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Experimental Control of Electrical Breakdown Variance in Atmospheric Conditions

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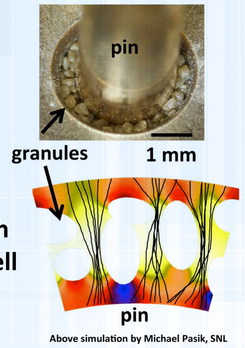
Motivation

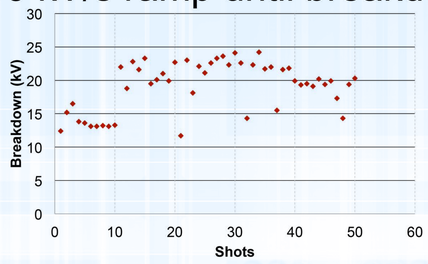
Lightning arrestor connectors (LACs) provide electrical protection against lightning strikes.

High-permittivity dielectrics concentrate the electric field and seed breakdown, shunting high voltage to ground, though this process is not well understood.



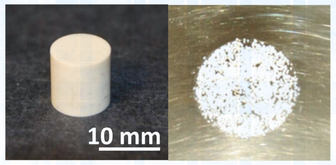
Above simulation by Michael Pasik, SNL

50 shot series @ 5mm open gap
10 kV/s ramp until breakdown



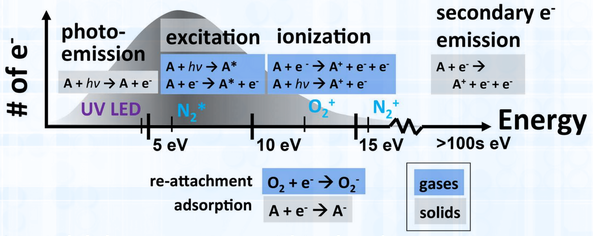
Improve experimental variance and understand breakdown mechanisms

1) Control variance during breakdown
2) Understand the role of dielectric interfaces



Rutile (ε_r ~ 100) is a material of interest for application in lightning arrestor connectors (LAC)

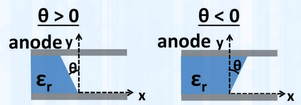
Primary collision processes in atmospheric breakdown



We model these reactions within the plasma
Inputs: Materials, gas composition, voltages, geometry,
Outputs: Electron and ion density, electric field, γ emitted
***** Presence of an initiating electron is assumed.

Dielectrics shape the electric field

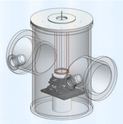
θ < 0: Triple-point junction at the dielectric-air-metal interface enhances E-field.
Enhancement increases with increasing ε_r

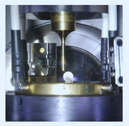


E-field converges; repelling e⁻

E-field diverges; attracting e⁻

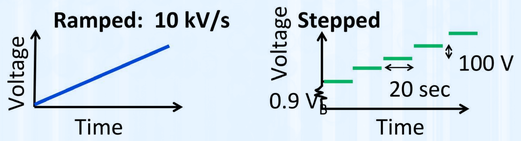
Reproducible measurements: Controlled atmosphere and E-field





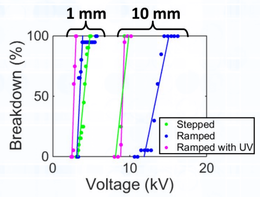
600 Torr dry air
d_{gap} = 1-10 mm
Brass electrodes

Ensure initiating electron with voltage profile and/or UV irradiation (265-nm)



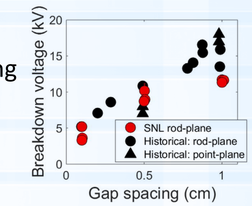
1) Controlled variance during atmospheric breakdown

Breakdown is probabilistic
- **Wait for an electron:** Stepped voltage profile
- **Add an electron**: UV-simulated photoemission from electrode surfaces



Demonstrated controlled atmospheric breakdown, validating models and enabling reproducible materials studies.

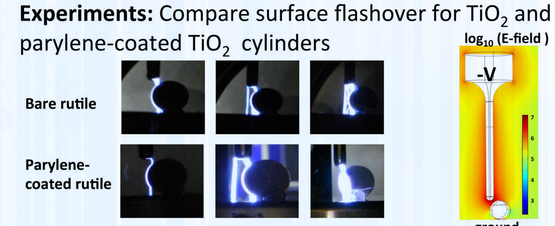
What mechanism seeds breakdown inside a LAC?



2) Dielectric directed breakdown

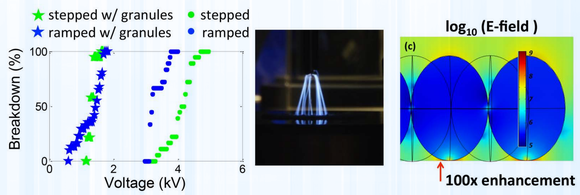
Hypothesis: e⁻ emission from TiO_2 nucleates breakdown

Experiments: Compare surface flashover for TiO_2 and parylene-coated TiO_2 cylinders



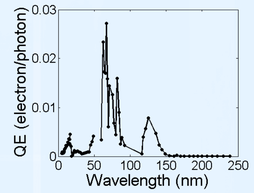
Result: Neither surface initiated breakdown

New hypothesis: Triple-point enhancement at the dielectric/air/ground interface seeds e⁻ emission



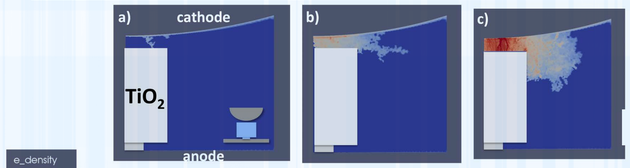
New quantum efficiency (QE) data from NIST

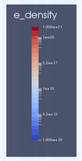
~ one e⁻ emitted per 50 photons
Rutile is a poor photoelectron source



5 nm-1200 nm QE data of TiO_2 surface

Particle-in-cell (PIC) models show plasma formation at the dielectric





Axisymmetric model of flashover over the TiO_2 cylinder

a) Initial surfaces are uncharged
b) Low PE, PI drives phonon emission from the electrode
c) Plasma bridges electrode-dielectric gap

Impact

- **Experimental validation of PIC models of plasma processes**
- **Understanding of triple-point field enhancement influences design of new materials and structures**

Future Work

- **Validate surface flashover with axisymmetric breakdown over dielectric cylinders.**
- **Control surface flashover with graded dielectrics and gratings.**
- **Investigate role of photoemission on streamer attraction**

Sandia National Laboratories

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