Metallized Hybrid Film for DC-Link Application

By
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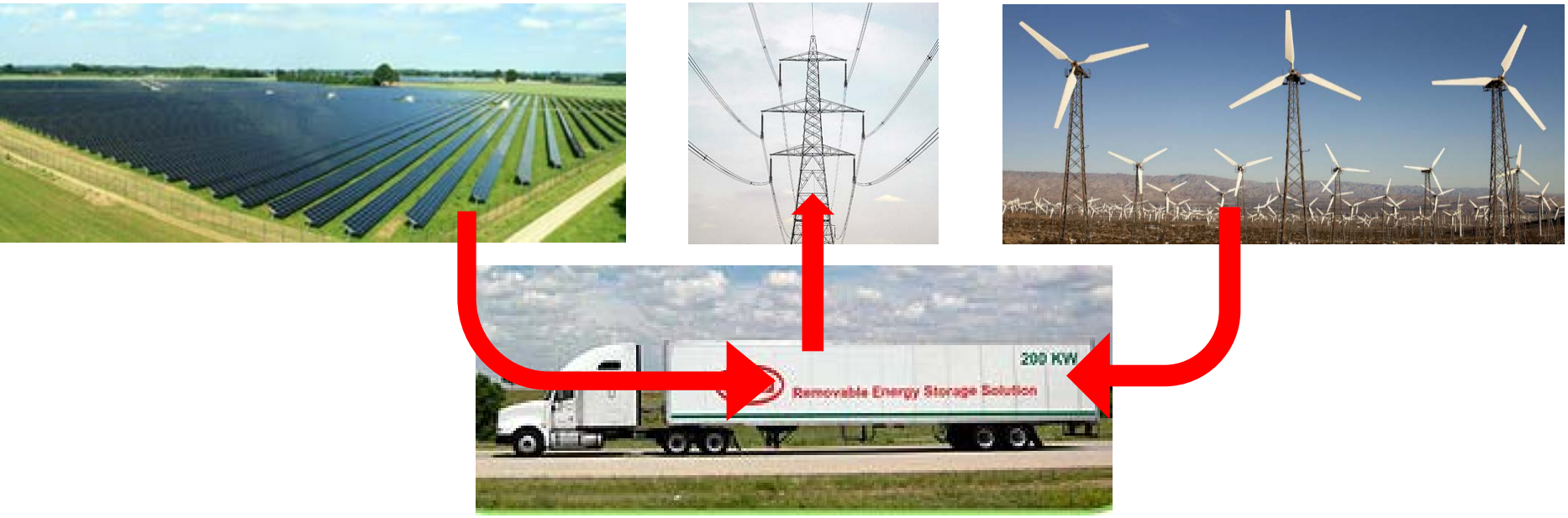
Sigma Technologies Int'l,

Phase II Program Funded by
The DOE Energy Storage Program
Office of Electricity Delivery and Energy Reliability Managed by

Dr. Imre Gyuk

TPOC: Dr. Stanley Atcitty

Transportable Energy Storage Systems For Grid Applications



Transportable energy storage systems will be used to:

- Integrate renewable energy sources and mitigate intermittency
- Improve grid stability and reliability by providing new capacity that can be deployed quickly
- Offer a cost effective way to balance the load

Use of DC-Link Capacitors

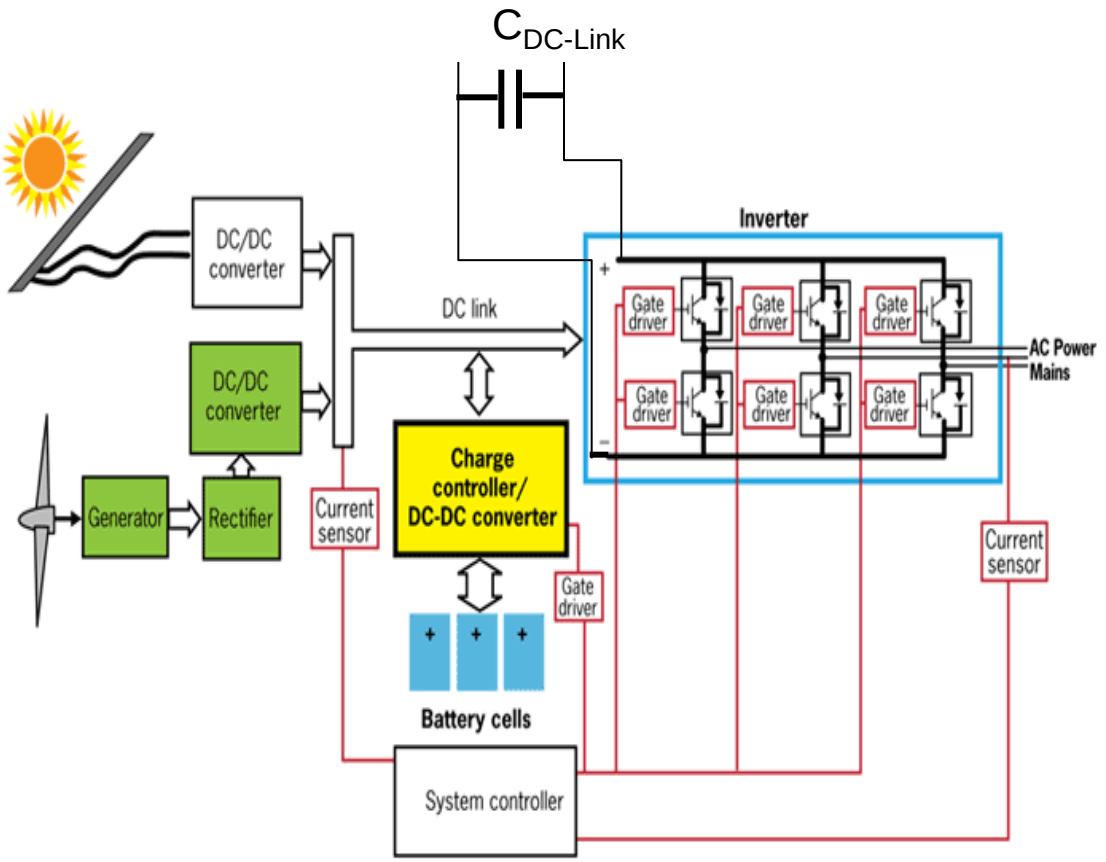
Metallized Hybrid Film Capacitor for DC-Link Applications

Each energy storage unit includes one or more high power inverters to convert DC voltage to three phase AC

A key component of the inverter circuit is the DC- link capacitor, used to minimize ripple current, voltage fluctuation and transient suppression.

The DC-link capacitor is one of the largest, costliest and most failure-prone components in today's inverter systems.

This holds true for all inverters used in applications that range from residential to automotive (HEV and EV) and grid based systems.



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Limitations of Current DC-Link Capacitor Technology

Metallized Polypropylene (MPP) capacitors are used almost exclusively in all HV and automotive DC-Link capacitor applications

PP films have low Dissipation Factor (DF) and high breakdown strength

The dielectric constant κ =2.2 limits the energy density of MPP capacitors to <1J/cc

MPP capacitors are rated to 85^{o}C with a maximum operating temperature of 105^{o}C with 30% derating, or a drop in energy density of 50%

The temperature limitation also impacts the ability of MPP capacitors to handle high ripple currents and high dV/dt transients at high ambient temperatures

High currents generate I^2R heating (R=ESR), which lowers the mechanical strength of the film at the termination, which causes loss of contact between the termination spray and the electrode layer, increasing the ESR, which leads to higher I^2R heating.

Solution to MPP Capacitor Limitations

EMERGING TECHNOLOGIES

Development of New High Temperature Films

- Polyphenylene Sulfide (PPS) already in use for some capacitor applications
  - lower energy density than PP poor self healing properties
- New high temperature films: for example PEI developed by GE and FEP and FPE films developed by 3M.
  - Not available in thin enough gages, very high cost, lower energy density than PP, some not self healing.

New high temperature capacitor films that match the dielectric properties and cost structure of polypropylene is at best a long-range endeavor

Solution to MPP Capacitor Limitations

SIGMA TECHNOLOGIES APPROACH

Improve the properties of polypropylene films by “converting” or coating the base PP film with a polymer dielectric that has superior thermomechanical properties

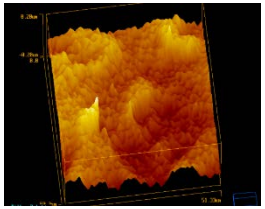
Converting is common practice in packaging films to improve strength, barrier, printability, heat sealability, etc

Capacitor films have not been converted before due to the lack of a coating technology capable of thin, uniform polymer coatings, that are economical to apply, pinhole free, high temperature, and have capacitor quality dielectric properties

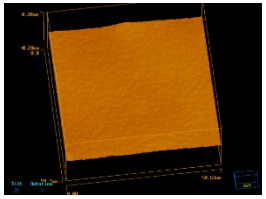
Solution to MPP Capacitor Limitations

SIGMA TECHNOLOGIES APPROACH

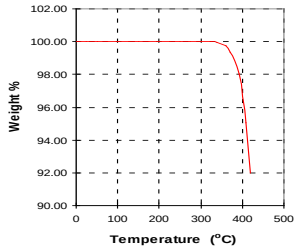
- Sigma has been working over 20 years in the development of an environmentally friendly nano-coating process using 100% solids
  - No solvents which require recovery
  - No water which requires energy to dry
  - No hazardous waste for disposal
  - No primers, surfactants and adhesion promoters
- Submicron thin, pinhole free coatings with surface leveling properties
- High temperature (>200°C)
- Excellent dielectric properties
- Amorphous cross linked polymers with breakdown strength >1000V/μm (higher than any polymer film)



Base Film



Acrylate Coated Film



TGA

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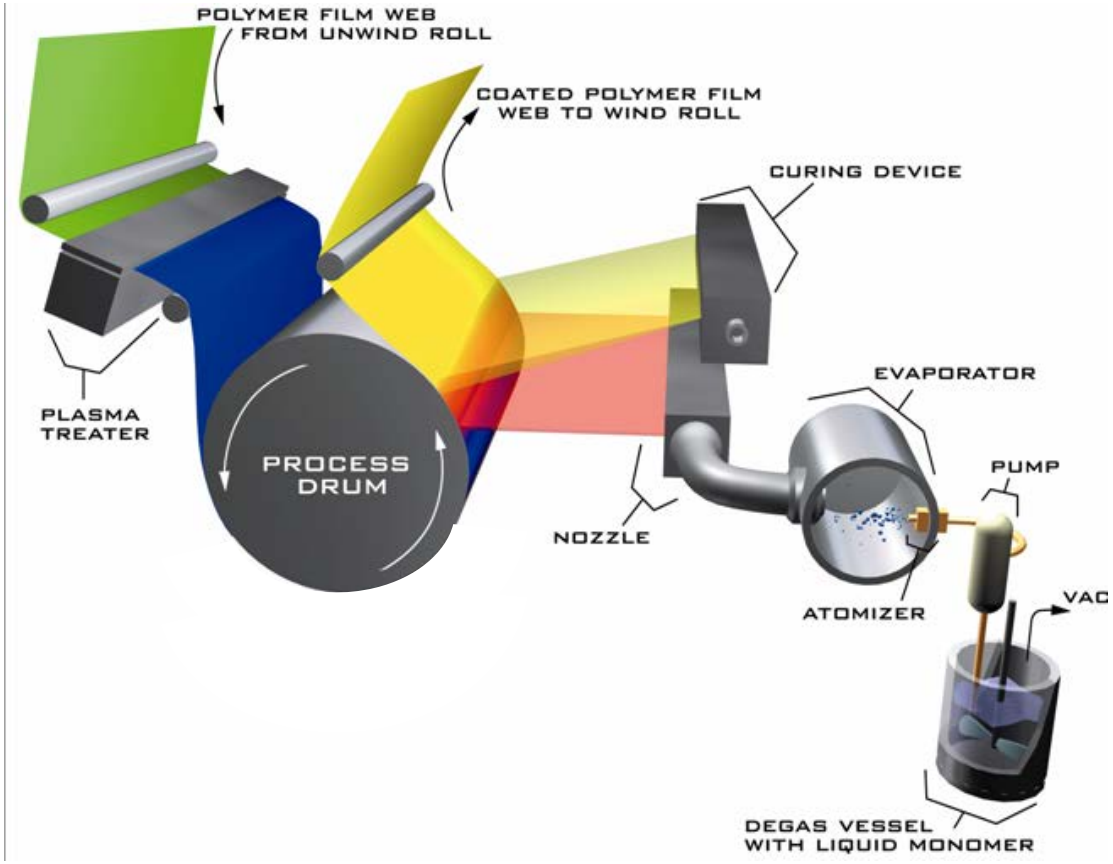
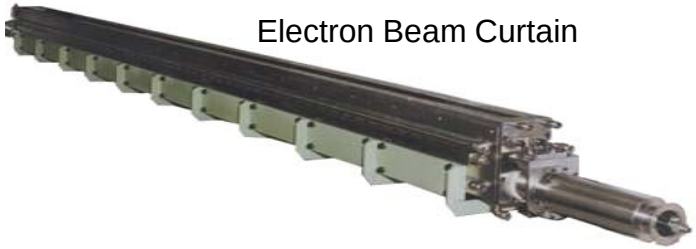
DIELECTRIC MATERIALS

- Multifunctional acrylate based monomer materials that are electron beam cured
- $H_2C=CHC(O)O\ \ R(X)\ \ OC(O)CH=CH_2$
- R = aliphatic, aromatic, heterocyclic
- X = any functional group, eg
  - amino, cyano, fluoroalkyl, nitrile, halogen, glycolyl, organometallic, other.

Unique Polymer Dielectric Deposition Process

Metallized Hybrid Film Capacitor for DC-Link Applications





Electron Beam Curtain

Monomer Storage

Monomer Evaporation System

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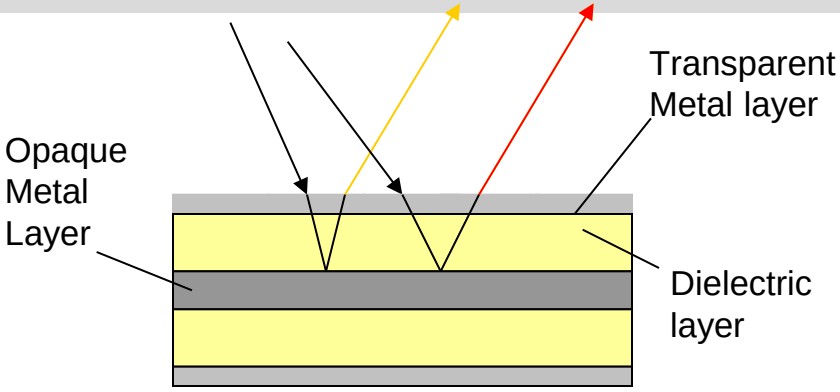
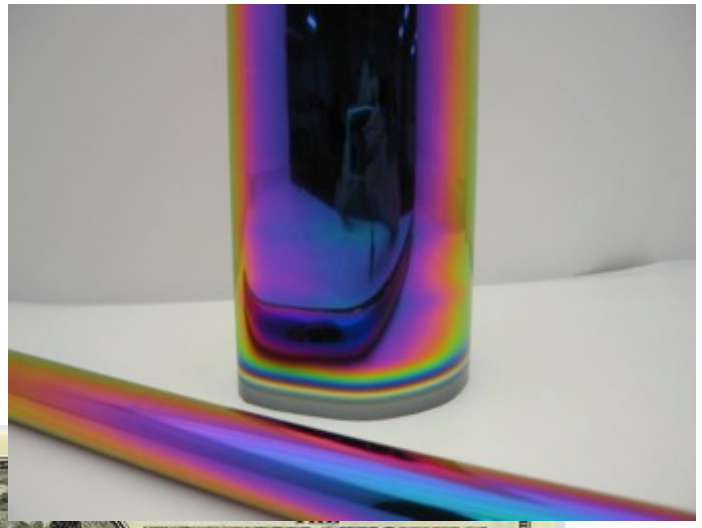
Commercial Applications of the Acrylate Coating Process
Flexible Optically Variable Devices

Metallized Hybrid Film Capacitor for DC-Link Applications





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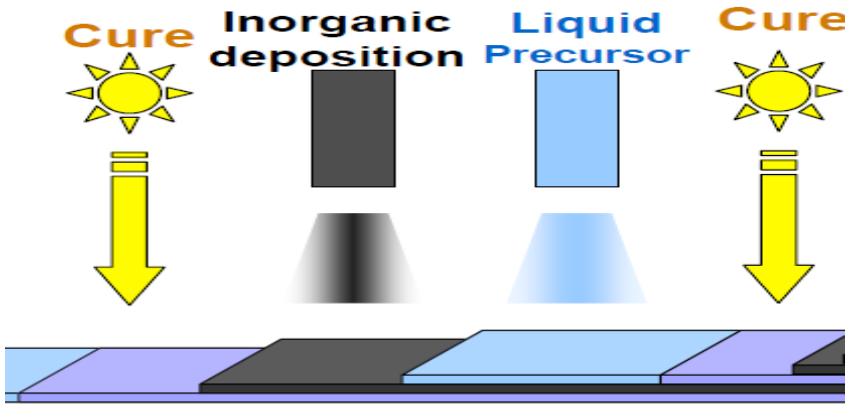
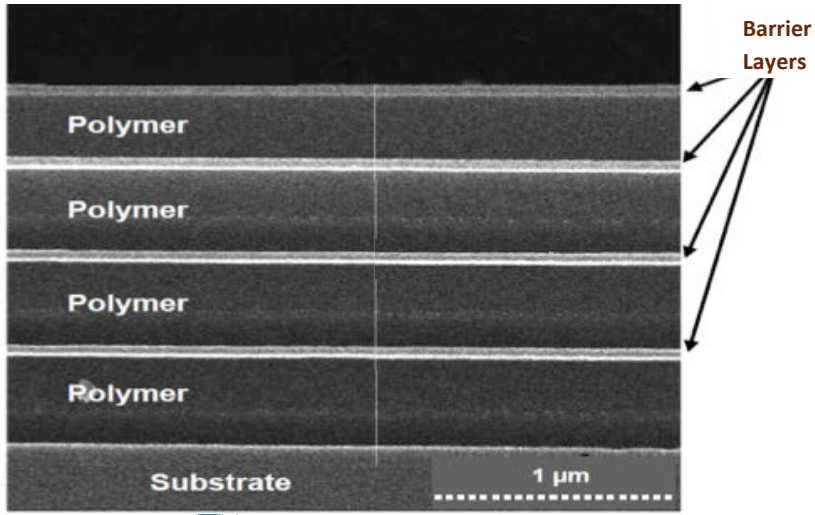
Commercial Applications of the Acrylate Coating Process
Ultra High Barrier Films Licensed For Use In New AMOLED Cell-Phones and OLED TVs





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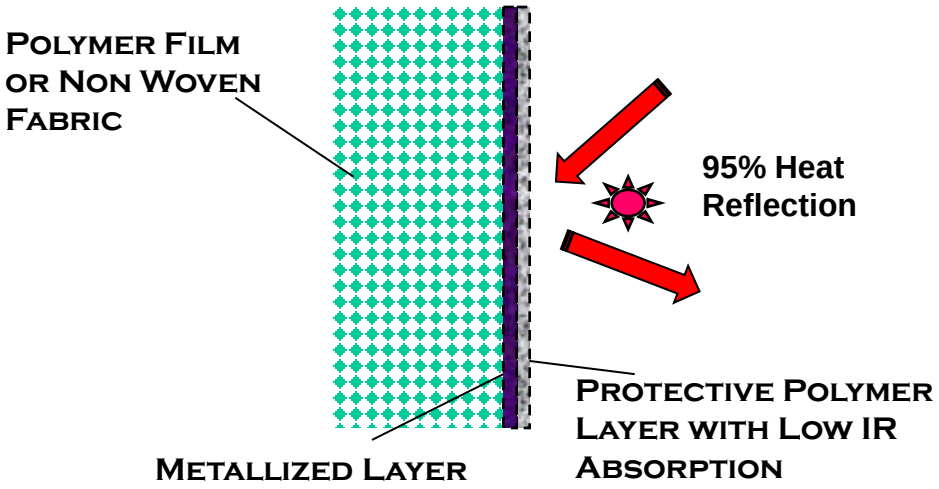
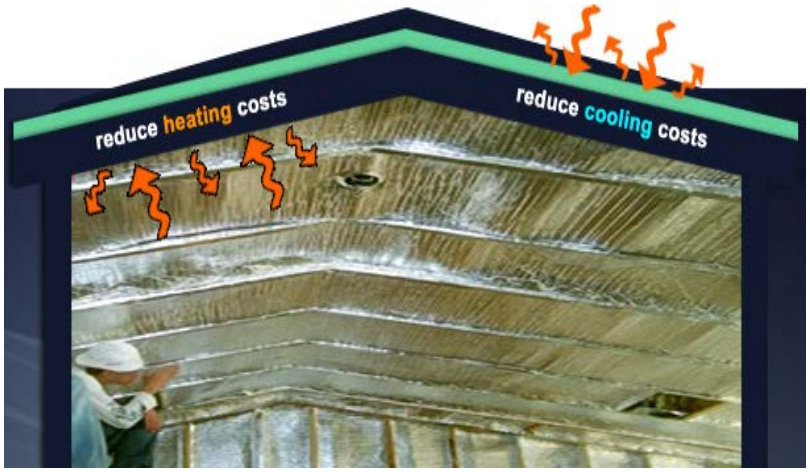
Commercial Applications of the Acrylate Coating Process
Radiant Barrier Materials For Heat Management
Sigma Technologies is a Leading US OEM

Metallized Hybrid Film Capacitor for DC-Link Applications

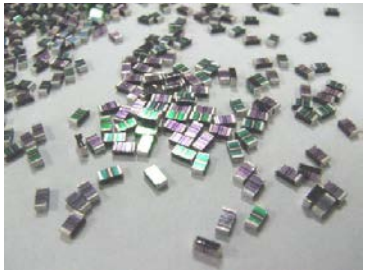




Commercial Applications of the Acrylate Coating Process
Low Voltage PML Capacitors for Consumer Electronic Applications
Licensed Technology to Rubycon and Panasonic

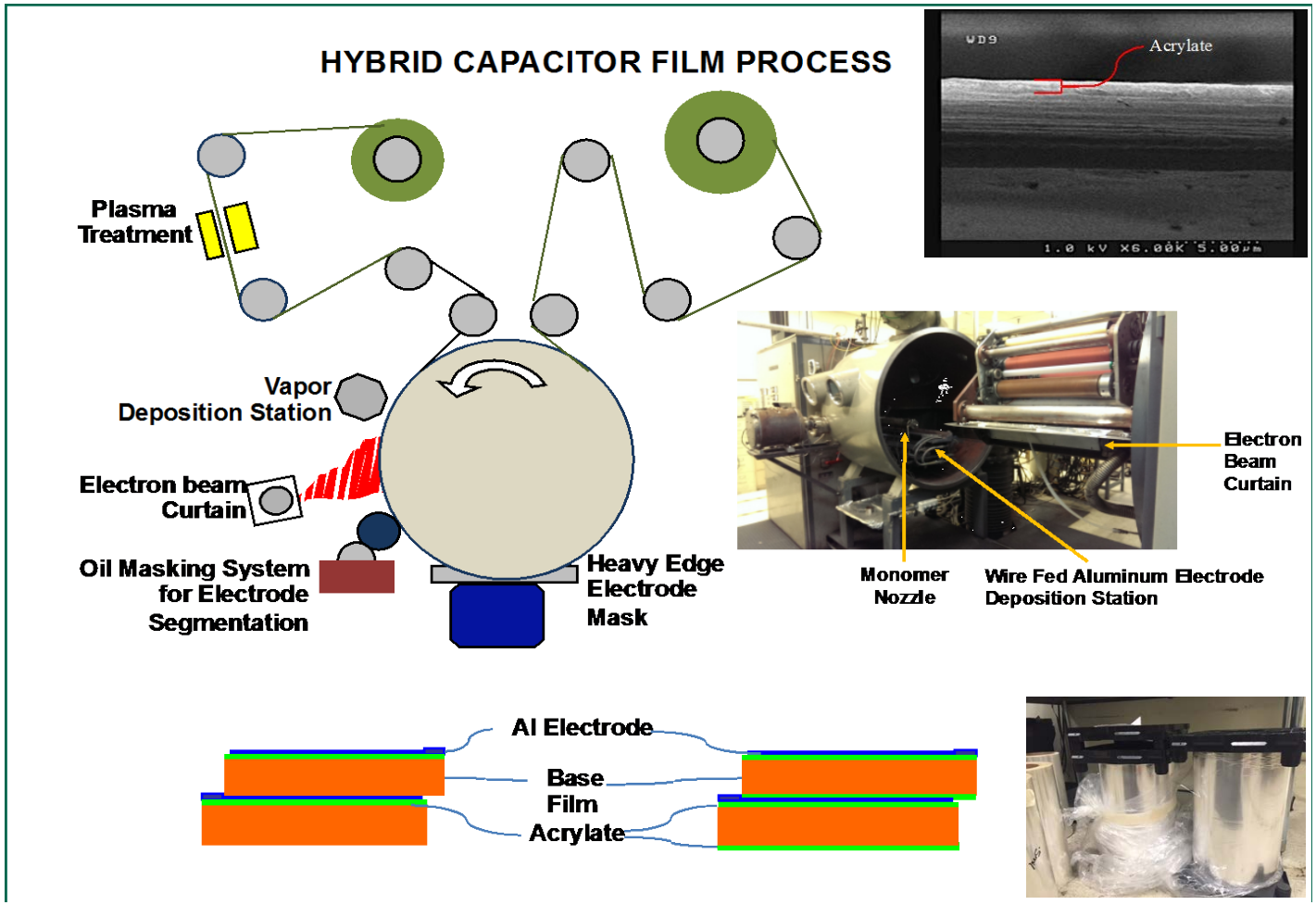
Metallized Hybrid Film Capacitor for DC-Link Applications

- Sigma dedicated more than 10 years developing the PML capacitor technology before licensing it to two multinational capacitor OEMs.
- Sigma developed the material and process technology and built production equipment for producing the Mother Capacitor material.
- Surface mount low voltage PML capacitors are now used in common consumer electronic devices such as digital cameras, LED and LCD TVs, audio amplifiers and others.



PML Chip compared to MKT type film capacitor (35v 10μF)*

Process of Converting Capacitor Films to “Hybrid” Polymer Films



Objectives and Impact of Phase II Program

KEY OBJECTIVES OF PHASE II PROGRAM

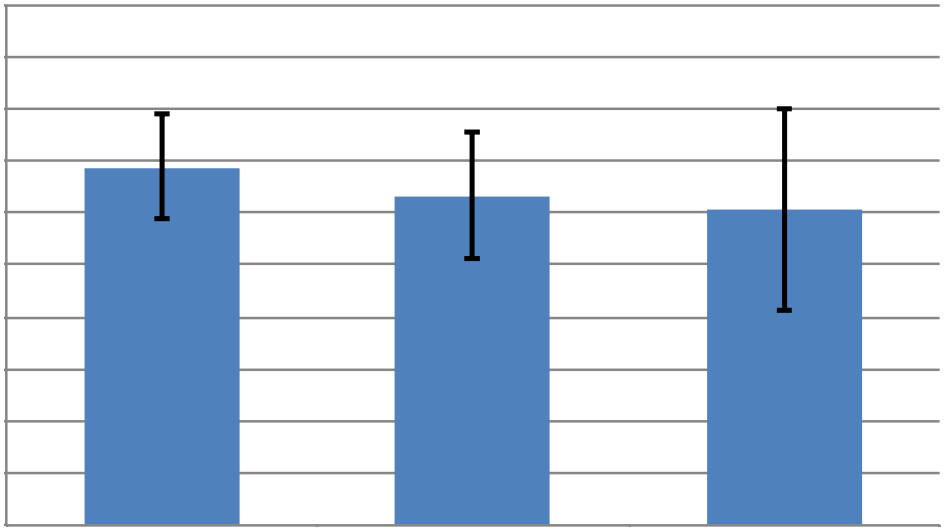
- Optimize acrylate dielectric materials
- Scale up to a roll to roll pilot line
- Produce Full Size HV DC-link Capacitors
- Demonstrate performance using application specific capacitor tests
- Develop a Business Plan to Transition Into Production

IMPACT ON POWER CONTROL SYSTEMS

- Compact inverter modules that can operate at higher temperature
- Improvement in life and system reliability
- Increase competitiveness of US OEMs

Selecting Radiation Source to Polymerize The Acrylate Coatings

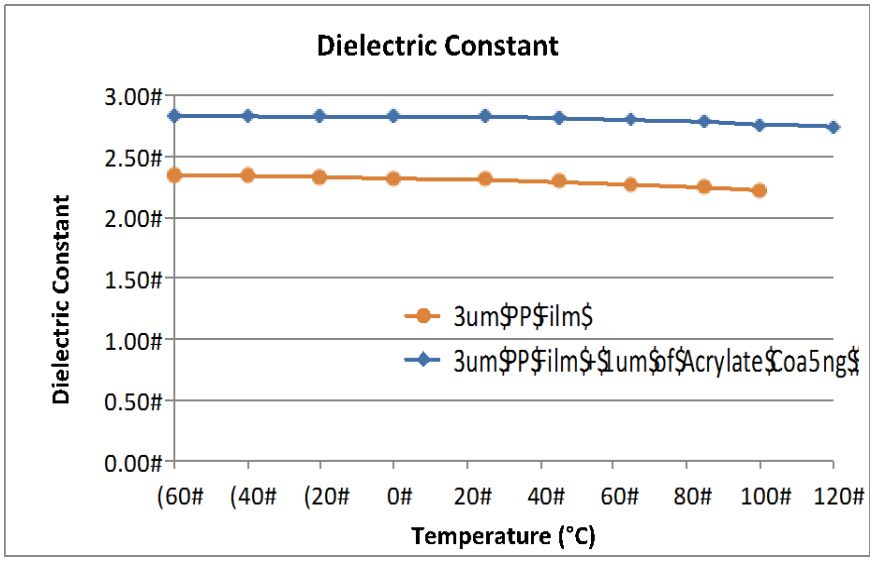
PP Film was exposed to 20 passes of Low Voltage Electron Beam and UV radiation with no acrylate coating

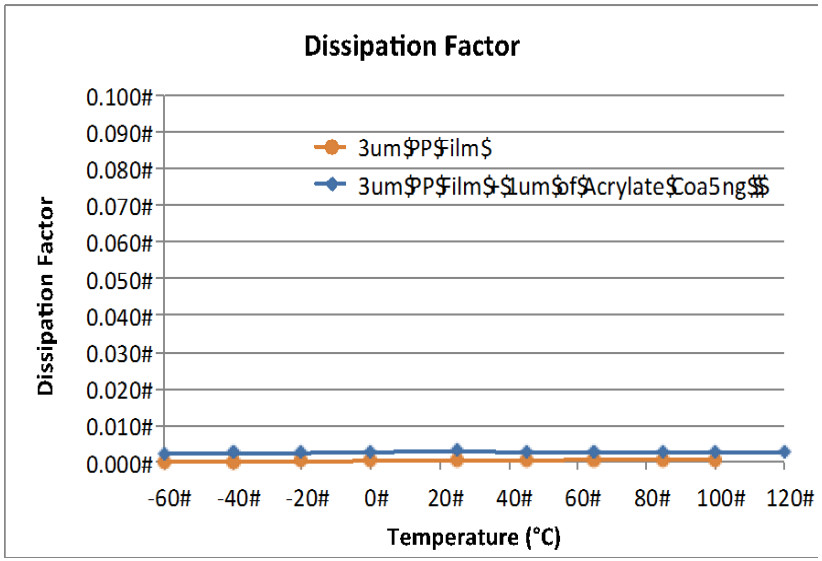


Low Voltage Electron Beam (<10KV) was selected
At this voltage level the electron penetration is <1μm

Dielectric Properties of Hybrid PP Films

Dielectric constant and dissipation factor performance as a function of temperature of a base PP film and a hybrid film produced by coating the PP film with a high temperature acrylate polymer dielectric.





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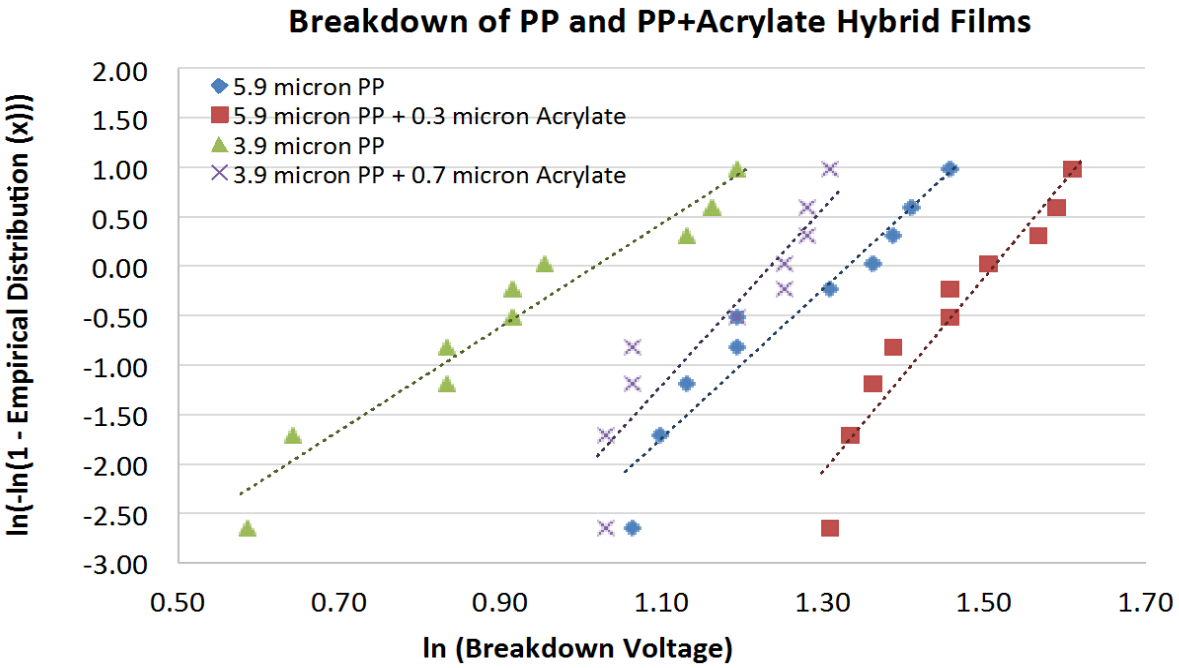
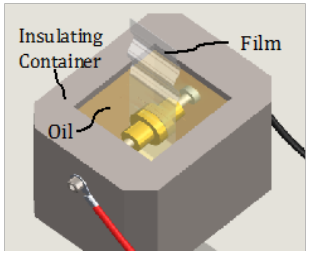
Breakdown Strength of Hybrid PP Films

Increase In Breakdown Strength

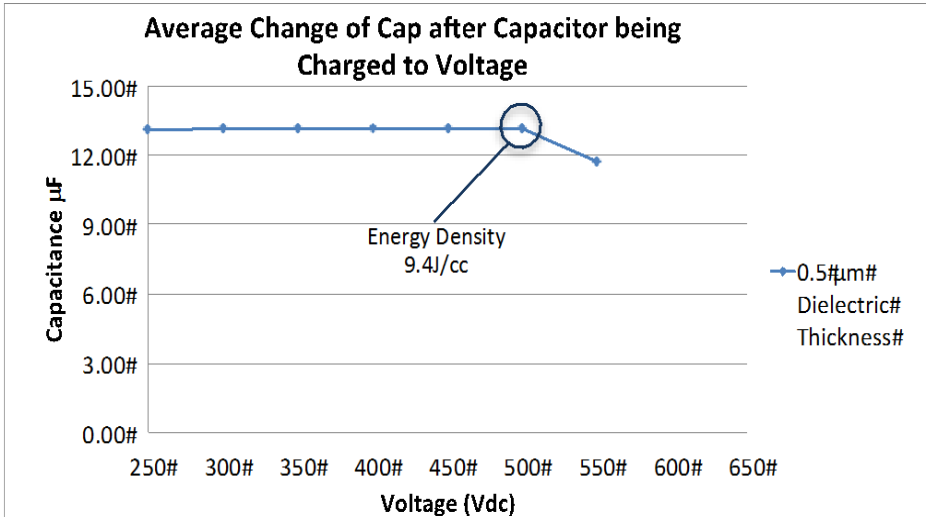




Breakdown Strength of Hybrid PP Films

Increase In Breakdown Strength

Film	Breakdown Voltage (kV)	Total Thickness (μm)	Breakdown Strength (kV/μm)	% Increase in Breakdown Strength
5.9 μm PP	3.8	5.9	0.6154	-
5.9 μm PP + 0.3 μm Acrylate	4.5	5.9 + 0.3	0.6981	13.4
3.9 μm PP	2.8	3.9	0.6753	-
3.9 μm PP + 0.7 μm Acrylate	3.4	3.9 + 0.7	0.7221	6.9



Using 0.5μm Acrylate 1000 layer PML capacitors was constructed and tested

At 500VDC the 0.5μm dielectric capacitors are stressed at 1000V/μm

This is higher than the intrinsic breakdown strength of polymer film dielectrics (which is in the range of 400V/μm to 700V/μm)

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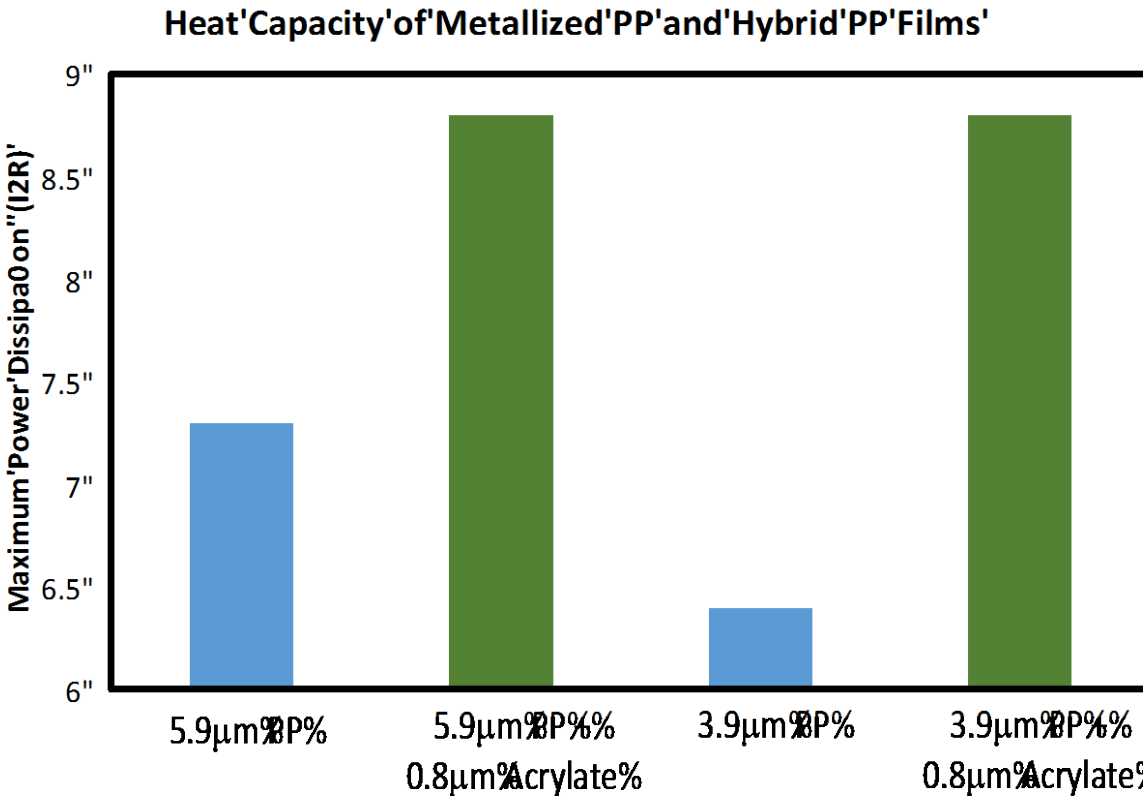
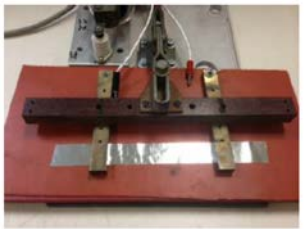
Thermal Properties of Hybrid PP Films

Increase in I^2R thermal capacity generated by ripple currents





Impact on HV Capacitors Impregnated with a Dielectric Fluid

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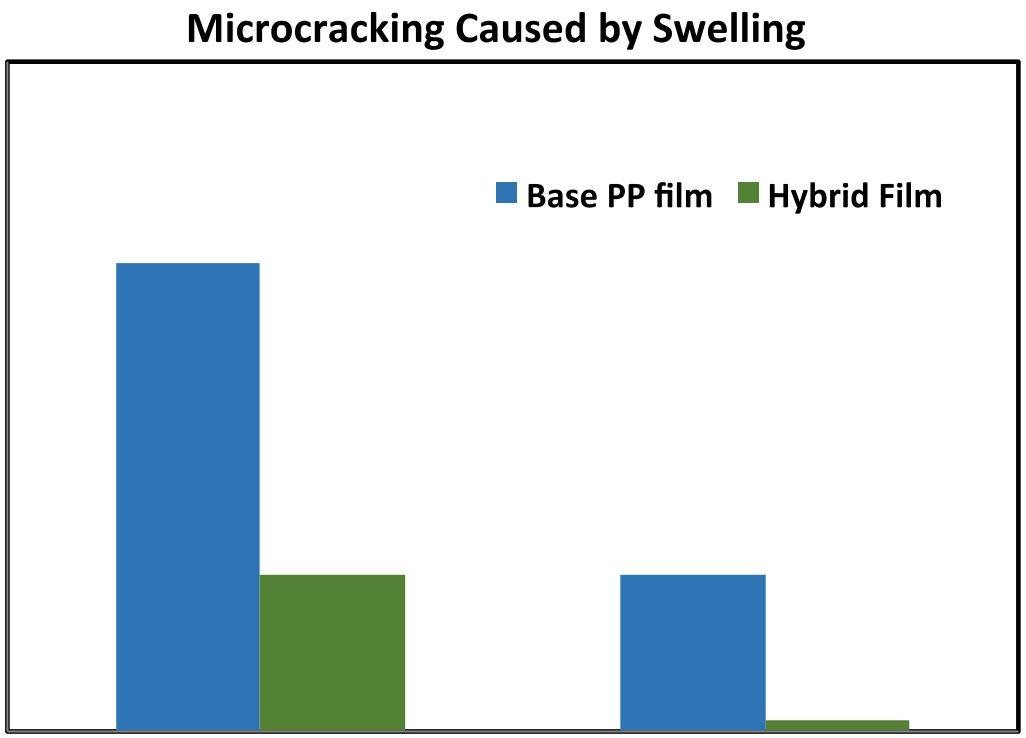
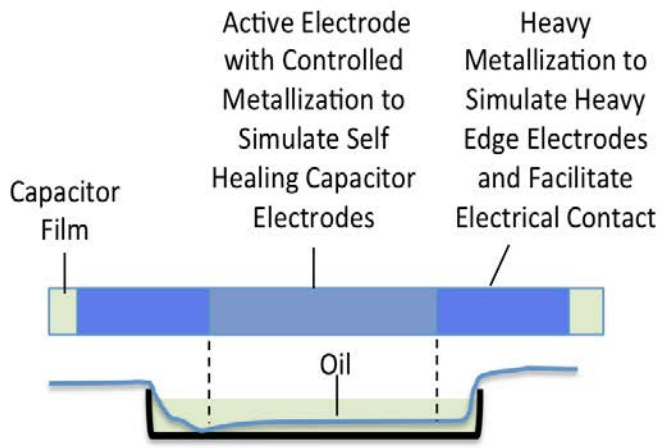
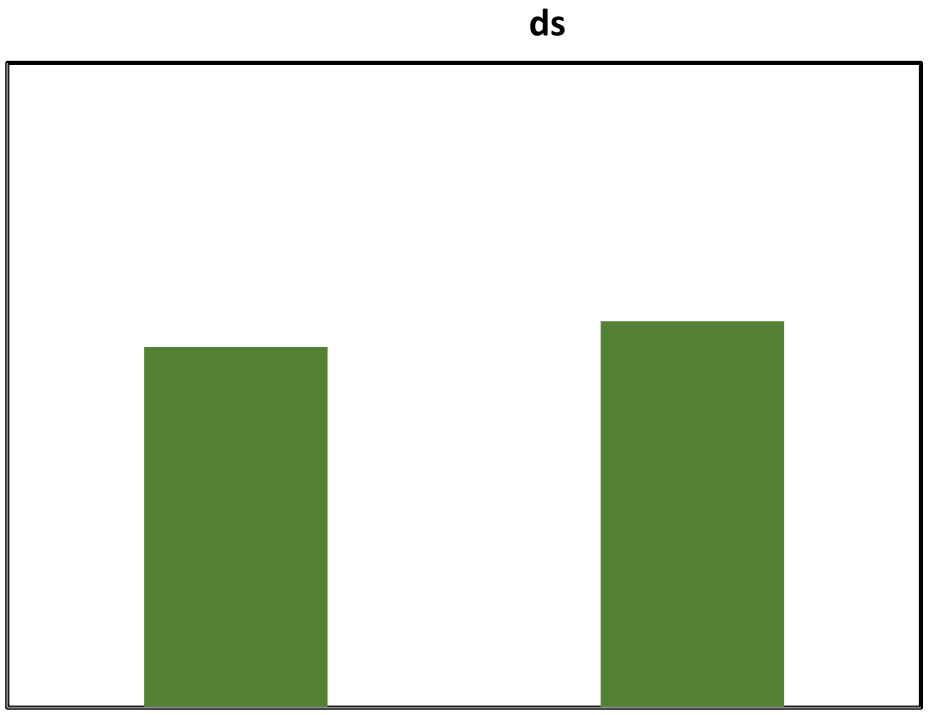
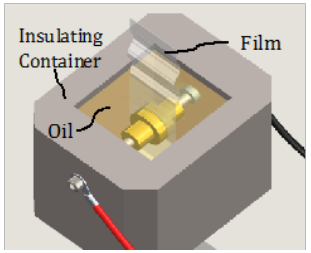




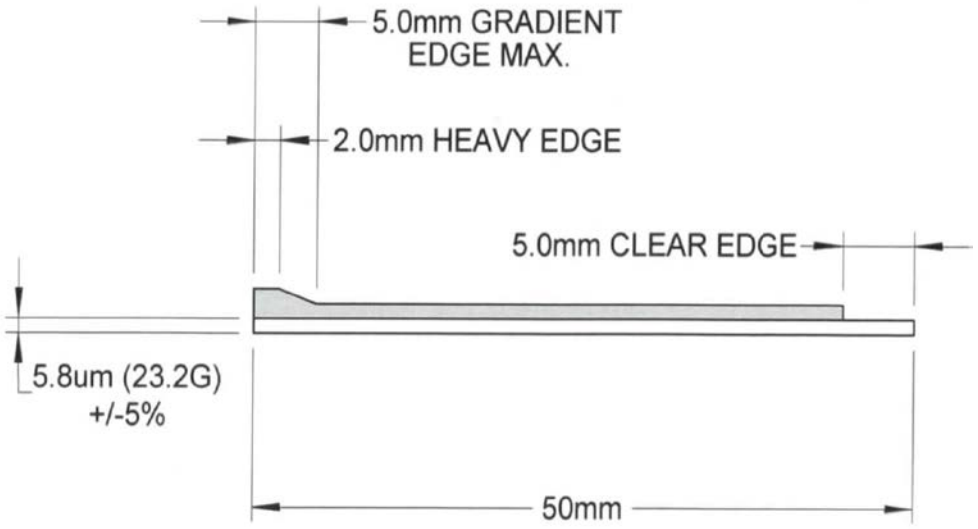
Breakdown of Dielectric Impregnants





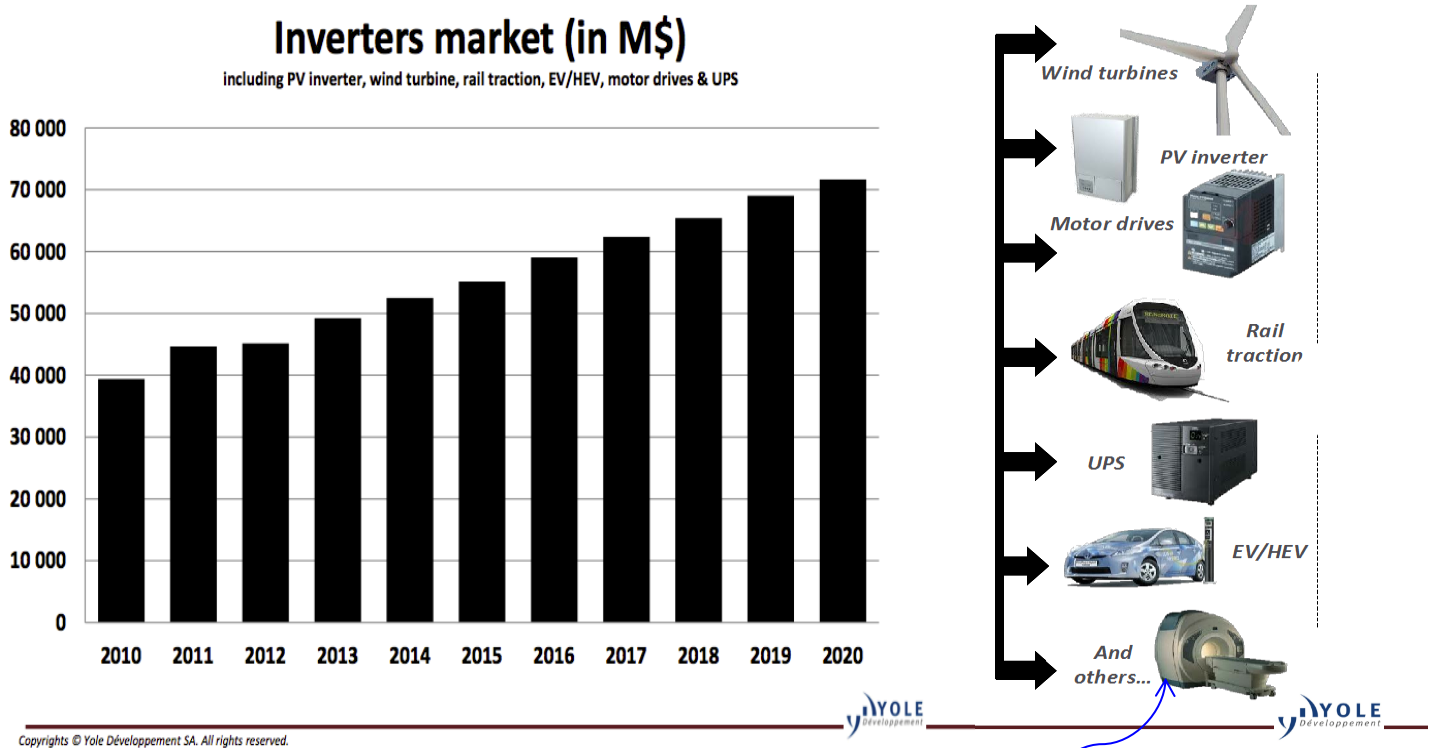
Castor oil was chosen based on reduced swelling and higher breakdown voltage

DC-link Hybrid Metallized Film Design



5.9μm and 3.9μm Control PP and Hybrid PP Metallized Films are Produced for Evaluation and Comparison of Key Capacitor Properties

Inverter Sales Market Forecast and Major Inverter Applications



Inverters Used in Storage Modules Tied to Renewable Energy Sources and the Grid

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Market Drivers

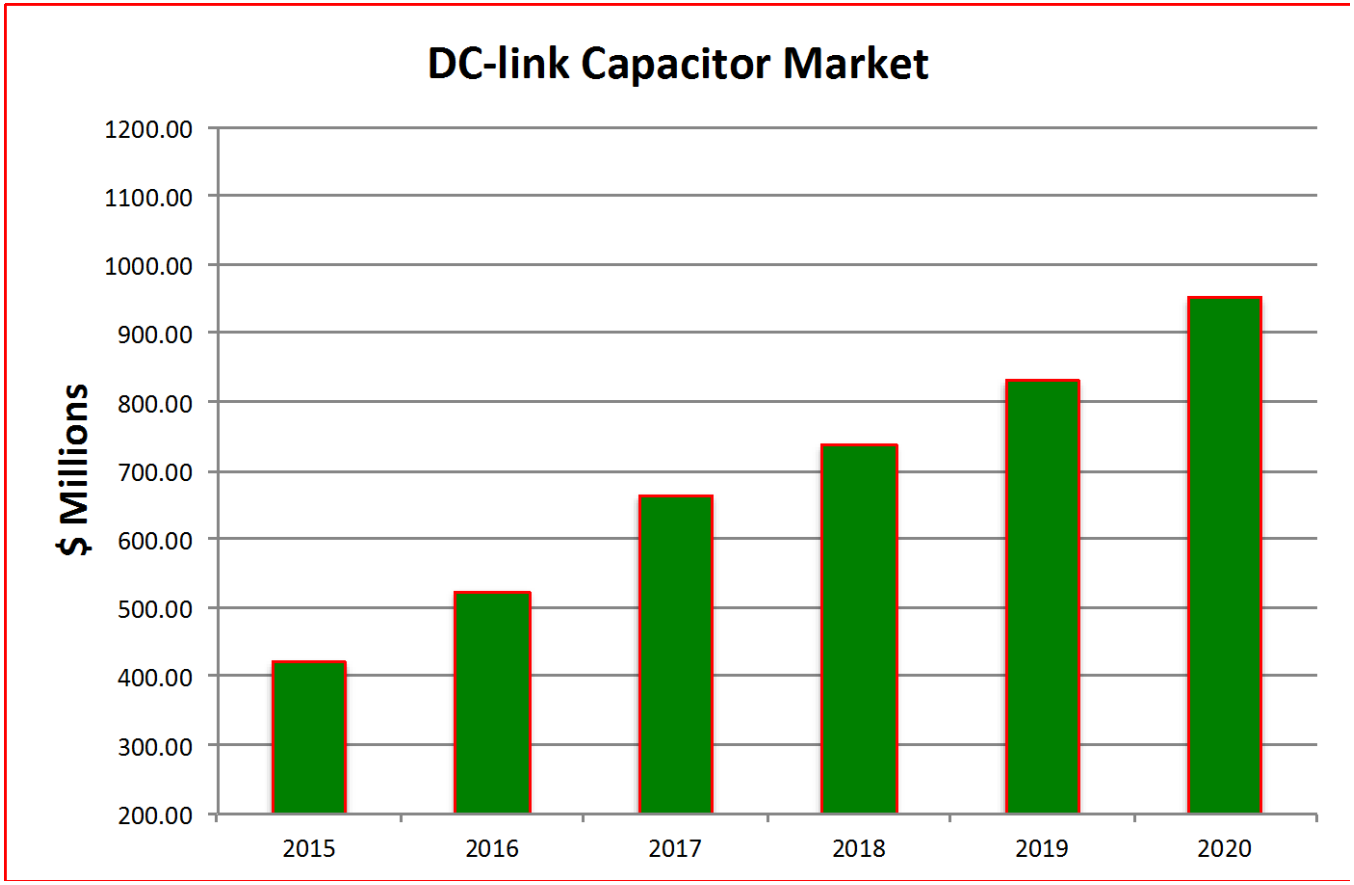
Application Priorities by Market Drivers

Priority ranking per application

+++: Strong driver
++: Medium driver
+: Low driver

Applications \ Drivers	Cost	Performance (efficiency)	Reliability Lifetime	Form factor	Weight
PV inverters	+++	+++	++	+	+
EV/HEV	++	+++	+++	+++	+++
Wind turbines	++	+++	++	+	+
Rail traction	+	+	++	++	+++
UPS	+++	+	+++	++	++
Grid Tied Storage	++	+++	+++	+	+

DC-link Capacitor Market Forecast



Significant Market Size for Any Passive or Active Component

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Summary

Hybrid PP films provide a low cost alternative to high temperature films with superior dielectric properties

Higher thermal capacity to handle high amplitude ripple currents and high dV/dt transients

Improved breakdown strength

Excellent self healing properties

Superior electrical contact of the arc-sprayed termination to the metallized electrodes

Superior performance in the presence of dielectric impregnating fluids

Thank You For Your Attention

Phase II Program Funded by The DOE Energy Storage Program

Office of Electricity Delivery and Energy Reliability

Sigma Technologies Acknowledges
Dr. Imre Gyuk For Providing Funding Support for this Project

and
TPOC: Dr. Stanley Atcitty