

Magnetolectric coupling using bulk single crystals of PMN-PT and Cobalt thin films

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National Institute of Standards and Technology

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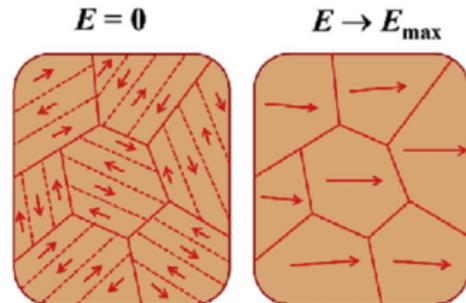
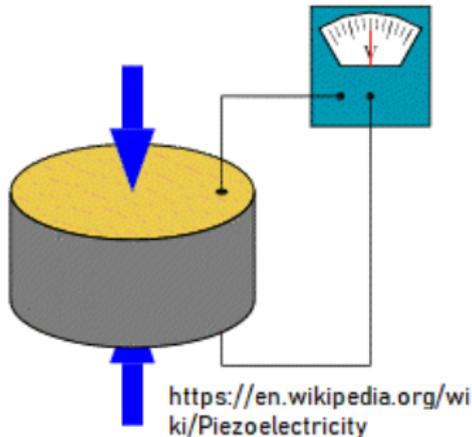
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Mentor: ▶ Shane Lindemann 

Ferroelectric hysteresis and piezoelectricity

Ferroelectric materials contain uniformly-oriented polarization domains.

- ▶ Domains switch polarization with sufficient electric field
- ▶ Crystal structure (polarization) changes

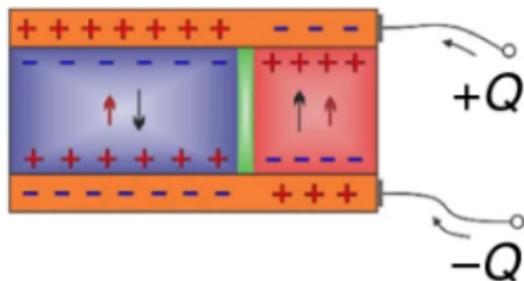


Current Applied Physics 19, 1040–1045 (2019).



Current measurement of ferroelectric switching

- ▶ Ferroelectric crystal is coated with electrodes
- ▶ Current detected as the polarization switches



Communications Physics 2, 22 (2019).

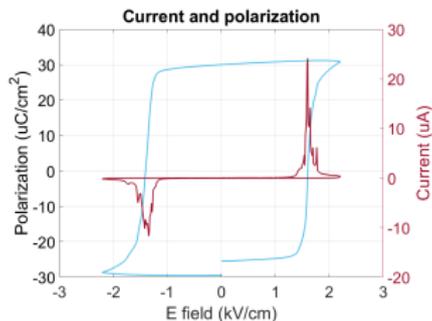
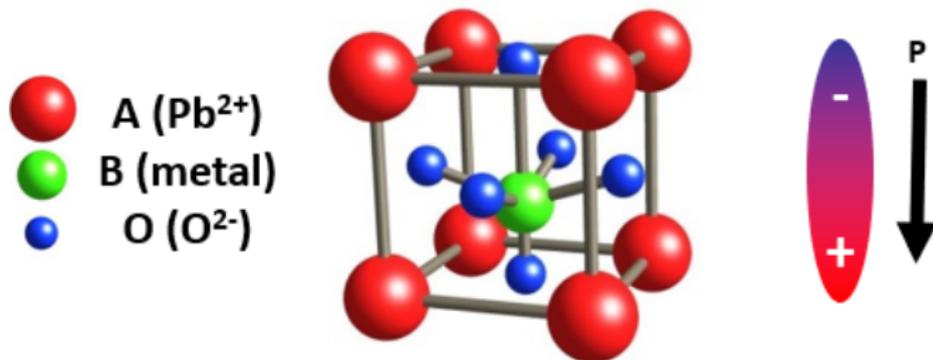


Figure: The capacitor's current is integrated and normalized to find the polarization of the crystal.

PMN-PT, or $[Pb(Mg_{1/3}Nb_{2/3})O_3]_{1-x} - [PbTiO_3]_x$

- ▶ Lead-oxide perovskite crystal with magnesium, niobium, and titanium.

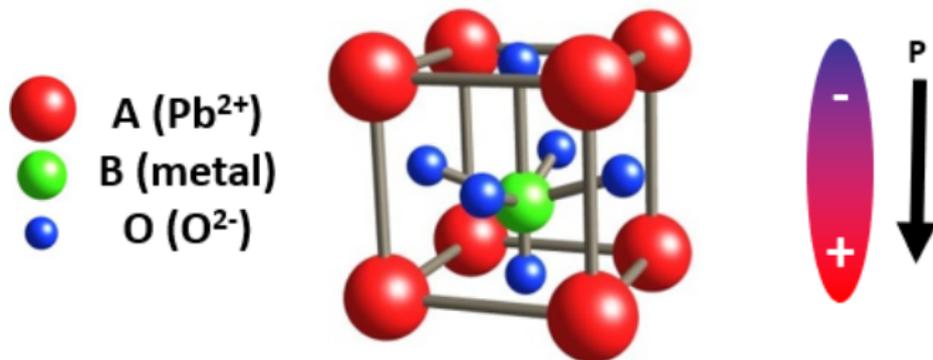


<https://slideplayer.com/slide/9730124/>

Figure: Unit cell of PMN-PT with dielectric polarization

PMN-PT, or $[Pb(Mg_{1/3}Nb_{2/3})O_3]_{1-x} - [PbTiO_3]_x$

- ▶ Lead-oxide perovskite crystal with magnesium, niobium, and titanium.
- ▶ The central atom has a stable polarization state in multiple directions



<https://slideplayer.com/slide/9730124/>

Figure: Unit cell of PMN-PT with dielectric polarization

Piezoelectric properties of (110) PMN-PT

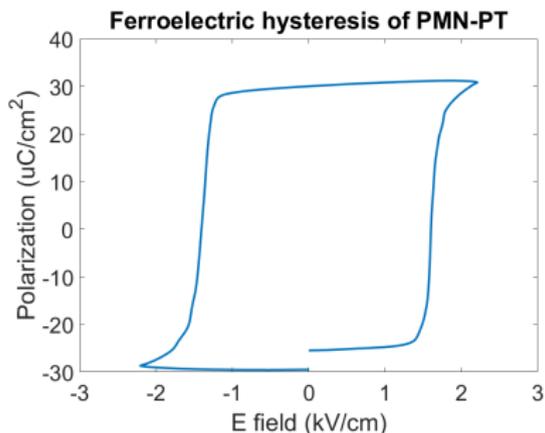


Figure: Ferroelectric Hysteresis loop of PMN-PT

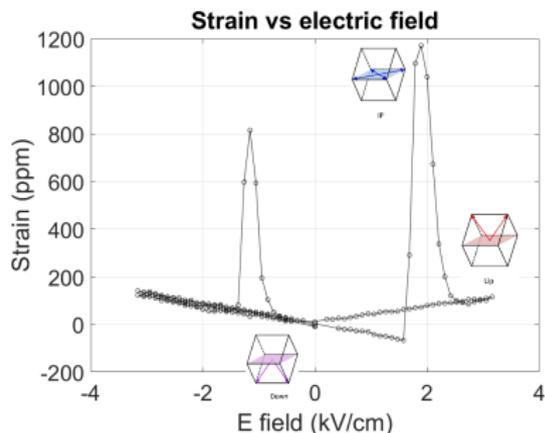
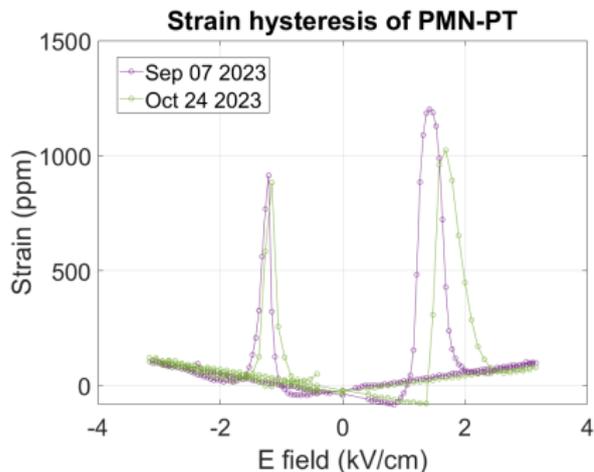


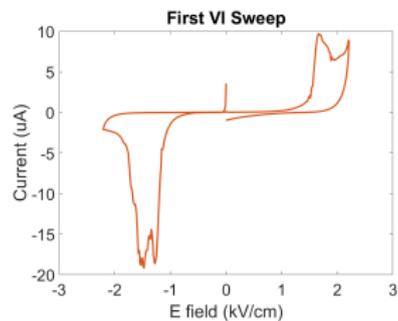
Figure: Piezoelectric strain behavior of PMN-PT

Reaching the in-plane state, part 1

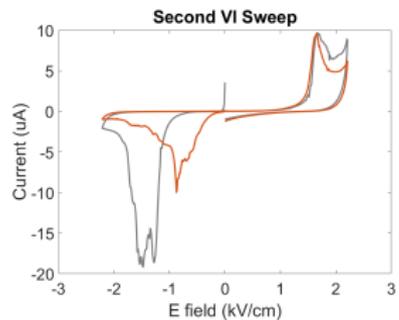
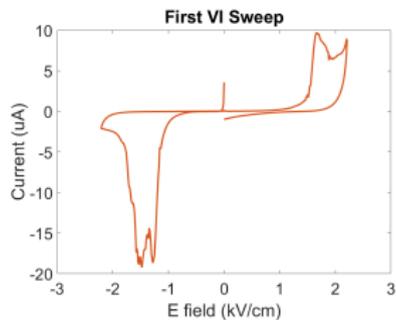


The history dependence of switching dynamics in PMN-PT leads to a "moving target" for the switching voltage.

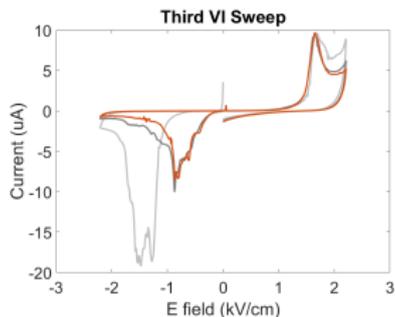
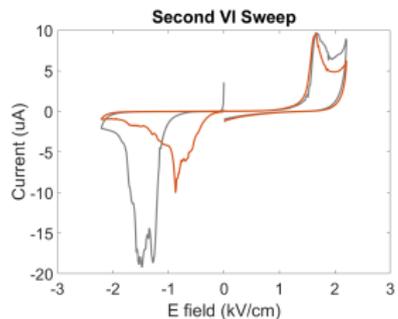
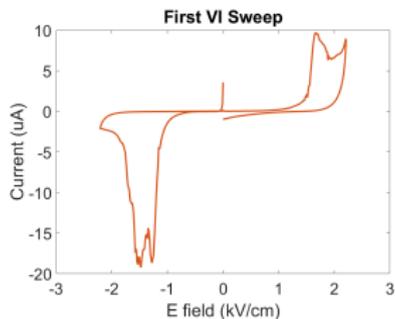
Reaching the in-plane state, part 2



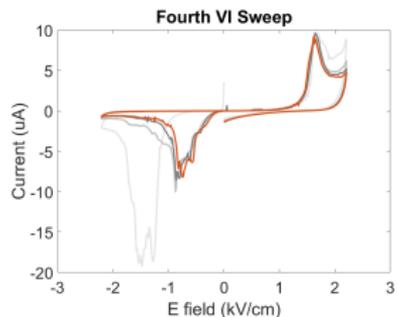
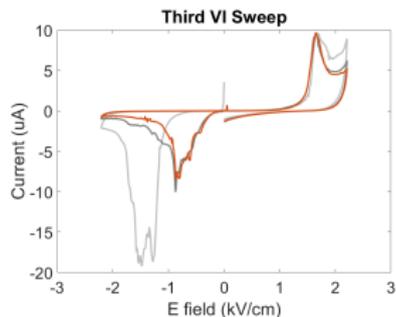
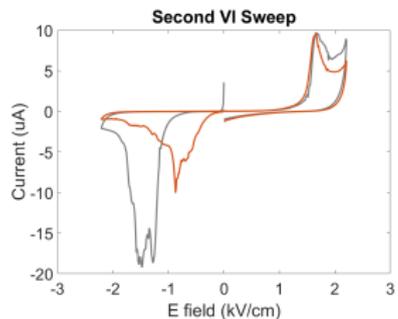
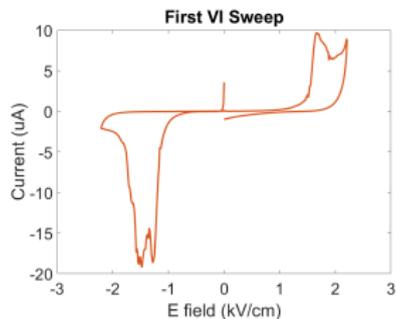
Reaching the in-plane state, part 2



Reaching the in-plane state, part 2

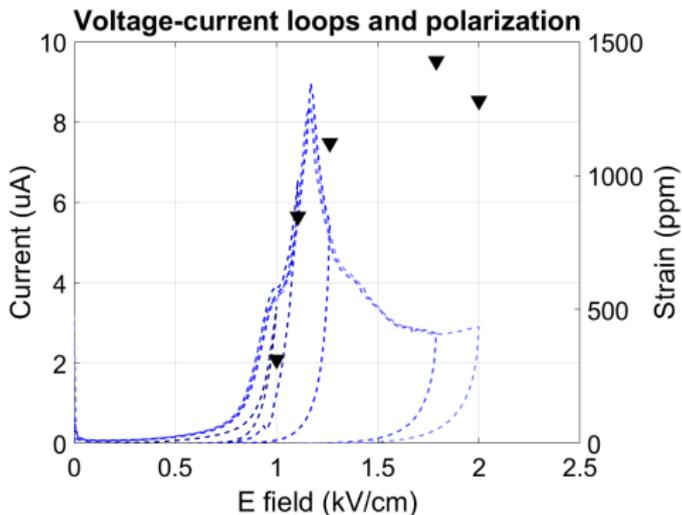


Reaching the in-plane state, part 2



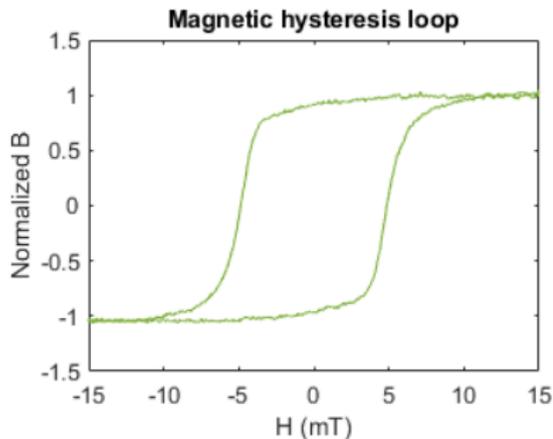
Reaching the in-plane state, part 3

Our samples demonstrated a well-defined strain curve associated with the voltage sweep.



Magnetic hysteresis

- ▶ Domain structure leads to similar behavior
- ▶ Some ferromagnets respond to strain with torque on the magnetic moment (magnetostriction)



<https://www.techtarget.com/searchstorage/definition/HDD-form-factor-hard-disk-drive-form-factor>

Strain-mediated magnetoelectric coupling

Attaching magnetostrictive and piezoelectric materials to each other to couple electric and magnetic behavior.

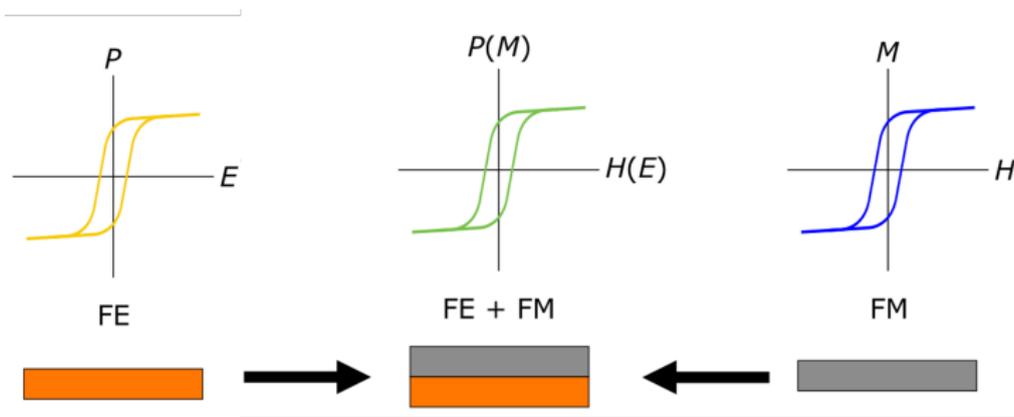


Figure: A piezoelectric substrate combined with a magnetostrictive thin film.

Experimental demonstration of magnetoelectric coupling

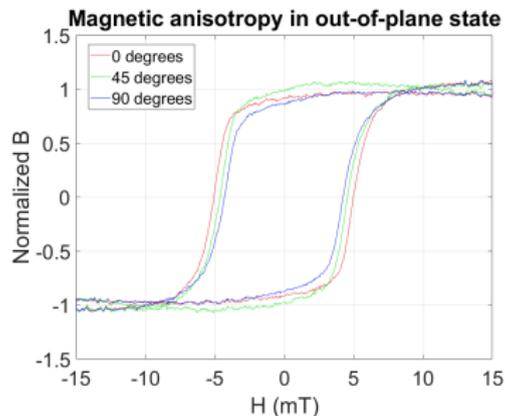


Figure: B-H Loop in the out-of-plane state.

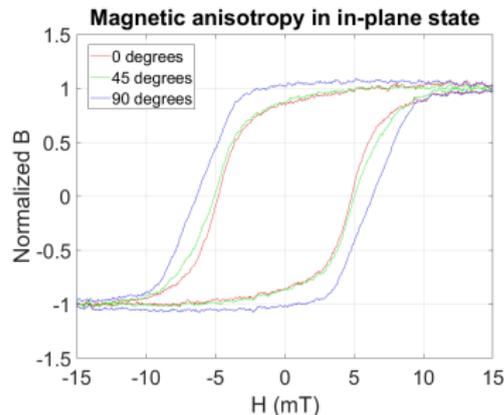
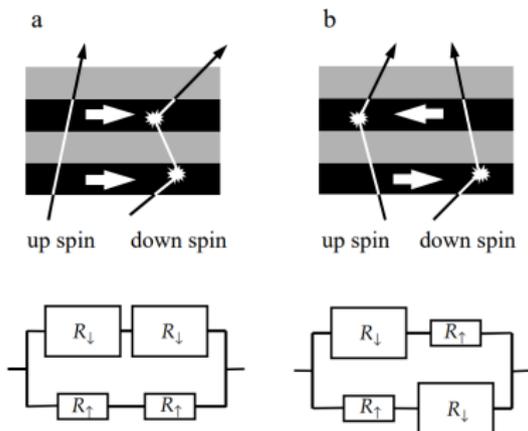


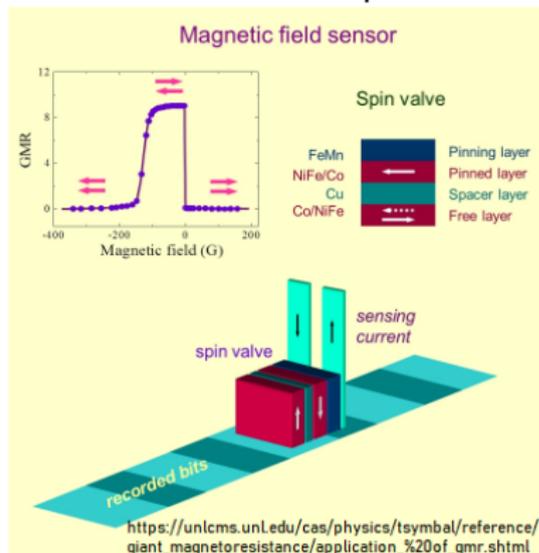
Figure: B-H Loop in the in-plane state. Angular dependence is expected due to magnetostriction.

GMR via strain-mediated ME coupling

- ▶ Giant magnetoresistance: stacked magnetic layers impact conductivity of a device
- ▶ Layer with switching magnetism creates electron "spin valve"



Tsybal, E.Y., and D.B. Poffifer: "Perspectives of Giant Magnetoresistance." Solid State Physics, 2001, pp. 113-237, [https://doi.org/10.1016/S0081-1967\(01\)00019-9](https://doi.org/10.1016/S0081-1967(01)00019-9).



Acknowledgements

Mentors:

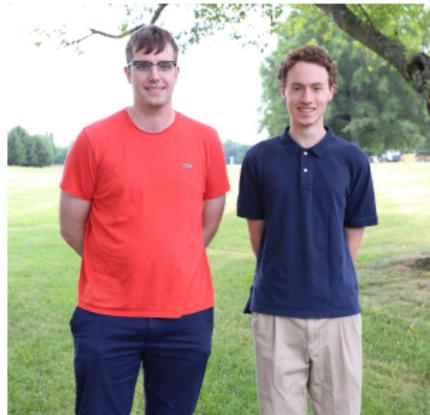
- ▶ Shane Lindemann
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- ▶ Leland Harringer
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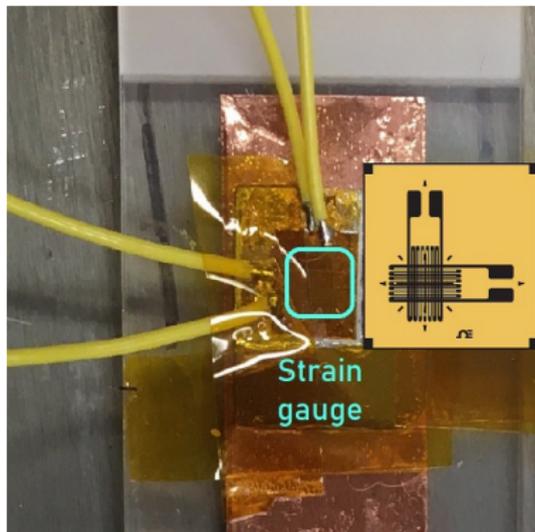
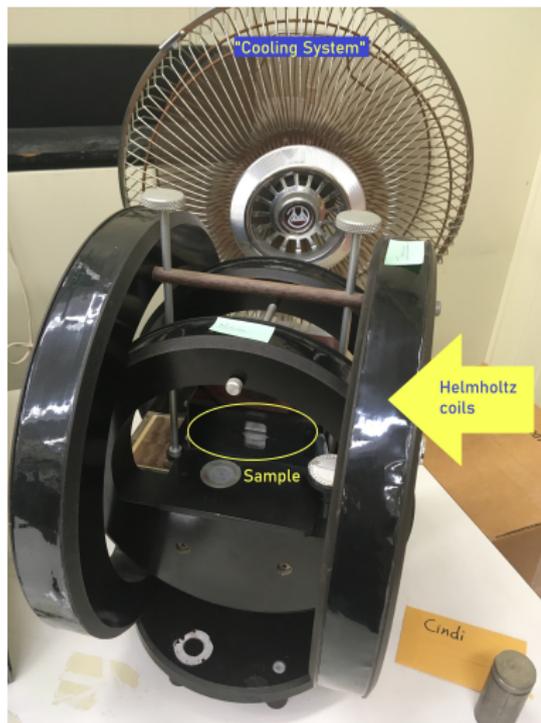
- ▶ Cindi Dennis
- ▶ Kerry Siebein



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Equipment and setup



X-ray diffraction measurements

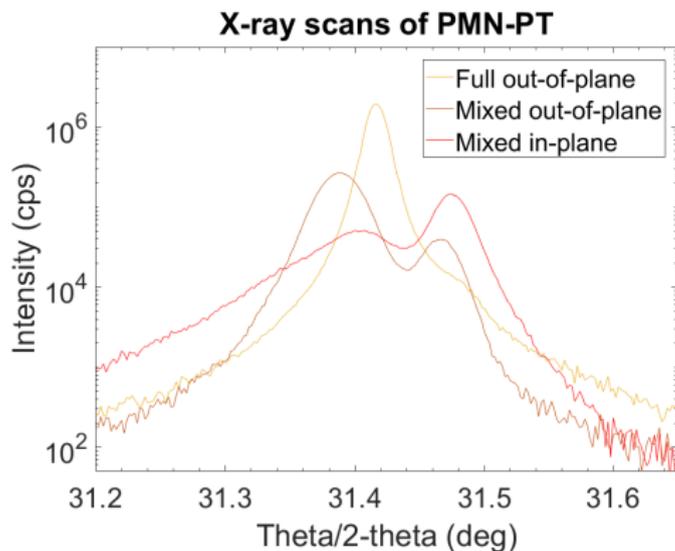


Figure: X-ray vertical measurement of PMN-PT

Bragg condition:

$$n\lambda = 2d \sin \theta$$

