Polarization Switching by Piezoresponse Force Microscopy

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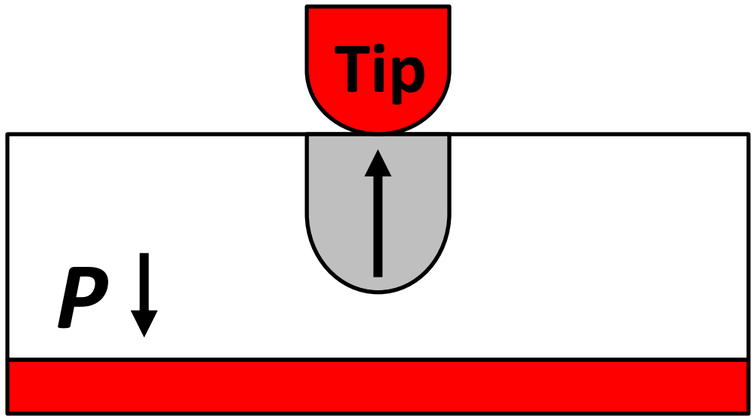
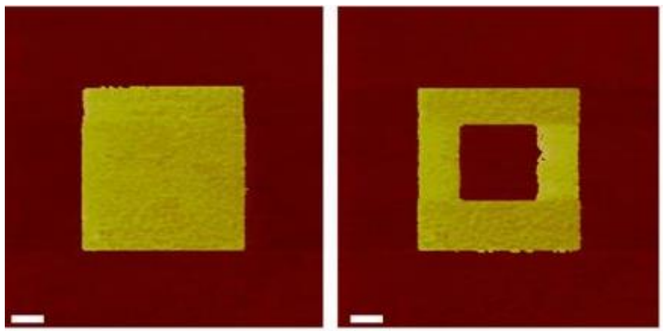
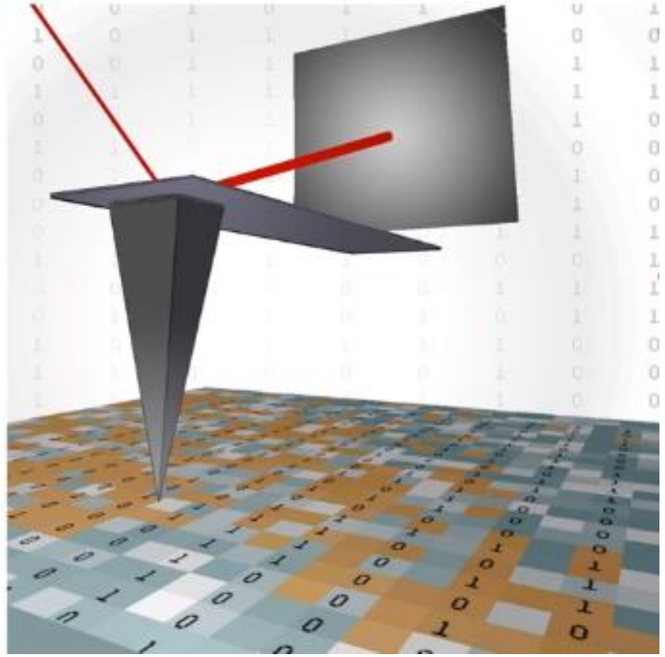
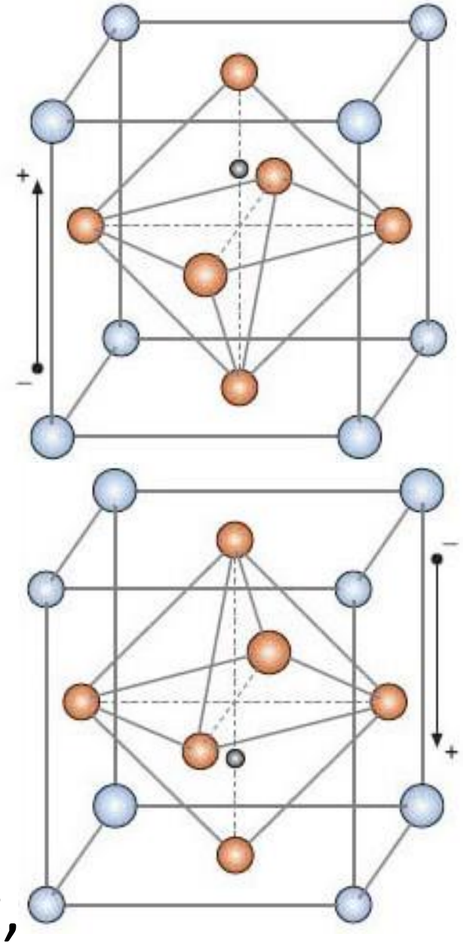
Piezoresponse Force Microscopy (PFM) of Ferroelectric Materials

FE materials → polarization can be altered by the electric field









Fundamental science: Physics of polarization switching, nucleation, domain wall motion

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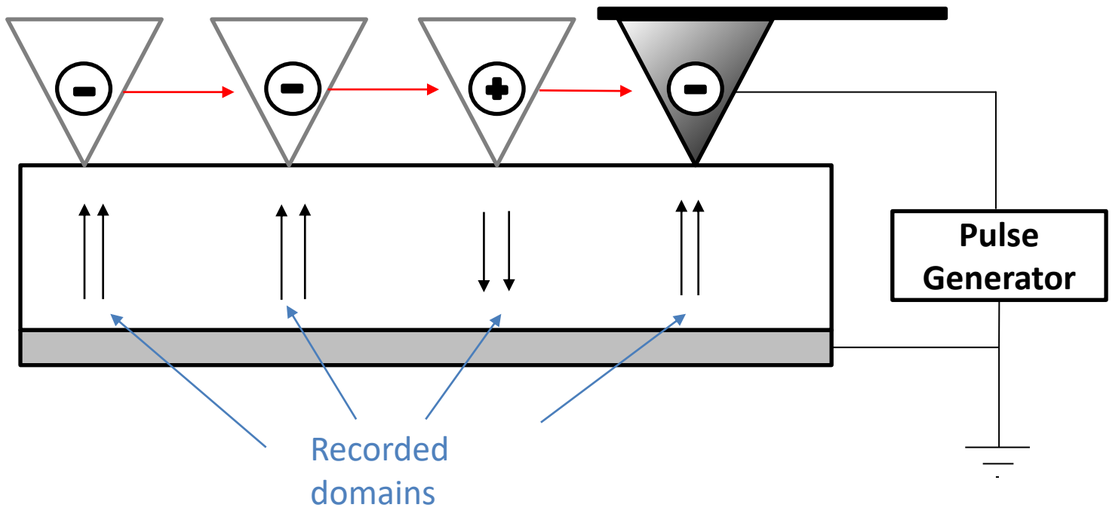
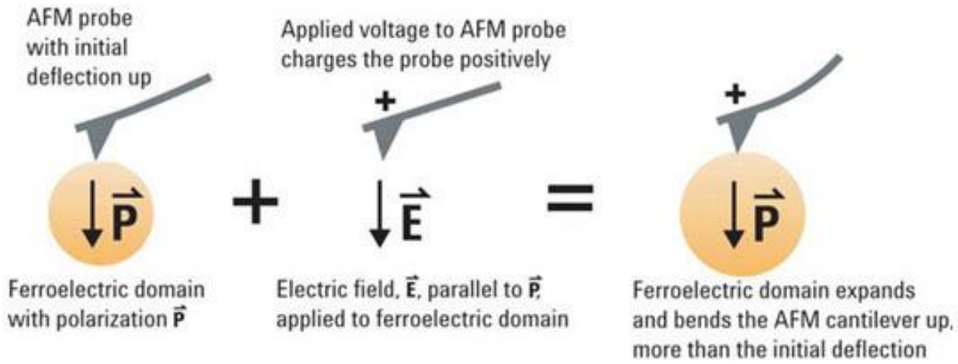
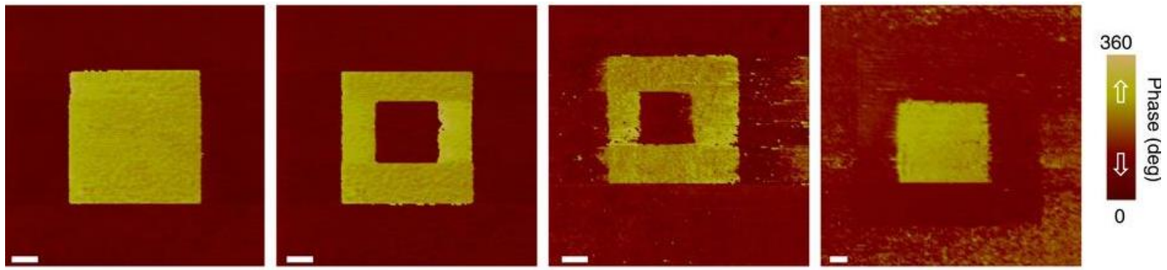
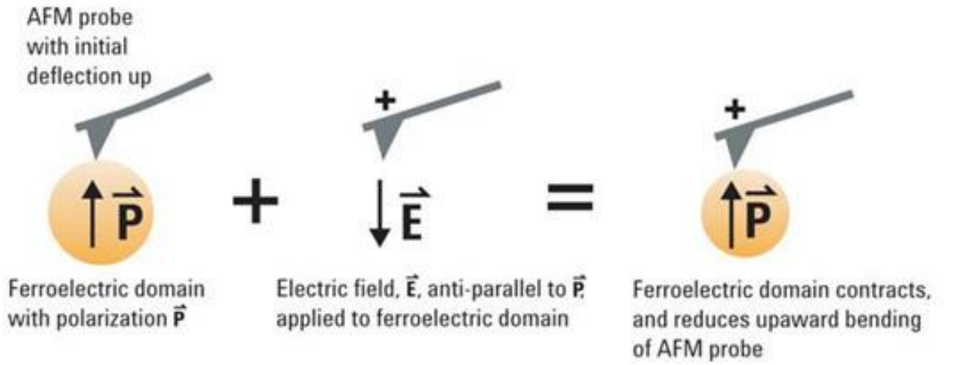




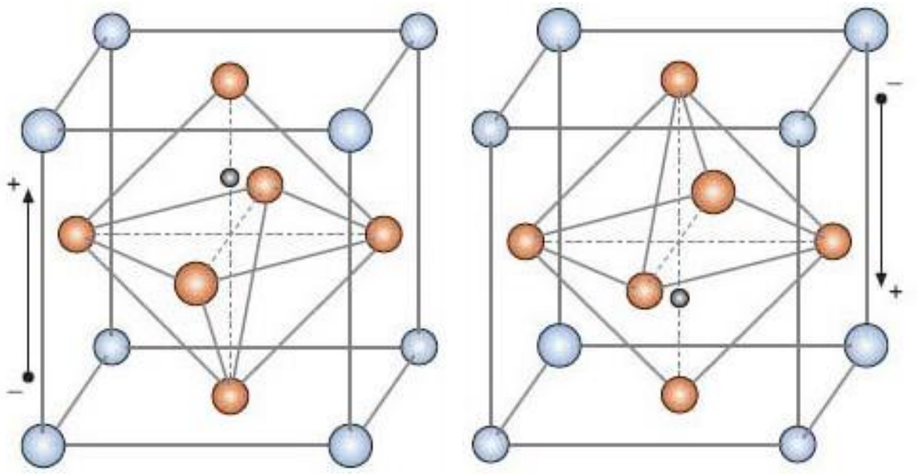
Different Shapes and Patterns



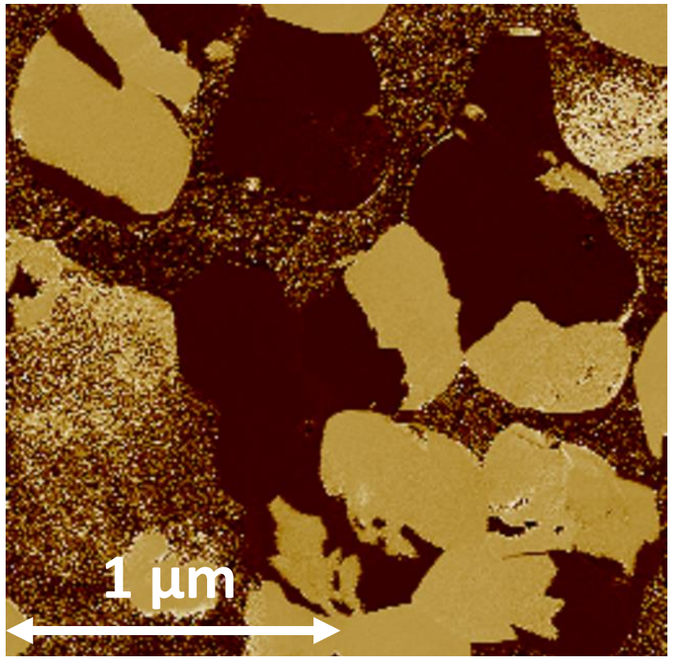


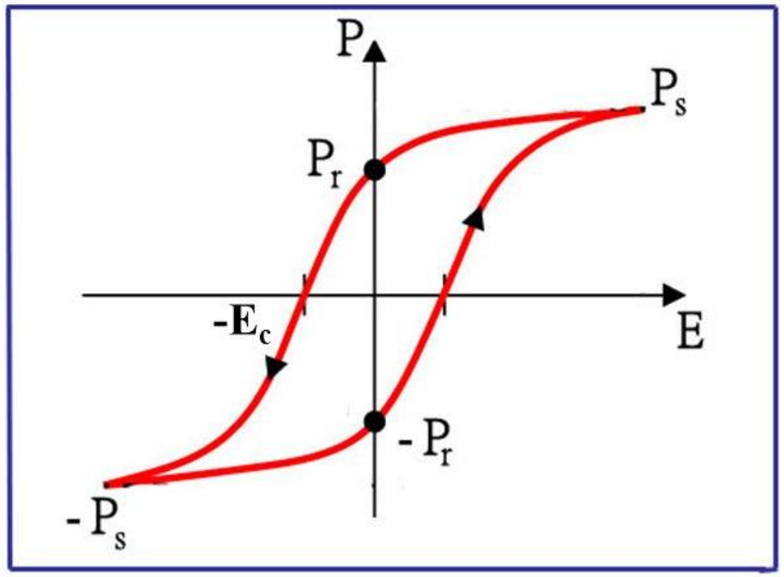
Writing in domain polarization can be useful for investigating polarization switching spectroscopy in PFM

Polarization Switching Spectroscopy in PFM – Polarization Dynamics

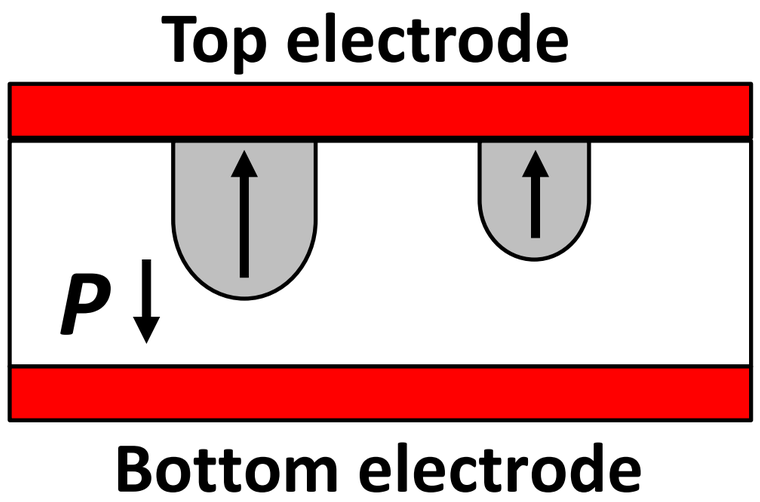


Tetragonal (orthorhombic) lattice, crystal has electric dipole

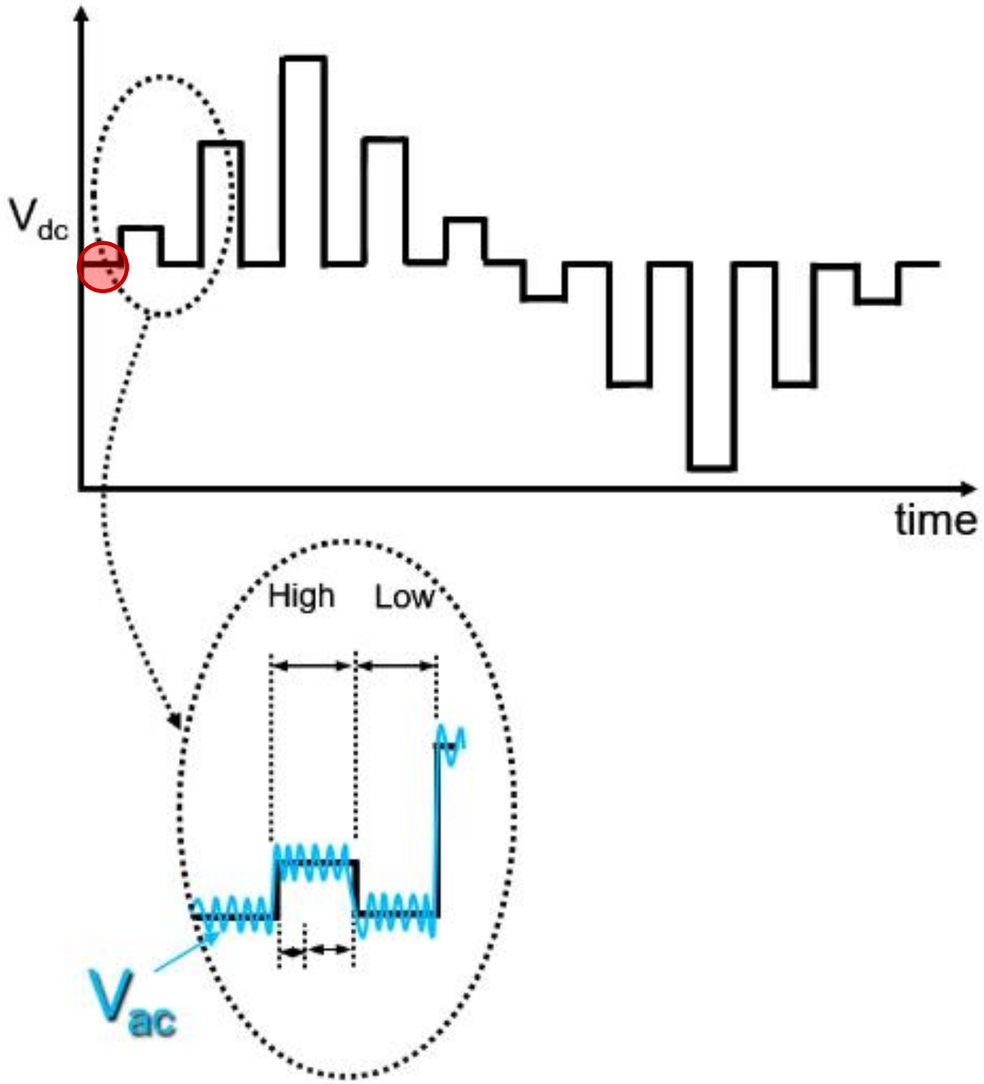


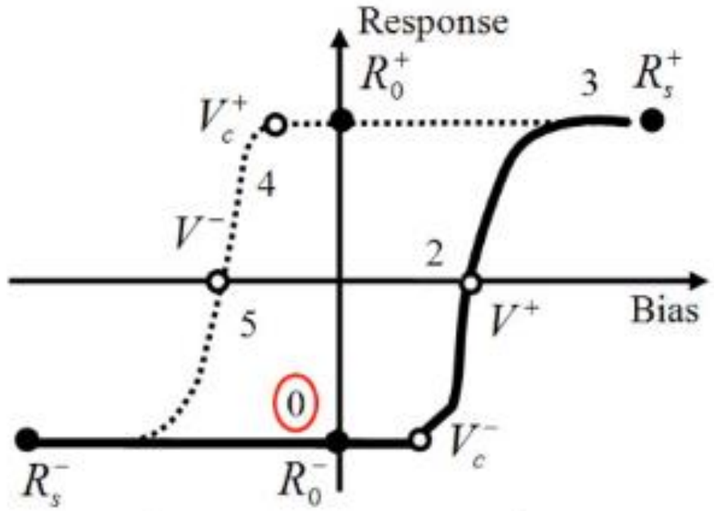


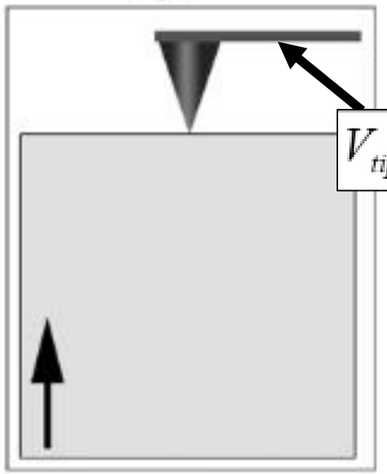
- Macroscopic hysteresis measurements are averaged across large areas
  - Gives information about macroscopic average properties
  - Gives insufficient information about local switching mechanism
  - Cannot be used to observe what happens inside a ferroelectric capacitor (domain wall motion and nucleation)



Polarization Switching Spectroscopy in PFM

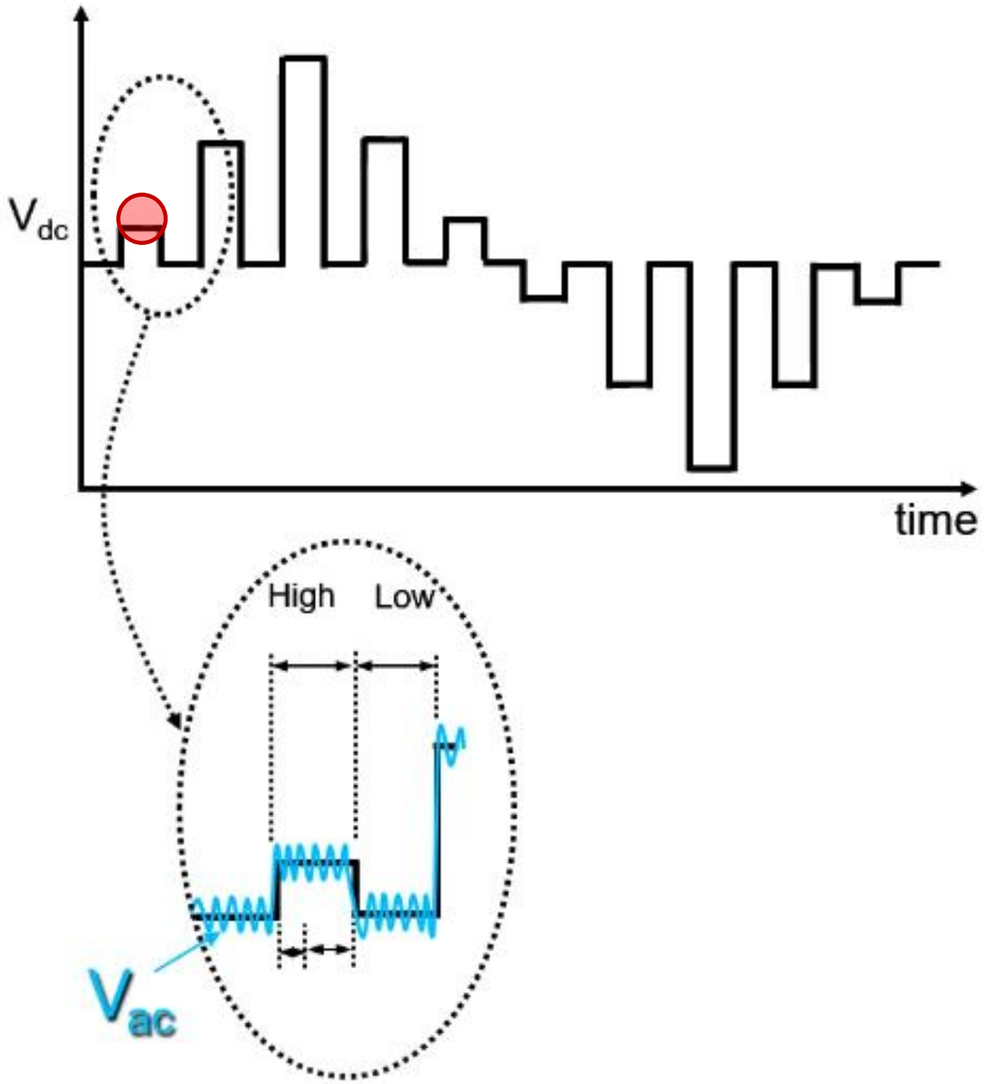


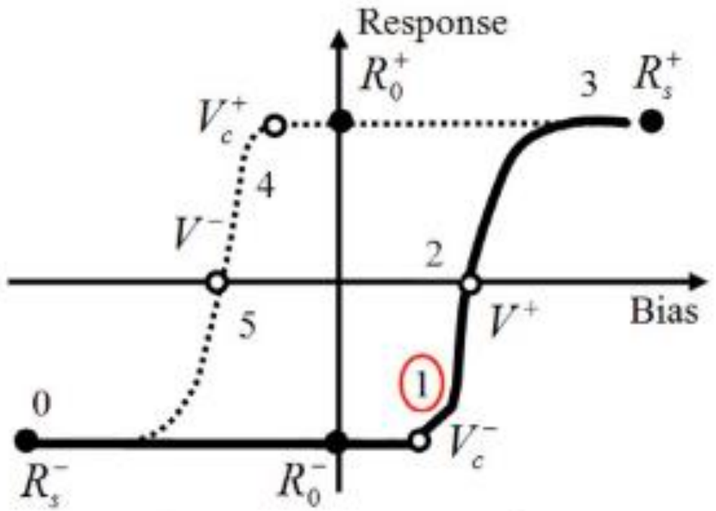


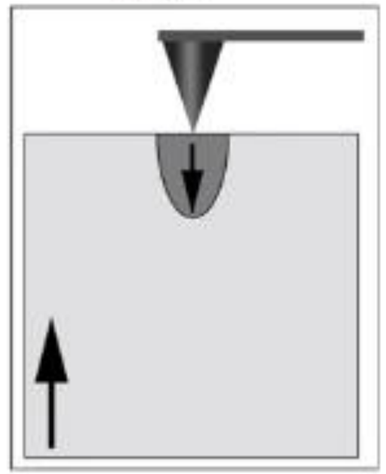


$$V_{tip} = V_{dc} + V_{ac} \sin \omega t$$

Polarization Switching Spectroscopy in PFM







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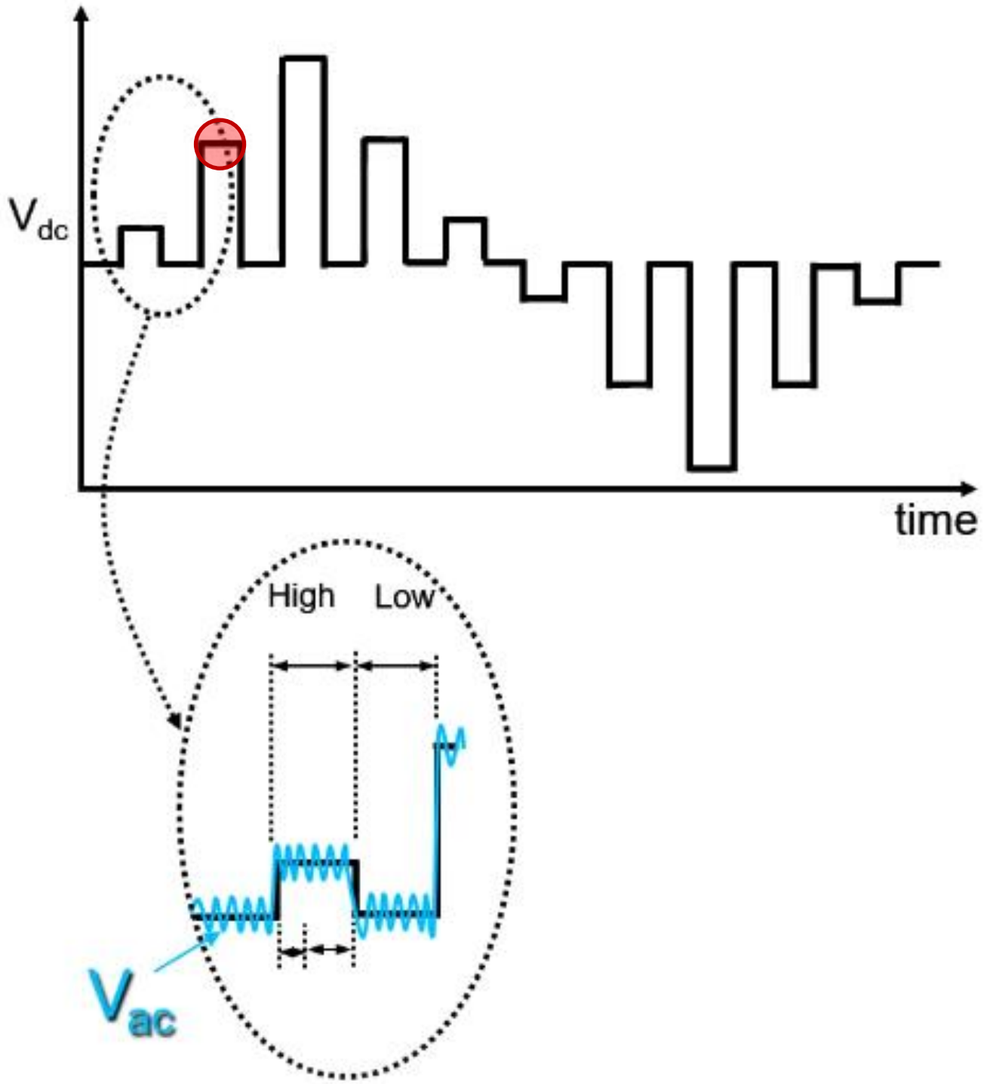

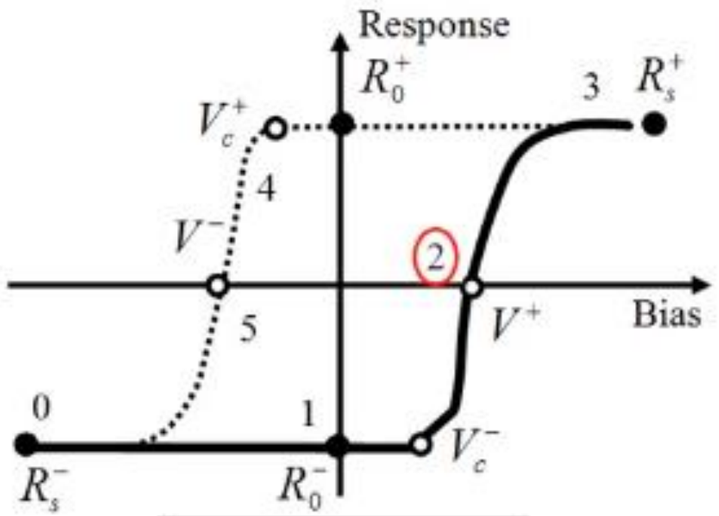

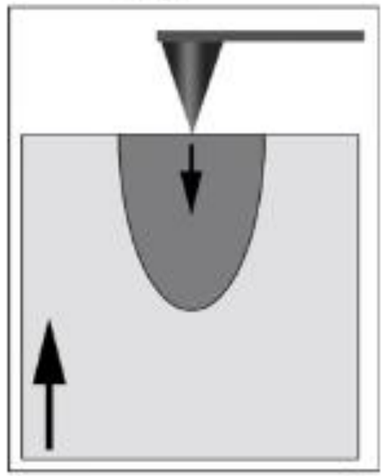

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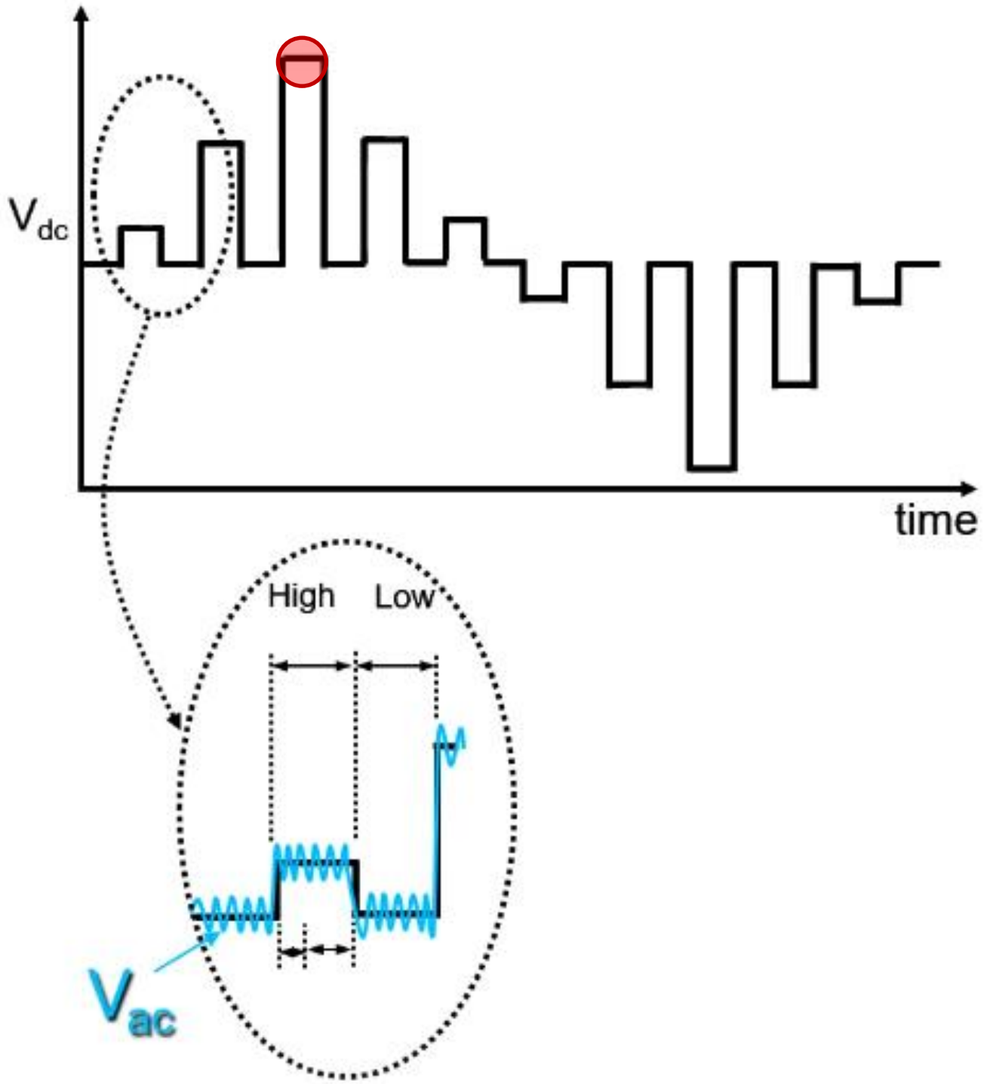

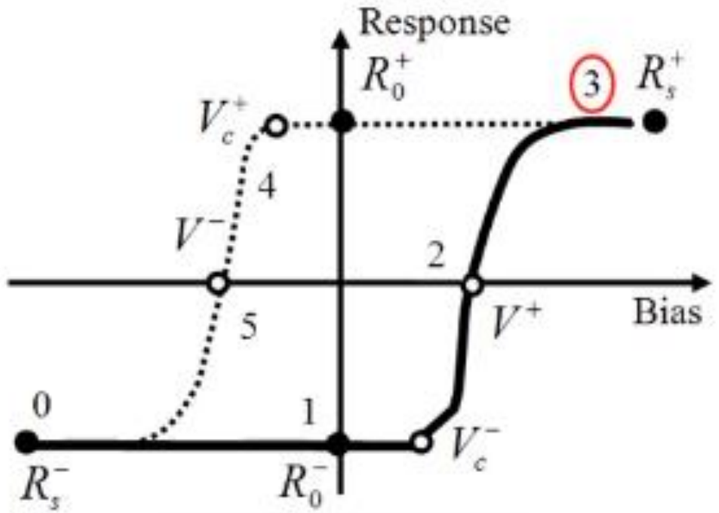

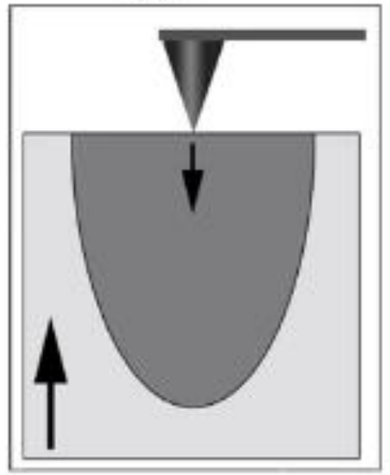

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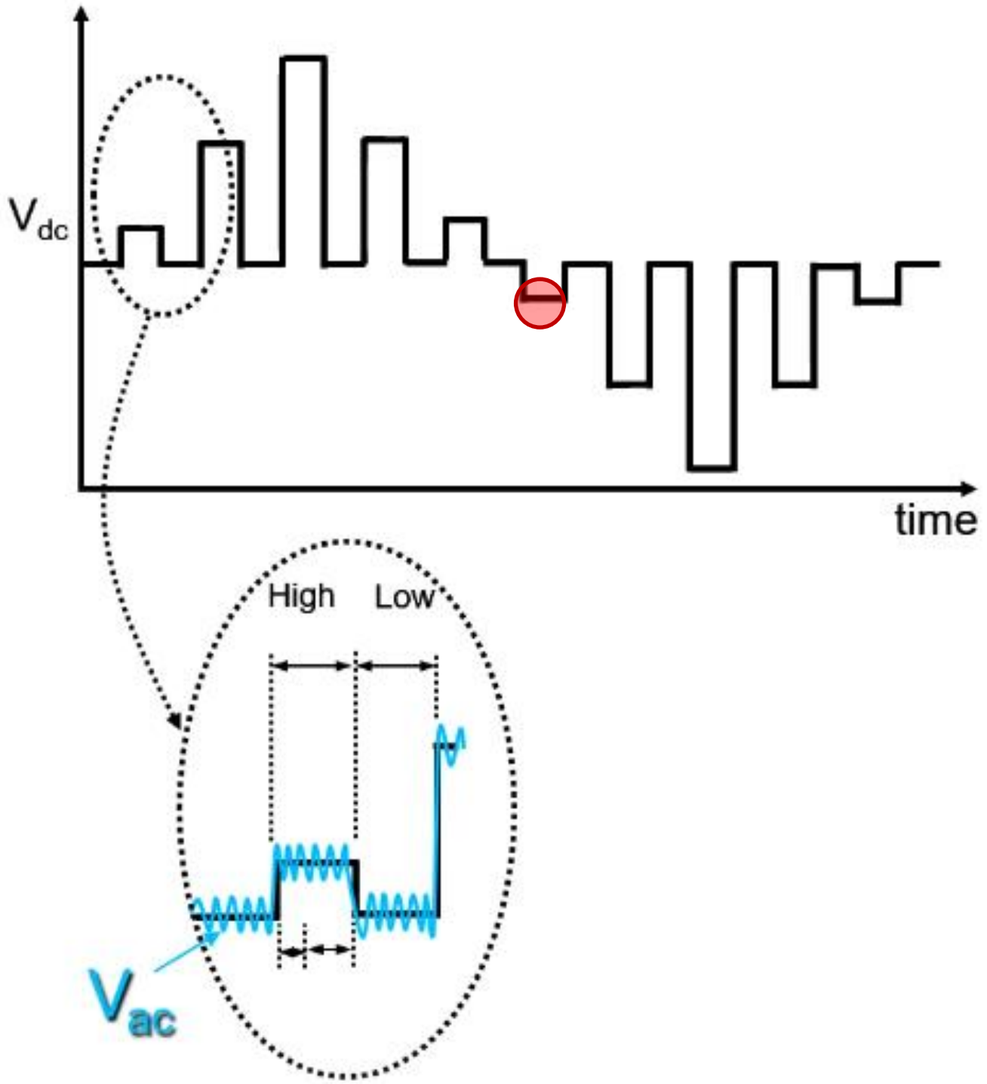

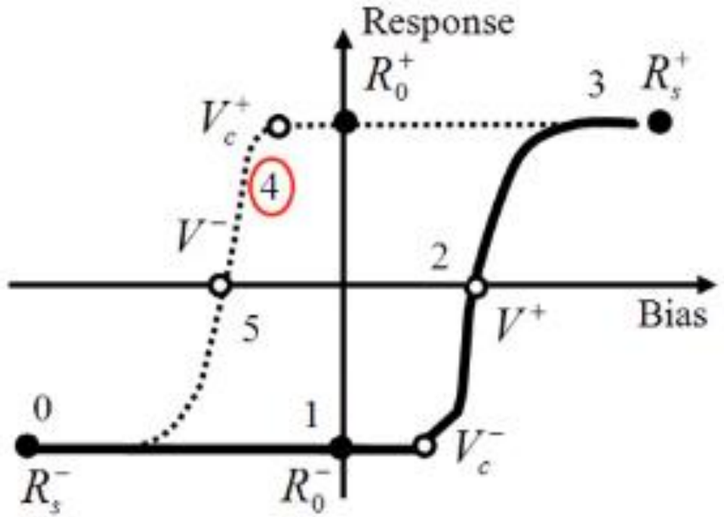

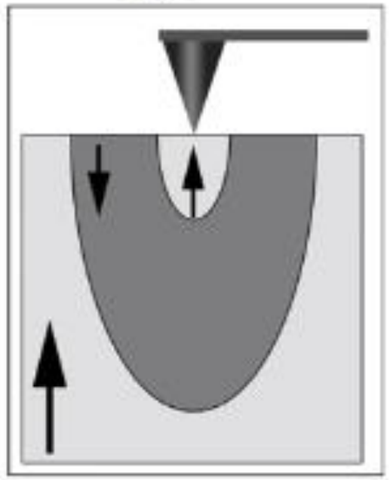

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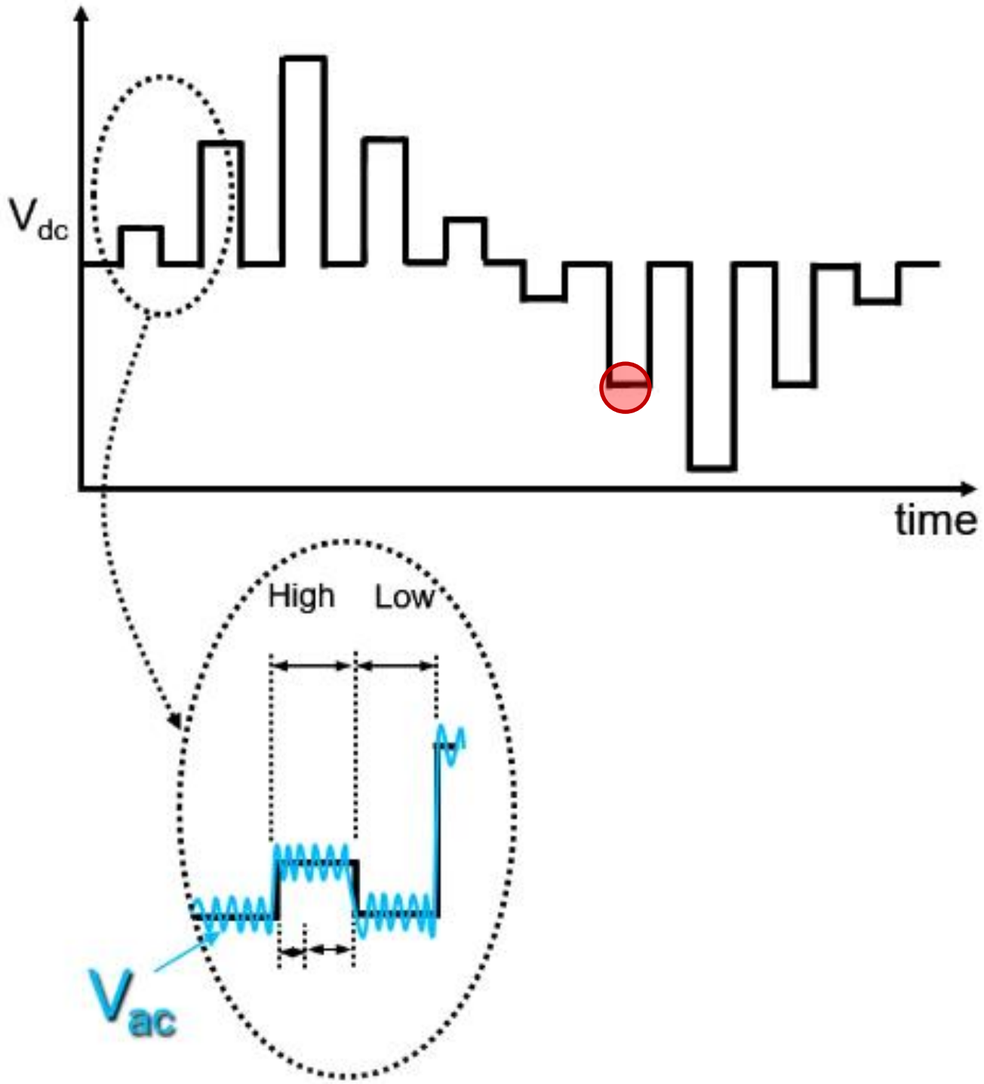

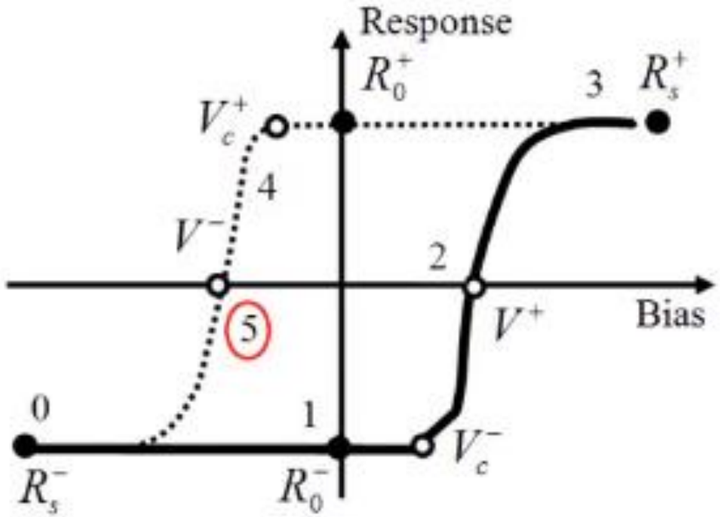

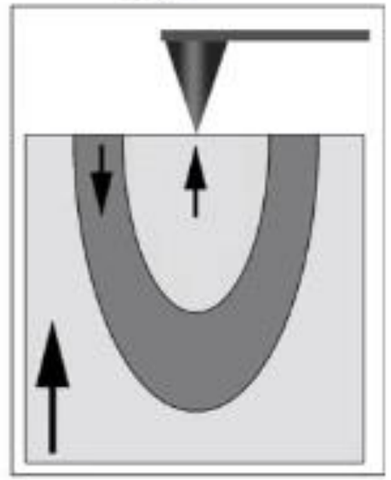

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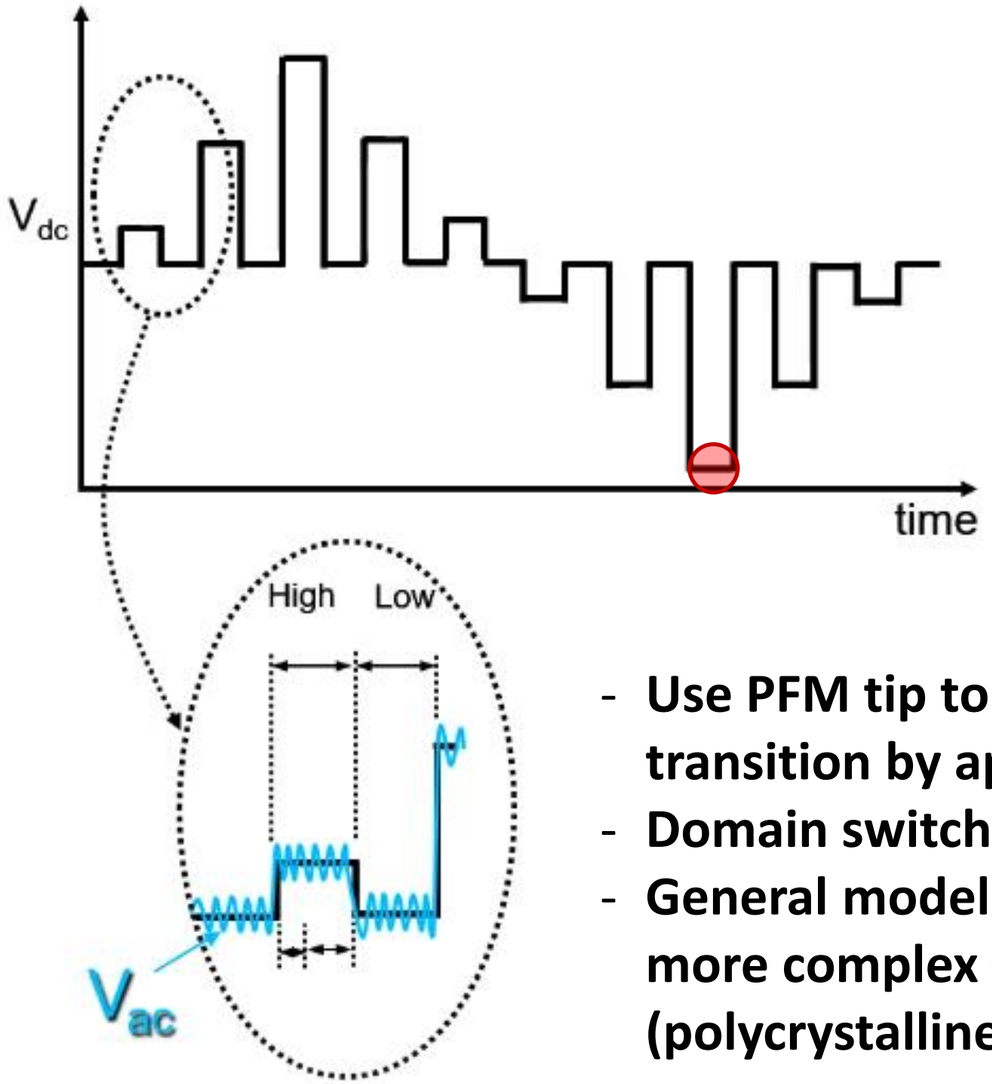
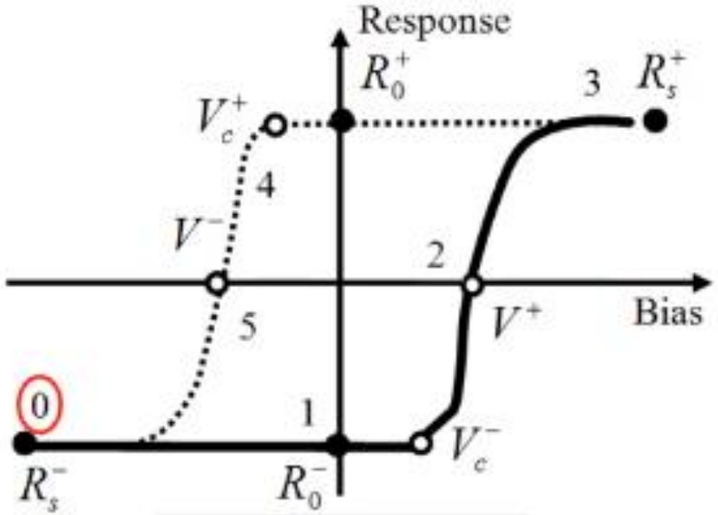
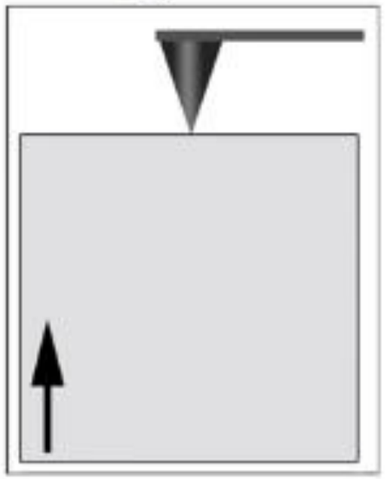
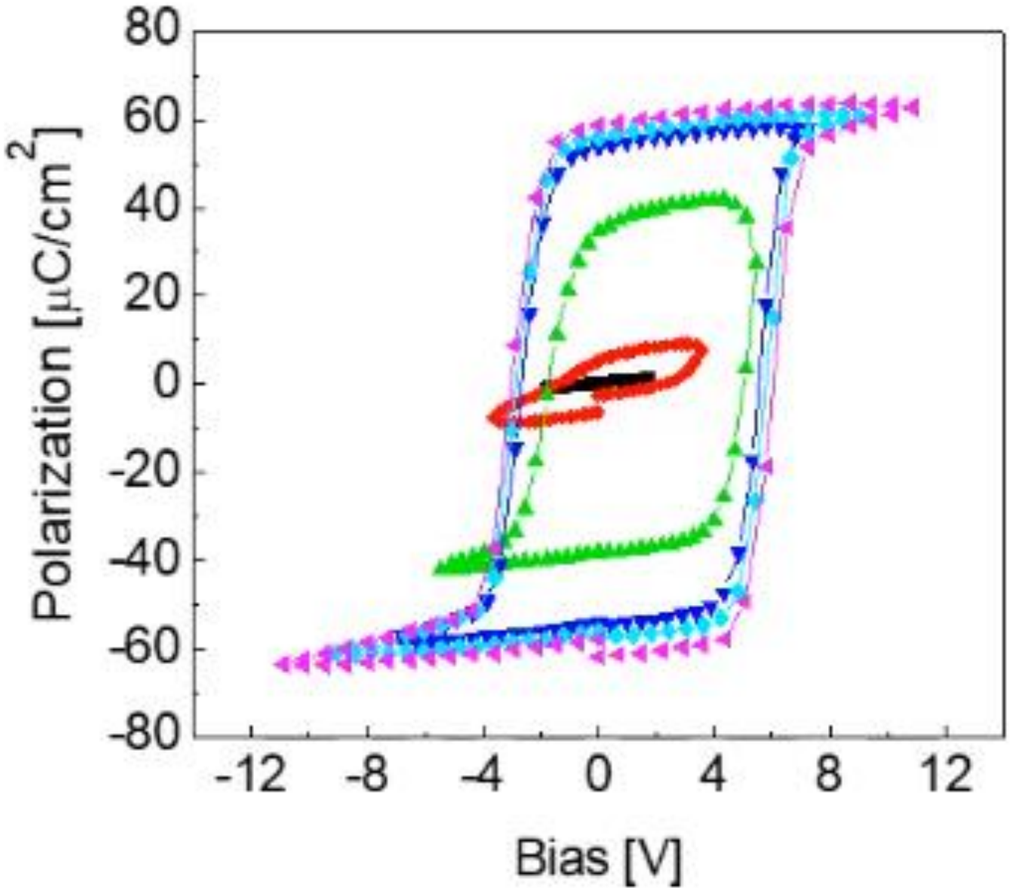


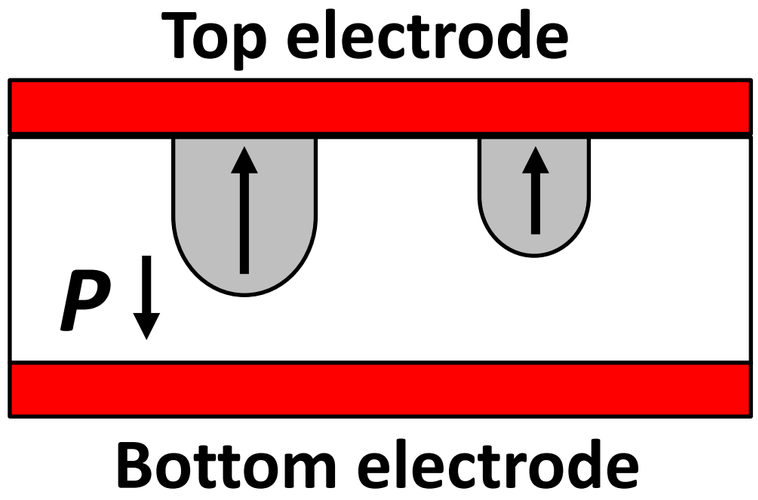




- **Use PFM tip to induce local phase transition by application of bias**
- **Domain switching reversible**
- **General model: can be used for more complex systems as well (polycrystalline materials)**

Polarization Switching in PFM





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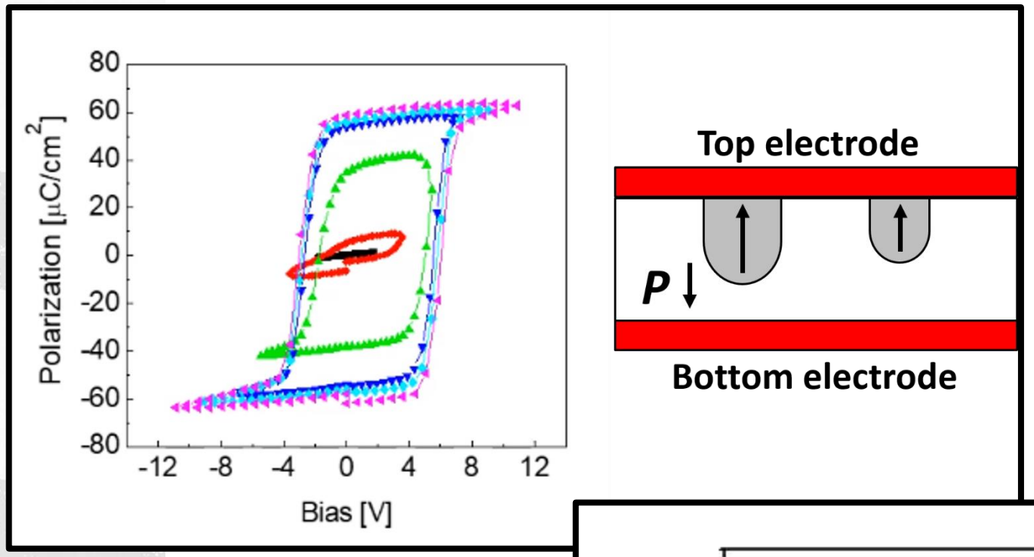

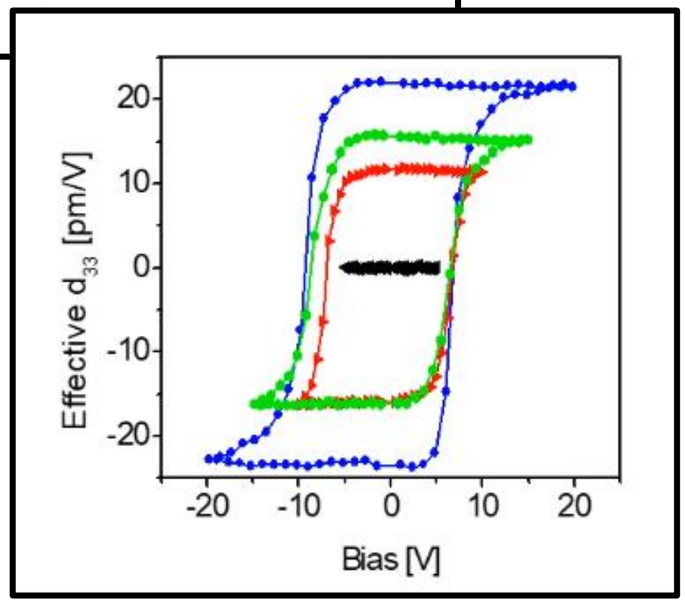

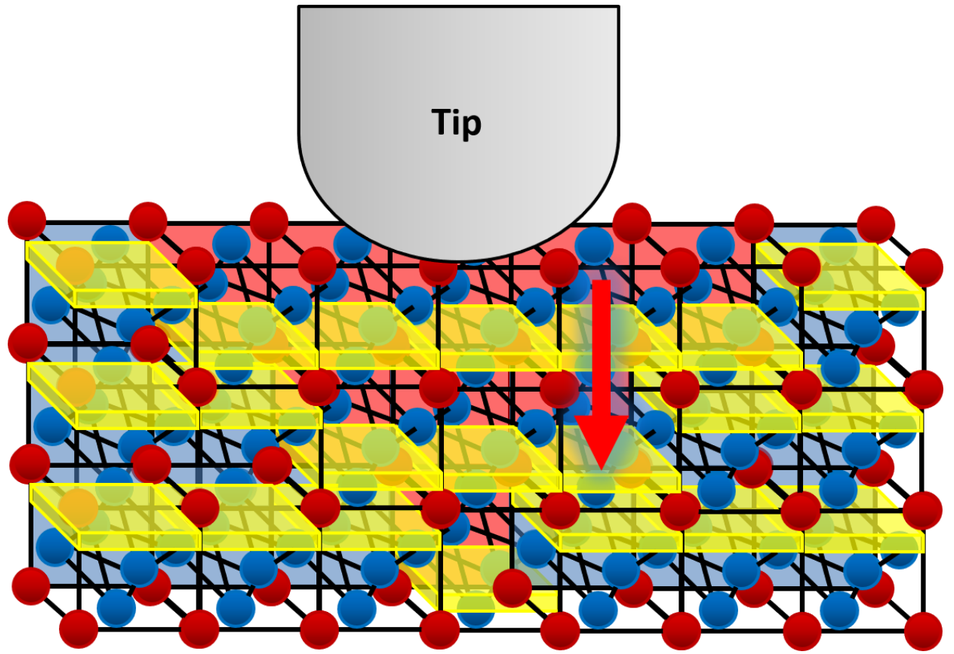

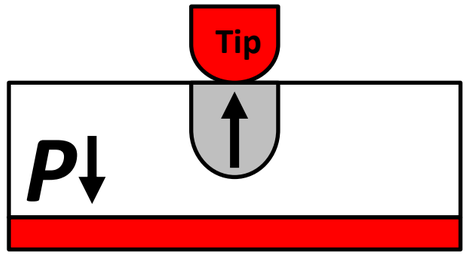

Local and macroscopic switching mechanisms

- **Domain nucleation at a finite bias**
- **Domain wall is strongly pinned (when bias is off → no relaxation)**
- **Both hysteresis loops display similar characteristic biases → possible mechanism similarities**

References

[1] Vasudevan, RK et al. , Appl Phys Rev 4 (2017) 021302.

[2] Kalinin, SV et al. , *Nano Lett* 2(6) (2002) 589–93.10.1021/nl025556u

[3] Jesse, S et al. , Rev Sci Instrum 77(7) (2006) 073702.

[4] Kalinin, SV et al. "PFM Lecture 4: Polarization switching by Piezoresponse Force Microscopy" ORNL, 21 Feb. 2019, https://youtu.be/mYeZQ8d3Mjk.

[5] Kalinin, SV et al. "PFM Lecture 5: Switching spectroscopy Piezoresponse Force Microscopy (SS-PFM)" ORNL, 21 Feb. 2019, https://youtu.be/53pqhCLURJg.