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Recommended Citation
Sim, Charles; Sim, Alec; and Dennison, JR, "Electric Field Dependence of the Time to Electrostatic Breakdown in Insulating Polymers" (2012). All Physics Faculty Presentations. Paper 119.
https://digitalcommons.usu.edu/physics_facpres/119
Electric Field Dependence of the Time to Electrostatic Breakdown in Insulating Polymers

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Electric Field Breakdown Theory

Electric aging occurs when the molecular bonds in a material are disrupted. In polymeric insulators, this electric aging causes a breakdown described as electrostatic breakdown or discharge (ESD). The literature has shown that electric aging can be characterized by the barrier energy between bond sites, bond destruction energy or cohesion energy, trap creation within the material, and stress upon the bonds due to local and applied electric fields (2, 3, and 4). The barrier energy between bond sites is given by an energy of activation which is either a constant or can be decreased by the applied stress (electric field), temperature, or time. The literature describes two competing processes that explain the breakdown and breakdown dependence of the applied stress for insulating polymers (2, 3, and 4). The first process is due to the creation of new traps (broken bonds) resulting from charge injection on molecular sites (Fig. 1a). This process (called a recoverable breakdown event) may not lead to failure at low electric fields (Fig. 2a) and cannot be described as a rate process of the reconfiguration and de-cohesion of the bonds. These recoverable events are evidenced by spikes in the measured current prior to breakdown and are absent at the electric field Fbreakdown (Fig. 3a and 3b). The second process describes the breakdown caused by the direct stress applied to the segments leading to permanent damage (Fig. 4b); this is known as the irreversible breakdown. This process is dominant at higher fields (Fig. 3b). The Utah State University Materials Physics Group (USU MPG) has developed a model that bridges the two processes and provides a way to calculate the trap concentration (rate of bond breaking) as a function of time and applied stress [5]. This model is the USB MPG dual mechanism multiphase trapping model given by:

\[ \frac{d\nabla}{dt} = k_{\text{rec}}(F, T) + k_{\text{irr}}(F, T) \]

with \( k_{\text{rec}} \) and \( k_{\text{irr}} \) being the time to breakdown. The activation energy, \( \Delta \) the number density of defects, \( n_0 \) and \( \alpha \) are constant values, \( \epsilon_0 \) is the permittivity of the material, and \( \Delta T \) is temperature. The activation energy \( \Delta \) and temperature \( T \) are variables that can be changed with each test.

Results

In the pre-breakdown region, the material being tested acts as an infinite resistor and negligible current (≤10 μA) can be measured. At breakdown, the current increases significantly (200 μA) and maintains a constant value by setting a limiting resistance in the circuit (Fig. 5). Tests conducted on the insulating polymer Low Density Polyethylene (LDPE) indicate the mean room temperature breakdown field occurs at (277 ± 8) MV/m and is the upper bound below which endurable breakdown cannot occur. These breakdown events only occur after the critical field value has been reached by an applied stress which eventual breakdown is only a matter of time.

Acknowledgements

Research was supported by a USU URI grant, the Howard J. Blood Memorial Scholarship, and funding from the NASA/JWST Electrical Systems Working Group at Goddard Space Flight Center.

References