

MODELING HIGH-VOLTAGE BREAKDOWN FOR ANGLED SINGLE- AND MULTI-STACK INSULATORS



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Outline



- I. Purpose and Motivation
- II. Overview of Previous Work
- III. Recent Work
 - Case study for a monolithic insulator configuration.
- IV. Remaining Work and Conclusions
- V. References and Thanks



Purpose and Motivation

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- What is breakdown?
 - Deleterious current develops and can grow, leading to damage.
- Why study breakdown?
 - Affects many disciplines.
 - Multiple causes^{1,2}, but no general consensus about
 - ✦ ramp up
 - ✦ sustainment

Goal: Characterize and order contributions to electrical breakdown from DC through RF and devise methods to ultimately control breakdown.

Approach: Simulate Jordan, et al.³, multipactor theory using Particle-In-Cell techniques (XOOPIC) and extending to the space-charge regime.

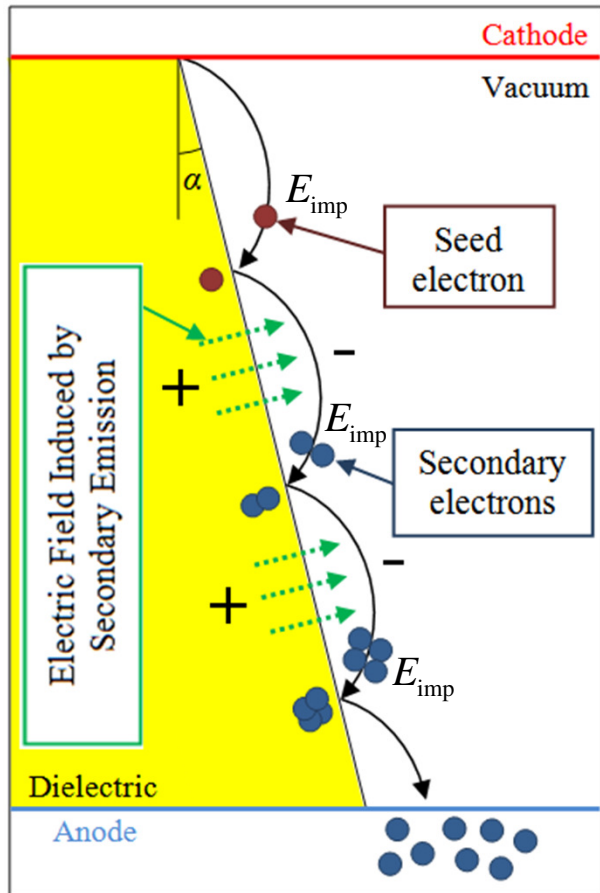
3. N.M. Jordan, Y.Y. Lau, D.M. French, R.M. Gilgenbach, and P. Pengvanich, “Electric field and electron orbits near a triple point”, Jour. Appl. Phys., Vol. 102, 033301, 2007.

1. R. Barker, E. Schamloglu, *High-Power Microwave Sources and Technology*, IEEE, New York, 2001.
2. R. Latham, *High Voltage Vacuum Insulation*, Academic, New York, 1995



Previous Work and Models

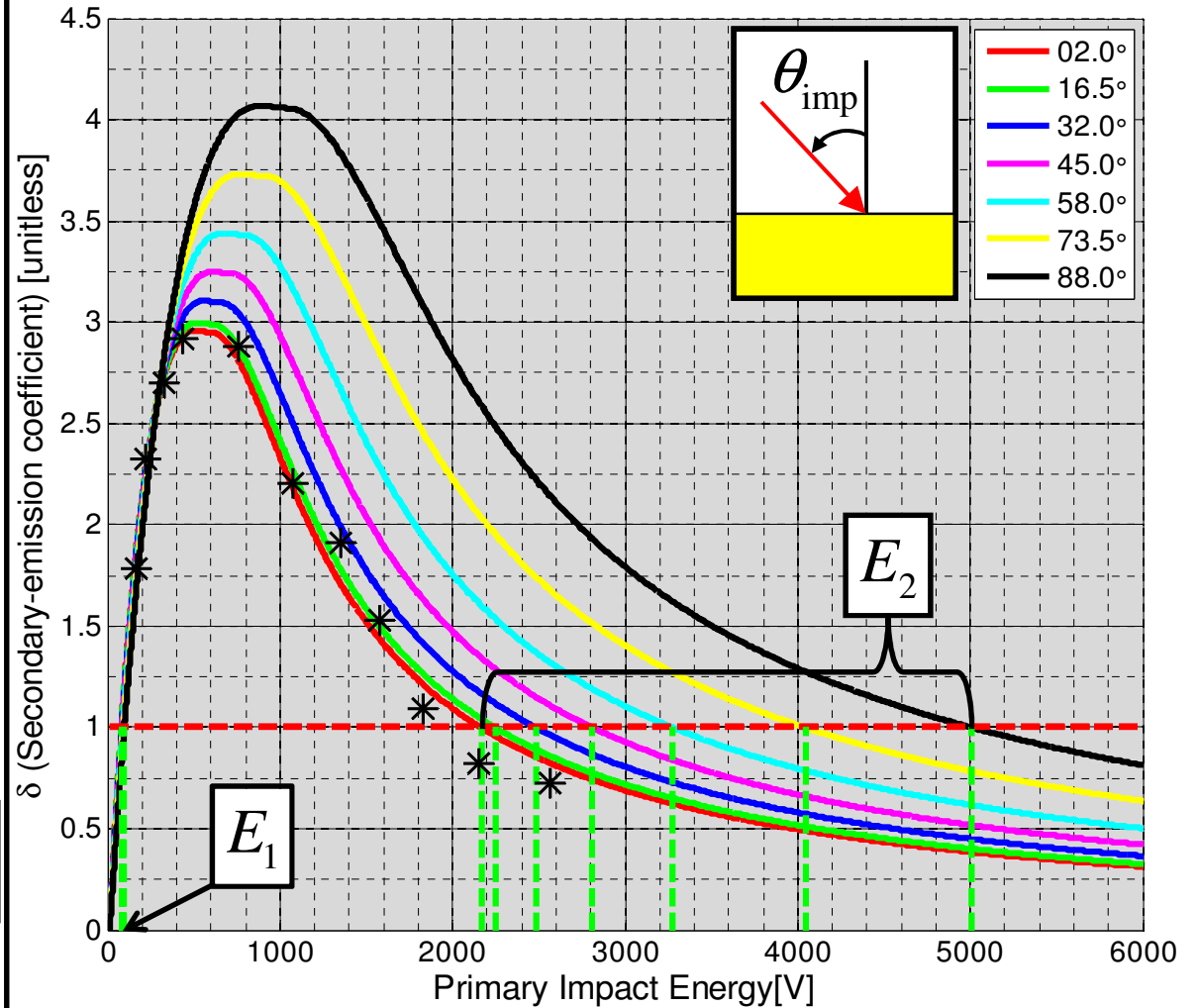
Multipactor



$$\delta = \frac{\text{Number of electrons emitted}}{\text{Number of impacting electrons}}$$

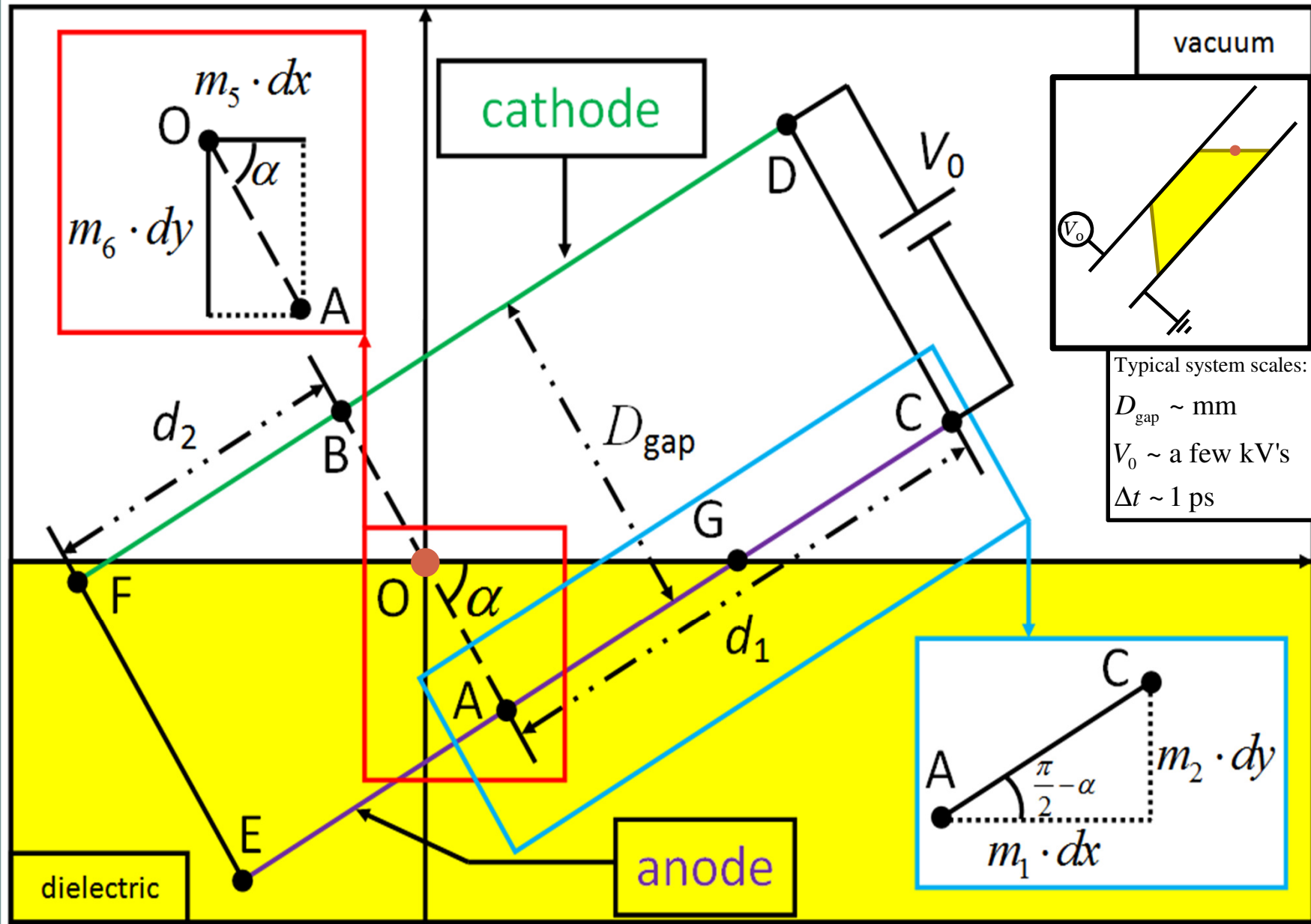
$$0 < \alpha < 9.1^\circ \times \left(\frac{\epsilon_r + 1}{\epsilon_r} \right) \times \sqrt{\frac{E_{om} / (1 \text{ eV})}{E_1 / (40 \text{ eV})}}$$

Secondary emission coefficient vs. energy for various angles;
 δ_{\max} at normal incidence (0°) = 2.95



1. R. Vaughan, "Secondary Emission Formulas", IEEE Trans. Elec. Dev., Vol. 40, No. 4, p. 830, 1993.
2. M.C. Baker, "Secondary electron emission from dielectrics", Master's Thesis, Texas Tech University.

Model Parameters in Simulation





Recent Work: Monolithic General Results

Case Study: $\alpha = 10.1^\circ$, in Breakdown

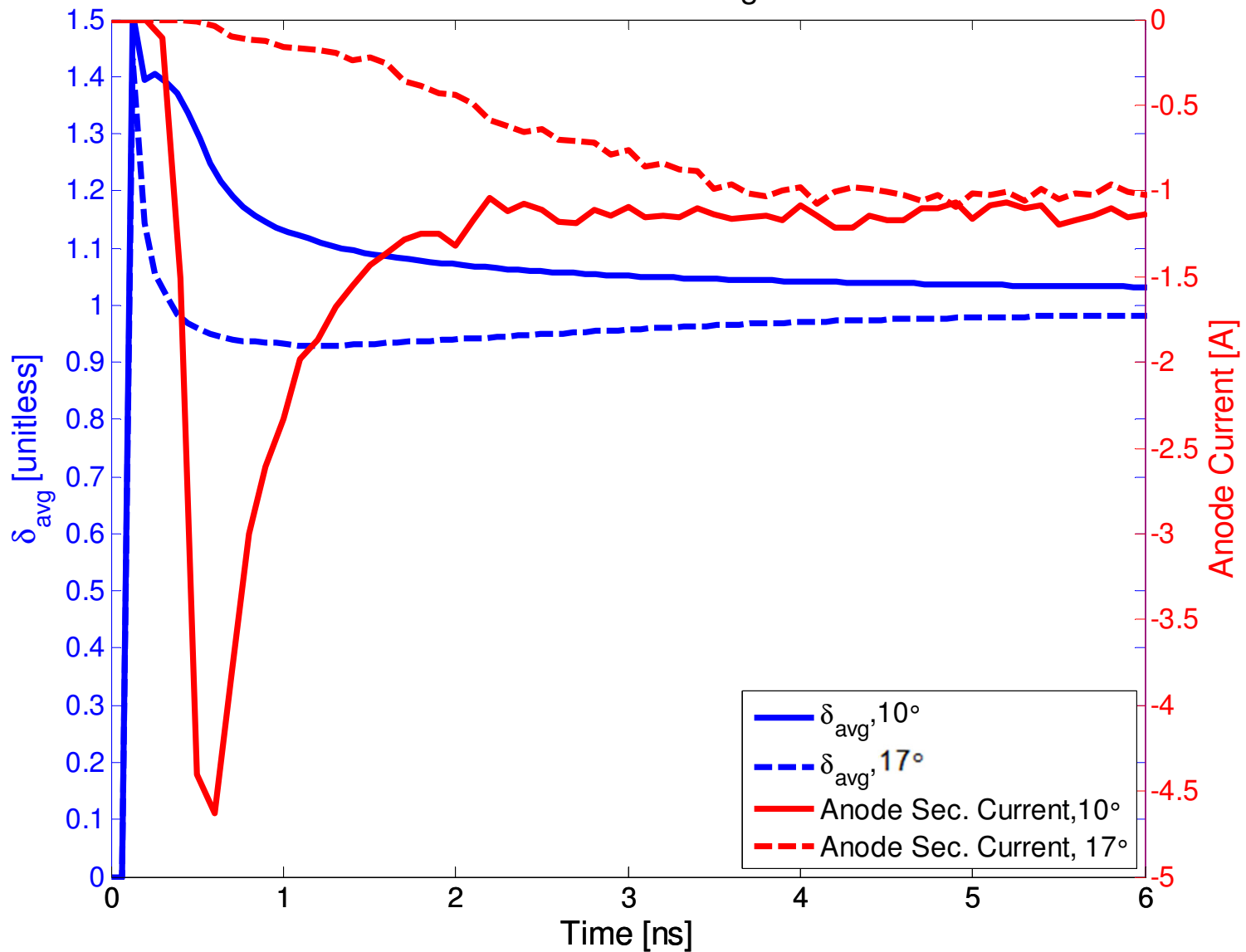
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(alpha10_1000V.avi)

Case Study: $\alpha = 16.5^\circ$, in Breakdown

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Figure of Merit: Average δ

Anode Current and δ_{avg} vs. Time





Remaining Work and Conclusions

Remaining Work

Triple-point emitter:

- Allow for multiple triple-point emitters; important for **multi-stack model**.

Multi-Stack:

- Secondary emission for **dielectrics and metals**.
- Finite-thickness electrodes.
- Floating capabilities.

Gases:

- Low-pressure collisions with gases
 - ionization, excitation, elastic scattering
 - Plasma formation over the surface
- Power deposition of secondaries
 - Gas kinetic theory + diffusion equation

Extension to RF fields:

- RF fields will:
 - contribute to escape fields
 - lead to additional constraints on breakdown voltage
- Differs from usual studies in that RF field is **not tangent** to surface.

Conclusions

Monolithic Insulators:

- Developed improved geometric and secondary emission models
 - Issues with increased resolution, but bulk quantities average out.
- Threshold for breakdown
 - Average secondary emission coefficient useful for defining multipactor-dominated breakdown.
 - See **multiplicative breakdown between 0° and 10°** ; otherwise dark-current-like regime.
- Understanding influence of spatial and temporal evolution of the dielectric surface charge.
 - **Positive dielectric charging facilitates multipactor breakdown.**
 - Negative dielectric charging facilitates the growth of dark current.
 - First crossover seems to be the stable point in steady state.

Multi-stack Insulators:

- Templates are in place.

Concerning general modeling:

- Need final model for triple-point current emission.
- Inclusion of gaseous species will finish DC studies.

References and Thanks!



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Dr. John Booske of the University of Wisconsin
Dr. John G. Leopold of Rafael Laboratories

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3. N.M. Jordan, Y.Y. Lau, D.M. French, R.M. Gilgenbach, and P. Pengvanich, "Electric field and electron orbits near a triple point", Jour. Appl. Phys., Vol. 102, 033301, 2007.
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