High Temperature Polymer Capacitor Dielectric Films

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APE009

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Overview

Timeline

- Project start: October 2009
- Project end: September 2012
- Percent complete (100%)

Budget

- Total project funding
  - DOE: $2800k
- Funding received in FY09-FY12 include:
  - FY09 - $350k
  - FY10 - $750k
  - FY11 - $850k
  - FY12 - $850k

Barriers

- Barriers
  - Capacitor Cost (up to 23% of inverter)
  - Thermal control
  - Volume (up to 23% of inverter)

Partners

- Electronic Concepts, Inc.
- Sandia National Laboratories
- Penn State
- Argonne National Laboratories

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Electronic Concepts, Inc.

Project Relevance

- **The Problem**

  DC bus capacitors are currently the largest and the least reliable component of fuel cell and electric hybrid vehicle inverters. Capacitors represent up to 23% of both inverter weight and inverter cost and up to 35-40% of the inverter volume. In addition current thin polymer film capacitors have a ceiling operation temperature (105 °C). High temperature polymer dielectrics are very expensive!

Project Relevance

Objective

- Our objective is to develop and engineer novel inexpensive high temperature polymeric material systems for use as next generation dielectric materials that can be used as a replacement technology for DC bus capacitors in hybrid electric vehicles (HEV) and fuel cell vehicles.
    - Solving problems associated with transitioning from “lab-scale” to “pilot-scale” operations and to produce prototype capacitors

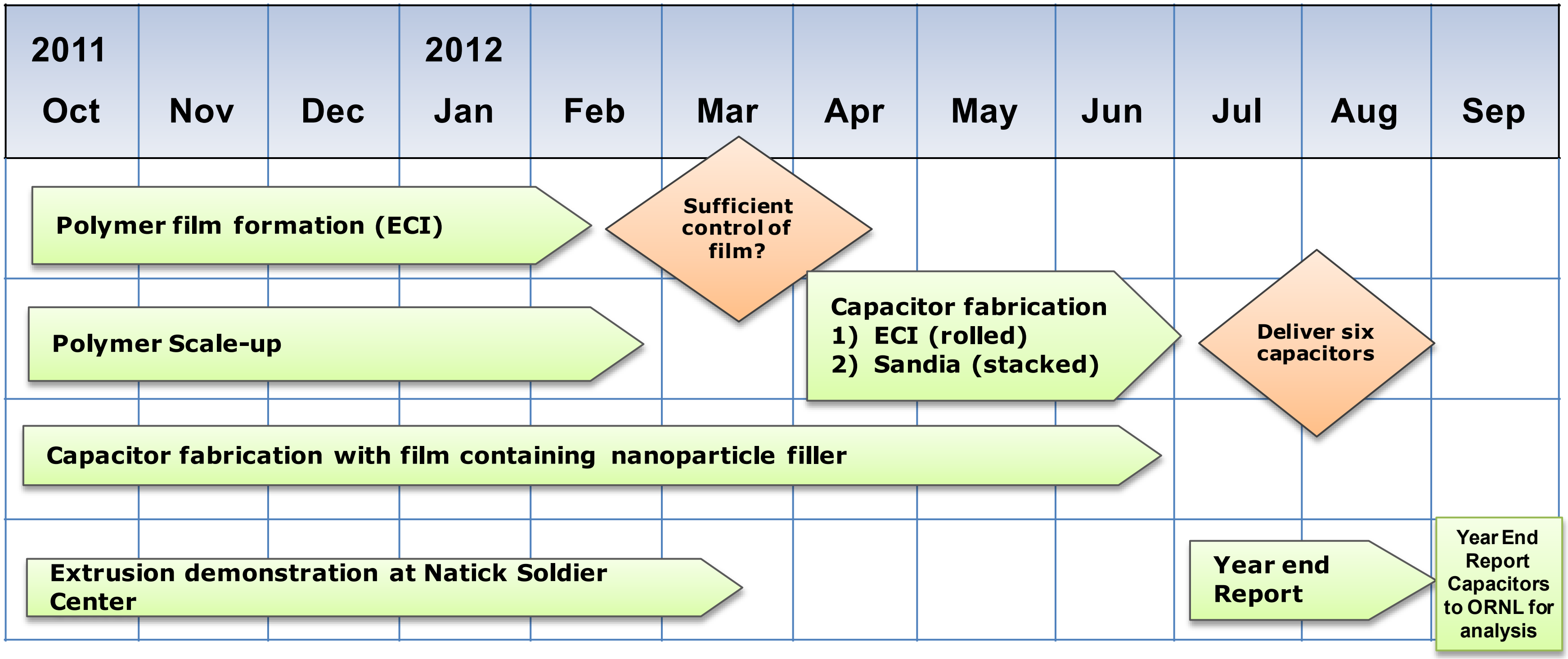
Addresses Targets

- Current capacitors lack the temperature, size, and price specifications required for future DC bus capacitors. Our approach simultaneously increases operational temperature (>150 °C), decreases size, and lowers the price of high temperature capacitors ($0.015/μF), while maintaining self-healing properties.

Uniqueness and Impacts

- Our approach uses inexpensive monomers/fillers to create a high temperature polymer dielectrics based on ROMP polymerizations which should meet DOE OVT requirements for high temperature capacitor dielectrics.

Milestones



Go No/Go Decision Point: Is the new hydrogenated polymer capable of being produced in lengths of 100 m or more? - Yes

Challenges/Barriers:

- Large scale polymer film production
- Increase energy density to meet volume requirements
- Nanoparticle dispersion

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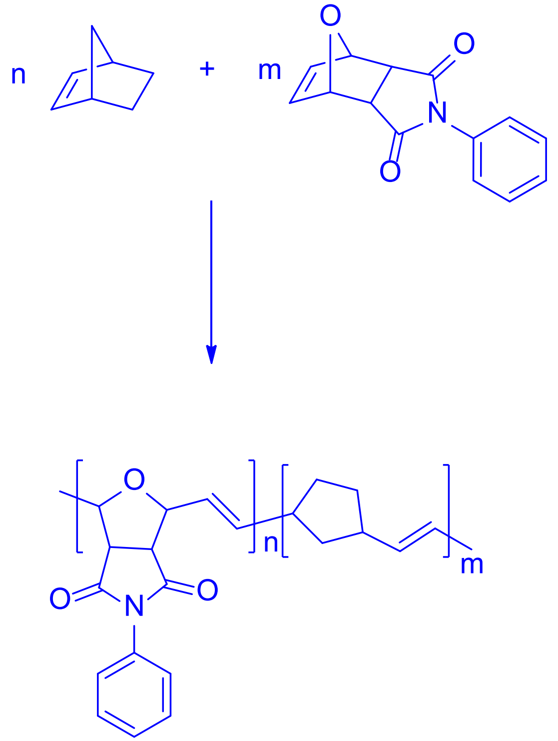
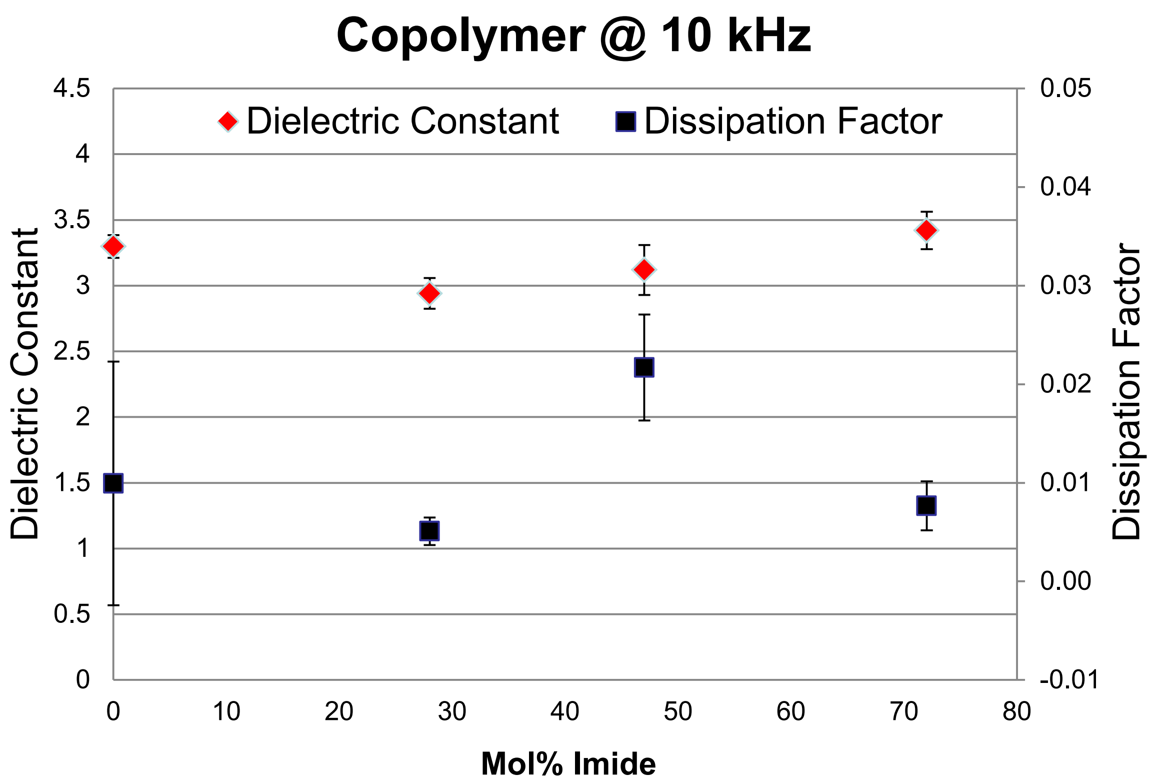
Approach

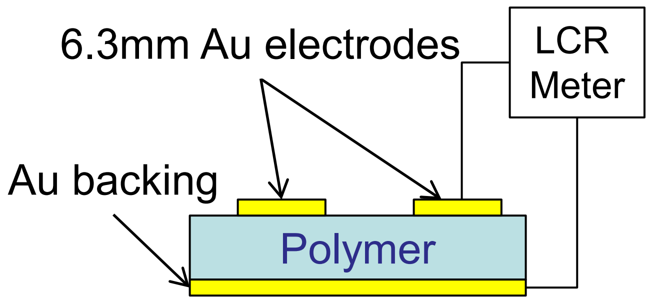
- Developing inexpensive high temperature, high dielectric polymer capable of forming very thin films
  - Controlled polymerization chemistry based on the Ring Opening Metathesis Polymerization (ROMP) allows for fine control of polymer composition and molecular weight
- Working with ECI to produce rolls of polymer film and prototype capacitors
- Working with Dr. Collin to prepare rolls of extruded films for processing into wound capacitors.
- Develop nano-composites of high temperature polymer dielectrics to improve energy density

Technical Accomplishments

% Imide	% Norbornene	% Imide by NMR	% Norbornene by NMR
0	100	0	100
25	75	28	72
50	50	47	53
75	25	72	28

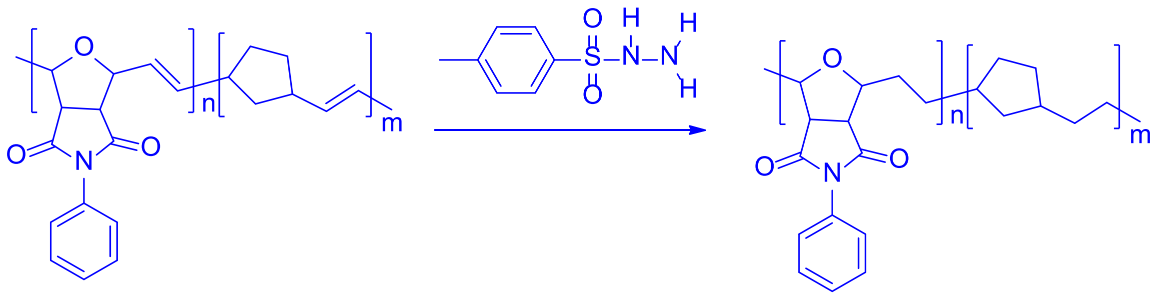




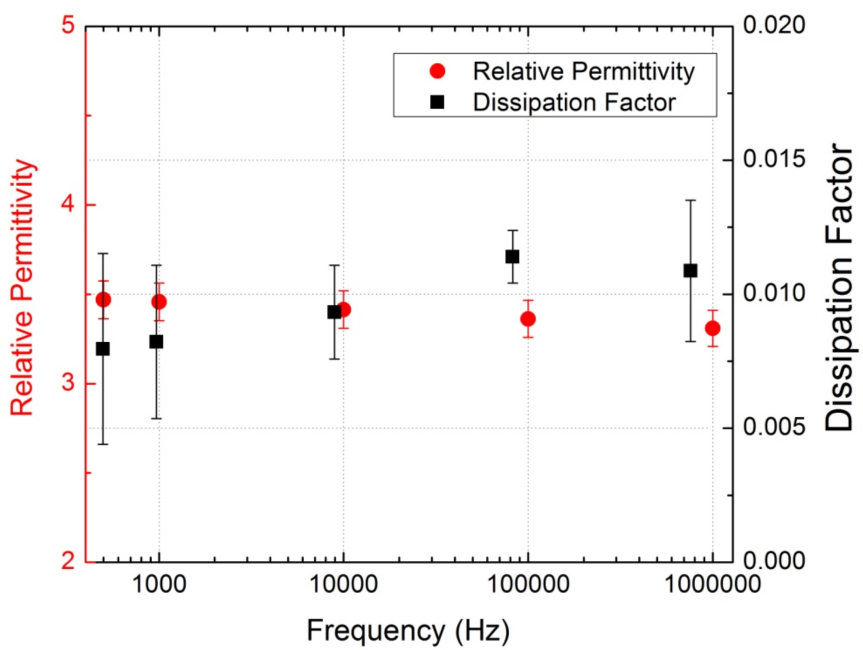


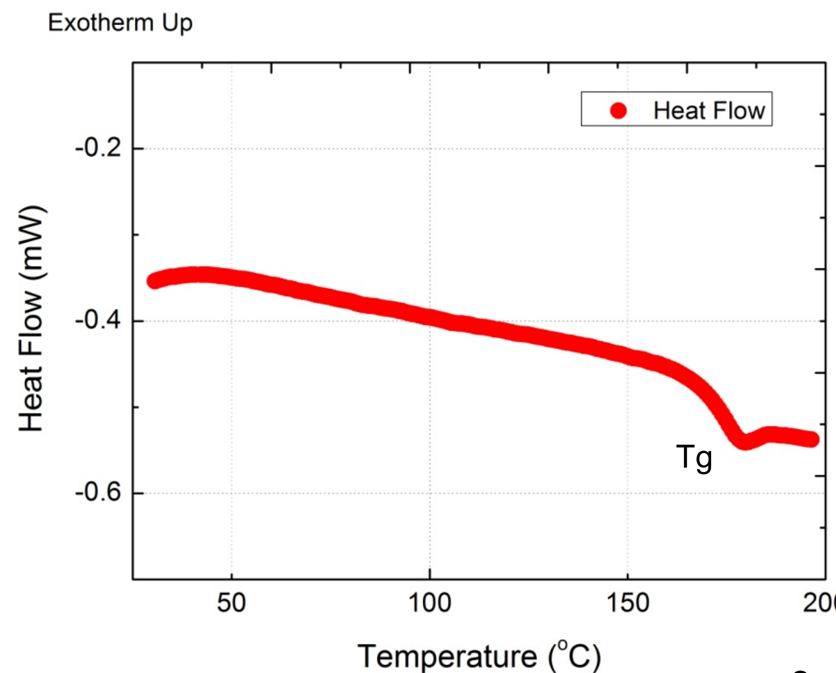
Technical Accomplishments

In order to produce large lengths of polymer film we removed the double bond completely via hydrogenation



Removal of the double bond also enables extrusion processing

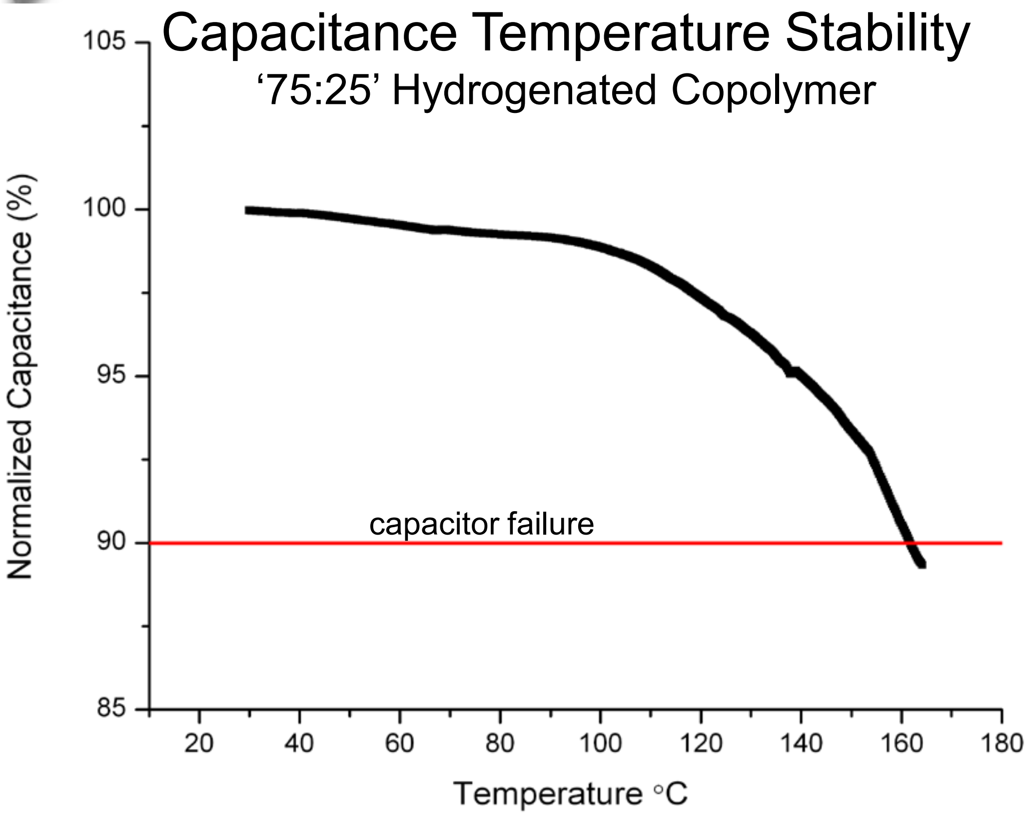




6.3 mm electrodes

8

Hydrogenated Copolymer



κ = 3.25

breakdown strength = 327 V/μm

energy density = 1.53 J/cm3

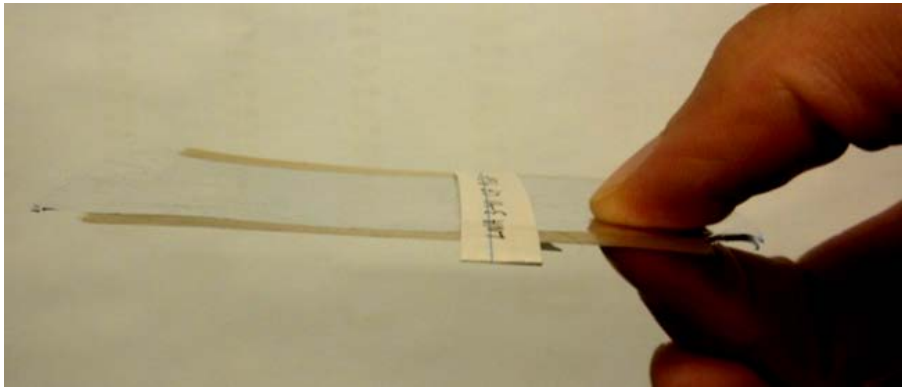
T stability >150 °C

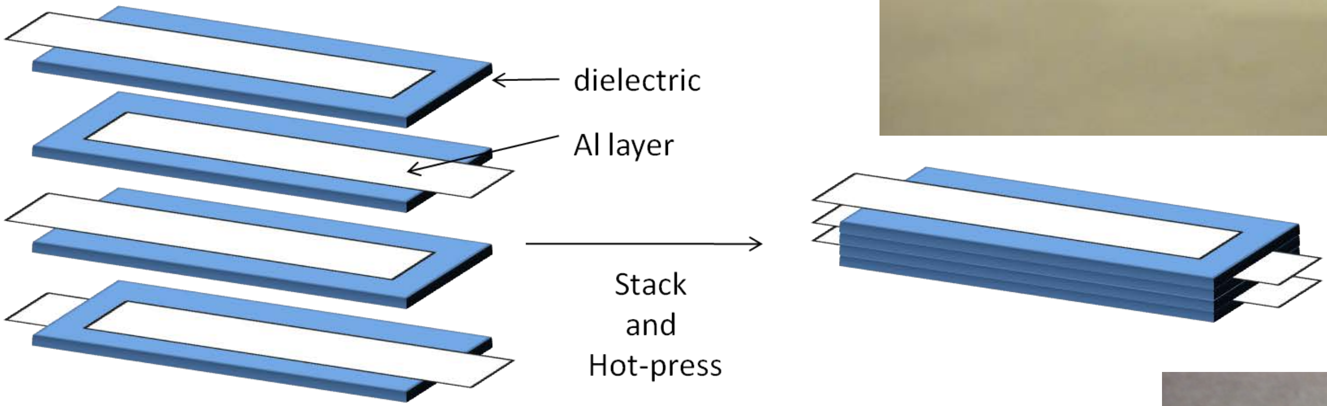
Tg = 175 °C

- Hydrogenated '75:25' co-poly(PhONDI)-poly(nbe) has good high temperature dielectric performance and stability.
- Hydrogenation and stoichiometry control tune properties for optimization of electrical and processing characteristics.

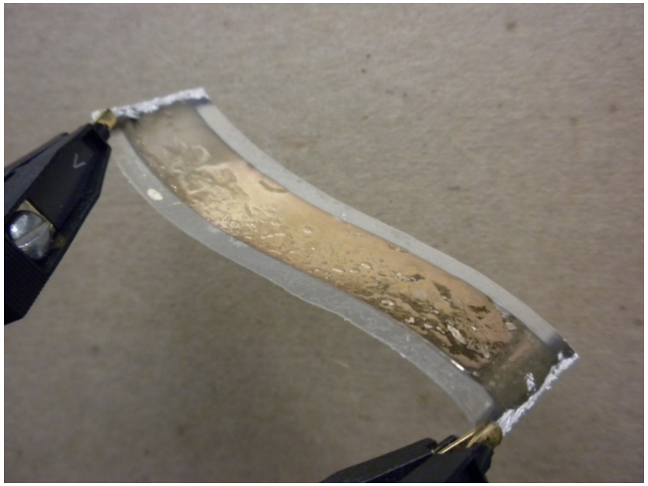
Technical Accomplishments

Dielectric film processed using a drawdown machine was used as the starting material





Capacitors were formed using a hot-press at a temperature above the T_g of the polymer to create a sealed capacitor. We have also begun to metalize the dielectric film with thin metal layers (50 nm) using sputter coating and have formed stacked capacitors.



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Stacked Capacitor Fabrication

- We have fabricated several stacked capacitors. To date, the largest has been **1.0 µF**.
- We are currently evaluating several methods to pot the stacked capacitors

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Rolled Capacitor Fabrication

- Fabricated rolled pressed capacitors from drawdown cast films (15-20μm) and 6μm Al foil.

layered

rolled
C = 41 nF

pressed
C = 85 nF

pressing improves form factor and capacitance

Rolled Capacitor Fabrication

- Rolled pressed capacitors are packaged in parallel to form capacitor banks.

534 nF
bank

1000 nF
(1 μF) bank

Rolled Capacitor Fabrication

- Single polymer layer rolled pressed capacitors significantly reduce volume compared to stacked capacitors.
- Hot or cold press
- Mechanical winding and thinner polymer films will further improve energy density.
- Total capacitance thus far for stacked and rolled capacitors 3.5 μF

~1 μF rolled pressed capacitor

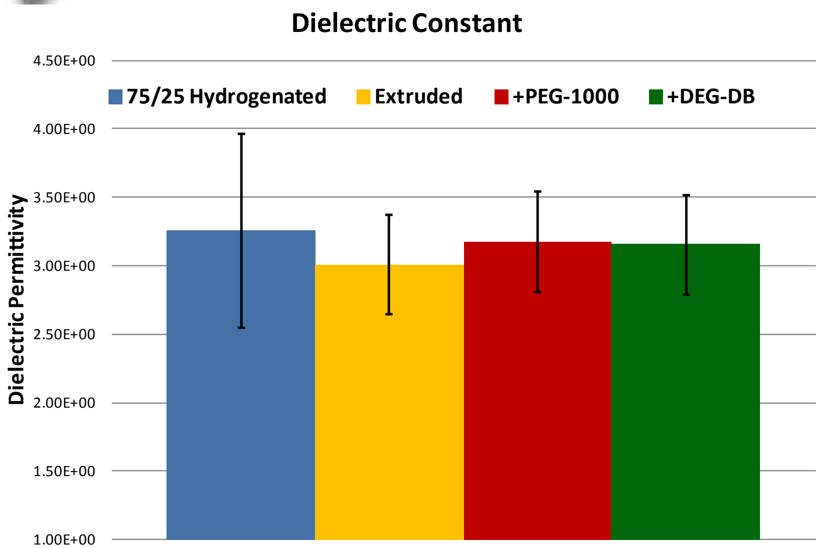
~1 μF stacked pressed capacitor

Several Approaches to Thin Films

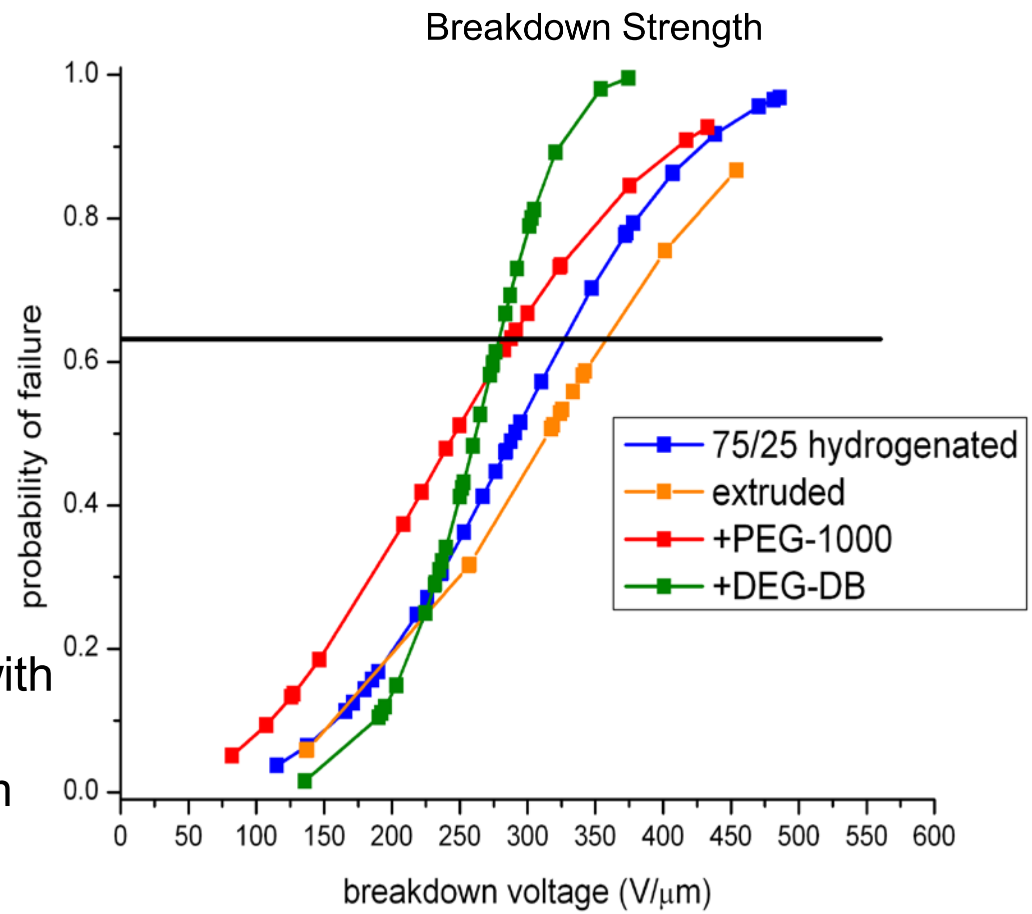
- Working with Joe Bond at ECI to produce polymer film (~12 μm) using the hydrogenated polymer material

- With Dr. Collin Co. demonstrated extrusion of thin films.
  - Initially extruded several rolls of polymer with thicknesses of 8-20 μm, but they were brittle.
  - Added plasticizer allows extrusion of 3 μm films with no significant degradation of electronic properties.

Extruded Films

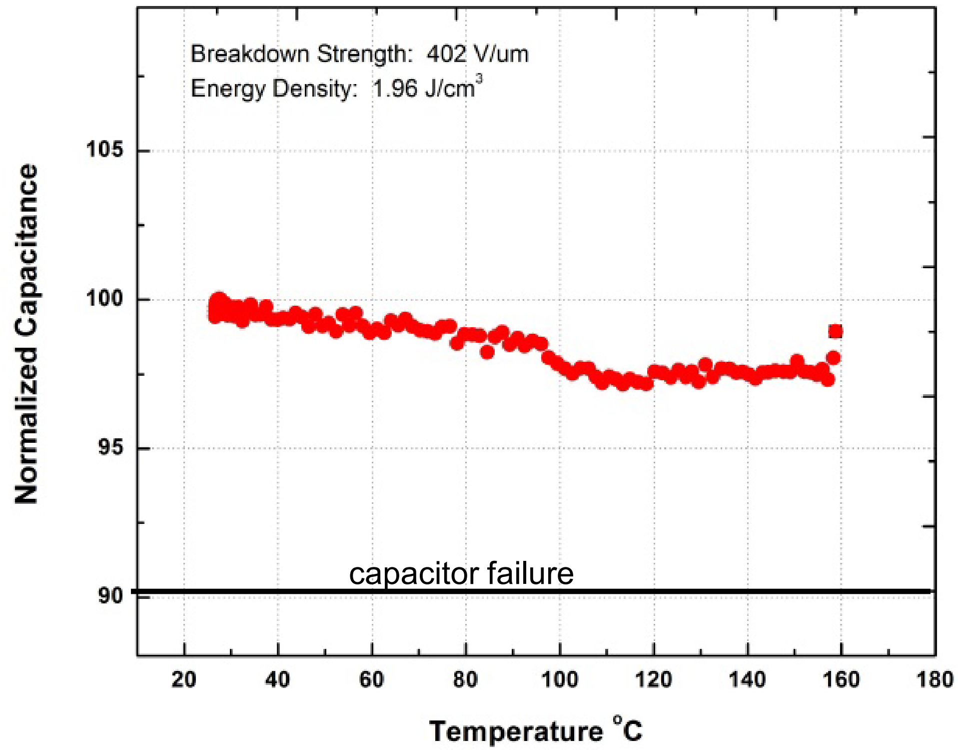


Extruded film with plasticizer
Length ~80 m
(3” wide)



Commercial Alternative (‘CA’)

- Identified a commercially available high temperature “polypropylene” like polymer
- Good breakdown strength, permittivity, and temperature stability.



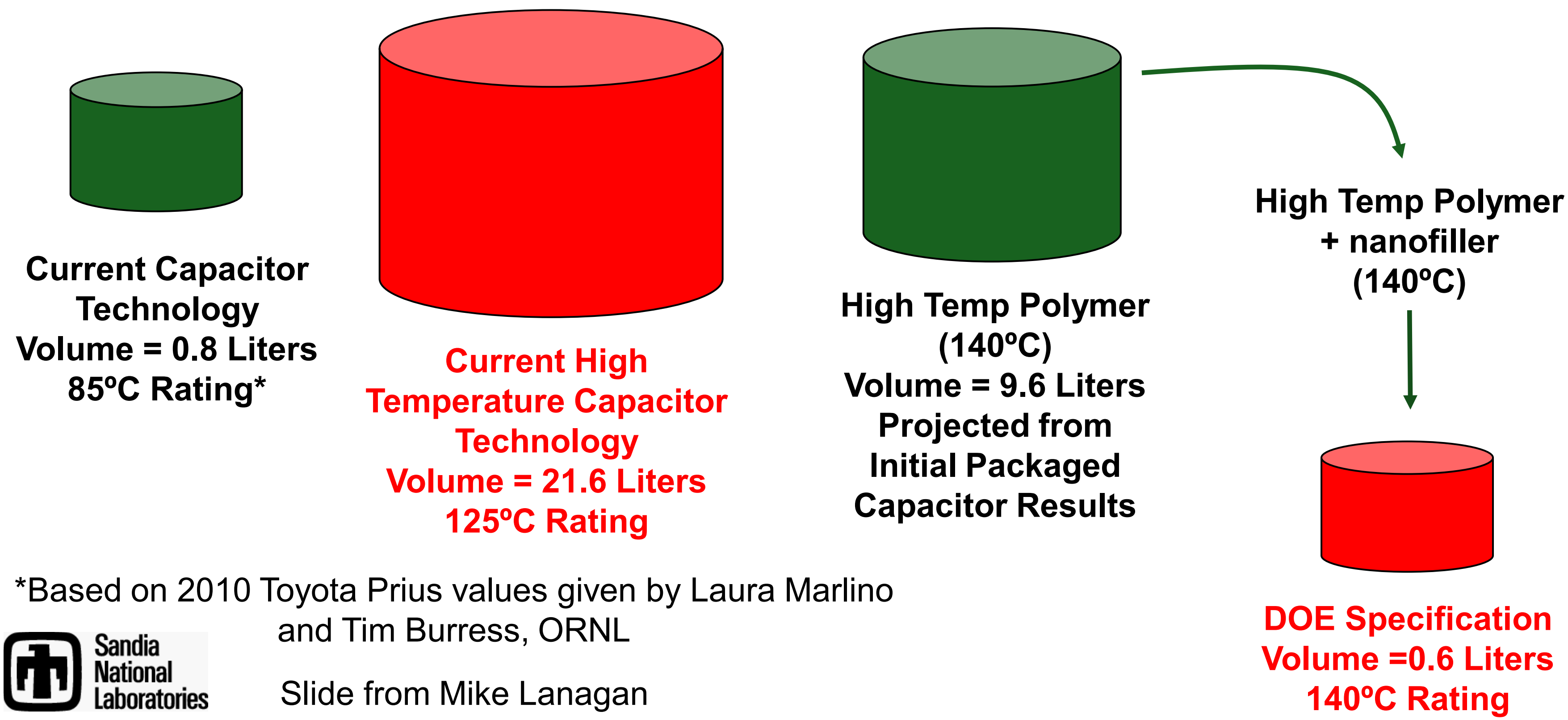
Commercially Available Polymers for Dielectrics

BOPP	$10/lb
PPS	$500/lb
‘CA’	$8/lb

κ = 2.7
breakdown strength = 402 V/μm
energy density = 1.96 J/cm3
T stability >150 °C
Tg = 178 °C

Capacitor Volume

- Our high temperature polymer will enable high temperature capacitor volume to be cut in half. Nanoparticle fillers will enable polymer capacitor volume to shrink even further.



*Based on 2010 Toyota Prius values given by Laura Marlino and Tim Burress, ORNL

Slide from Mike Lanagan

Collaborations and Coordination with Other Institutions

- Working to fabricate polymer films
  - Joe Bond
  - Dr. Collin Company

Electronic Concepts, Inc.

- Coordination
  - Penn State
    - Mike Lanagan
  - Argonne National Laboratories
    - Uthamalingam (Balu) Balachandran

Future Work

- Continue to transition polymer film technology to industry - Producing films and prototype capacitors at ECI and Dr. Collin
  - Fabrication of capacitors at ECI with film produced from hydrogenated polymer

- Producing six stacked or rolled capacitors "in-house"

- If larger scale experiments using nanoparticle loaded material shows improvement in breakdown strength, begin production of prototype capacitors and evaluate
  - A specific goal will be the production of a prototype "stacked capacitor"

Summary

- We have characterized the high temperature film electrical properties to identify the stoichiometry that meets high temperature performance metrics while allowing for film processing
- Working with ECI to produce prototype capacitors and solving problems as they occur related to transitioning from a laboratory to a pilot scale operation
- Demonstrated production of extruded polymer with length of ~80 m
- Working to produce “in-house” fabricated stacked and hand rolled capacitors
- Identified and evaluated an inexpensive commercially available norbornene-based high temp polymer as an alternative dielectric material