Investigation of graphene layer application to RF-grade copper surfaces

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Motivation

- High gradient research includes empirical studies of different materials, coatings and surface treatment procedures that may reduce probability or severity of RF breakdown events.

- Graphene is a recently discovered form of carbon which is uniquely stable at monoatomic thickness. Has outstanding mechanical, structural, and electromagnetic properties.

- Monatomic layer is **not** a good shield in a case of a full scale breakdown event.

- On the other hand, it can have an effect on a field emission (thermal and electric conductance, magnetic field).
Experimental Plan

- A thorough modeling of the system is beyond our present capabilities, hence an experimental study was proposed.

- Objectives:
  - Study the ability to perform graphene layer synthesis on a copper surface pretreated for RF applications (before it was only done on copper foils).
  - Conduct the RF breakdown studies on a graphene coated copper in a specialized test facilities (CERN DC breakdown chamber, SLAC RF pulse heating chamber).

- Acknowledgement
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Graphene synthesis

- Copper sample treatment is achieved by chemical vapor deposition (CVD) growth of graphene by decomposition of hydrocarbons on transition metal surfaces at elevated temperatures.
- A mixture of $\text{H}_2/\text{Ar}/\text{CH}_4$ is blown over the target plates at 1000 °C to grow the graphene layers.

(courtesy of E. Polyakova, Graphene Laboratories Inc., and CVD Equipment Corp Application Lab)
QA procedure

- Visual inspection (color changes with respect to untreated surface)
- Raman spectroscopy
- Scanning Electron Microscopy (SEM)
Synthesis Results

- Prepared 15 samples in a geometry suitable for CERN DC breakdown chamber
- Surfaced polished and cleaned, following the best practices
- 3 of the samples were left uncoated for reference, 8 samples were coated with monolayer graphene, and 4 samples were nickel coated in an attempt to develop a multilayer graphene.
- Results: success with the monolayer (after some process development), and failed attempt with the multilayer (Ni coating is destroyed in the process).
DC Spark Chamber Tests

- Samples were tested at CERN, using their standard spark chamber set up
- The idea was to see if graphene coated samples would have higher breakdown threshold than the reference samples.

Adapted from: S. Calatroni, “DC breakdown measurements”, presentation at RF breakdown workshop at CERN, June 2010
No improvement has been observed with the graphene coated samples.

After the first few sparks, the behavior is nearly identical with and without graphene, which indicates graphene layer removal.

During the initial sparks, graphene coated layer behave worse than uncoated ones, but the difference is not statistically significant.

Comparison: Effect of a Graphene Layer on a Copper Sample

An overview of the main breakdown parameters found in the experiments for both samples is given in Table 1, while Figure 5 shows them graphically. The main difference between both materials is given by their initial breakdown values: a graphene layer on a copper sample decreases the initial breakdown field compared to standard copper. However, the error bars overlap so what could be perceived as a main difference between the two samples might not be so. When the graphene layer has been removed after a couple of breakdowns, both samples behave almost identically as they reach approximately the same $E_{sat}$.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$E_{b1}$ [MV/m]</th>
<th>$E_{sat}$ [MV/m]</th>
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<tbody>
<tr>
<td>Cu49</td>
<td>181.67 ± 64.56</td>
<td>206.01 ± 32.76</td>
</tr>
<tr>
<td>Cu50</td>
<td>265.87 ± 74.43</td>
<td>179.62 ± 14.83</td>
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</tbody>
</table>

(measurements and data analysis are performed by R. Santiago Kern at CERN)
Conclusions and future plans

- Graphene layer has been successfully synthesized on the copper sample pretreated for RF applications.
- So far, no improvement due to graphene coating has been observed in the DC spark chamber experiments.
- Next steps (if any):
  - testing graphene coated copper with RF in the pulse heating cell configuration (SLAC);
  - repeat DC spark chamber tests;
  - further surface engineering studies: multilayer synthesis and surface planarization techniques;
  - effects on multipactoring, SEY studies.
- Thank you to all the collaborators for supporting this work.