Annealing Study of ALD Deposited Ferroelectric Al-doped HfO_2

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Project Objectives

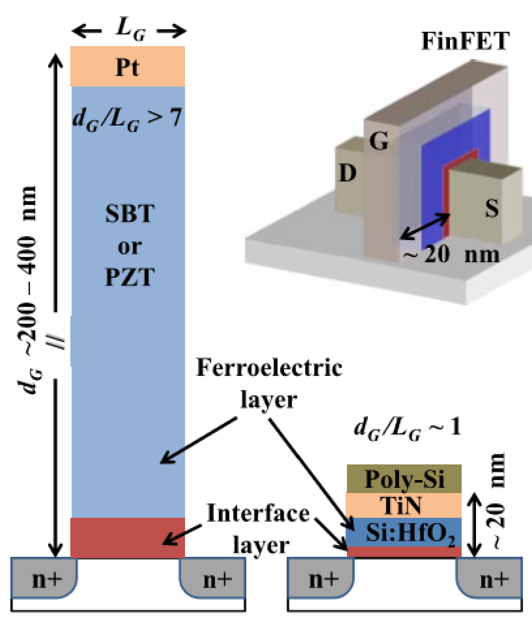
Goal: To deposit ferroelectric HfAlO using ALD at RIT

1. Develop ALD recipe for ferroelectric Al-doped HfO_2
2. Fabricating capacitors with ferroelectric Al:HfO_2 as dielectric
   a) Fabricate both PMA and PDA devices
3. Perform polarization and current testing on fabricated capacitors to verify ferroelectricity
   a) Compare PMA devices to PDA devices

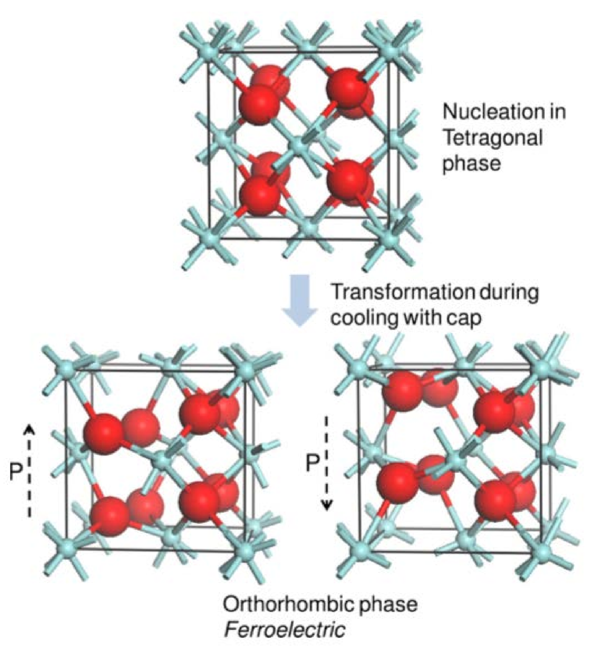
Background

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

• Ferroelectricity in HfO2 is stronger than ceramic films (1MV/cm vs 50 kV/cm), enabling reduction in gate height. [1]



[1]



[2]

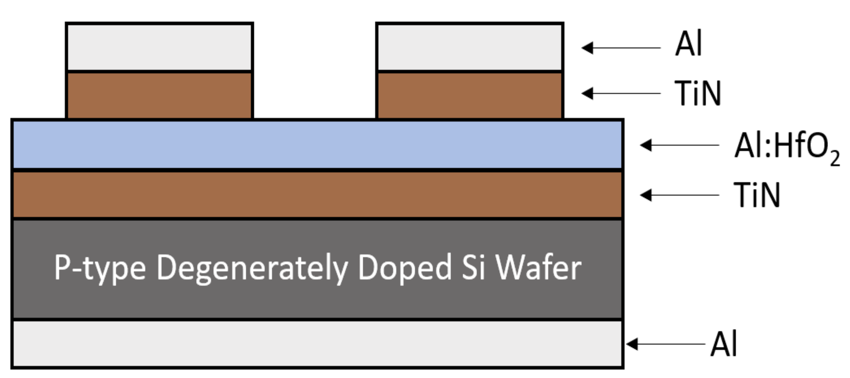
• Doping of HfO_2 makes the ferroelectric phase more favorable. Ferroelectricity reported in ALD HfO2 with Al, Y, or Si dopants. Results also seen with Y and Hf reactive co-sputtering. [3, 4]

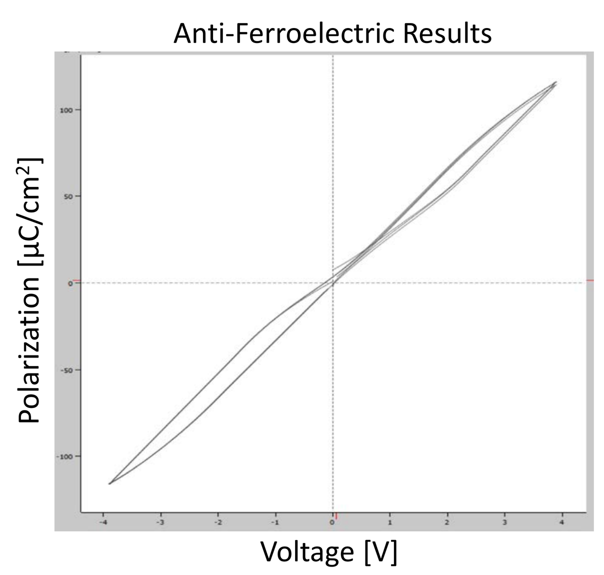
• TiN or SiO_xN_y used as an interfacial layer between ferroelectric capacitor and substrate [1]

• TiN layer used above ferroelectric gate to help coerce the HfO2 layer into a ferroelectric (FE) phase [2]

Previous RIT Work

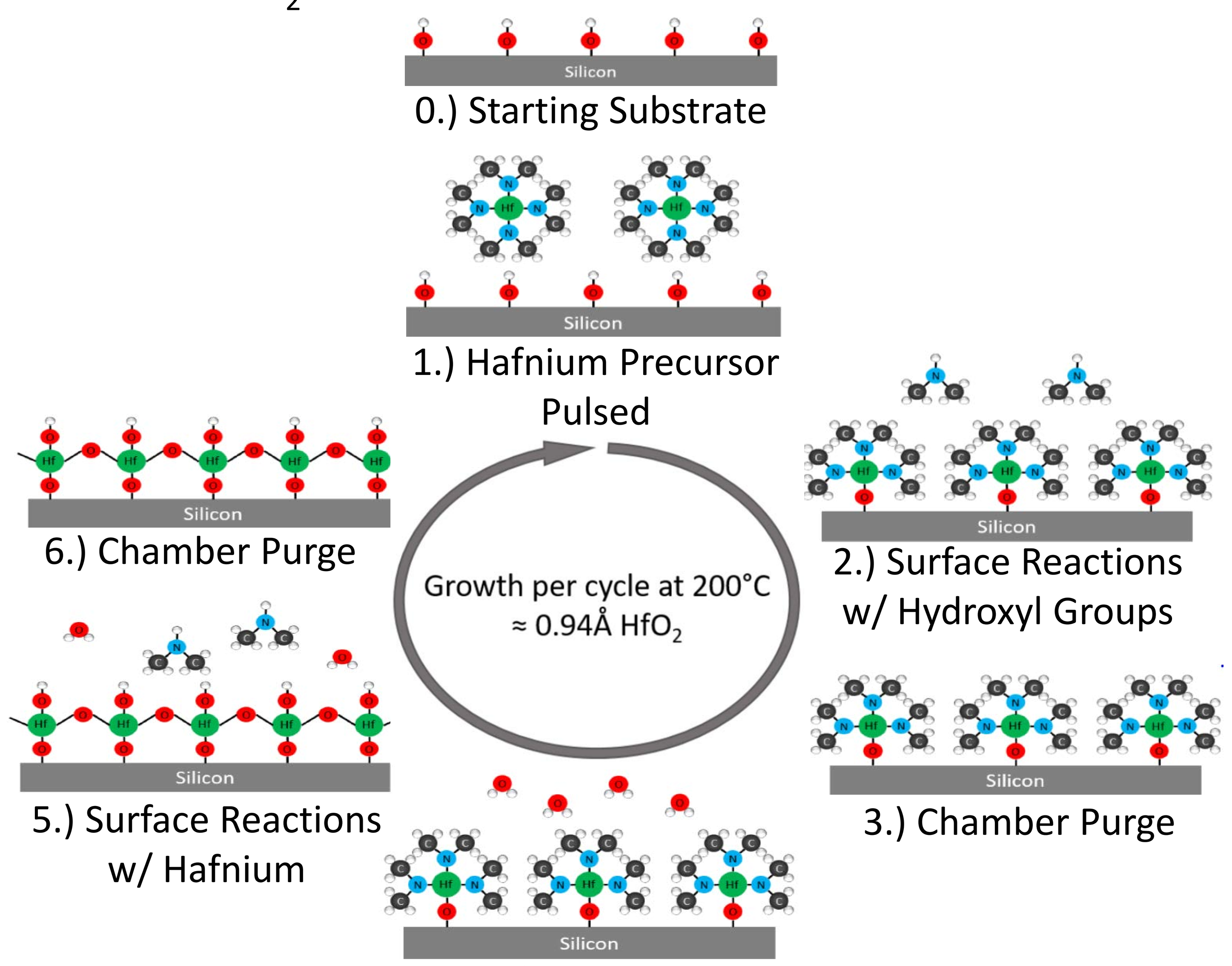
- ALD Deposited Al:HfO_2 ferroelectric capacitors have been attempted at RIT by Casey Gonta
  - aixACCT TF 1000 Ferroelectric Tester measurements indicated anti-ferroelectricity





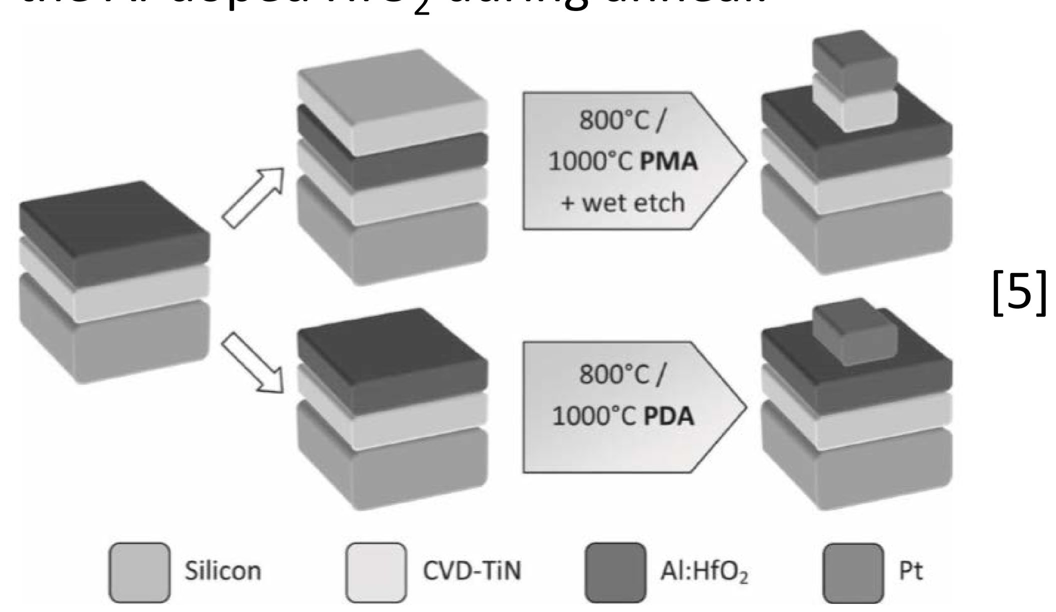
ALD Deposition

- Atomic Layer Deposition (ALD) of ferroelectric Al:HfO_2 performed using Savannah ALD System
- TDMAHf – Tetrakis(dimethlyamido)hafnium(IV) – used as Hf precursor along with H_2O to produce HfO_2 film
- HfO_2 is deposited using self-limiting reactions by alternating pulses of TDMAHf and H_2O
- Aluminum dopant introduced into the film by pulsing Al precursor TMA – Trimethyl Aluminum – every "X" TDMAHf cycles, where "X" is calculated based on desired percentage of Al in the HfO_2 film



Post-Metallization vs. Post-Deposition Annealing

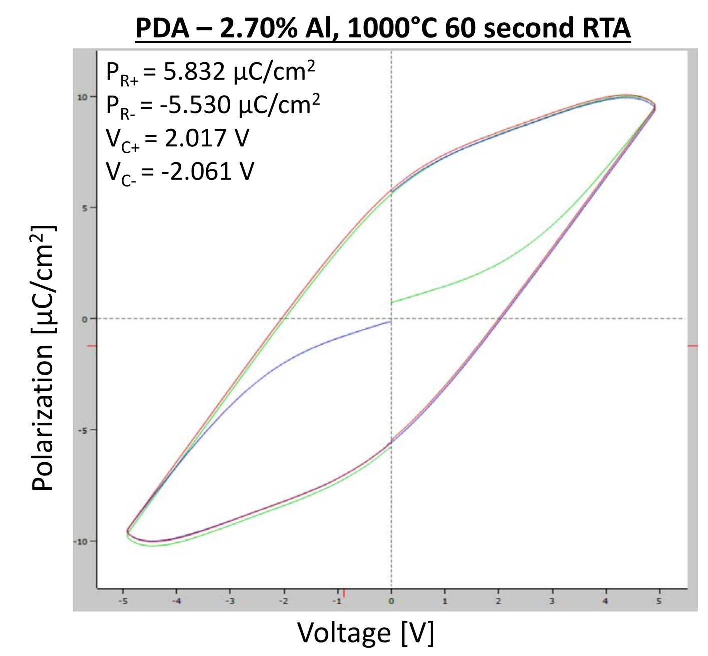
- PMA (Post-metallization Annealing): Annealing after a TiN layer is deposited on top of the Al-doped HfO_2. The purpose of the top TiN is to provide additional mechanical confinement of the Al-doped HfO_2. [5]
- PDA (Post-deposition Annealing): Annealing directly after the Al-doped HfO_2 is deposited. There is no top electrode to help confine the Al-doped HfO_2 during anneal.

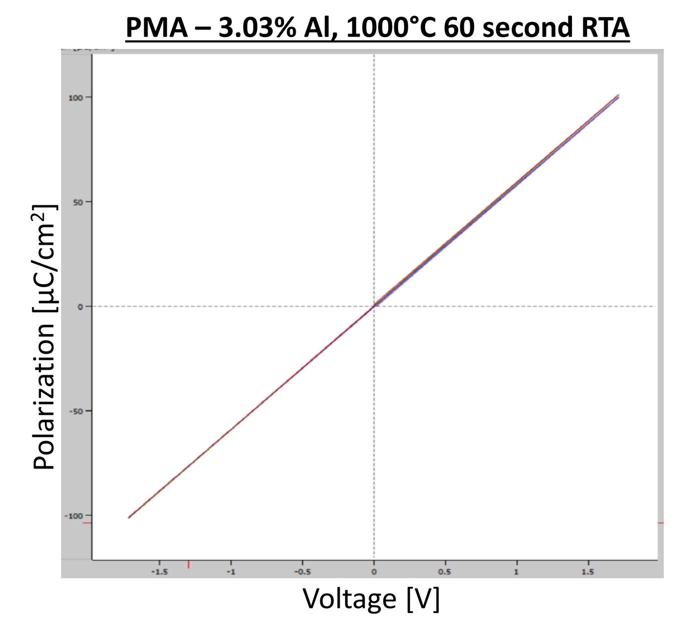


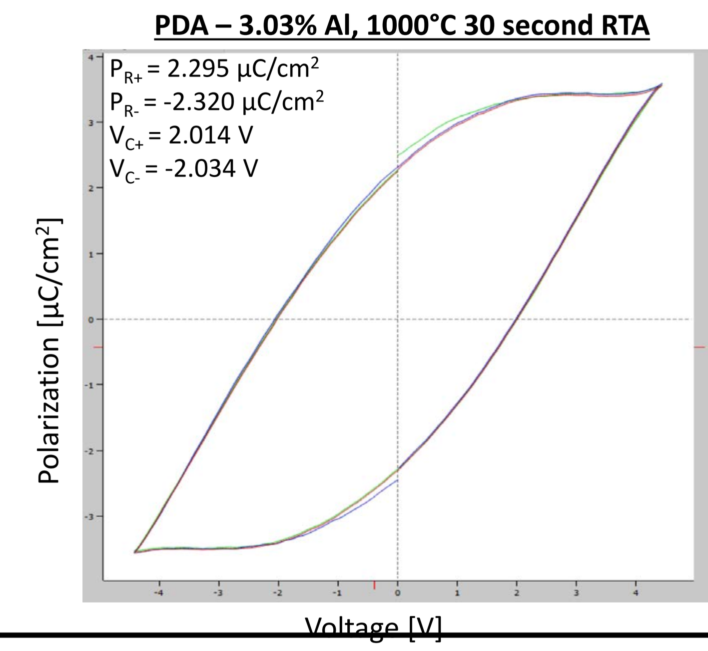
[5]

aixACCT TF 1000 Ferroelectric Tester Measurements

- Ferroelectricity observed in PDA samples
- No ferroelectricity observed in PMA samples – capacitors
- Sample 3 → Ferroelectric PDA, 3.03% Al concentration RTA – 30 seconds at 1000°C
- Sample 5 → Ferroelectric PDA, 2.70% Al concentration RTA – 60 seconds at 1000°C







Conclusions

Ferroelectricity was only observed in PDA samples, both of which had similar coercive voltage values (V_C), which were around ±2V. The sample with the longer annealing time, Sample 5, displayed a significantly larger remnant polarization (P_R), which is likely due to larger domain sizes being formed in the Al:HfO_2 layer during the longer anneal step. It is possible that the lack of ferroelectricity in the PMA devices was due to an imperfect top TiN layer absorbing some of the heat during the RTA steps. This may have limited the domain growth in the Al:HfO_2 layer, preventing ferroelectricity.

References

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[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.

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[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] S. Mueller, et al., "Incipient Ferroelectricity in Al-Doped HfO2 Thin Films," Advanced Function Materials vol.22, pp. 2412 – 2417, 2012.

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