radiabeam TECHNOLOGIES

Investigation of graphene layer application to RF-grade copper surfaces

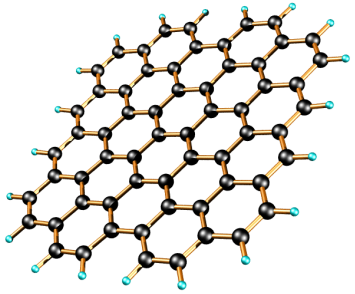
Alex Murokh
RadiaBeam Technologies, LLC.

SLAC National Accelerator Laboratory, February 10, 2011

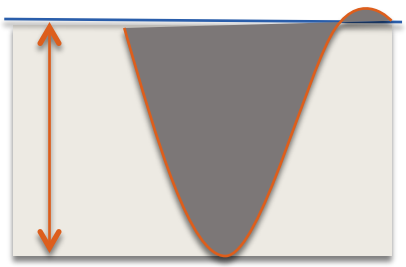
US High Gradient Research Collaboration Workshop 2011

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 electro-magnetic properties.

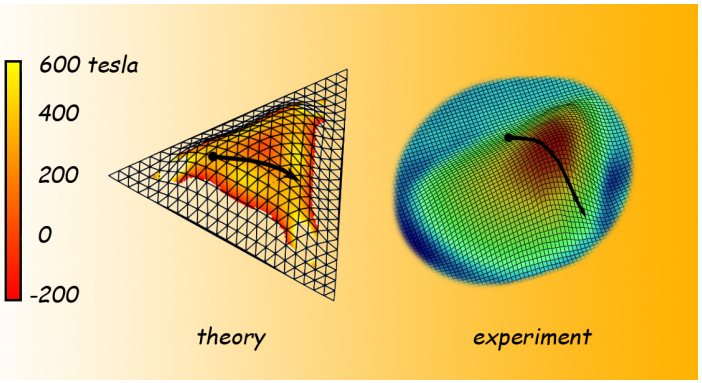


single atomic layer



10s of μm crater

- 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**
  - R. Agustsson (RadiaBeam Technologies LLC), S. Calatroni and R. Santiago Kern (CERN), V. Dolgashev (SLAC), R. Kaner (UCLA), E. Polyakova (Graphene Laboratories Inc), V. Solovyov (BNL).

Graphene synthesis

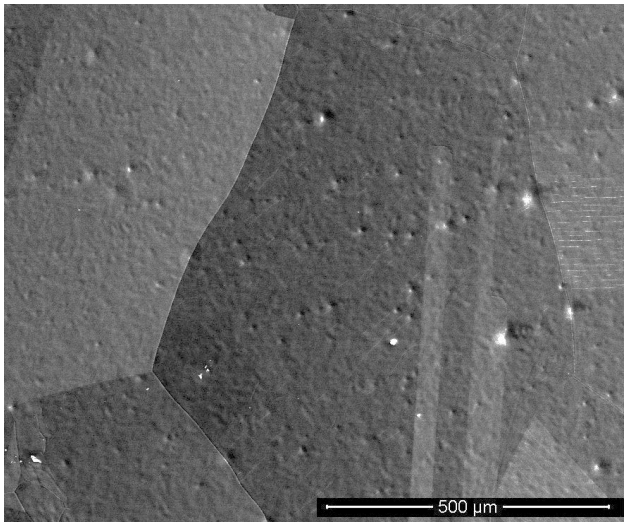
- Copper sample treatment is achieved by chemical vapor deposition (CVD) growth of graphene by decomposition of hydrocarbons on transition metal surfaces at elevated temperatures.
- A mixture of $H_2/Ar/CH_4$ is blown over the target plates at 1000 °C to grow the graphene layers.

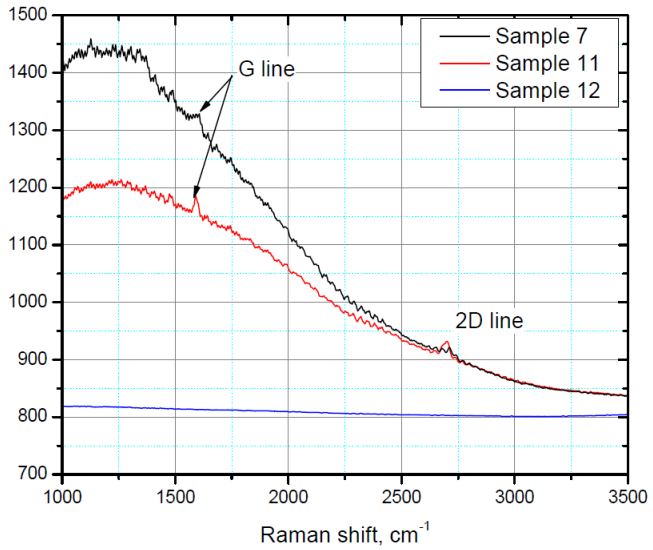
(courtesy of E. Polyakova, Graphene Laboratories Inc., and CVD Equipment Corp Application Lab)

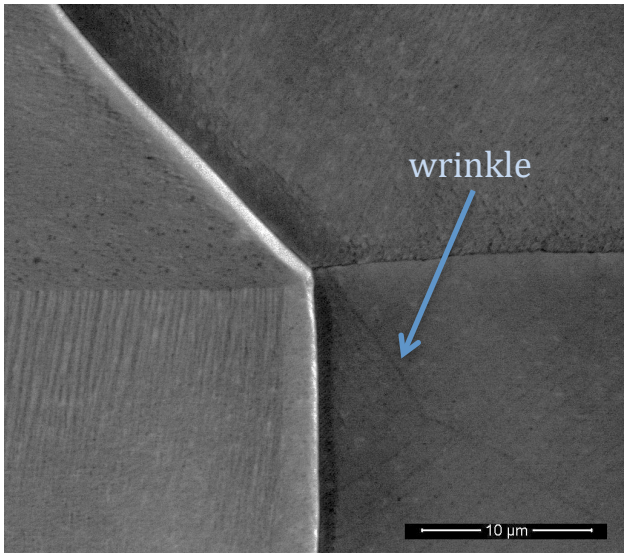
GRAPHENE LABORATORIES

QA procedure

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

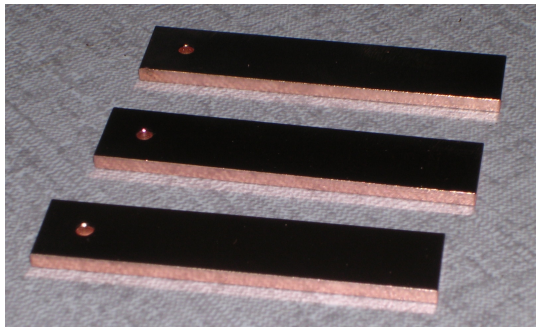


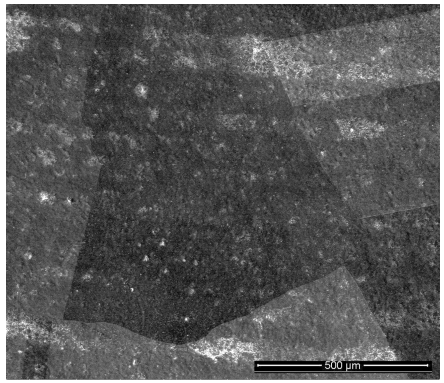




Synthesis Results

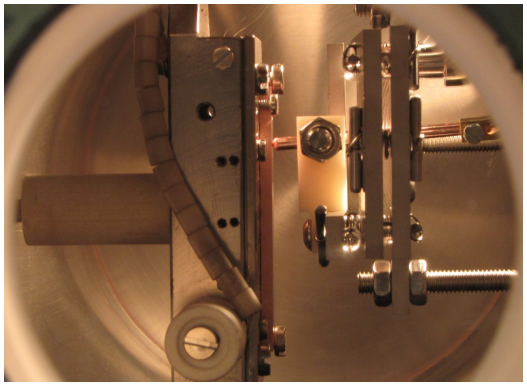
- Prepared 15 samples in a geometry suitable for CERN DC breakdown chamber
- Surfaced polished and cleaned, following the best practices
- 3 of the samples were left uncoated for reference, 8 samples were coated with monolayer graphene, and 4 samples were nickel coated in an attempt to develop a multilayer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

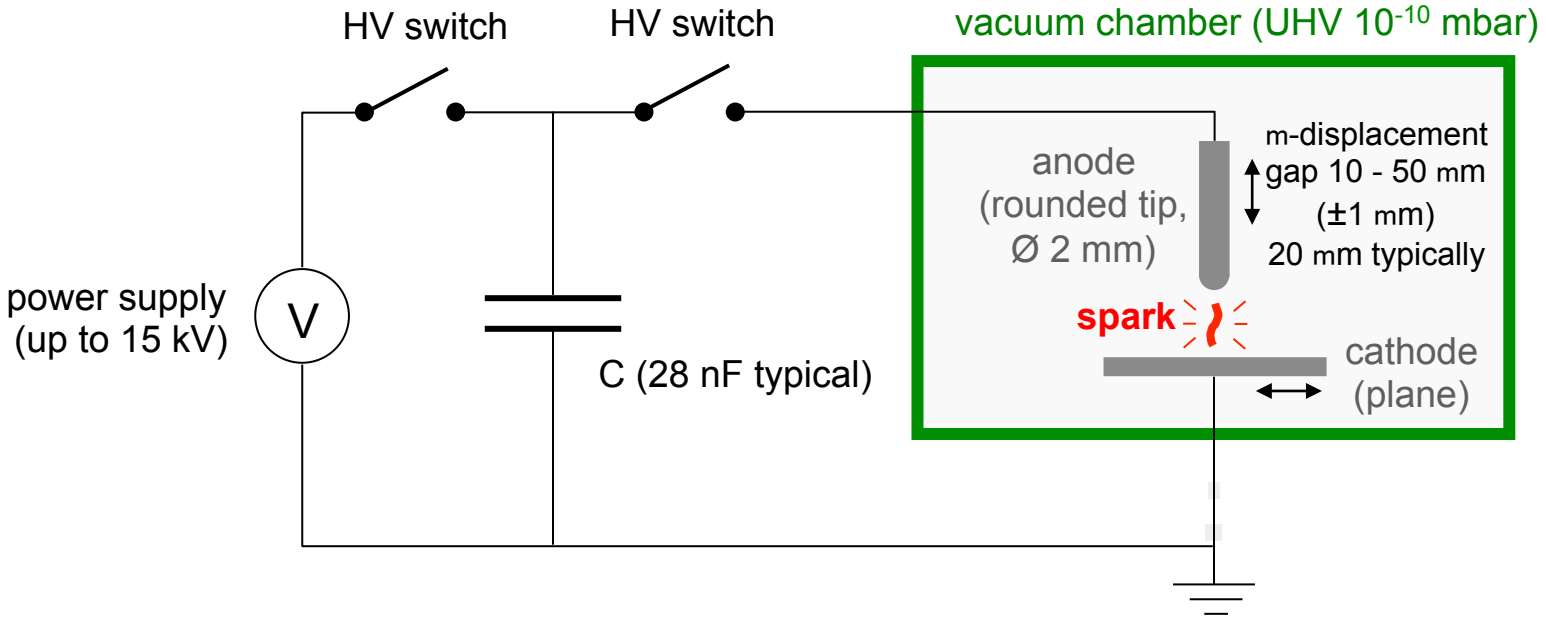




DC Spark Chamber Tests

- 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.

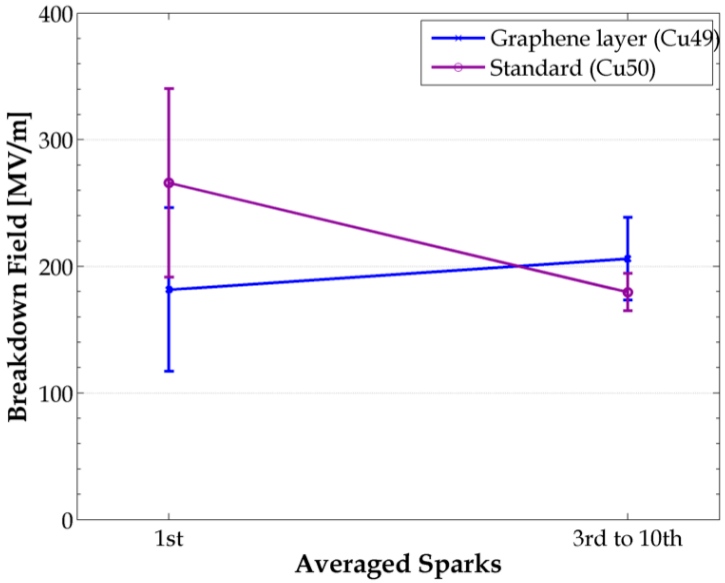




Adapted from: S. Calatroni, "DC breakdown measurements ", presentation at RF breakdown workshop at CERN, June 2010

DC Spark Chamber Test Results

- No improvement has been observed with the graphene coated samples.
- After the first few sparks, the behavior is nearly identical w/ 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.

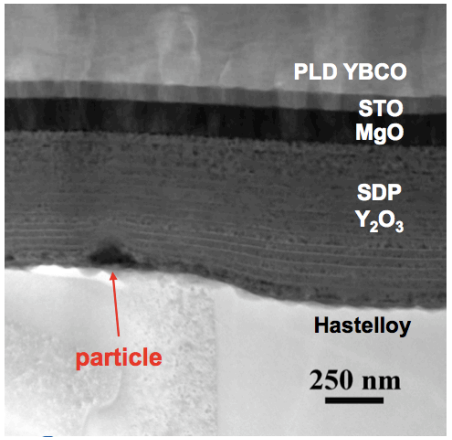


Sample	E_{b1} [MV/m]	E_{sat} [MV/m]
Cu49	181.67 ± 64.56	206.01 ± 32.76
Cu50	265.87 ± 74.43	179.62 ± 14.83

(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.