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Temperature Dependency of Electrostatic Breakdown in LDPE and PEEK

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Introduction and Methods
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. It is therefore critical to understand how the breakdown electric field strength varies due to changing environmental conditions, including temperature and radiation dose.

Methods: Our method uses step-up to electrostatic discharge (ESD) tests on low density polyethylene (LDPE) and polyetheretherketone (PEEK) at temperatures ranging from 300 K to 350 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.

\[ P(F) = 1 - \exp \left( - \frac{F}{F_0} \right) \]  

Equation (2)

Results
Initially these tests were done to test how both the radiation dose and temperature affect the breakdown field strength in PEEK. At first look, using the average breakdown field strength and the standard deviation, neither appeared to have a significant effect. This is because the normal average and standard deviation don’t model ESD very well. Under further analysis using Weibull statistics, which have been shown to better match with breakdown field curves compared to Gaussian or other forms of analysis, this yielded much better results and lead to a new model.

In figure 3a we see that at high temperature the curve shifts to the right while at low temperature the curve shifts to the right through interestingly also narrows. This is easier to notice when we linearize our data from the Weibull fit in figure 3b. Now the centers and parameters roughly correspond to the slope and intercept.

Looking at the fitting parameters in figure 4c, we can see this affect. The breakdown field strength does not seem to follow a pattern though at low temperatures the breakdown curve appears to narrow.

To further test the effect of radiation damage on breakdown, we applied our model and used the Weibull distribution and linearized it that we were able to obtain results.

Conclusions and Future Work
Conclusions:
- 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.
- Using better models and statistics makes a difference. When we analyzed the data using the normal average we didn’t see any difference between the different temperatures. It wasn’t until we applied our model and used the Weibull distribution and linearized it that we were able to obtain results.

Future Work:
- Perform more tests on LDPE and PEEK to develop a better data set.
- Test the effects of extreme low temperatures using liquid nitrogen and additional high temperatures to gain a better range of data.
- Test other materials, specifically Kapton, to better understand how much the effect of temperature depends on the material.

Figure 1a - Probability of a sample of LDPE breaking down compared to the breakdown field using a Weibull fit. Notice how at higher temperatures the breakdown field strength decreases while shifts to the left while the opposite appears to happen at lower temperatures.

Figure 1b - Linearization of figure 1a. In these coordinates the width and center roughly correspond to the slope and intercept of the linearized curve. Note that the slopes are different between temperatures.

Figure 3c - Fitting parameters F0 and b of the graph. F0 controls the center location of the curve while b controls the width. Notice that as temperature increases, the breakdown field strength decreases while b changes slightly.

Figure 4a - Probability of breakdown from LDPE, with the low temperature curve being narrower than the high temperature curve.

Figure 4b - Linearization of figure 4a. Notice that with these data, the slopes at higher temperatures are similar though distinctly different from the slope of the low temperature curve.

Figure 4c - The Weibull parameters, F0 and b, for each curve. Especially of note is that while F0 does not seem to follow a trend, b decreases as temperature increases.

References

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