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Modeling of Glass and Polymer 100 kV High Energy Density Capacitors

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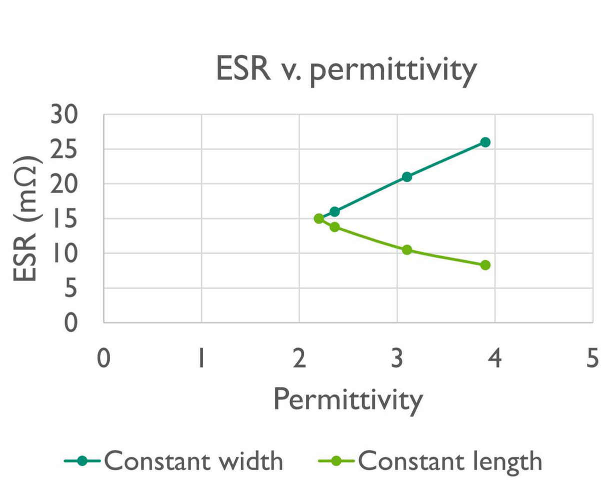
Introduction

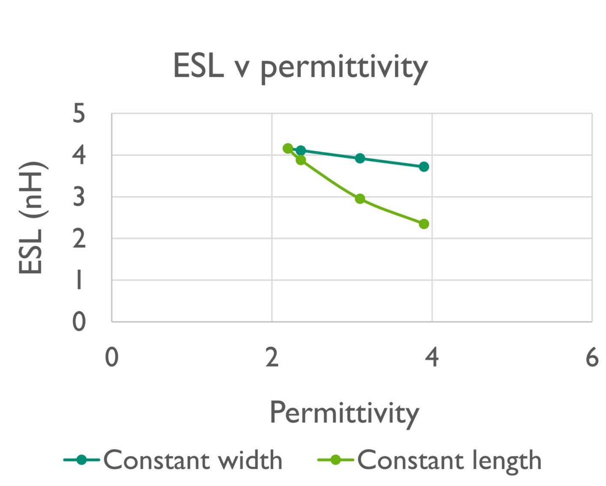
For applications such as pulsed power, higher energy density capacitors would benefit design and performance. Factors that are considered include low equivalent series inductance (ESL) and resistance (ESR), self-clearing during discharge, and the capacitor energy density. The design trade-offs were considered by modeling and testing different dielectric materials, metals, and capacitor structures.

Modeling Results

ESR/ESL

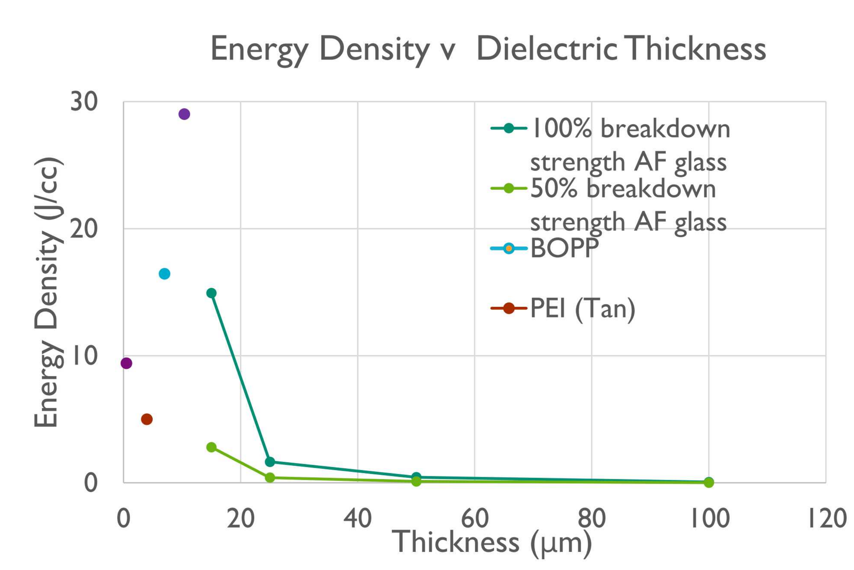
- Capacitors are treated as in series with resistors and inductors due to nonidealities
- For pulsed power specs, ESR < 100 mΩ, ESL < 50 nH
- Modeled at dependence of ESL and ESR on permittivity of dielectric and dimensions of capacitor, assuming constant capacitance





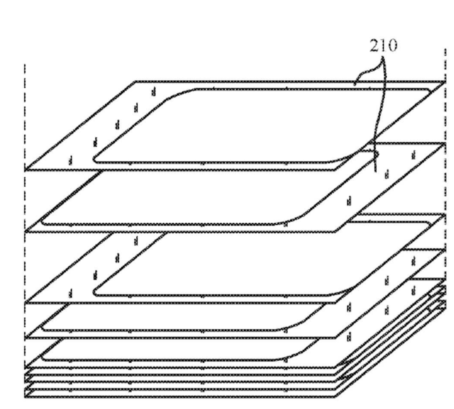
Dielectric Materials

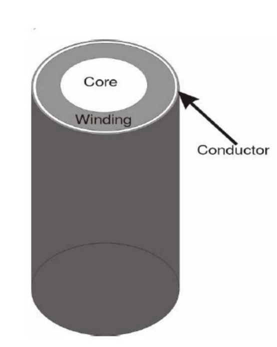
- $Energy\ Density = \frac{1}{2}\varepsilon_0 \varepsilon E^2$
- For higher energy density, we want to increase either permittivity or breakdown strength
- For many materials, breakdown strength is a function of thickness
- Current capacitors have energy densities of about 0.1 - 3 J/cc
- Plotted at a polymer and glass dielectrics of varying thicknesses from literature and from Sandia

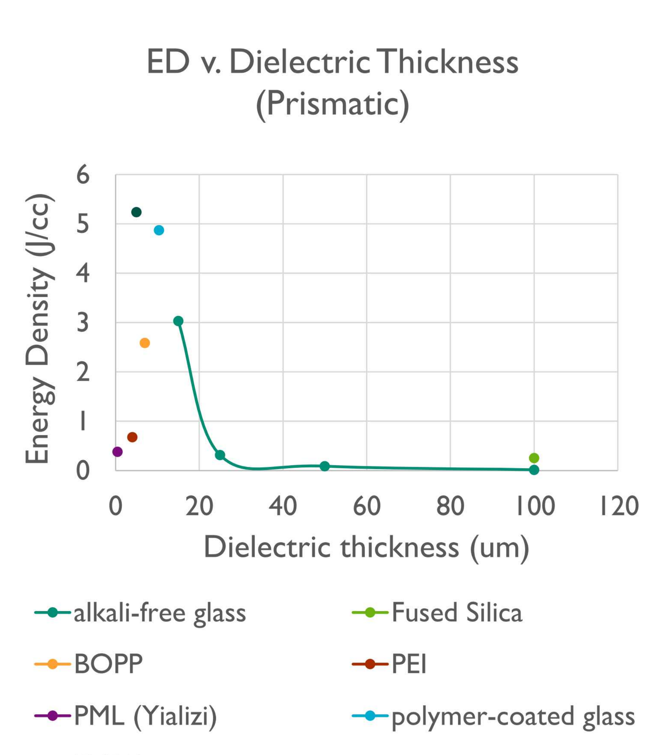


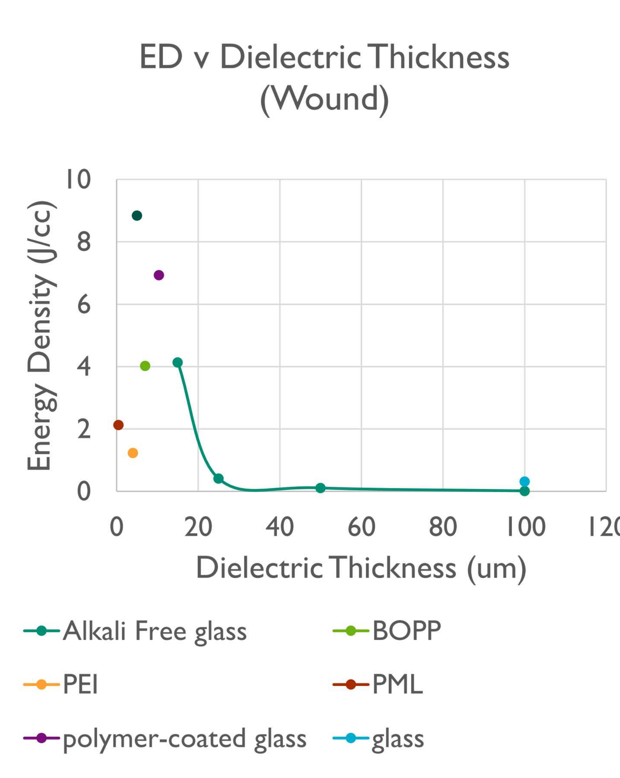
Capacitor Structures

- Considered two different capacitor structures: cylindrical wound and prismatic
- Varied in volumetric efficiency, the ratio between volume used to store charge and total capacitor volume
- Modeled energy density with different polymers for each structure[1][2]







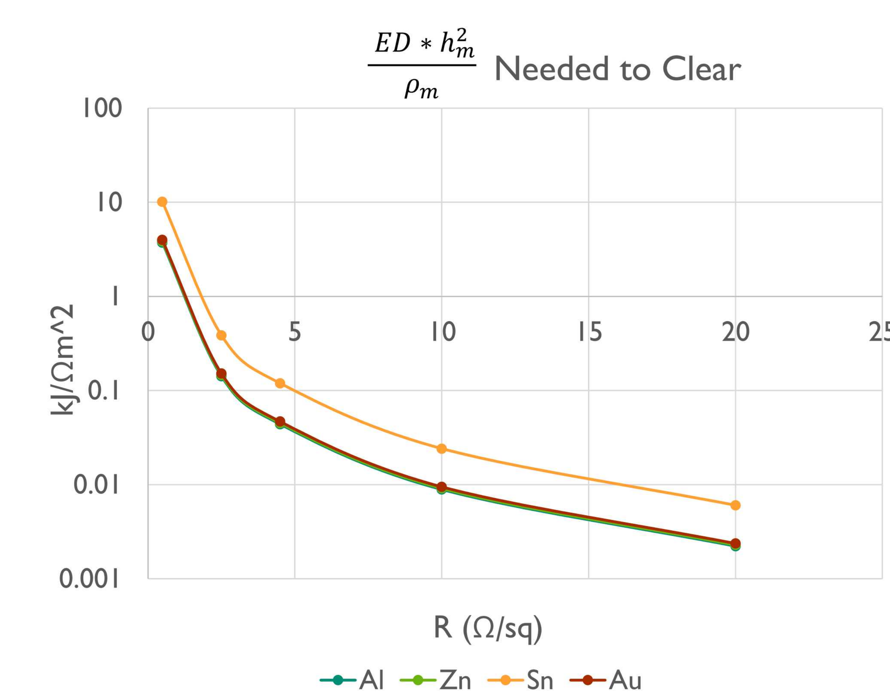


Self-Healing

- Self-healing occurs when energy from a dielectric breakdown vaporizes the metal electrode, isolates the breakdown site, and prevents further damage to the capacitor
- Destroyed area results in small loss of capacitance, but capacitor can continue to operate
- Dependence on resistivity and latent heat of vaporization of metal
- Energy criteria for clearing[3]:

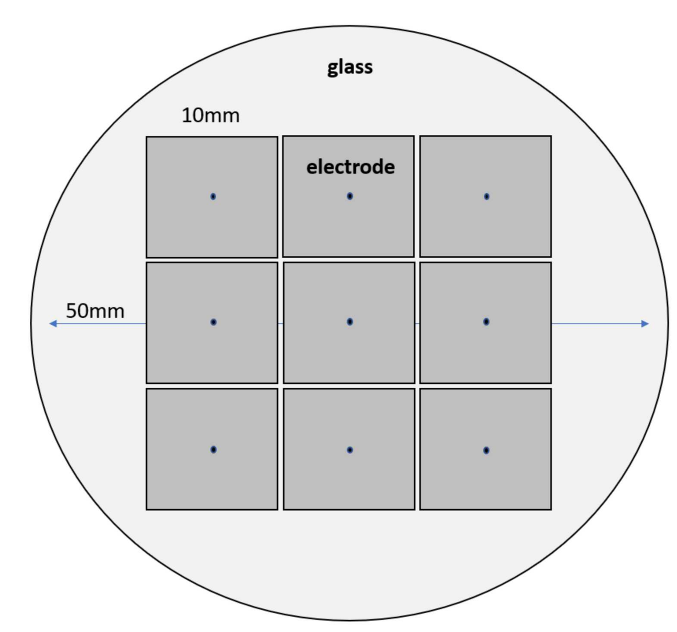
$$\frac{\epsilon_0 \epsilon \rho_m A_c \log\left(\frac{A_c}{A_m}\right) F_B^2}{8\pi \rho_i h_m^2} \geq q_m$$

- Modeled energy needed for aluminum, zinc, tin, and gold electrodes at different sheet resistances



Next Steps

- Study on ability of glass to self-heal and effects of using different metals for electrodes



- Test breakdown strength of glass samples and develop Weibull plots

References
[1] J. MacDonald *et al*, "Glass dielectrics capacitors and manufacturing processes for glass dielectric capacitors," U.S. Patent 0 198 247 A1, June 27, 2019.
[2] S. Qin and S. A. Boggs, "Design of longitudinal multisection foil-film capacitors," *IEEE Trans. Dielectrics and Elec. Insulation*, vol. 17, no. 6, pp. 1884-1887, Dec. 2010.
[3] N. Klein, "Advances in Electronics and Electron Physics", pp. 309-424, 26, Academic Press, New York, 1969.

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