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Leakage Currents in MLCCs Under Gamma Irradiation

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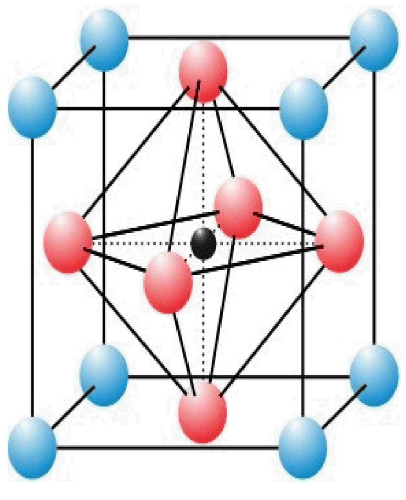
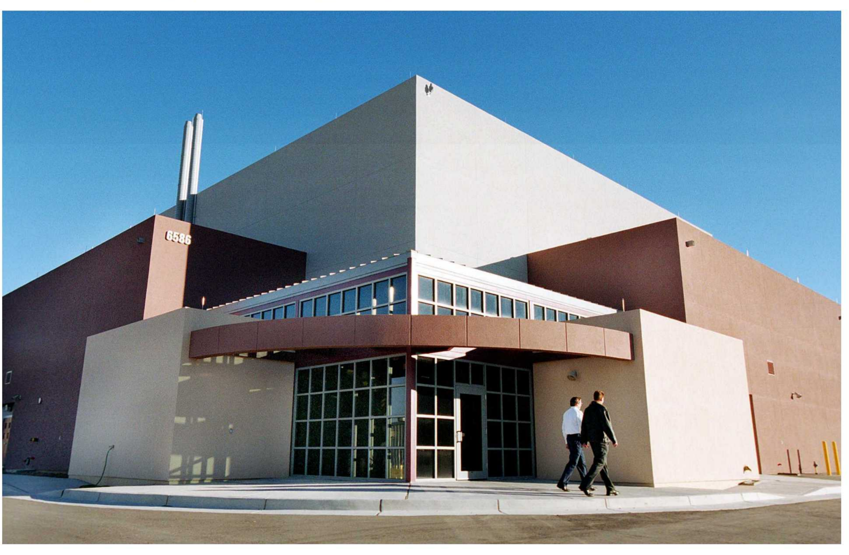
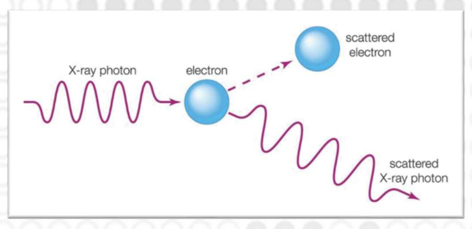




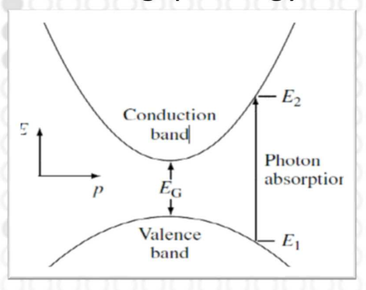
Discharge of Capacitors under Gamma Irradiation

Or: Under gamma, everything is a photoconductor

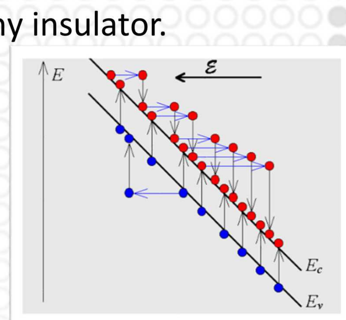
- Photons from radioactive sources (gamma rays) have very large energies (often >1MeV), well above the band gap energy of any insulator.



Compton Scattering

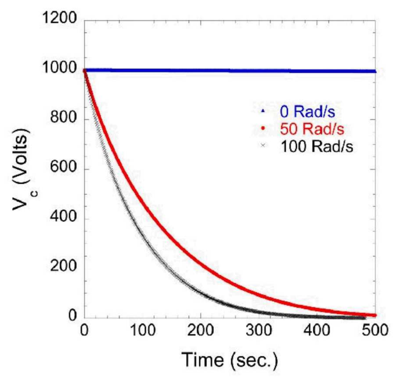


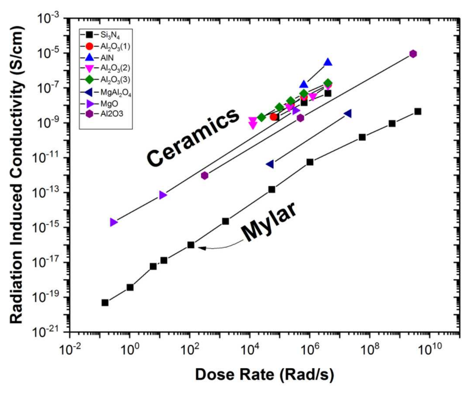
Photoelectric Effect



Impact Ionization

- These free charge carriers reduce the insulation resistance of the dielectric. This causes charge loss and voltage droop while under irradiation

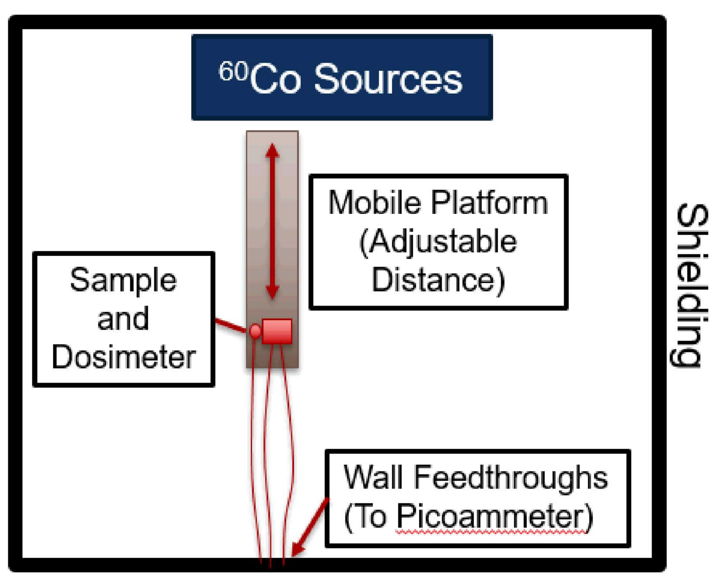




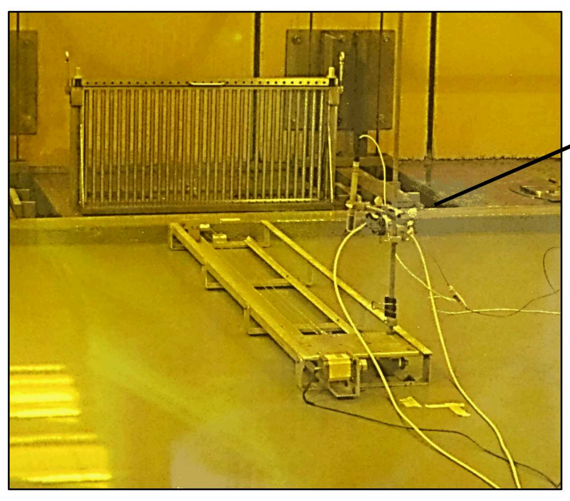
- Decrease in capacitor voltage over time under gamma irradiation.
- Ceramics show orders of magnitude higher radiation-induced conductivity than polymeric dielectrics [1][2]
- Minimization of this effect from a materials and device standpoint is helpful in the design of electronics resistant to radiation upset ('Rad-hard' devices).

Leakage Current Measurements under ^{60}Co Gamma Irradiation

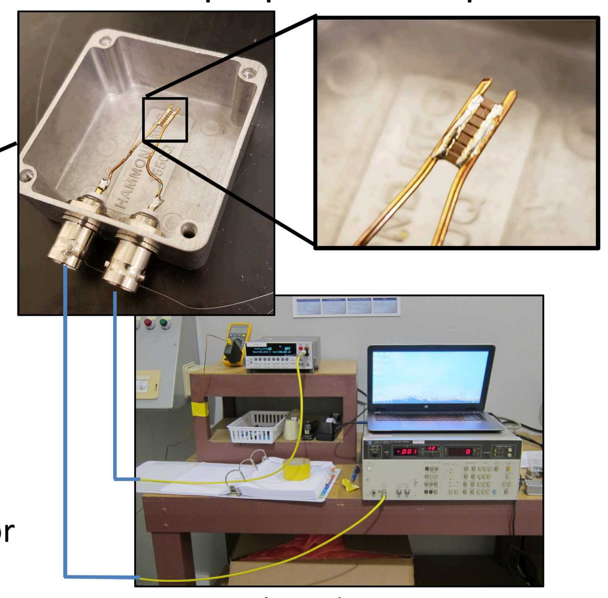
Gamma Irradiation Facility



- Multiple ^{60}Co sources raised into chamber, providing 1.17MeV and 1.33MeV gamma rays
- 0.2 to 450 Rad/s, depending on placement in chamber (3000 Rad/s available at facility)
- Wall feedthroughs available for connection of electrical test equipment
- Recent transition to user facility – external proposals accepted



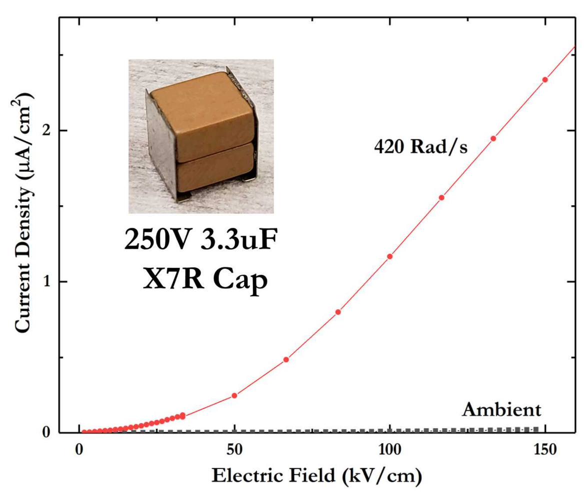
Mobile platform used to pinpoint and/or adjust dose rate

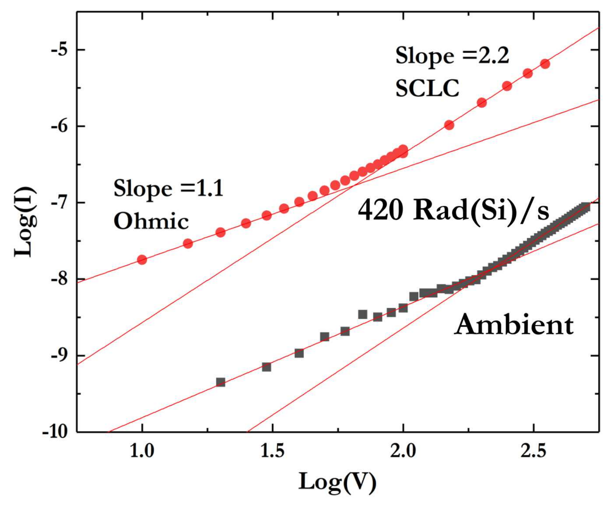


HV Supply and Picoammeter for Leakage Current Testing

E-Field Dependence of Leakage Currents

- To minimize radiation induced leakage currents, we must understand their mechanism. I-V curves can give hints into the mechanism.





- Current magnitude increases by >2 orders of magnitude under 420 Rad(Si)/s
- Log-Log plots show 'Ohmic' regimes at very low fields (Slope~1), and Space Charge Limited Current (SCLC) regime at higher fields (Slope~2-2.4)
- Shift in Ohmic to SCLC transition to lower fields possibly due to decreased internal field due to space charge buildup

'Ohmic'
(Linear)

↓ ~20kV/cm

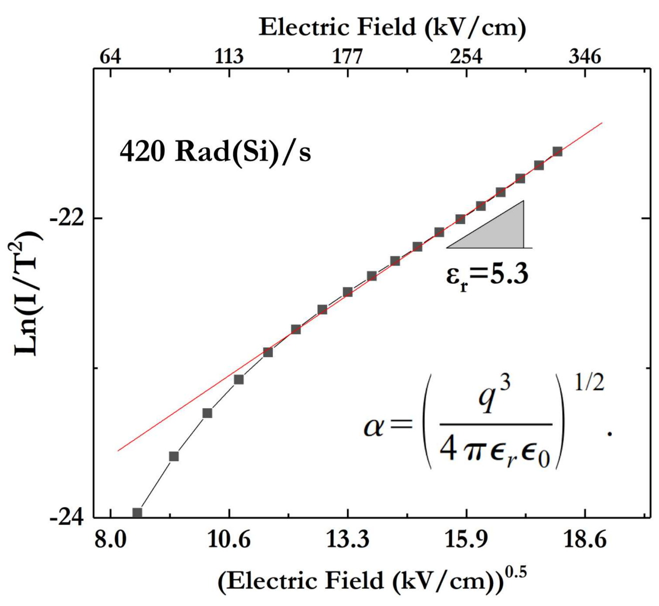
Space Charge Limited Currents

$$J = \frac{9}{8}\varepsilon\theta\mu\frac{V^{2+n}}{L^3}$$

↓ ~100kV/cm

Schottky Barrier Limited

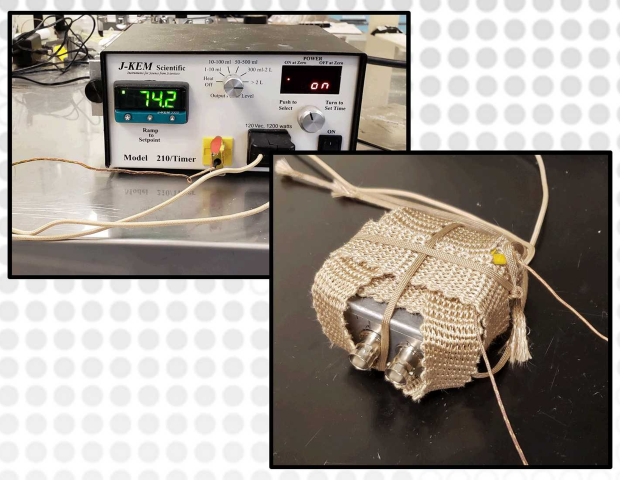
$$J = A^*T^2\exp\left(\frac{\varphi_b - \alpha\sqrt{E}}{kT}\right)$$



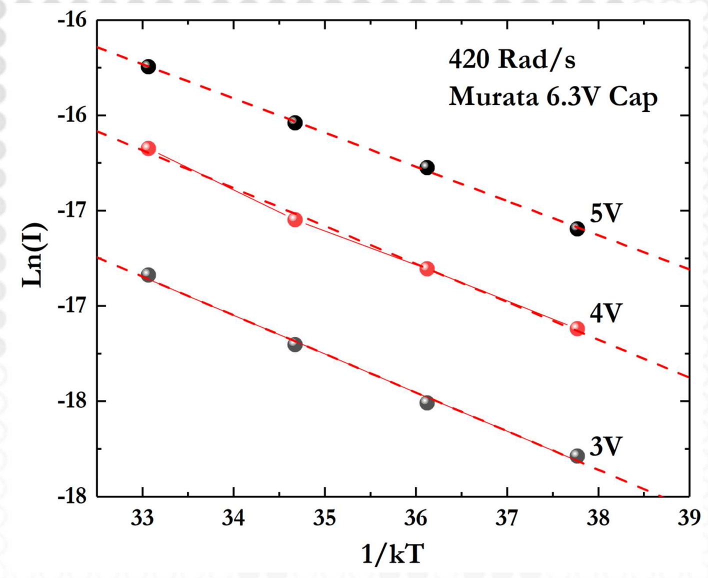
$$\alpha = \left(\frac{q^3}{4\pi\epsilon_r\epsilon_0}\right)^{1/2}$$

- Schottky barrier limits conductivity only at very high fields (~2-3x rated voltage of MLCC)
- No mechanistic changes found between non-radiation and radiation conditions - only larger current magnitudes

Temperature Dependence Of Leakage Currents

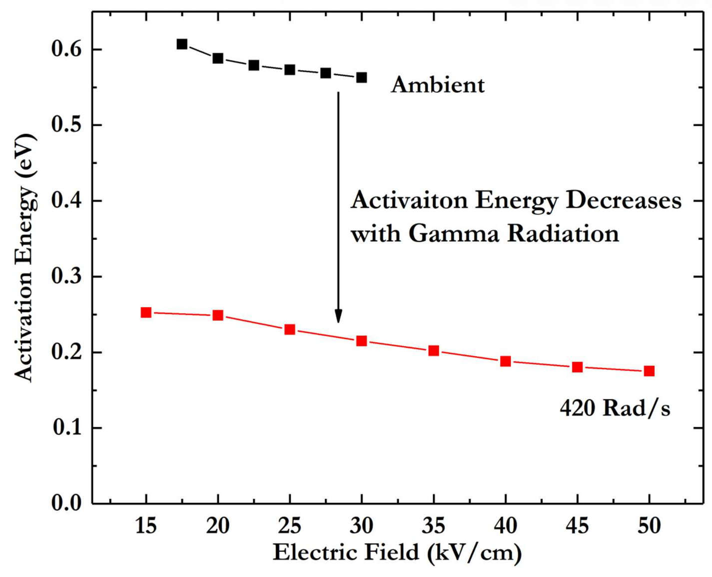


- Heating inside radiation chamber is a challenge due to high radiation dose levels
  - Destruction of electronics
  - AC power causes noise in cabling
- Rad-hard oven with external DC power supply located outside GIF chamber has been fabricated for future use.



- Temperature dependence measured in SCLC voltage regime
- Temperature dependence was found to be Arrhenius

- E-field dependence of conduction found
  - Slope too steep to be consistent with Schottky conduction ($\varepsilon_r \sim 0.3$)
  - Likely associated with lowering potential for escape of trapped charge
- Activation energy for conduction decreases substantially with radiation
  - Filling of traps leads to decreased donor ionization energy



Temperature dependence of leakage currents seem to be consistent with SCLC model

Effect of Dopants/Traps

- As leakage currents seem to be controlled by SCLC, engineering of traps may be beneficial to minimization of radiation-induced leakage currents
  - Initial studies of doping bulk samples have been conducted

30% Reduction in RIC via Ce_{Ti}^{x} substitution

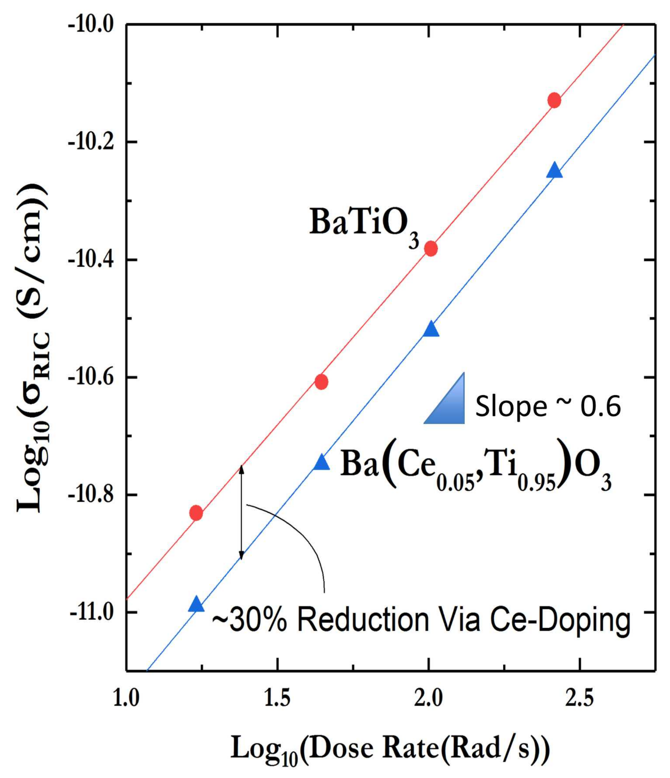
- Initial dopant used as Ce due to it's mid-state gap level
  - Distribution of f-orbital traps throughout material
- Ce_{Ti}^{x} is neutral
  - Increased reduction of RIC expected for positively charged deep traps
- More comprehensive studies of common X7R dopants will be of use

- Experiments fit well with photoconductivity literature

$$RIC = (Dose\ Rate)^x$$

x measured here= ~0.59-0.62
x from photoconduction = ~0.6 [1]

- Assumption of photoconduction model holds up



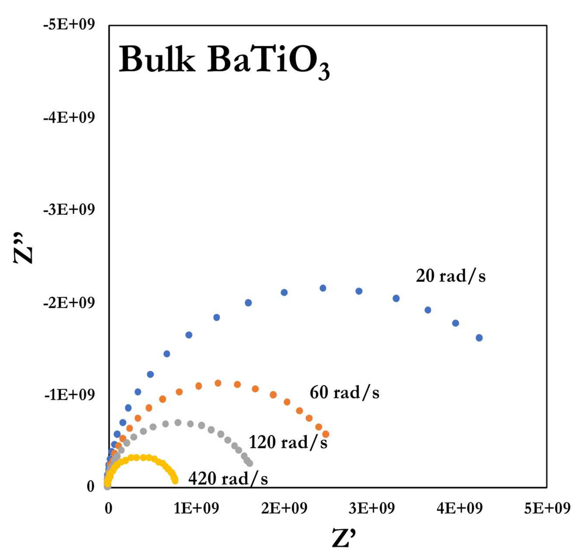
Gamma dose-rate dependence of conductivity for $BaTiO_3$ and $Ce{:}BaTiO_3$

Conclusions

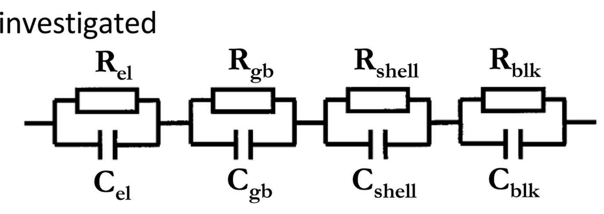
- Radiation-induced conductivity in MLCC's seems to be limited by space charge limited currents under common working fields
- Schottky-limited conduction appears, but is found only at fields greater than the voltage ratings of capacitors
- Activation energy dependence on temperature, radiation, and field, agree with SCLC model
- Comparisons between undoped and doped $BaTiO_3$ in bulk samples agree that increasing trap density decreases radiation induced conductivity
- Further studies are necessary on different dopants as well as doing additional work on MLCC's such as impedance spec under irradiation.

Future Work

In-situ Impedance Spectroscopy Under Irradiation



- Impedance spectroscopy on bulk BTO shows clear dose-rate dependence
- Rad-hard furnaces built to measure MLCC's (RC to low at room temp)
- Effect of gamma rays on electrode-ceramic interface, bulk conduction, etc. can be investigated



Which components are a function of dose rate??

References

[1] J. Gillespie, M.S. Thesis, Utah State University (2013)
[2] R.H. Goulding et al., J. App. Phys. 79, 2920 (1996)

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