Investigation of Dielectric Breakdown in Filled Silicone Elastomer Composites for Improved Dielectric Elastomer Actuators and Sensors

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Project Objectives:

The primary goal of this project is to enhance the fundamental understanding of dielectric breakdown phenomena in polymer composites. More specifically, the implications of knowledge about polymer matrix/filler interactions within silicone elastomer composites on dielectric breakdown properties will facilitate the ability to produce improved dielectric elastomer membranes for actuation and sensing purposes through materials design and engineering.

Project Description:

Dielectric elastomer actuators (DEAs) are a relatively new class of lightweight electroactive polymers which can provide extremely large strains (>100%) over large areas, useful for applications such as ultrasonic transducers, camera lens autofocus devices or precision valves and pumps. DEAs can be described as compliant capacitors, wherein a membrane of elastomeric material is electroded on two opposite faces and a potential difference is applied between them, as illustrated in Figure 1. The resulting buildup of electrostatic charge on either electrode causes an attractive force to develop over the thickness direction of the membrane; per unit area this force is referred to as the Maxwell Pressure, which can be described as $P = \varepsilon_r\varepsilon_o E^2$, where ε_r is the relative dielectric constant of the membrane, ε_o is the permittivity of free space, and E is the applied electric field.

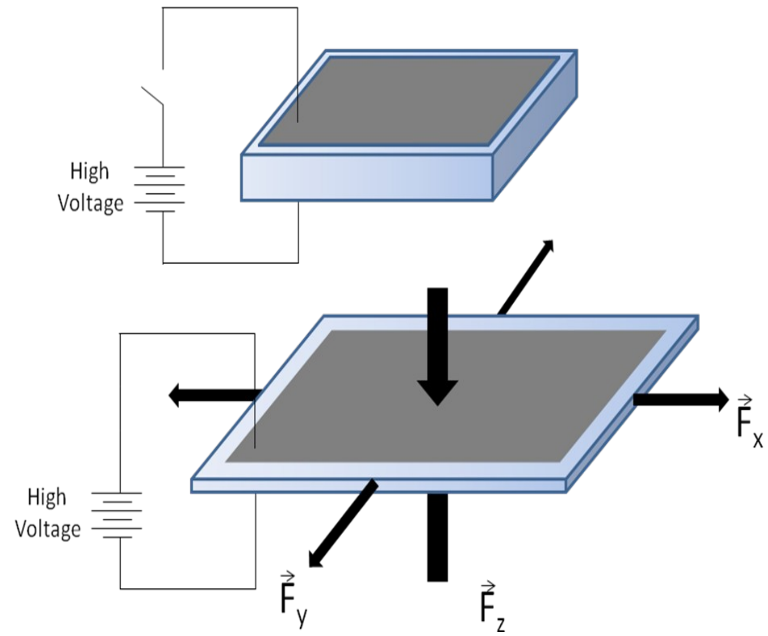

Figure 1: Schematic of a dielectric elastomer actuator device in non-activated and activated states. Grey color indicates areas of compliant electrodes, which expand with the device.

The maximization of this Maxwell Pressure is vital to the improvement of DEA systems as it governs the achievable strain and acceleration of movement. However, there generally exists an inverse relationship between dielectric constant and dielectric breakdown strength. Through the design of filler nanoparticles and the modification of their surface chemistry, our preliminary results obtained at LANL show that it is possible to simultaneously increase the dielectric constant and breakdown strength of silicone elastomer composites at very low volume fractions of filler particles. The synthesis of different filler particles is an active area of exploration in this project with different geometry, surface chemistry, morphology, and processing all playing significant roles in determining the electrical and mechanical properties of the composite.

Dielectric breakdown strength is of particular interest as it is measured in many different ways and often inadequately characterized. Large numbers of data are necessary to accurately estimate the probability of failure of a particular material as the nature of dielectric breakdown is inherently stochastic and highly dependent on processing conditions and the presence of flaws within the material. The apparatus used to measure dielectric breakdown of polymer composites located at UCSB is a customized hipot with the capability to output up to 60kV DC at 1 mA. The system is fully enclosed in a glovebox and is LabVIEW controlled, allowing real time monitoring of IV characteristics as well as variable waveform outputs and ramp rates. The sample holder was designed at LANL in conjunction with Chuck Swenson at the NHMFL during the summer of 2008 specifically to prevent surface flashover without immersion in oil or the use of sulfur hexafluoride. Kapton CR sheets with small holes are used as 'sandwich' barriers to surface breakdown over the sample, which are compressed between two Teflon collars which contain steel electrodes as shown in Figure 2.

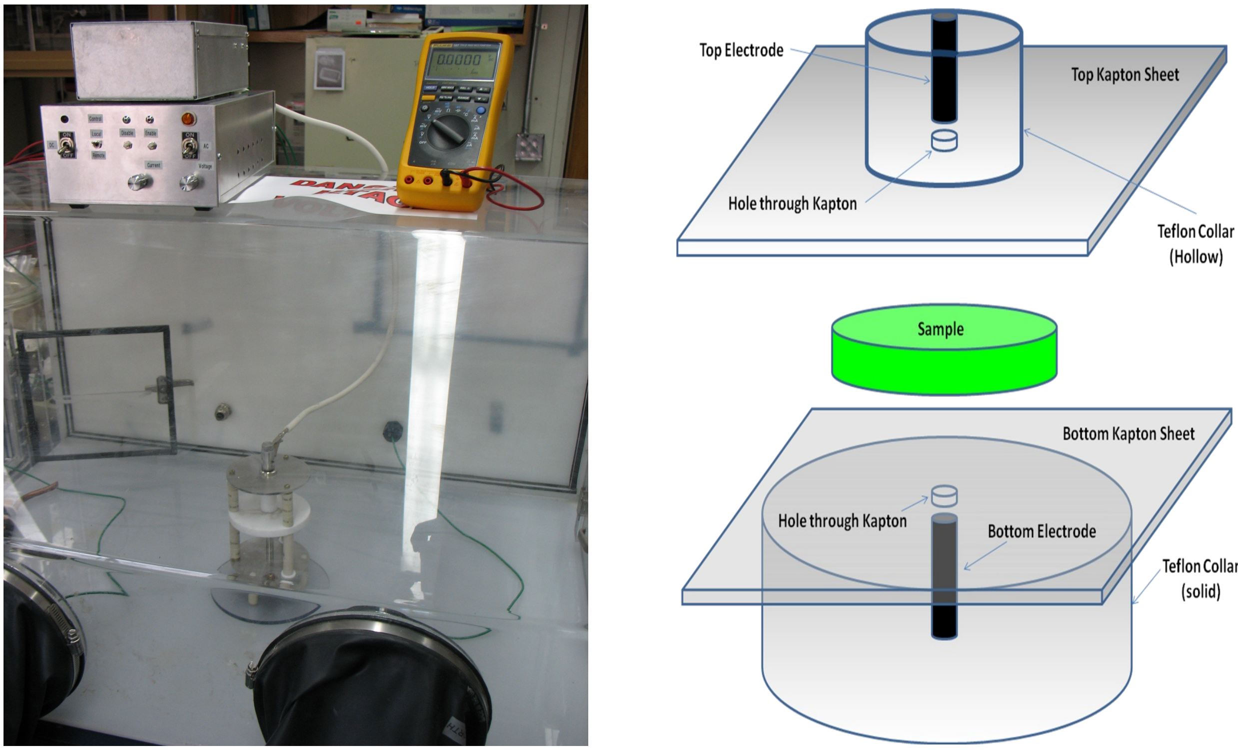

Figure 2: Dielectric breakdown apparatus at UCSB. Computer and A/D converter not shown (left). Schematic of sample 'sandwiched' by Kapton sheets (right).

The electrodes are positioned directly over the openings in the Kapton sheets where the sample is exposed. Using a small amount of torque, the top Teflon collar ensures sufficient compression contact while observing St. Venant's rule of thumb to avoid disturbing the thickness of the sample between the electrodes. The compression of the sample between the Kapton sheets and the enclosure of the electrodes in Teflon collars directs the path of least electrical resistance directly through the exposed sample, effectively eliminating surface flashover. This apparatus has been tested successfully and the results are repeatable as well as consistent with tests obtained on different hipot systems.