ALD of Ferroelectric HfO_2 Thin Films

Casey Gonta – Advisors: Jackson Anderson and Dr. Santosh Kurinec

Rochester Institute of Technology, Department of Electrical and Microelectronic Engineering, Rochester NY 14623

R·I·T Kate Gleason College of Engineering

MicroE Microelectronic Engineering

Project Objectives

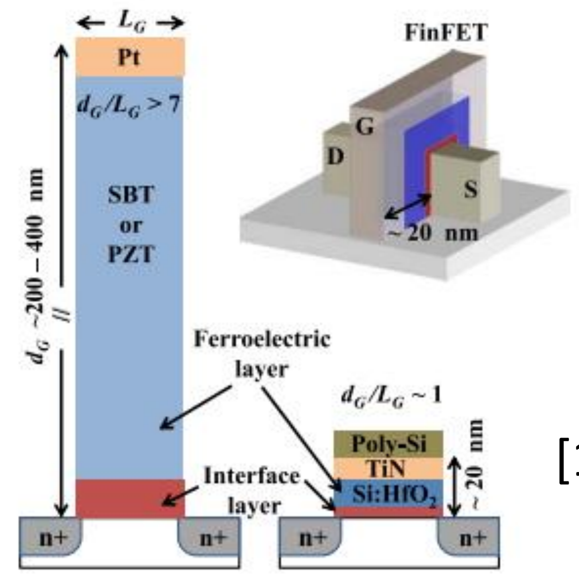
Goal: To engineer ferroelectric HfO_2 solely at RIT by:

1. Developing a recipe for atomic layer deposition of aluminum doped HfO_2
2. Fabricating capacitor structures with ALD of doped HfO_2 as the dielectric
3. Conducting polarization and current testing on capacitors to observe and verify ferroelectric properties

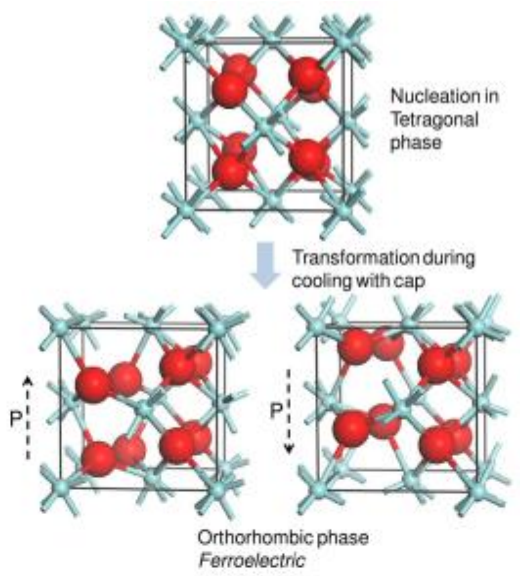
Background

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]

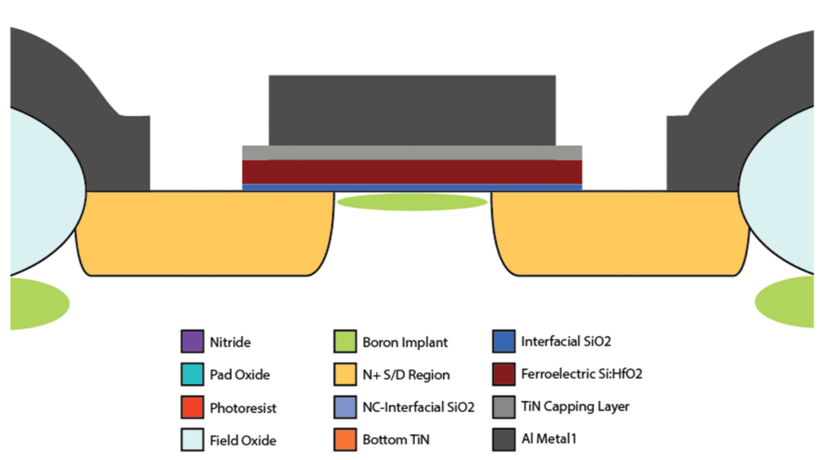


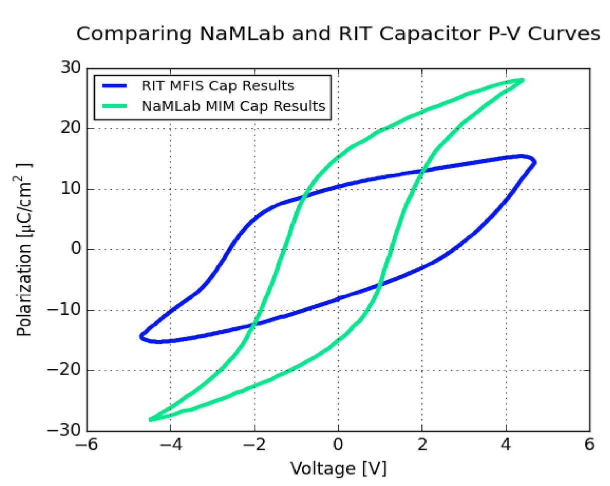
[2]

- Doping of HfO_2 makes the ferroelectric phase more favorable. 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 Work at RIT

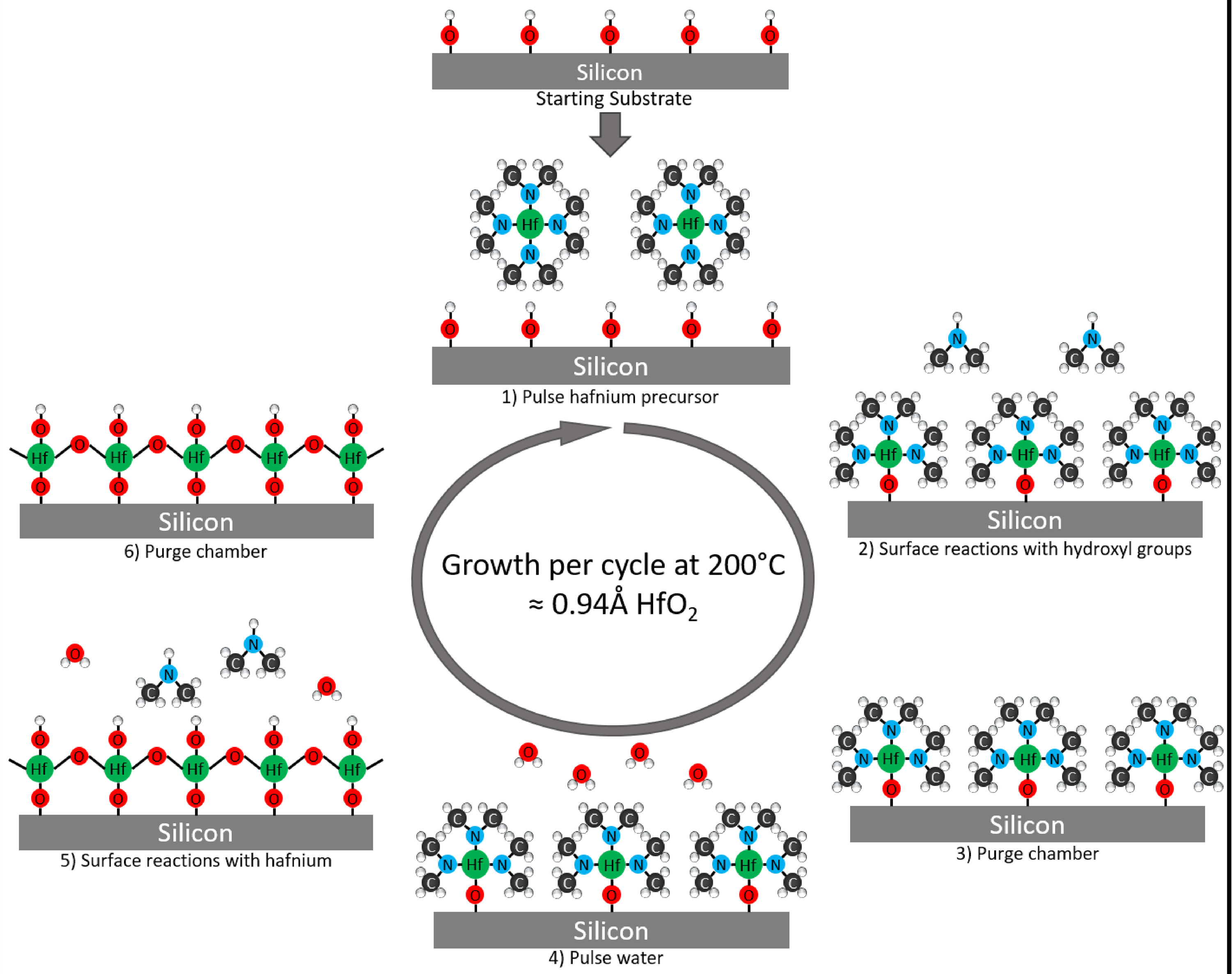
- Ferroelectric transistors have been fabricated at RIT by Joe McGlone with collaboration and ferroelectric Si:HfO_2 depositions from NaMLaB





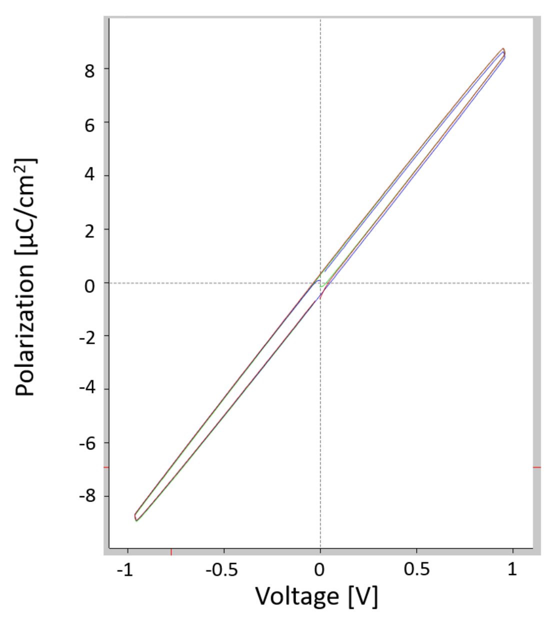
Process Development

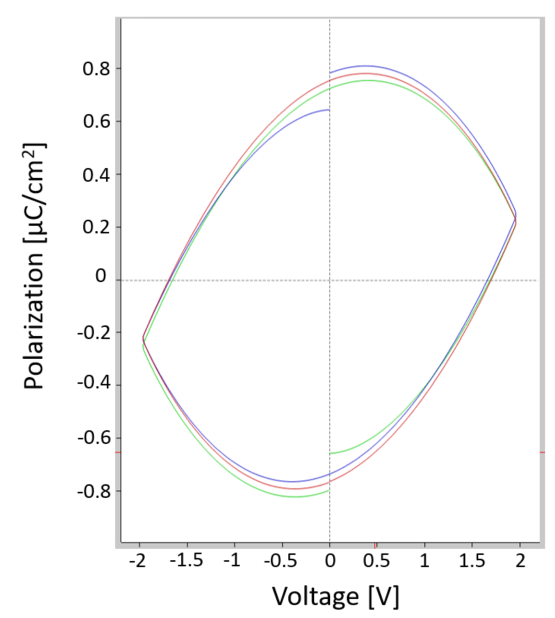
ALD of Al:HfO_2



- The Savannah ALD system at RIT is equipped with the hafnium precursor TDMAHf - Tetrakis(dimethylamido)hafnium(IV)
- HfO_2 is deposited in a cyclical fashion by alternating pulses of the hafnium precursor and water
- In both cases, a self limiting reaction occurs with the surface
- To introduce aluminum dopant to the film, the Al precursor TMA – trimethyl aluminum is pulsed every "X" cycles instead of the Hf precursor where X is calculated based on the desired percentage of Al in the HfO_2 film
- After the entire film is deposited, a capping TiN is sputter deposited and a rapid thermal anneal is performed at high temperature

Ferroelectric Testing

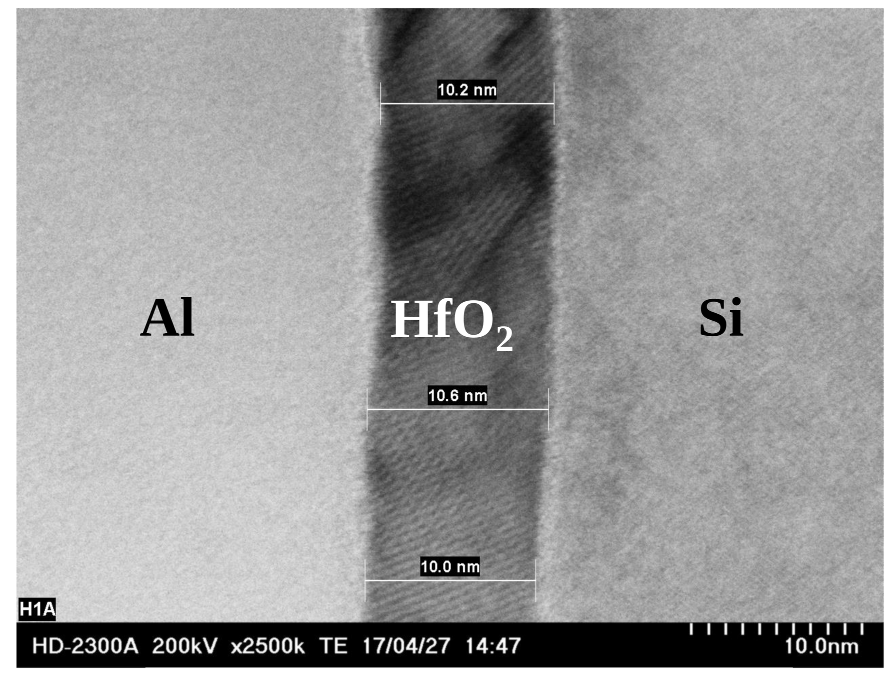


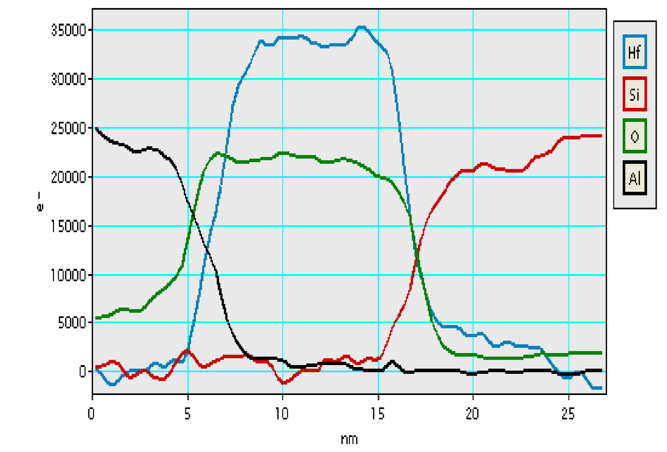


- Capacitors were fabricated using the Al:HfO_2 and tested
- It can be seen that at small applied voltages, only dielectric behavior is observed and breakdown occurs before a voltage is reached where ferroelectric behavior can be seen

TEM and EELS

- TEM and EELS of HfO_2 samples demonstrated that the new Savannah ALD system at RIT is capable of depositing the desired material as well as the desired thickness (target was 10nm)
- Possible grains in the HfO_2 layer can be seen from the TEM image
- The current annealing conditions may be causing partial crystallization, but may not be fully inducing the orthorhombic crystal phase desired for ferroelectric behavior





TEM/EELS - Courtesy of David MacMahon (Micron) and Dr. Santosh Kurinec

Conclusions

- HfO_2 and Al:HfO_2 have both been successfully deposited by ALD at RIT
- Capacitors with the deposited materials were fabricated and tested. Low breakdown voltage as well as high leakage current was observed.

Future Work

- Fabrication variations will be considered to possibly limit interfacial oxide that could be lowering capacitance
- A study of annealing conditions will be done to achieve the proper orthorhombic crystal phase
- XRD on samples will be done to calculate crystal structure

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.

Acknowledgements

Jackson Anderson, Karine Florent, Joe McGlone, Chris O'Connel, Spencer Pringle

Drs. Kurinec, Hirschman, Ewbank, and Pearson, Patricia Meller, SMFL Staff, NaMLab

FeDR@RIT namlab NSF R·I·T Semiconductor & Microsystems Fabrication Laboratory

This work was supported in part by the National Science Foundation, Grant # ECCS-1541090

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.