Effects of High-Energy Radiation Exposure of the Dielectric and Piezoelectric Response of Relaxor-Ferroelectric Single Crystals

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Introduction

- Ferroelectrics with large piezoelectric and dielectric response are important for numerous applications:
  - Multilayer ceramic capacitors
  - Actuators and high-precision micropositioners
  - Environmental energy harvesters
  - Random access memories[1]
- Piezoelectric ultrasound transducers and probes[2] are instrumental in:
  - Non-destructive structural evaluation
  - Monitoring of light water nuclear power plants
  - Monitoring of conditions in spent fuel repositories[2]
  - Advanced reactor designs[3]
- Especially of interest are autonomous microsystems operating in locations with high radiation exposure.

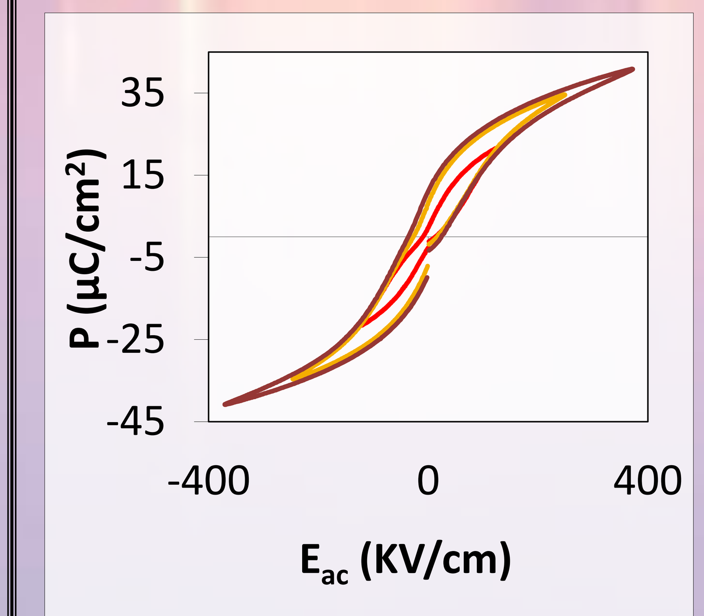
Research Objective: Investigate effects of irradiation on the dielectric and piezoelectric response of

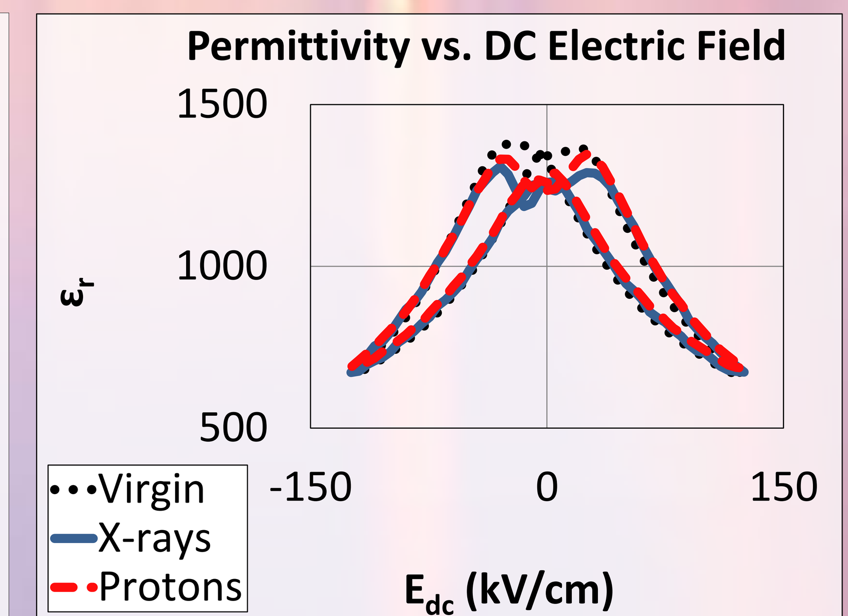
- $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PMN–PT)
- [001] [011] and [111] orientation
- 0.5 mm thick

single crystals as a function of irradiation source and energy.

Background

- Previous study on $Pb(Zr_xTi_{1-x})O_3$ (PZT) thin films showed up to a 20% radiation induced piezoelectric response degradation.
- Characterization suggests a reduction of the extrinsic contributions to the response by the increased pinning of the domain walls by radiation-induced point defects.[4]





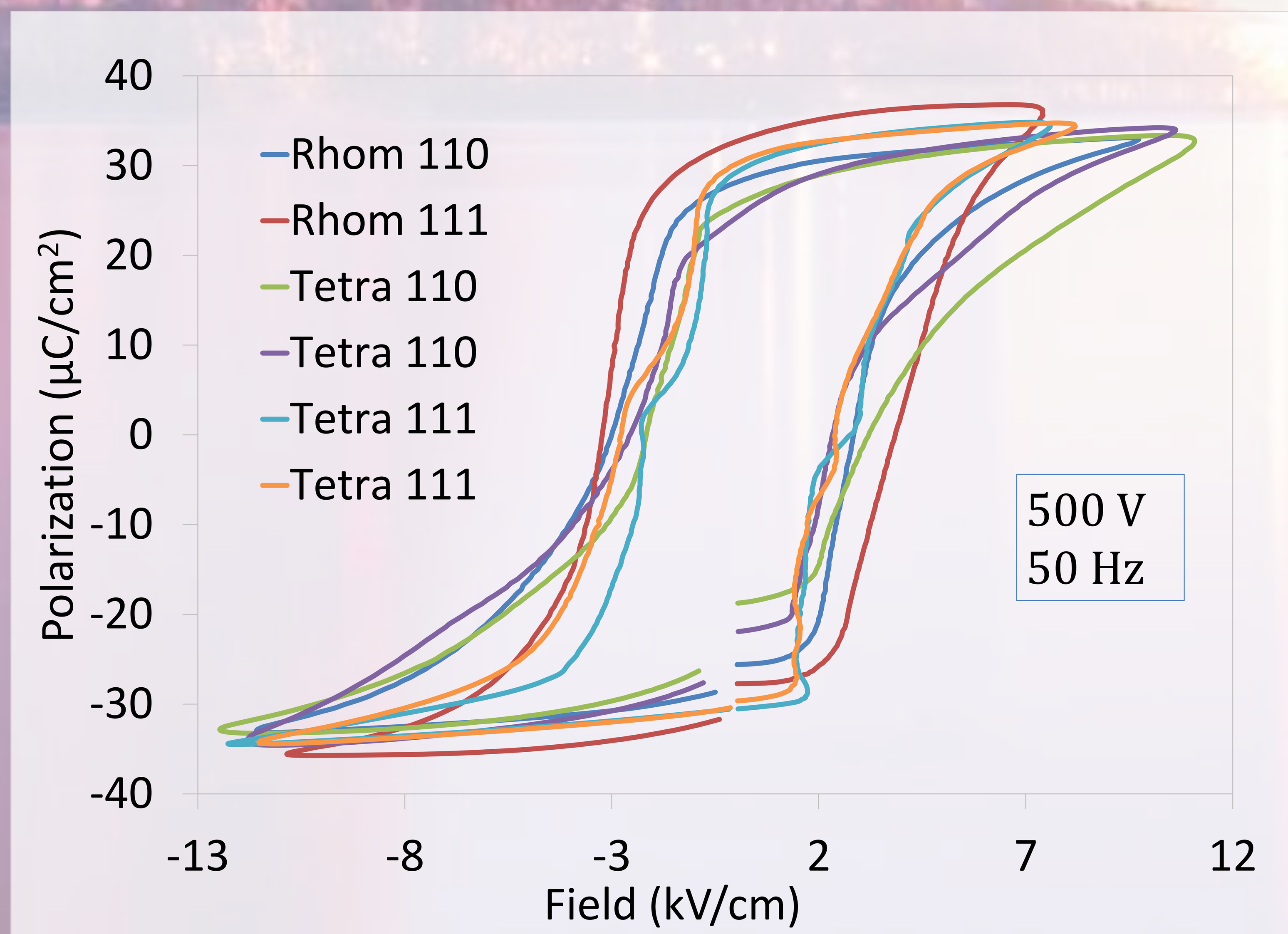
- [001]-poled lead titanate-based relaxor-ferroelectric single crystals were chosen for the study because:
  - higher piezoelectric response[5,6]
  - lower surface to volume ratio
  - lack of grain boundaries

Low Field Dielectric Response

	Orientation	Capacitance (nF)	Dissipation factor (%)	Permittivity
Tetragonal 35-36% PT	001	1.88	0.86	2912
	001	1.73	1.2	2671
	110	2.42	0.7	3724
	110	2.43	0.7	3739
	111	2.43	0.6	3739
	111	1.92	0.6	2954
Rhombohedral 28% PT	001	1.24	0.4	1921
	001	1.27	0.4	1944
	110	1.37	1	2069
	110	1.34	1	2064
	111	1.3	0.8	2002
	111	1.3	0.6	2000

- Low field dielectric permittivity has been characterized prior to radiation.

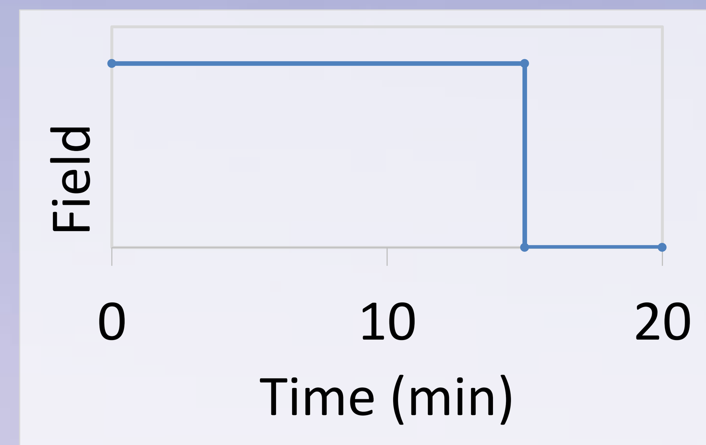
High-Field Dielectric Response



- The coercive field and voltage found was E_c = 2.78 KV/cm, and V_c = 139 V respectively.

Poling Study

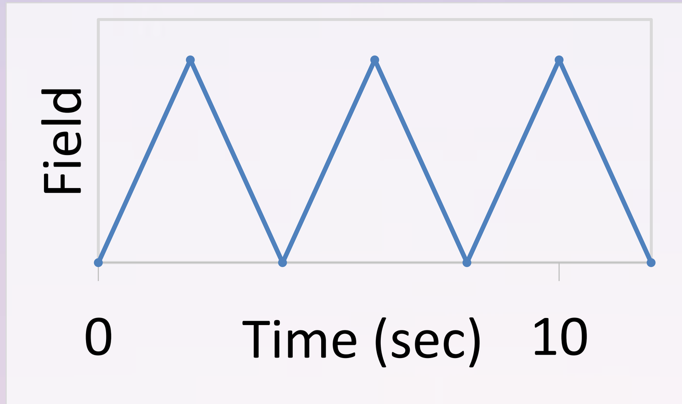
DC Field Poling: applies a large bias for a long duration allowing the defects to realign themselves with the domain walls.



Vc	(V)	(KV/cm)
1xVc	100	2
2xVc	250	5
3xVc	400	8
4xVc	500	10

- Temperatures: 25°C & 125°C. Duration: 15 min.
- Cool below transition temperature with the stable field.
- Measure $d_{33,f}$ 1min, 60min, 120 min after each run.

Unipolar Fast Pulsed Poling: applies large bias pulses for a short duration which dislodges the domain walls from the pinning centers.



- Duration: 10sec
- Frequency 55Hz
- Voltages: 150V to 500 V at steps of 50 V.
- Measure d33

- Raise temperature to 175°C to disorient dipoles.
- Radiation can disorder current pinning sites and create new ones, limiting domain wall movement.
- The best method is expected to be pulsed poling because it reduces the correlation between the location of pinning sites and domain walls.

Future Work

- Optimize the capacitance-voltage, dielectric and piezoelectric responses as a function of the poling profile.
- Irradiate samples with X-rays and protons up to 5 Mrads.
- Repeat all measurements after irradiation to avoid recovery from the treatment.

References

[1] Long-Term Nuclear Technology Research and Development Plan, U.S. Department of Energy, Office of Nuclear Energy, http://energy.gov/ne/downloads/report-long-term-nuclear-technology-research-and-development-plan.

[2] V. Giurgiutiu and A. Mendez Torres, "Opportunities and Challenges for Structural Health Monitoring of Radioactive Waste Systems and Structures," in 15th ASME Int. Conf. on Environmental Remediation and Radioactive Waste Management, Brussels, Belgium, Sept. 8-12, 2013.

[3] R. Kažys, A. Voleišis, R. Šliteris, B. Voleišienė, L. Mažeika, P.H. Kupschus, H.A. Abderrahim, IEEE Sensors Journal, 6, 5 (2006) 1134-1143.

[4] Bastani, Y., Cortes-Pena, A.Y. et al. "Effects of high energy x ray and proton irradiation on lead zirconate titanate thin films' dielectric and piezoelectric response." *Applied Physics Letters* 102.19 (2013): 192906-192906.A

[5] Kwon, Seongtae, et al. "High Strain, <001> Textured 0.675 Pb $(Mg_{1/3}Nb_{2/3})$ O_3–0.325$PbTiO_3$ Ceramics: Templated Grain Growth and Piezoelectric Properties." *Journal of the American Ceramic Society* 88.2 (2005): 312-317.

[6] Park, Seung-Eek, and Thomas R. Shrout. "Ultrahigh strain and piezoelectric behavior in relaxor based ferroelectric single crystals." *Journal of Applied Physics* 82 (1997): 1804.