

Development of High Temperature Capacitors for High Density, High Temperature Applications

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ABSTRACT

A number of alternative capacitor technologies have been studied and high-temperature extruded polymer film capacitors hold the promise to meet the critical needs for temperature, energy density, reliability, cost and availability. Polymer resins capable of continuous use up to 200°C can be extruded into very thin films thereby permitting higher capacitor operating temperatures, higher energy density and improved cost structure compared to films manufactured by solvent casting processes. Studies of polymeric resins have shown that high-engineered polyetherimides show great promise for use as dielectric capacitor films. Polyetherimides can be melt extruded into thin films providing a low cost, environmentally friendly dielectric material. Discussions of the results of melt extrusion, metallization, and winding into electrostatic polyetherimide film capacitors will be given comparing and contrasting the results to other electrostatic film capacitor designs.

INTRODUCTION

Aviation equipment manufacturers are designing advanced avionics systems that cannot be fully realized without advanced lightweight, high temperature capacitors providing greater power and energy densities. In addition, the lack of high temperature capacitors has the potential to be disruptive to the automotive, power generation and transmission industries. New high-energy density capacitors will provide a "game changing technology" to create hybrid electric vehicles that are more cost effective and energy efficient than the commercially available designs. Most existing high power capacitors use 20+ year-old technologies employing biaxially oriented polypropylene as the

dielectric. This material can only operate up to 90-125°C, severely limiting range of applications. The need for more compact and higher temperature capacitors with better reliability will meet an increasing demand in the power electronics industry and military arena. In the 1980's and 1990's pulsed power and more compact power electronics research catalyzed interest in advancing technologies in the categories of electrostatic devices including ceramics and polymers, electrolytic, multilayer and mica capacitors^{1, 2}. Miniaturization of electronic systems increases the device operating temperature thereby requiring all components to perform reliably at these higher temperatures and also age in a non-catastrophic manner, generally described as "graceful" failure.

The defined temperature goals of 200-300°C has proven difficult to achieve due to the lack of adequate dielectric materials and a means to process them with good properties and in a cost effective manner. In addition, graceful failure aging mechanisms suggest the electrostatic capacitors designs using metallized thin polymeric films offer an advantage. This paper will describe the evaluation of metallized polyetherimide films in a cylindrically wound capacitor.

EXPERIMENTAL

13-micrometer thick, thermoplastic polyetherimide (PEI) film was chosen for this study due to its commercial availability and the excellent quality of the film. The original melt-extruded film was 530 mm wide and 2000 meters in length.

DIELECTRIC PROPERTIES – The polyetherimide film was evaluated for several dielectric properties including DC dielectric breakdown strength, dielectric constant,

and dissipation factor. Dielectric breakdown strength was measured under silicone oil following ASTM D149, Method A using a ¼" brass upper electrode and a brass lower electrode. Dielectric constant and dissipation factor measurements were measured using a Novocontrols broadband dielectric spectrometer from room temperature to 200°C and 20 Hz to 10 kHz. Gold and platinum electrodes were applied using sputtering techniques or thermal evaporation.

SURFACE QUALITY AND FILM THICKNESS – Accurate and precise measurements of the thin films are difficult to achieve using mechanical devices such as micrometers at thicknesses less than 25 micrometers and in particular as film thicknesses approach 1 micrometer. Therefore, spectral reflectance at infrared wavelengths was employed using a Filmetrics F-20 spectral reflectance film thickness instrument, capable of measuring film thicknesses between 30 Å and 450 µm. Surface quality was measured using Micro XAM Optical Profilometer from ADE Phase Shift Technologies. This optical profilometer uses white interferometry to map the topography of reflective and fairly flat surfaces. The vertical resolution of this system is 0.1nm in Z on highly polished surfaces and 1µm in X, Y over a 700µm x 500µm area.

FILM METALLIZATION – The capacitor design chosen for evaluation required film metallization using standard commercial film processing with an aluminum body of 6 to 12 ohm/ resistivity, a zinc heavy edge of 1 to 3 ohm/ , and a 6 mm margin. After metallization the film was cleared at 50volts DC.

CAPACITOR WINDING AND PACKAGING - Two microfarad, 900 VDC capacitors were wound and potted using a 200°C high temperature potting compound and packaged in a 200°C package for elevated temperature testing. Zinc thermal end spray was employed to provide electrical connection from the metallized film to the metal leads. The capacitor testing data was compared to high temperature capacitors manufactured by other researchers.

RESULTS AND DISCUSSION

A number of polymeric films have been evaluated for electrostatic capacitor designs. In each case the goal of the research was to identify dielectric resins with higher dielectric constants and the capability of being processed into thin films with good DC breakdown strengths. Polycarbonate (PC) films were the traditional dielectric material for high temperature capacitors for a number of years until the lack of dielectric-quality polycarbonate film availability forced the elimination of this capacitor from the market. Other films have been transformed into alternative high temperature electrostatic capacitors such as Teflon® fluoropolymer,

Kapton® polyimide, polyphenylene sulfide (PPS), or a proprietary aromatic polyester film (FPE)^{3, 4}. These materials have favorable intrinsic dielectric properties suggesting further evaluation is warranted. Table 1 summarizes the properties of these materials in comparison to polyetherimide (PEI) and biaxially oriented polypropylene (BOPP), the benchmark for all capacitor designs. In most cases, the resulting capacitors were either difficult to manufacture, showed poor dielectric properties, the films were available in limited commercial quantities or were manufactured with costly techniques such as solvent casting.

Table 1 Polymer Properties

DIELECTRIC	T _g , C	DIELECTRIC CONSTANT	TANGENT DELTA, 1KHZ	FILM MFG
BOPP	-10	2.2	<0.0002	Extrusion
Teflon	-97	1.9	0.0003	Extrusion
Kapton	360	3.2	0.0018	Solvent cast & extrusion
FPE	335	3.5	0.0026	Solvent cast
PPS	285 (MP)	3	0.0018	Extrusion
PEI	217	3.2	0.002	Extrusion

FILM PROPERTIES – PEI film, the focus of this paper, was evaluated for the following properties, dielectric breakdown strength, dielectric constant, dissipation factor, and roughness. Other properties are currently under evaluation and will be presented in a future paper. A full discussion of the advantages and disadvantages of various processing techniques and the ease of achieving thin films is beyond the scope of this paper therefore nearly all of the films evaluated in a capacitor will be limited to extrusion, with the exception of the FPE film which is solvent cast.

Dielectric constant and dissipation factor - The PEI film showed a stable dielectric constant and dissipation factor at temperatures up to 200°C and frequencies up to 10 kHz, (Figure 1). Higher frequency response and low temperature behavior are currently under investigation. A flat and stable dielectric constant and dissipation factor are desirable for reliable and long life capacitors.

Dielectric breakdown strength - Stable breakdown strength is also a requirement for long and reliable life at high operating temperatures and thermal cycling, (Figure 2). PEI films manufactured in the laboratory using an extrusion cast process were compared to large-scale extruded films. In either case, little change in the breakdown strength was observed as the temperature was increased.