Resistivity change from DPA estimates for IR7 collimators

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With contribution of
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**DPA induced by Ca ion: GSI 2019 test**

- Beam uniform over the sample surface
- Parallel resistance model \( \rightarrow \) we infer the irradiated resistivity only
- Penetration depth calculated with FLUKA, considering the density of each samples

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**Parameter**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Species</strong></td>
<td>Ca48</td>
</tr>
<tr>
<td><strong>Charge state</strong></td>
<td>+10</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td>4.8 MeV/u</td>
</tr>
<tr>
<td><strong>Flux</strong></td>
<td>( 5 \div 8.5 ) ion/cm²·s</td>
</tr>
<tr>
<td><strong>Time pulse</strong></td>
<td>( 1.8 \div 5.2 ) ms</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>5 Hz</td>
</tr>
<tr>
<td><strong>Beam size</strong></td>
<td>2.5x2.5cm² or 2.7x2.7cm²</td>
</tr>
</tbody>
</table>
Electrical conductivity degradation

Resistivity is increasing with the peak DPA of CFC FS140

<table>
<thead>
<tr>
<th>Fluences</th>
<th>1e12</th>
<th>1e13</th>
<th>7e13</th>
<th>4e14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak DPA</td>
<td>8.2e-5</td>
<td>8.2e-4</td>
<td>5.8e-3</td>
<td>3.3e-2</td>
</tr>
</tbody>
</table>
## Additional reference

**Ryazanov 2008**

Changes in physical-mechanical properties of AC-150 composite after irradiation.

<table>
<thead>
<tr>
<th>Sample Nr.</th>
<th>( E_{\text{init}}/E_{\text{irr}} ) GPa</th>
<th>( \Delta E/E ) %</th>
<th>( \rho_{\text{init}}/\rho_{\text{irr}} ) ( 10^6 ) Ohm*m</th>
<th>( \Delta \rho/\rho ) %</th>
<th>( \Delta \lambda/\lambda ) %</th>
<th>( \sigma_{\text{init}}/\sigma_{\text{irr}} ) MPa</th>
<th>( \Delta \sigma/\sigma ) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>4R(TA-1)</td>
<td>3.5/4.0</td>
<td>14</td>
<td>28.8/29.65</td>
<td>3</td>
<td>50/48</td>
<td>6</td>
<td>6.0/7</td>
</tr>
<tr>
<td>4T(AR-1)</td>
<td>8.1/8.86</td>
<td>9</td>
<td>5.65/3</td>
<td>42</td>
<td>215/150</td>
<td>30</td>
<td>5.8/5</td>
</tr>
<tr>
<td>4A(RT-1)</td>
<td>9.2/9.6</td>
<td>4</td>
<td>6.2/9.4</td>
<td>52</td>
<td>215/130</td>
<td>39</td>
<td>6.1/2</td>
</tr>
</tbody>
</table>

**First irradiation (0.0002 dpa)**

<table>
<thead>
<tr>
<th>Sample Nr.</th>
<th>( E_{\text{init}}/E_{\text{irr}} ) GPa</th>
<th>( \Delta E/E ) %</th>
<th>( \rho_{\text{init}}/\rho_{\text{irr}} ) ( 10^6 ) Ohm*m</th>
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<th>( \sigma_{\text{init}}/\sigma_{\text{irr}} ) MPa</th>
<th>( \Delta \sigma/\sigma ) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>4R(TA-2)</td>
<td>4.8/7.0</td>
<td>46</td>
<td>29.9/62.5</td>
<td>109</td>
<td>51/25</td>
<td>51</td>
<td>6.0/21</td>
</tr>
<tr>
<td>4T(AR-2)</td>
<td>9.3/10.4</td>
<td>12</td>
<td>5.7/17</td>
<td>198</td>
<td>215/80</td>
<td>62</td>
<td>5.8/6</td>
</tr>
<tr>
<td>4A(RT-2)</td>
<td>8.8/9.5</td>
<td>8</td>
<td>5.75/12</td>
<td>109</td>
<td>215/105</td>
<td>51</td>
<td>6.1/4</td>
</tr>
</tbody>
</table>

**Second irradiation (0.0002 dpa)**

- Proton beam 20-35 MeV
Comparison with IR collimators

DPA scaling process:

Peak DPA value simulated for CFC TSCG secondary collimator in slot A6R7 for HL-LHC optics (1E17 protons lost): $1.5 \times 10^{-4}$

- All of Run 2 (7.1E15 protons lost): $1.1 \times 10^{-5}$
- 2018 (w/ TCSPM prototype in slot D4R7.B2), (4.5E15 protons lost): $6.75 \times 10^{-6}$

Scaling by proton losses

- All of Run 2: $\sim 1 \times 10^{-6}$
- 2018: $\sim 5 \times 10^{-7}$

Scaling by total power

- 1 order of magnitude difference in total power, also for collimators further downstream
Comparison with IR collimators
Summary

- Resistivity degradation as a function of DPA from two experiments (GSI and Kurchatov)
- All the peak DPA estimated for IR collimator 1 order below the DPA observed in the irradiation campaign → we can only estimate the maximum resistivity increase factor (1.5-2)
Thank you
Comparison with LHC

A. Waets, HL Annual meeting
CFC 150AK installed vs FS140 tested: initial conductivity of material installed 5000nOhmm

Ca ion GSI 2019

Ryazanov 2008

Changes in physical-mechanical properties of AC-150 composite after irradiation.

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<th>$E_{\text{res}}/E_{\text{irr}}$ GPa</th>
<th>$\Delta E/E$ %</th>
<th>$\rho_{\text{res}}/\rho_{\text{irr}}$ $10^5$ Ohm$^{-\text{cm}}$</th>
<th>$\Delta \rho/\rho$ %</th>
<th>$\Delta \rho_{\omega}/\rho_{\omega}$ %</th>
<th>(\rho_{\omega}/\rho_{\omega,\text{max}}) MPa</th>
<th>$\Delta \sigma/\sigma$ %</th>
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<tr>
<td>1R(TA-1)</td>
<td>3.5/4.0</td>
<td>14</td>
<td>28.8/29.65</td>
<td>3</td>
<td>50/48</td>
<td>6</td>
<td>6/0</td>
</tr>
<tr>
<td>4R(TM-1)</td>
<td>8.1/8.8</td>
<td>9</td>
<td>5.65/8</td>
<td>42</td>
<td>215/150</td>
<td>30</td>
<td>5/8</td>
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<tr>
<td>4AR(RT-1)</td>
<td>9.2/9.6</td>
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First irradiation (0.0002 dpa)

Second irradiation (0.002 dpa)

Third irradiation (0.02 dpa)
UNCOATED

[Graph showing the relationship between fluence, peak DPA, and bulk resistance for different materials.]

Fluences [ions/cm² s]

$\rho_{\text{bulk, irradiated}} / \rho_{\text{bulk, pristine}}$

Peak DPA

$\rho_{\text{bulk, irradiated}}$ [nOhm.m]