>10 mm²).
Thallium is toxic!
A new lab for safe manipulation of azareous material have been realized
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Superconducting coating for beam impedance mitigation

€ RF e- losses

Sample Preparation

Atomistitut Jc Grain Boundaries

Microscopie TEM/EBSD

1,6 M€ Project