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Reduction of Radiation Induced Conductivity in $BaTiO_3$

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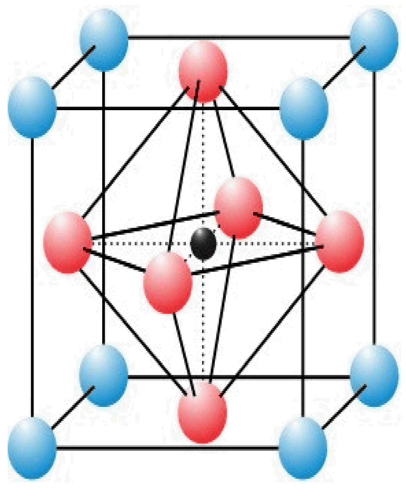
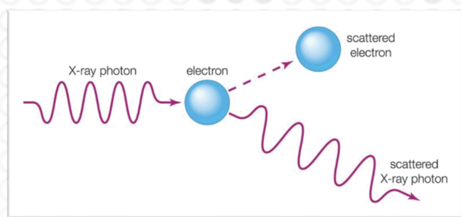


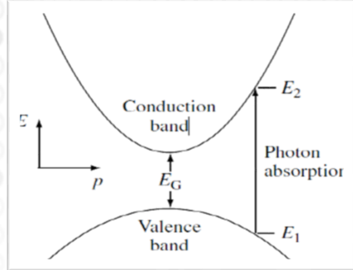

Discharge of Capacitors under Gamma Irradiation

Or: Under gamma, everything's a photoconductor

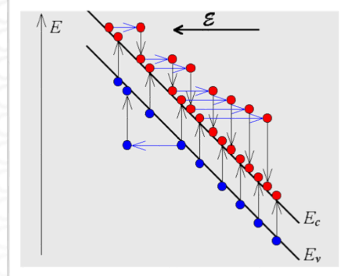
- Photons from radioactive sources (gamma rays) have very large energies (often >1MeV), well above the band gap energy of any insulator.
- Absorption of gamma rays results in highly energetic electrons, resulting in impact ionization and therefore a large number of free electrons.



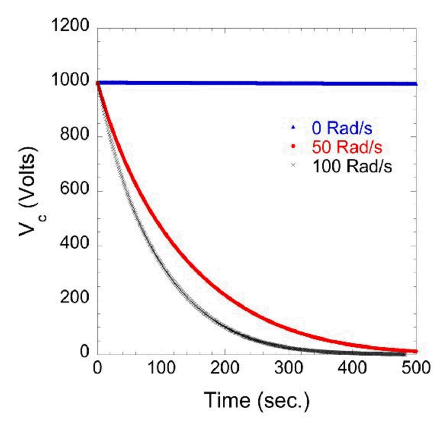
Compton Scattering



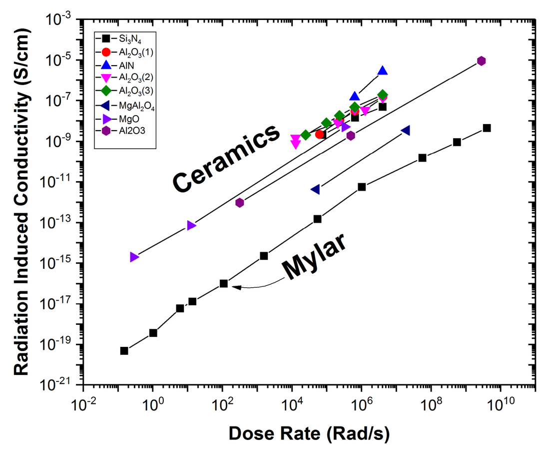
Photoelectric Effect


Impact Ionization

- Free charge carriers reduce the insulation resistance of the dielectric, causing charge loss.

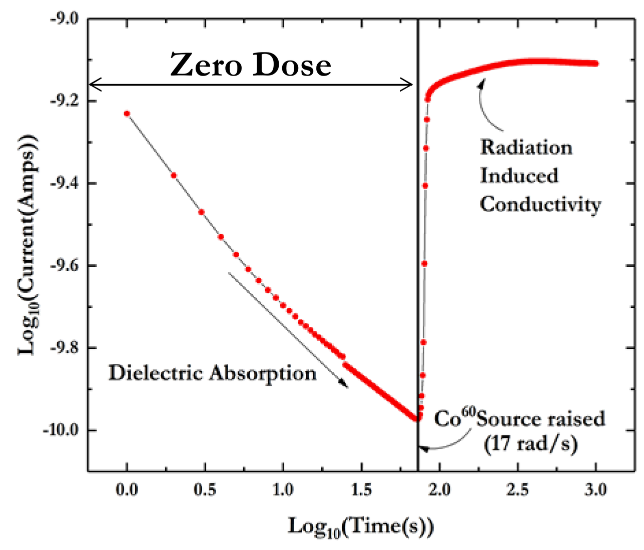


- Decrease in capacitor voltage over time under gamma irradiation.



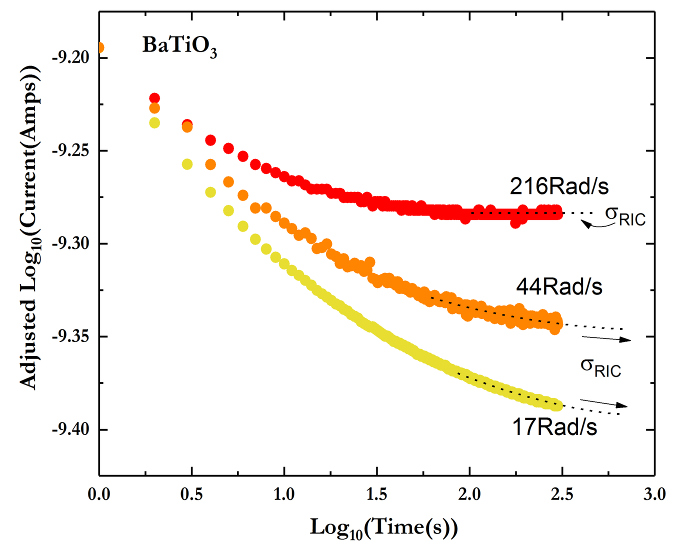
- Ceramics show orders of magnitude higher radiation-induced conductivity than polymeric dielectrics [1][2]

Results and Discussion



Current vs Time plot (log-log) of a $BaTiO_3$ sample as gamma irradiation is initiated

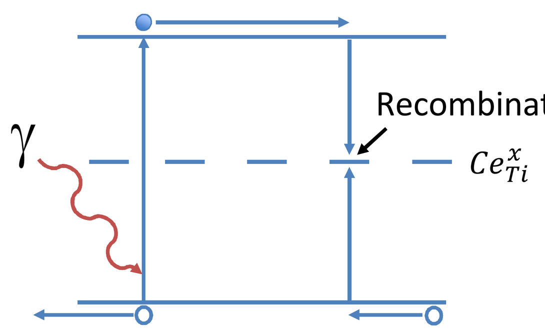
- Under zero dose-rate only the dielectric absorption current is measured
  - Follows Curie-Von Schweidler, as expected.
- Exposure to ^{60}Co radiation increases leakage current



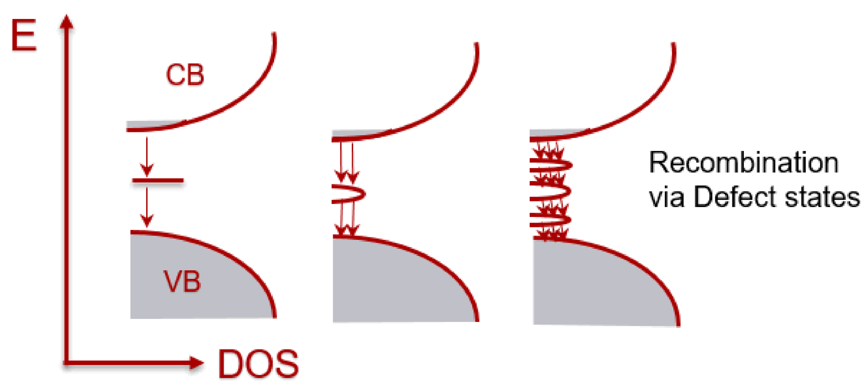
Current vs Time plot (log-log) of $BaTiO_3$ under different gamma dose rates. Adjusted so current at t=0 is equal.

- Dielectric absorption outweighs RIC at short times under lower does rates (e.g. 17rad/s(left))
- Significant time (~5+min) necessary to measure DC leakage (RIC).
- Need higher dose rates, lower energies (increased absorption), higher temperatures or voltages to allow for impedance spectroscopy.

Radiation Induced Conductivity Reduction Strategy



- Assume photoconductivity physics adequately explains conductivity under gamma irradiation
- Goal: Minimize mobility-lifetime product
- Decrease lifetime by adding deep traps



- Recombination rate should depend on many factors:
  - Photocarrier concentration (Does Rate)
  - Trap concentration
  - Capture Cross Section (trap charge, temperature)
  - Acceptor-Donor distances
  - Etc…

Experiments fit well with photoconductivity literature

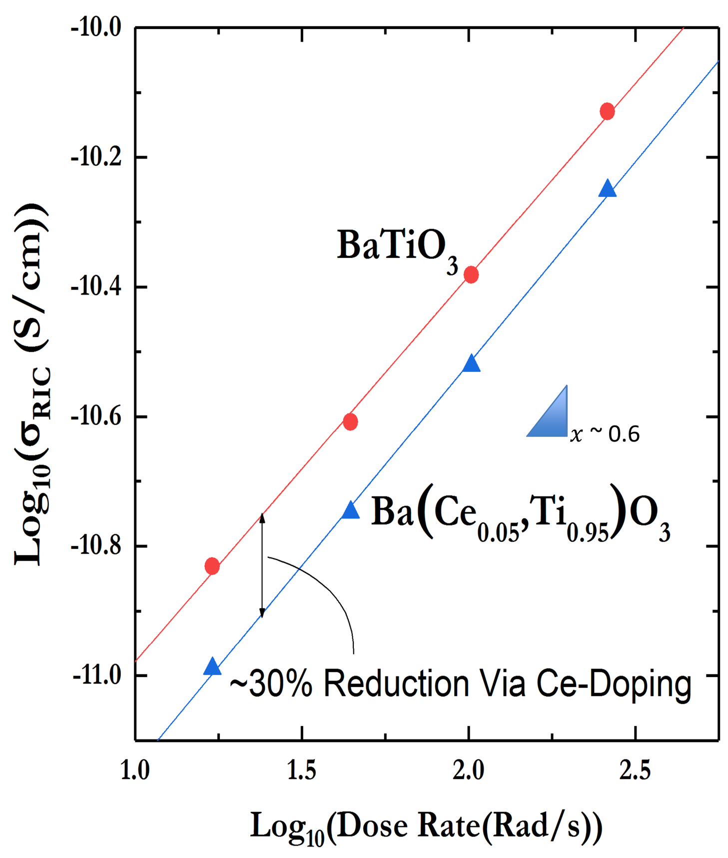
$$RIC = (Dose\ Rate)^x$$

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

- Assumption of photoconduction model holds up

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

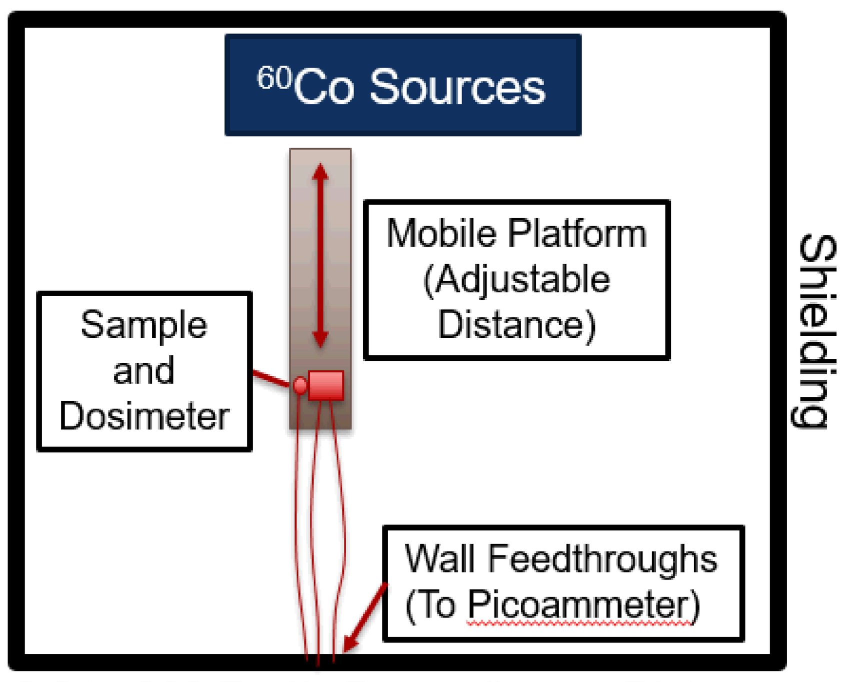
- Thought of as distributing f-orbital traps throughout material
- Ce_{Ti}^{x} is neutral
  - Increased reduction of RIC expected for positively charged deep traps



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

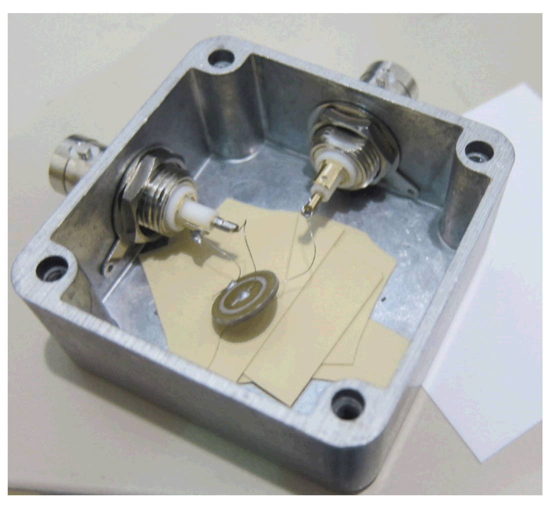
Measurement of Radiation-Induced Conductivity

Gamma Irradiation Facility

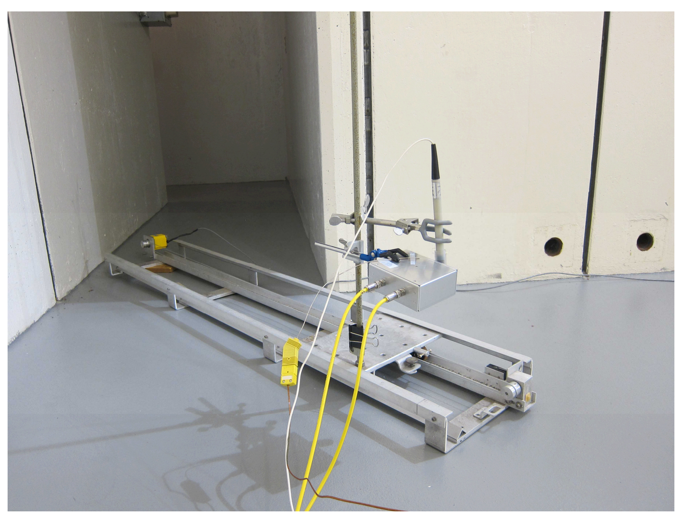


~0.2 to 300 Rad/s Depending on Distance

- Gamma produced via ^{60}Co
- Sources raised into {}x{}m room
- Dose rate modified my adjusting distance from source and number of sources
- 0.2 to 300 rad/s in single chamber
- Feedthroughs available to connection of electrical equipment for in-situ testing
- Up to 3 krad/s available in other arrangements
- Recent transition to user facility – external proposals accepted.



- Guard electrode employed to block surface conductivity contributions
- Radiation-induced currents in cables constitute ~20pA (<1% of signal)



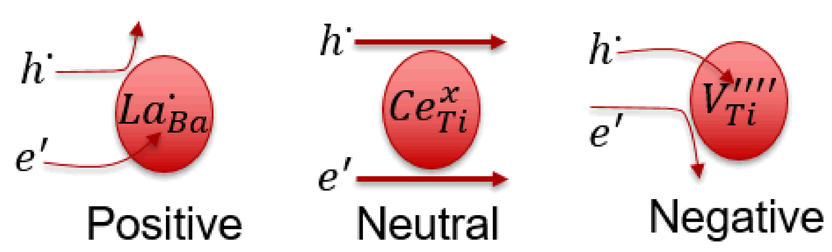
- Mobile platform used to adjust dose rate
- Voltage source and picoammeter used to measure RIC

Conclusions

- Radiation induced conductivity follows similar intensity-dependence at photoconductivity
  - Assumed photoconduction model holds up to initial testing
- Dielectric absorption is a roadblock to measuring RIC at lower dose rates
- Addition of 5 mol% Ce into BTO results in ~30% reduction in radiation induced conductivity
- Detailed analysis of grain/grain boundary/interface effects will require different dose rate/temperature/voltage regimes

Future Work

Different dopants should capture free electrons/holes at different rates (columbic attraction)



- Goal: Investigate effectiveness of Donor and Acceptor dopants in reduction of RIC vs neutral dopants (e.g. f-orbitals from Ce)
  - Understanding effect of individual defects is difficult due to the necessity of ionically compensating defects
  - Investigate in groups: Neutral Dopants, Extrinsically Donors, Extrinsic Acceptors (intrinsically compensated).

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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