Sandia National Laboratories

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Characterization of photon-assisted plasma breakdown and development of *in-situ* surface spectroscopy in plane-to-plane discharges

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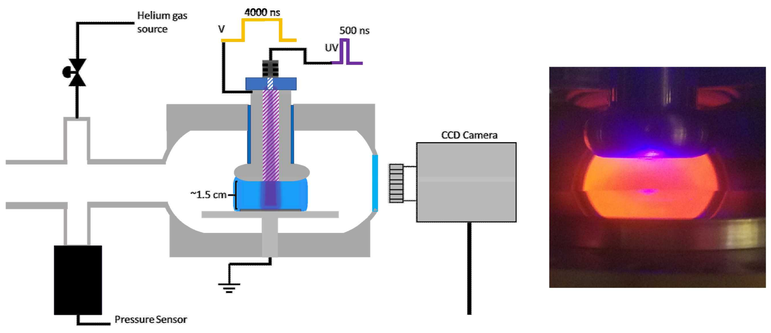
Gaining fundamental insight into plasma physics and breakdown phenomenon is critical in validating the predictive capabilities of Sandia's device performance codes. Of particular interest is surface-coupled breakdown processes induced by both cathode electron emission and ion/photon impingement. At t=0 s, a DC voltage pulse was applied to plane-to-plane electrodes for 4 us; concurrently, a UV diode produced 300 nm photons for 700 ns, initiating breakdown. Use of the diode forced a known breakdown solution, generating seed electrons from the cathode via photoionization of surface impurities, and removes the breakdown time stochasticity previously seen in DC pulse-only studies, The discharge has been run at 1, 5, and 10 Hz repetition rates to quantify a conditioning effect of the platinum cathode. This effect, potentially due to cathode surface chemistry has been observed and is the focus of current and future studies.

Experimental Set-up

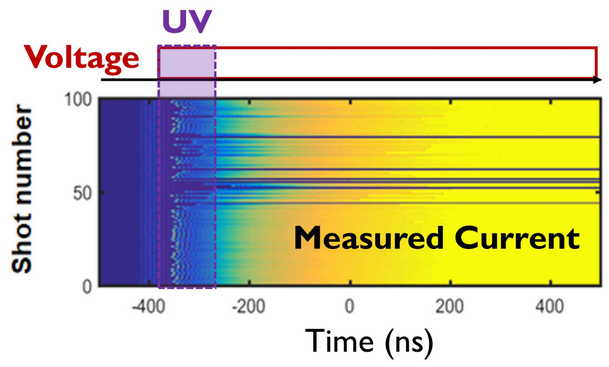
Schematic and image of UV-illuminated plane-to-plane electrodes in helium



Anode: Stainless Steel
Cathode: 4" Pt wafer
Gas Pressure (p): 100 Torr

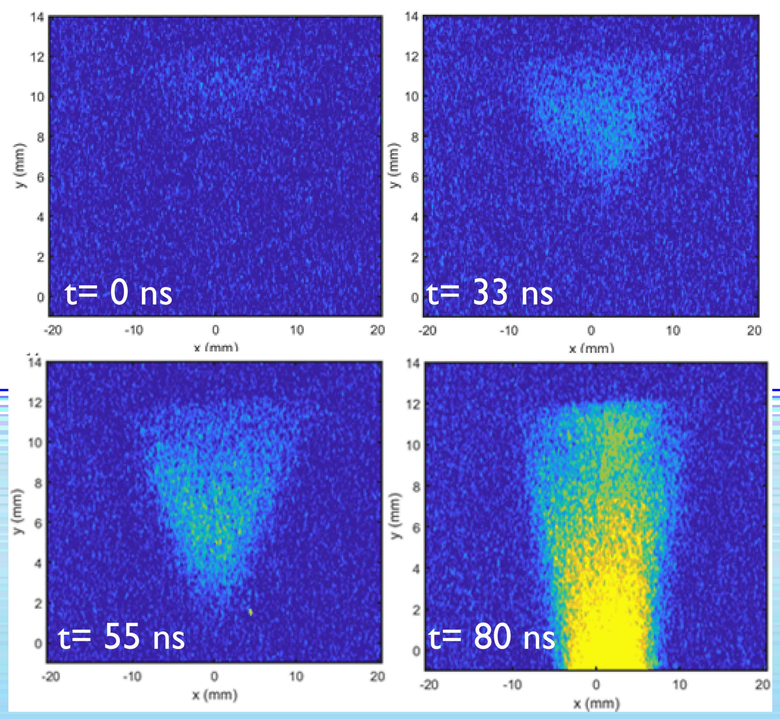
Gap (d): 1.5 cm
pd: 150 Torr cm
Paschen Breakdown: ~1.6 kV

Timing diagram for 100 shot sequence



Ionization wave

Single shot ICCD images of plasma

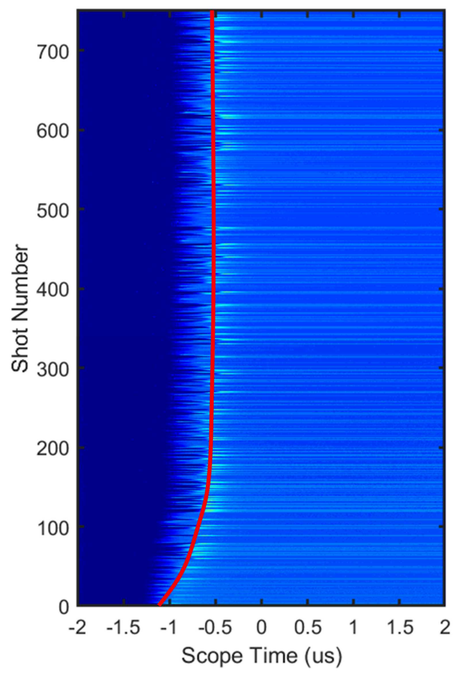


Helium, P = 50 Torr, V = 2 kV

- Propagation from anode to cathode shows diffuse breakdown wave front over the first 80 ns

Breakdown trends

Timing as a metric for surface conditioning



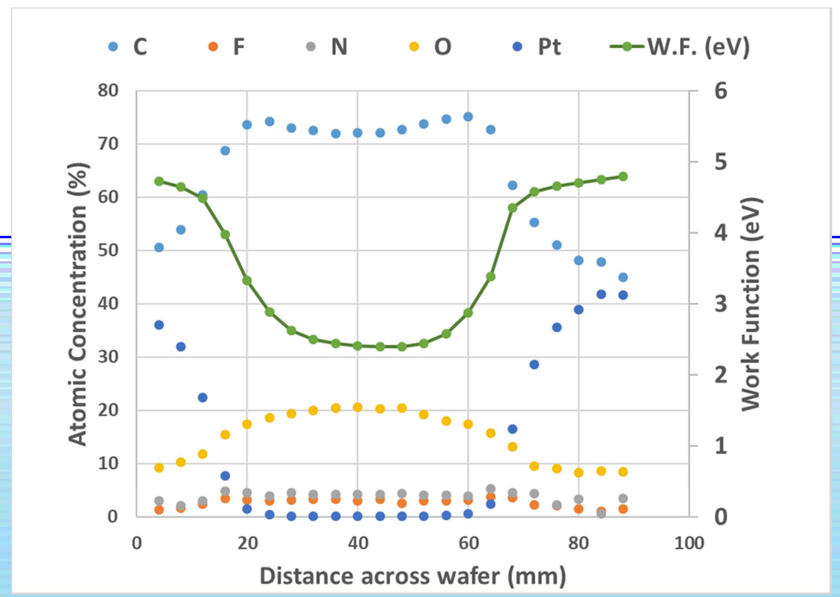
***P* = 100 Torr, *V* = 1.5 kV, 10 Hz rep. rate, Data recorded at 1 Hz**

- Breakdown time, τ, is defined as time for $I \geq 0.1\ A$
- Measured $|\tau_s| = 1.3\ us$ after V_{app}, $600\ ns$ after UV diode illumination ends
- Stability achieved after 504 shots → 5040 breakdown events

X-ray Photoelectron Spectroscopy

Ex-situ focused x-ray beam measures spatially resolved surface species

Atomic concentration (%) across Pt wafer

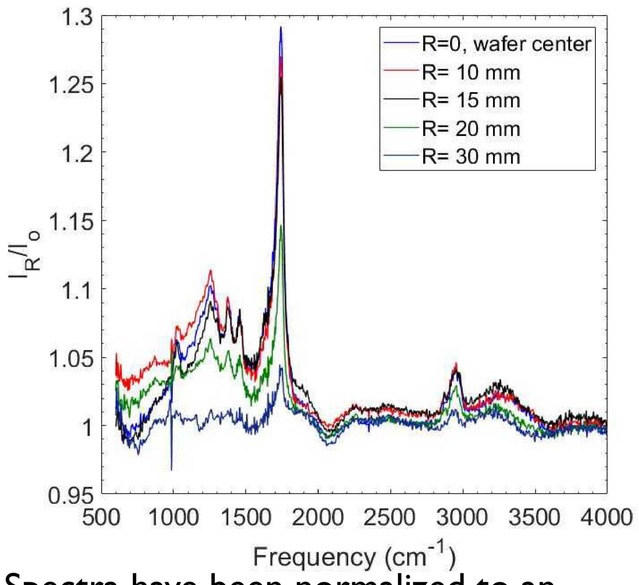


- Presence of platinum decreases while carbon and oxygen increase radially into region of plasma breakdown

Infrared Reflection Absorption Spectroscopy

- Both *ex-situ* and *in-situ* configurations
- Uses a commercially available FTIR
- Spectra averaged over 250 scans
- Sensitive to both gas and surface species

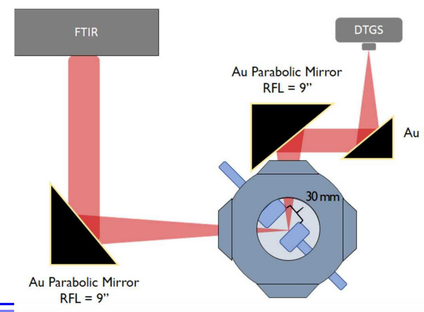
Ex-situ Spectra from Pt wafer



- Spectra have been normalized to an untreated wafer
- Intensity of C-bonds at 1700 cm^{-1} and 2900 cm^{-1} increase radially to wafer center
- IRRAS confirms XPS measured radial distribution of surface species

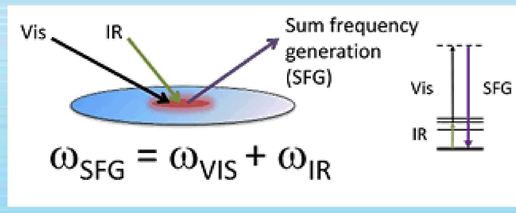
Future work: *in-situ* diagnostics

Schematic and images of IRRAS coupled to test cell



Anode: Stainless Steel
Cathode: 1" Pt wafer
Gap (d): 3 cm

Sum Frequency Generation (SFG)



- Current collaboration between S. Baldelli at the University of Houston and Sandia
- SFG further confirmed the presence of C-bonds on wafer

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