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Ferroelectric HfO_2 Thin Films

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MicroE Microelectronic Engineering

Project Objectives

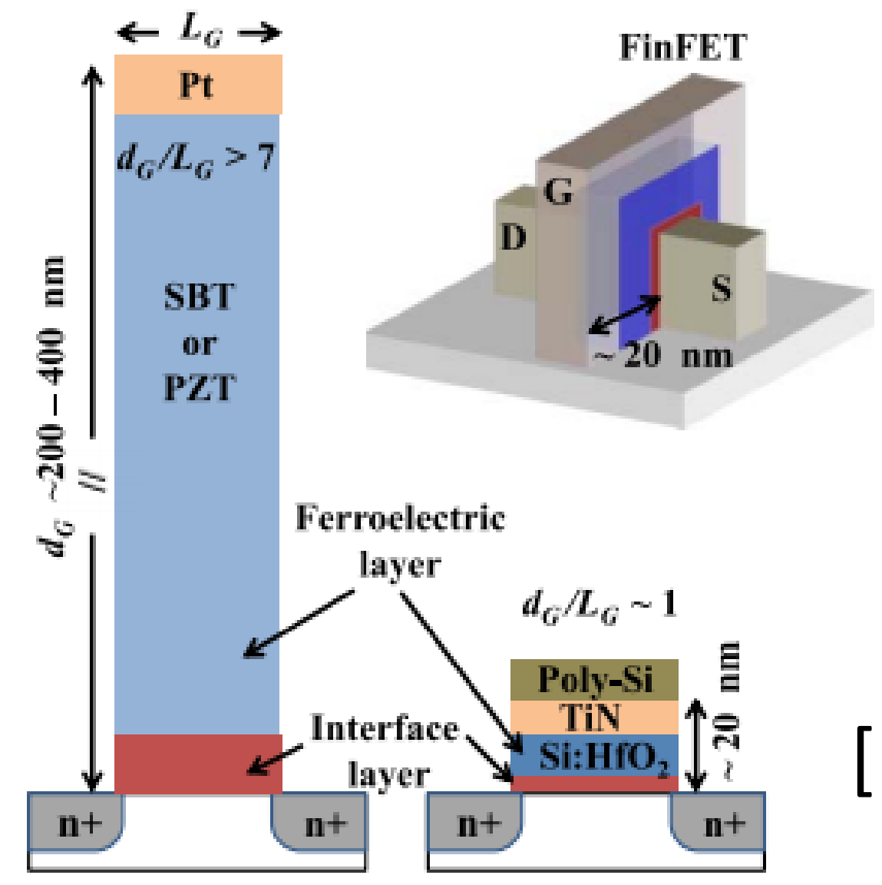
Goal: To enable ferroelectric device research at RIT and to that end:

1. Developing an RIT process for fabrication of ferroelectric HfO_2 devices
2. Enabling characterization of said films through set-up of a new ferroelectric test system

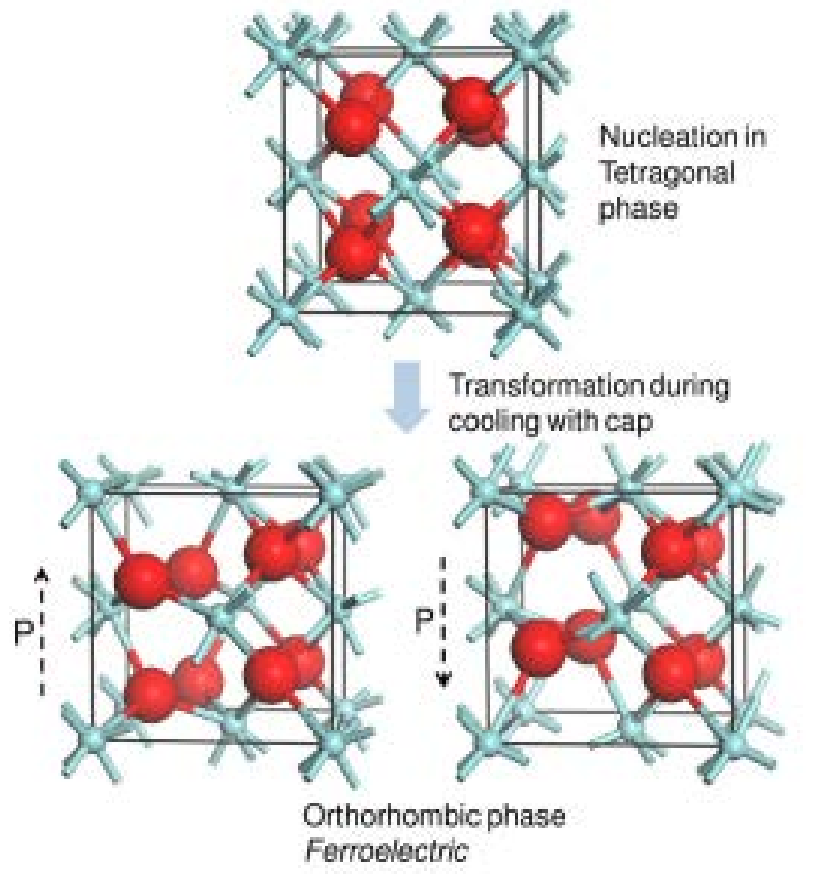
Background

Ferroelectricity - electrically induced polarization in the crystal lattice - is a promising candidate for non-charge based memory.

- Ferroelectricity in HfO_2 is stronger than ceramic films (1MV/cm vs 50 kV/cm), enabling reduction in gate height. [1]



[1]



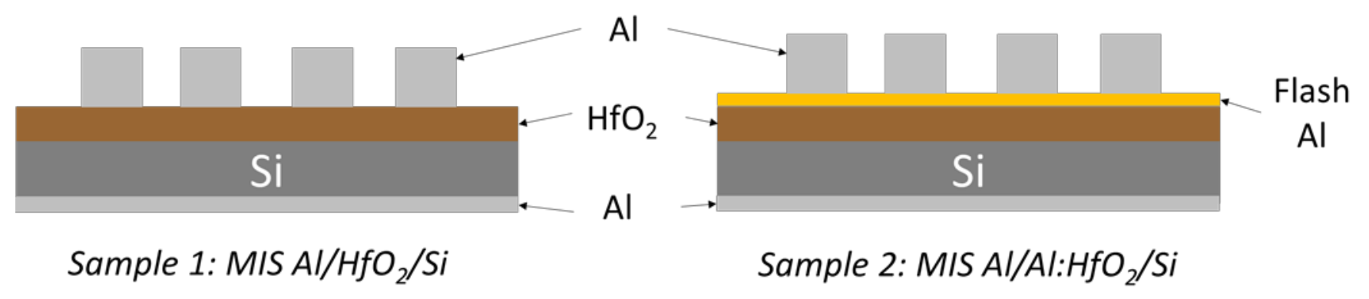
[2]

- Doping of HfO_2 makes the ferroelectric phase more favourable. Ferroelectricity reported in ALD HfO_2 with Al, Y, or Si dopants. Results also seen with Y and Hf reactive co-sputtering. [3, 4]
- TiN or SiO_xN_y used as an interfacial layer between ferroelectric capacitor and substrate [1]
- TiN layer used above ferroelectric gate to help coerce the HfO_2 layer into a ferroelectric (FE) phase [2]

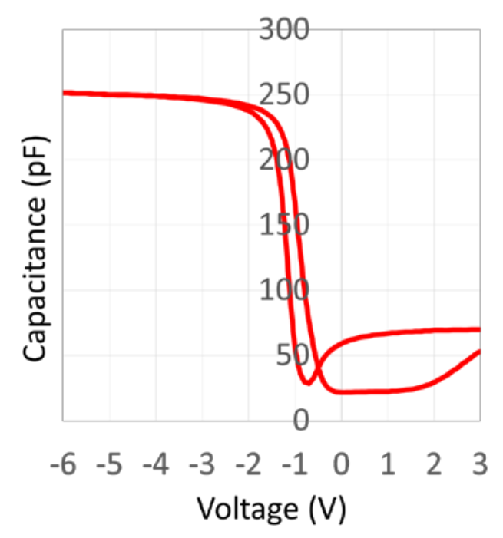
Previous RIT Work

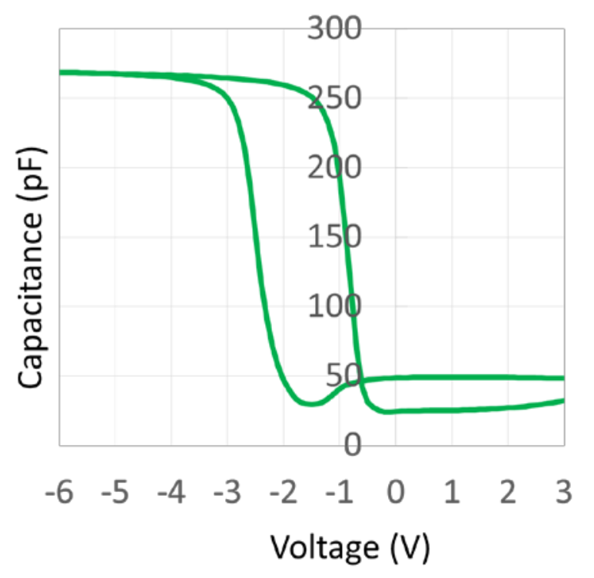
RIT fabricated samples yielded what was potentially a ferroelectric film

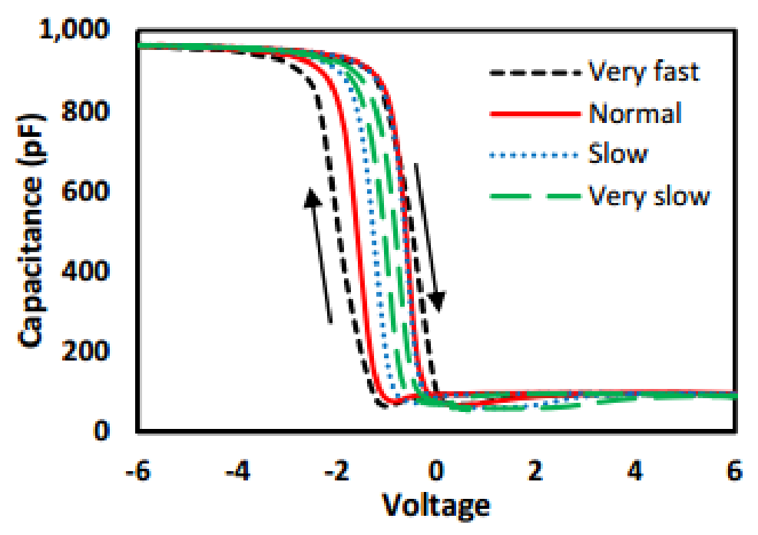
- Further testing showed that memory window was dependent on CV sweep speed, ruling out ferroelectricity as the cause



Speed	Speed measurement	Sweep step (V)	Delay (s)
Fast	Fast	0.5	0.5
Normal	Normal	0.1	1
Slow	Slow	0.04	3
Very slow	Slow	0.02	10







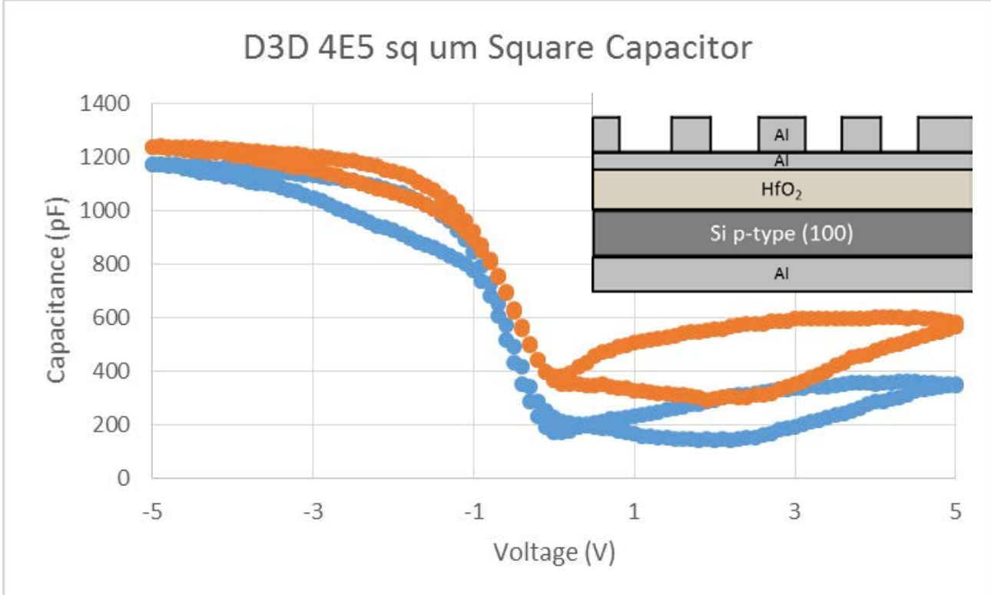
Process Development

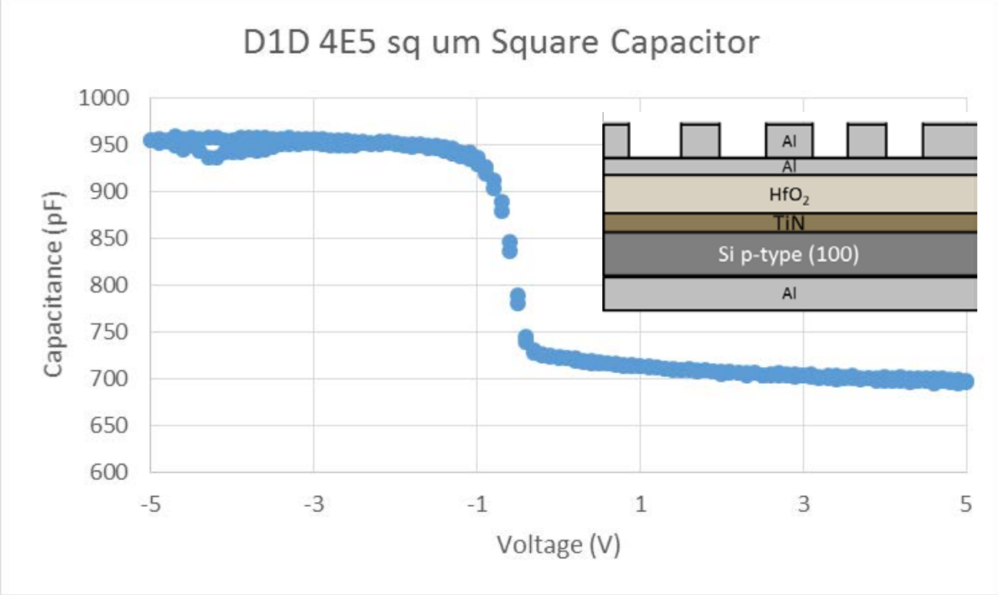
Experimental Setup and Results

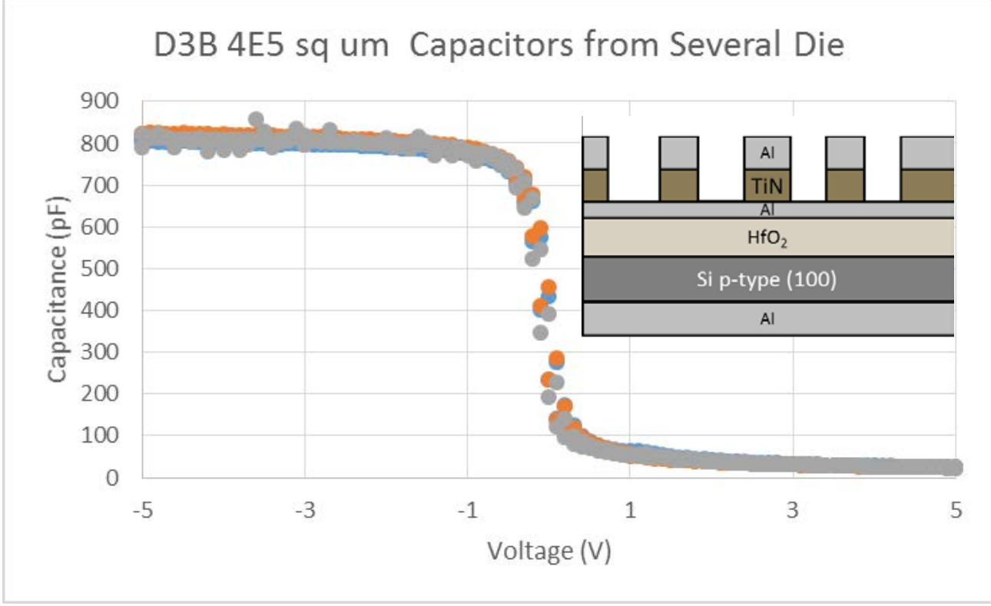
The effects of top TiN, bottom TiN, anneal method (rapid thermal vs. furnace), and Al deposition method (sputtered vs evaporated) were investigated

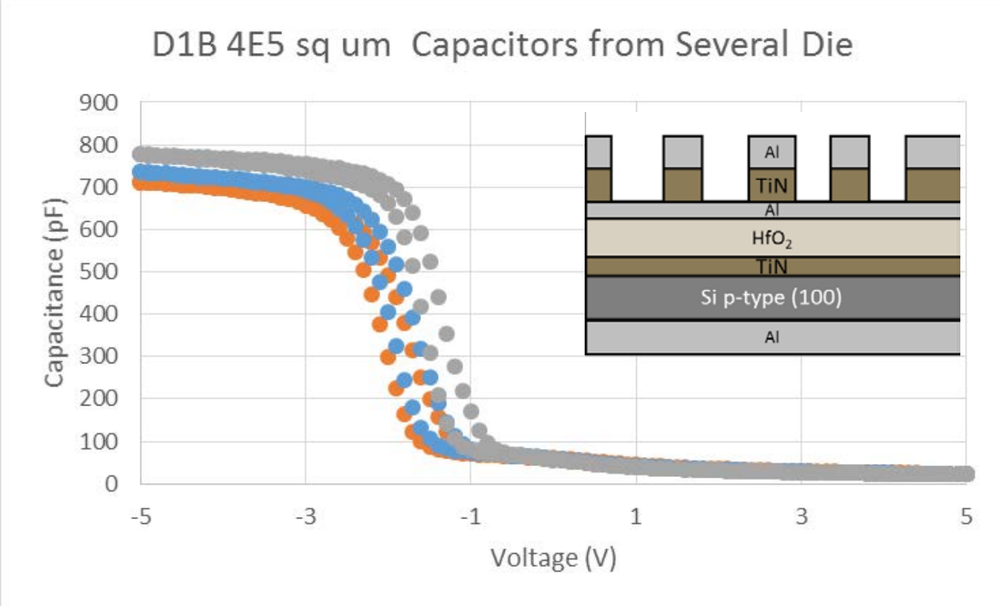
- Thin Al deposited via sputtering dissolved during 2nd level lithography development
- Samples with top TiN layer show potential ferroelectricity
- Sample with bottom TiN shows larger memory window than the sample without a diffusion barrier
- Samples have 3 < k < 5, similar to the NaMLab sample (4.2)

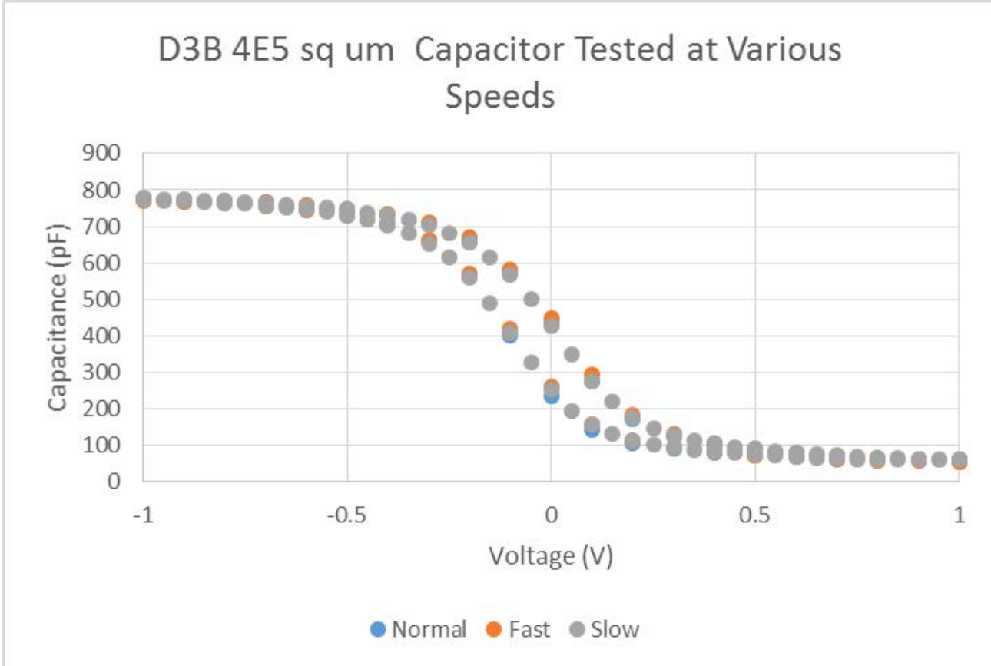
CV Results – Furnace Anneal (1hr 600°C)

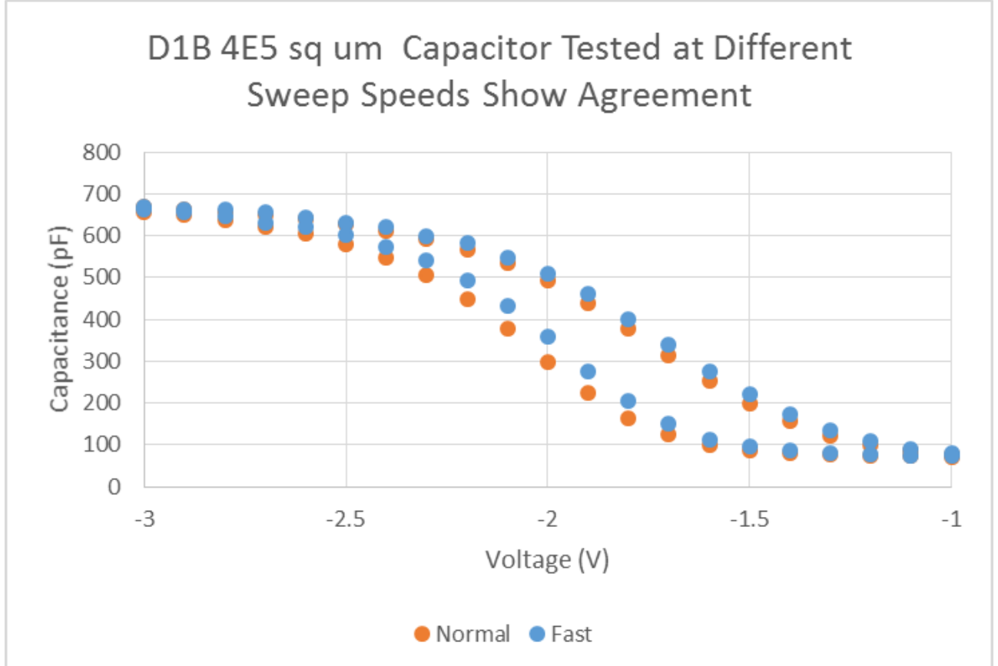




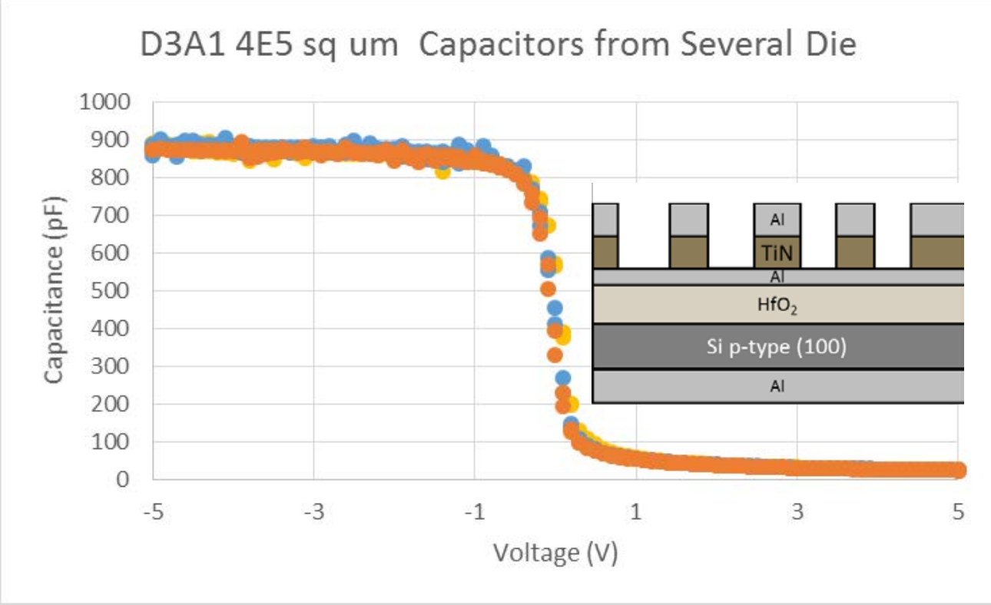


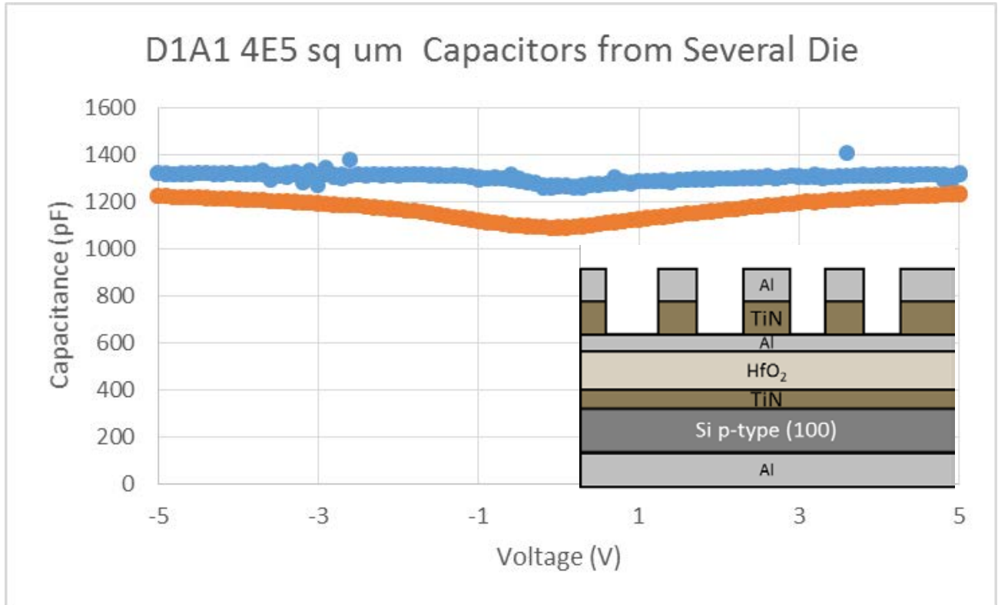




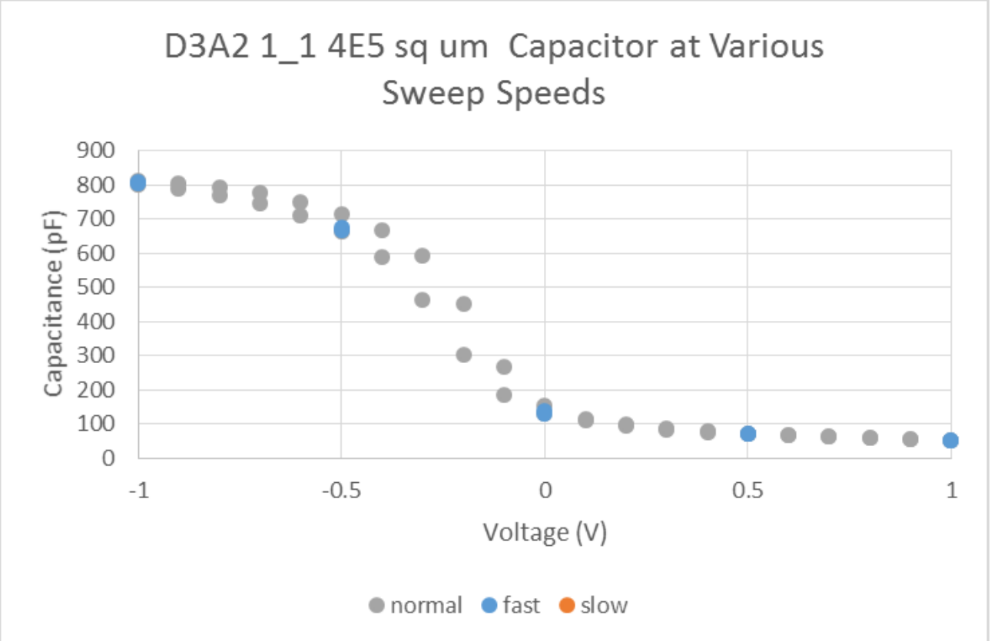


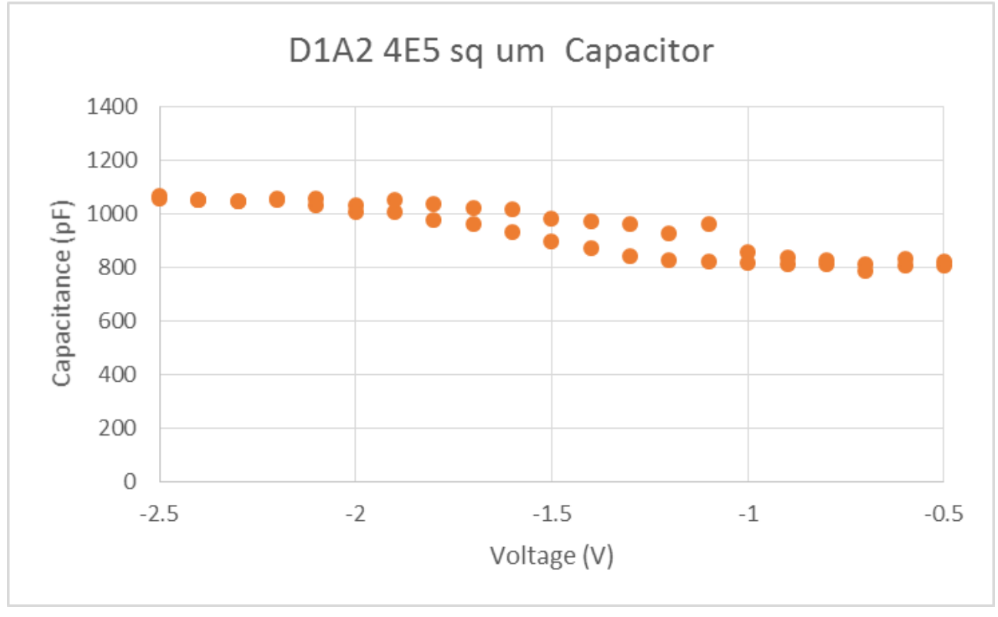
CV Results – Rapid Thermal Anneal



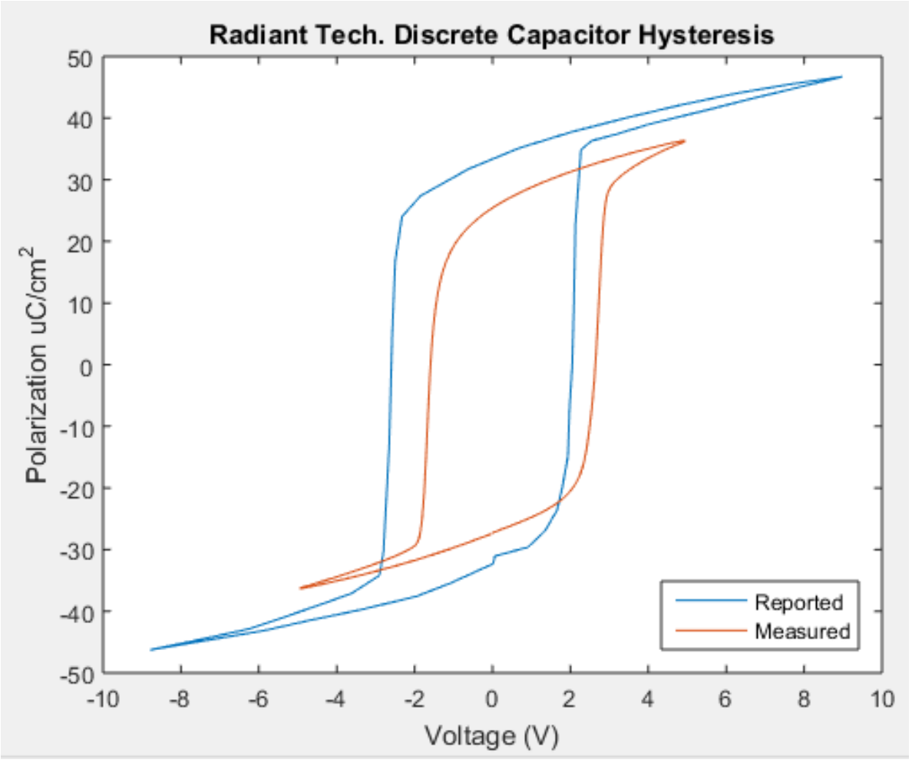


1s 1000°C anneal (above) and 20s 850°C anneal (below)

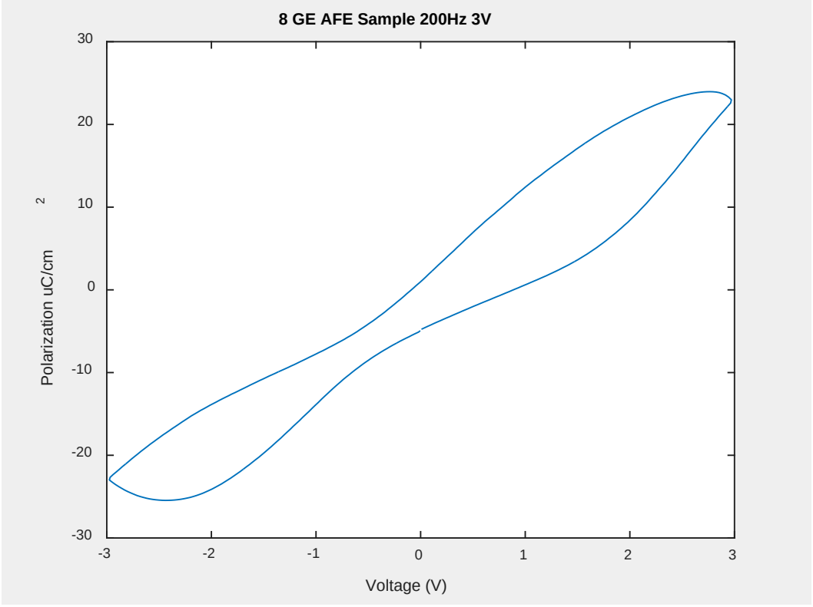


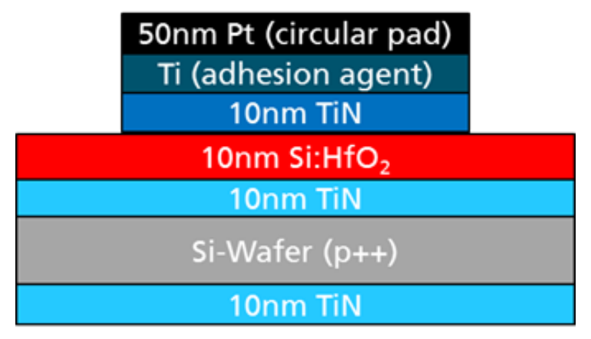


aixACCT TF1000 Ferroelectric Tester

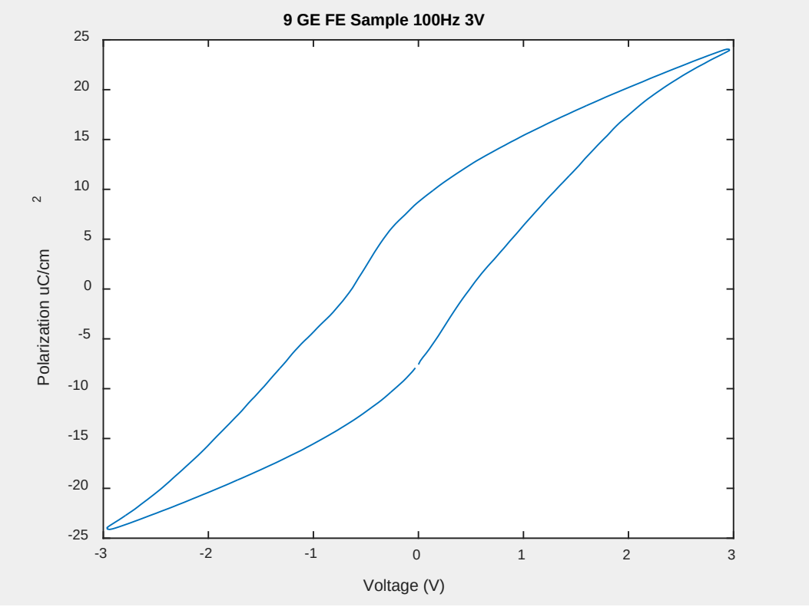


- Discrete ferroelectric (PZT) capacitors measured and compared to company-reported "typical" performance data (above). Small differences likely caused by process variation [5]
- NaMLab fabricated anti-ferroelectric and ferroelectric HfO_2 samples measured by RIT (below).





namlab nanoelectronic materials laboratory



Conclusions

- Sputtered Al thin films may be less dense than evaporated films given their differences in dissolution rate when exposed to a base
- A TiN cap is seen to have a large contributing effect to inducing a ferroelectric phase in Al doped HfO_2
- Doped HfO_2 samples show a comparable memory window to PZT with a film that is a tenth of the thickness

References

[1] E. Yurchuk, J. Muller, J. Paul, T. Schlosser, D. Martin, R. Hoffmann, *et al.*, "Impact of Scaling on the Performance of HfO2-Based Ferroelectric Field Effect Transistors," *Ieee Transactions on Electron Devices,* vol. 61, pp. 3699-3706, Nov 2014.

[2] T. S. Boescke, J. Muller, D. Brauhaus, U. Schroder, and U. Bottger, "Ferroelectricity in hafnium oxide thin films," *Applied Physics Letters,* vol. 99, p. 3, Sep 2011.

[3]T. Olsen, U. Schroder, S. Muller, A. Krause, D. Martin, A. Singh, *et al.*, "Co-sputtering yttrium into hafnium oxide thin films to produce ferroelectric properties," *Applied Physics Letters,* vol. 101, p. 4, Aug 2012.

[4]U. Schroeder, S. Mueller, J. Mueller, E. Yurchuk, D. Martin, C. Adelmann, *et al.*, "Hafnium Oxide Based CMOS Compatible Ferroelectric Materials," *Ecs Journal of Solid State Science and Technology,* vol. 2, pp. N69-N72, 2013.

[5] J. Joe T. Evans, "The Relationship between Hysteresis and PUND Responses," ed: Radiant Technologies, Inc., 2008.

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