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Dielectric-Directed Control of Atmospheric High Voltage Breakdown

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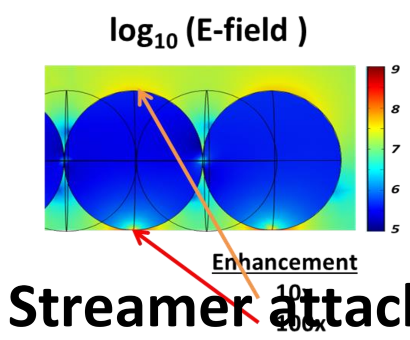
Dielectric stimulated breakdown

Dielectric granules concentrate the electric field and seed breakdown in gaps, shunting high voltage to ground, but fundamental mechanisms for surge protection are not fully understood.

- Field enhancement
- Streamer attachment
- Photoemission
- Secondary electron emission

- **Field enhancement**



10-100x field increase at air/electrode/TiO_2 triple point

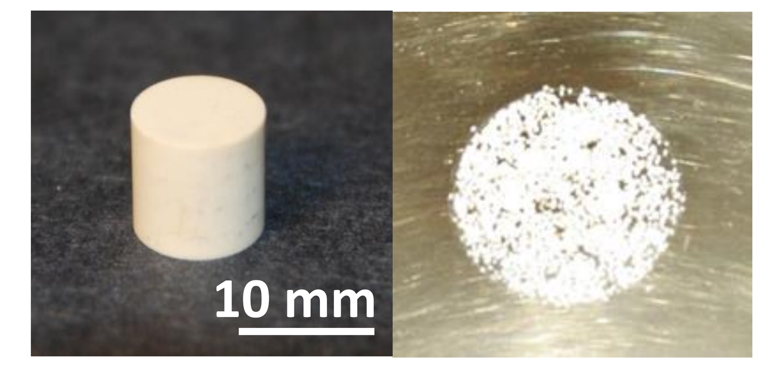
- **Streamer attachment**

Streamers observed to track high permittivity surfaces, directing breakdown path

Above simulation by Michael Pasik, SNL

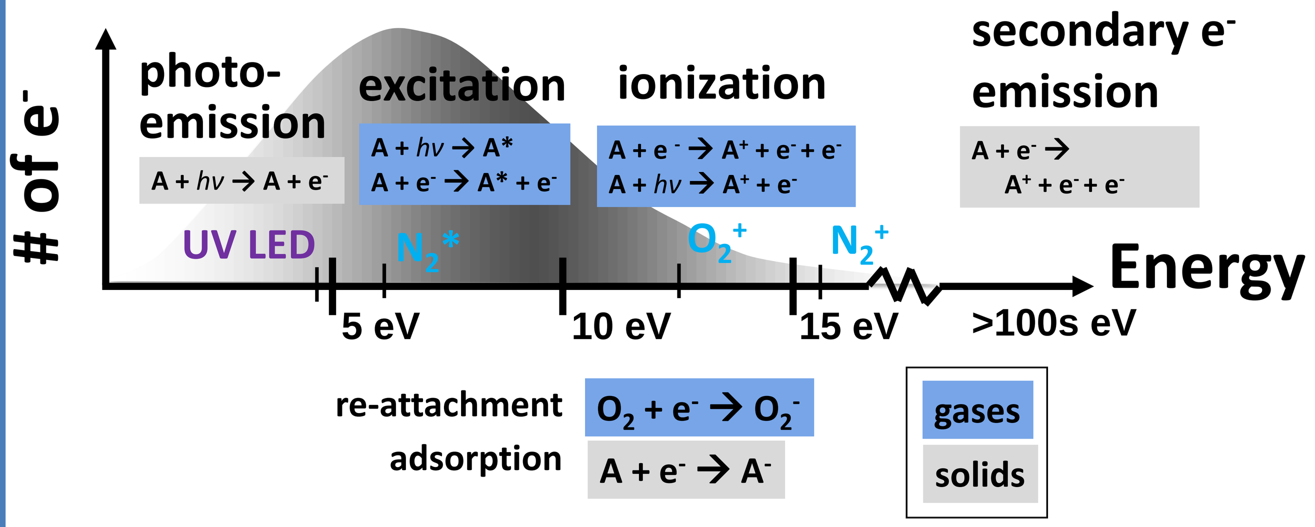
Goal: understand and predict breakdown mechanisms

1) **Control variance during breakdown**
2) **Understand the role of the rutile surface?**



We investigate dielectric stimulated breakdown with rutile cylinders and granules

Primary collision processes in atmospheric breakdown



We model these reactions within the plasma

Inputs: Materials, gas composition, voltages, geometry,

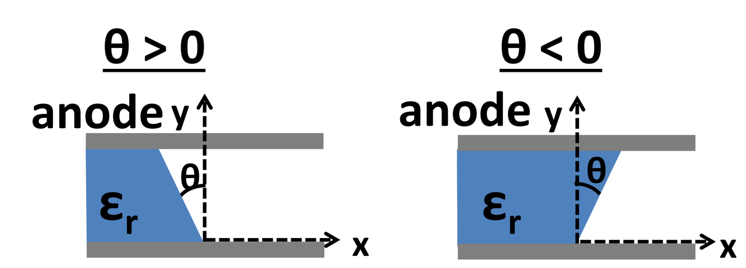
Outputs: Electron and ion density, electric field, γ emitted

* 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.

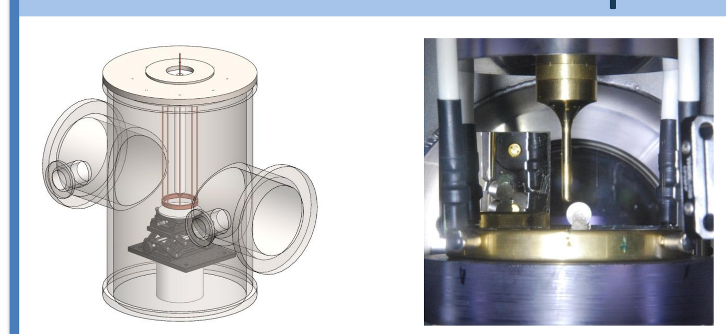
Enhancement increases with increasing ε_r



E-field converges; repelling e⁻

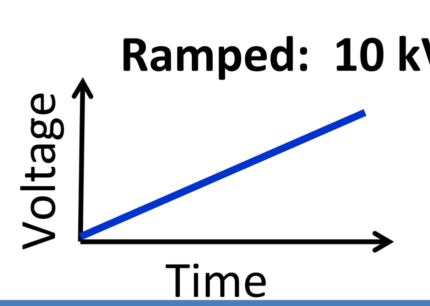
E-field diverges; attracting e⁻

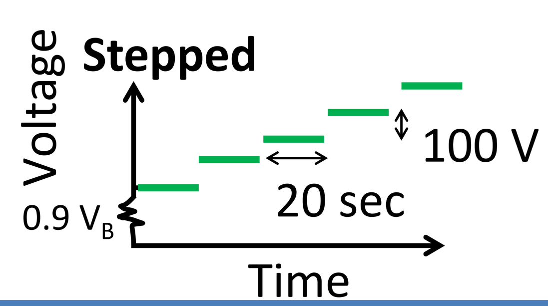
Reproducible measurements:
Controlled atmosphere and E-field



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

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

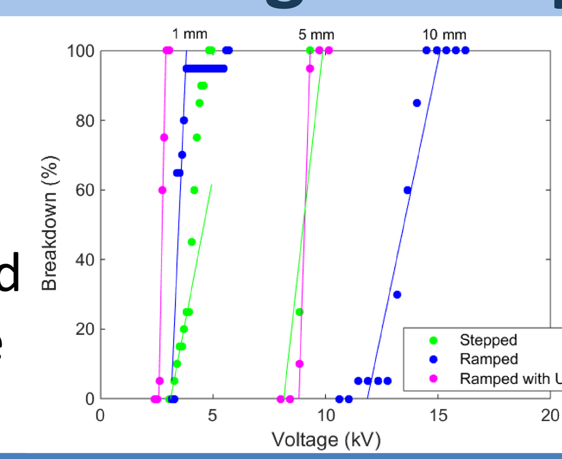




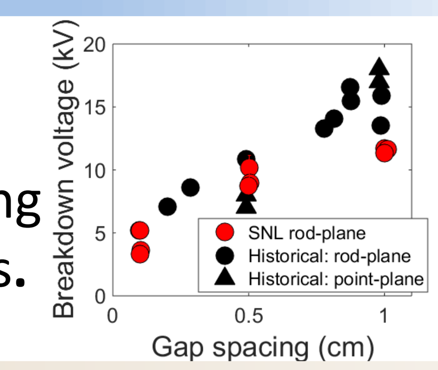
1) Controlled variance during atmospheric breakdown

Breakdown is probabilistic

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



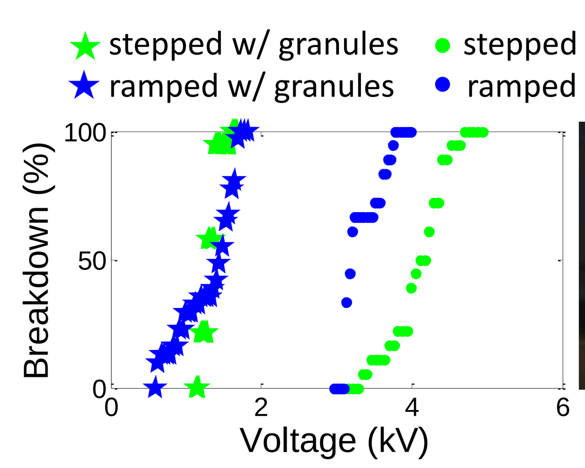
Demonstrated controlled atmospheric breakdown, validating models and enabling reproducible materials studies.

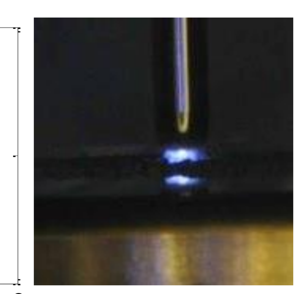


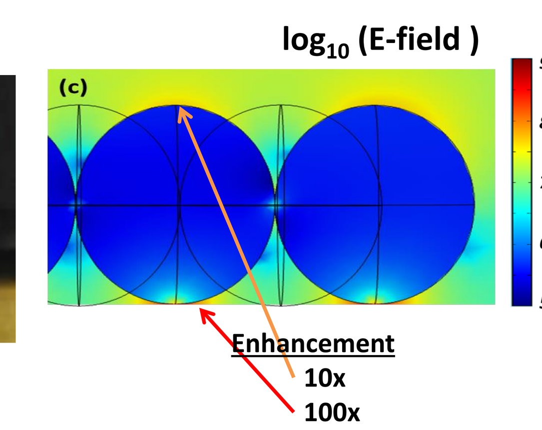
What mechanism seeds breakdown?

2) Dielectric directed breakdown

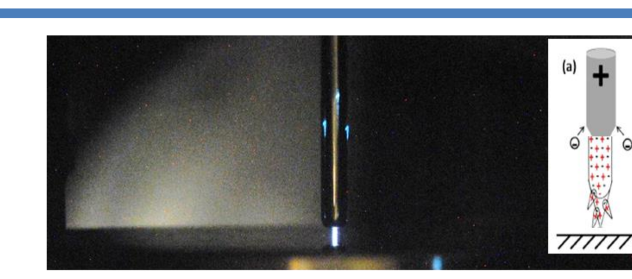
Hypothesis: Triple-point enhancement at the TiO_2 dielectric/air/ground interface seeds e⁻ field emission



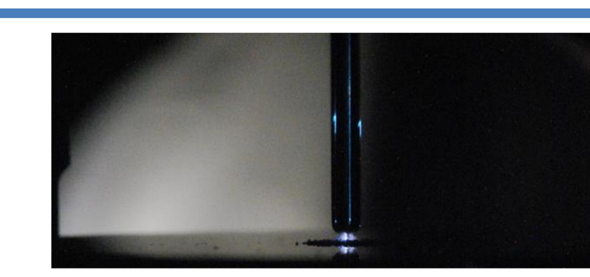




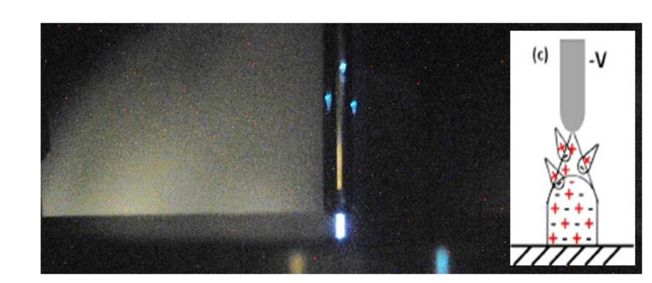
Rutile granules decrease V_B and variance



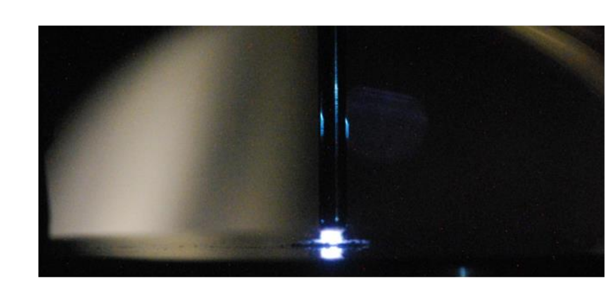
Empty 1mm gap, positive pin voltage: 2.92 kV



TiO_2 granules, positive pin voltage: 1.73 kV



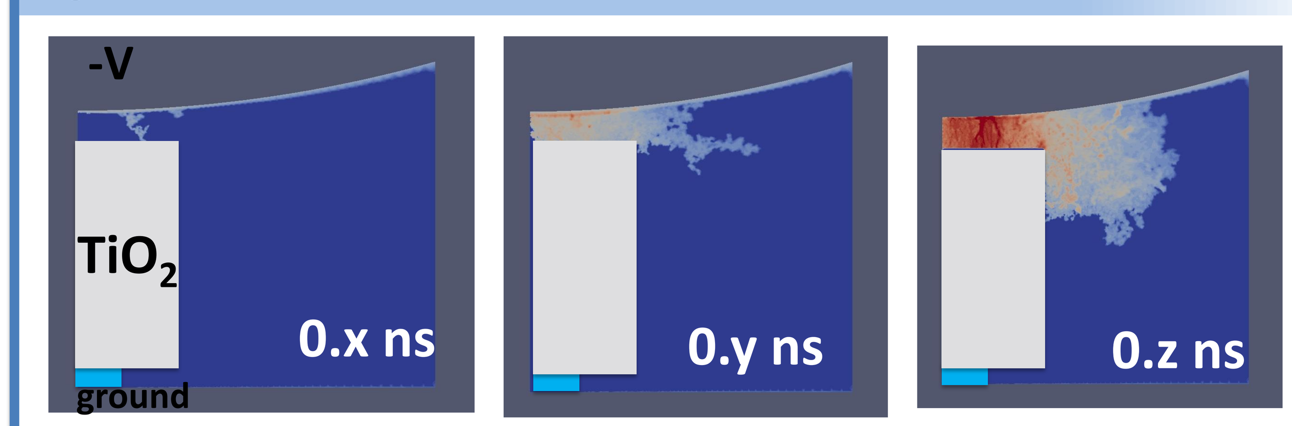
Empty 1mm gap, negative pin voltage: -3.05 kV

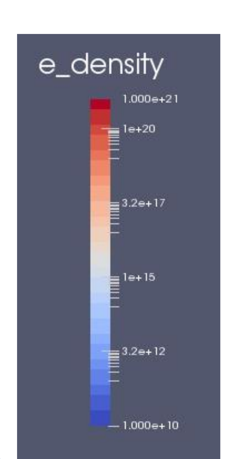


TiO_2 granules, negative pin voltage: -2.4 kV

Polarity dependence suggests cathode field emission seeds dielectric-stimulated arcing

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 photon emission from the electrode
c) Plasma bridges electrode-solid 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.
- Investigate control of field emission
- Investigate influence of permittivity contrast on streamer attraction to dielectrics

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