Enhanced Dielectric-Barrier-Discharge Body-Force Generation using Nanofoam Materials with Infused Catalytic Layer

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Outline

- Background
- Innovation
- Approach
- Results
  - Dielectric Measurements
  - DBD Actuator Force Measurements
- Summary
- Future work
- Dissemination

Background

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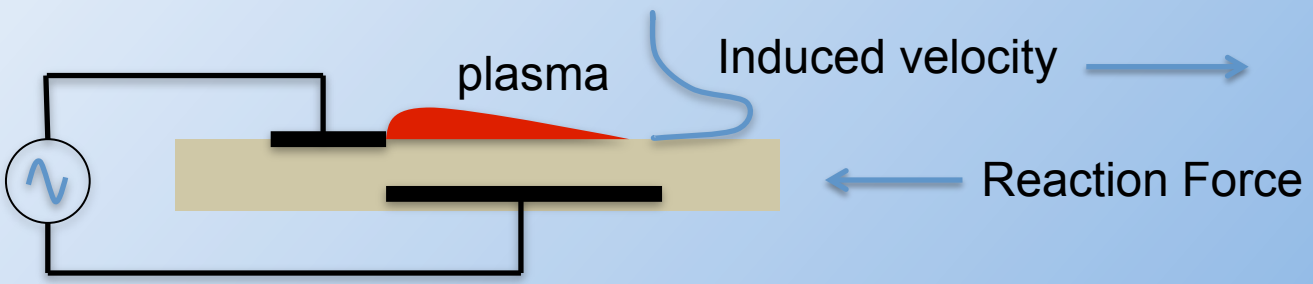
- The Dielectric Barrier Discharge or DBD actuator is a plasma device that converts AC electrical energy to kinetic energy through electrostatic forces on ionized air particles.



- Studies show that <u>thick dielectrics</u> (5< t <15 mm) made from <u>low dielectric coefficient</u> (ε_r<3) materials have the highest reaction force.

DBD Discharge on Glass Actuator

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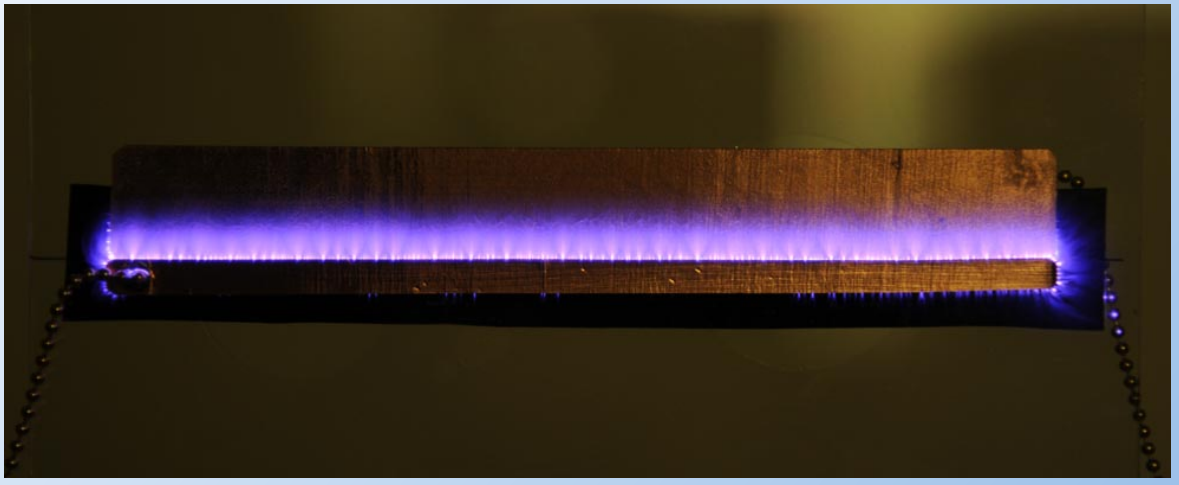

f=5 kHz
V=20 kV p-p
t=2.5 mm

ε_r = 7.98 @ 5 kHz
(Model S115)

(5 sec exposure)

- A DBD plasma is classified as a non-equilibrium, non-thermal discharge.
- The fundamental physics of the force generation are not completely understood, especially in the area of dielectric surface effects.
- The current maximum reaction force is approximately 0.25 Newton per meter of electrode length at high voltages, O(50kV).

Impact

- **The DBD actuator has generated interest in many areas of flow control.**
  - Steady and unsteady boundary layer separation
    - Airfoils, circular cylinders and the base flows of blunt bodies
  - Laminar boundary layer transition control
    - Plasma DRE (distributed roughness elements), 2D TS wave cancellation
  - Turbulent skin friction control by various wall streak interference concepts
  - Investigations are in varying stages of development ranging from conceptual proposals to mid-TRL level.

- **Advantages over existing, active flow control methods:**
  - Non-mechanical
  - Surface mount (retrofittable)
  - Predictable response
  - High frequency response
  - Low total power in discrete applications

Motivation

- DBD research to date has primarily been focused on understanding the fundamentals of force creation and engineering actuators for maximum performance.

- In this process, easily acquired, off-the-shelf dielectrics are generally used based mainly on breakdown strength.

- Less attention has been paid to chemical composition/structure of the dielectric material and how that relates to DBD performance.

Objective

- Determine how dielectric chemical composition and chemical structure can contribute to improved actuator performance

Technical Innovation/Approach

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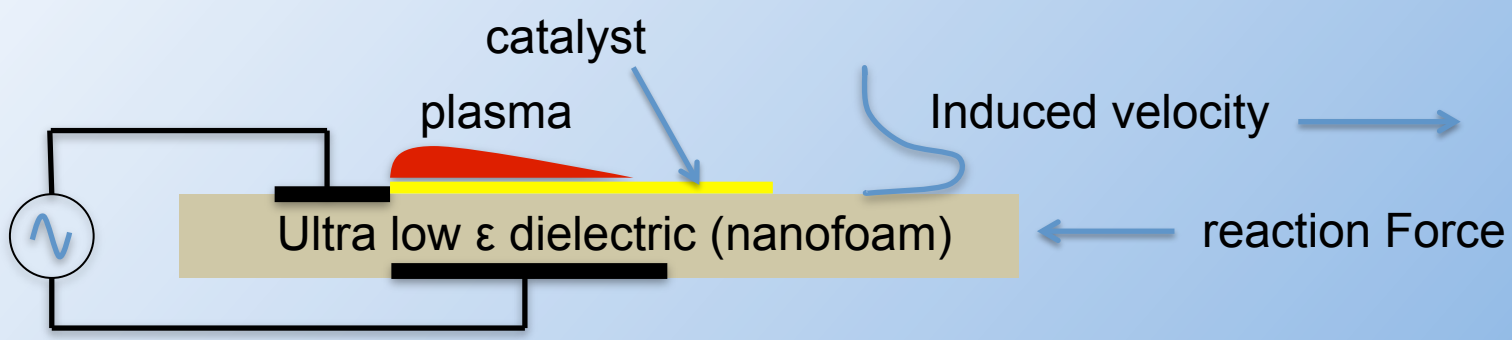

- Establish capability for characterizing dielectric materials and measuring reaction forces in still air.
- Develop techniques for testing fragile, ultra-low dielectric coefficient materials.
- Investigate use of surface catalysts for enhancing DBD force performance.
- Measure reaction force and total applied electric field for different materials.

Materials Selection

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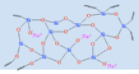
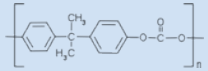
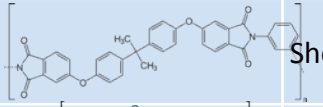
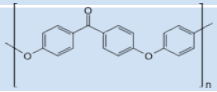
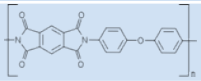
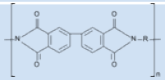
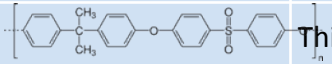
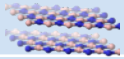
Trade (Common) Name	Chemical Name/Class	Unit Formula	Form
Glass	Silica	$SiO_2 + Na_2O + CaO$ 	Sheet, Nanofoam (Aerogel)
Teflon (PTFE)	Polyterafluoroetylene	C_2F_4	Sheet
PMMA (Acrylic)	Polymethymethyacrylate	$C_5O_2H_8$	Sheet
Lexan	Polycarbonate	$C_{18}H_{20}O_3$ 	Sheet
ULTEM	Polyetherimide	$C_{37}H_{24}O_6N_2$ 	Sheet, Foam
PEEK	Polyetheretherketone	$C_{21}H_{18}O_3$ 	Sheet
Kapton	Polyimide	$C_{24}H_{20}N_2O_5$ 	Thin* Sheet
Upilex	Polyimide	$C_{18}H_{12}N_2O_4$ 	Thin Sheet, Foam
Solimide	Polyimide	-	Foam (3 densities)
Performa H	Polyimide	-	Foam
Thermalux	Polysulfone	$C_{27}H_{26}O_6S$ 	Thin Sheet
Boron Nitride (hBN)	Ceramic	BN 	Sheet, Spray
PZT	Ceramic	$Pb[Zr_xTi_{1-x}]O_3$ $0 \le x \le 1$	Disk

* t < 1 mm

Forms of the Test Materials

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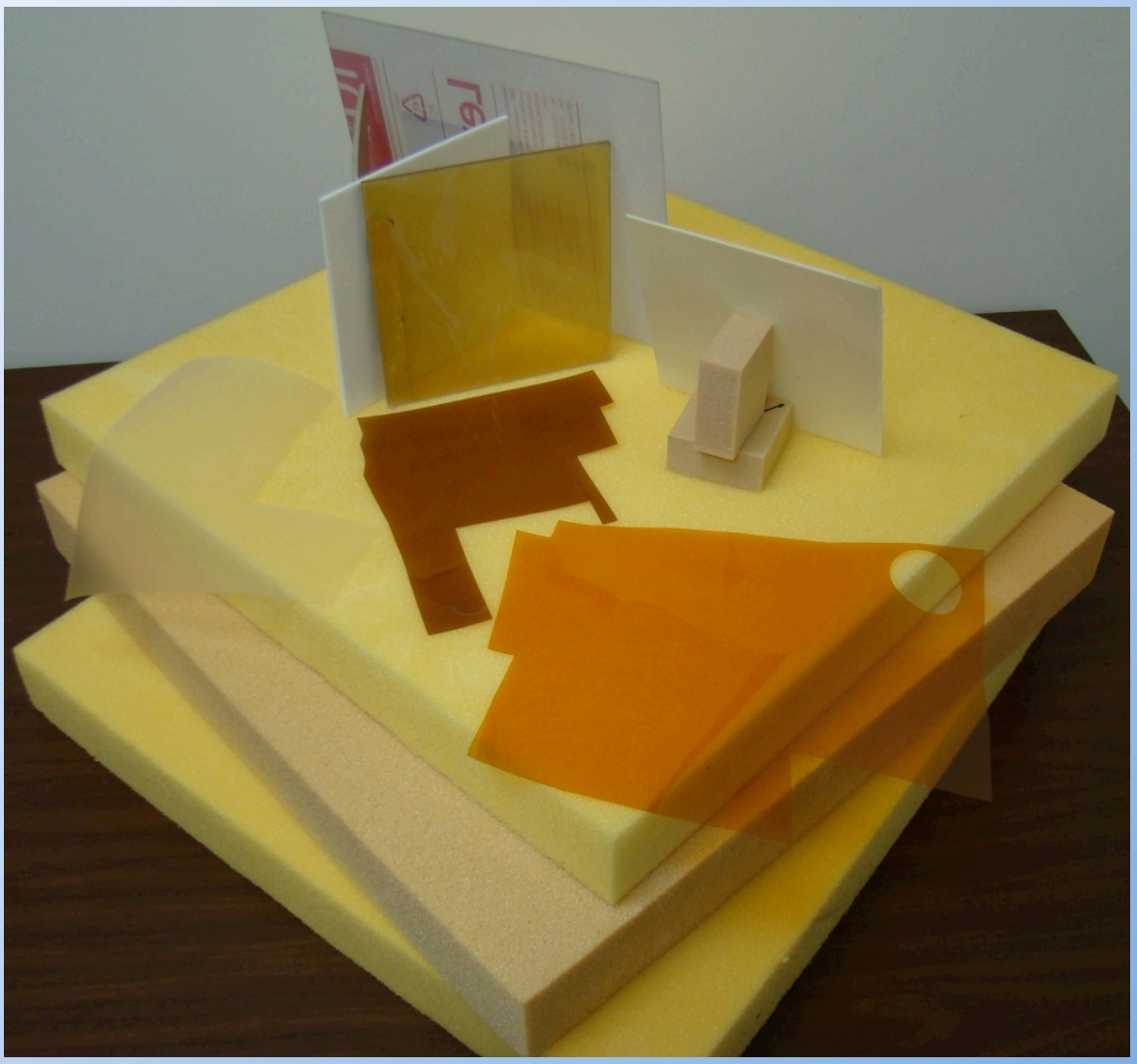

Dielectric Constant Measurement Setup

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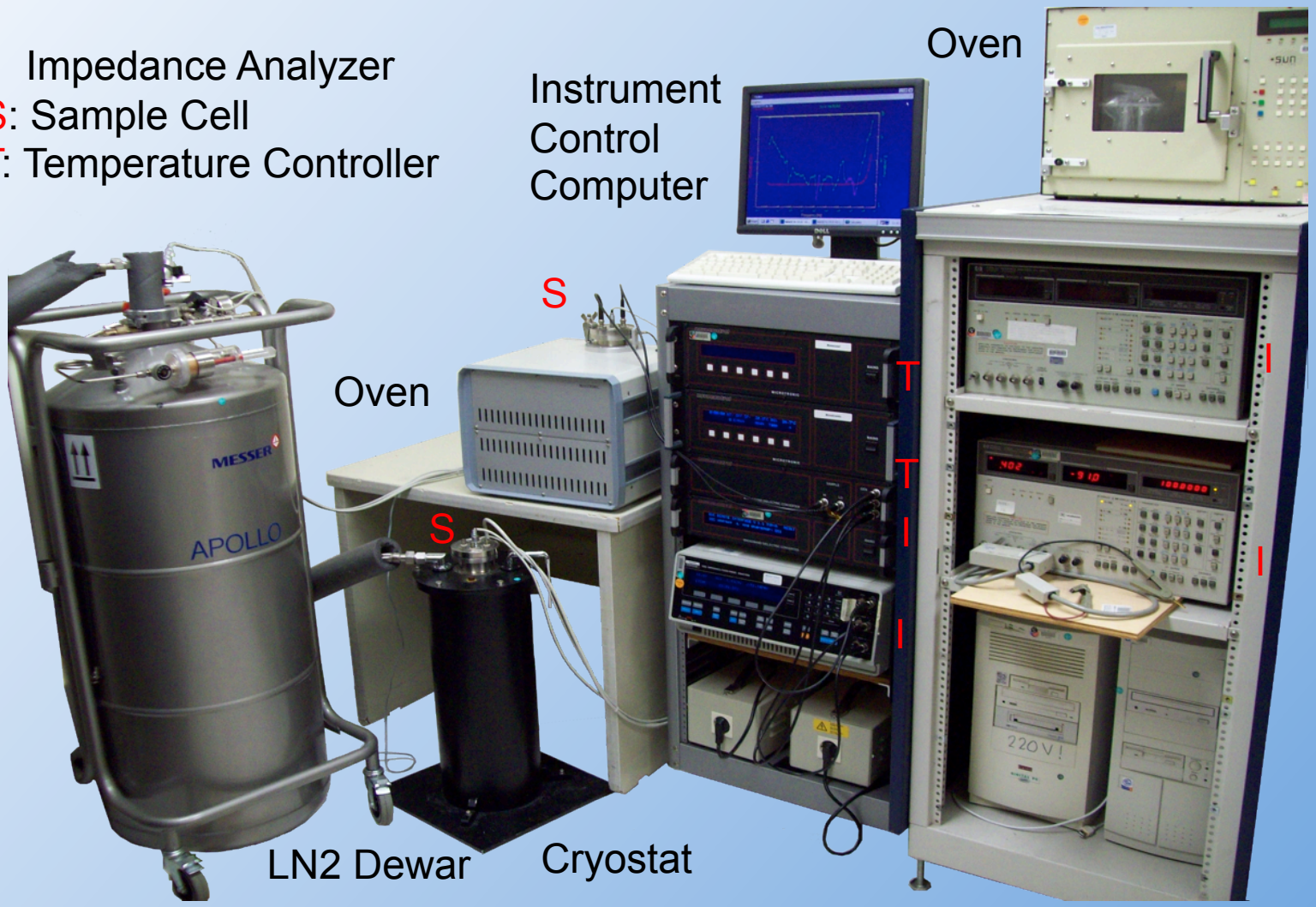
I: Impedance Analyzer
S: Sample Cell
T: Temperature Controller



Frequency Dependence of the Dielectric Properties

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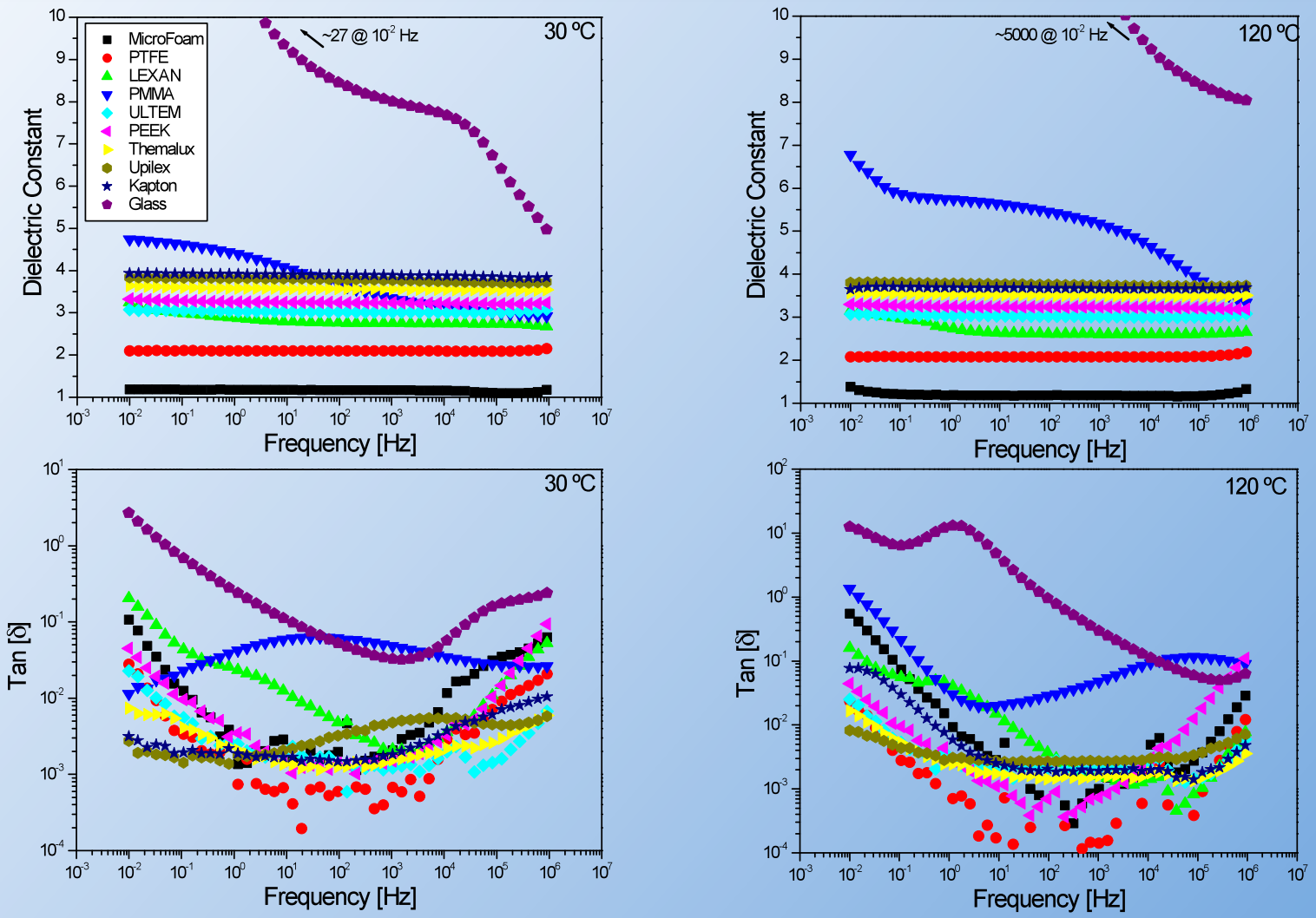

Dielectric Constants @ 5 kHz

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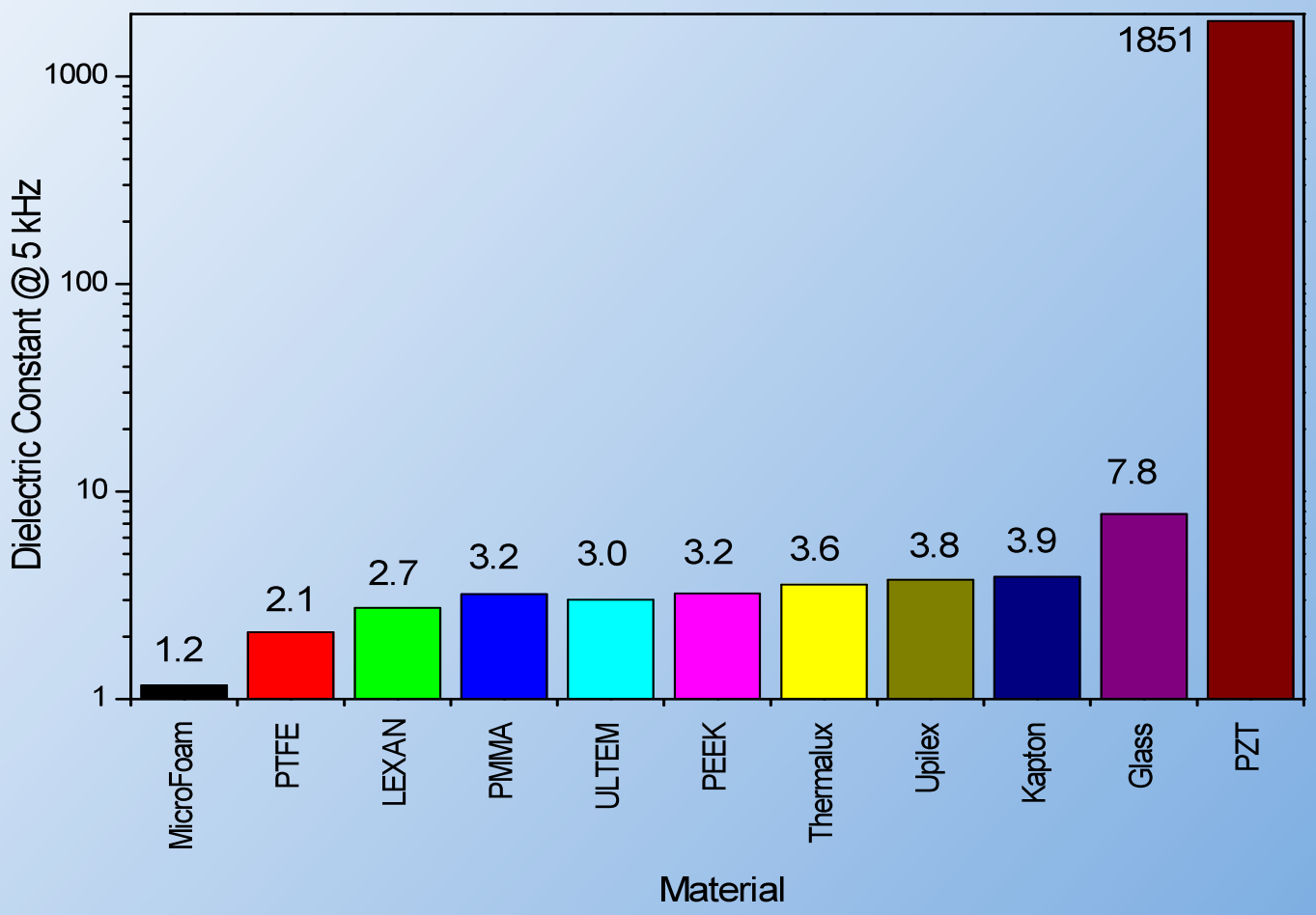

Dielectric Breakdown Test Set-Up Schematic

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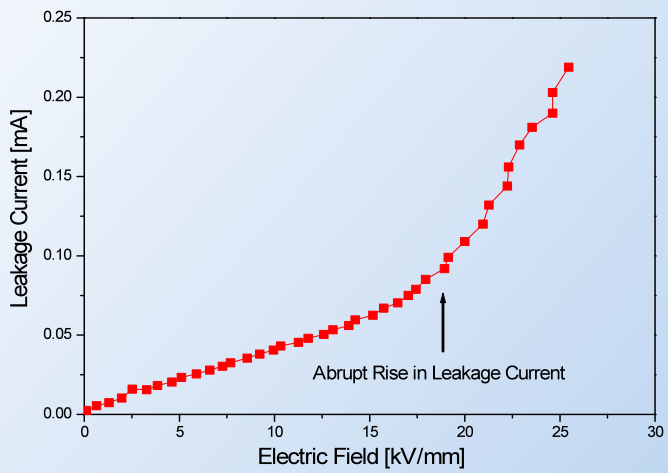

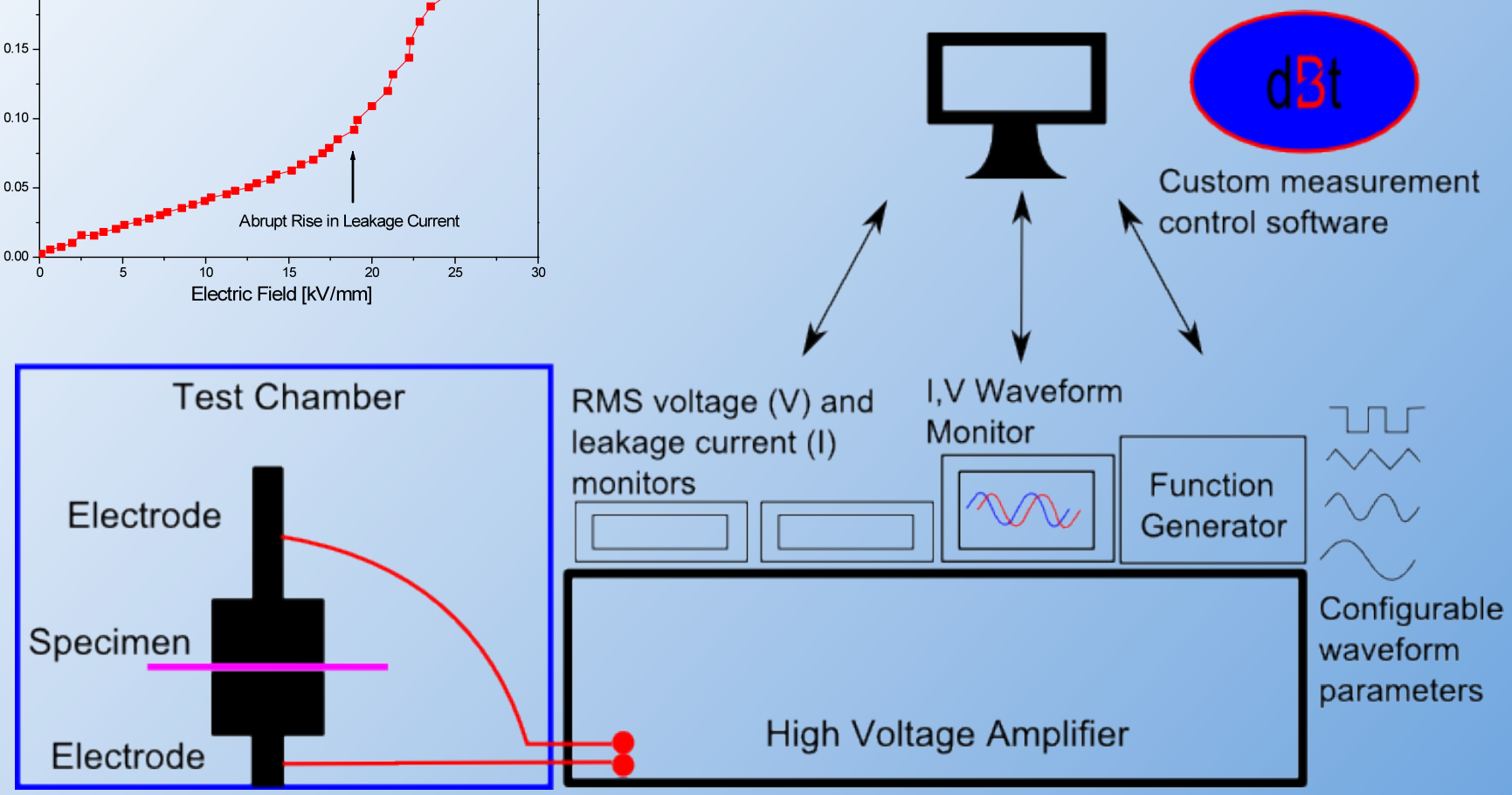

Dielectric Breakdown Test Equipment

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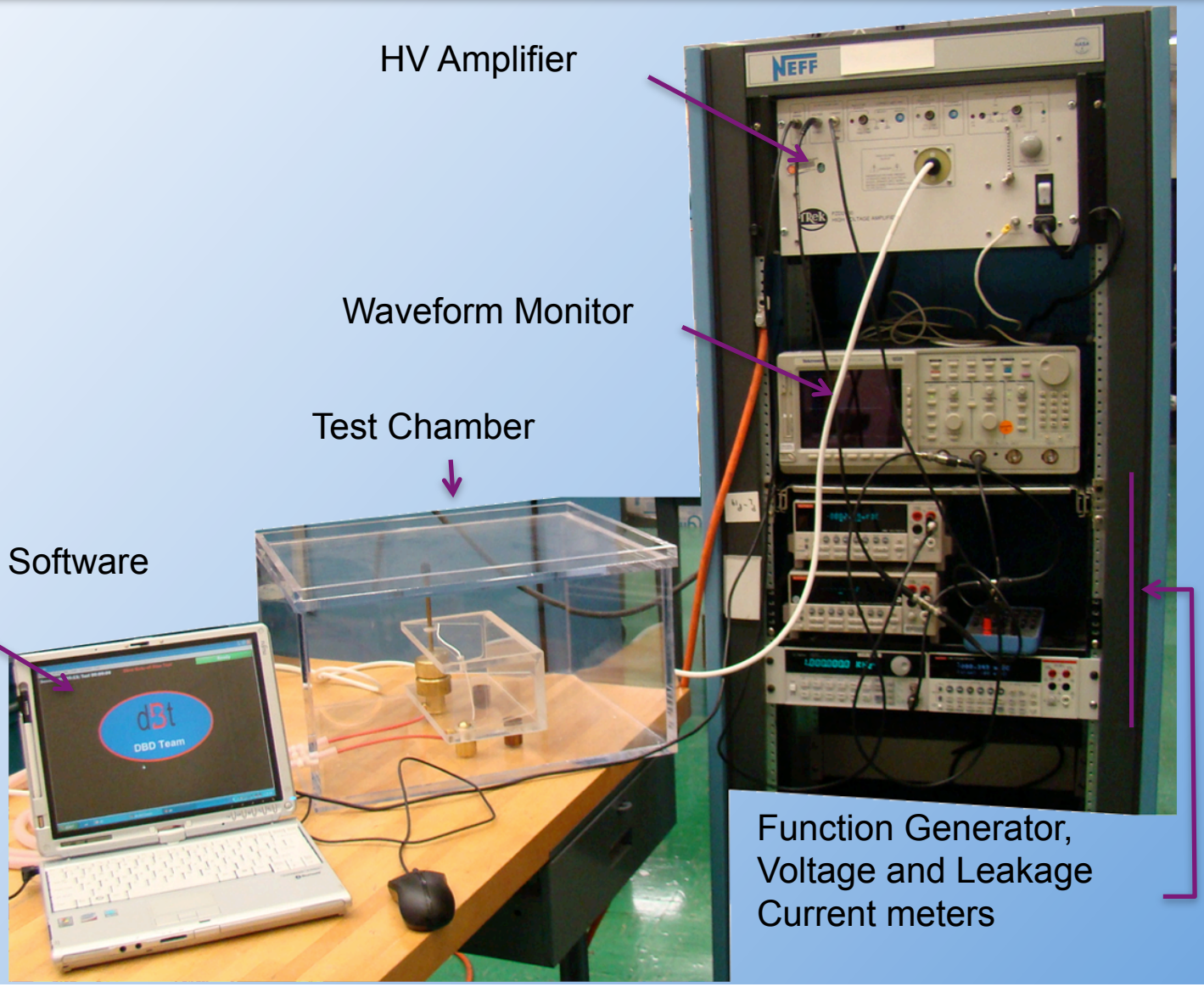

Dielectric Breakdown Strength

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Name	Dielectric Strength @ 50 Hz kV/mm
Ultem	32.7
PEEK	18.9
Teflon	15.7-19.7
Lexan	15.0
Kapton	118 (very thin films)
Upilex	272 (very thin films)
Thermalux	16.7
Solimide Foam	2.2-4.69
MicroFoam	>2

Force Balance Set-Up and Enclosure

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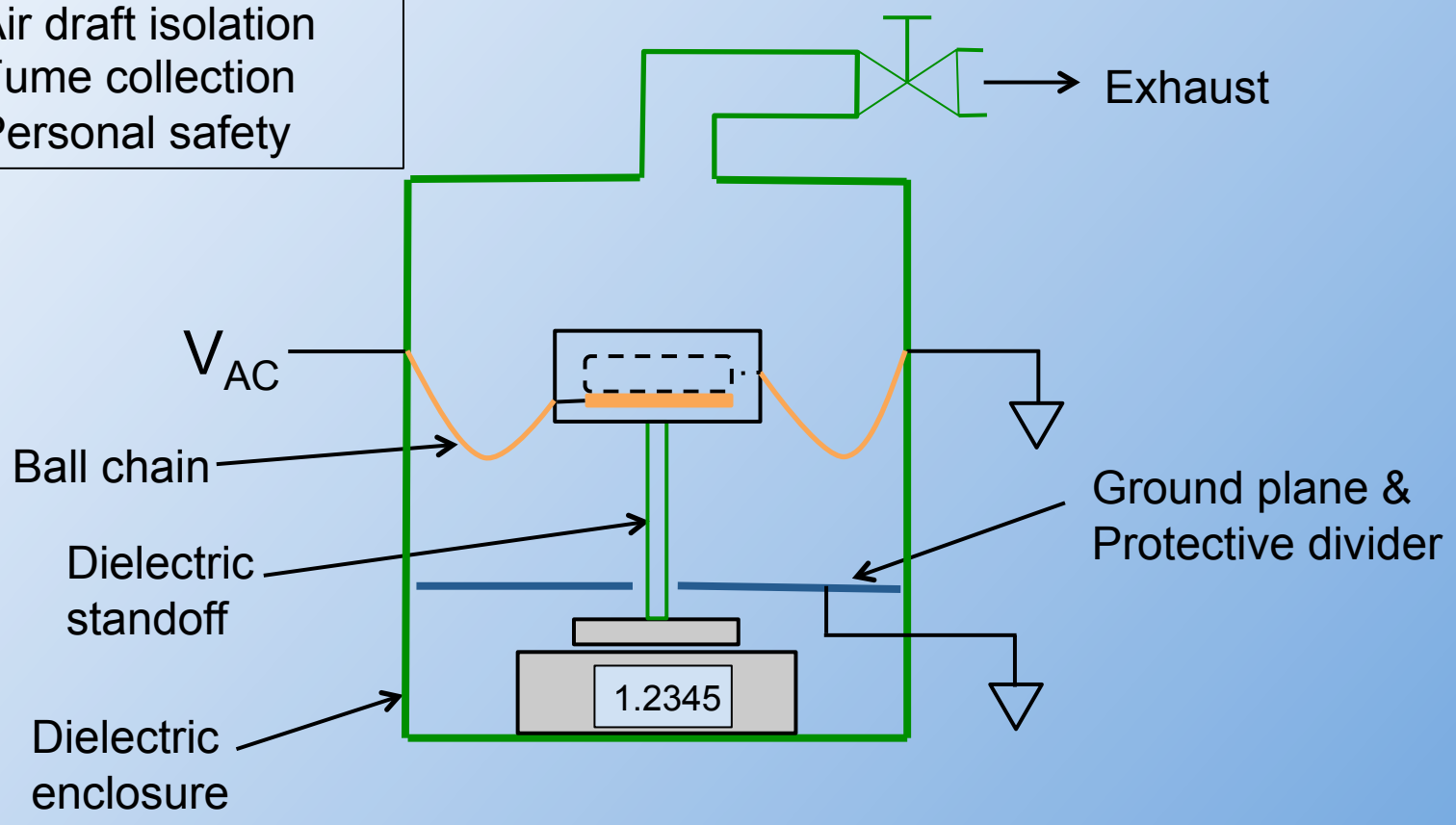
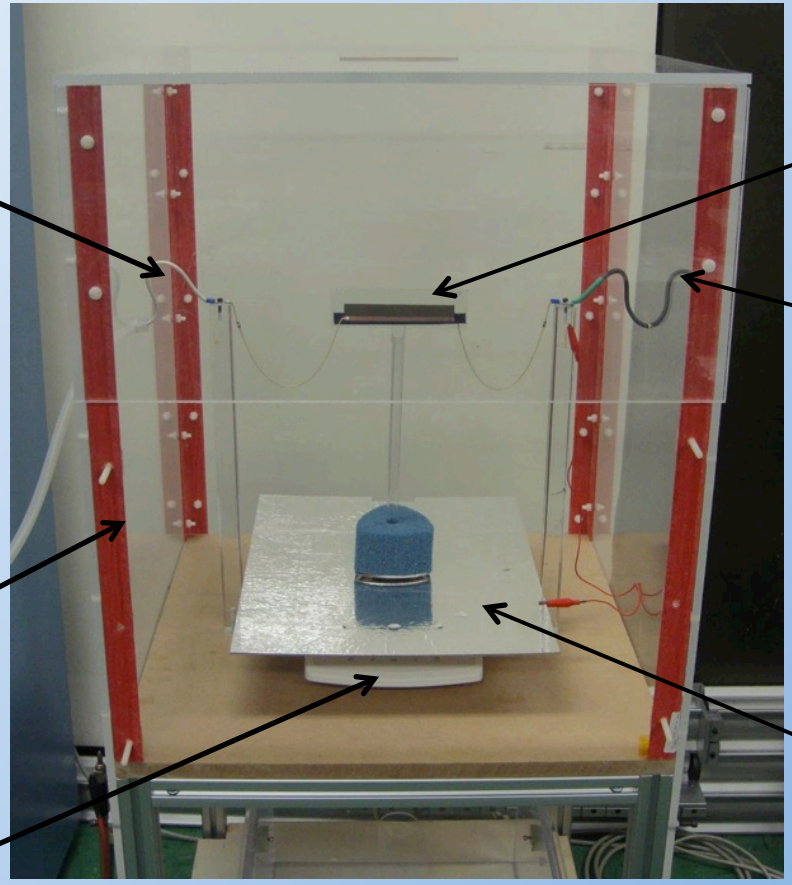
Enclosure required for:
- Air draft isolation
- Fume collection
- Personal safety



Acrylic Enclosure (Approx 12 cubic feet)



Model Configuration For DBD Force Measurements

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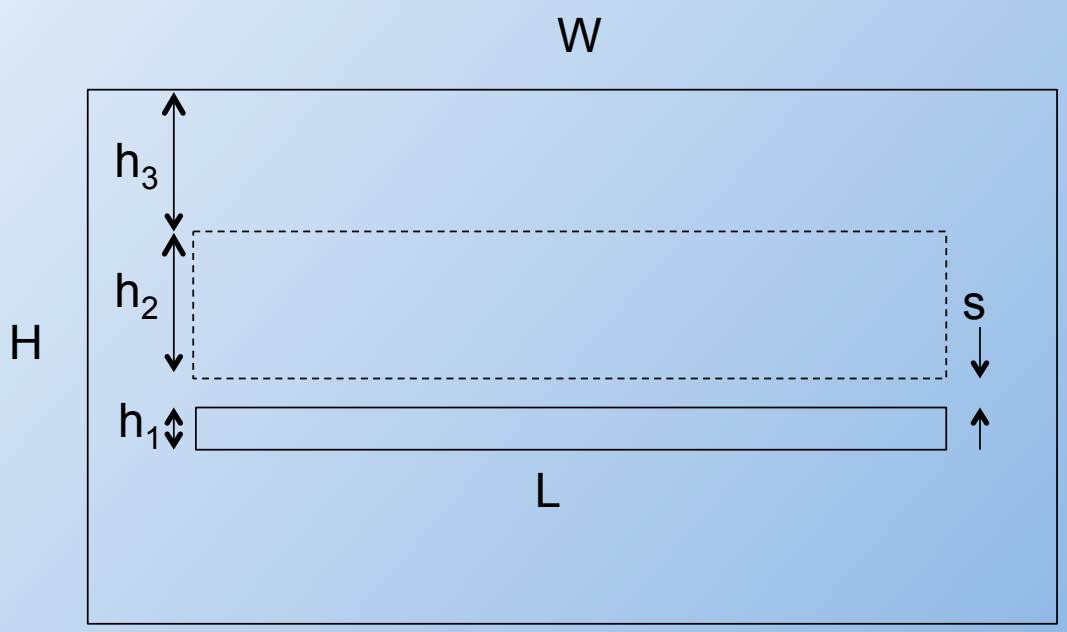

t = thickness

Test Matrix and Dimensions for Common Dielectrics

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Model	Material	H	W	t	h1	h2	h3	L	s	Plasma Initiation kVpp / kHz
S108	PMMA	124	197	2	5	15	61	150	0	6.3/5
S109	LEXAN	120	203	2.3	5	15	60	150	0	6.6/5
S110	ULTEM	120	153	3.2	5	15	60	124	0	6.9/5
S111	PEEK	116	153	3.1	5	15	58	120	0	7.6/5
S113	GLASS	104	153	1.2	5	15	57	120	0	5.6/5
S114	PFTE	120	153	3.3	5	15	60	113	0	8.6/5

All dimensions millimeters

Thrust vs. Applied Voltage

(Corrected for Thickness and Plasma Initiation Voltage)

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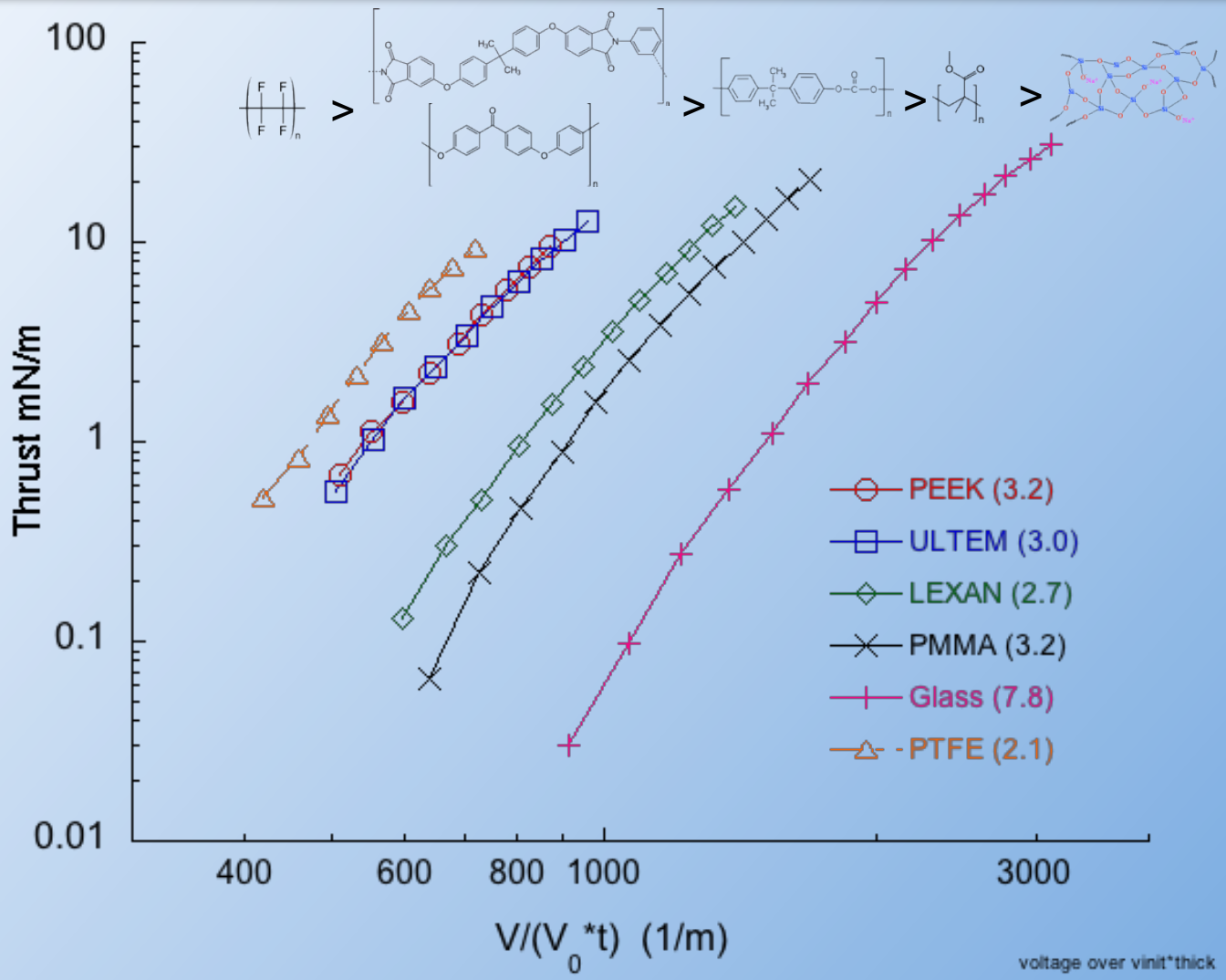

Summary

- Dielectric and force characterization capability established in-house.
- Dielectric properties of bulk and foam materials were determined.
- Reaction force was determined for materials tested.
- Elucidated relationship between molecular structure and aerodynamic parameter.
- Multidisciplinary effort yielded finding that opens up design space for DBD actuators.

Future Work

- Extend force and dielectric testing to thicker dielectrics and higher voltages to maximize force production and observe force saturation effects
- Enlarge the dielectric material database
- Develop high thrust DBD actuators based on new materials knowledge.
- Begin low speed wind tunnel force testing to assess effects of incident flow (direct drag, velocity profiles)

Dissemination

- Findings will be presented at a conference.
- Results will be documented in a refereed publication.
- Invention Disclosure was filed in March 2012, provisional patent in the process.
- Custom test software for dielectric breakdown test will be made available through NASA TM.

Back-Up Slides

Chemical Structures of Select Materials

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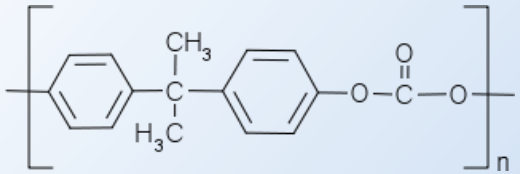
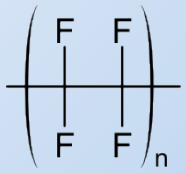
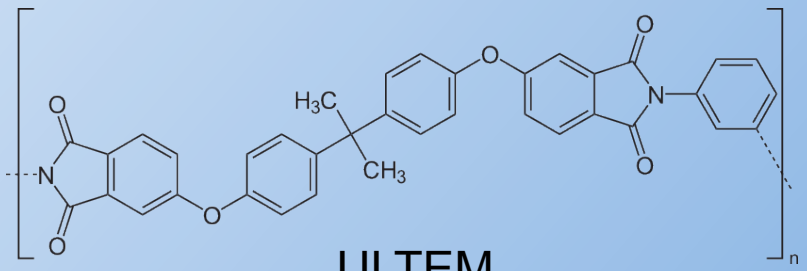


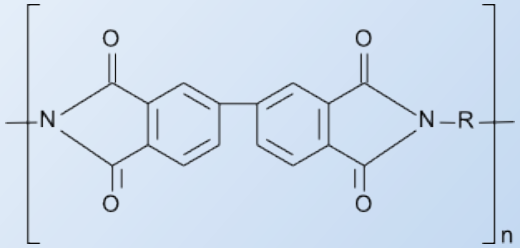
LEXAN



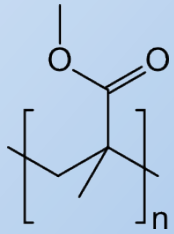
PTFE



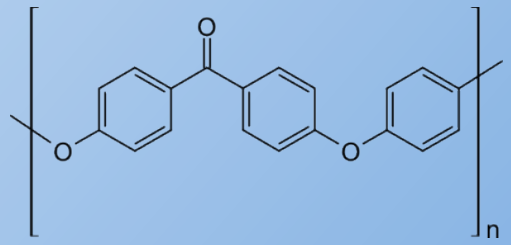
ULTEM



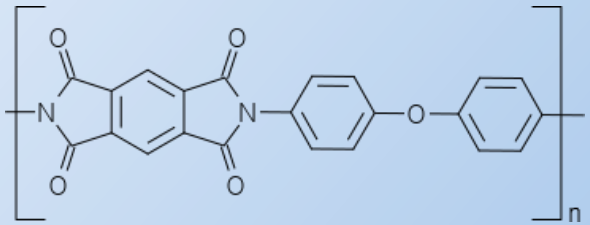
UPILEX



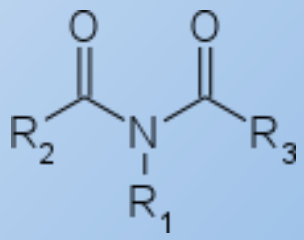
PMMA



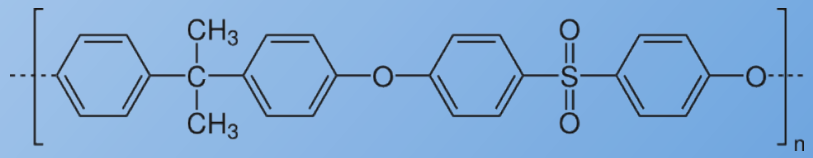
PEEK



Kapton



Polyimide
(generic)



Thermalux

Theoretical Explanations

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- Thrust depends on the net plasma charge density (*ρ)*, voltage (V) drift from the charge generated location to the ground

$$Thrust \propto \rho^{\alpha} V^{\beta}$$

where α and β are constant to be defined by more detail studies

- The plasma charge density can be governed by
  - Surface charge density of the plasma generation zone

$$\rho \propto \varepsilon_0 \varepsilon_r (E) E$$

Where ε_0 is dielectric of vacuum $\varepsilon_r(E)$ is relative dielectric constant at high electric field, and *E* is electrical field

  - Other surface properties of the dielectric material