High Performance DC Bus Film Capacitor

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GE Global Research

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Project ID: #APE060

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Overview

Timeline

- Project start: October 2013
- Project end: Sept. 2016
- Percent complete (16%)

Barriers

- Temperature limit >140ºC
- Volume down by 25-50%
- Cost reduction to $30

Budget

- Total funding: $2646k
  - DOE share $1750k
  - Contractor share $896k
- Funding received in FY13 - $698k
- Funding for FY14 - $925k

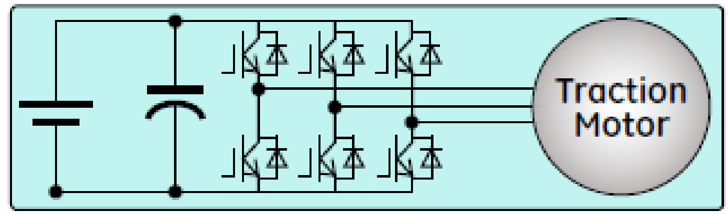
Partners

- Delphi / subcontractor
- US film and capacitor manufacturers

DELPHI

Relevance of Capacitors

DC bus capacitor Invertor for vehicles



- **The largest component**
- **<125ºC use temperature**
- **Expensive**

<u>Objectives</u>: High temperature benign capacitors made of thin polymer films to target at capacitors of 180ºC, less volume, lower cost, and self healing.

DC Bus Capacitor Targets	DOE Metrics	GE technology
Temperature range of ambient air, °C	-40 to +140	PEI (-40 to +180)
Volume requirement, L	≤ 0.6	3-5 µm film (0.3-0.5)
Cost ($)	≤ 30	≤ 30
Failure mode	Benign	Self-clearing (Benign)
Life @operating condition, hr	>13,000	200,000

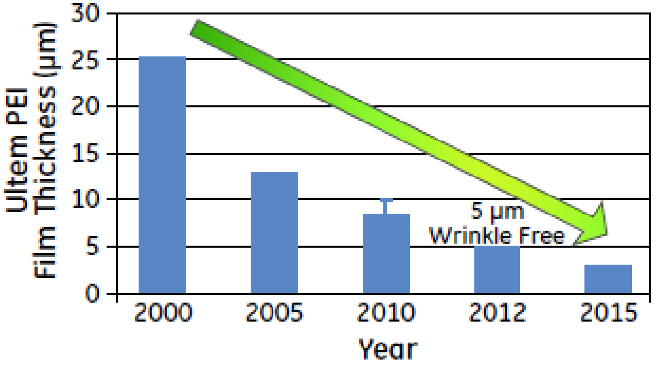
<u>Uniqueness and impacts</u>:
High-Tg Polyetherimide (PEI) thin films to meet DOE requirements and broader application.

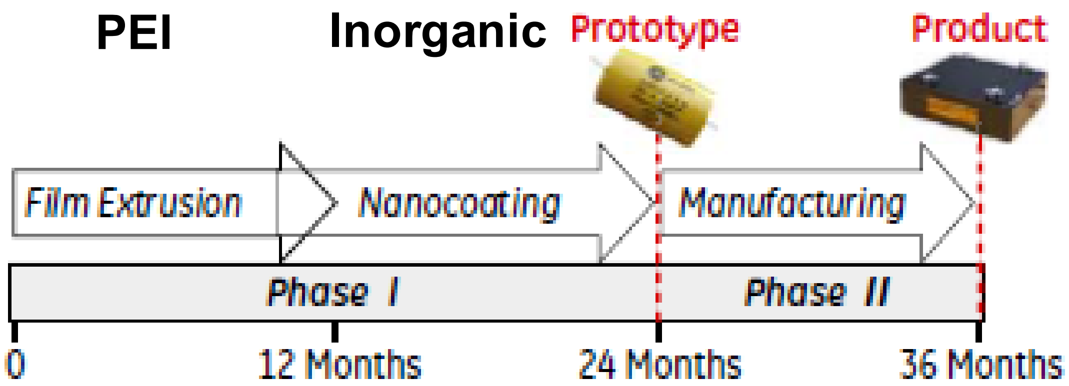
Milestones

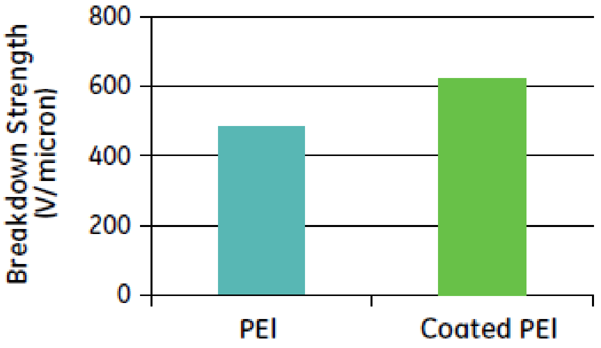
Month /Year	Milestone or Go/No-go Decision	Description	Status
December 2013	Milestone	Set-up program and establish working relationship with film manufacturers to develop extruded films	Complete
January 2014	Milestone	Demonstrate extrusion feasibility for 5um film	Complete
February 2014	Milestone	Test dielectric properties and surface morphology of 5 μm PEI film	Complete
March 2014	Go/No-go decision	Validate extrusion process for 5 μm PEI film. Is film thickness variation <10% and wrinkles-free? Yes	Complete
May – Dec. 2014	Milestone	Identify inorganic coating vendors and test coating feasibility	On schedule
May - Dec. 2014	Milestone	Test mechanical and dielectric properties Develop 3 μm film with minimal defects	On schedule
June - Sept. 2014	Go/No-go decision	Demonstrate 5 μm film rolls (500 meter). Check film properties, thickness variability and cost model.	On schedule

Approach/Strategy

- **Develop high temperature PEI film to overcome the shortcomings of BOPP and cooling system.**
- **Higher dielectric constant and thinner film for higher capacitance density and smaller volume than state-of-the-art.**
- **Enhanced dielectric strength via inorganic coating of PEI films for smaller volume.**







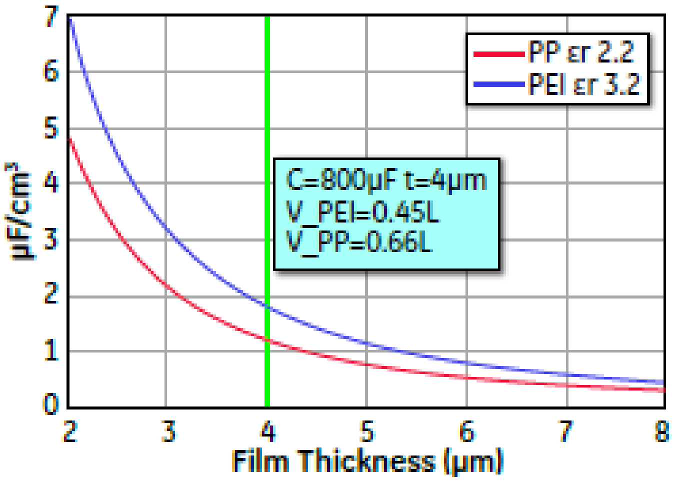
High temperature extruded polymer film capacitor

Accomplishments/Progresses: Extruding Thinner Polymer Film

Wrinkle free thinner films with high dielectric strength were being extruded.

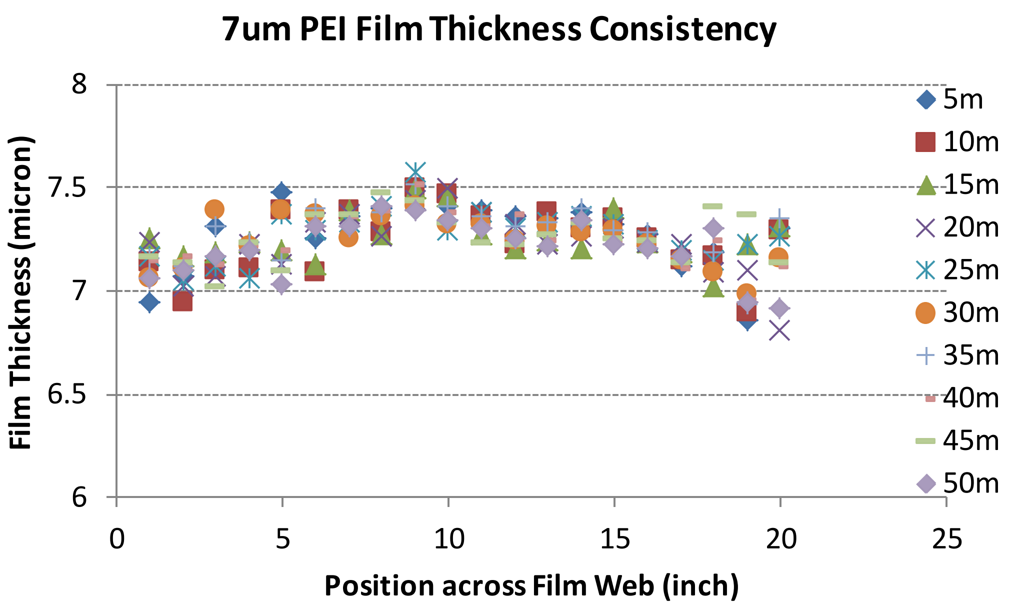
$$D = \varepsilon_o K E_{BD}^2 / 2$$

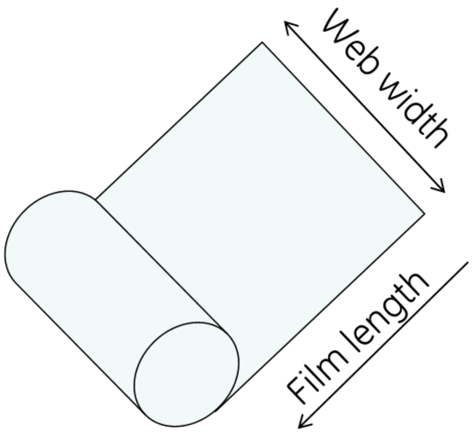
High dielectric strength and thinner films are desirable allowing more design space and maximization of film properties.

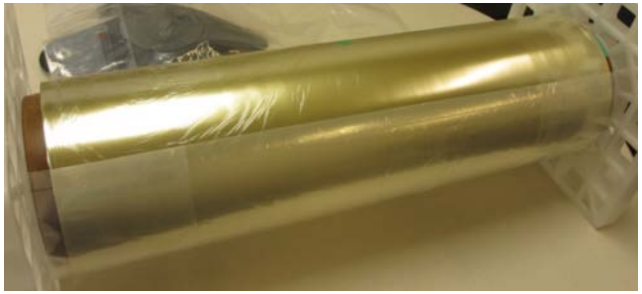


Capacitance density increases with decreasing film thickness, leading to smaller capacitor volume.

Traditional Extrusion of Free-Standing Film (7 µm)

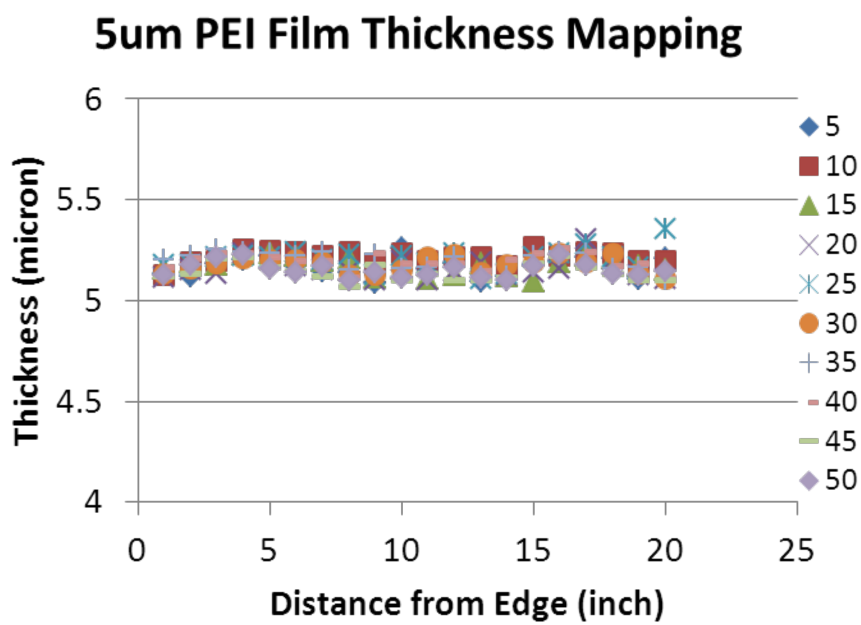


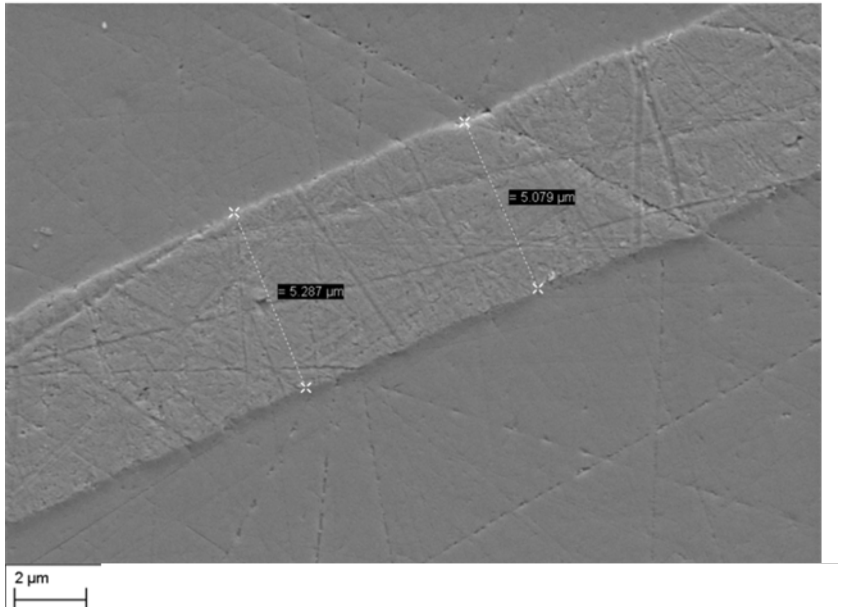




Min-6.9; Max-7.6
Thickness variation of 10% achieved

Traditional Extrusion of Free-standing Film (5-μm)





Films with thickness variation of 6% achieved.

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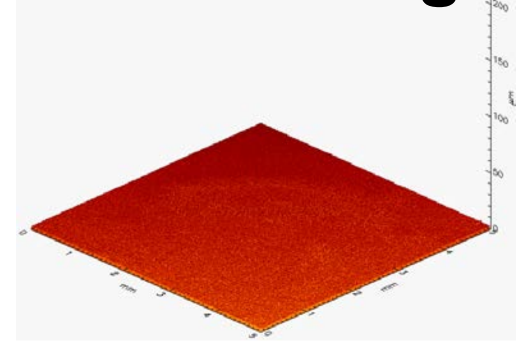
Surface Profilometry of 5μm Film

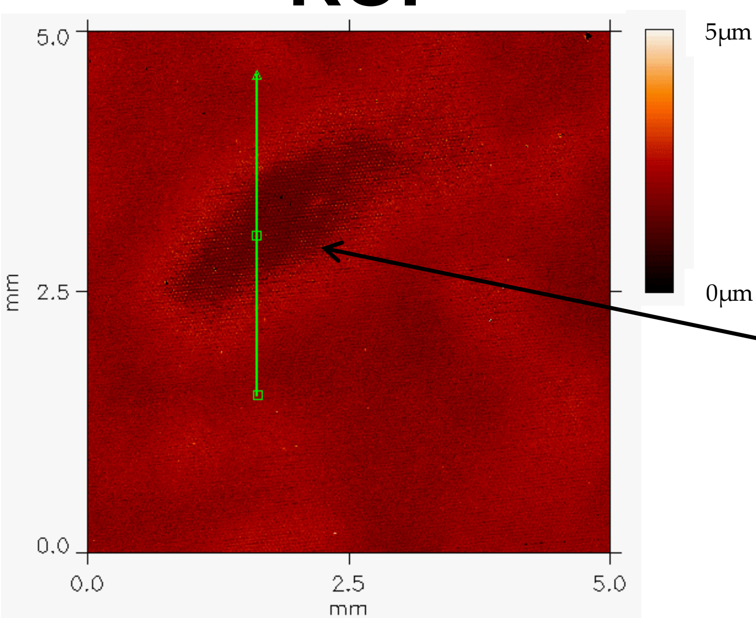
Sensor: 300-μm
Detection speed: 1000Hz
Scan size: 5mm x 5mm
Step size: 5μm
Data processing: segmentation, plane fit

3D Topography

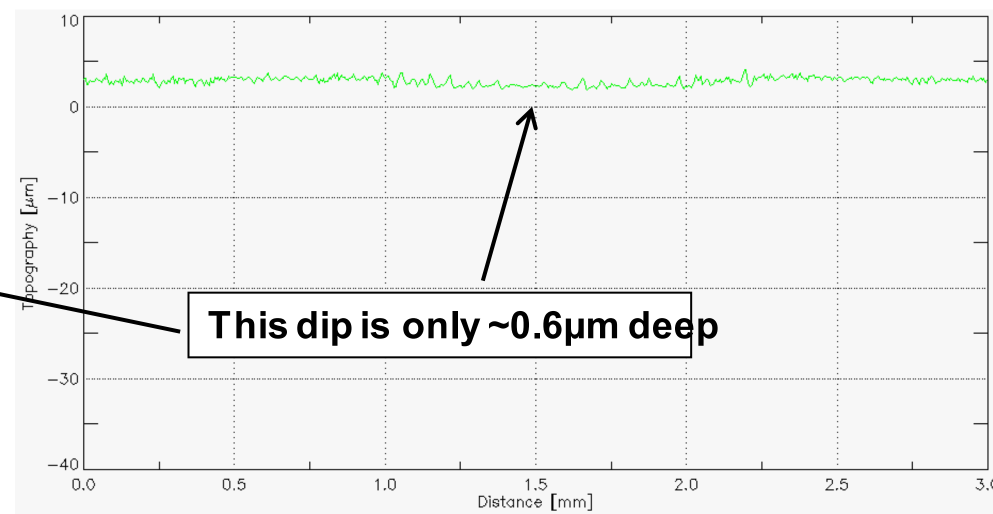
3D Shading



ROI



2D Profile

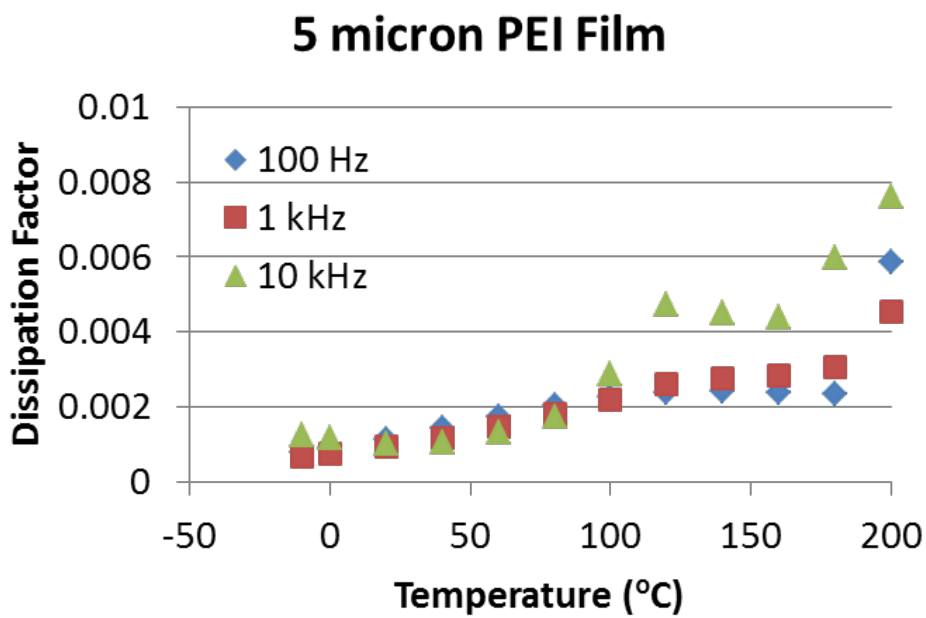


This dip is only ~0.6μm deep

Films surface morphology and roughness is acceptable.

Dielectric Constant and Loss

Dielectric constant remains 3.16-3.2 in the range of temperature and frequency of measurements.



Extruded film exhibits low dielectric loss and stable dielectric constant.

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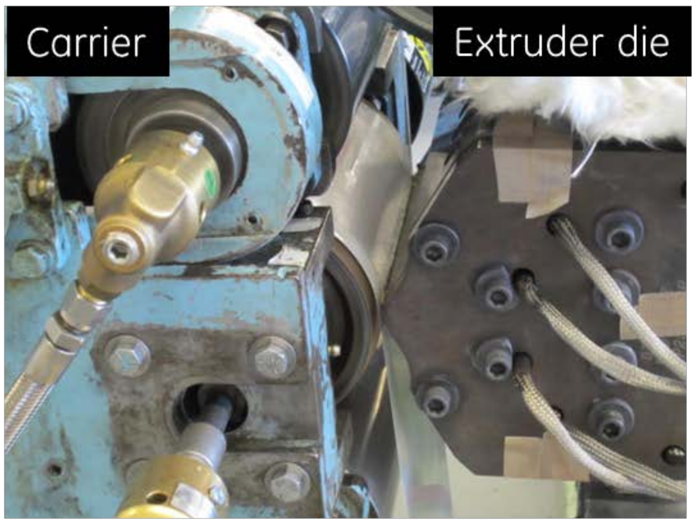
New Extrusion Mechanism-Carried Films



Controlling screw speed, film take-up speed of carrier, die lip gap and temperature, carrier, etc.

Film wrinkle issues avoided by using a carrier.

Carrier Treatment and Performance

Carrier #1

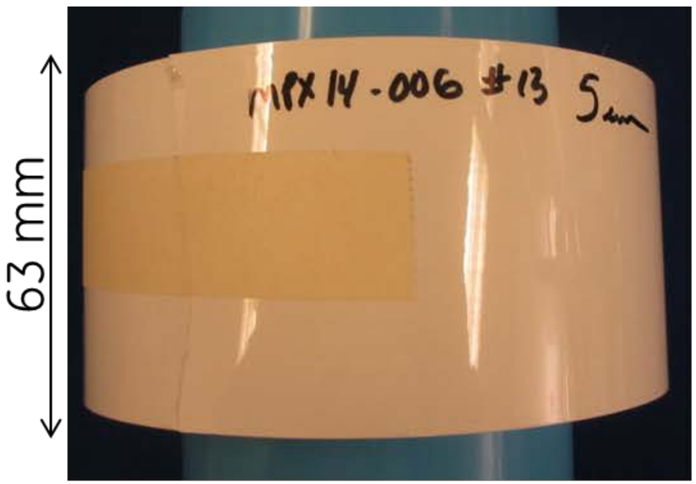
Thinner
Cheaper
Know-how

Carrier #2

Two carriers developed for good adhesion and delamination.

Slitting and Delamination Feasibility:
5 µm Film

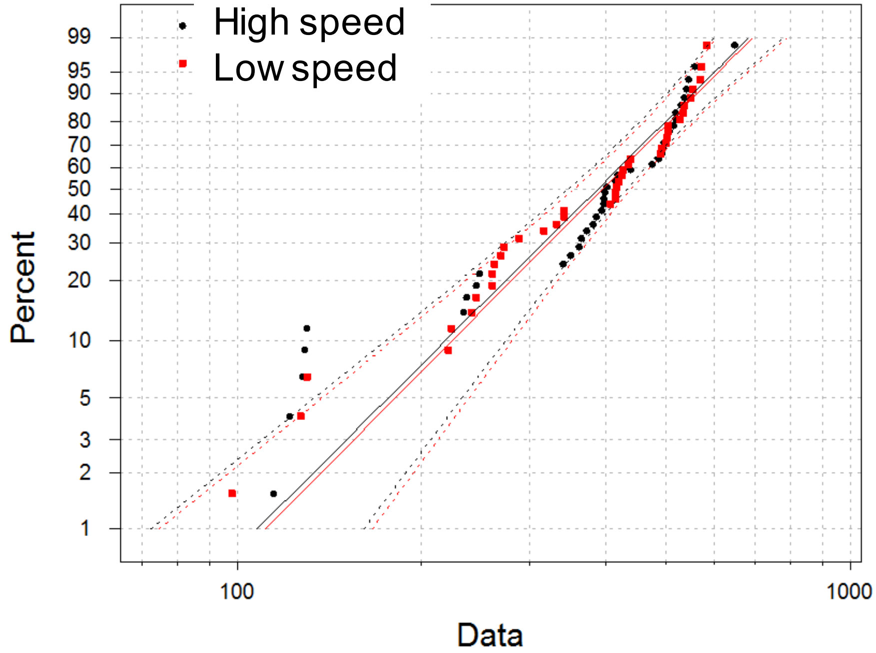
After slitting

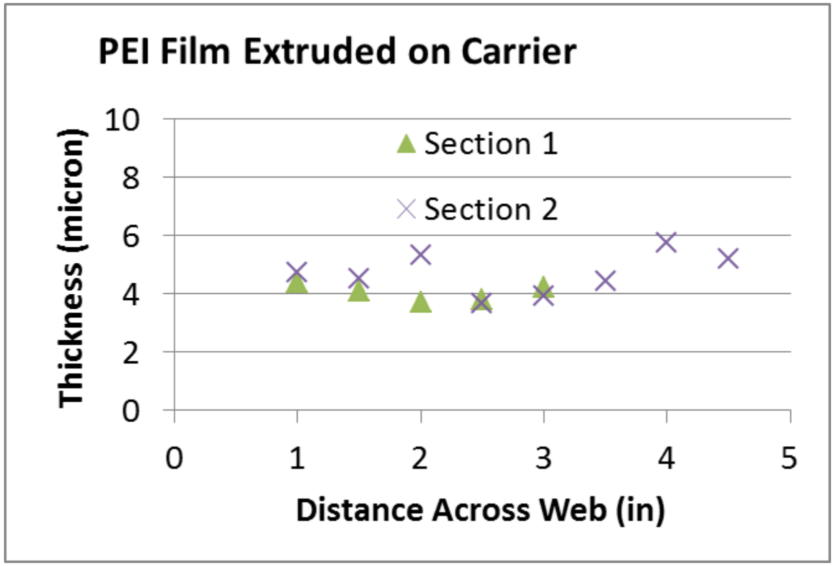


After delamination

All film processing appears to be feasible

Properties of PEI Films Released from Carrier





Thinner film shows lower breakdown strength (458.2 kV/mm for 5 μm, 574.1 kV/mm for 10 μm, beta~9)

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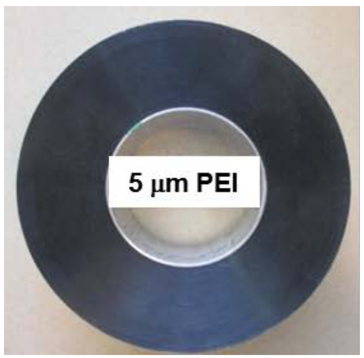
Collaboration and Coordination with Other Institutions

- Film extrusion
  - Japan film manufacturer (e.g. MPI)
  - US film manufacturer
- Capacitor specs definition and testing
  - Ralph Taylor / Delphi
- Coordination of services
  - Materion for inorganic coating
  - Bollore for metallization service
  - DEI and ECI for capacitor winding service

Feasibility of Metallization and Capacitor Fabrication for 5-7 µm Films



Disregard the challenges for thinner PEI films at metallization and capacitor winding, capacitors were produced. Yield is to be improved.

Remaining Challenges

- Procurement of scale-up rolls of 5 μm film takes longer time due to certain limitation of film vendors.
- Extrusion and thickness variation for 3 μm films need improvement.
- Nanocoating on thin films requires high tear strength of polymer films. Process optimization is required.

Proposed Future Work

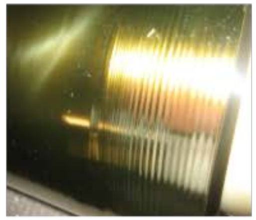
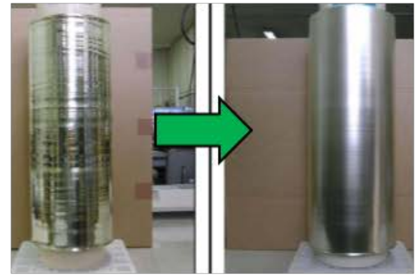
- Optimize extrusion parameters in film scale-up processes for both extrusion mechanisms. Confirm film delamination and windability on wider rolls (Q3FW14).
- Fully evaluate scale-up films to understand dielectric strength, mechanical strength, thermal stability and rewinding issue (Q2FY14).
- Demonstrate nanocoating effect on PEI films. Experiments will be performed in GE labs (Q3FY14) and using pilot equipment at commercial vendors (Q1FY15).
- Key milestones will be the downselection of film thickness and nanocoating recipes (Q4FY14).
- Verify film processing cost model (Q4FY14).

Summary

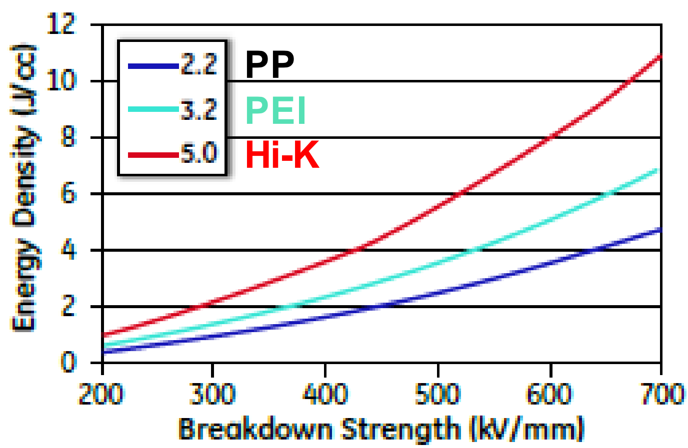
- **Project relevant to DOE capacitor and inverter development**
  - GE team established to develop polymer film capacitors meeting DOE's goals
  - Scale-up of 3 μm PEI films are desirable to meet all capacitor requirements.
- **Year 1 focused on polymer film extrusion and scale-up**
  - Developed wrinkle free PEI films (5-7 μm) using melt extrusion
  - Demonstrated satisfactory performance 5-7 μm PEI films
  - Developed a carrier-supported film extrusion method in US
- **Collaboration expanded to different film and capacitor vendors**
  - Established collaborative relationships with subcontractors, film processing vendors
  - Plan to explore different metallization schemes and capacitor winding at vendors

Technical Back-Up Slides

Progressive Effects in PEI Film Development


13 μm/2005 6 μm/2008 5 μm/2009-2013 3 μm/2014+



- wrinkle minimized
- thickness consistency improved

Capacitor Volume and Cost Reduction

Volume: **40% (50% higher permittivity, capacitor factor, component number, potting and casing free)**

Weight: **40% (less connection, potting and casing free**

Cost: **$30 (less film~$24, less package)**

$$C/N=\varepsilon_0\varepsilon \text{ Area/thickness}$$

800 µF capacitor	3 µm PEI	2.5 µm PP
Film volume (L)	0.254	0.257
Capacitor volume (L)	0.5	0.6
Capacitor shape	Flat/16 parts	Round/48 parts
Space fill factor	0.05	0.25
Potting casing (L)	No potting needed Casing optional	0.15
Final Volume (L)	**0.53**	1
Capacitor weight(g)	800-900	700
Overall weight (g)	**≤1000**	1800

Capacitor of $30 and 0.6L is possible.

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