# Ferroelectric $HfO_2$ Thin Films

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## Project Objectives

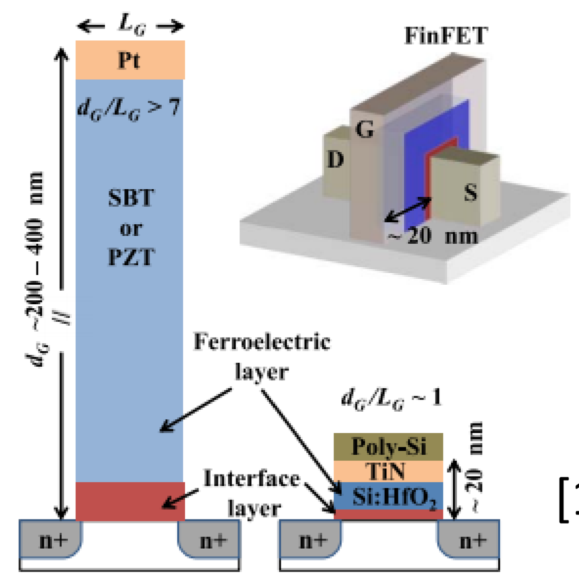
**Goal: To enable ferroelectric device research at RIT and to that end:**

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

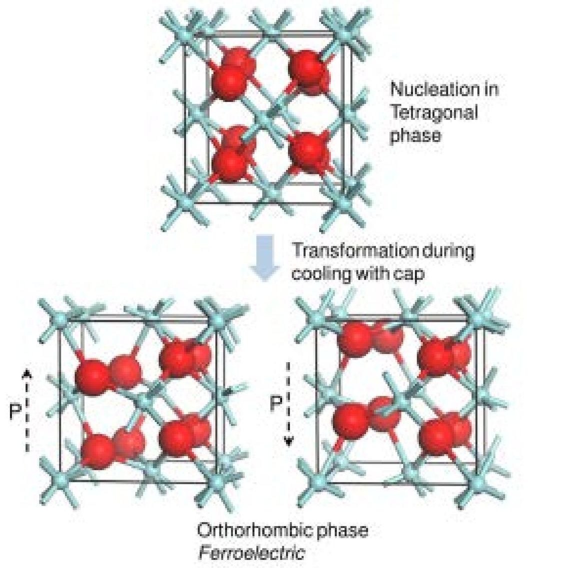
## Background

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]



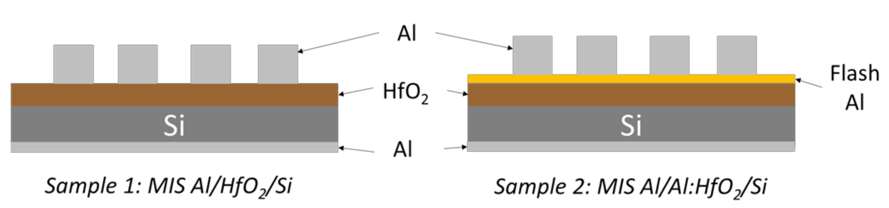

[2]

- 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]

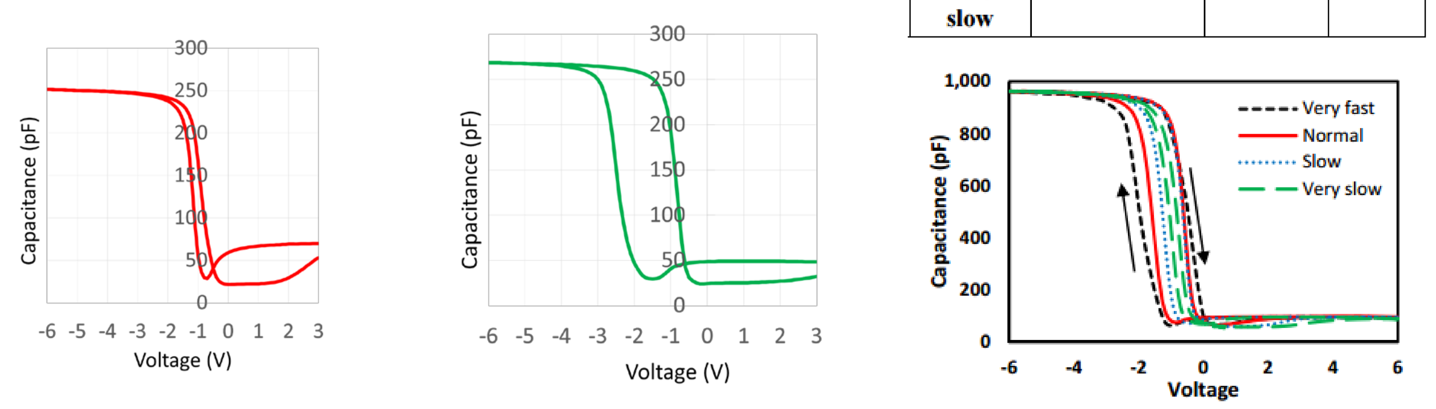
## Previous RIT Work

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 |



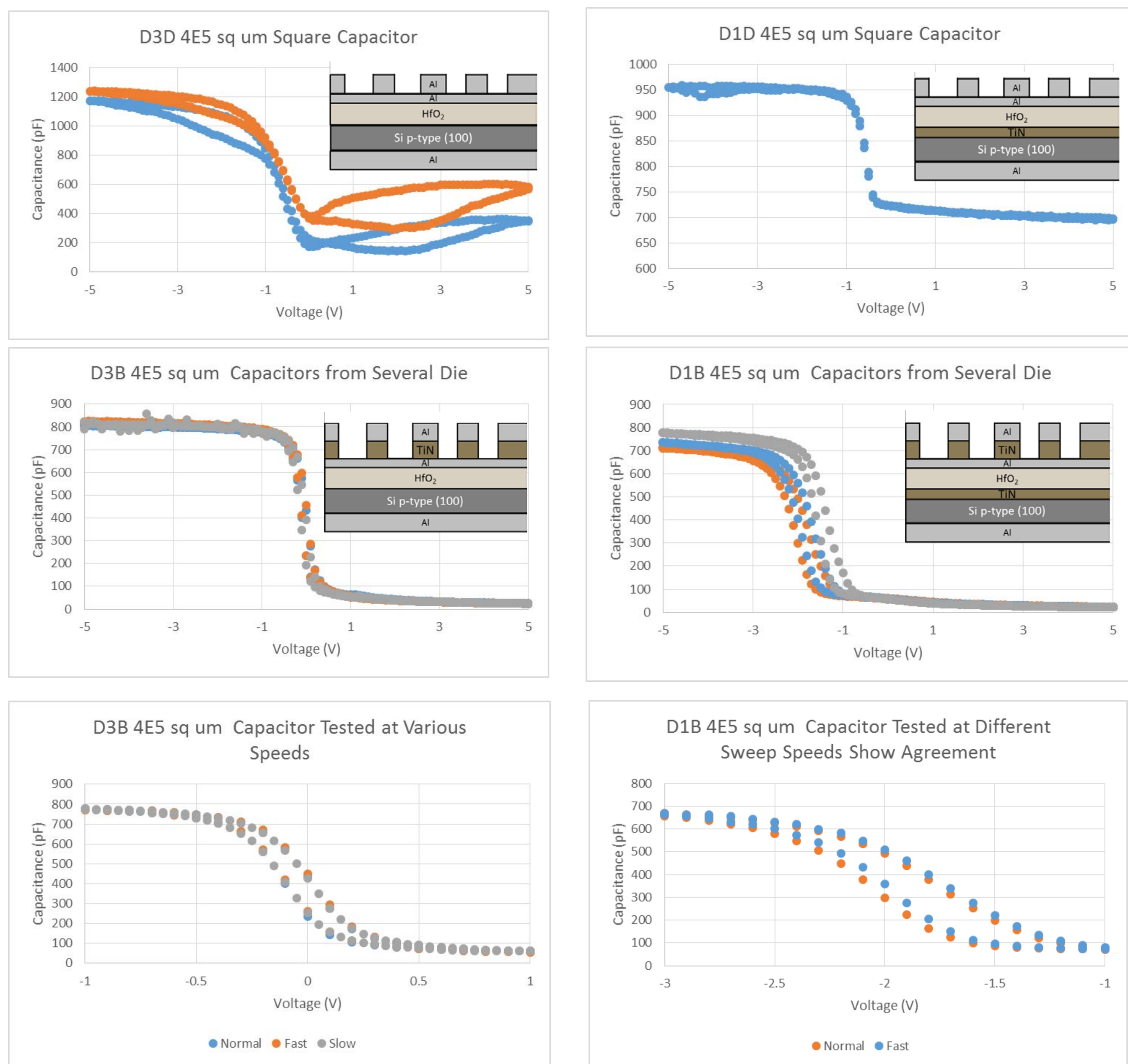

## Process Development

### Experimental Setup and Results

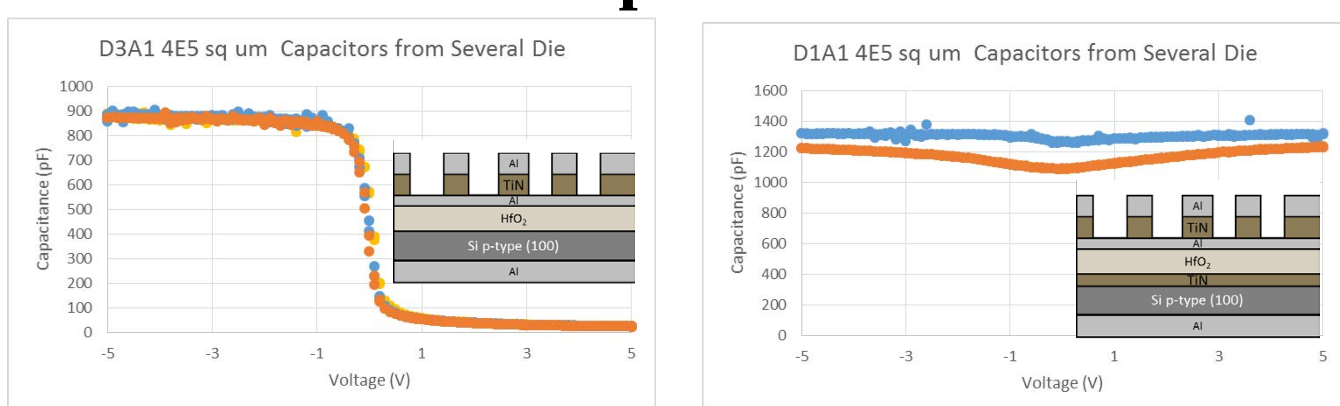
The effects of top TiN, bottom TiN, anneal method (rapid thermal vs. furnace), and Al deposition method (sputtered vs evaporated) were investigated

- 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)

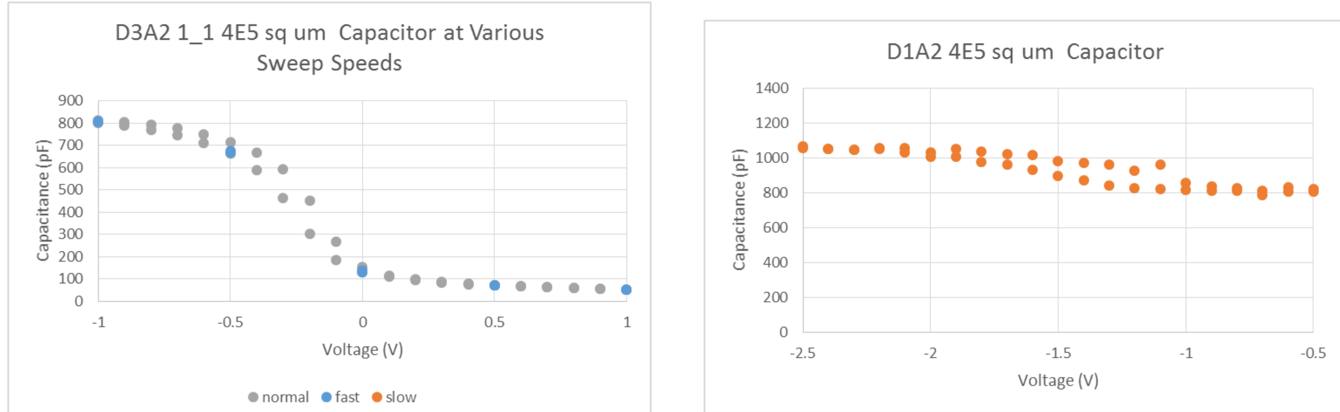
### CV Results – Furnace Anneal (1hr 600°C)



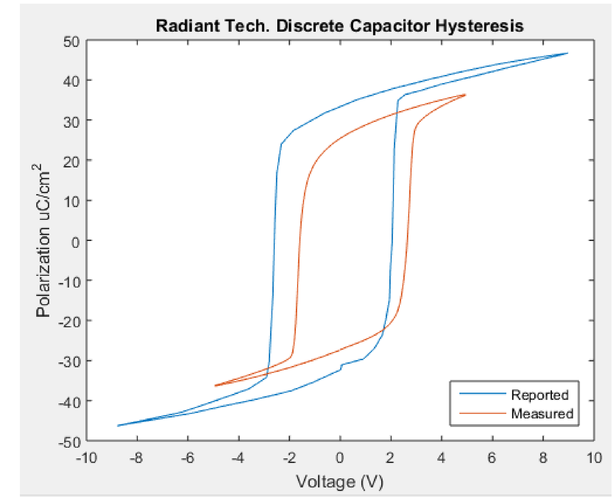

### CV Results – Rapid Thermal Anneal

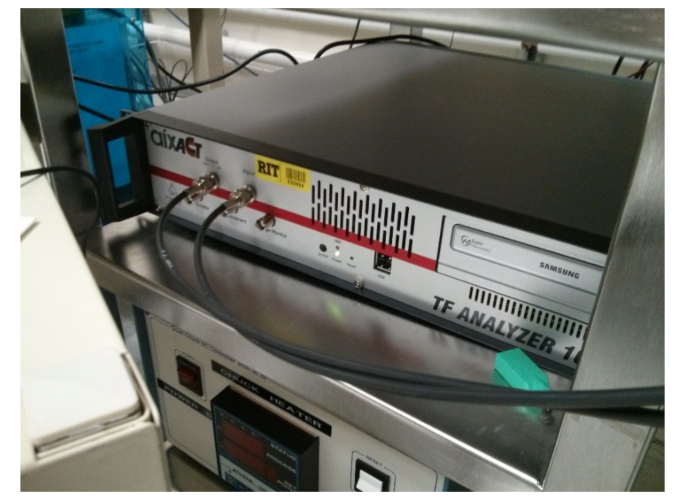



1s 1000°C anneal (above) and 20s 850°C anneal (below)

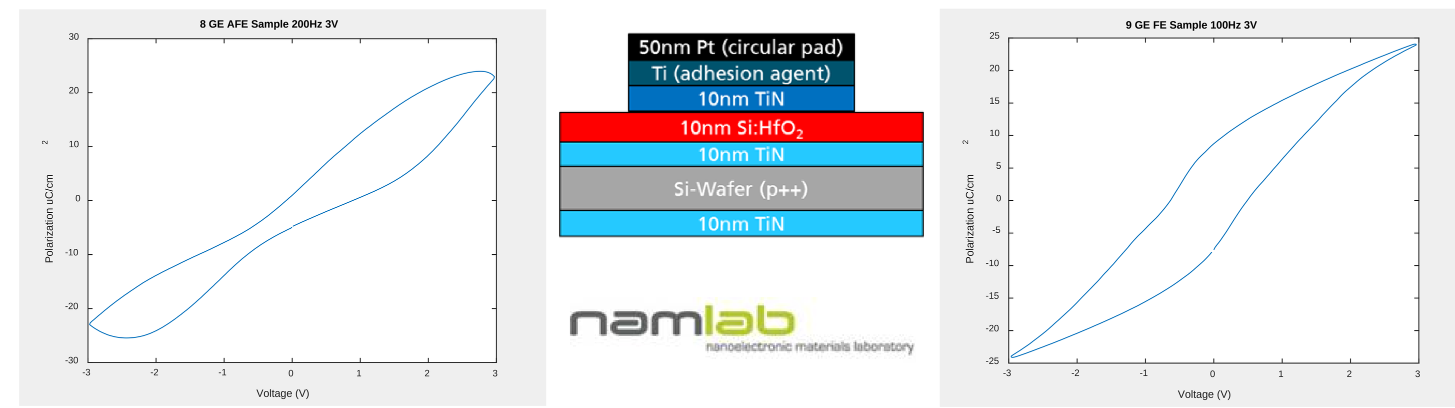



## aixACCT TF1000 Ferroelectric Tester




- 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).




## 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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