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MODELING FIELD EMISSION FROM REAL SURFACES

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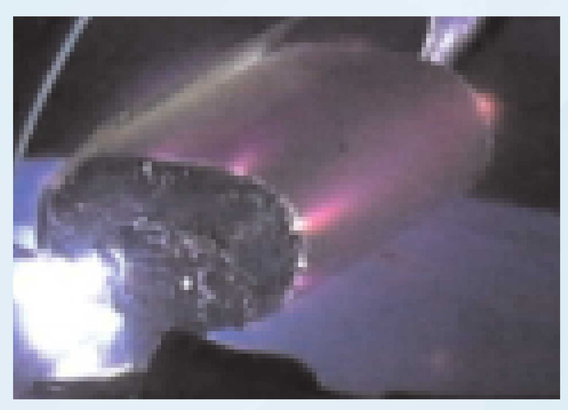
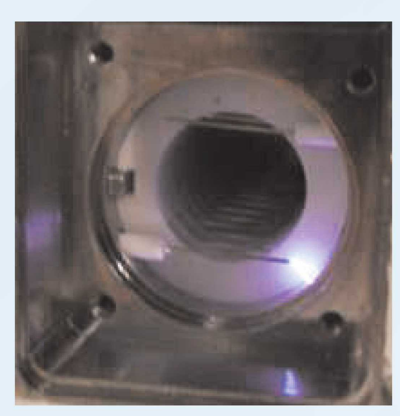
MOTIVATION

Electrical discharge occurs when the resistance between two electrodes drops significantly resulting in large currents. Discharge is a critical phenomenon for many electronic devices of interest to national security as well as scientific and commercial purposes.



Capacitors

The goal of the project is to move towards a predictive modeling capability for vacuum discharge that, once validated, can suggest improvements to designs, materials, and manufacture processes for vacuum devices by providing predictive bounds for discharge voltages based on as-built real surface variability.



Strong Links

CHALLENGE

Vacuum discharge is generally initiated (and sustained) by electric field induced emission of electrons from a surface. However, field emission from real surfaces with roughness, grain boundaries, and contamination layers is not understood. Currently field emission is described by curve-fitting a "field enhancement" β for the Fowler-Nordheim equation:

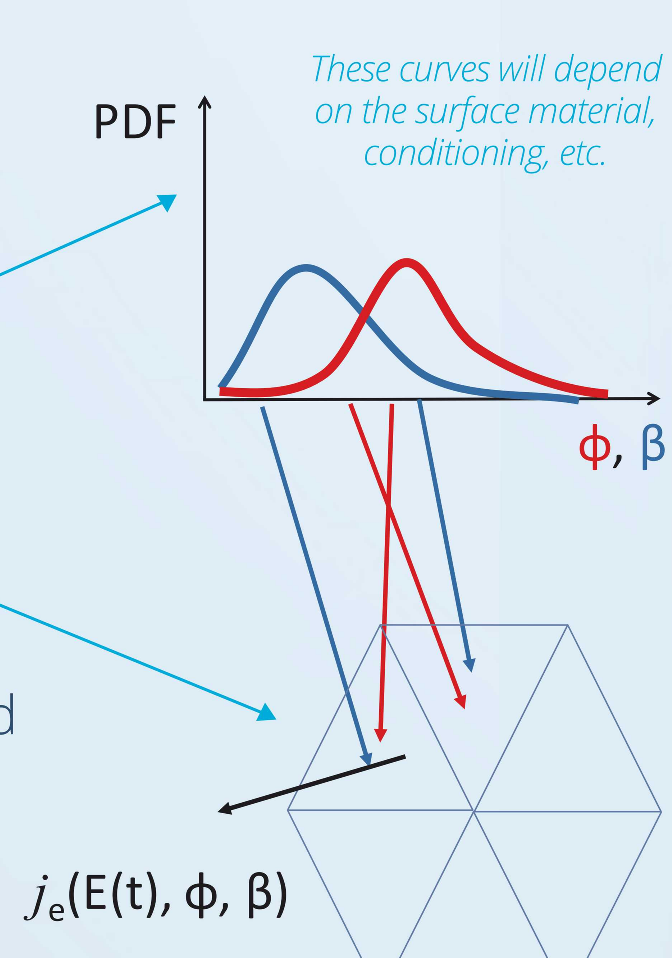
$$j = A_{eff} A_{FN} \frac{(\beta E)^2}{\phi} exp\left[-\frac{B_{FN}\phi^{3/2}}{\beta E}\right]$$

We desire to eliminate β as a "fit parameter":

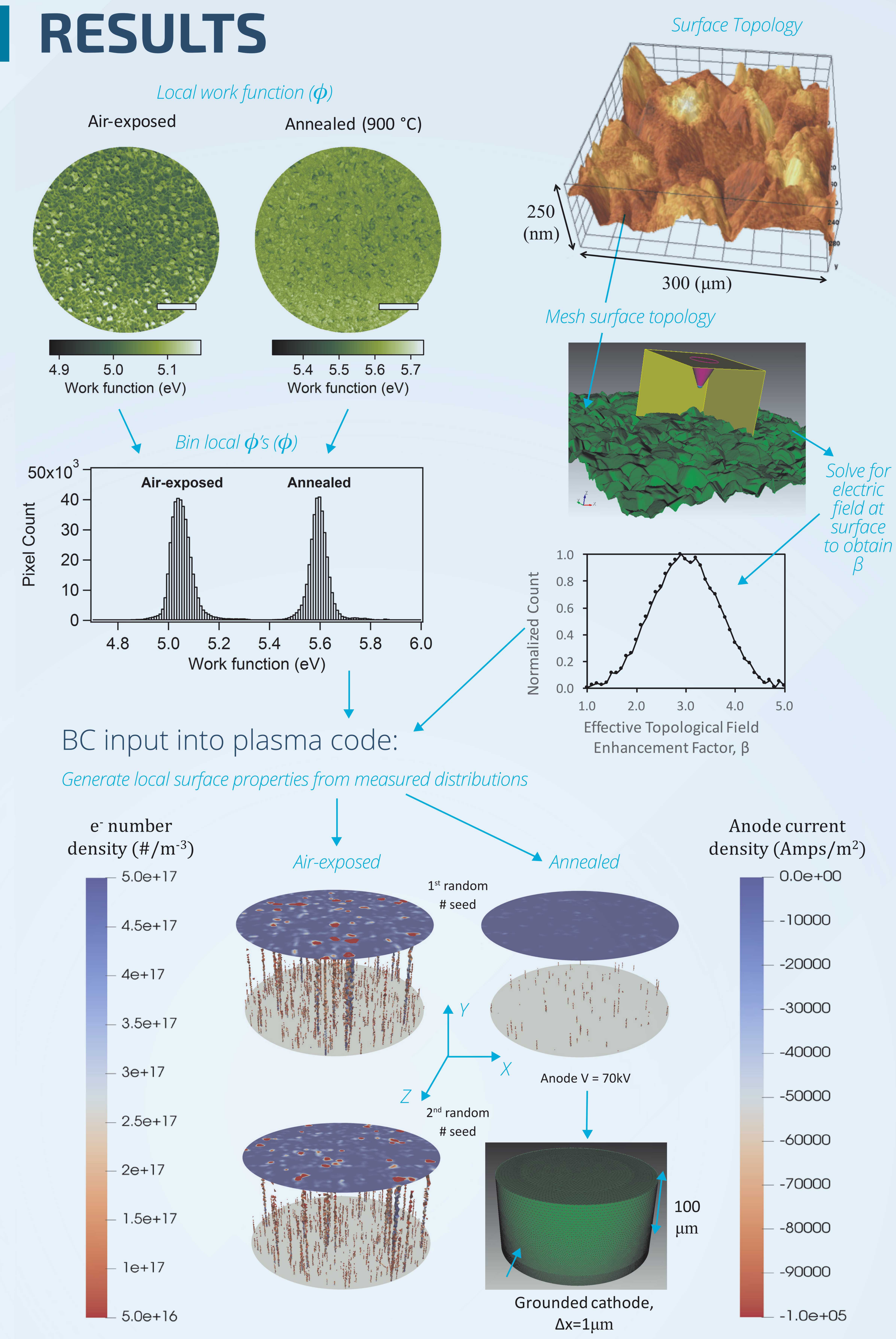
- Use Atomic Force Microscopy (AFM) to measure topology (β)
- Use PhotoEmission Electron Microscopy (PEEM) to measure work function (ϕ)
- Use measured distributions for ϕ and β in discharge simulations

TECHNICAL APPROACH

1. Create sample electrode (Pt, Pt with MgO layer)
2. Measure local topology, work function, and electron emission for sample
3. Generate probability distribution functions (PDF) for local work functions and effective topological field enhancement
4. Incorporate measured distributions into discharge simulations by populating time-varying element-based data from the PDFs
5. Compare family of plasma discharge simulations to measured breakdown behavior



RESULTS



SUMMARY AND FUTURE WORK

We can now model field emission based on local surface properties (β, φ) allowing for simulations of vacuum discharge that incorporate surface variability and avoid using a calibrated parameter.

- We have characterized the local function and topology of Pt and developed distributions of work function and topological β
- We have developed the capability in Sandia's kinetic plasma code to generate variable local work functions and topological β

Going forward we will:

- Incorporate exp. results for various controlled contaminants (e.g. TiO_2 and MgO) into our model for field emission
- Add fiducials on the surface to understand (and capture)

References

1. Berg, et al., 2018, "Work function of textured Pt thin films with disorder", in preparation.
2. Moore et al., 2018, "Modeling vacuum arc initiation for realistic Pt electrodes.", in preparation.

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