

Fall 10-19-2014

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Recommended Citation

Andersen, Allen and Dennison, JR, "Pre-breakdown Arcing and Electrostatic Discharge in Dielectrics under High DC Electric Field Stress" (2014). 2014 IEEE Conference on Electrical Insulation and Dielectric Phenomena. *Presentations*. Paper 11.
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2014 IEEE CONFERENCE ON ELECTRICAL INSULATION AND DIELECTRIC PHENOMENA

Des Moines, Iowa
October 19 – 22, 2014



Pre-breakdown Arcing and Electrostatic Discharge in Dielectrics under High DC Electric Field Stress

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Abstract

Highly disordered insulating materials (HDIM) exposed to high electric fields will, over time, degrade and fail, potentially causing catastrophic damage to devices. Enhanced understanding of DC aging based on expanded experimental studies is of critical importance not only to understand the physics of HDIM, but also for applications in spacecraft charging, high voltage DC power transmission and switching, thin film dielectrics, and semiconductor devices and sensors. High electric field stress phenomena associated with electrostatic discharge (ESD) were studied for dielectrics, including low density polyethylene, polyimide, and disordered SiO₂. The critical field for ESD breakdown was determined by increasing the voltage across ~25 μm samples in 20 V steps, and monitoring the leakage current. A simple parallel-plate capacitor geometry was used, under high vacuum, to achieve field strengths of up to 590 MV/m. Prior to destructive ESD breakdown, pre-breakdown current arcs or partial discharge (PD) can occur through a dielectric. For polymers, pre-ESD breakdown transient PD was observed, using both slow and high speed detection. The field at which onset of pre-breakdown arcing begins was compared to the critical breakdown field for each material studied, at which complete breakdown occurred. PD was also observed as part of endurance time measurements, where the sample was maintained at a fraction of the critical breakdown field until breakdown occurred. These pre-ESD discharge phenomena are explained in terms of breakdown modes and defect generation on a microscopic scale. Pre-breakdown PD is modeled in terms of thermally repairable defects, whereas ESD requires the formation of defects associated with bond breaking in the material. Our preliminary measurements have shown that in some materials pre-breakdown PD occurs below the average breakdown field for ESD. We have developed a preliminary model of when breakdown will eventually occur, dependent on field strength, temperature and exposure time and based on the spatial and energy distributions of both recoverable and irrecoverable defects in HDIM. Our measurements suggest that these lower limit fields for PD may be consistent with the critical field where the time-to-breakdown curve diverges to very long times. Thus, the important parameter to consider in design may not be the maximum field for breakdown, as much as the defect structure in the materials and the onset field where PD begins in a material.

*Supported through funding from NASA Goddard Space Flight Center, a Senior Fellowship from the National Research Council and AFRL and a USU Blood Fellowship.