Critical Thickness in Thin Ferroelectric Films

Corbyn Mellinger

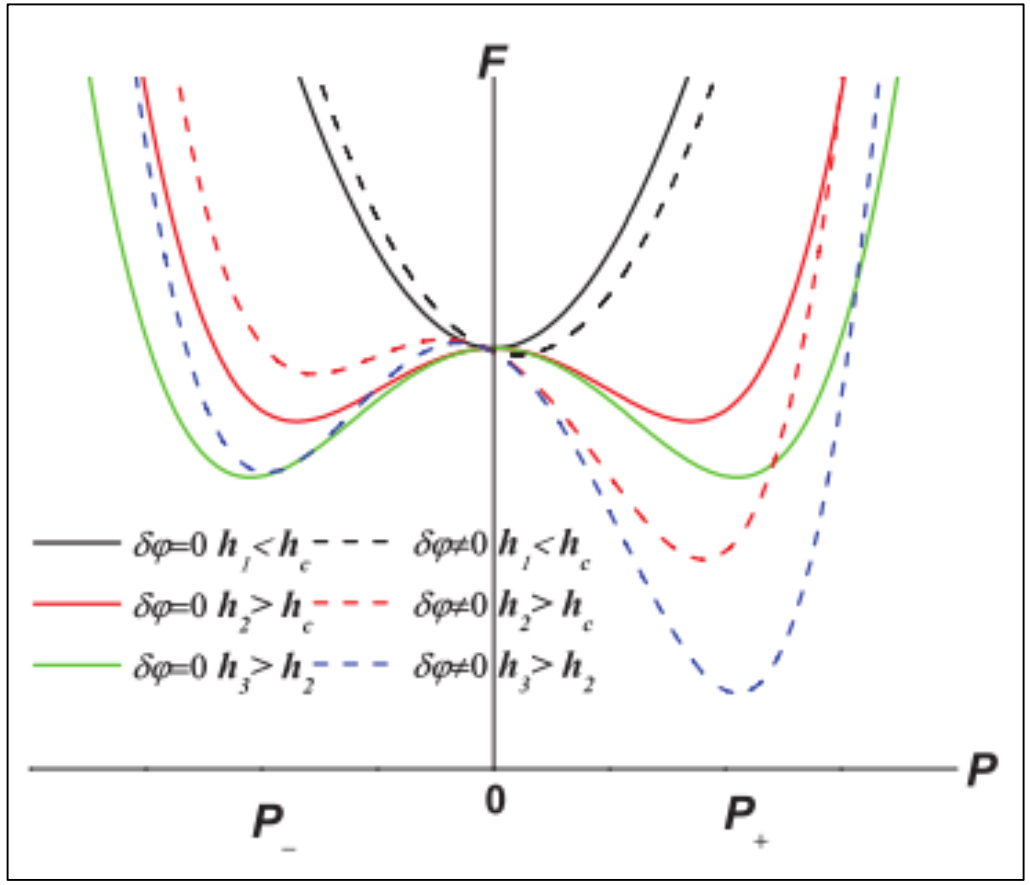
Xu Group Meeting

2018-02-09

Review of Critical Thickness

- Recall last presentation:

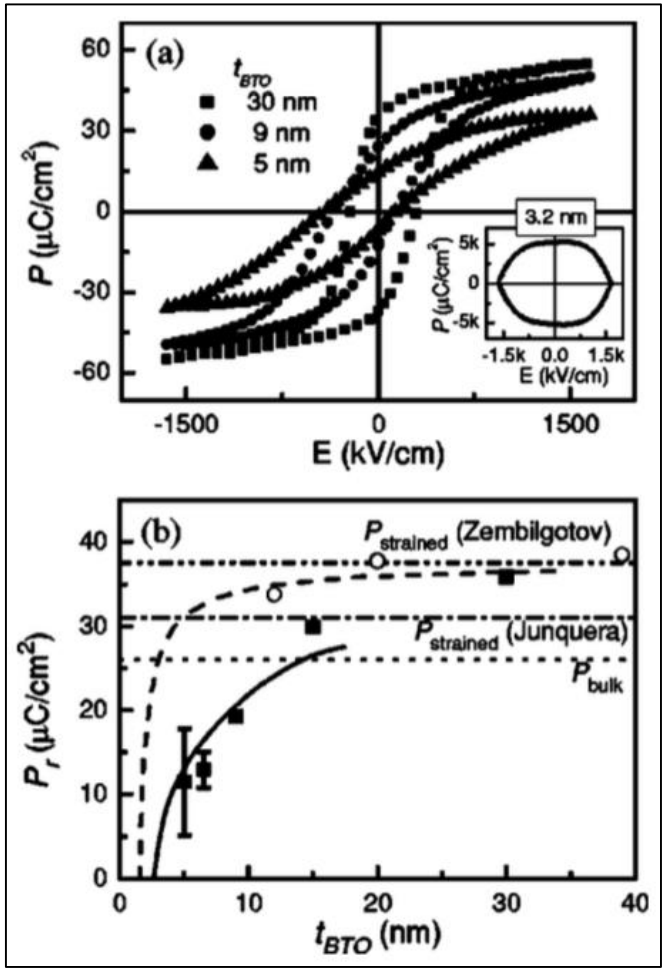
- Emerge in Landau-type treatments and in first-principles calculations



Liu, Lou, Bibes, and Dkhil, PRB **88**, 024106 (2013)

Determinations of Critical Thickness

- Polarization vs. Field loops (P-E loops)
- Scanning tunneling electron microscopy (STEM) analysis of polarization
- UV Raman Spectroscopy



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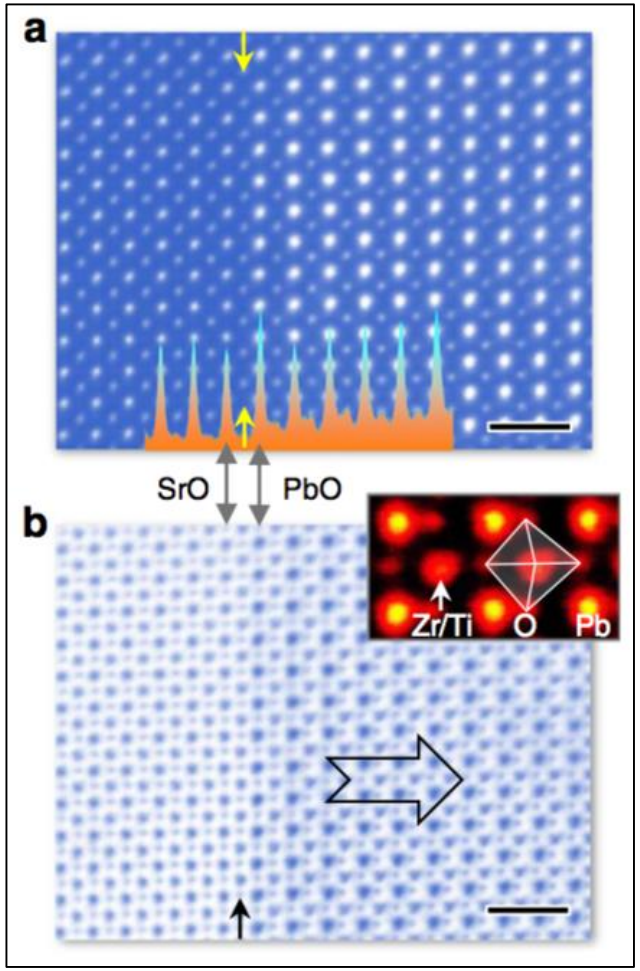

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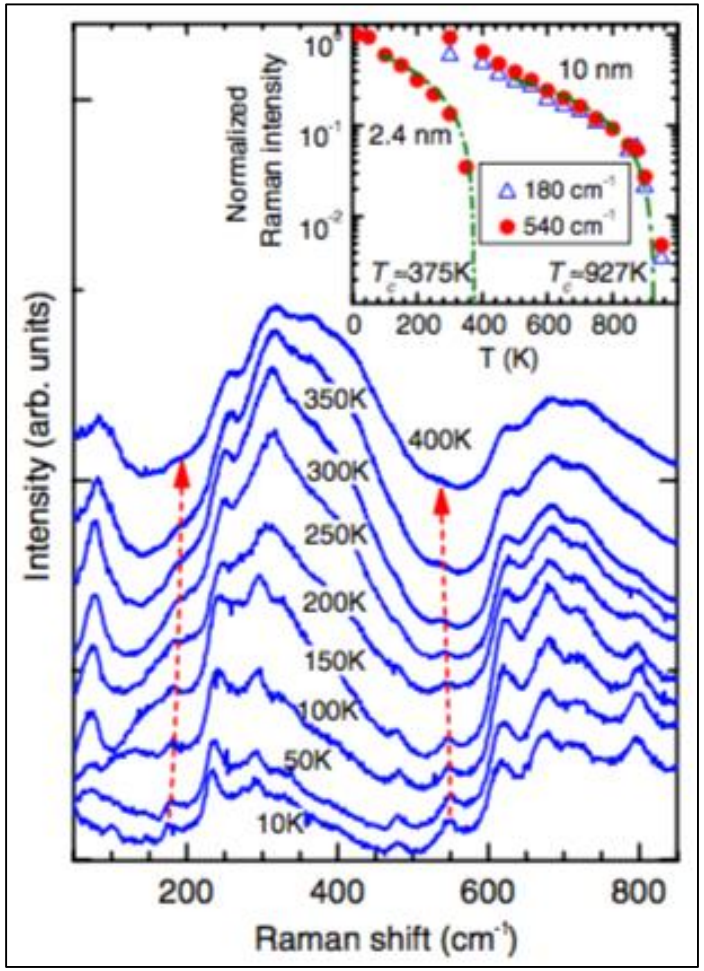
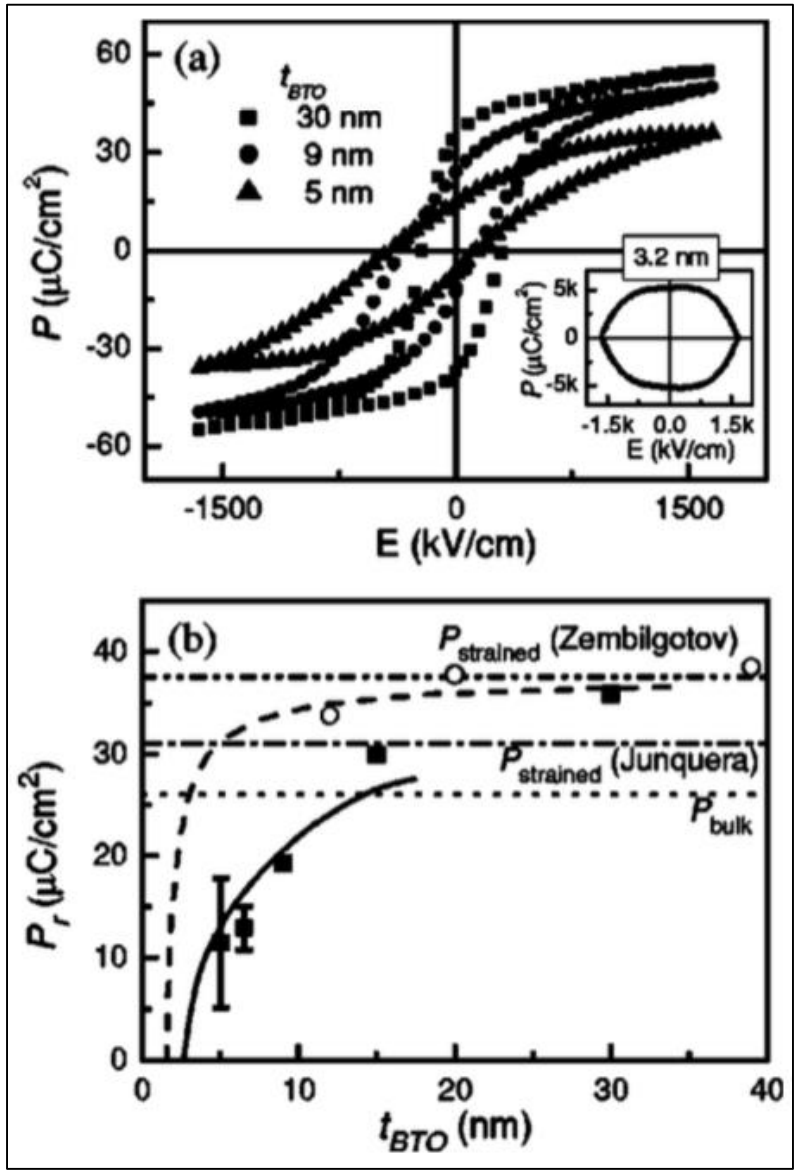


P-E Measurement

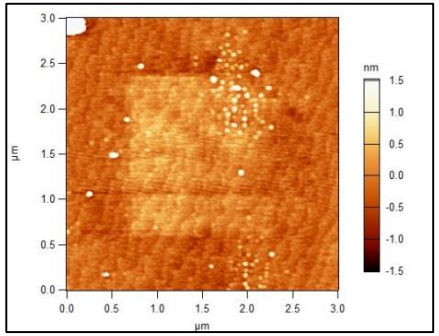
- May be simplest to visualize
- Look for disappearing hysteresis loops
- Extrapolate zero polarization as function of thickness



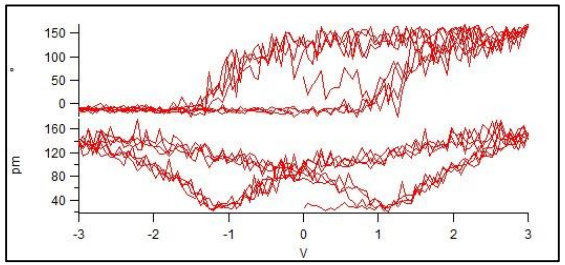
P-E Measurements

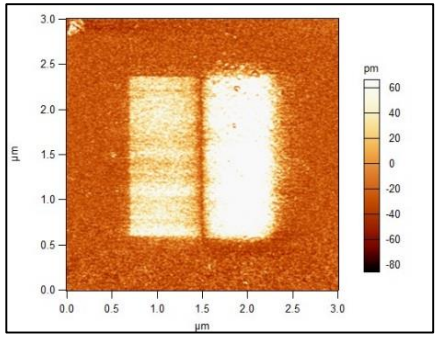
- Can perform with PFM (Prof. Gruverman's group)

Topography

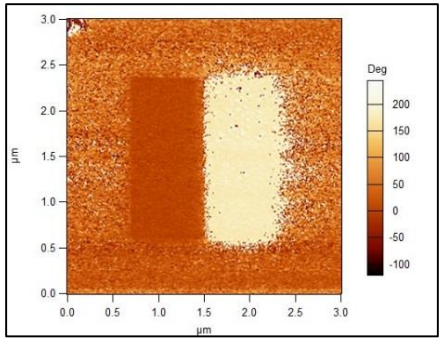


Hysteresis loops

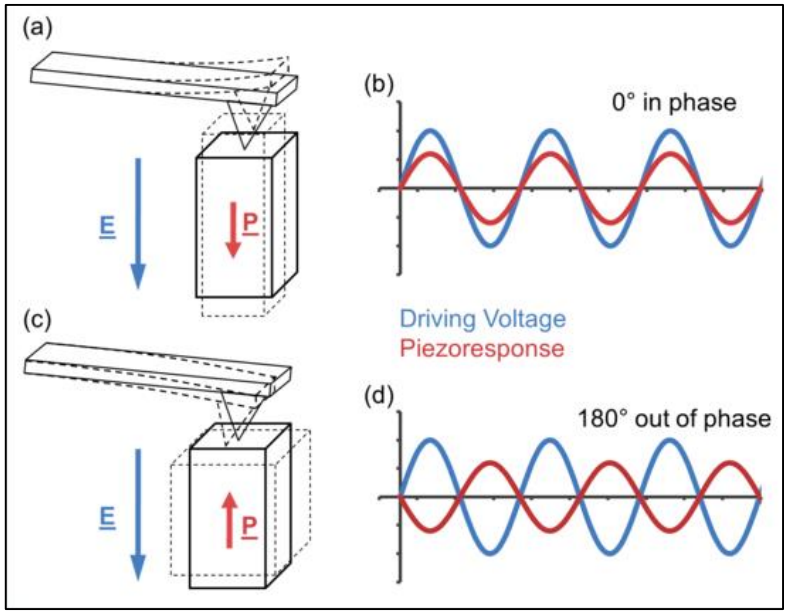




Amplitude



Phase

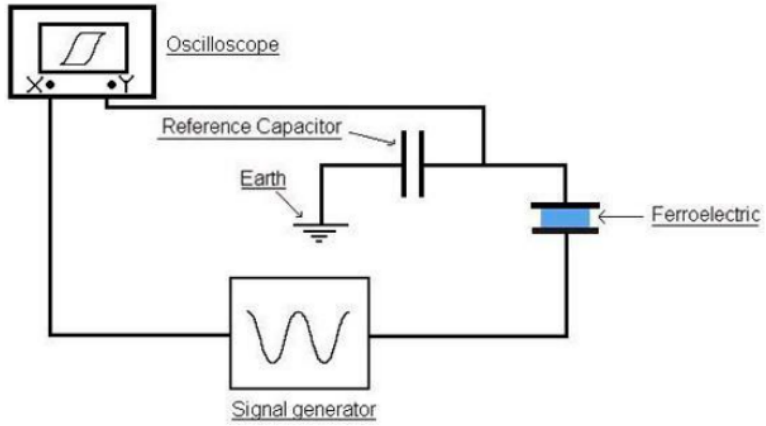


P-E Measurements

- Can perform with PFM (Prof. Gruverman's group)
- More basic: Sawyer-Tower measurement

Sawyer-Tower (ST) circuit measurement

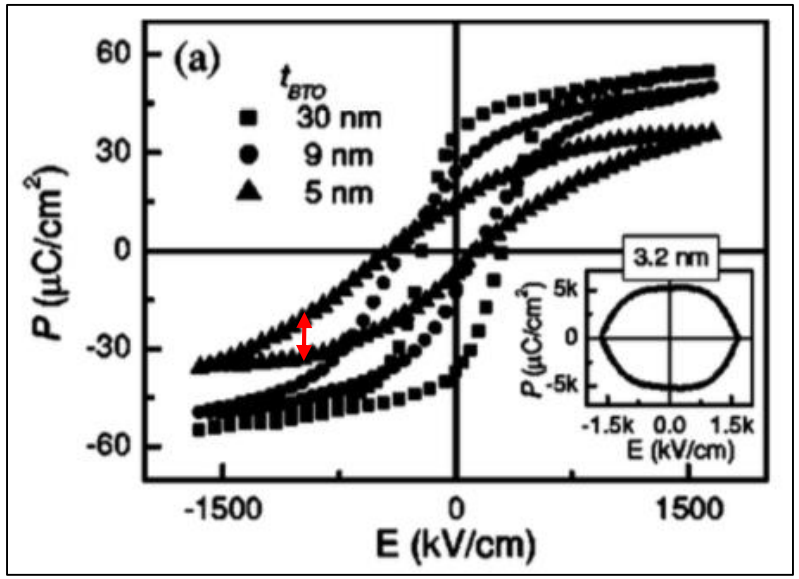
The circuit consists of two capacitors, one due to sample (C_x) and other one is a linear-known-valued sense-capacitor (C_{sense}). They are in series, where C_{sense} is chosen much greater than C_x so that voltage drop across C_{sense} is much less than that across C_x (sample). So the drive voltage V_d is almost equal to voltage across C_x. The voltage across C_{sense}, which gives polarization of the sample, is applied to
vertical plates of the oscilloscope and the drive voltage after safe attenuation is applied to horizontal plates of the oscilloscope to measure electric field across the sample.



Yuewei's FE measurement presentation: 2016-01-29

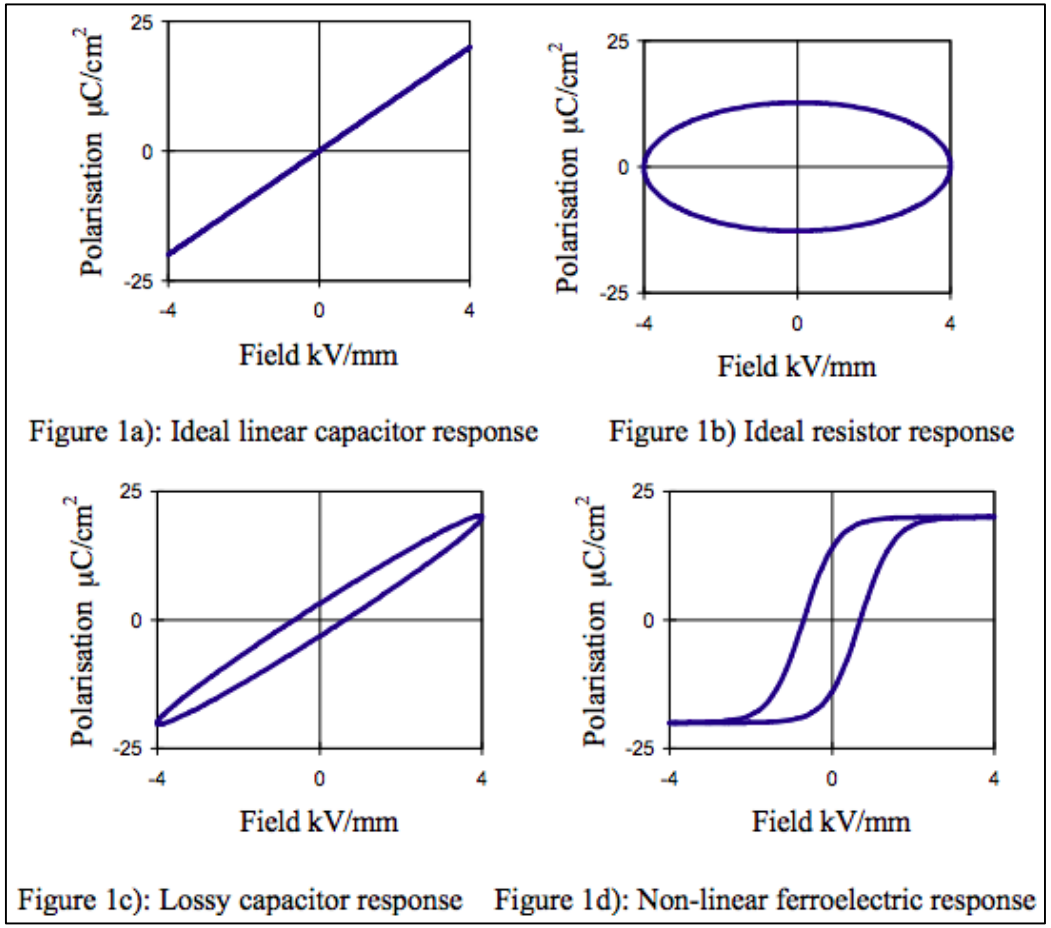
P-E Measurement

- Limitations due to current leakage
  - "…P-E loop shows a slightly wide shape near the saturation electric-field region, suggesting a contribution from leakage current."
- Domain relaxation time influences measurement
  - Effect of depolarization field E_d may pose greater effect on critical thickness



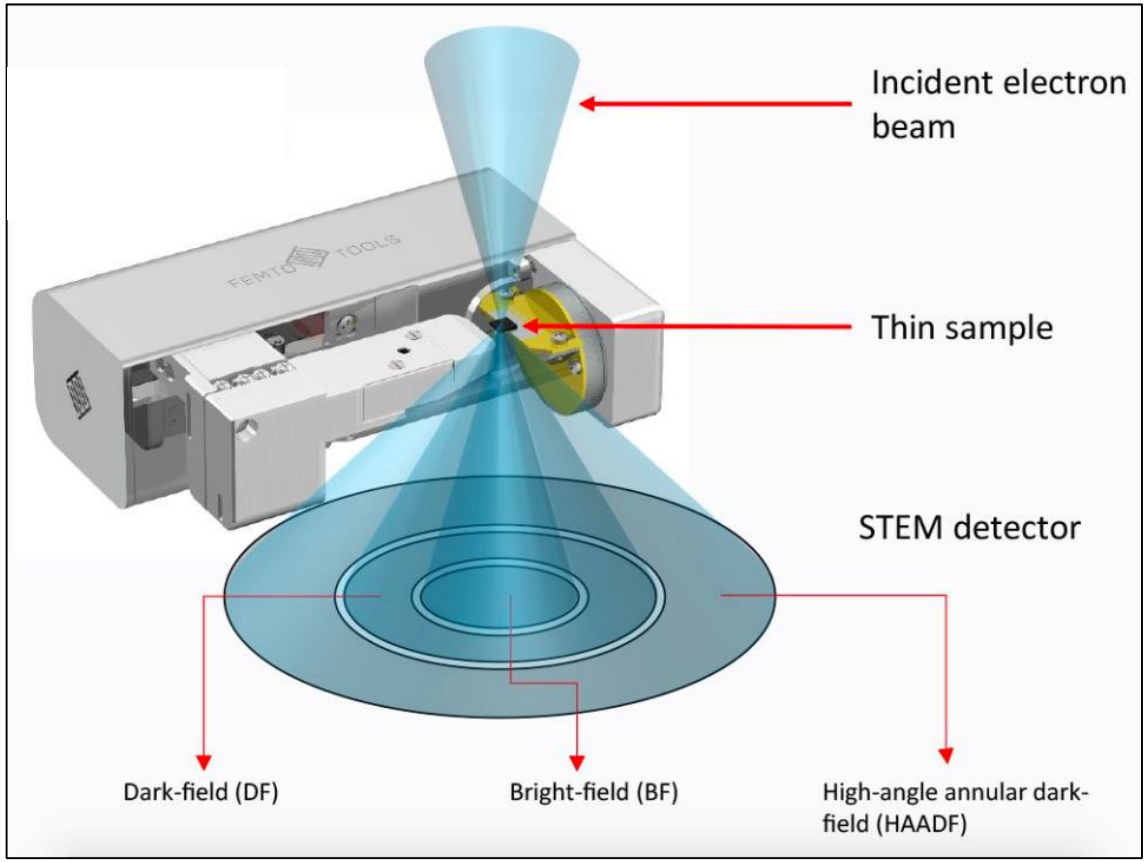
P-E Measurement

- Lossy capacitor (i.e. leaky film) similar to hysteresis response
- Mechanisms exist to account and correct for leakage current



STEM Analysis

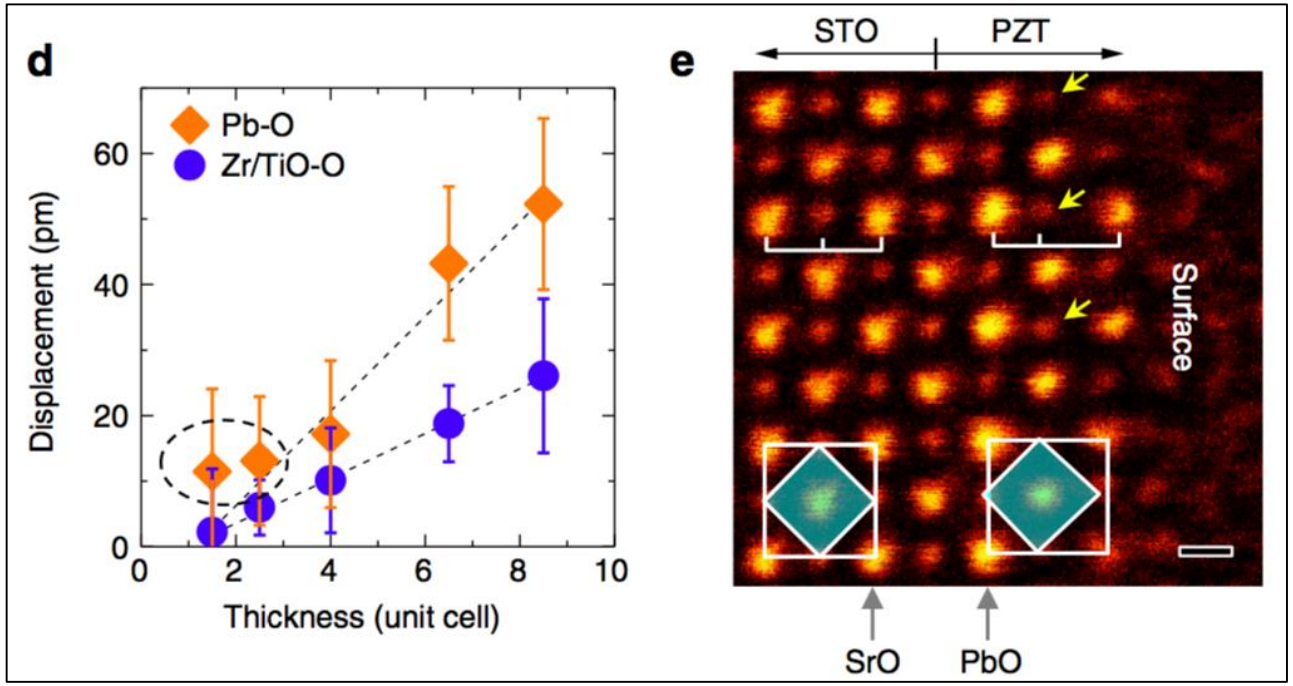
- Dipole comes from displacement of film atoms
  - STEM directly images atoms for sign of relative displacements
- Bright-field: detection within incident path
  - Better resolution of light elements (e.g. oxygen)



STEM Analysis

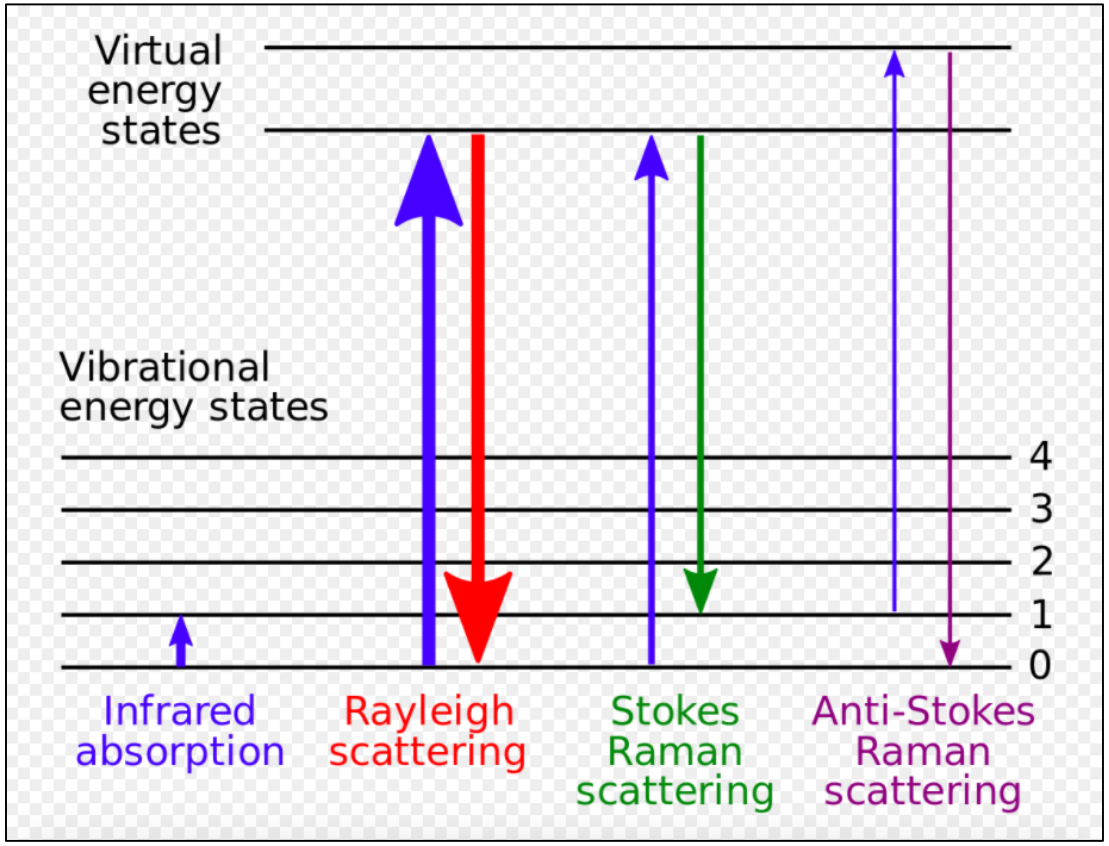
- Paper compares polarizations for various PZT thicknesses on STO

- Predictions have t_c~3 u.c.
  - Saw polarization below this thickness
  - Attributes to non-vanishing Pb-O displacements, despite interfacial dead layer



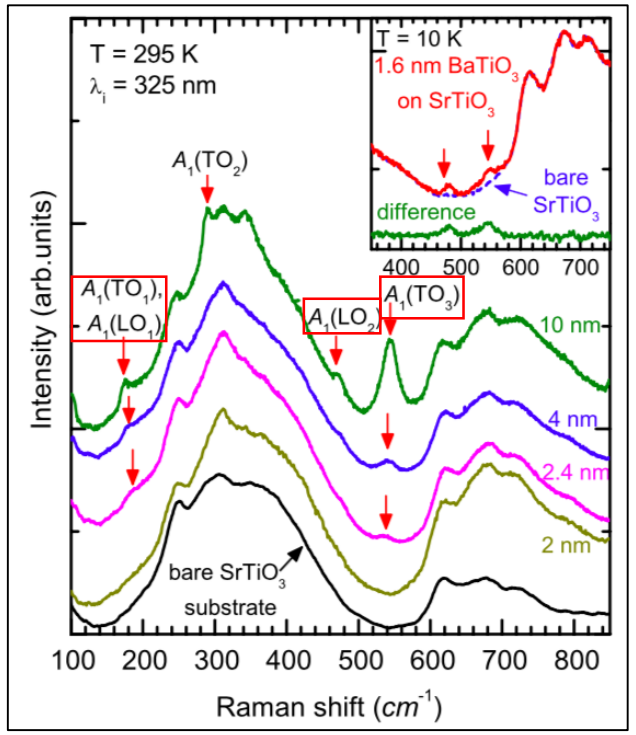
UV Raman Spectroscopy

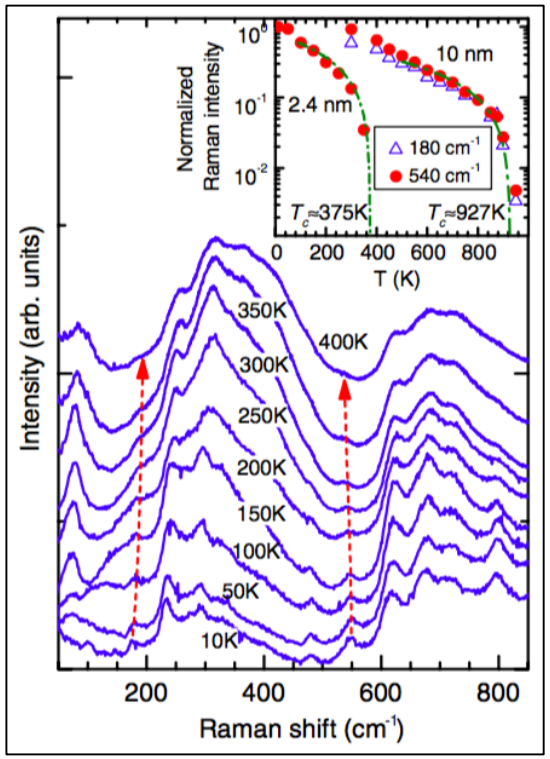
- Similar to STEM measurement
  - Detects atomic displacements
- Actually measures T_c : loss of ferroelectricity means T_c=0K
- Vibrational modes characteristic of material being measured
  - Track known BTO shifts and watch for disappearance of features

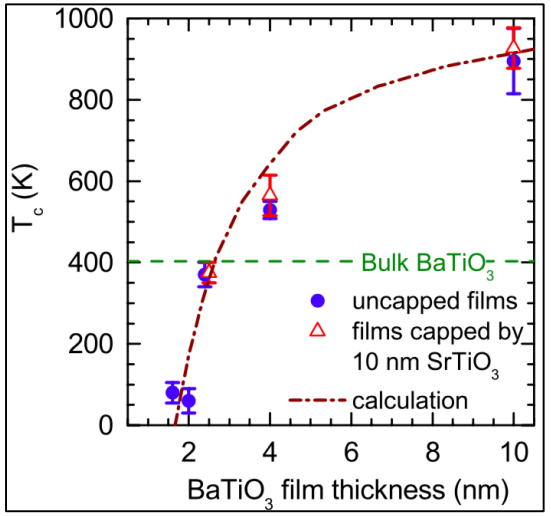


UV Raman Spectroscopy

- BTO on STO(100) grown by MBE
- $BaTiO_3$ peaks at 180, 475, 540 cm^{-1} tracked
- $T_c \rightarrow 0K$ for t_c=1.6nm (4 unit cells
  - In agreement with calculations for film interface with vacuum







Thank you