Enhanced Plasma Actuator Forces through Plasma Catalysis

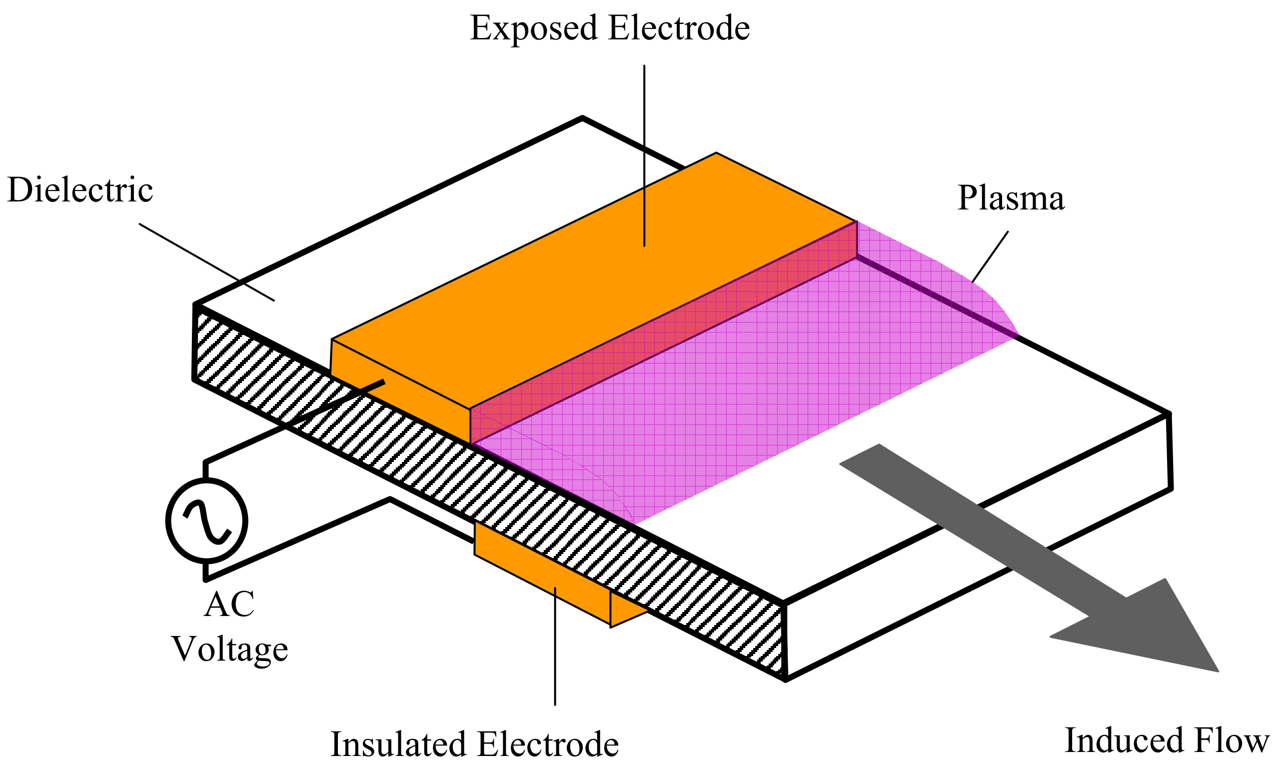
Applied Science Products, Inc

Neal E. Fine, PhD, ASPI

Steven J. Brickner, PhD, Consultant

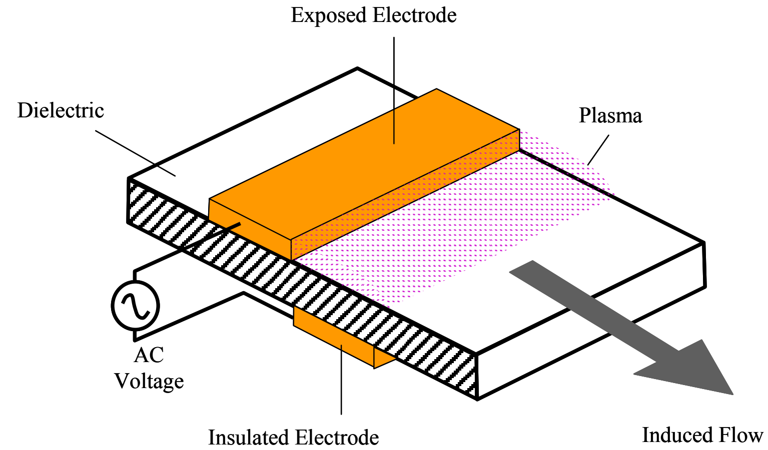
July, 2010

THE PLASMA ACTUATOR



THE PLASMA ACTUATOR…

- …is an electrical device that induces flow in a background gas (such as air) with no moving parts.



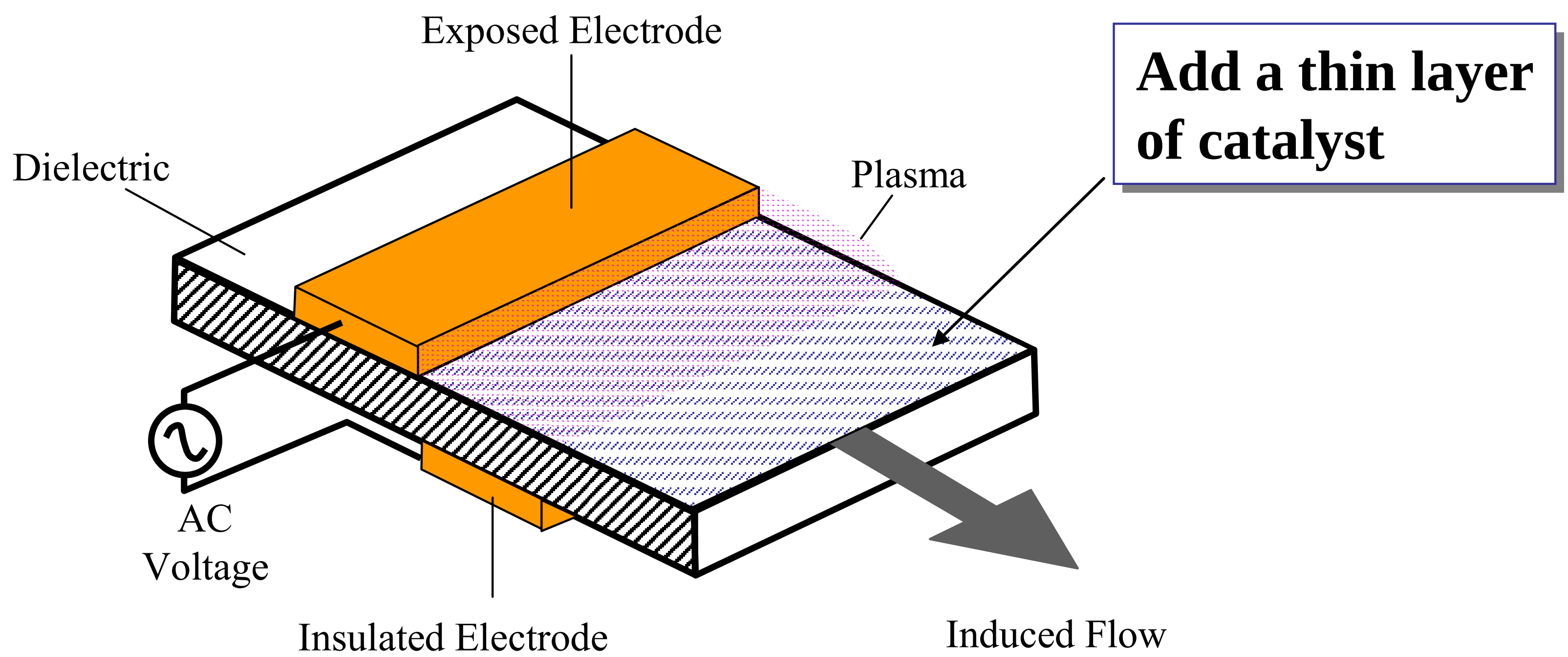
- … is favored by aerodynamicists for active flow control because:
  - it has no moving parts
  - it mounts flush to a surface (no "parasitic" drag)
  - it consumes very little power

See recent review article by Corke, et al: "Dielectric Barrier Discharge Plasma Actuators for Flow Control," *Annual Review of Fluid Mechanics*, Vol. 43, pp505-529.

Despite their promise, plasma actuators have limited control authority and researchers are searching for new methods to enhance the force generated by the actuators.

One way to improve the control authority may be to apply a catalyst to the surface of the dielectric where the plasma forms.

HYPOTHESIS: Certain heterogeneous in-plasma catalysts may cause more efficient production of reactive species, including ions. Possible catalysts include titania (TiO_2), aluminum oxide (Al_2O_3), zinc oxide (ZnO) and others. The greater number of ions in the plasma could then result in greater momentum transfer from the ions to the neutral air molecules, potentially increasing the actuator control authority.



THEORY:

$$\vec{f} = \rho\vec{E} = -\frac{\varepsilon_0}{\lambda_D^2}\phi\vec{E}$$

where

$$\lambda_D^2 = \frac{\varepsilon_0 k}{e^2 n_0}\left[\frac{1}{T_i} + \frac{1}{T_e}\right]^{-1}$$

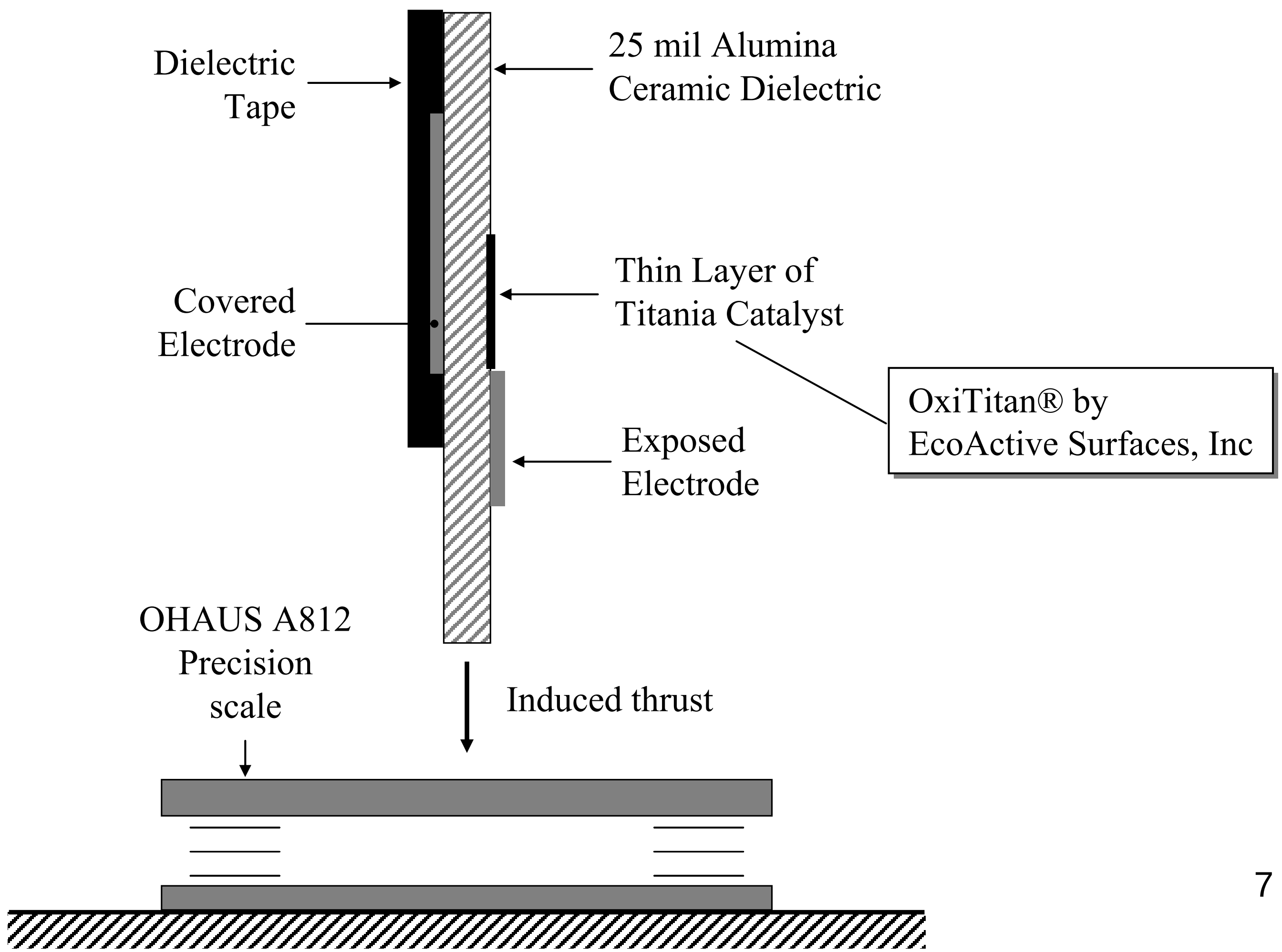
ρ = charge density
E = electric field
ϕ = electric potential
ε_0 = permittivity
k = Boltzman constant
e = electron charge
T_i = ion temperature
T_e = electron temperature

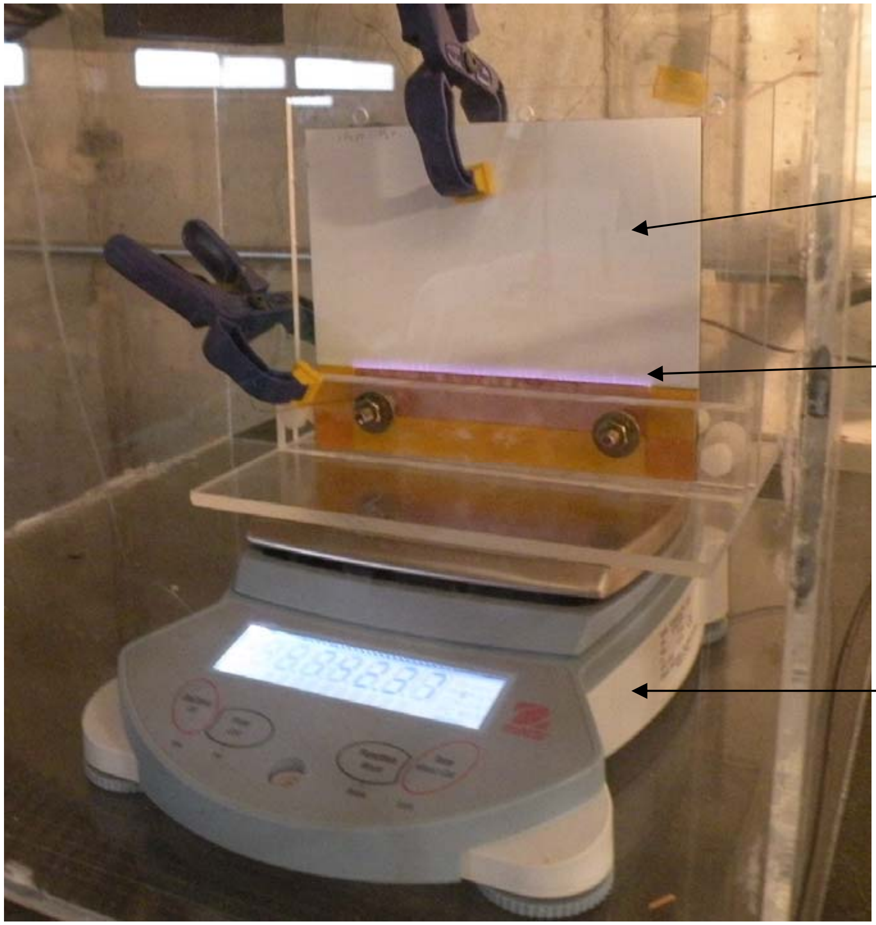
Increasing the ion density, n_0, will result in increased force, f, provided changes in the electric field, E, do not offset the increase.

Reference: Enloe et al., "Mechanisms and Responses of a Single Dielectric Barrier Plasma Actuator: Geometric Effects," AIAA Journal, Vol. 42, No. 3, March 2004.

EXPERIMENT:

We measured the force generated by a plasma actuator before and after applying a titania (TiO_2) photocatalyst on the dielectric surface above the covered electrode.



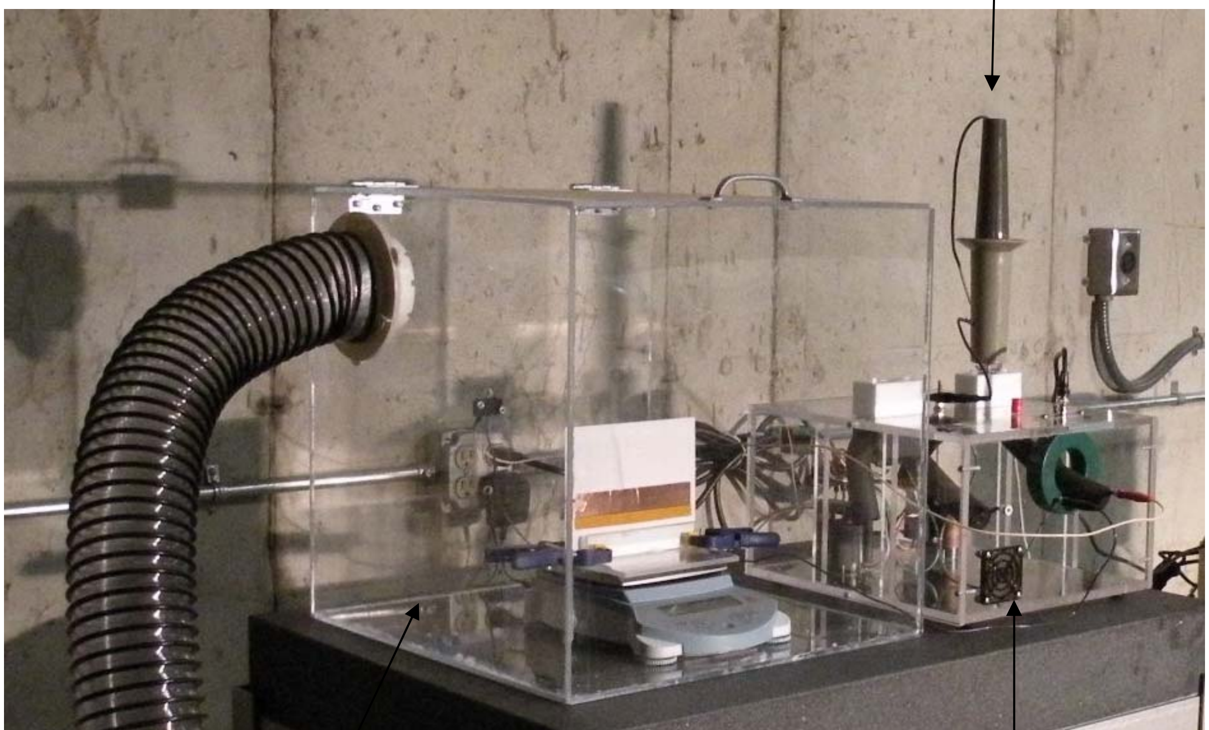


Alumina ceramic dielectric (25 mil thickness)

Plasma zone

OHAUS precision scale

HV Probe

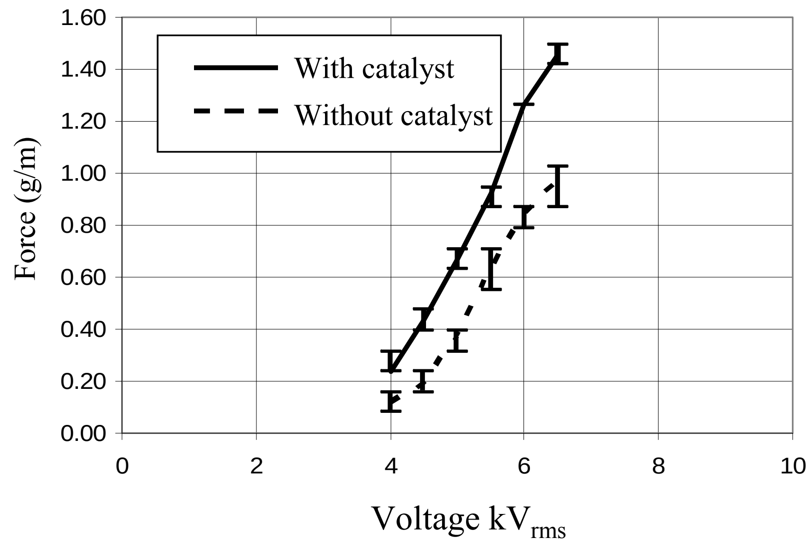


PlexiGlas® containment box

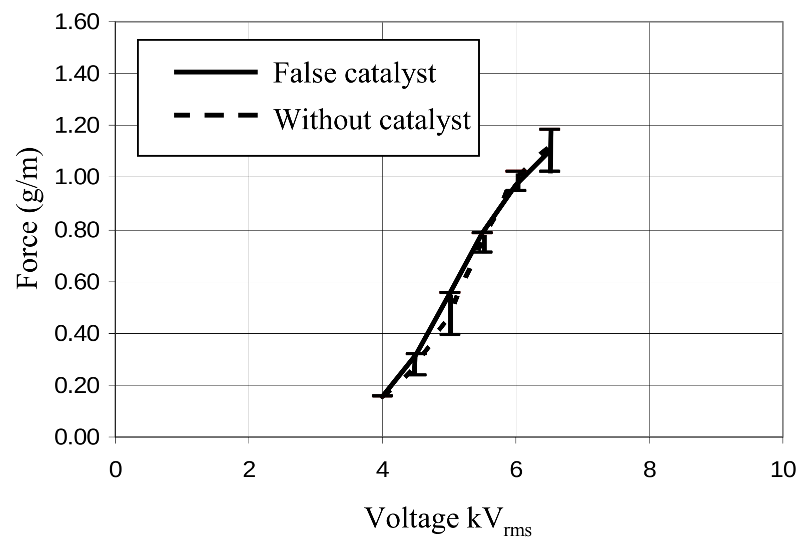
Power Supply

RESULTS

The force per meter of actuator generated by a plasma actuator and measured with and without the titania catalyst.

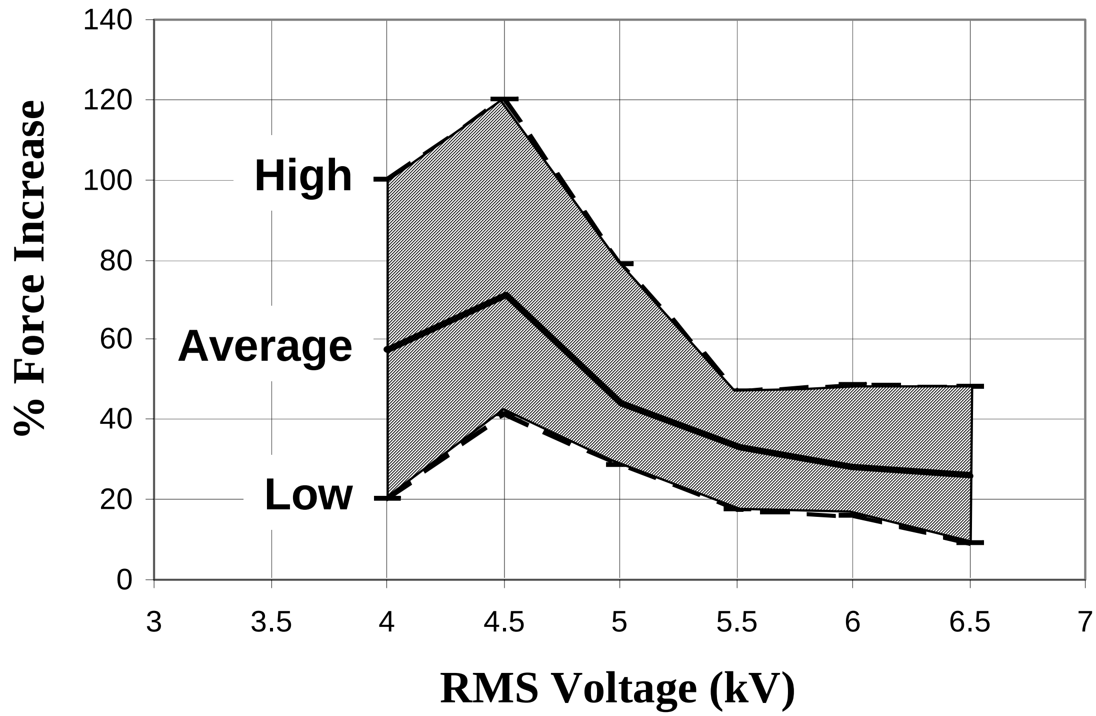


A "false catalyst" (tap water) produces no additional force, indicating that the force enhancement with the catalyst is not introduced by the measurement procedure.



The error bars show the high and low measurement for each voltage and are a measure of the variability in the results.

RESULTS



Composite %-increase of catalyst-enhanced thrust measured in the proof-of-principle experiment (solid line represents the average force increase, the two dashed lines are maximum and minimum force increase). The composite results represent five separate experiments, using five actuators constructed using an identical protocol. While the intent was to create identical test conditions for the five actuators, clearly a variety of factors influenced the variability (such as variations in the electrode length and the overlap or gap between the exposed and covered electrodes).

SUMMARY & CONCLUSIONS

- The TiO_2 catalyst appears to produce significant (as high as 120%) and repeatable increases in plasma actuation force.
- This phenomenon could help to make plasma actuators more effective for active flow control applications.
- The proposed mechanism (increased charge density) remains a hypothesis. Further experiments will clarify the phenomenon, including the effects of other catalysts. The following detailed plasma chemistry experiments are planned:
  - Optical Emission Spectroscopic (OES) measurement of the concentration of certain charged species
  - OES measurement of the electron temperature and density
  - Electric field strength measurement
  - Surface voltammetry
  - Power consumption
- The results of the proof-of-principle experiment described here were submitted for publication in the *AIAA Journal* in June, 2010.

NOTES

The proof-of-principle experiment was supported in part by funding from Navatek, Ltd.

Further experimentation has been proposed in coordination with University of Connecticut Department of Chemistry Chair and Board of Trustees Distinguished Professor Steven L. Suib. A joint proposal has been submitted to the Air Force Office of Scientific Research for review and consideration for FY2011 funding.

ASPI owns a license to U.S. Patent No. 6,200,529 ("Paralectric Gas Flow Accelerator"), which appears to be the first to make claims describing what is now commonly referred to as the plasma actuator.