US Air Force Academy Dielectric Barrier Discharge Plasma Investigations

What we know and what we need to know

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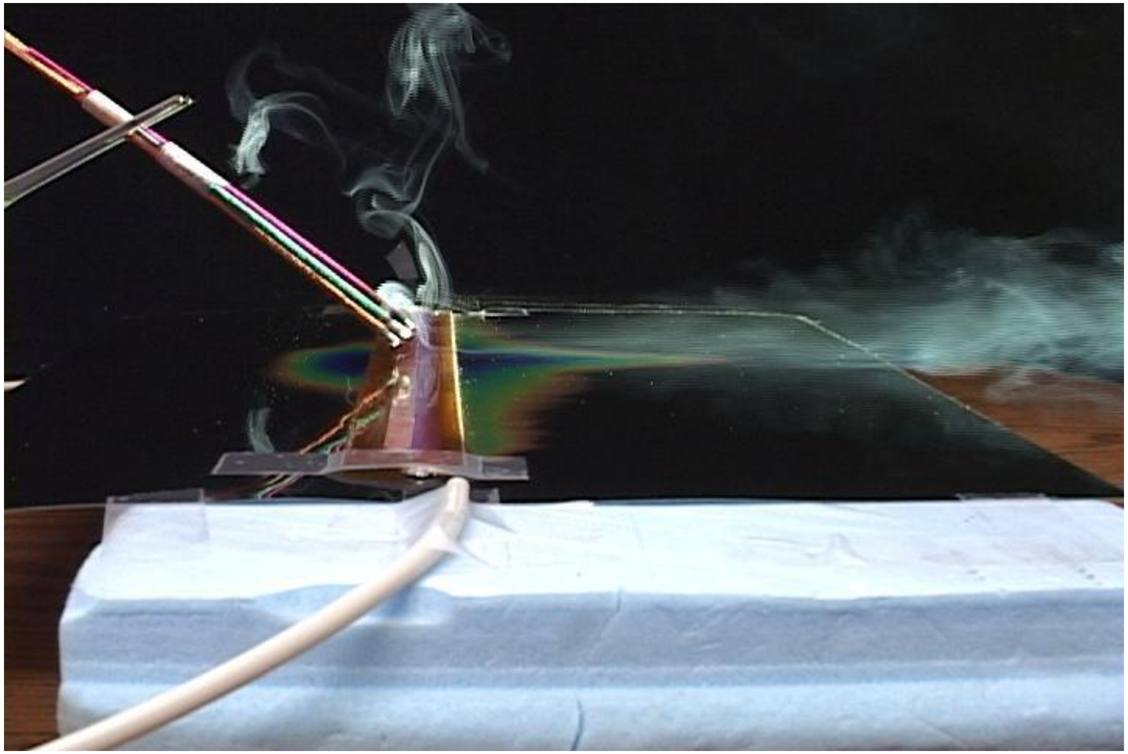
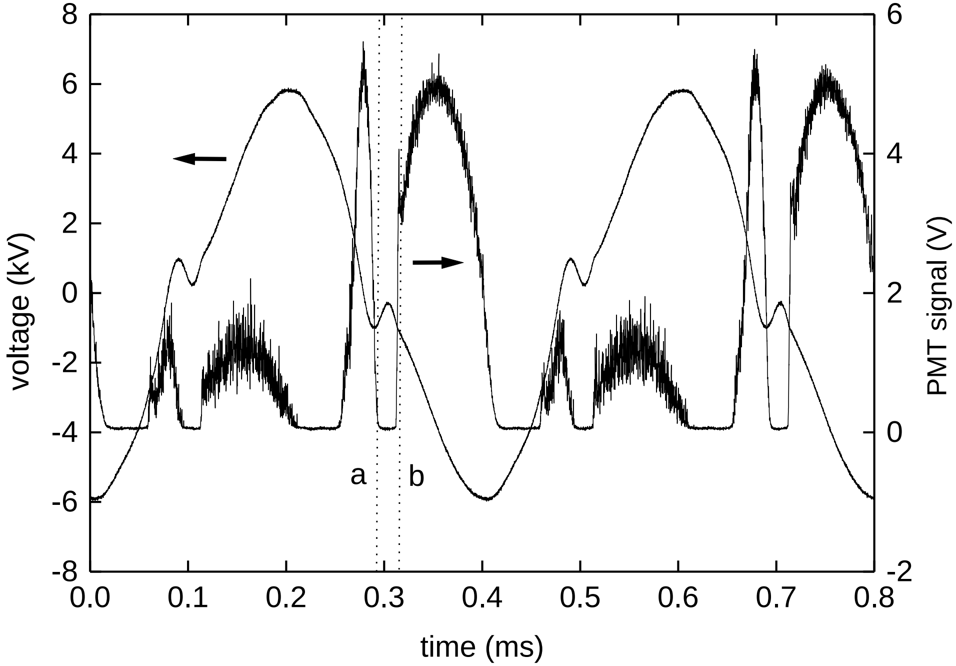
Overview

- Physics Investigations
- Applications

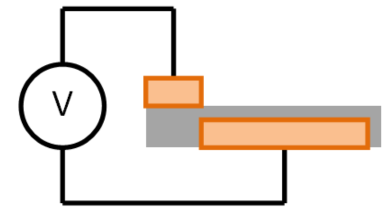
Stable Plasmas at Atmospheric Pressure with Aerodynamic Effects



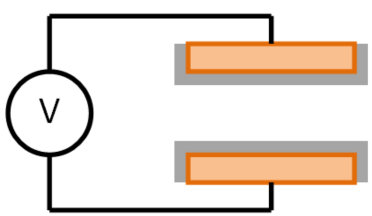
Identifying the Plasma Actuator as a Dielectric Barrier Discharge



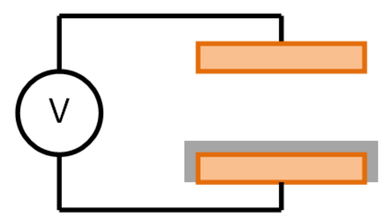
Single Dielectric Barrier (Aerodynamic Applications)



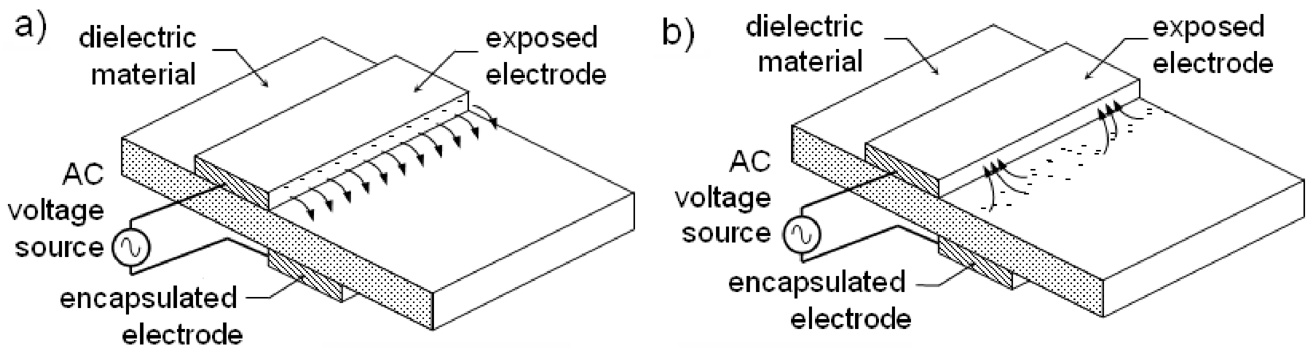
Double Dielectric Barrier (Plasma Processing Applications)



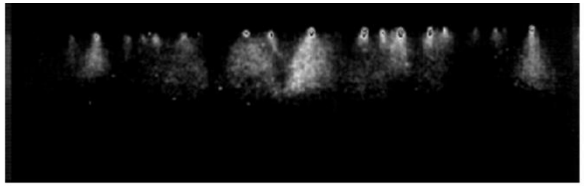
Single Dielectric Barrier (Research)



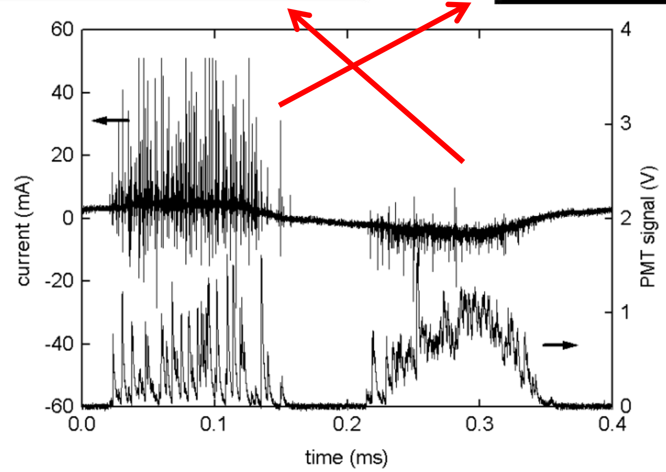
“Forward” vs. “Backward” Strokes in the Single Dielectric Barrier Discharge



Visual Evidence

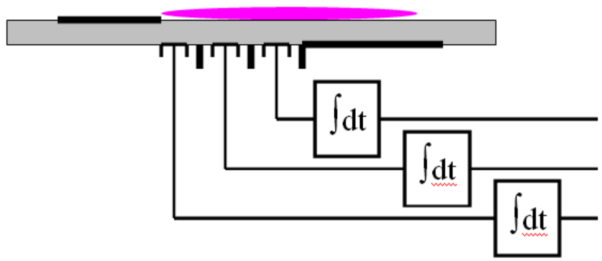


Electrical Evidence

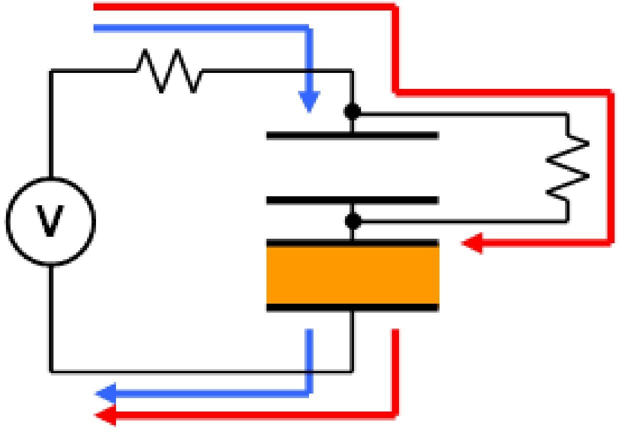


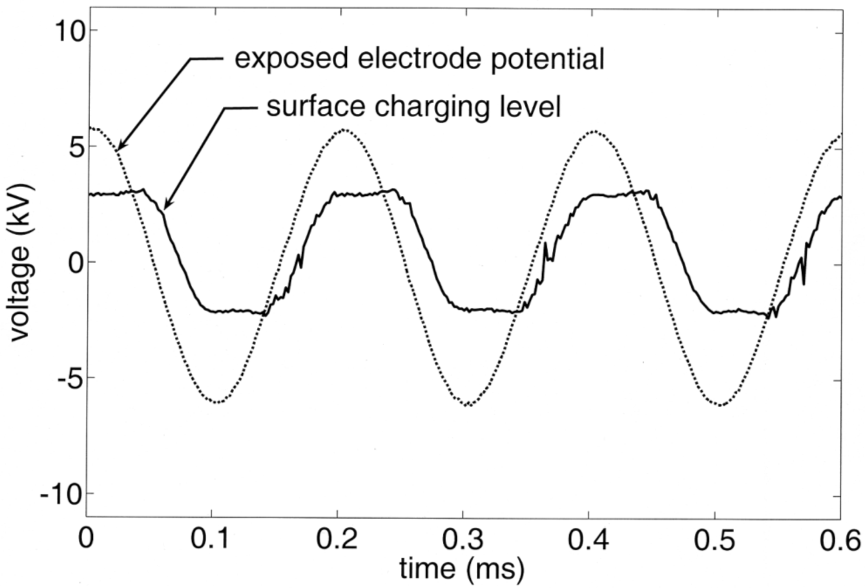
Unique, Innovative Diagnostics: The V-Dot Probe

Technique adapted from the pulsed power community



Ability to separate displacement current from ohmic current

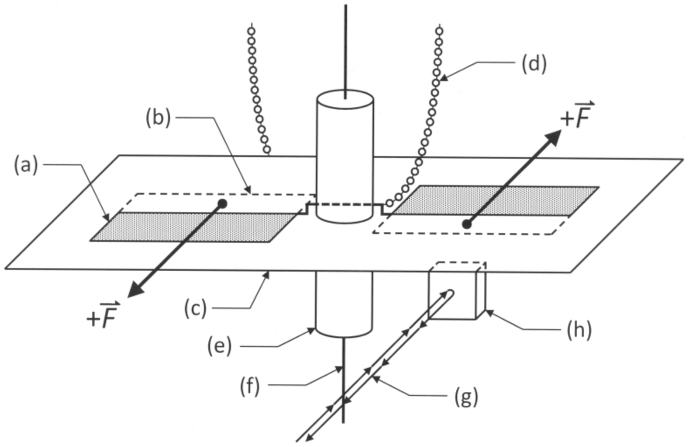




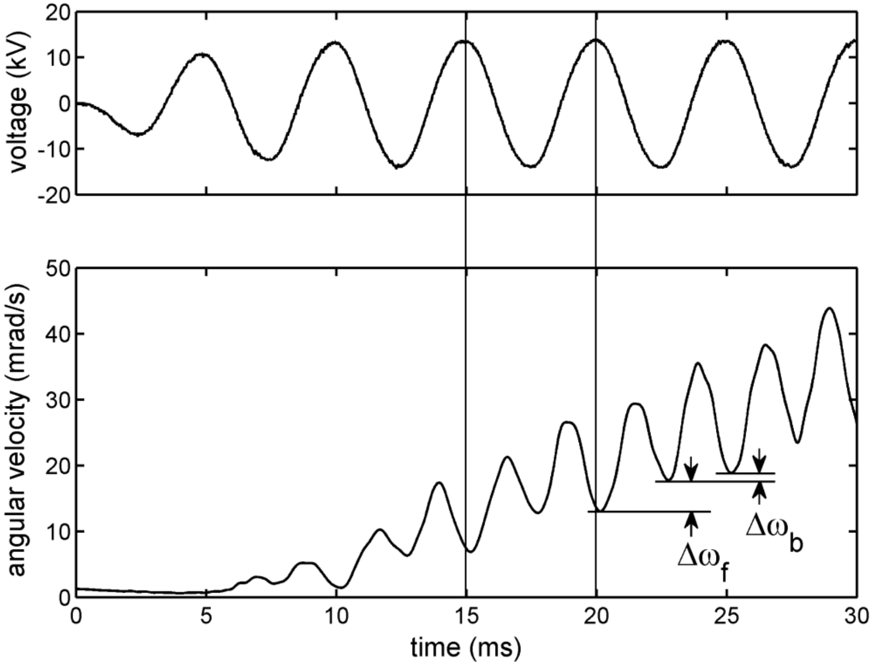
One boundary of the DBD actuator plasma is NOT under direct control of the experimenter

Surface charge state IS important; to what extent is it "controllable"?

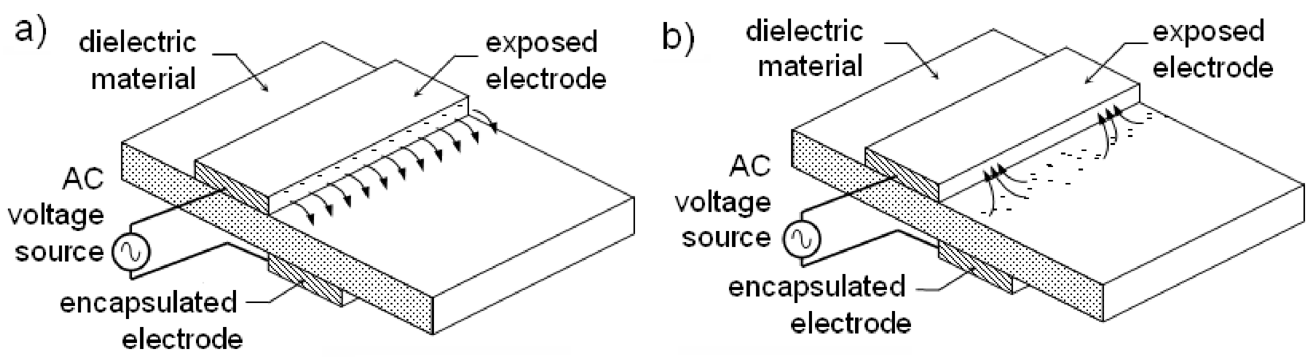
Unique, Innovative Diagnostics: Laser Interferometry



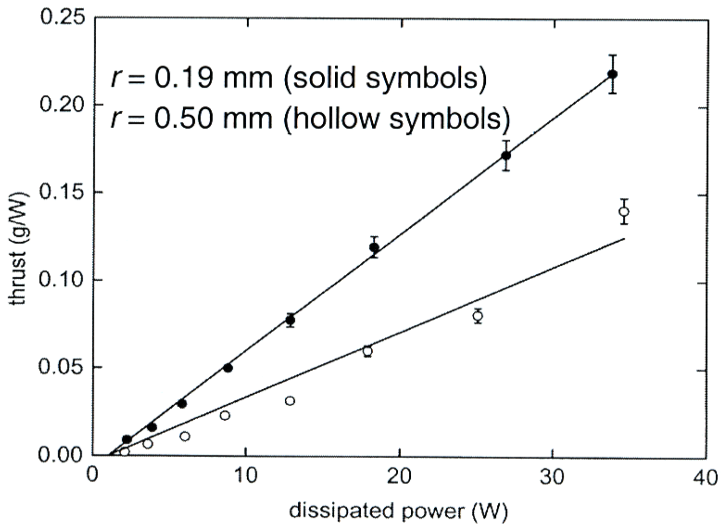
Results are straightforward to interpret



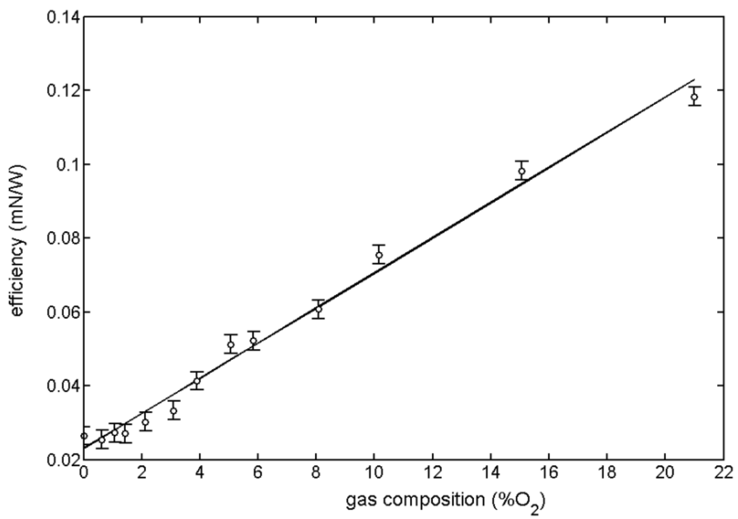
Parametric Studies to Reveal Actuator Physics



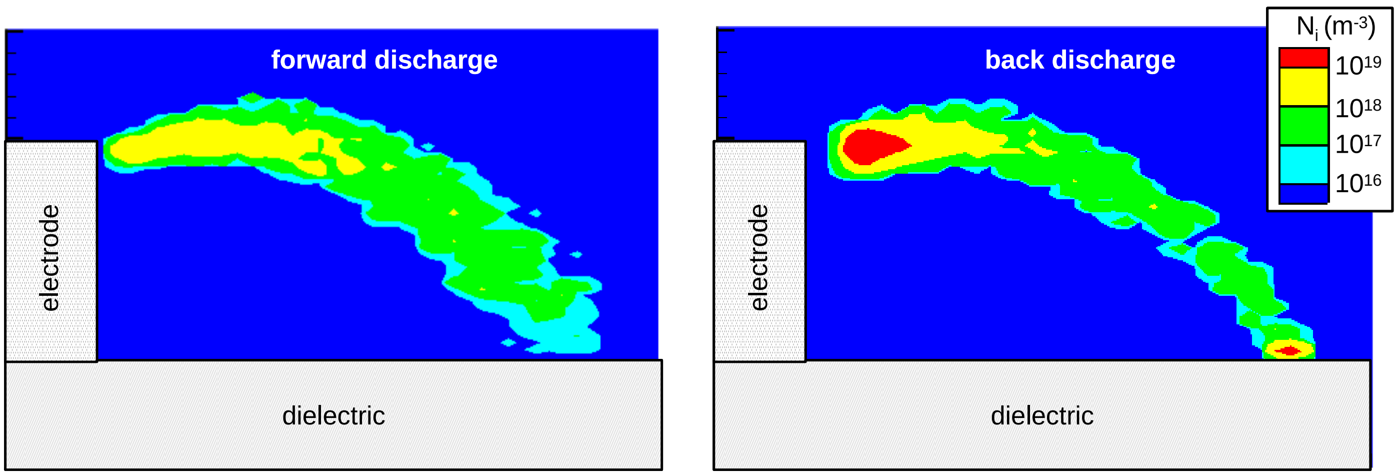
Electrode Geometry Effects



Importance of Oxygen Content



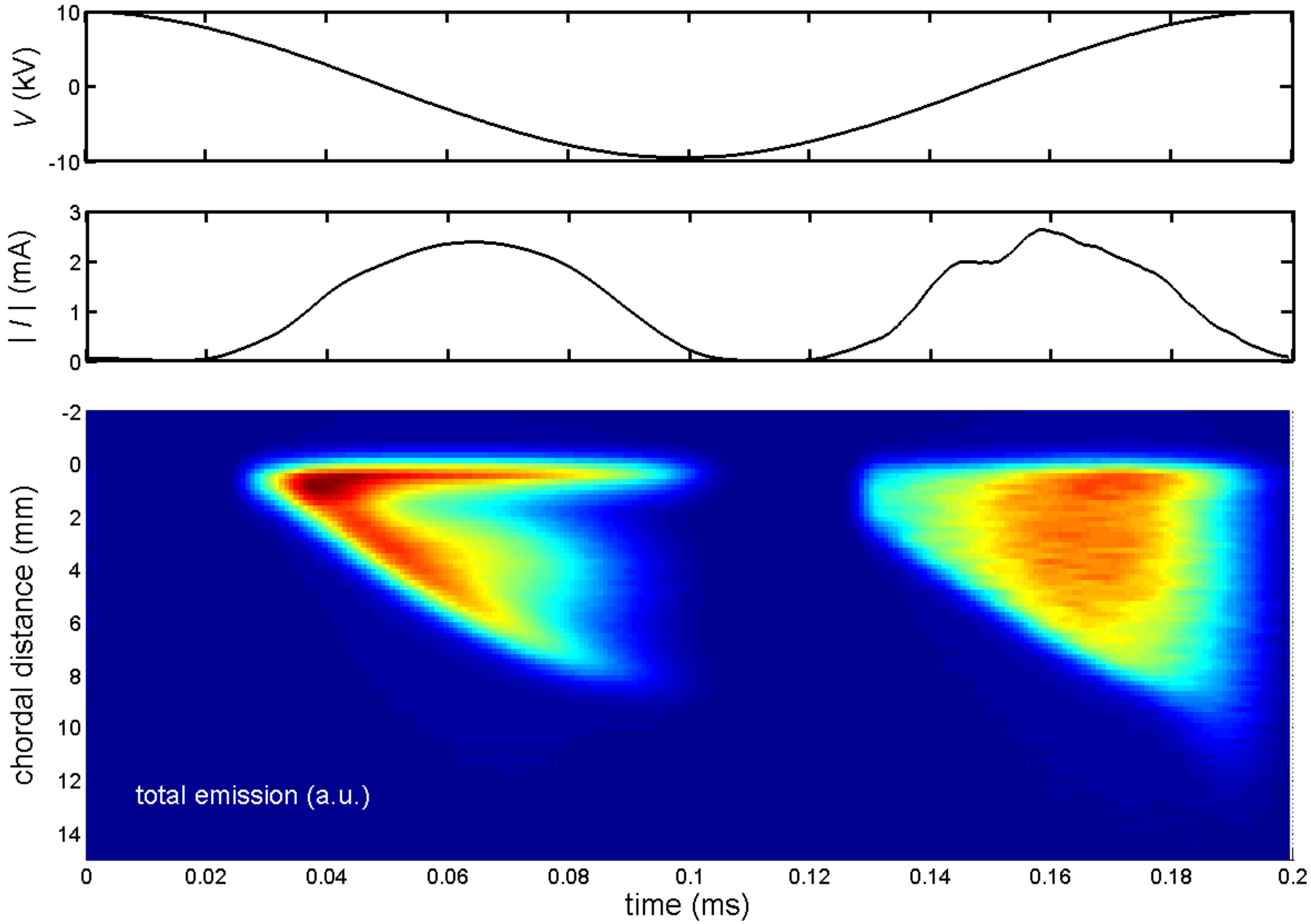
Numerical Modeling: The Challenge of Multiple Timescales



Particle-in-Cell Code Results

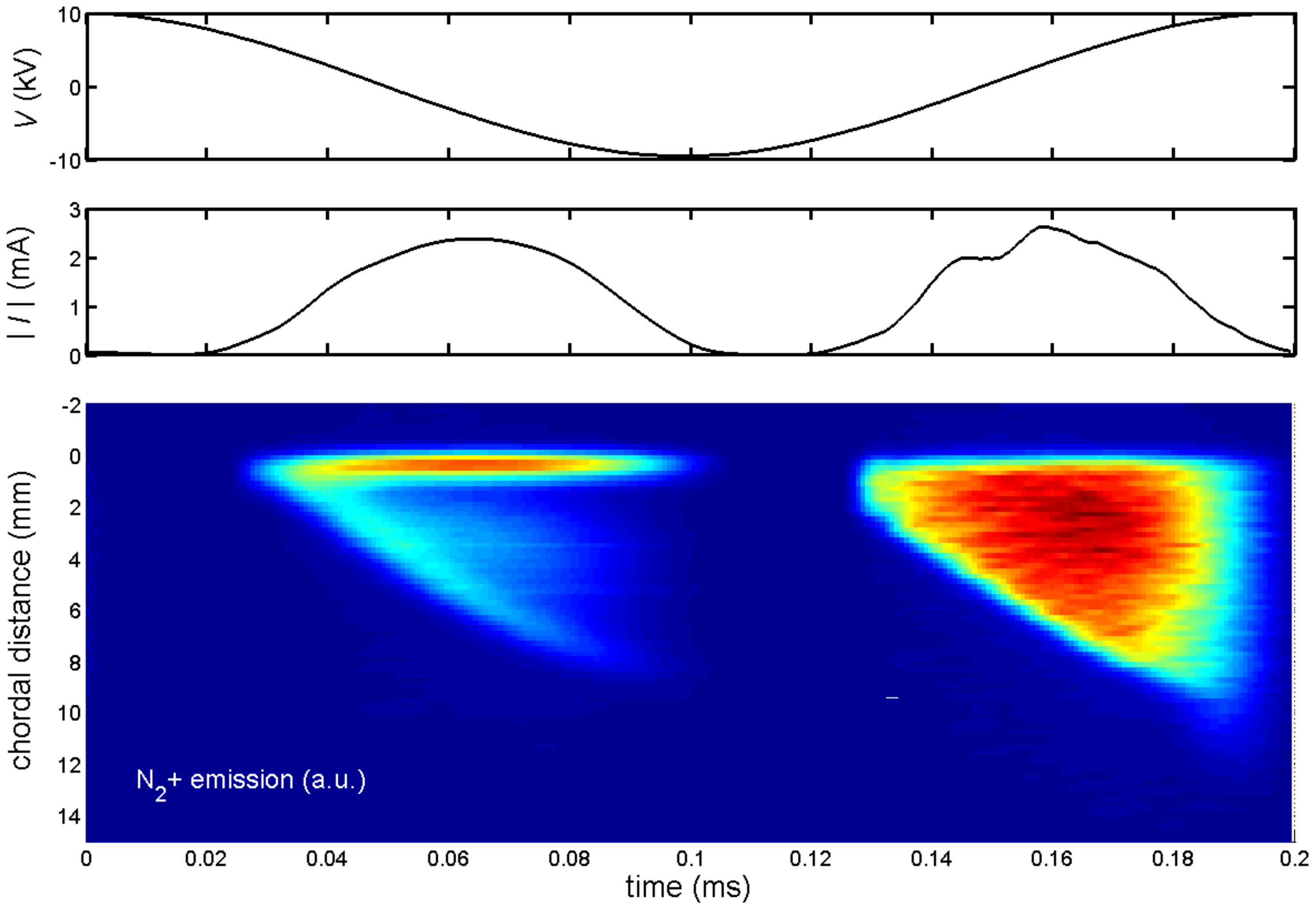
Plasma: multiple nsec, μsec
Fluids: msec to DC
Bulk behavior: quasi DC to variation over minutes

Current Actuator Physics Research: Time/Space Resolved Spectroscopy



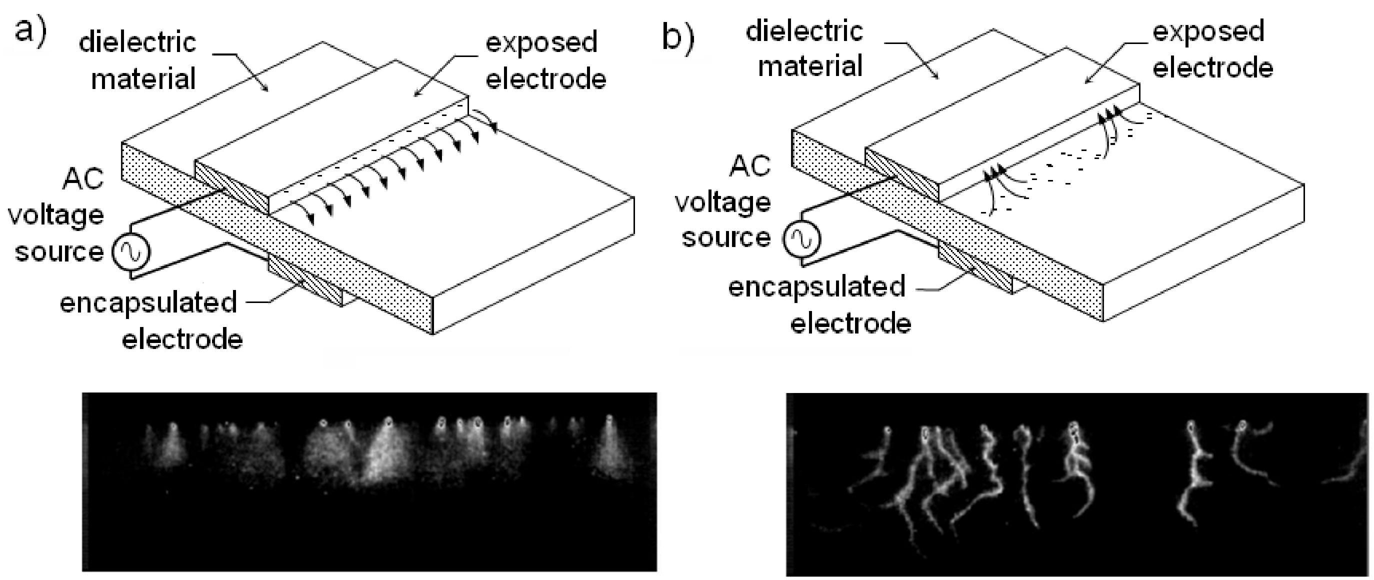
Total emission gives us information about plasma structure vs. time

Current Actuator Physics Research: Time/Space Resolved Spectroscopy



Only charged species can be involved in force production

Simple Setup ≠ Simple Physics



Where We Were: What can we do to ~~control~~ manipulate the *E*-field?

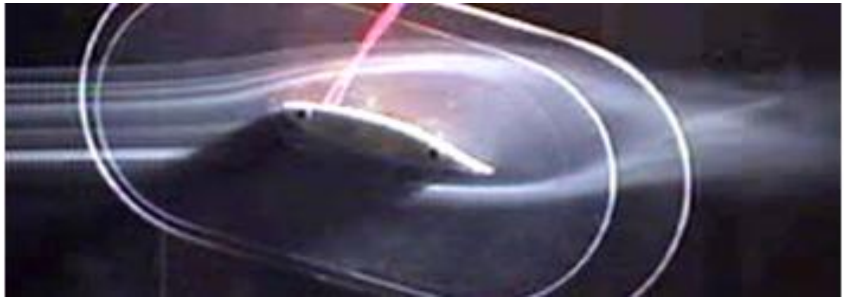
Where We Are: What can we do to manipulate E, n_e , n_{i+} , n_{i-} ?

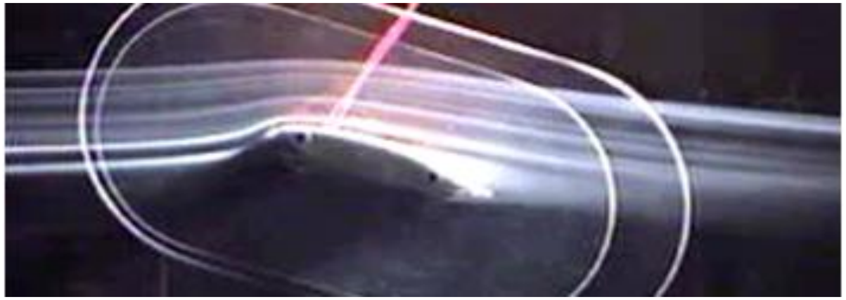
The actuator of the future may not be the actuator of current experiments

Is the Payoff Worthwhile?
We Believe So

Mechanical Flow Re-Attachment

Electrical Flow Re-Attachment

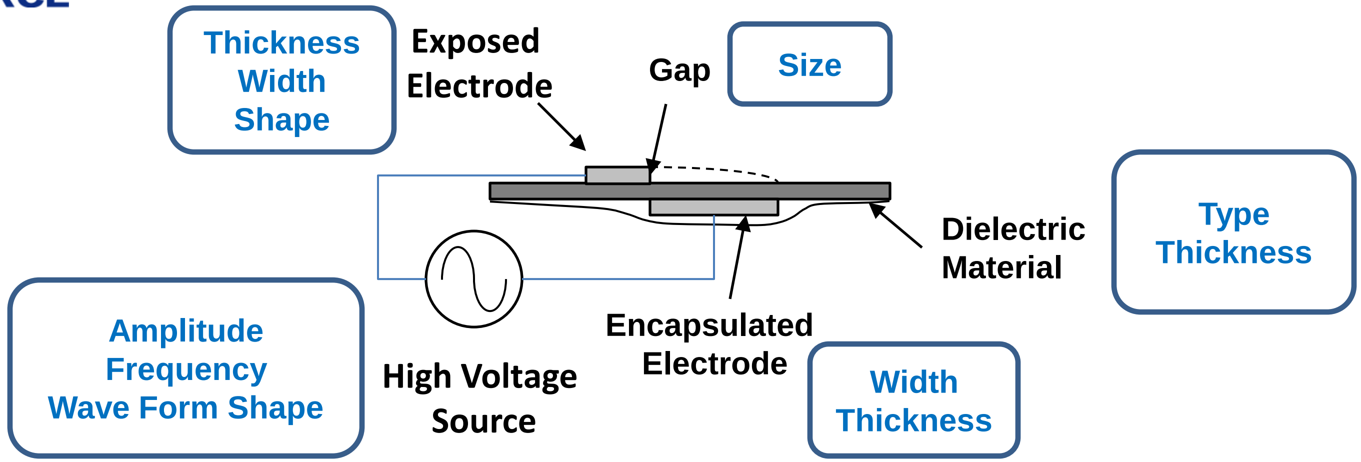




Photos courtesy of the University of Notre Dame

Aerodynamic Investigations and Applications

Parametric Studies



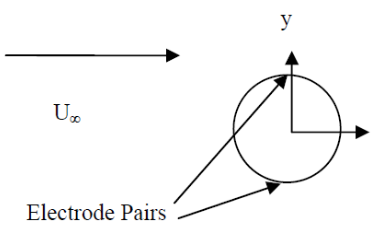
Exposed Electrode

- Thinner is better – sharp edge provides easier electron flow
- Sawtooth shape is better - longer surface for electron emission
  - Optimal separation of 2mm

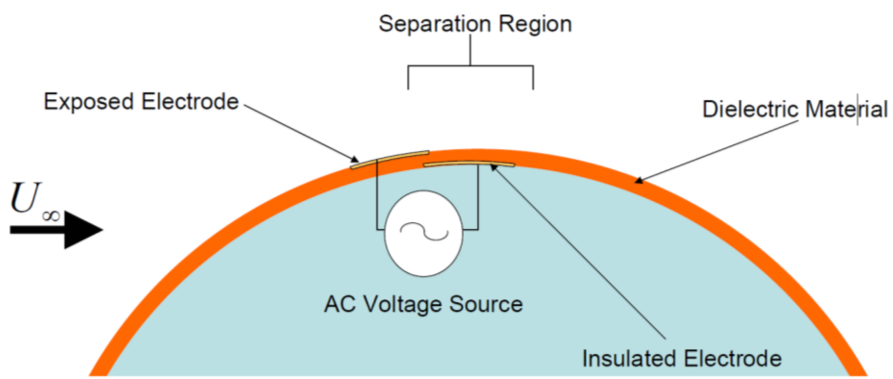
High Voltage/Encapsulated Electrode

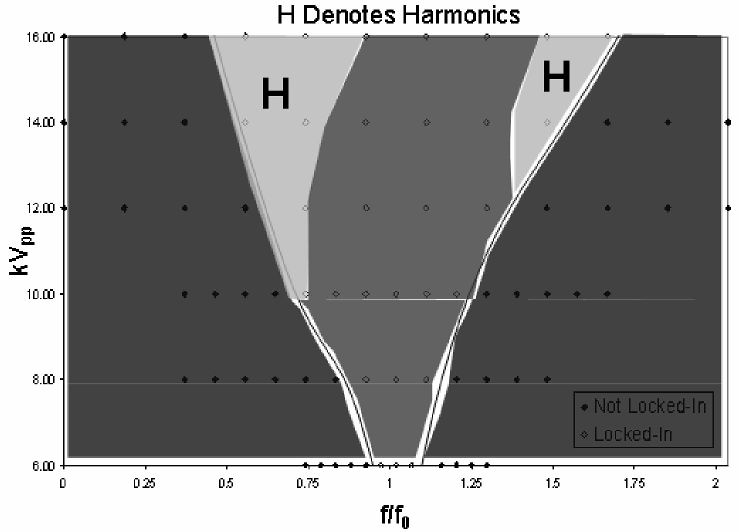
- Higher Frequency and Amplitude provide better force production
  - limited by the width of the encapsulated electrode
- Higher Frequency performance is less efficient,(mN/W)

Controlling Cylinder Wake Flow 2004 - 2006



- Controlling the wake of a bluff body can reduce drag, improve mixing and heat transfer, enhance combustion
- Used two plasma actuators to control vortex shedding in a circular cylinder wake
- Forced lock-in for a range of frequencies around the natural frequency for Re up to 300,000





Jet Vectoring (2008)

- Experiments have shown that waviness of the leading or trailing edges can reduce drag

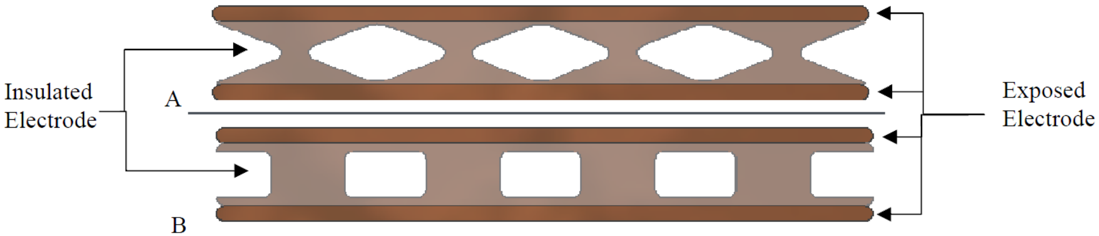
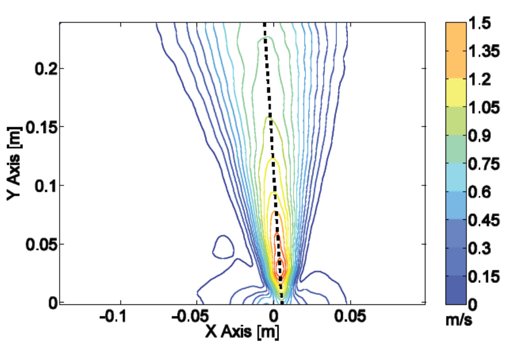


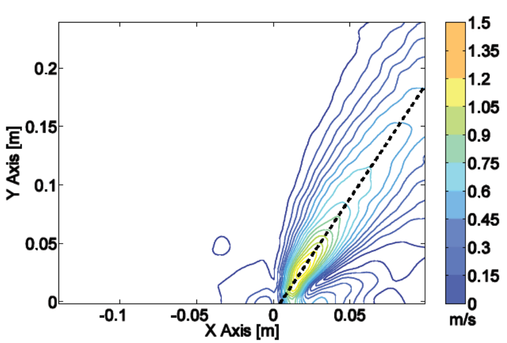
Figure 4. Distributed plasma synthetic jets, each creating four distinct jets. A) Triangular plasma synthetic jet. B) Binary plasma synthetic jet

- Demonstrated that plasma actuators can simulate the waviness by opposing plasma actuators and tailoring the insulated electrode
- Demonstrated control of the jet over a range of angles

ΔV = 0.56 kV



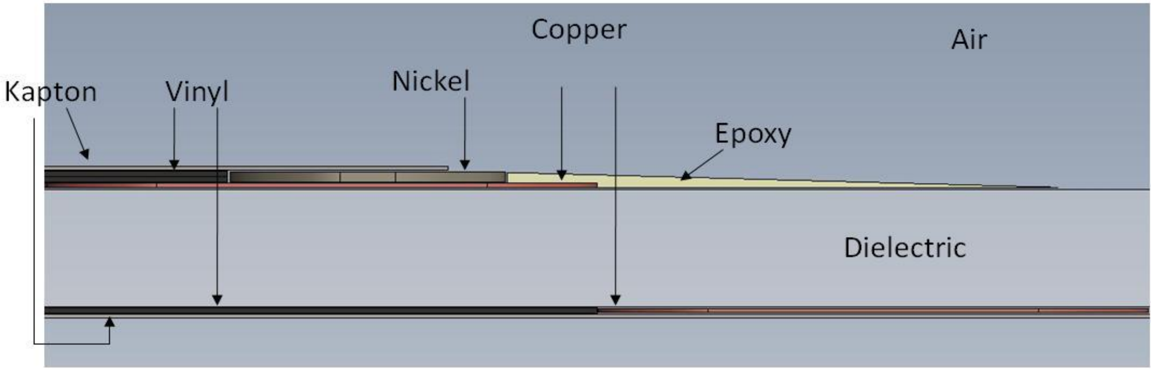
ΔV = 0.23 kV



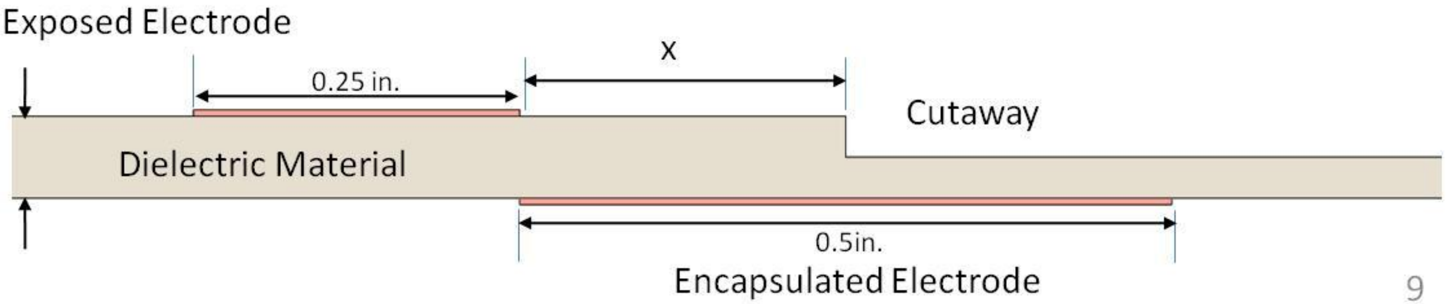
ΔV = -0.32 kV

Tailoring the Actuator (2009 -)

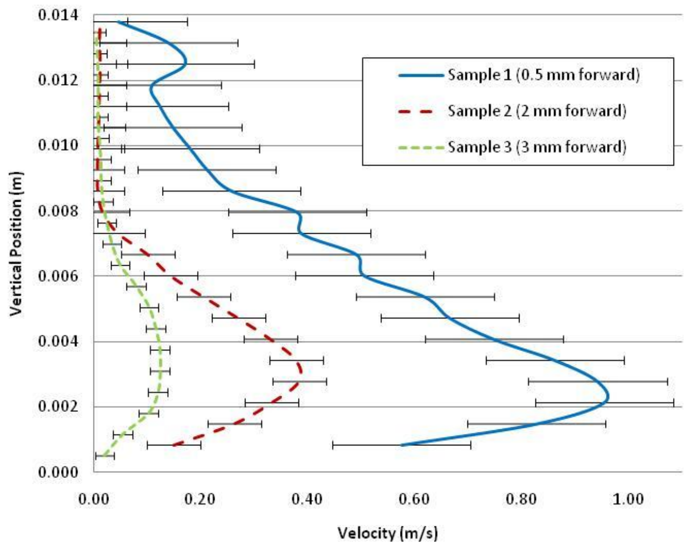
- The actuator operates by periodically producing a higher velocity flow very close to the wall
- Much of the momentum is lost to shear stresses



- The actuators were tailored to attempt to move the jet away from the surface
  - One by moving the source of the electron emission away from the strongest point in the electric field
  - The other by moving the wall away, giving us measurement access to more of the flow



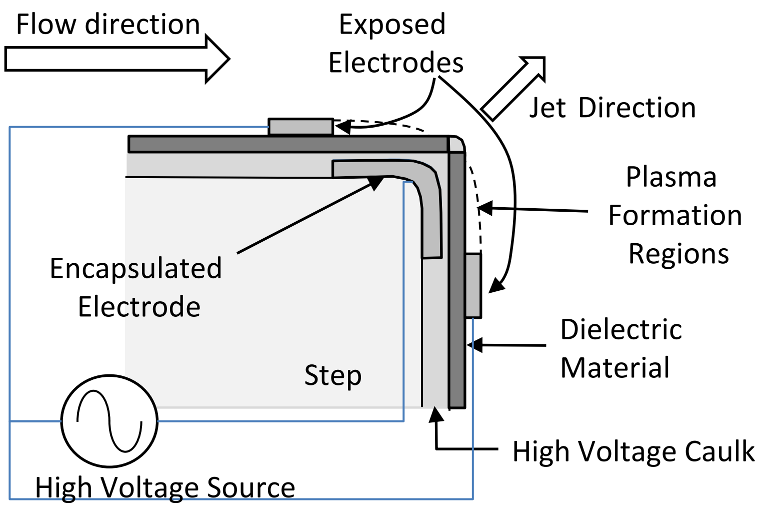
Tailoring the Actuator (2009 -)



Particle Image Velocimetry results from moving the electron source forward

- Moving the electron source forward did not provide higher velocities
- Suspect a reduction in the electric field strength and changing the electrode thickness
- Unique periodic PIV data over the cycle
- Tracking some of the previous plasma structure, density, and force findings to velocity changes
- Preliminary results from moving the wall, however, show a 20% increase in the momentum produced by the jet for one cutaway location
-

Corner Plasma Actuator 2009-

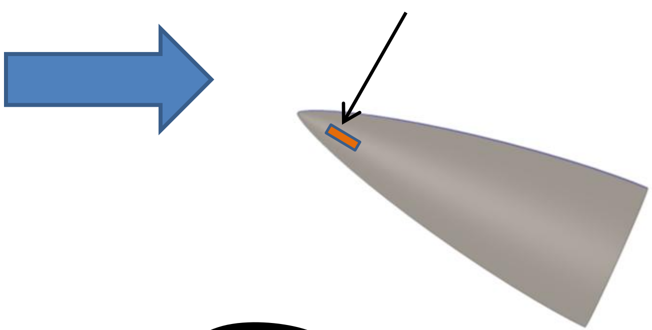


- Controlling shear layer from an optical turret can aid the adaptive optics and improve the efficiency of optical transmissions
  - Producing the periodic jet forces the shear instabilities (100 – 200 Hz)
- Based another successful effort in the lab to force the shear layer
- Built on what we learned about Jet Vectoring
- Expect performance increase with less wall exposure

Plasma Actuator Fluid Dynamics (2011-)

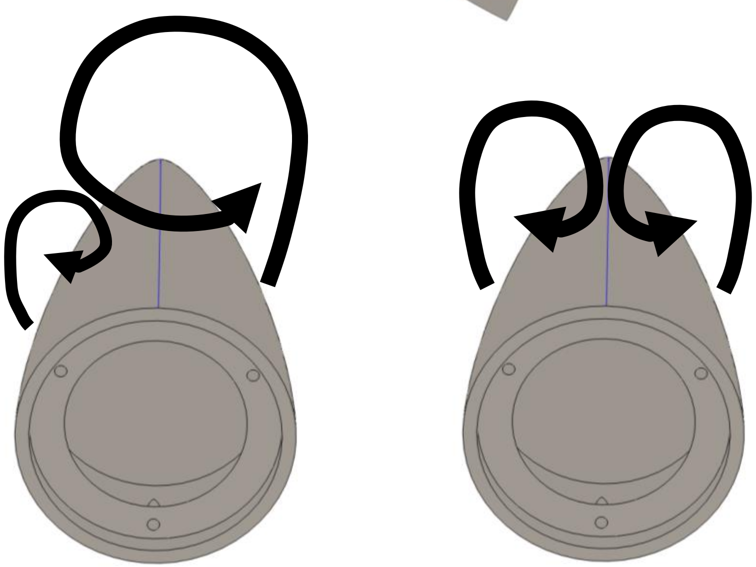
- Take additional measurements around the actuator to provide the pressure profiles and the shear stress to provide the most complete picture possible
- Make sure we understand how the fluid dynamic mechanisms are driving the formation of the wall jet

Ogive Nosecone
(2011)



•Provide pseudo-symmetric flow over a nosecone at an angle of attack

- Pulsing actuators force the asymmetric flow back and forth
- Smoothness is critical, plasma actuators are ideal,



Notional Separated Flow

Plasma Actuator Applications (2011-)

- continue to use new revelations into the plasma physics to produce more effective actuators
  - Help to develop an empirical model
- continue to demonstrate the plasma actuator in flow control applications
  - Pulsed jet applications for shear layer control