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Sandia National Laboratories

# High Temperature Reliable Dielectrics for DC-link Capacitors

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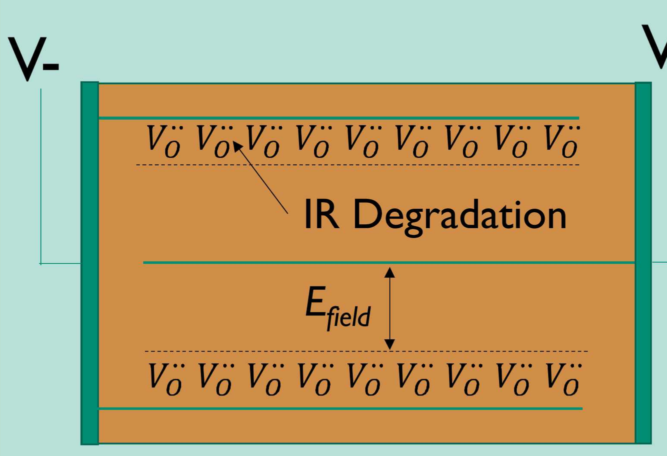
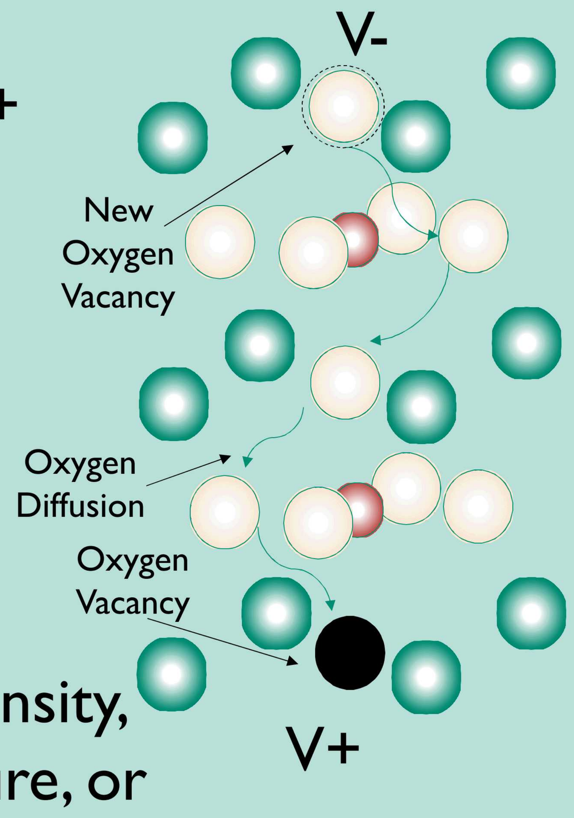
## Background

Power electronics require capacitive energy storage devices to smooth switching transients and provide input and output filtering. Thermal losses in the switch, ripple currents in the capacitor and dielectric losses all can increase the temperature of the capacitor. Elevated temperature operation accelerates dielectric degradation and circuit failure.

## Capacitor Aging

Aging in ceramic capacitors is caused by the diffusion of oxygen anions toward the anode and an accumulation of oxygen vacancies at the cathode. This process reduces the insulation resistance of the device and leads to failure by shorting or thermal runaway



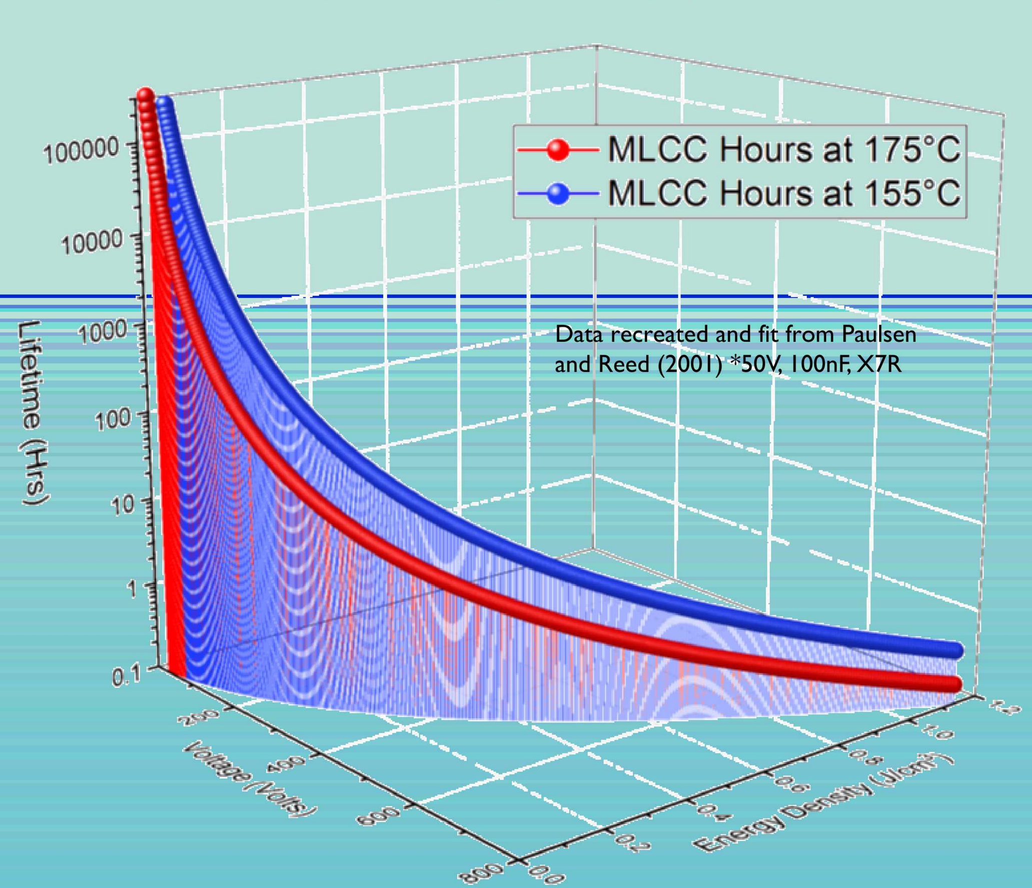

You Pick Two

1. Capacitor Energy Density,
2. Operating Temperature, or
3. Lifetime

Temperature and $E_{field}$ accelerate dielectric degradation and reduce mean time to failure

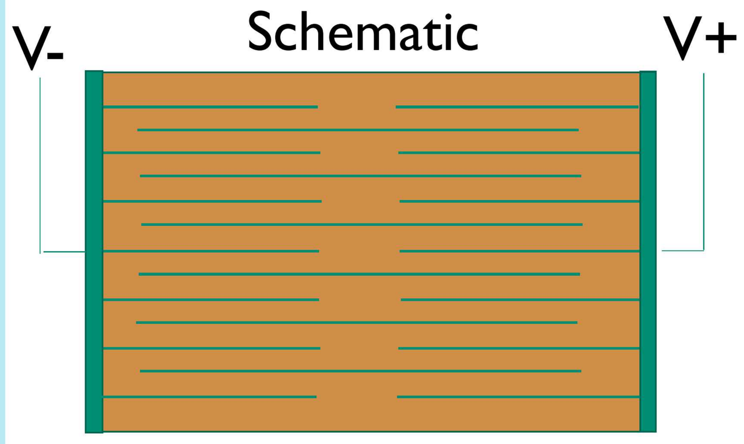
$$U/_{vol.} = \frac{CV^2}{2 * vol.} = 1/_2 \varepsilon_r \varepsilon_0 E_{field}^2$$

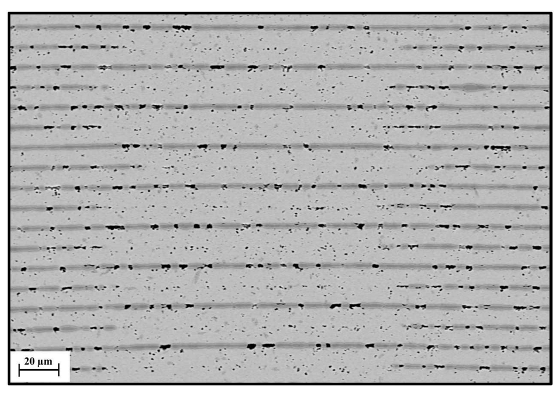
Energy density is proportional to the square of electric field (operating voltage)

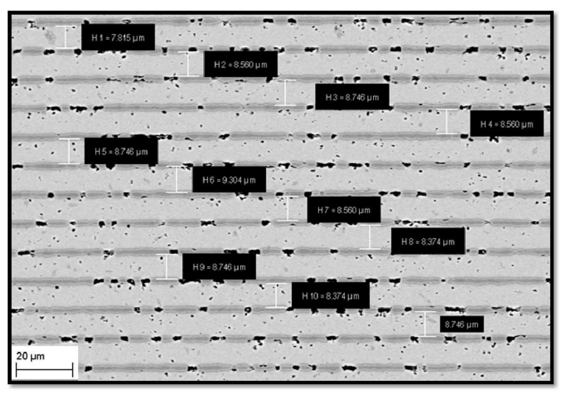


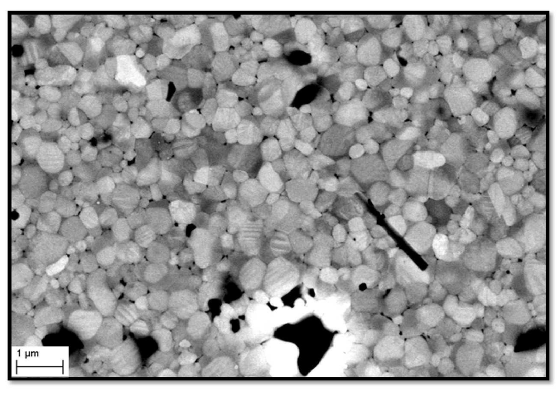

## Multilayer Ceramic Capacitor Characterization

Floating electrode design reduces mechanical degradation associated with thermal cycling

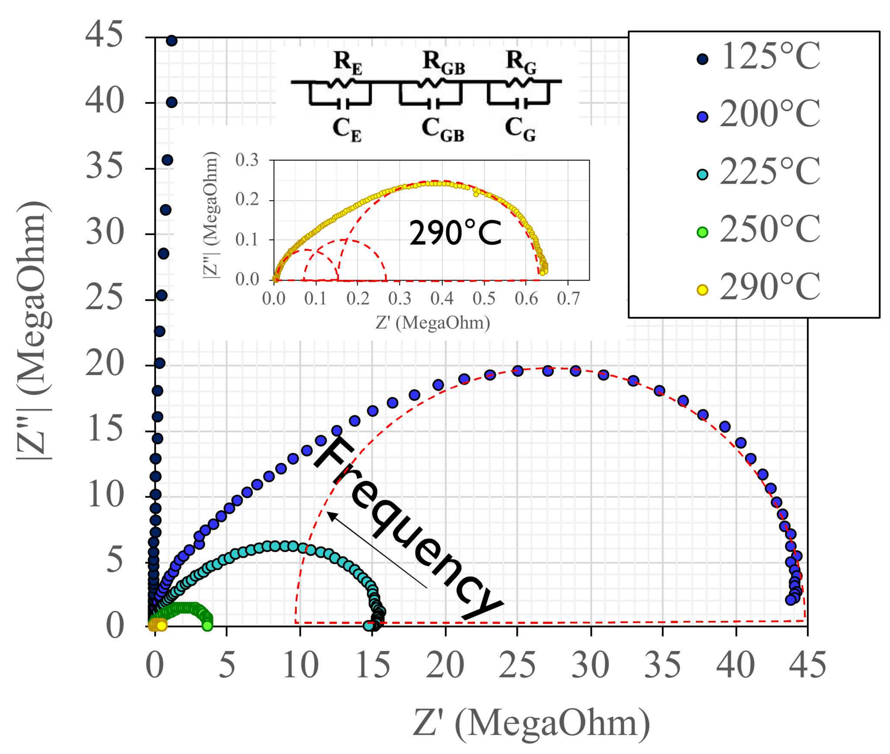


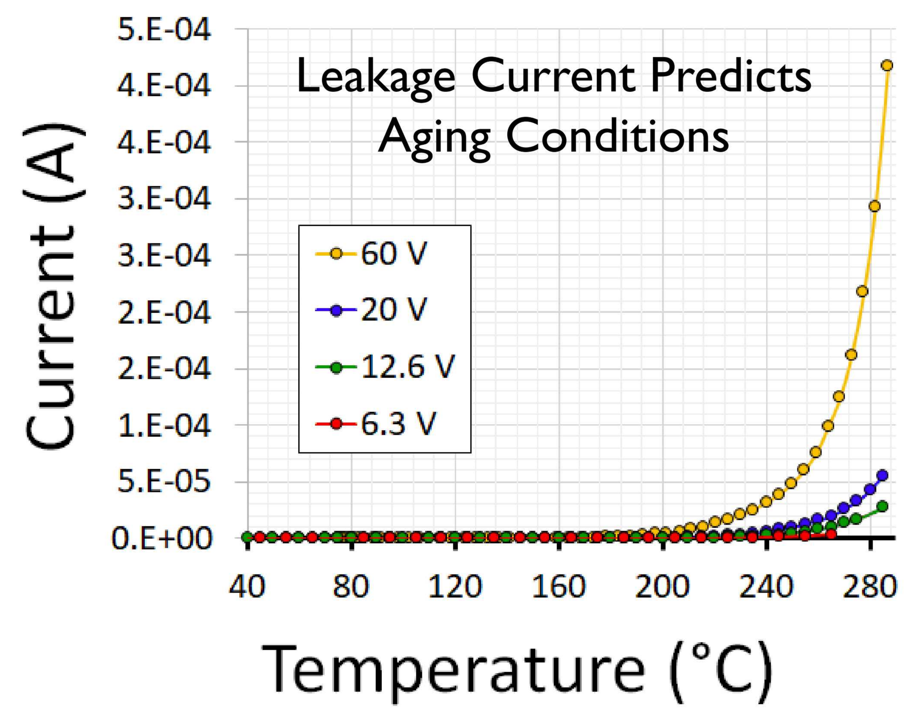



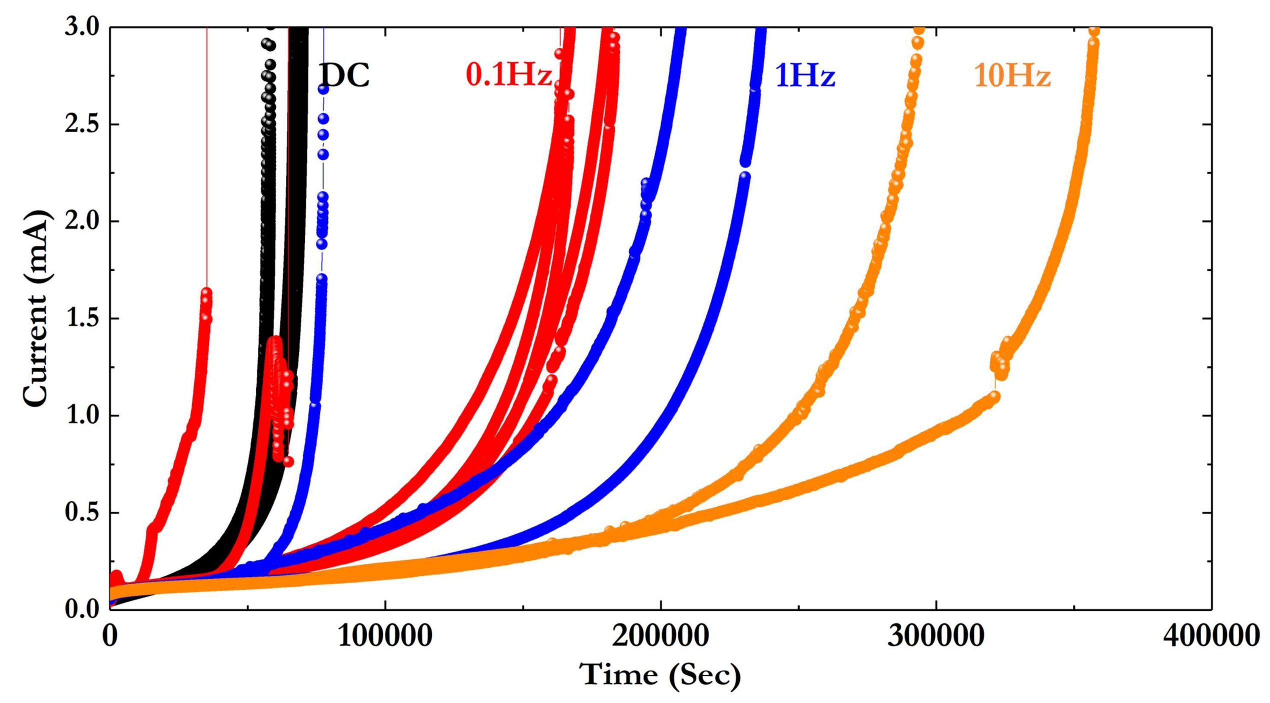

Impedance spectroscopy reveals multiple RC circuit elements




## DC vs AC Aging at 255°C




### Extension of lifetime in AC conditions




Bipolar switching at ~10x the rated voltage and 125°C above the rated temperature can increase the time to failure.

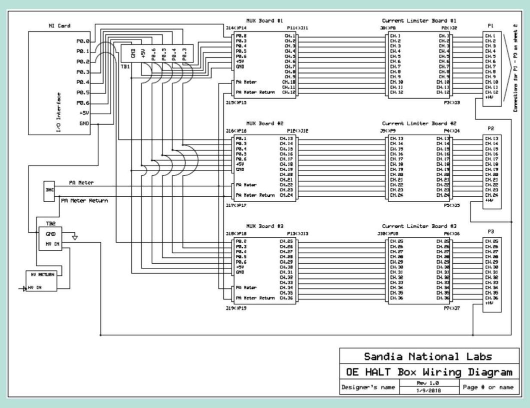
Open Questions:

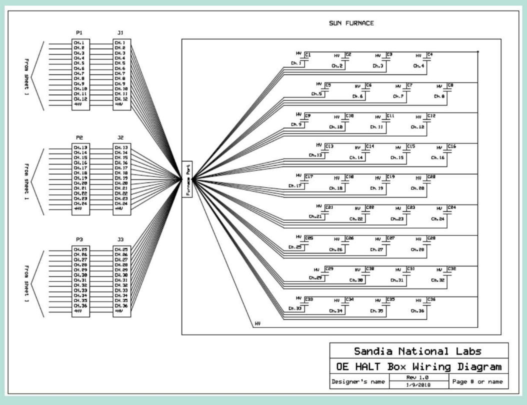
- How does temperature affect this process? (a.k.a. If we decrease temperature can we get extended lifetime at lower frequencies?)
- What opportunities or challenges are there with a 'AC' version of a DC-link capacitor from a electrical engineering perspective?
- What is the distribution of oxygen vaccancies in the microstructure after AC failure?
- How does the AC extension of lifetime relate to grain size?
- Can this be extended to systems where lifetime solutions are needed – e.g. BZT-BT and other high temperature dielectrics

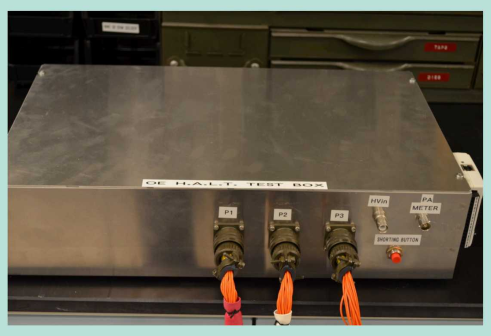
## DC Degradation Study Requires HALT System

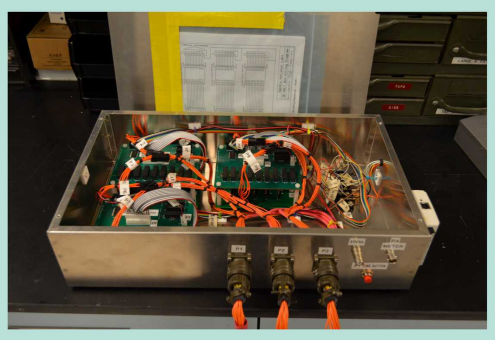
- Statistically relevant sample sets are required to study dielectric degradation
- HALT systems are typically custom built by user

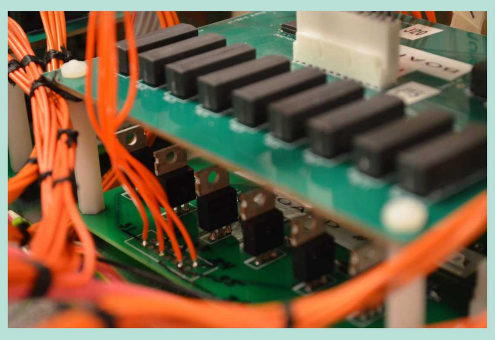
Sandia designed a 1000V 350°C+ HALT tester











Circuits are built and integrated with National Instruments control DAC

## Conclusions

1) AC degradation occurs more slowly than DC degradation
2) AC degradation likely tied to oxygen vacancy migration and proceeds via oxygen diffusion
3) Statistics are required to determine the impact to MLCC lifetimes

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