Glass Dielectrics for DC Bus Capacitors

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APE010

Overview

Timeline

- Start date October 10
- End date September 12
- Percent complete 50%

Budget

- Total project funding
- FY10 $150k
- FY11 $150k

Barriers

- Barriers
  - Availability of high temperature capacitor components to reduce the overall cost and increase performance of APEEM electric propulsion systems.
  - Materials with sufficient high temperature performance for incorporation into a DC BUS capacitor.

Partners

- Argonne National Lab
- Sandia National Lab
- NEG
- Strategic Polymers

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Project Objectives

- The overall objective is to build glass capacitors with high temperature reliability. The purpose is to build and test a capacitor prototype that is capable of operating at 140 °C at 600V (Advanced Power Electronics and Electric Motors - APEEM Goal).
- The research directly addresses the DOE APEEM requirements for HEV/EV/PHEV power modules that do not need internal cooling.
- Leverage the substantial investment has occurred in flat panel display glass for the development for high-temperature capacitors.
- Specific May 2011 – May 2012 objective is to demonstrate that glass can be wound into a capacitor configuration, similar to polymer film capacitors.

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Milestone Slide

Month/Year	Milestone or Go/No-Go Decision
October 10	Milestone: Demonstration of a rolled glass coil. Glass sheet dimensions were length = 2.8 m, thickness = 50 µm and width = 3 cm. Coil radius was 5 cm.
May-11	Milestone: High temperature dielectric breakdown system. Design and construct a system with 5 kV max voltage and a temperature range of 100ºC to 450ºC
Dec-11	Milestone: Construction of a wound capacitor prototype. Co-wind the glass sheet with aluminum foil for a metal-insulator-metal construction. Test ESR, capacitance and high temperature performance of prototype.

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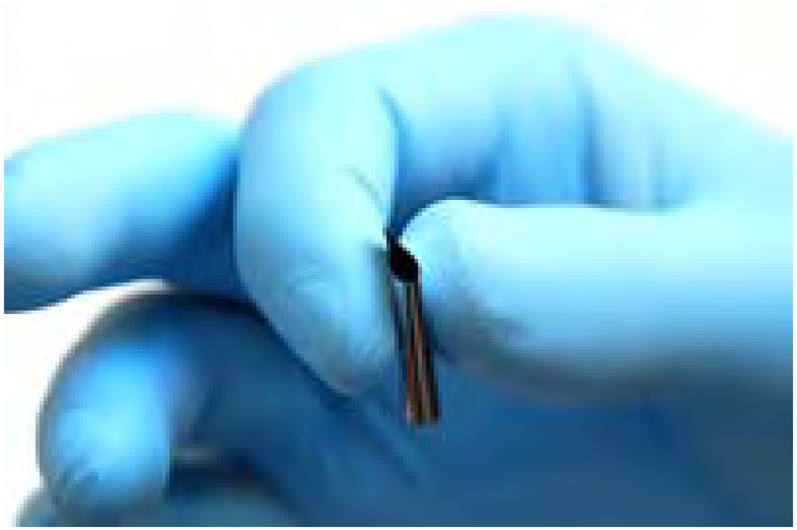
Approach and Strategy

- Approach: Glass is a promising high temperature material that is easily incorporated into a capacitor structure.
- To address reliable capacitor performance, self healing mechanisms are explored in prototype glass capacitors.

Flexibility Demonstration of flat panel display glass

Commercially available thicknesses of 50 µm

Experimental glass available in thicknesses of 5 µm



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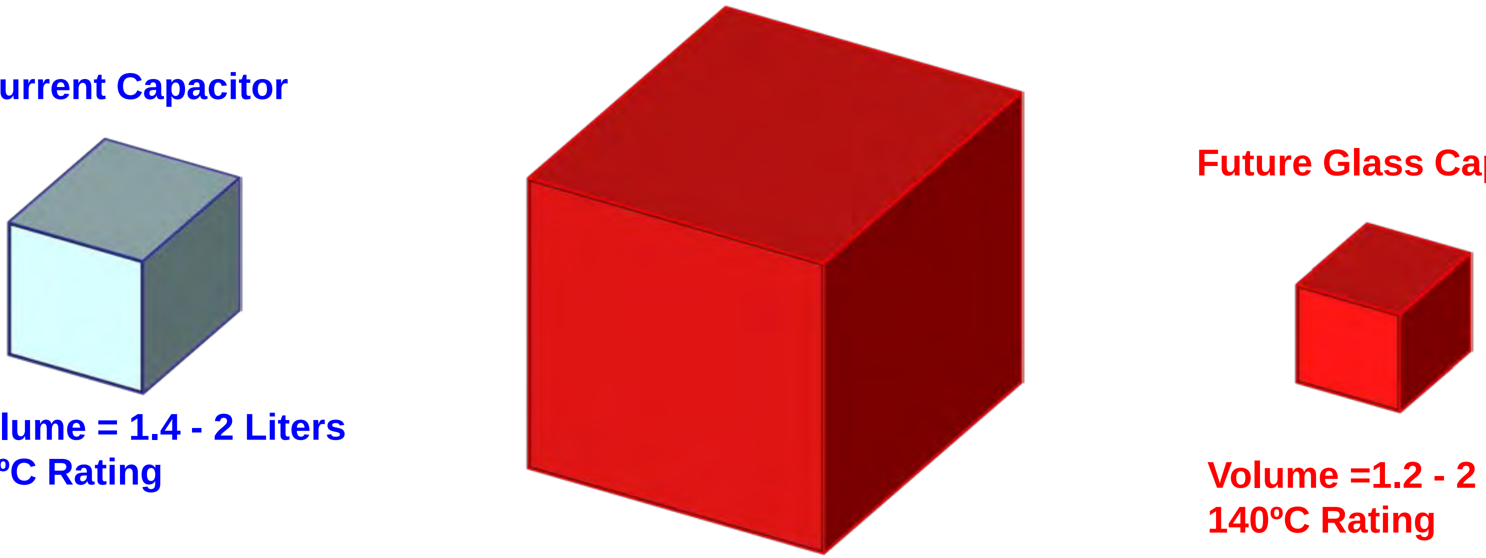
Approach and Strategy

- Use low-cost flat panel display glass in a DC Bus capacitor
- Reduce the total volume of a DC Bus capacitor by incorporating glass materials in the capacitor construction
- Glass has a substantially higher melting point (1400°C) than the melting point of plastics (150ºC) that are presently used in capacitors

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



Technical Progress and Accomplishments

- FY10: Demonstrated thickness dependent dielectric breakdown and the statistics for making glass capacitors more reliable.

- FY11:
  - Characterized electrode thickness dependence on capacitance and dielectric breakdown.
  - Designed and tested highly acclerated life test system for temperatures up to 450ºC.
  - Submitted Patent Application “Self healing high energy glass capacitors”.

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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.

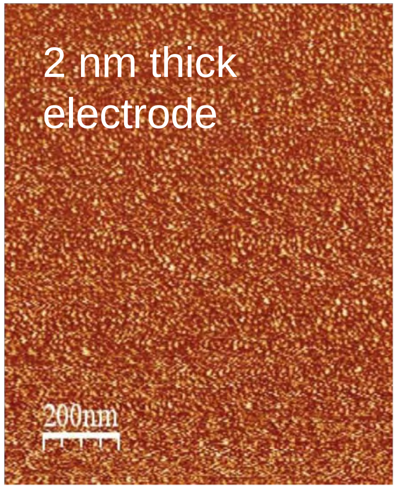
- Glass capacitor projected performance
  - Dielectric volume for a 600 V 1000 µF capacitor with 10 µm thick glass film is 1.9 L.
  - No ripple current decrease between 85ºC and 140ºC. Projection based on dielectric breakdown data and dielectric loss data at high temperature.

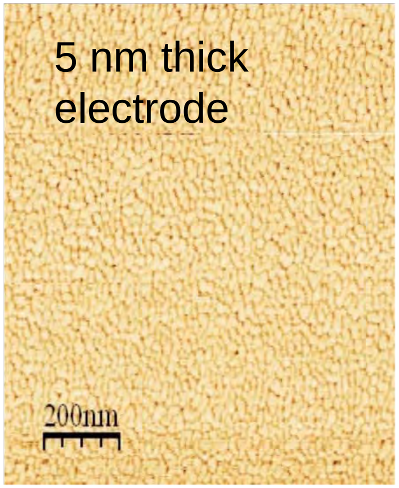
- Glass has a substantially higher melting point (1400°C) than the melting point of polymers (150ºC) that are presently used in film capacitors

* SBE Power Ring Part # 700D10896-348

Electrode Thickness Effect on Capacitor Performance

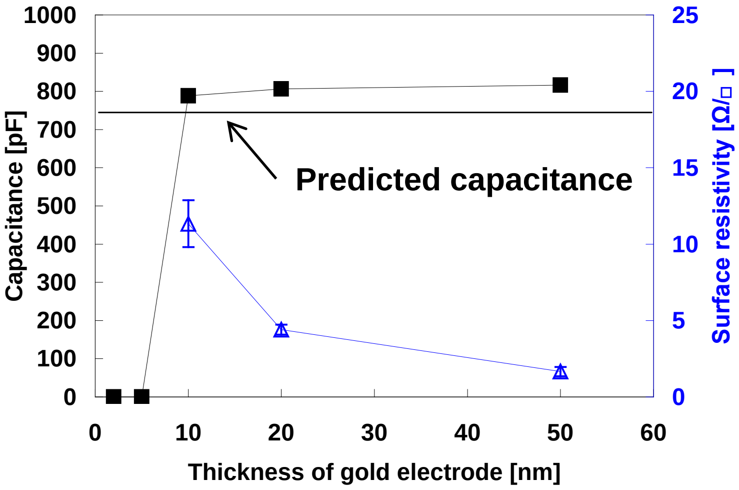
Atomic Force Microscopy (AFM) of Electrode Surface





- Electrode thickness studies are for sputtered Au on glass.
- AFM shows isolated island formation for electrode thickness of 2 nm. Islands become connected at 5 nm.

- Capacitance results are equal to predicted values until electrode continuity is interrupted below 10 nm
- Resistivity is consistent with commercial polymer film caps*
  - 2.5-10 nm thick films →50-100 Ω/□
  - 30-50 nm thick films →1.5-3 Ω/□



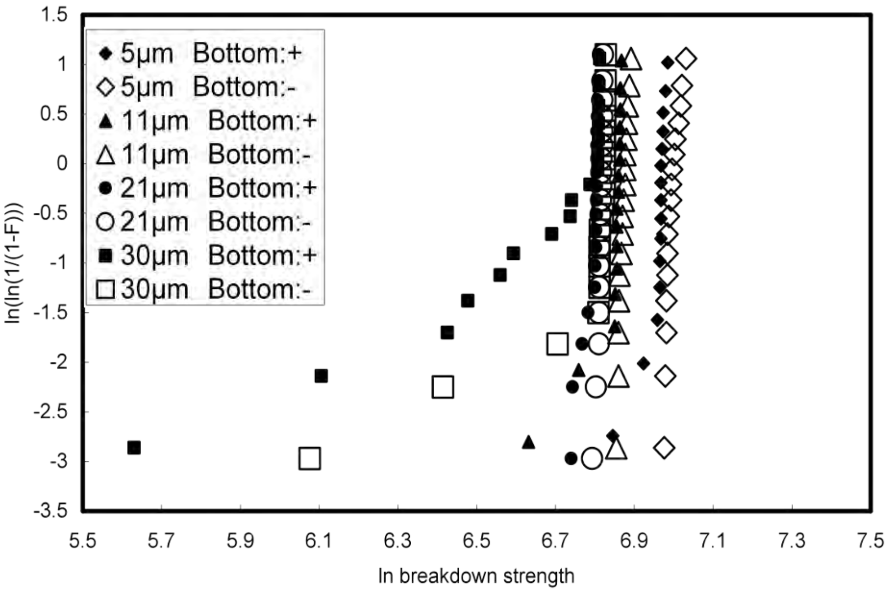
*Communication with Joe Bond, Electronic Concepts
Results were generated in collaboration with NEG

Reliability Testing at Room and at High Temperature

1. Developed a test chamber to characterize capacitor breakdown (up to 5 kV) above 400ºC (needed to accelerate testing for reliability predictions at 140ºC.
2. Use high temperature data to predict performance for DC Bus capacitors in hybrid and electric vehicles.
3. Last step is to add a high voltage switch system to increase sample through put for Weibull analysis (by May 2011).

High Temperature System for Capacitor Reliability Testing

Typical Weibull Plot demonstrating the need for testing many samples

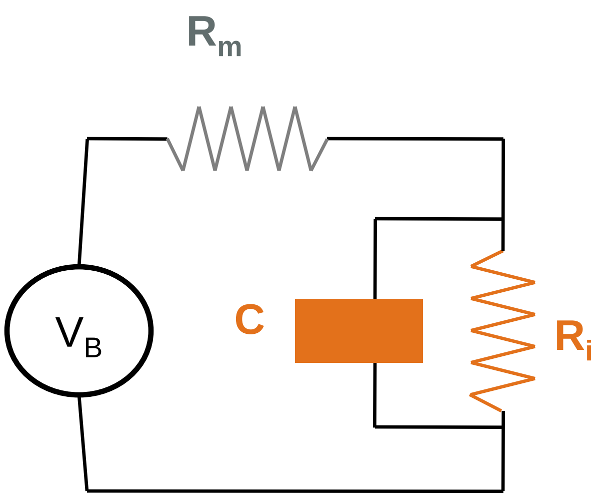


Energy Balance During Capacitor Failure

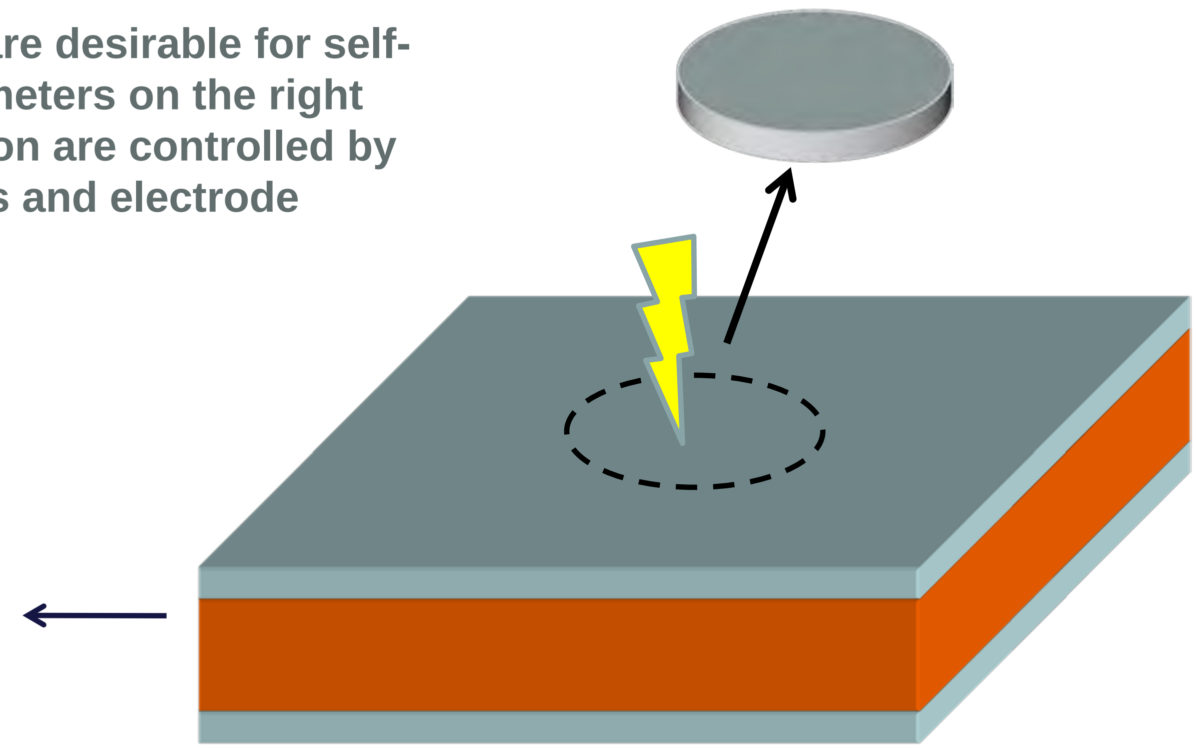
$$Sv = \frac{1}{tq_m}\left(\frac{CV_B^2}{2}\right)\left[\frac{2R_m}{\left(2R_m + R_i\right)}\right]$$

Larger Sv values are desirable for self-healing. The parameters on the right side of this equation are controlled by material properties and electrode thickness.

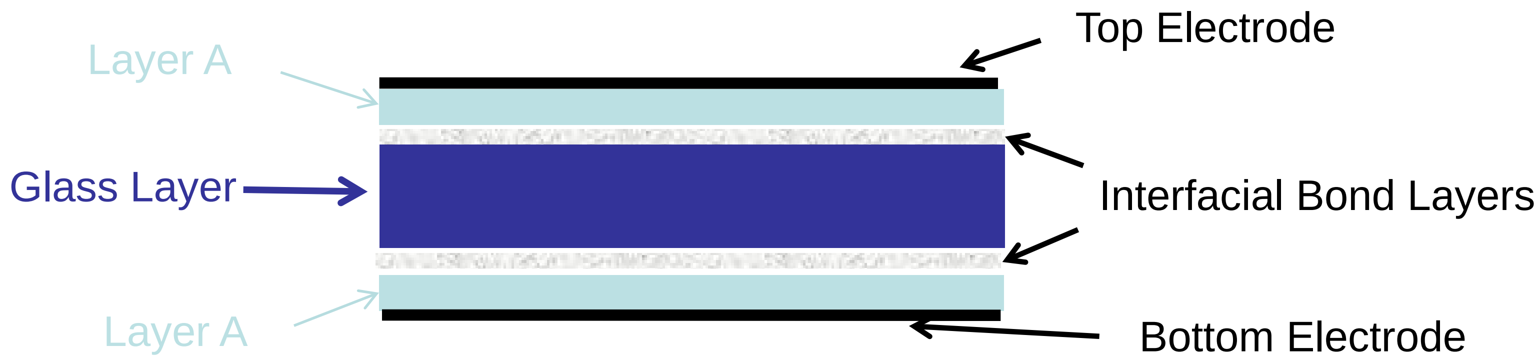
Sv = Surface area of metal that is vaporized



Equivalent Circuit



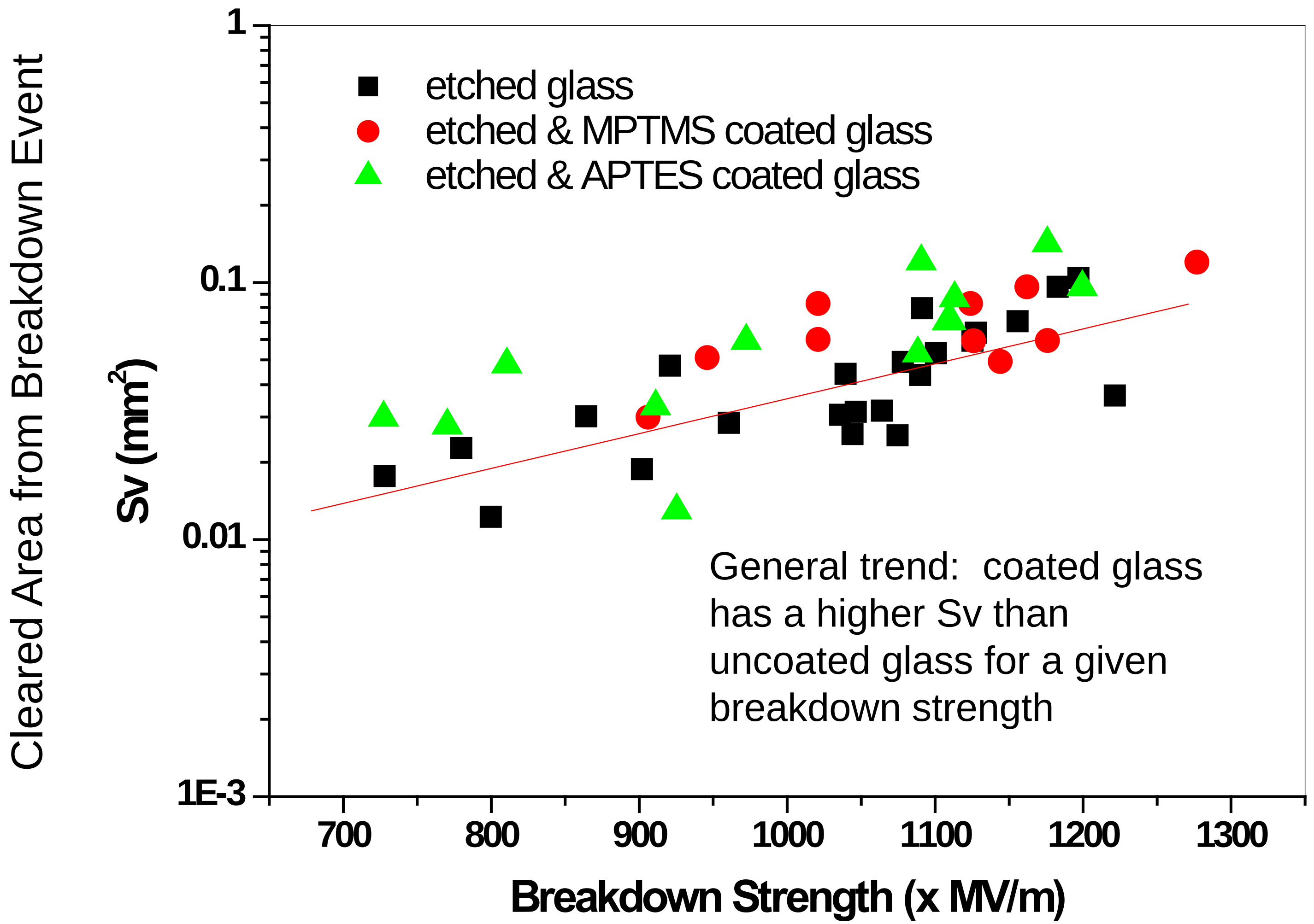
Self Healing Glass Capacitor Configuration



Patent Application: “Self Healing High Energy Density Capacitors”

Silane coating: Cleaned Area

Self healing is promoted with larger cleared area



Patent Application: “Self Healing High Energy Density Capacitors”

Collaborators

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

Glass sheet supplied by NEG corporation

↓

Glass will be wound into a capacitor configuration by SPS and Sandia
(Anticipated task completion by May 2011)

↓

Prototype capacitors will be tested at Penn State
(Test results will be reported at the DOE vehicle review in November 2011.

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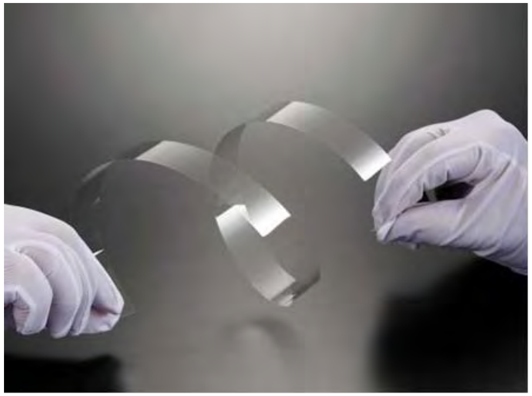
Proposed Future Work

- Highly Accelerated Life Test (HALT) of 10 µm thick glass.
  - Temperatures up to 450 C
  - Voltages up to 5 kV
  - Life predictions for DC bus capacitors in electric vehicles
- Continue to test high voltage reliability of thin glass sheets.
- Characterization of wound glass capacitors

Bend radius is inversely proportional to the glass sheet thickness.

Photo from collaborator T. Murata, NEG



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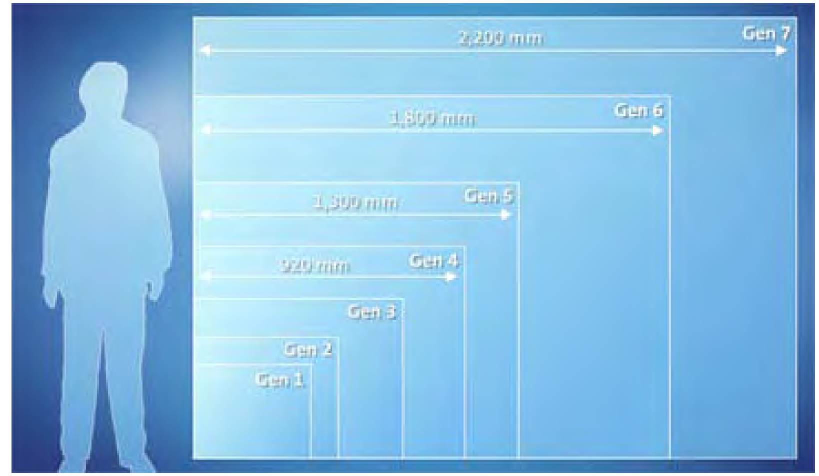
Summary Slide

- **There has been a substantial world-wide expansion in flat panel display glass in the past decade.**
- **This project leverages a large investment ($30B) that has been made in display glass for a completely different technology* – DC bus capacitors for Power Electronics.**



Corning projections for flat panel display sizes

- **In FY11 a wound glass capacitor concept has been introduced and prototypes will be characterized.**

*http://investintaiwan.nat.gov.tw/en/news/200601/2006010401.html