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Imaging the Effect of Electrical Breakdown in Multilayer Polymer Capacitor Films[1]

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Multilayer polymer films show great promise as the dielectric material in high energy density capacitors. Such films show enhancement in both dielectric strength (E_{B}) and energy density (U_{d}) relative to monolithic films of either source polymer. Composites are typically comprised of alternating layers of a high E_{B} polymer and a high permittivity polymer. Here, we discuss a multilayer system based on polycarbonate (PC) interleaved with polyvinylidene fluoride-hexafluoropropylene (PVDF-HFP). The dielectric properties of the PC/PVDF-HFP films are influenced by both composition and individual layer thickness. Optimized films show E_{B} =750 kV/mm and U_{d} =13 J/cm^3. Further enhancements in E_{B} and U_{d} are expected through optimization of the component polymers, composition, and layer structure. To guide next generation design, it is important to understand the breakdown mechanism, as it directly influences E_{B}. To elucidate the role of the layer structure during electrical breakdown, we use a tandem focused ion beam (FIB) / scanning electron microscope (SEM) imaging technique. The technique allows us to image the internal layer structure of both 'as fabricated' control films, and those subjected to high electric fields. It is therefore a powerful tool to assess film quality and analyze failure mechanisms. Specifically, the FIB is used to mill site-specific holes in a film and the resulting cross-sections are imaged via SEM. Individual layers are easily resolved down to 50 nm. For films subjected to electrical breakdown, the location and propagation of damage is tracked with sequential FIB milling and SEM imaging. Spatially resolved FIB/SEM imaging allows preparation of quasi-3D maps displaying the evolution of internal voids in areas adjacent to the breakdown location (pinhole of d = 30-80 microns). A majority of the voids are localized at the interfaces between layers and may propagate as far as 30-50 microns from the pinhole. The data suggest that the enhancement in dielectric strength arises from a barrier effect, whereby the propagation of an electrical breakdown in the direction of the applied field is impeded by the layer interfaces. We will also discuss recent TEM imaging results that are used to characterize the interfacial length scale and chemical makeup, factors that may influence breakdown.

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