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Allen Andersen
Utah State University

JR Dennison
Utah State University

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**A Dual-defect Model for Predicting Lifetimes for Polymeric Discharges from Accelerating Testing**

Allen Andersen and JR Dennison
USU Materials Physics Group
Utah State University, Logan, UT 84324-4144

Phone: (435) 363-4704, E-mail: allen.andersen@aggiemail.usu.edu

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**Introduction to the Problem of ESD**

ESD can cause catastrophic failures in electronic devices. Estimating the lifetime of dielectrics is critical to ensure the reliability of electronic systems. Dielectric healing and stress relaxation can result in changes in the dielectric constant and dielectric strength, which can affect the performance of the system.

**Enhanced Predictions of Dielectric Lifetime for Electrostatic Discharge (ESD) are Critical for Applications Such as:**
- Spacecraft Charging: ESD is the most common and most devastating result of interactions between spacecraft and the space plasma environment.
- High Voltage DC Power Transmission: ESD and corona discharge can cause parasitic loss and total failure of components.
- Any Electron Device: Especially as devices get smaller, insulators are more vulnerable to ESD.

**Variability of Dielectric Strength**

- A material's observed dielectric strength varies significantly with:
  - Temperature
  - Charging history and voltage ramp rate.
  - Surrounding medium e.g., vacuum, air, or oil.
- Dielectric strengths listed in engineering handbooks state values as constants or at best a range of values with a temperature but without other vital experimental conditions.
- ASTM standards for determining material breakdown strength using ≤ 500 V/s. Results from such tests have poor repeatability. Charging occurs much faster than in many real applications.

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**Abstract**

Electrostatic discharge (ESD) can cause catastrophic failures in electronic devices. Estimating the lifetime of dielectrics is critical to ensure the reliability of electronic systems. Dielectric healing and stress relaxation can result in changes in the dielectric constant and dielectric strength, which can affect the performance of the system.

**Statistical Voltage Endurance Time Fits on LDPE Data**

The probability of a product surviving the voltage step-up processes for $N_m$ steps is:

$$P(E_{step}) = \frac{1}{2} \left( \frac{1}{2} \right)^{N_m}$$

For the ramp rate used here the product term is $N_m = 10$ steps. Both A and B type defects are needed to fit the data.

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**Results and Conclusions**

- **Polymeric insulators in applications need to last years or decades.** Accelerated laboratory tests are imperative, especially when comparing many candidate materials.
- The 11 static voltage endurance data shown took nearly 10 days of testing time. This data does not include sample preparation, vacuum breaks, etc. More long duration tests are needed to fully characterize material behavior.
- The 20 LDPE step-up tests shown took just over 3 days of testing time. There was an example of 10 years of ESD step-up test, if the end where arcing begins is a good indicator of minimum breakdown field only about 1 day of testing time could be needed per material. This is potentially a 2 orders of magnitude savings in test time!

**References and Acknowledgements**

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**Dual-defect Model**

Dielectric strength is not a constant. ESD depends on temperature, charge history, and material strength.

Our dual-defect model is consistent with measurements of pre-arc temperature- and ramp-rate dependent breakdown field distributions and lifetime times.

The model provides tentative physics-based links between pre-arc and ESD.

**Future Work**

- Acquire time endurance data for Kapton and extend the LDPE data sets to longer times.
- Extend pre-arc studies of ESD and pre-arc.
- Perform ESD tests on other materials with very different structures such as SiO$_2$.
- Expand the model to include other dynamic density of static and defect occupation profiles.

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**Aims**

- To develop a model for predicting the lifetime of polymeric materials under ESD conditions.
- To validate the model using experimental data from accelerated testing.
- To understand the mechanisms of dielectric strength degradation under ESD.

**Contributions**

- Improved understanding of the role of pre-arc phenomena in ESD.
- Development of a dual-defect model for ESD lifetime prediction.

**Methods**

- Accelerated testing using a high-voltage power supply.
- Dielectric breakdown measurements using a custom-built system.
- Statistical analysis of experimental data.

**Keywords**

- Electrostatic Discharge (ESD)
- Polymeric Materials
- Lifetime Prediction
- Dual-defect Model

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**Figure 1: Static Voltage Endurance Time Fits on LDPE Data**

The probability of a product surviving the voltage step-up processes for $N_m$ steps is:

$$P(E_{step}) = \frac{1}{2} \left( \frac{1}{2} \right)^{N_m}$$

For the ramp rate used here the product term is $N_m = 10$ steps. Both A and B type defects are needed to fit the data.

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**Dynamic Model**

This dual-defect model is an extension of the single defect model for many species and field conditions. It accounts for the jumping probability for a charge $q_j$ in field $F_j$ at temperature $T_j$ with mean defect spacing $d_j$ is:

$$P_j = \frac{d_j}{q_j F_j} 
\approx \frac{d_j}{q_j F_j} \left( \frac{d_j}{q_j F_j} \right)^{2/3} 
\approx \frac{d_j}{q_j F_j} \left( \frac{d_j}{q_j F_j} \right)^{2/3}$$

Setting $P_j$ to one and inverting:

$$\frac{d_j}{q_j F_j} = \left( \frac{d_j}{q_j F_j} \right)^{2/3} 
\frac{d_j}{q_j F_j} = \left( \frac{d_j}{q_j F_j} \right)^{2/3}$$

Then for a 2D slab model define:

$$\frac{d_j}{q_j F_j} = \frac{1}{N_j}$$

Where $N_j$ is the defect density.

For two defect species (A and B), we simply add terms for each defect type:

$$P_j = \sum_{j=A,B} P_{j,A} P_{j,B}$$

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**References**