Studies of Fiber Optics for HTS Magnet Fabrication and Monitoring*

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Background

- Phase I SBIR to study fiber optic sensors for HTS magnets
- Ultimate goal is to monitor locally along the length of the magnet with one system:
  - Temperature*
  - Strain*
  - Quench initiation
  - Irradiation
  *Phase I
Phase I Tasks

• High temperature survivability of fiber
• Effects on superconducting material during heat treatment due to presence of fiber
• Low temperature (cryogenic) sensitivity
  – Temperature
  – Strain
• Irradiation survivability and effects: shown by other groups
Basic Design

- Fiber optic cable
- Au coating
- Bi2212 superconductor in Ag matrix

Magnifications:
- 70x mag, 3 keV
- 300x mag, 3 keV
Sensing Methods

• Fiber Bragg Gratings (FBGs)*
  – Fast readings: speeds up to 1 kHz
  – Relatively inexpensive monitoring systems ($20K)
  – Requires post-processing of fiber

• Brillouin and Rayleigh* Scatter
  – Slower due to higher processing times (2 s to 6 s)
  – High cost of systems ($100K)
  – No modifications needed to fiber

*Phase I
Cryogenic Monitoring

• Monitor temperature and strain during operation: leads to quench protection
• Quench is one of the biggest concerns for magnet design – LHC!
• In LTS, can use voltage taps to detect quench
• Not possible in HTS due to slow QPV (Quench Propagation Velocity) and higher Tc
• Fiber optic sensors can solve this
Temperature Monitoring

- High temperature heat treatment of Bi2212 (Bi$_2$Sr$_2$Ca$_1$Cu$_2$O$_8$) up to ~890 °C
- Use fiber optics as heat treatment process monitors
- Ensure entire magnet is at thermal equilibrium for partial melt stage
- Possibly improve quality of superconductor
- Fiber must be able to survive heat treatment
Bi2212 Heat Treatment

NOT TO SCALE
Heat Treatment Effect Testing

• Heat treated Bi2212 straight sample in contact with an Au coated fiber
  – Tested Bi2212 for Ic degradation: compared to control sample
  – Examined both Bi2212 and fiber using SEM and EDS methods
  – Fiber will be brought to subcontractor to verify survivability and drifting effects
Short Sample Tests

SEM Mounted Sample

Wire

Ic Test Sample

3 2 1
Ic (Critical Current) Test Results

• Tested two short straight samples: one with fiber, one without (as reference)
• Background field of 5 T at 4.2 K
• Showed negligible Ic loss of 4 to 5 A, only ~2%, which is within error margin

<table>
<thead>
<tr>
<th>Sample</th>
<th>1μV/cm Ic (A)</th>
<th>.1μV/cm Ic (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With fiber</td>
<td>279</td>
<td>231</td>
</tr>
<tr>
<td>W/o fiber</td>
<td>284</td>
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# Ic Test Results

![Graph showing Ic test results at 4.2 K and 5 T](image)

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2/27/09
SEM – Sample 1

No visible damage to fiber

No visible change between Au and Ag: indicates diffusion

Insulating sheath

300x mag
3 keV

70x mag
3 keV
SEM/EDS
Sample 1, Point a

No apparent damage to fiber: EDS confirms only Si and O present.

Faint outline of fiber to superconductor transition.

300x mag
20 keV

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<tr>
<th>Element</th>
<th>Wt %</th>
<th>At %</th>
</tr>
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<tbody>
<tr>
<td>AgL</td>
<td>66.26</td>
<td>78.19</td>
</tr>
<tr>
<td>AuL</td>
<td>33.74</td>
<td>21.81</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>
SEM/EDS
Sample 1, Point b

Au wt% decreased from 33.74% to 21.60%
SEM/EDS
Sample 1, Point c

No Au present, mostly Ag
SEM – Sample 2

Scratches from grinding/polishing

Can see faint crack in fiber optic, will examine next
SEM – Sample 2

Crack is easily visible in high-energy (20 keV) scan, and can be seen at the lower energy (1 keV) level as well.
Visual inspection of fiber shows no damage

Can see separation of fiber coating from superconductor – appears to have ‘pulled’ during heat treatment; Bi2212 is visually affected, but no perf. losses
Sample 3. Point a

Both Au and Ag present (~50 wt% each), indicates fiber and superconductor were ‘merged’ at some point and then split.
SEM/EDS
Sample 3, Point b

Higher concentration of Ag at this point
Almost all Ag (97 wt%), no Au present

At higher energy, fiber appears intact
Au and Ag make up ~80 wt% (expected), however, Sr has a 17 wt% presence; this is bad! May indicate leakage as Sr only located in Bi2212 inner filaments.
Sr again present (we were looking for it this time); seems to be in darker pitted (or hilly) regions
Results

• Ic Test showed no degradation in Bi2212
  – Only 2% decrease
  – Perform same test on a short wound coil next week

• SEM/EDS images:
  – Fiber intact
  – Diffusion of Au and Ag (expected)
  – Leakage of superconductor (Sr)
  – Thermal contraction may cause split between fiber and superconductor
Future Work

• Test survivability of fibers due to heat treatment (next week in VA)
• Perform cryogenic fiber tests using Rayleigh scatter (next week in VA)
• Test short wound samples for Bi2212 degradation (Tallahassee)
• Examine cryogenic strain and temperature response of FBGs (Tallahassee)
Future Work (cont)

• Submit Phase II Proposal in April
• Pending Phase I
  – Fiber optics for fusion applications
  – Fiber optics for HTS degaussing cables (Navy)
• Conferences/Papers
  – PAC09 in May
  – SOFE in June
  – CEC-ICMC in June/July
Questions?