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Temperature Dependence of Electrostatic Discharge in Highly Disordered Polymers

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Introduction and Methods
Modern electronics operate in many different environments, from burning deserts to freezing tundras and even to the cold darkness of space. The temperature is different in each of these locations, and from the controlled testing environment of the lab. For this reason it is important to understand how the materials used to insulate these electronics react to changing temperatures, especially when it comes to their probability of breaking down.

Electrostatic breakdown is an abrupt reduction in the resistance of an electrical insulator when a voltage that is being applied across it exceeds a breakdown voltage. This results in the insulator becoming electrically conductive. Breakdown occurs in most dielectric materials at tens to hundreds of MV/m, reflecting the similarities in atomic spacings and bond strengths in most materials.

Methods: Our method uses step-up to electrostatic discharge (ESD) tests on low density polyethylene (LDPE) and polyethyleneketone (PEEK) at temperatures ranging from 250 K to 360 K. These tests involve applying a voltage across a thin-film sample, and slowly ramping up the voltage until the sample breaks down [1].

Dual-Defect Model

Equation (1) is a model of ESD developed at USU that considers two types of breakdown processes, A and B, where the probability of breakdown is the sum of the probabilities of A and B [3]. For equation (1) it should be particularly noted that:

- Temperature, T, appears in each term, implying a high temperature dependence.
- The exponential term involves the ratio of the defect energy, \( \Delta E_{def} \), to the thermal energy, where \( k_B \) is Boltzmann’s constant.
- The hyperbolic sine function involves the ratio of the energy gained in the electric field, \( F \), from charge moving from one defect (density \( N_{def} \)) to the next, to the thermal energy.
- It is important to define Planck’s constant, \( h \), the tunneling frequency, \( \nu_{tunnel} \), and the vacuum and relative permittivity, \( \varepsilon_0 \) and \( \varepsilon_r \) [4].

\[
P_{breakdown}(F,T) = \sum_{i=A,B} P_{def,i} = \sum_{i=A,B} \left( \frac{2\pi k_B T}{h \nu_{tunnel}} \right)^{3/2} \sinh \left( \frac{\varepsilon_0 \varepsilon_r F^2}{2 k_B T \varepsilon_r} \right).
\]

Results

The recorded breakdown field strengths were analyzed using Weibull statistics and the resulting curves are displayed in figures 3-5 [2]. From these data we see:

- In figure 3 we see that the breakdown field strength appears to decrease as the temperature increases.
- In figure 4 we see that for LDPE the breakdown curve narrows, which implies that the material is more stable at lower temperatures.
- Looking at figure 5, the average breakdown strength of the 300 K tests is significantly higher than any other data set. This could be because most this data was taken in 2013 and used a different batch of Kapton. There may have been small differences in the material that caused the discrepancy.

Conclusions and Future Work

Conclusion:
Temperature appears to affect breakdown field strength, but it seems dependent on the material. This is in line with our model, because the breakdown probability depends on material specific parameters such as the defect energy or defect density.

Future Work:
- Perform more tests on LDPE,PEEK, and Kapton to develop a better data set.
- Test additional insulating polymers.
- Test the effects of extreme low temperatures using liquid nitrogen. Test the effect of radiation damage on breakdown. This would examine more closely the effects that high energy defects have on the breakdown field strength. This should have a separate effect from temperature, because temperature mostly affects the low energy defects where the applied temperature can anneal some of the defects.

REFERENCES