Center for Industrial Electronics

SDU

Institute of Mechanical and Electrical Engineering

PhD Defence

by

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Title:

Optimization of Film Capacitors

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POPULAR SCIENTIFIC ABSTRACT

ODYSSEAS GKIONIS-KONSTANTATOS
OPTIMIZATION OF FILM CAPACITORS

In the realm of green energy technologies, the demand for capacitors capable of operating under elevated electric fields and high temperatures has become increasingly urgent. Metallized polypropylene film capacitors (MPPFCs) have long served as a cornerstone of energy storage in high-voltage and high-frequency applications, owing to their exceptional dielectric properties, self-clearing capability, and cost-effectiveness. However, MPPFCs face substantial challenges including limited dielectric energy density, temperature constraints, and performance inconsistencies arising from material defects, impurities, and variations in manufacturing processes. Hence, despite over 70 years of research and industrial deployment, the intrinsic dynamics of polypropylene and its optimization potential remain only partially understood, underscoring the need for performance enhancement and standardization.

This dissertation addresses these critical challenges through a comprehensive, multi-faceted approach aimed at enhancing the performance of the thinnest commercially available biaxially oriented polypropylene (BOPP) film. Therefore, the main research question driving this work lies on the trade-off effect which focuses on how the film dielectric thickness reduction can maintain or even optimize its electrical, mechanical and thermal properties. The answer has been found in the thermal annealing treatment and inorganic multilayer integration, which can mitigate the inherent limitations of MPPFCs while ensuring long-term functionality and industrial feasibility.

The investigation into dielectric thinning explores the impact of reducing BOPP thickness from 3.8 μm to 1.9 μm on breakdown strength, capacitance, and defect susceptibility. Dielectric strength analysis revealed an inevitable contradiction: while thinner films facilitate miniaturization, they exhibit increased defect sensitivity and lower breakdown strength (412 V/μm for 1.9 μm vs. 428 V/μm for 3.8 μm). To address this vulnerability, thermal annealing treatment at 60°C for five minutes was employed, resulting in a 1.30% increase in crystallinity, a 28.57% and 20% rise in Young's modulus (in the linear and transverse directions, respectively), and a 29.7 V/μm increase in breakdown strength. Notably, this enhancement established the dielectric strength of the treated 1.9 μm film as superior to that of the 3.8 μm MPPFC. Further validation of the annealing treatment's efficacy was demonstrated through improved heat dissipation and reduced defect concentration. Finally, the integration of ultrathin inorganic coatings yielded significant improvements in thermal management and electrical performance. Thermal imaging revealed a reduction in peak temperature from 31°C to 28.8°C, while Weibull analysis indicated enhanced breakdown strength (436.32 V/μm) and greater failure consistency.

Together, these findings establish a robust framework for the development of the next-generation MPPFCs, striking a balance between miniaturization and performance stability and offering practical, cost-efficient scalable solutions for industrial adoption.