Strain-mediated parallel to antiparallel magnetization reorientation in Co/Cu multilayers

Prepared for CORE Summer 2023
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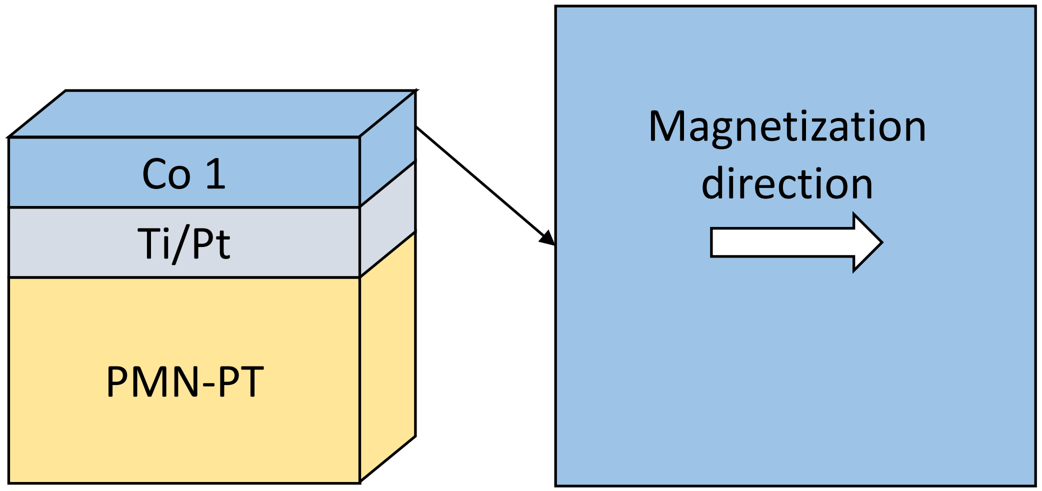
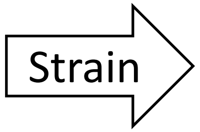
Strain-Mediated Magnetoelectric Coupling

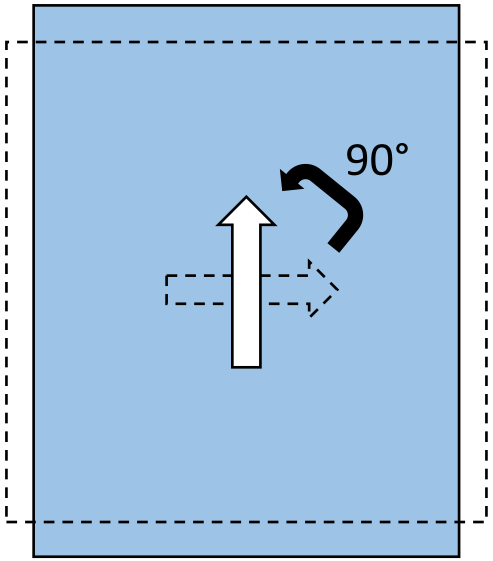


Oblique view

Top view



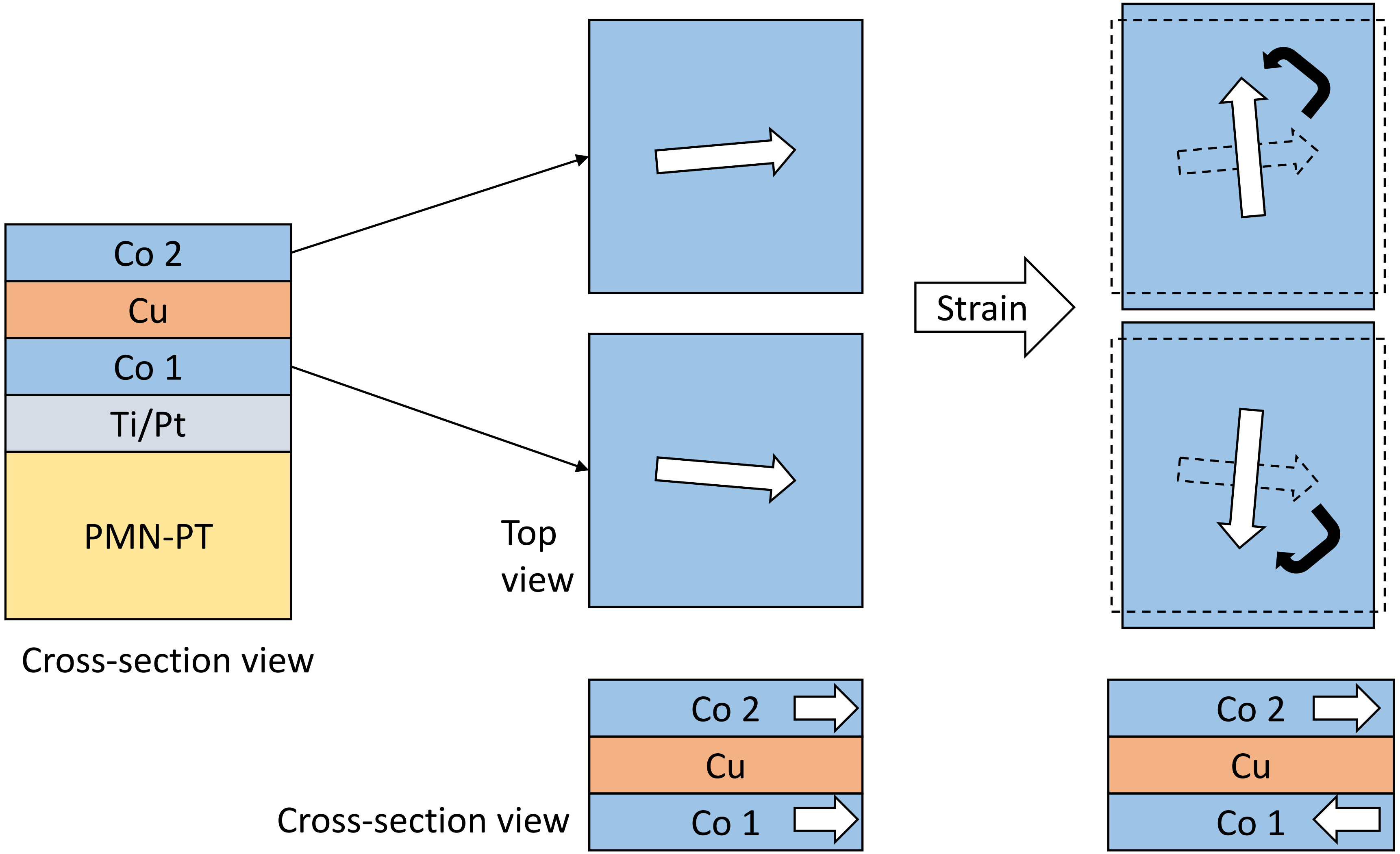
Ferroelectric PMN-PT produces strain under applied electric field



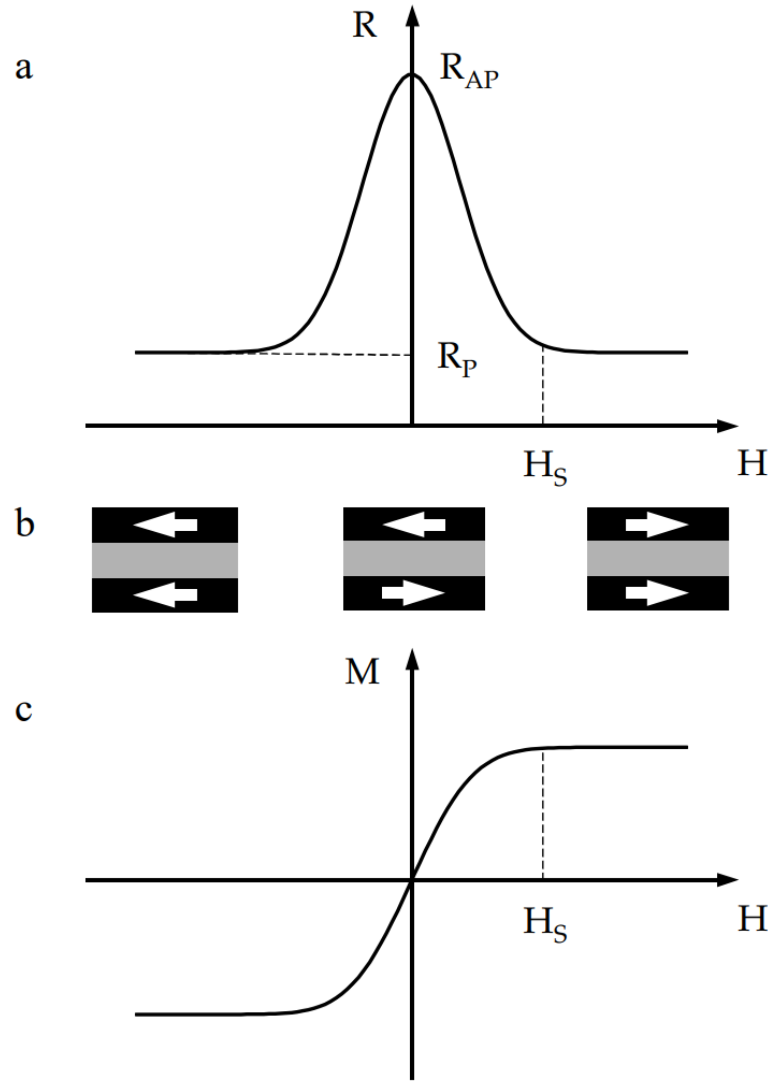
Magnetostrictive effect: Co changes magnetization direction under strain

Favored rotation direction exists due to magnetic anisotropy

Parallel-Antiparallel Magnetization Reorientation



Giant Magnetoresistance (GMR)



Achieve a large change in electrical resistance using an applied **magnetic** field

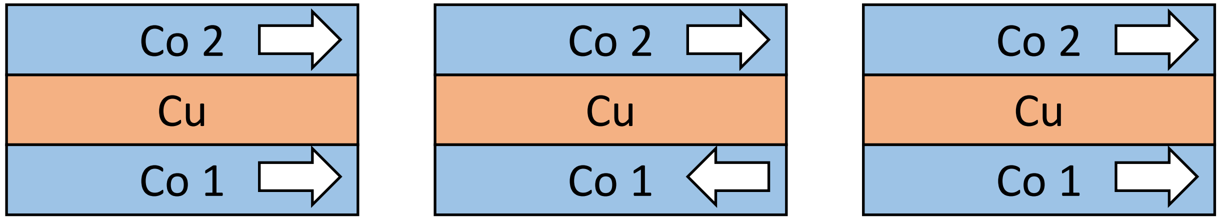


Figure from: Tsymbal & Pettifor, "Perspectives of Giant Magnetoresistance" (2001). [1]

Magnetic Memory

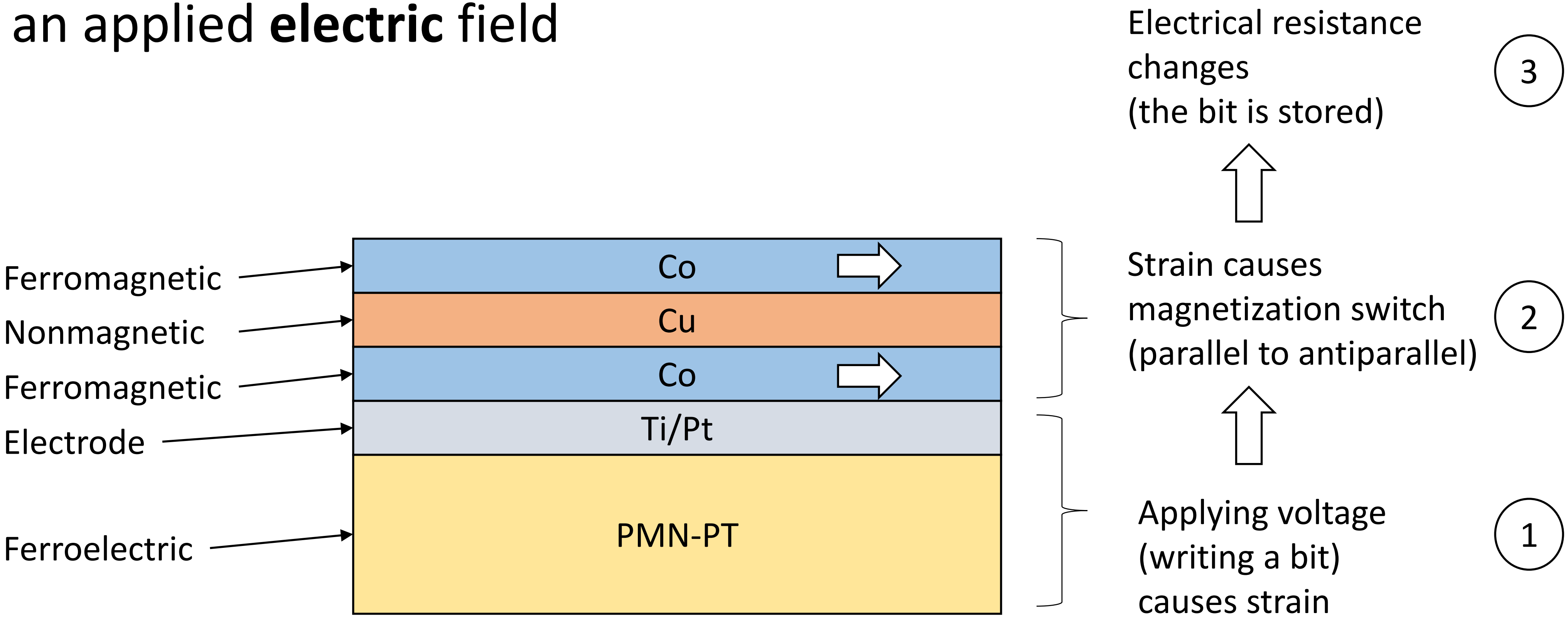
	Flash-NAND	MRAM	STT-RAM	SME-RAM
Storage capacity	>1 Gb	16 Mb	1 Gb	>>1 Gb
Write time	1 ms	20 ns	3-10 ns	<10 ns
Read time	50 ns	10 ns	10 ns	10 ns
Write energy (pJ per bit)	>0.01	70	0.1	1.6×10^{-4}

Table values transcribed from: Hu et al., *Nat Commun* **2**, 553 (2011). [2]

- Strain-mediated magnetic memory (SME-RAM)
  - No write current needed
  - Potential for much lower write energy

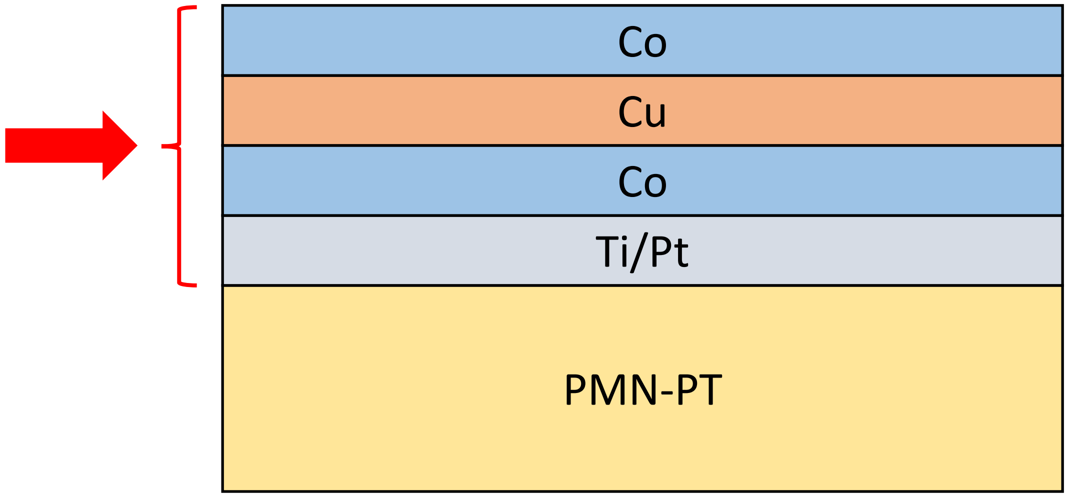
Project Overview

Achieve a large change in electrical resistance using an applied **electric** field



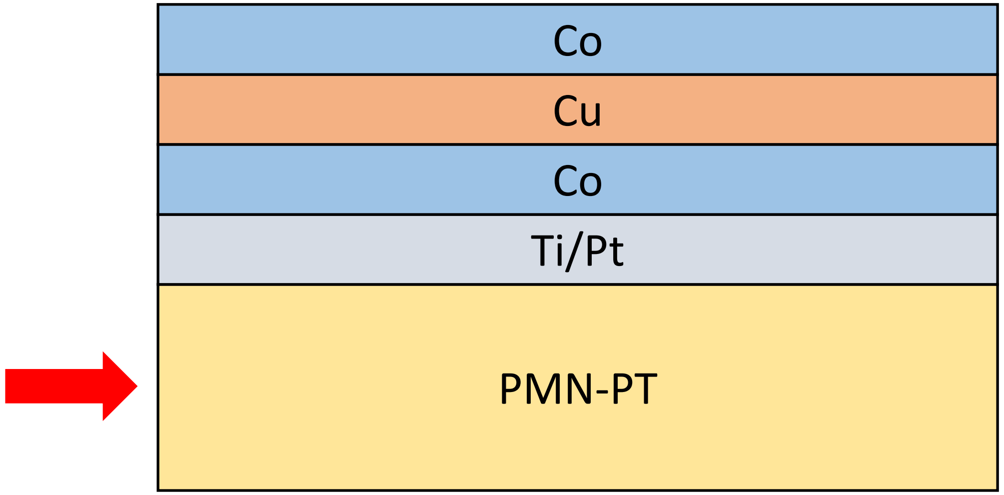
Outline

- Film growth
  - Depositing the electrode and multilayer



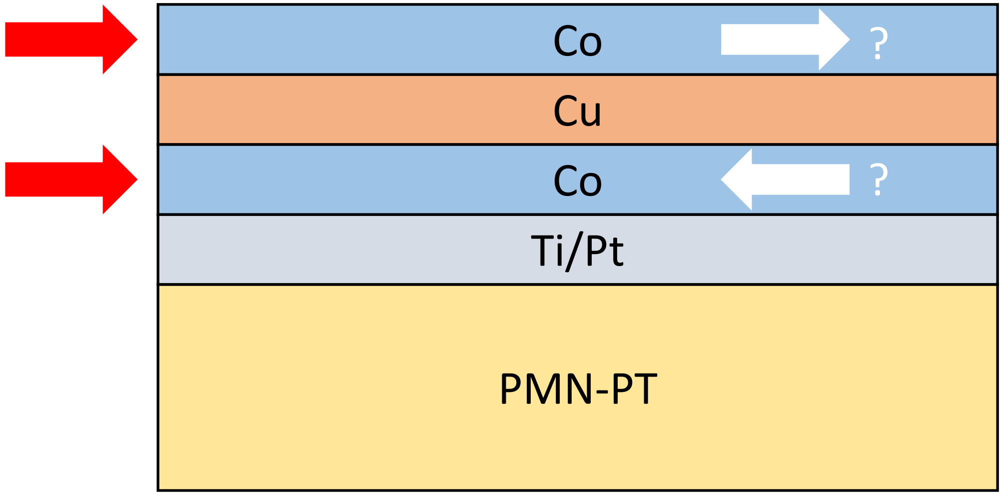
Outline

- Film growth
  - Depositing the electrode and multilayer
- Strain hysteresis
  - Measuring the bulk PMN-PT substrate



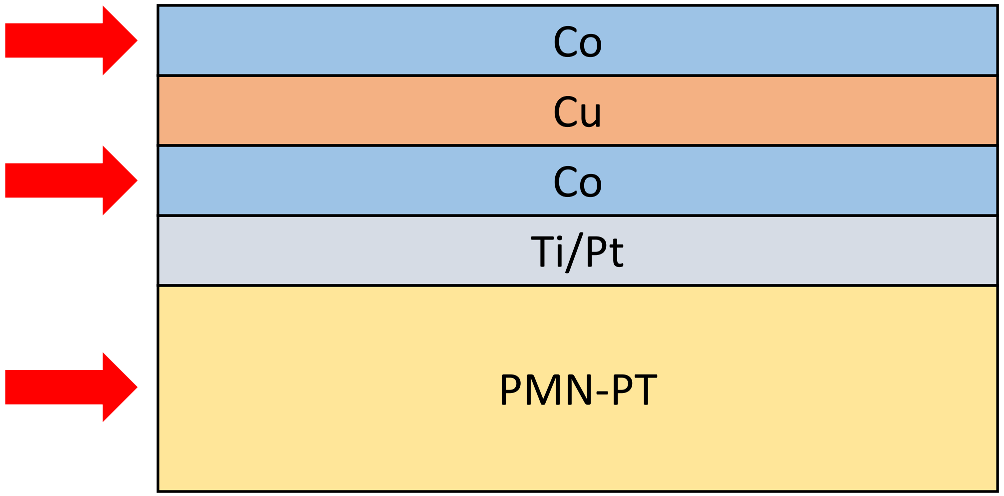
Outline

- Film growth
  - Depositing the electrode and multilayer
- Strain hysteresis
  - Measuring the bulk PMN-PT substrate
- Magnetic hysteresis
  - Characterizing the magnetic properties under different growth conditions

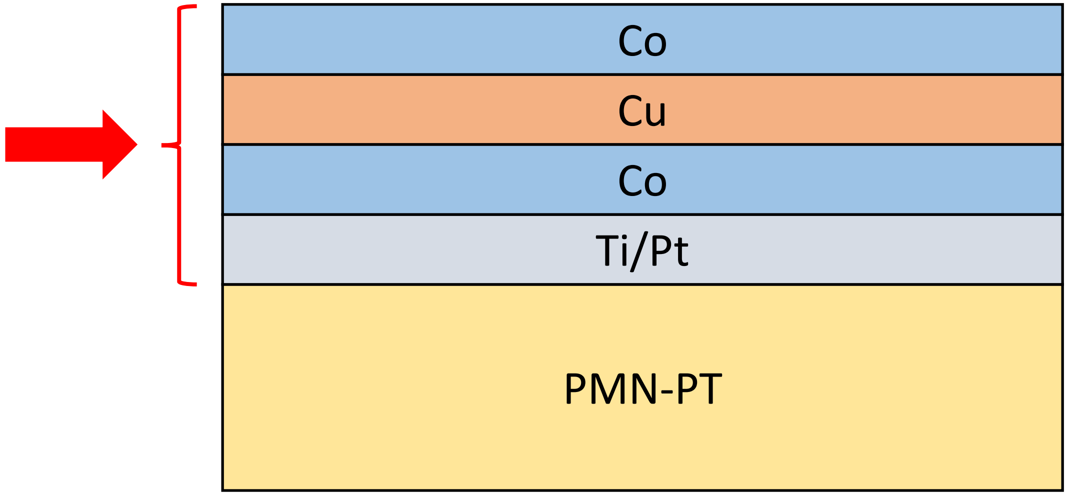


Outline

- Film growth
  - Depositing the electrode and multilayer
- Strain hysteresis
  - Measuring the bulk PMN-PT substrate
- Magnetic hysteresis
  - Characterizing the magnetic properties under different growth conditions
- X-ray diffraction & reflectivity
  - Verifying the structure of the materials



Film Growth



Film growth

- Objectives
  - Grow electrodes, Co & Cu thin films
  - Control magnetic anisotropy of Co by placing magnets in sputter chamber

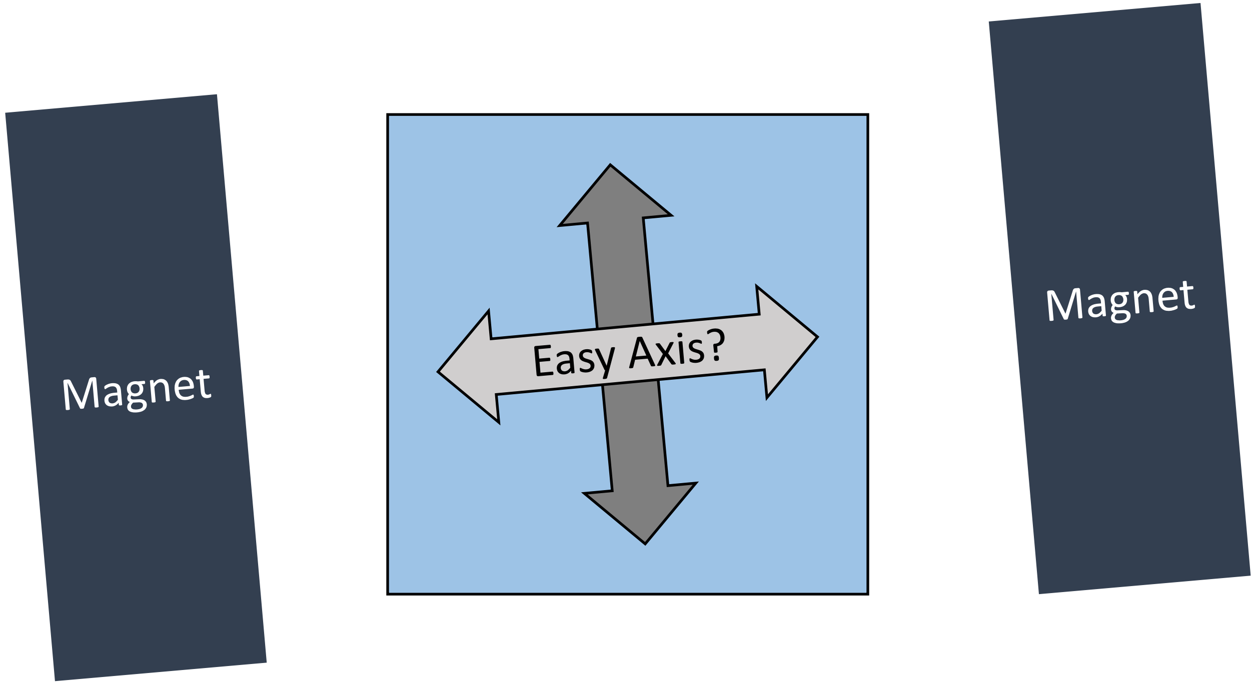
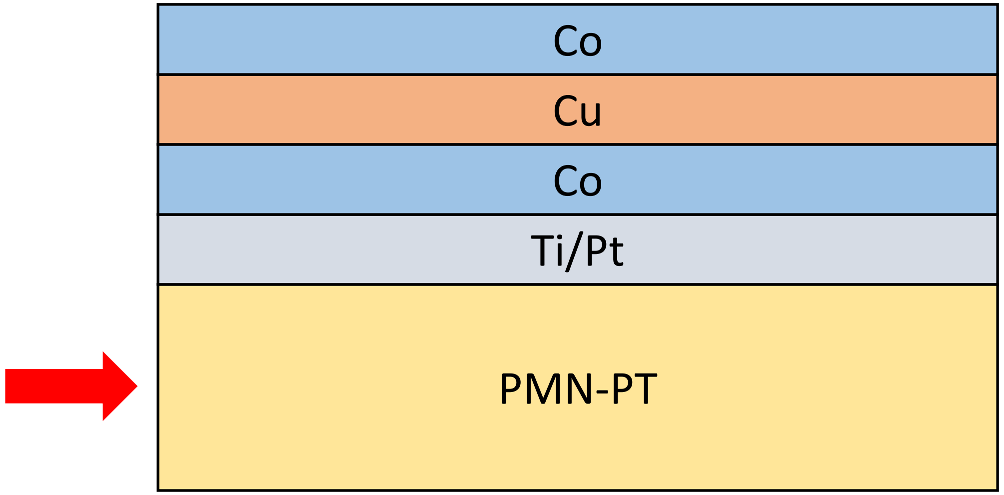


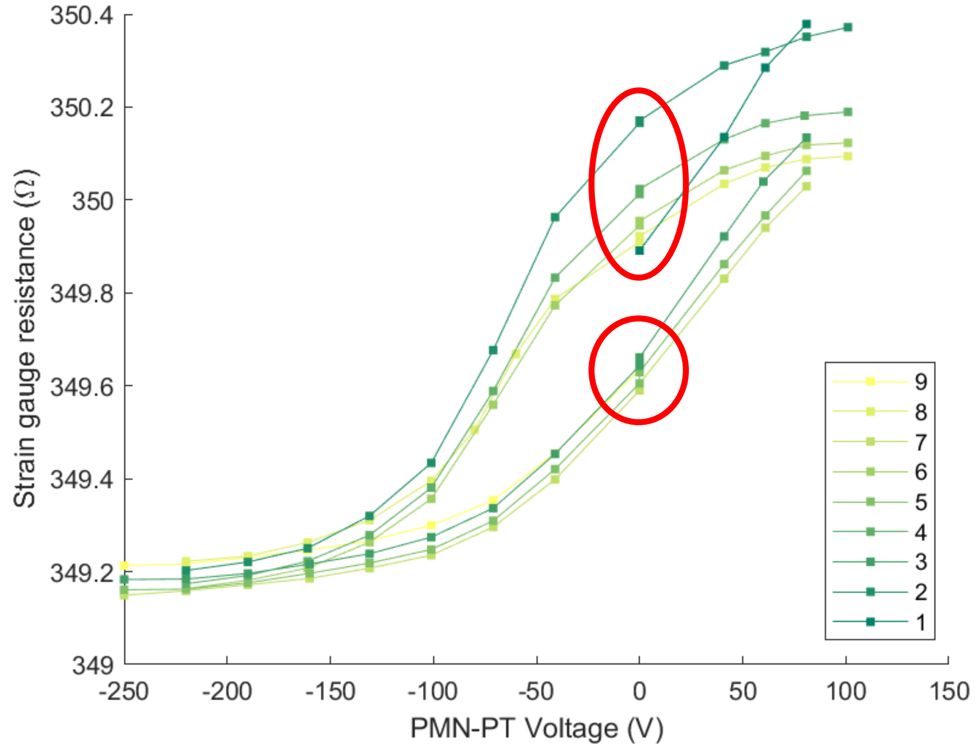
Image: NanoFab Tool: Denton Vacuum Discovery 550 Sputtering System B104 Right | NIST

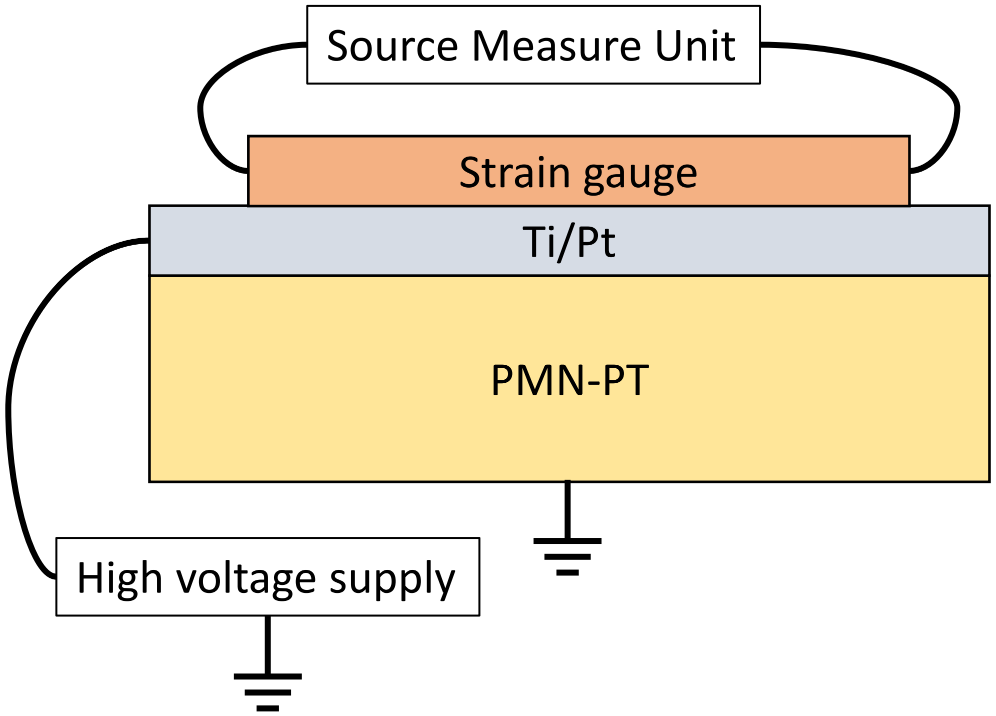
Strain hysteresis

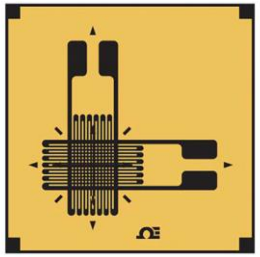


Measurement Setup

- Objective: demonstrate that we can place PMN-PT in two distinct strain states at zero voltage

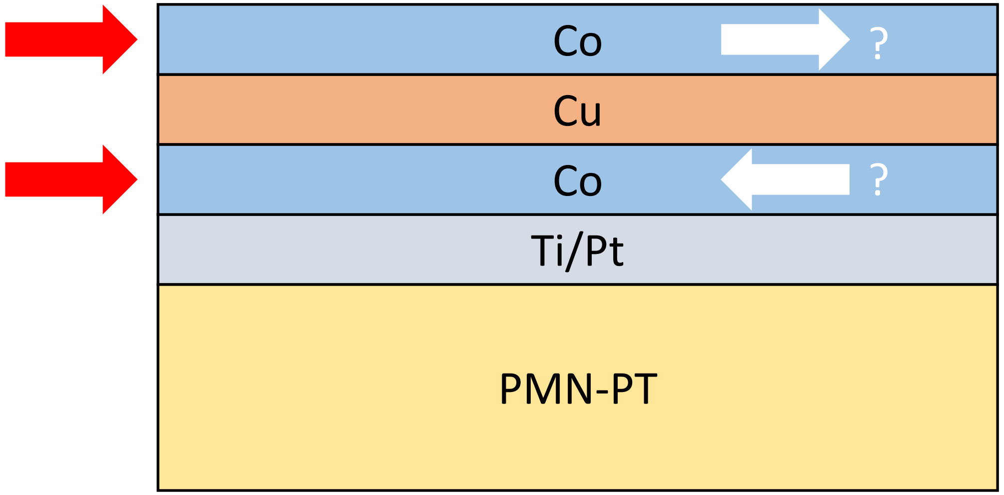






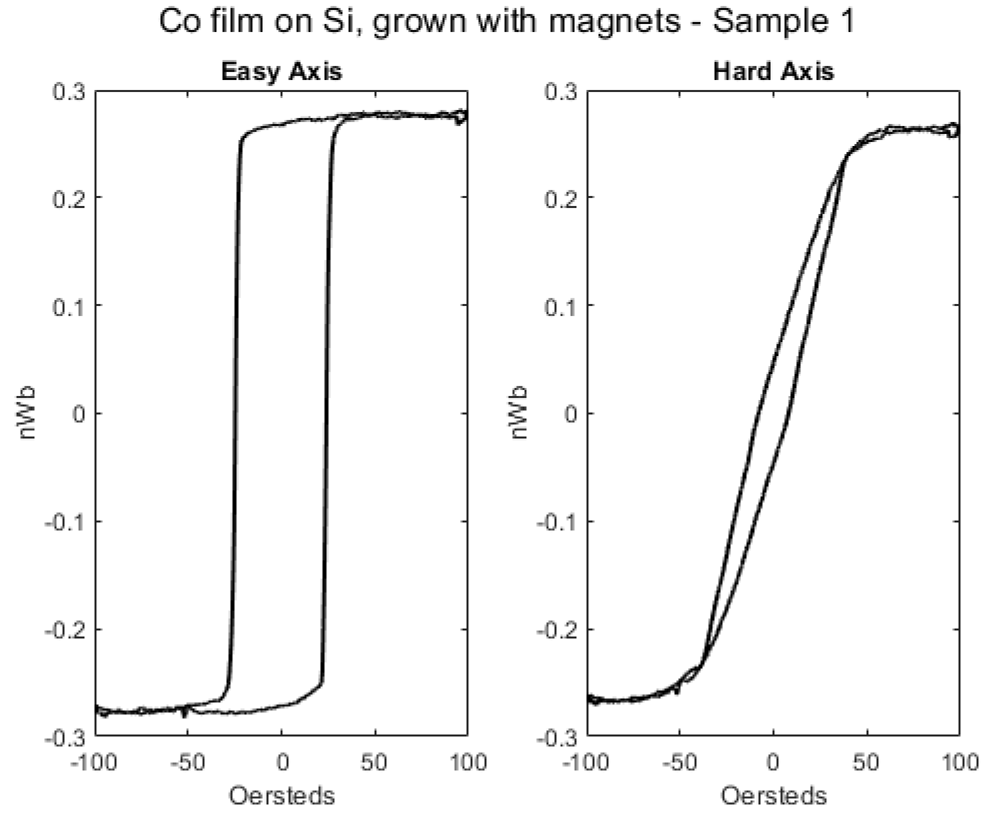
Strain gauge used
Image from: omega.com

Magnetic Hysteresis



Magnetic hysteresis measurement

- Objective: show that placing magnets in sputter growth chamber controls magnetic anisotropy direction



Hard axis directions

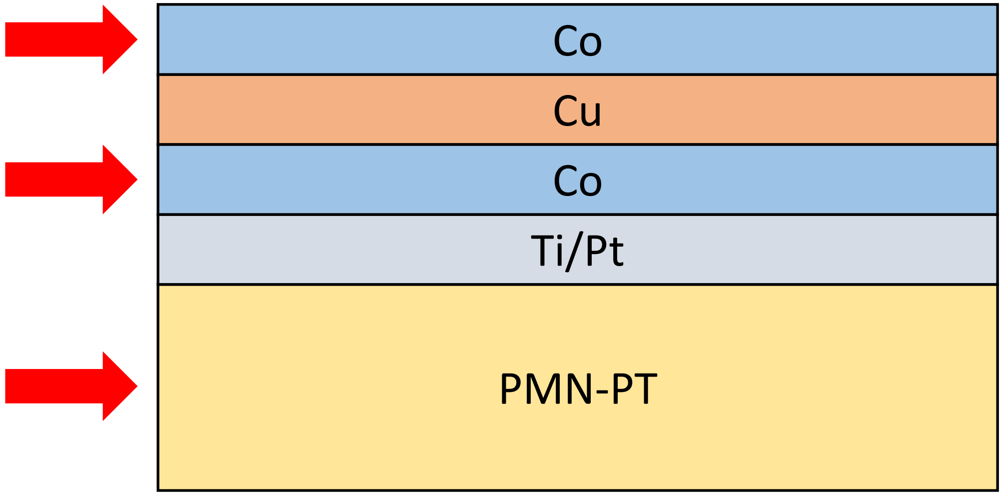
Grown without magnets

	3	5	7	9
2	4	6	8	10

Grown with magnets

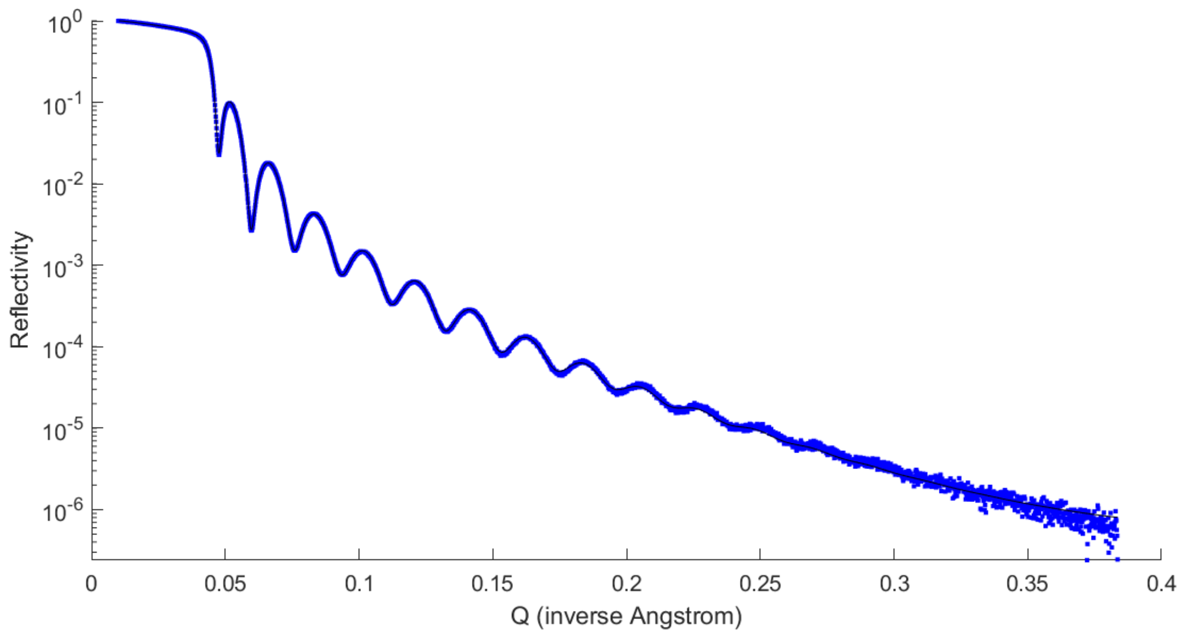
		5	7	9
2	4		8	10

X-Ray Measurements



X-ray Diffraction & Reflectivity

- Objectives
  - Estimate film thicknesses to determine sputter growth rates
  - Determine PMN-PT substrate orientations
  - Identify possible texturing in Co films



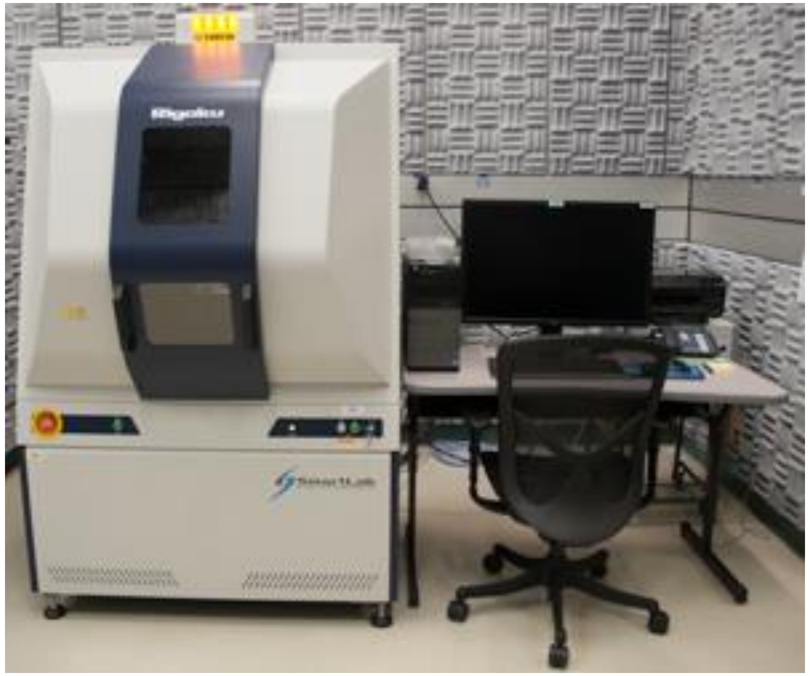


Image: NanoFab Tool: Rigaku SmartLab X-Ray Diffraction | NIST

Conclusions

Summary

- Grew electrodes, Co, Cu films by sputter deposition
- Began x-ray diffraction and reflectivity measurements for these films
- Demonstrated that two PMN-PT strain states can be achieved
- Showed effects of magnets during growth on magnetic anisotropy of sputtered Co films

Further Work

- Continue x-ray characterization
  - Identify structure changes in Co when magnets used during growth
- Take more strain hysteresis measurements of PMN-PT
  - Measure both directions with a new sample
- Take magnetic hysteresis measurements of Co films from all angles
  - Understand magnetic anisotropy characteristics
- Grow Co/Cu multilayers for magnetic measurement
  - Verify parallel to antiparallel reorientation
- Grow Co/Cu on PMN-PT to complete the device
  - Verify giant magnetoresistance-like effect

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References

1. E. Y. Tsymbal and D. G. Pettifor, "Perspectives of Giant Magnetoresistance,“ in *Solid State Physics*, H. Ehrenreich and F. Spaepen, Ed., Academic Press, 2001, vol. 56, pp. 113-237.
2. J.-M. Hu, Z. Li, L.-Q. Chen, and C.-W. Nan, *“*High-density magnetoresistive random access memory operating at ultralow voltage at room temperature,” *Nat. Commun.*, vol. 2, no. 553, Nov. 2011, doi:10.1038/ncomms1564
3. J.-J. Wang, T.-N. Yang, B. Wang, M. S. Rzchowski, C.-B. Eom, and L.-Q. Chen, “Strain-Induced Interlayer Parallel-to-Antiparallel Magnetic Transitions of Twisted Bilayers,” *Adv. Theory Simul.*, vol. 4, no. 2000215, Mar. 2021, doi:10.1002/adts.202000215

Extra Slides

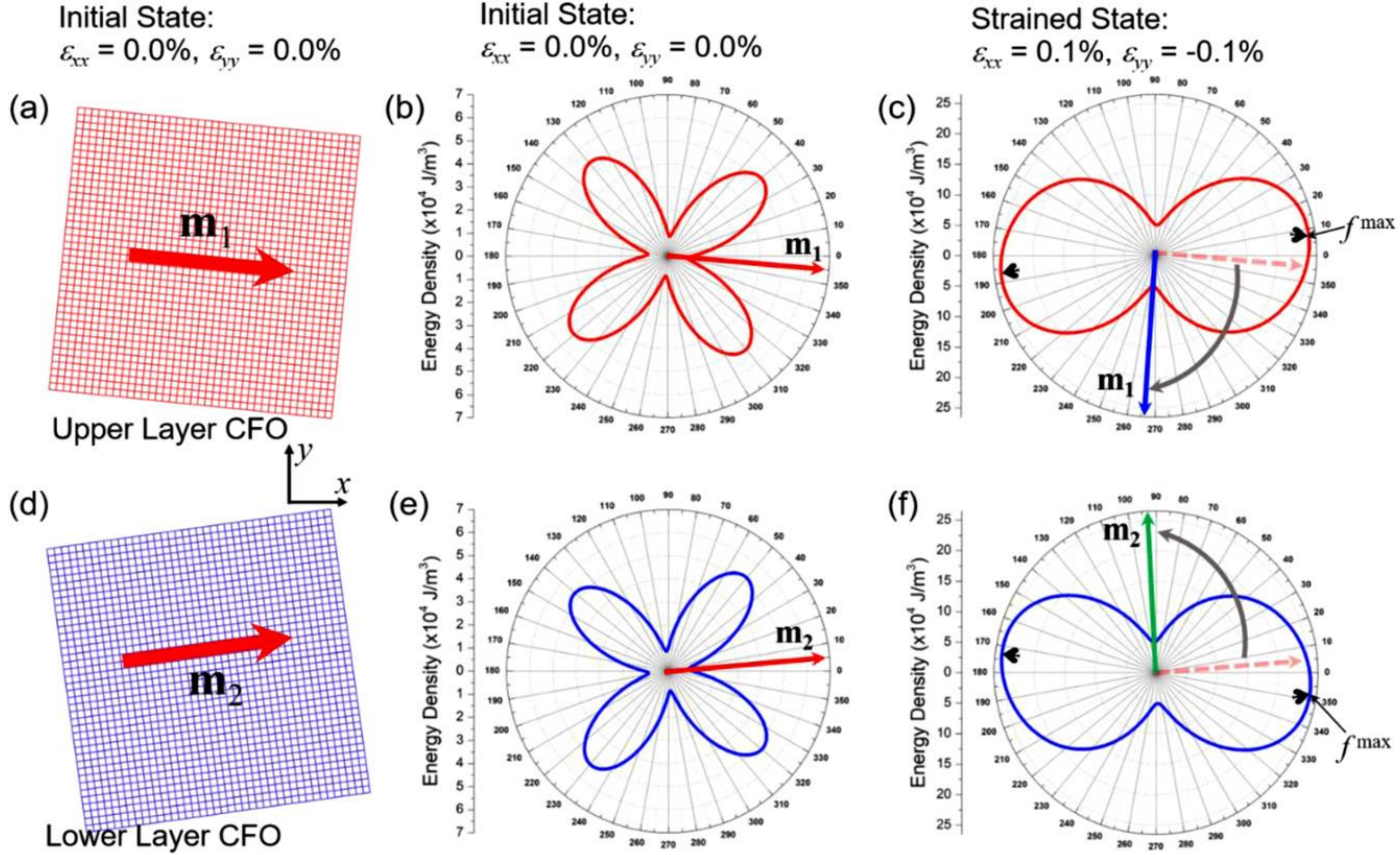

Figure from: Wang et al., *Adv Theory Simul* **4**, 3 (2021). [3]

Wheatstone Bridge Setup