Study Of Breakdown Of Solid Dielectrics In Divergent Fields With COMSOL Multiphysics

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Abstract

Electric forces acting on a neutral matter in divergent electric fields generate mechanical stresses even in absence of charged species. This mechanism is invoked here as a factor in solid dielectric breakdown (BD). Closed form analysis for coaxial cylinders and point-to-plane gaps is complemented by numerical simulations. A simpler, 1D case of coaxes provides a clear qualitative and quantitative grasp of the phenomenon. It shows that the electric forces can be of the order of GN/m3. Then point (needle)-to-plane case is studied. First, electrostatic analysis for the geometry matching experimental conditions [1] were made. Parametric curves for E-field spanning different needle angles and tip radii were generated and compared to analytical expressions available in literature. Electric forces that are proportional to gradE2 were inputted as body forces for stress analysis that was performed in an elastic formulation, both in stationary and transient cases. Stress analysis for practical voltage levels predicts stresses of the order of several MPa which exceeds yield stress of many technical insulating materials including those used in the experiments. Notably, shear stresses arise in the vicinity of the needle tip. Especially at repetitive pulsing, they may affect the sensitive metal-dielectric boundary. Thus, solid insulation BD can be initiated or assisted by mechanical damage induced by the electric forces in absence of ionization! This appears to be an unnoticed mechanism of electric breakdown in solids in a nonuniform field. It may be a dominant mechanism or a part of complex combination of other processes, such as ionization and avalanching, field emission from cathode, crack propagation, etc.
This paper is an extended version of [2] complemented by considering additional geometries, transient cases, and comparison to wider experimental data.

Reference

[1] A. Pokryvailo, "Pulsed Techniques for Accelerated Electrical Aging of Solid Insulation Materials and Components of HV Power Supplies," 2023 IEEE Electrical Insulation Conference (EIC), Quebec City, QC, Canada, 2023, pp. 1-4.
[2] A. Pokryvailo, "On the Mechanism of Electromechanical Breakdown of Solids in Strongly Nonuniform Fields in Absence of Ionization and Space Charges," in IEEE Trans. Diel. Electrical Ins., Early Access.