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Time Dependent Conductivity of Low Density Polyethylene

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Time Dependent Conductivity of Low Density Polyethylene

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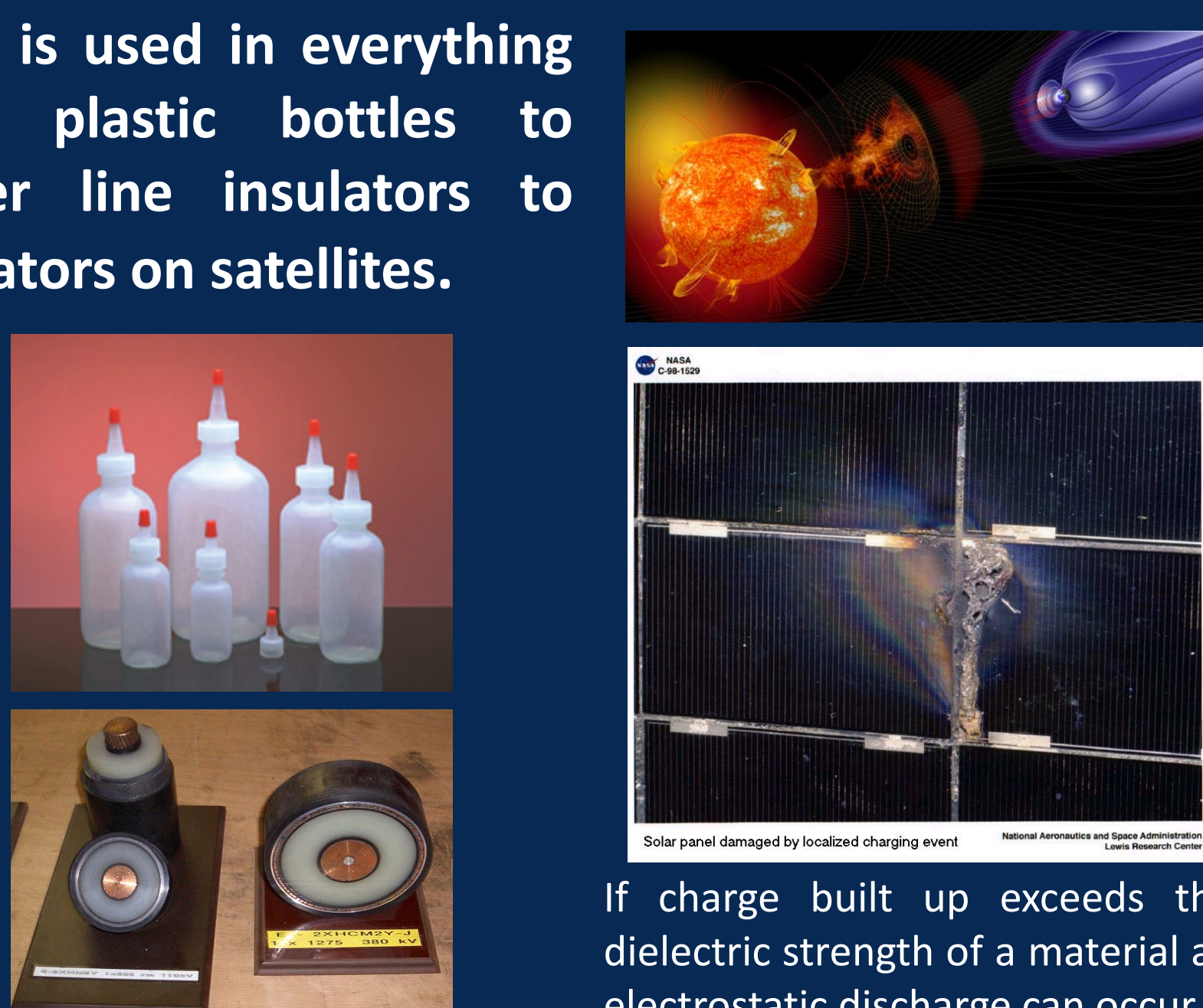
I. Abstract

The time independent conductivity of Low Density Polyethylene (LDPE) is useful in determining rates of conductivity based on intrinsic properties of a material. A simple, yet elegant, parallel plate capacitor setup allowed for data collection which extended beyond 97 hours. Through precise measurements the different stages of charge distribution were determined to the level of $3 \cdot 10^{-16}$ A. Through the use of data analysis programs, the dielectric constant and dispersion constant were both determined for LDPE and then compared with a simple, macroscopic, first-principles model to determine the quality of the fit.

II. Purpose

LDPE is a highly disordered material used as an insulator for many electrical applications on spacecraft. Understanding the conductivity and charge/discharge rate for a sample of LDPE or other highly disordered materials is paramount for studies in spacecraft charging. Should the rate of charge exceed that of the rate of discharge for a sample, there could be a sudden electrical discharge which could be cataclysmic for some of the sensitive instruments onboard a spacecraft. Something as simple as a wire's housing, if not considered carefully, could be the cause of millions of dollars of irreparable damage.

LDPE is used in everything from plastic bottles to power line insulators to insulators on satellites.

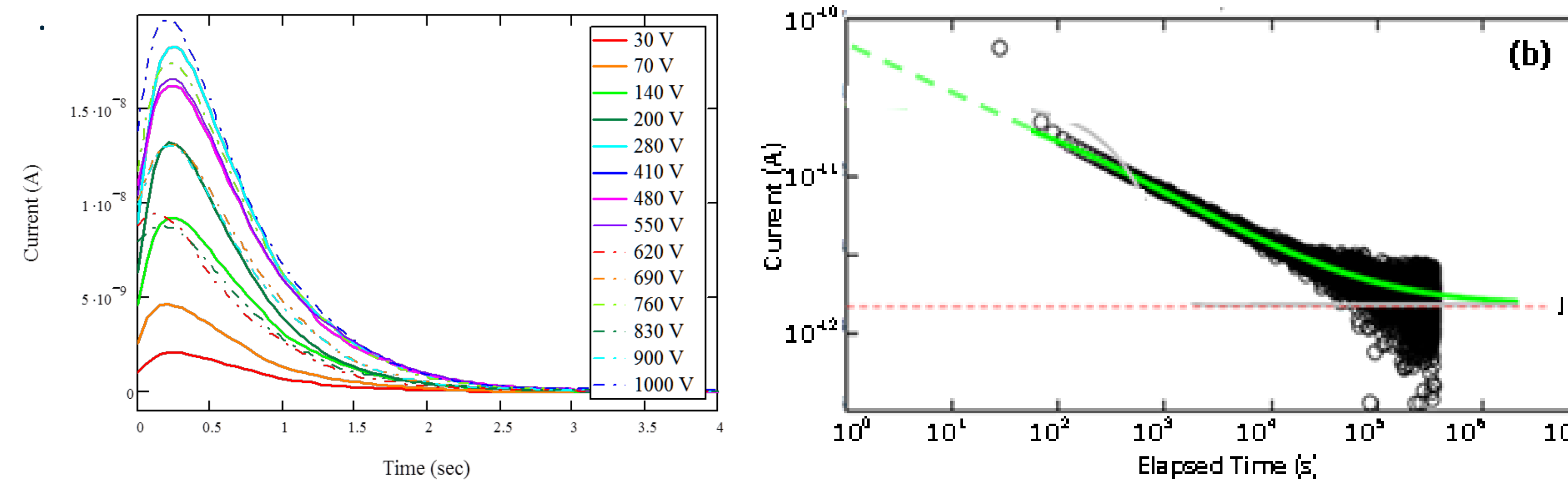


Star panel damaged by localized charging event

If charge built up exceeds the dielectric strength of a material an electrostatic discharge can occur.

IV. Results

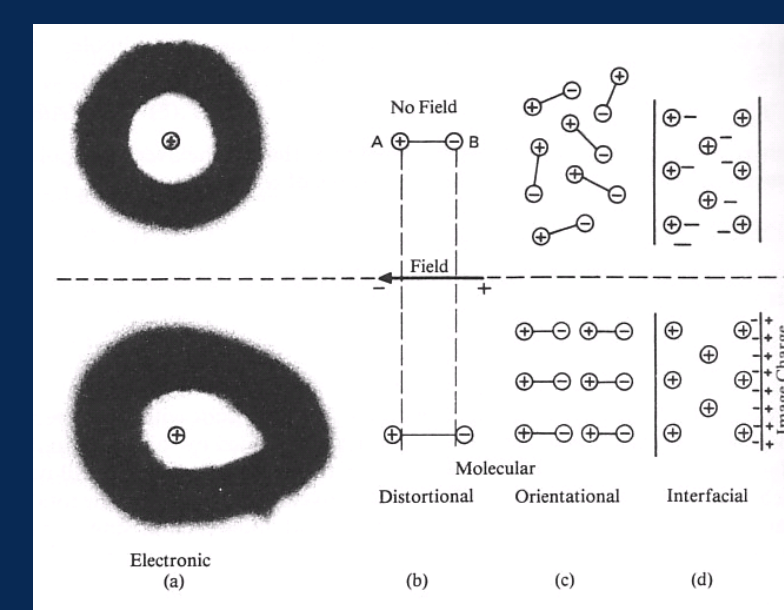
The equation for conductivity σ is, $\sigma = \frac{J}{F} = \frac{I d}{A V}$ equal to the current density J caused by an electric field F (or the current I per unit area A divided by the applied voltage V divided by the sample thickness d). Through the use of the Constant Voltage Conductivity (CVC) test chamber, we are able to measure the current and voltage across a sample. Because the thickness and area of the sample are held constant we are able to calculate the conductivity. This current can then be divided further into five different time-dependent terms (see below). As a material begins to be charged in a parallel plate orientation, the first few minutes are dominated by the polarization current. This current decays exponentially as the material begins to charge. As electrons began to diffuse through the material and the charge distribution in the material disperses the current declines as a power law in time. At very long times, as evidenced by the right-hand graph, current comes to equilibrium at the saturation current. This is the current which the charge distribution is uniform across the material. It occurs at the end of the graph as the green line (current) approaches an asymptote.



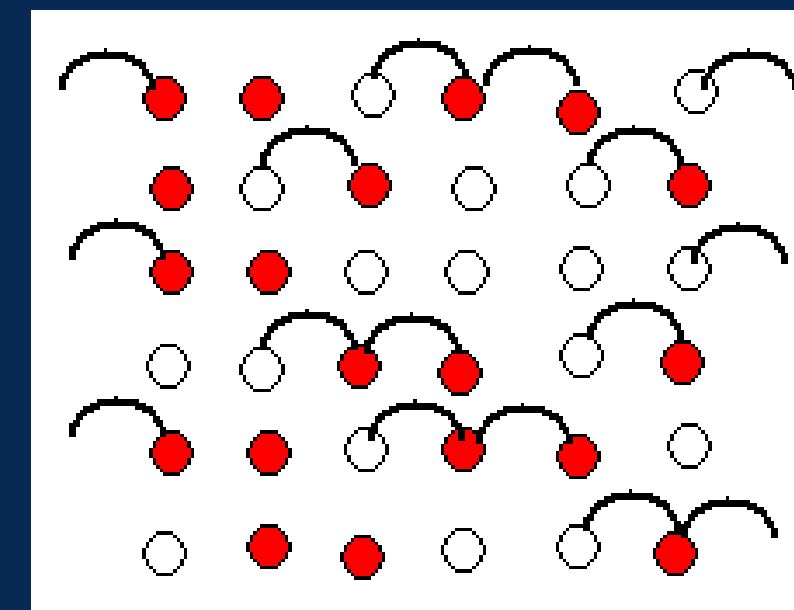
In the first few seconds, when a voltage potential is first applied the polarization current dominates the overall current equation for a material.

As the charge nears the opposite side of the sample, the dispersion and transit currents decrease until all that is left is the saturation current.

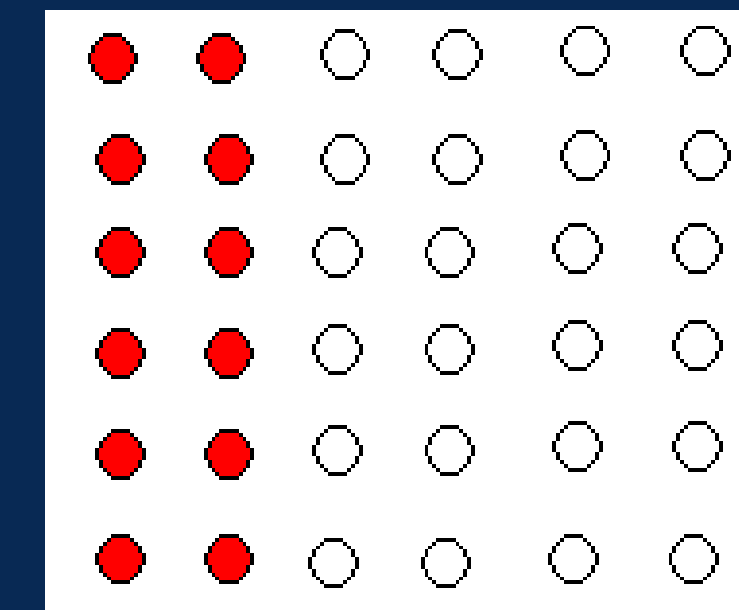
$$\sigma(t) = \sigma_{polarization}(t) + \sigma_{Diffusion}(t) + \sigma_{Dispersion}(t) + \sigma_{Transit}(t) + \sigma_{Saturation}(t)$$



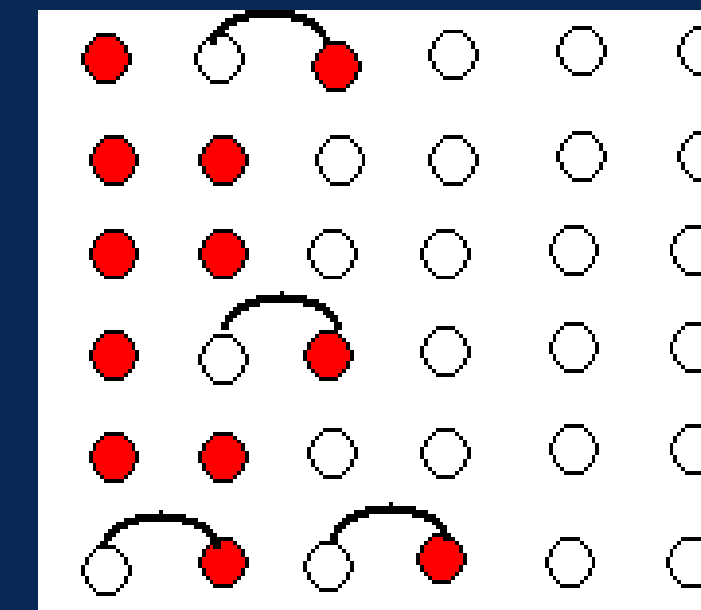
Polarization of molecules in material



Diffusion through a material (electron hopping)



Dispersion of charge distribution in a material

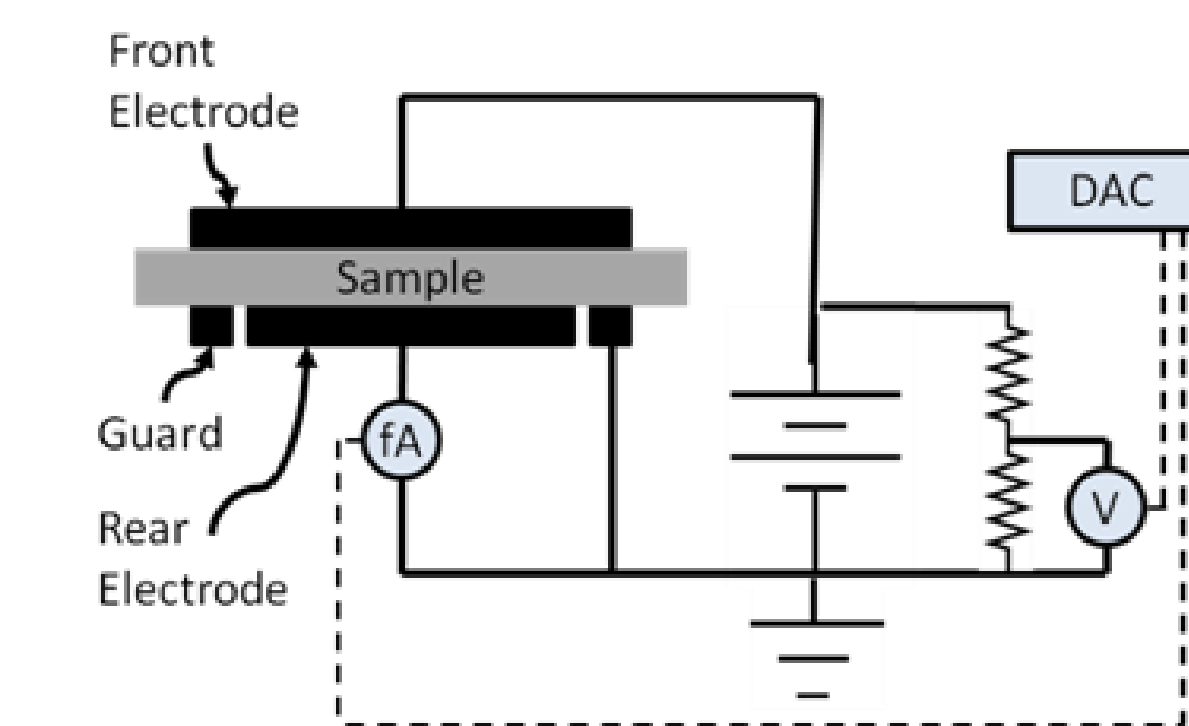


VI. What's Next

Proposed improvements to measure lower conductivities with less uncertainty include the use of higher voltages with batteries aligned in series for a 1000 V power supply. The theoretical improvement over present methods would be an order of magnitude decrease in error. Another possible idea to lower the amount of error, is the use of a capacitor charged to high voltages as a power supply for the CVC chamber.

III. Methods

The LDPE that was used for this experiment had a thickness of $(27.4 \pm 0.2) \mu\text{m}$, a density of 0.92 g/cm^3 , an estimated crystallinity of 50% and a relative dielectric constant of 2.26. All samples were chemically cleaned with methanol prior to bake out at $65 \pm 1 \text{ C}$ under $\sim 10^{-3} \text{ Pa}$ vacuum for >24hr. Samples were then placed in a parallel plate capacitor setup in a $\sim 10^{-5} \text{ Pa}$ vacuum. Potentials of varying voltages were then applied to the front electrode of the sample, and the current was measured as a function of time from the back electrode. The data were then plotted in a log-current vs log-time graph, and the results were used to describe the different portions of current.



Simplified schematic for a CVC circuit.



CVC chamber interior.



CVC chamber exterior.

V. Conclusions

From these data we are able to view the individual portions of the conductivities for a sample and even view the rate which is required for a sample to begin its next conductivity step. From graph one we are able to determine that no matter the potential the rates for polarization and diffusion are the same. There was however a growth of uncertainty in the second graph as the samples approached the equilibrium (saturation current). This is a problem which we hope to address in future modifications to the current setup.

