Center for Energy Efficient Electronics Science
A National Science Foundation Science & Technology Center

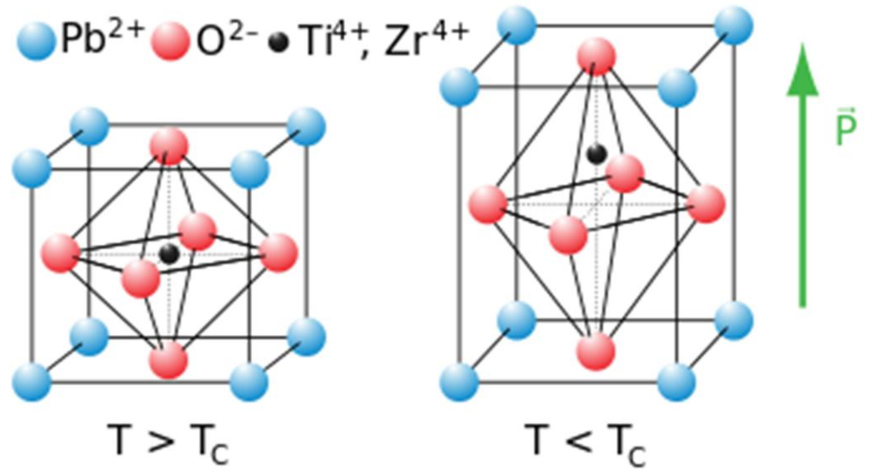
X-Ray Diffraction Characterization of Lead Zirconate Thin Films

Azzedin Jackson[1], Claudy Serrao[2], Sayeef Salahuddin[2]
[1]Purdue University, [2]University of California, Berkeley

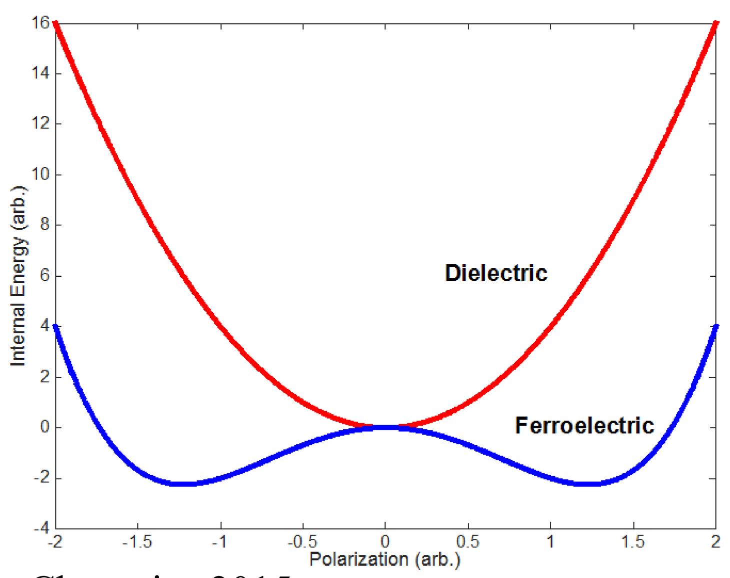
It has been demonstrated that ferroelectric insulators exhibit negative capacitance, which could lead to the operation of FETs at lower voltages. However, while the ferroelectric capacitor reduces the total amount of power needed to operate the FET, some of the power used in the FET operation is necessary to switch off the ferroelectric insulating layer. One approach to removing the need for this extra voltage is to use an antiferroelectric insulating layer. To begin to better understand antiferroelectrics for this potential application, lead zirconate (PZO), an antiferroelectric, was grown on different oxide substrates with conductive strontium ruthenate (SRO) as a bottom electrode and examined via X-Ray Diffraction (XRD). We found that the PZO-SRO grows well on STO, DSO, GSO, and that the c lattice parameter of the PZO layer decreases as substrate lattice parameter increases.

Background

Ferroelectric materials have a spontaneous polarization that can be changed by an applied electric field

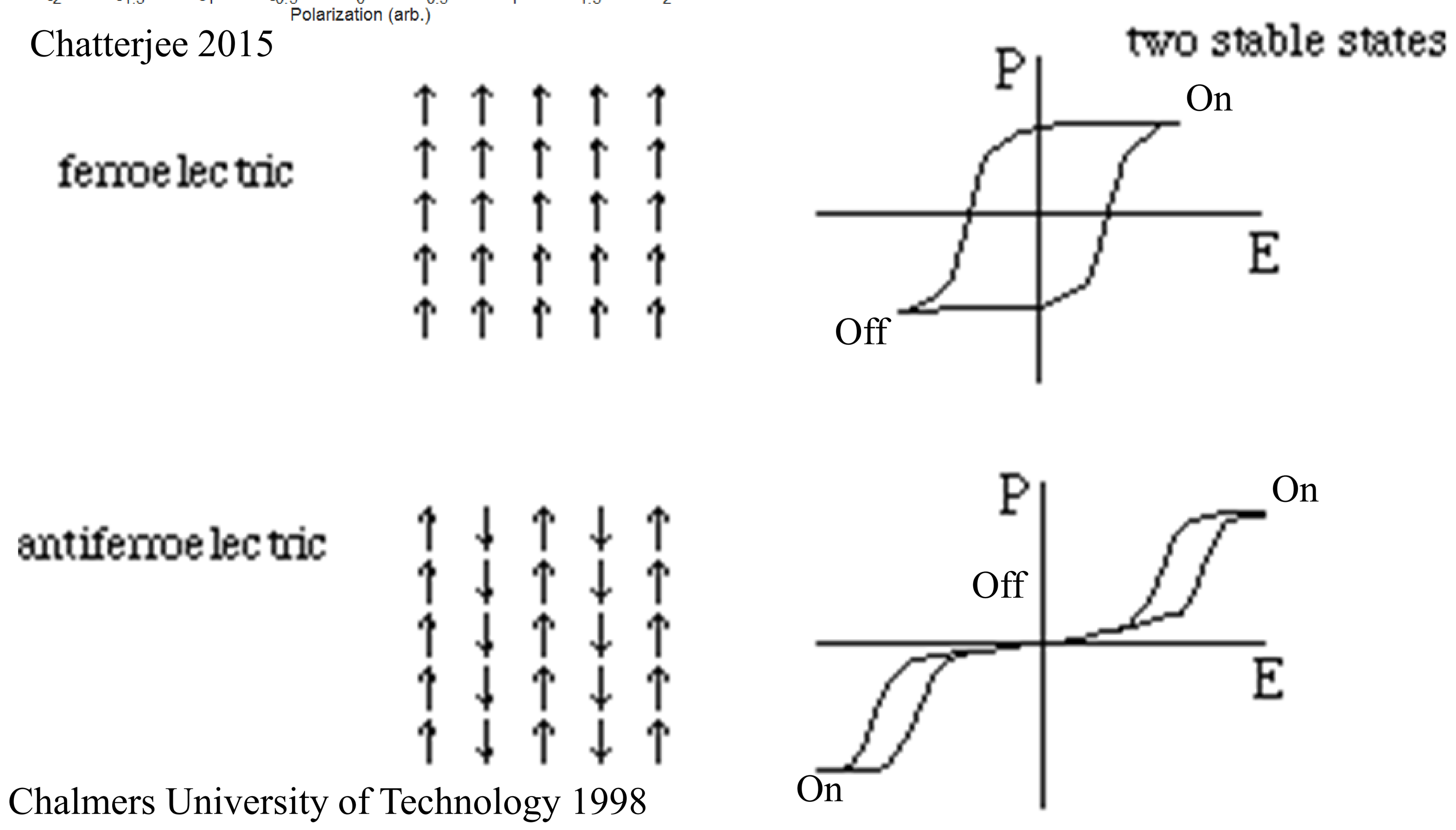


Wikipedia 2006



Chatterjee 2015

Ferroelectric insulators have exhibited negative capacitance. In a FET, this acts like a voltage amplifier for our gate voltage, lowing the subthreshold swing.



Chalmers University of Technology 1998

An Antiferroelectric material has a spontaneous electrical polarization, but the neighboring polarization directions within the crystal are antiparallel. Antiferroelectric materials can transform into a metastable ferroelectric when energy is applied.

One benefit for using antiferroelectrics for our device over ferroelectrics is that ferroelectrics need energy to switch into the off state, while antiferroelectrics do not.

Contact Information
azzedinr@outlook.com

Support Information
This work was funded by National Science Foundation Award ECCS-0939514.

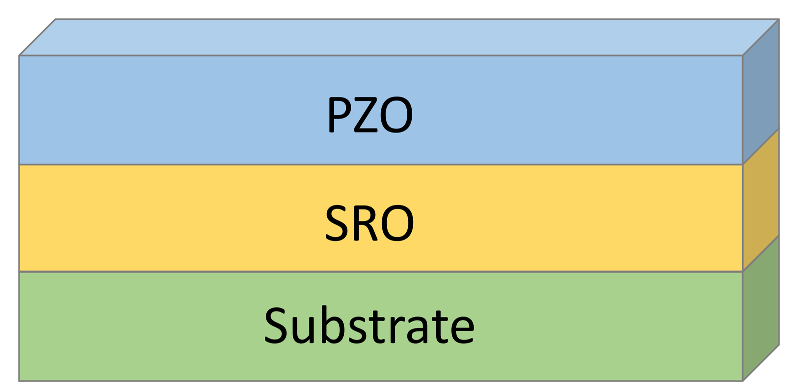
Our Experiment

We studied lead zirconate (PZO), which transitions from an antiferroelectric to a ferroelectric when strain is applied. It has been reported that PZO grown on STO exhibits ferroelectric behavior when the PZO thickness is 22 nm.

We grew PZO on a layer of strontium ruthenate, a conductive material, and four different substrates with different lattice parameters in order to see the effects of epitaxial strain on the PZO and used X Ray Diffraction to characterize the film.

Substrate	Lattice Parameter (Å)
Strontium Titanate ($SrTiO_3$)	3.905
Dysprosium Scandate ($DyScO_3$)	3.94
Gadolinium Scandate ($GdScO_3$)	3.97
Magnesium Oxide (MgO)	4.2111

*pseudocubic lattice parameter



Sample Layers
Note: Not to scale

Each sample was grown using Pulsed Laser Deposition (PLD) and characterized using XRD using a 15-55 degree omega scan

Pulsed Laser Deposition Growth Conditions:

- Substrates were heated to 700 C to grow the SRO and then lowered to 550 C to grow the PZO
- The laser was set to 125 mJ at a frequency of 10 Hz
- The target was ablated for 4 minutes in the 100 mTorr oxygen atmosphere

References

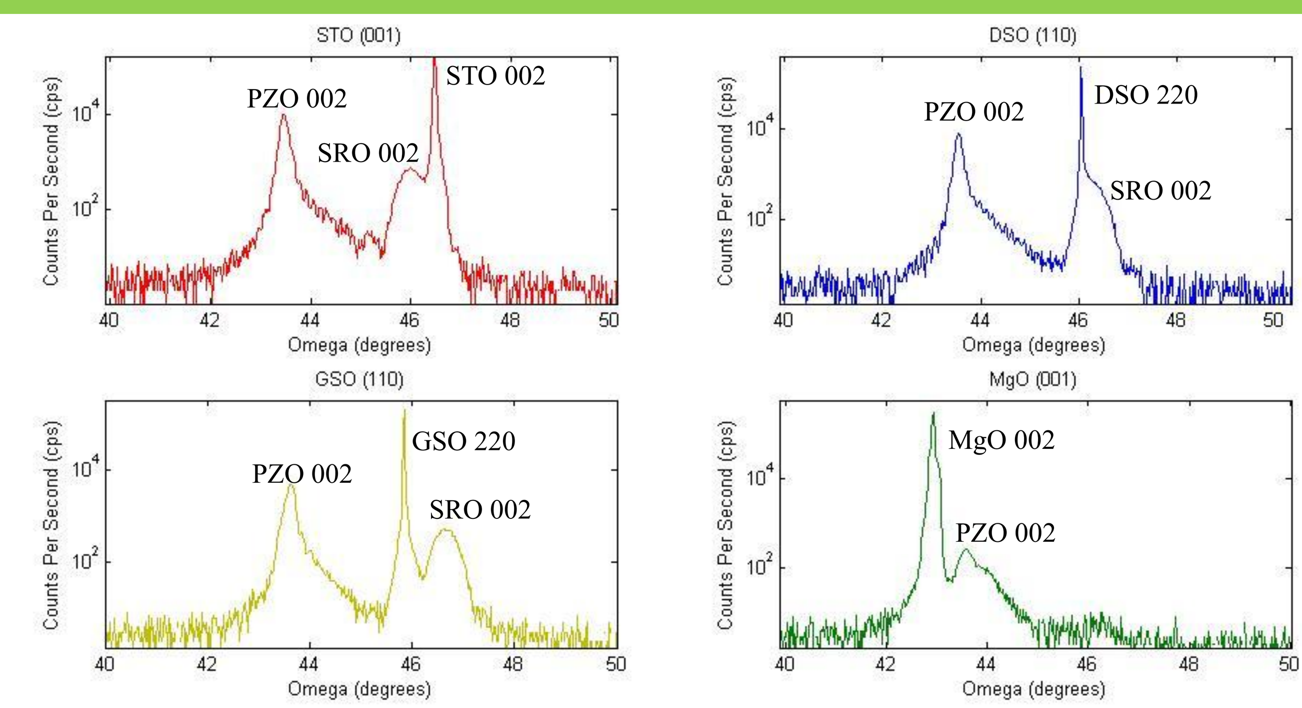
KarinM. Rabe Charles, Charles H. Ahn and Jean-Marc Triscone (Eds.). *Topics in Applied Physics Volume 105 Topics in Applied Physics*. Vol. 105. N.p., 2007. Print.

Kittel, C. "Theory of Antiferroelectric Crystals." *Physical Review* 82.5 (1951): 729–732. Print.

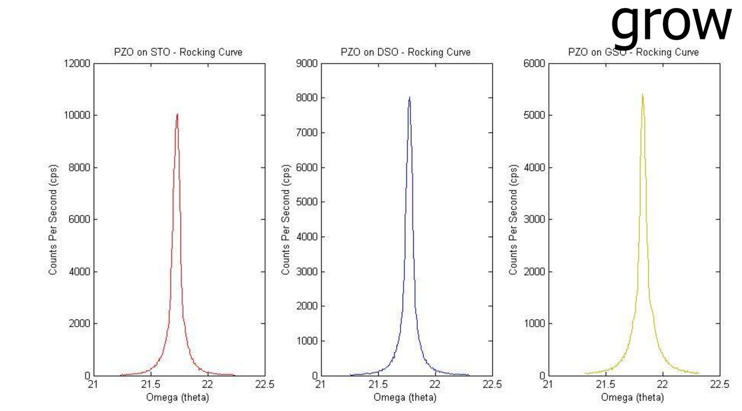
Roy Chaudhuri, Ayan et al. "Epitaxial Strain Stabilization of a Ferroelectric Phase in PbZrO 3 Thin Films." *Physical Review B - Condensed Matter and Materials Physics* 84.5 (2011): 1–8. Web.

Salahuddin, Sayeef, and Supriyo Datta. "Use of Negative Capacitance to Provide Voltage Amplification for Low Power Nanoscale Devices." *Nano Letters* 8 (2008): 405–410. Web.

Results



The labeled peaks of the XRD scan. Note that there is no visible SRO peak for the MgO, meaning that the SRO didn't grow well.



The PZO grown on STO, DSO, and GSO had sharp rocking curves, which means the PZO unit cells were stacked neatly, and the PZO film had a high crystallinity.

Film Substrate	PZO Thickness (nm)	Substrate Lattice parameter (Å)	'c' lattice parameter (Å)
STO	75	3.905	4.16054
DSO	79.9	3.94	4.15322
GSO	62.5	3.97	4.14498

We see our 'c' lattice parameter decreasing as the substrate lattice parameter increases. We also measured the thickness of our samples using Kiesseg fringes.

Conclusions

- A new conductive layer must be found to grow on MgO so we can test the PZO's electrical properties on MgO
- We must grow thinner films to isolate the ferroelectric phase of PZO
- More characterization work must be done in order to see fully understand PZO

Acknowledgements

- Sayeef Salahuddin
- Lea Marlor
- The National Science Foundation
- Korok Chatterjee
- Claudy Serrao
- Samuel Smith