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Lifetimes of Polymeric Dielectrics: a Dual-defect Model

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Introduction to the Problem of ESD

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 losses and total failure of components.
- Any Electronic 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, 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. Results from such tests have poor repeatability. Charging occurs much faster than in many real applications.

Electrostatic Discharge Test Analysis

Electrostatic discharge (ESD) can cause catastrophic failures in electronic devices. Estimating the lifetime of discharged devices and contaminants high field exposure is a major design and test challenge. The effects of ESD include:
- Static Electricity: ESD discharges are 
  - Very quick: <10 ns
  - Very high power density: typically on the order of 10^8 W/cm^2
- Phenomena: A typical ESD discharge may produce:
  - Graphs
  - Voltage
  - Current
  - Resistance
- Results: The probability of a discharge leading to damage depends on:
  - Strength and duration of the applied field
  - Material properties
  - Electrode geometry
- **Static Voltage Endurance Time (SVET) Test**
  - Purpose: To determine the time to breakdown of a material under constant voltage
  - Test Conditions: Voltage applied to a small area of the material
  - Endurance Time: Time to failure of a material under constant voltage

Abstract

This dual-defect model is an extension of the single defect model to include species mean-field approximation. For a single defect energy, AG, the hopping probability for a charge q, in field F at a temperature T with mean defect spacing q is

\[ P_h = \frac{2\pi e VH}{\Delta E} e^{-\Delta E/k_BT} \]

where \( \Delta E \) is the energy gap between the defect levels.

For the ramp rate used here the product term \( \Delta E \) between the terms \( P_h \) is expected to be very small. Both A and B type defects are needed to fit the data.

Results and Conclusions

- **Predicting the Lifetime for ESD**
  - Polymeric insulators in applications need to last years or decades. Accelerated laboratory tests are imperative, especially when comparing many candidate materials.
  - This data clearly suggests that ESD lifetime data show clear 100 year or more lifetime.
  - The 1% of the polymeric insulator are tested using a series of 100/year of data.
  - The number of failures in the field is reduced by 100 and the reliability of polymeric insulator is improved.

References and Acknowledgements

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