THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

10th Wernher von Braun Memorial Symposium
October 24 – 26, 2017

American Astronautical Society

New approach to improve the breakdown strength for thick dielectrics: A theoretical study

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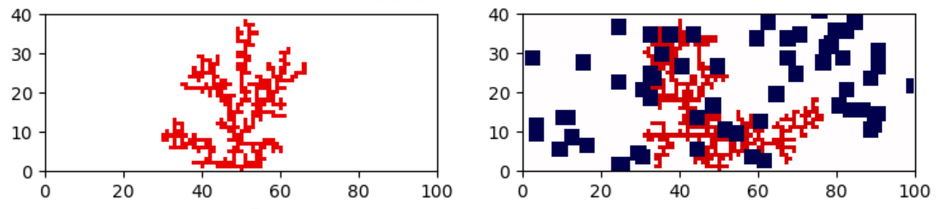
Overview

High voltage insulators are used in many aerospace electronic components and the performance of the devices is affected when dielectric breakdown occurs. In this poster, we would like to present a generalized theory for thick dielectric breakdown. The theory applies to all kinds of dielectric breakdown under high voltage even for the breakdown in our nature as we see the lighting strike in the air. In order to strengthen dielectrics, we propose incorporating insulating fillers in dielectric materials. Our computer simulation supports the perspective.


(a) Dielectric breakdown in air.


(b) Dielectric breakdown in solid.


(c) Laboratory experiment on dielectric breakdown.


(d) Computer simulation on dielectric breakdown.

Methodology

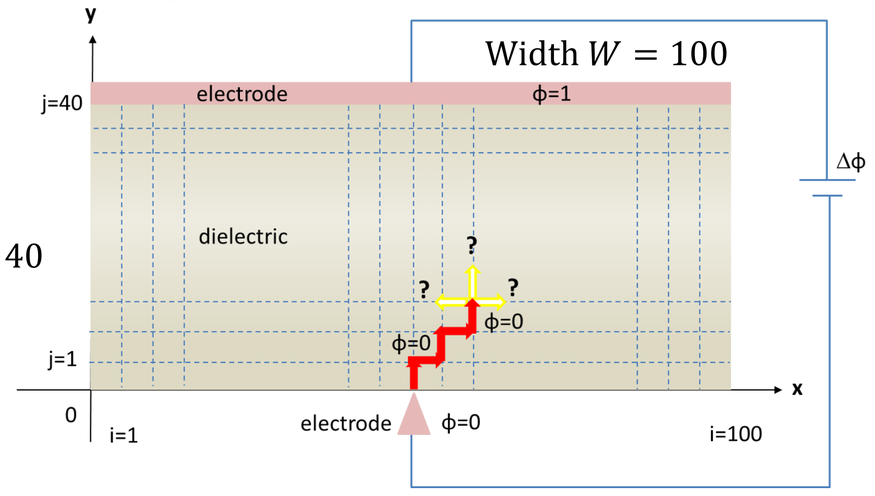
This electrostatic problem obeys the Laplace's equation with the boundary condition. It can be numerically solved to obtain the electric potential distribution inside the dielectric under high voltage. The Monte Carlo method is used for locating random paths of the molecular bond breaking (electrical treeing) w.r.t. the local electric field in both 0% and 20% by volume of randomly distributed insulating fillers in polymers.

$$\nabla^2\phi(x,y) = 0, \quad 0 < x \le W,\ 0 < y \le T.$$

Boundary condition:

$$\phi(x,0) = 0, \qquad \phi(x,T) = 1.$$

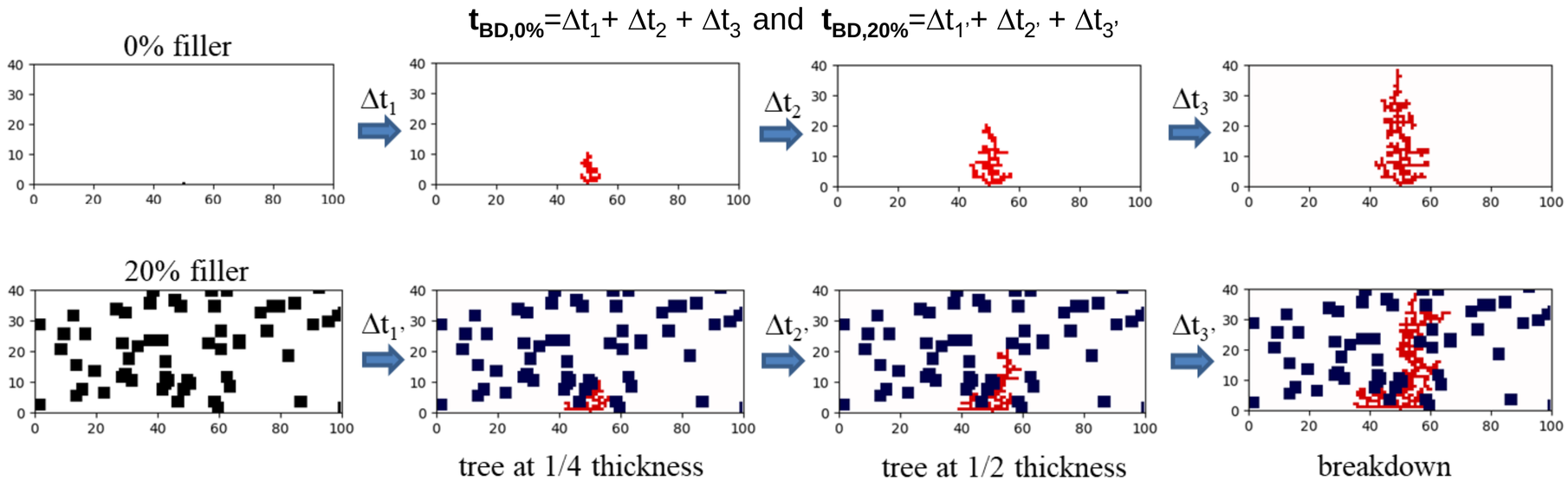
$$\frac{\partial\phi(x,y)}{\partial x} = 0. \quad \text{(for insulating fillers)}$$

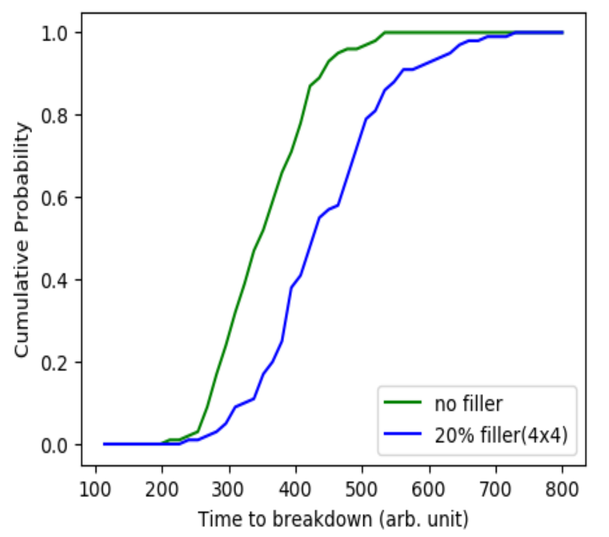


Key Findings

The sample results of the electrical treeing process and the statistical analysis of time to breakdown ($\mathbf{t_{BD}}$) in a pure polymer and that with 20 vol% insulating fillers are as follows:

$\mathbf{t_{BD,0\%}} = \Delta t_1 + \Delta t_2 + \Delta t_3$ and $\mathbf{t_{BD,20\%}} = \Delta t_{1'} + \Delta t_{2'} + \Delta t_{3'}$





The simulation with statistical analysis shows that $\mathbf{t_{BD,20\%}} > \mathbf{t_{BD,0\%}}$. Therefore, incorporating insulating fillers with a certain concentration prolongs the breakdown time, which is of advantage to electronic devices used under extreme condition in space environment such as solar heat, radiation, energetic particles and cosmic rays.

Impact

This simulation work enable us to not only predict the breakdown time but also improve the dielectric strength by (1) incorporating insulating fillers, (2) changing filler concentrations, and (3) modifying the filler shape. The quality enhancement of dielectrics with our proposed technique elongates the life of insulators.

Acknowledgements

This study is supported by the Graduate Teaching Assistantship from Department of Electrical and Computer Engineering, College of Engineering.

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