Glass Dielectrics for DC Bus Capacitors

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APE010

Overview

Timeline

- Start date 10/1/10
- End date 9/3013
- Percent complete 90%

Budget

- Total project funding
- FY11 $150k
- FY12 $170k
- FY 13 $50k

Partners

- Argonne National Lab
- Sandia National Lab
- NEG and Corning

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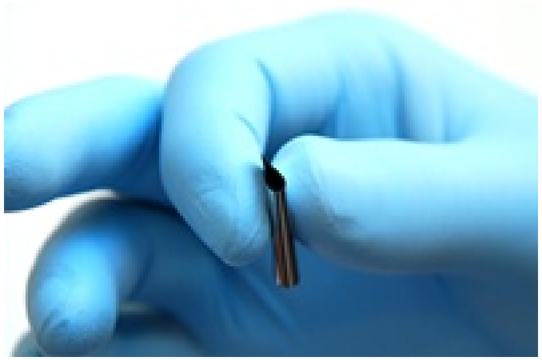
APEEM Barriers Addressed

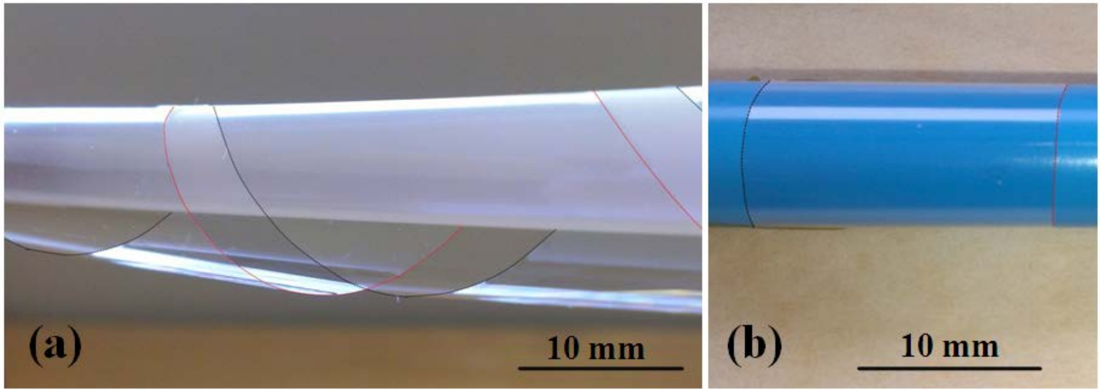
- **Cost**: Glass is a low-cost commodity material with substantial investment from the raw materials industry for flexible displays.
- **Performance and Life**: Glass has high-temperature performance for uncooled DC BUS capacitors.



Flexibility Demonstration of flat panel display glass

Objectives/Relevance

- Characterize the high temperature electrical properties of flat panel display glass. Relevance – APEEM capacitor goal 140°C and 650V
- Fabricate and test coiled glass capacitors. Relevance – Leverage the substantial investment has occurred in flat panel display glass for the development for high-temperature capacitors. Addresses the DOE PEEM requirements for low cost.
- Demonstrate the long-term reliability of glass capacitors through highly accelerated life testing (HALT). Relevance – APEEM capacitor life goal of >13,000 hrs. under EV/HEV operating conditions.



a) Flexible glass with thickness of 10 µm, (b) glass ribbon wound on 8 mm diameter mandrel

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Milestone Slide

Month/Year	Milestone or Go/No-Go Decision
Dec-12	Milestone: Test coiled glass capacitor at high voltage (>1kV) and 140ºC.
May -13	Milestone: Complete first round of tests and modeling of capacitor life at high temperature an voltage
Oct-13	Milestone: Complete Highly Accelerated Life Testing (HALT) of commercial flat panel display glass and estimate performance lifetime of capacitors made from glass.

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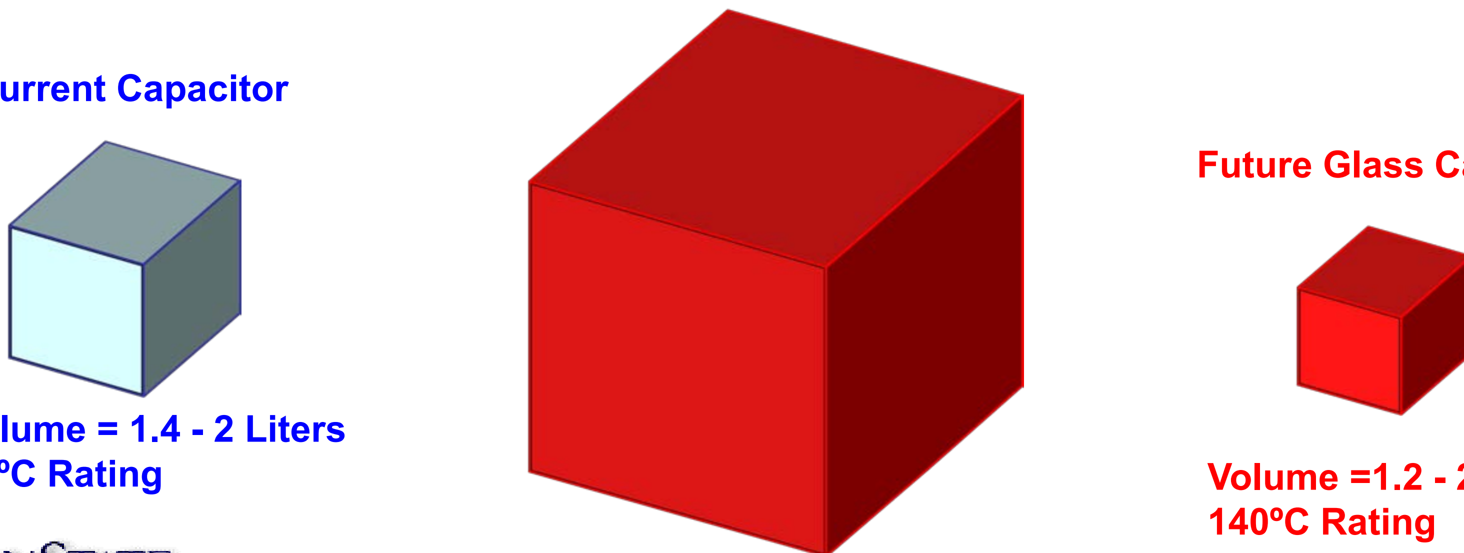
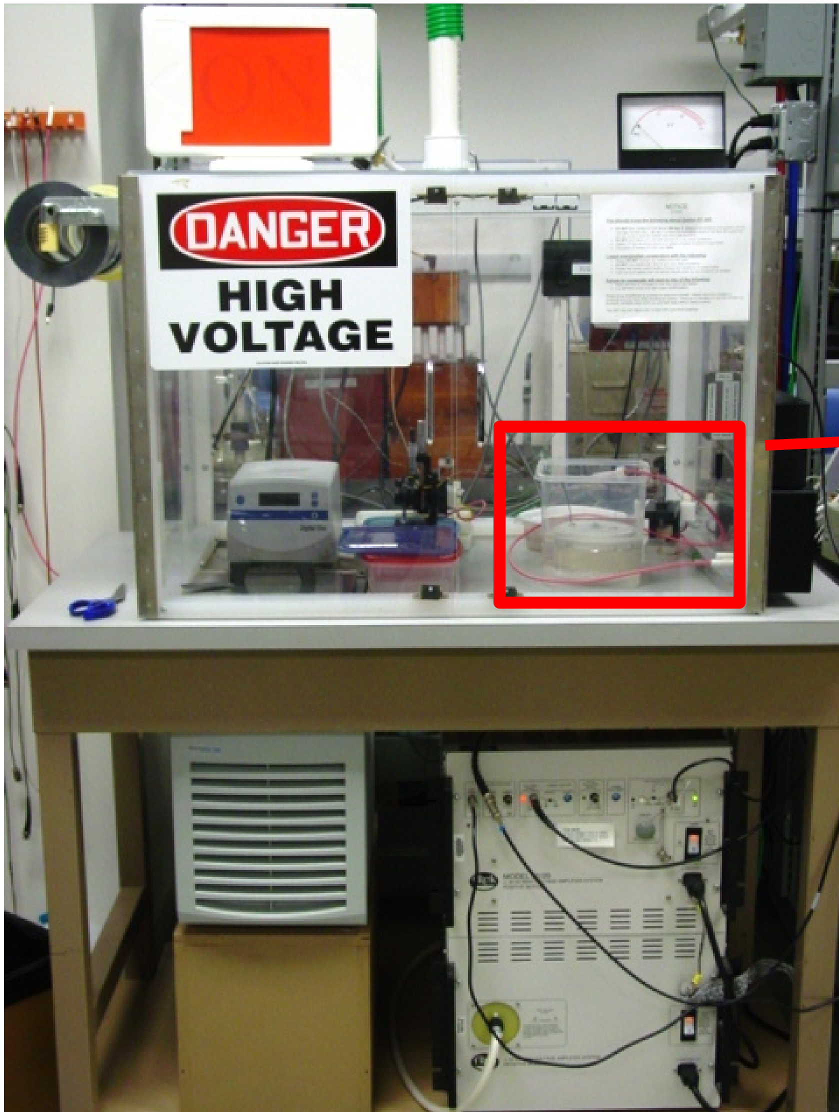
Approach and Strategy

- Develop a glass capacitor to meet the APEEM temperature specifications of 140ºC.   Glass has a substantially higher melting point (1400°C) than the melting point of plastics (150ºC) that are presently used in capacitors.
- Determine failure modes and predict life of a glass DC BUS capacitor based on highly accelerated life testing.

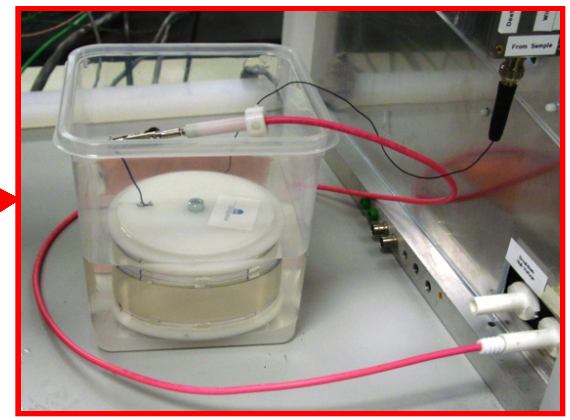
Volume of 1000 µF 600V capacitors in a Hybrid Electric Power Converter



Technical Progress and Accomplishments
Capacitor Breakdown Test Development



Coiled Glass Capacitor in Dielectric Fluid



Breakdown System Hardware Developed at PSU

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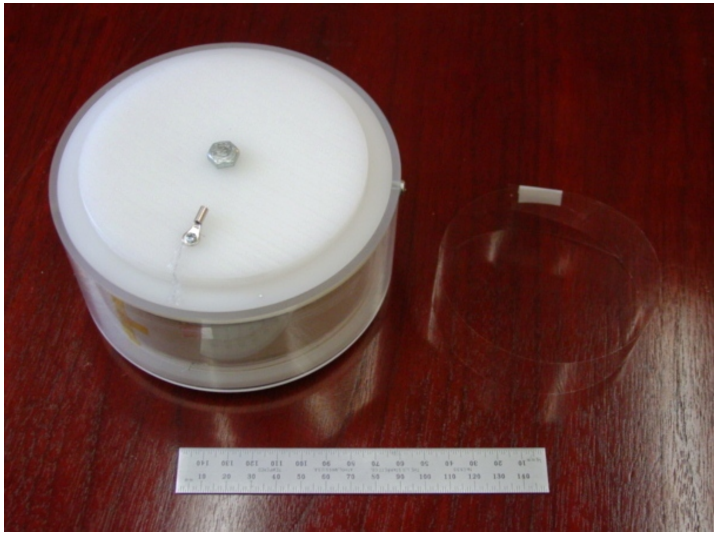
Technical Progress and Accomplishments

High Voltage AC Test of Penn State Glass Capacitor



DC test to 1000V, 200V/sec ramp rate – ***passed***

AC test to 500V, at 10Hz - ***passed***

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Technical Progress and Accomplishments Highly Accelerated Life Testing (HALT)

- Combine high temperature (500ºC) and high voltage (1 kV)
- 15 sample positions
- Monitor leakage current as a function of time

HALT system designed and built at Penn State University

Highly Accelerated Life Tests (HALT): Relationship between two conditions (experimental and predicted)

Acceleration Factor (Determined from space charge distribution in glass)

Activation Energy (Determined from ionic transport in glass)

Predicted time to Failure

Measured time to Failure

$$\frac{t_1}{t_2} = \left[\frac{V_2}{V_1}\right]^n \exp \frac{E_A}{K}\left[\frac{1}{T_1} - \frac{1}{T_2}\right]$$

Voltage

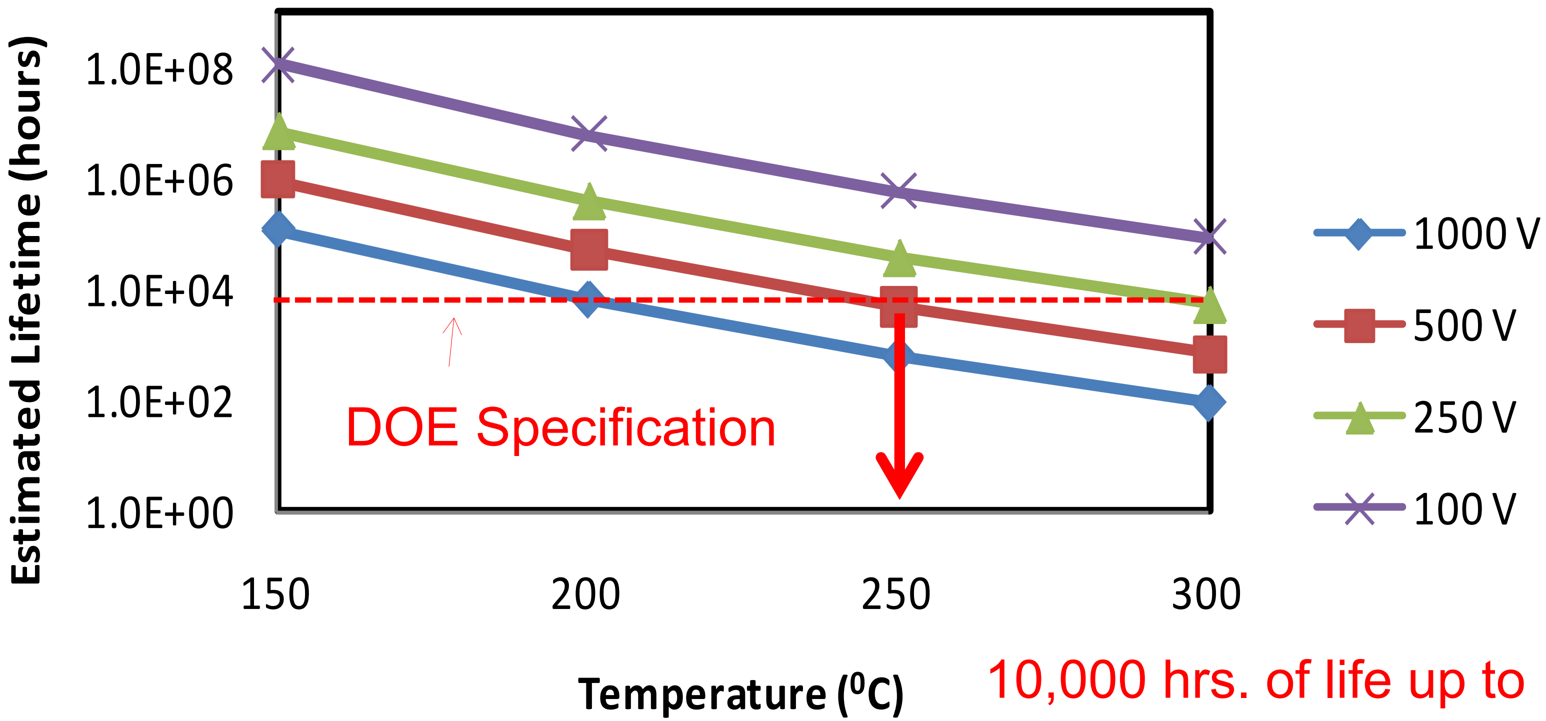
Temperature

,
where the subscripts *1* and *2* describe the test conditions, *t* is the median time to failure, *V* is voltage, *n* is the voltage acceleration factor, E_A is the activation energy for failure, *K* is the Boltzmann constant, and *T* is absolute temperature. The acceleration factor, *n*, and activation energy, E_A, will be determined by performing HALT at different temperatures and voltages.

Reliability testing at high temperature

1. Developed a test chamber to characterize capacitor life above 400ºC
2. Use high temperature data to predict performance for DC Bus capacitors in hybrid and electric vehicles.

Predicted capacitor life for glass capacitors based on HALT.



10,000 hrs. of life up to 250°C at 500 V

Technical Progress: Benchmarking State-of-the-Art Power Capacitors

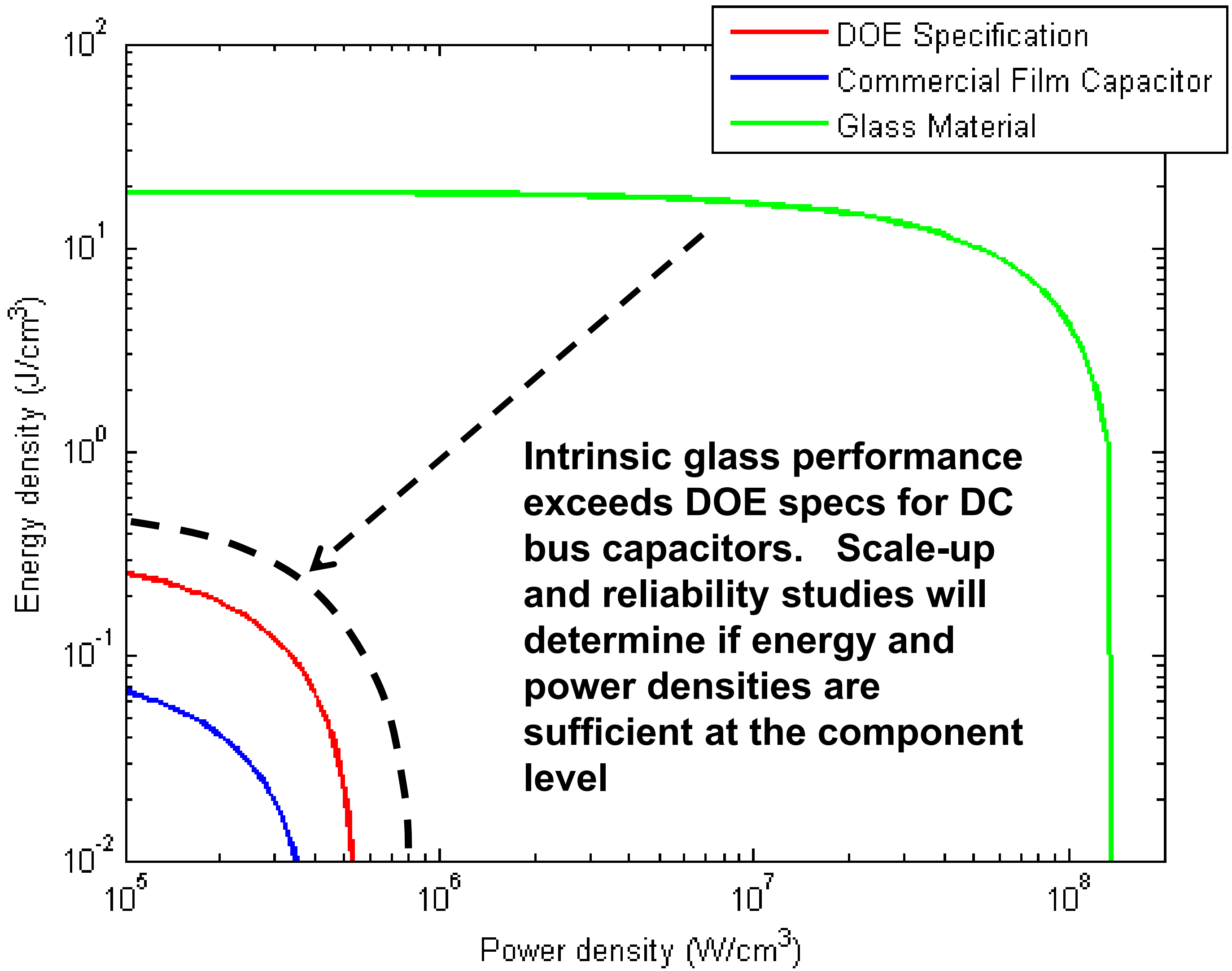
- Specifications for State-of-the-Art SBE capacitors*
  - Volume of the 600 V 1000 μF component is 1.8 L
  - Ripple current at 105ºC is 20% of the 85ºC value. Excellent performance for a capacitor made from polypropylene.

- Glass capacitor projected performance
  - Dielectric volume for a 600 V 1000 μF capacitor with 10 μm thick glass film is 1.9 L.
  - No ripple current decrease between 85ºC and 140ºC. Projection based on dielectric breakdown data and dielectric loss data at high temperature.

- Glass has a substantially higher melting point (1400°C) than the melting point of polymers (150ºC) that are presently used in film capacitors

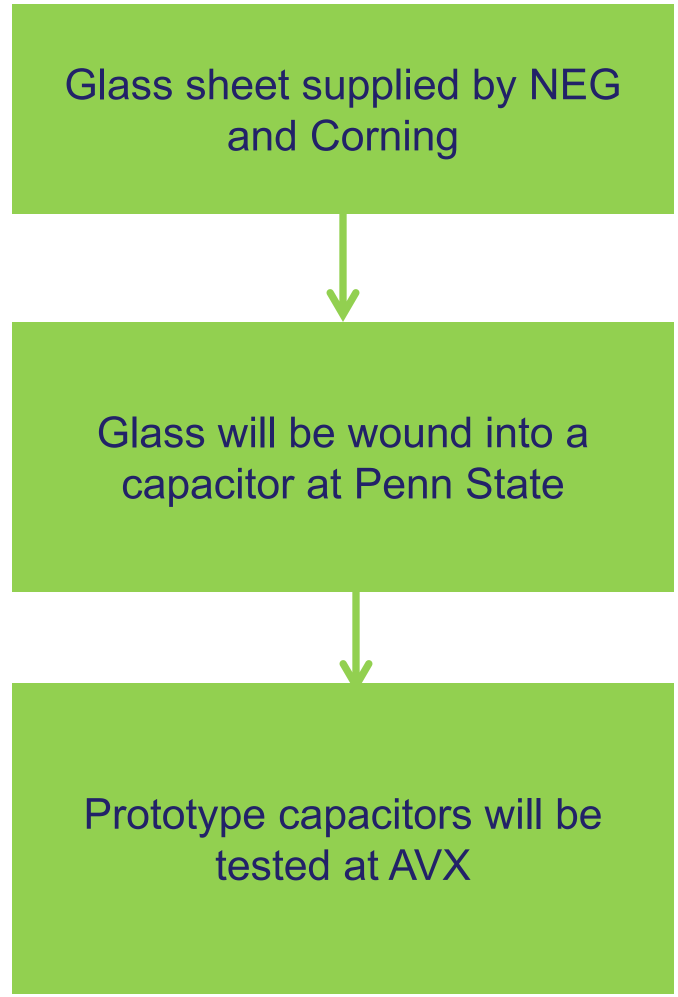
* SBE Power Ring Part # 700D10896-348

Benchmarking Dielectric Materials and Capacitors Against DOE Specifications



Collaborators

- Argonne National Laboratory
  - Prime contractor
  - Penn State characterizes Argonne capacitors
- Sandia National Laboratory
  - Collaborate on the defining capacitor specifications for PEEM
- Industry
  - AVX (capacitor manufacturer)
  - NEG (glass manufacturer)



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Proposed Future Work

- Apply scaling protocols, based on Weibull analysis, to extrapolate life predictions of small glass capacitors to large DC Bus capacitors. See area scaling of breakdown strength below.
- Relate HALT equation activation energy parameters to sodium impurity migration in glass.
- Area dependent breakdown strength:
  - Important for scale up
  - Related to Weibull modulus, β (Typical values = 10)
  - Self healing capacitor structures will increase β (>30?).

$$\frac{E_{b1}}{E_{b2}} = \left(\frac{Area_2}{Area_1}\right)^{1/\beta}$$

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Summary Slide

- There has been a substantial world-wide expansion in flat panel display glass during the past decade. This plentiful material has excellent high temperature dielectric properties.
- In FY13, coiled glass capacitors were fabricated and tested under high AC voltage.
- Future work for the remainder of FY13 will focus on life testing and long-term aging of flat panel display glass. This is important for capacitor performance over the HEV lifetime.
- In the remainder of FY13, the fundamental material limitations on glass capacitor reliability will be determined (i.e. sodium mobility).

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Technical Back-Up Slides

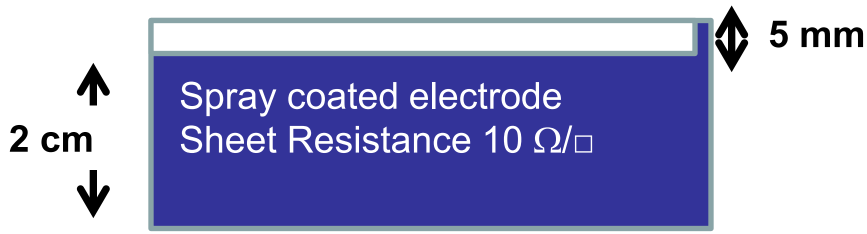
(Note: please include this "separator" slide if you are including back-up technical slides (maximum of five). These back-up technical slides will be available for your presentation and will be included in the DVD and Web PDF files released to the public.)

Table 1: DOE Vehicle Technologies Program DC Bus Capacitor Targets

Typical Capacitor Bank Requirements	
Capacitance, µF	1000 +10% / -0%
Operating voltage, VDC	450
Peak transient voltage, VDC for 50 ms	650
Leakage current at operating voltage, mA	≤ 1
Dissipation factor at 10 kHz[1], %	< 2
Equivalent series inductance (ESL), nH	≤ 5
Ripple current, amps RMS continuous	90
Temperature range of ambient air, °C	-40 to +140
Volume requirement, l	≤ 0.6
Cost	≤ $30
Failure mode	Benign
Life @ operating conditions, hr	>13,000

Coil Fabrication

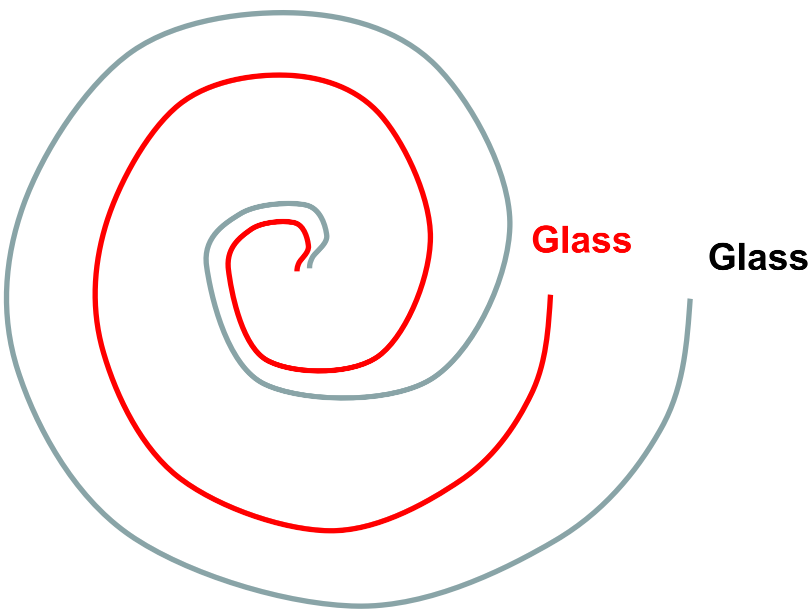
Glass Sheet Side 1



Glass Sheet Side 2

Uncoated margin on opposite sides for voltage isolation

Co-wind glass



Glass Sheet

Steve Perini and Amanda Baker

Coil Measurement Procedure

- Glass spacer layer is required to separate + and – sides of glass layer.
- Connections are made at several points along the length of the glass ribbon
- Excellent frequency response expected in this configuration