Atomic Layer Deposition of High Constant Gate Dielectrics for Thin Film Transistors

Du Nguyen

Physics, Michigan State University

NNIN REU Site: Lurie Nanofabrication Facility, University of Michigan, Ann Arbor, MI
NNIN REU Principal Investigator(s): Jamie Phillips, Electrical Engr. and Computer Science, University of Michigan
NNIN REU Mentor(s): Jeffrey Siddiqui, Electrical Engineering and Computer Science, University of Michigan
Contact: nguye191@msu.edu, jphilli@umich.edu, jjameel@umich.edu

Abstract:

Transparent insulating oxides with high dielectric constant (κ) are desired for thin film transistors that form the basis of current flat panel displays and future flexible and transparent electronics. This project uses atomic layer deposition (ALD) in order to grow these oxide films. ALD deposits precisely one monolayer of film with every cycle so that thicknesses can be controlled at the atomic level. An Oxford OpAL ALD tool was used in this work to deposit thin films of aluminum oxide (Al_2O_3) and hafnium oxide (HfO_2) under varying parameters of temperature, plasma power, and pressure. In addition, the effects of thermal annealing the films after deposition were examined. Optimal growth parameters were found in order to maximize the dielectric constant and minimize leakage current density through the films, as these parameters are critical in determining the ultimate performance of thin film transistors. By maximizing the dielectric constant and maintaining low leakage in a thin dielectric layer, a higher capacitance from the oxide is achieved which allows for better gate control of the drain current in a thin film transistor. The results of the study will be applied to current research on zinc oxide and zinc telluride thin film transistors.

Experimental Procedure:

In the ALD process, the films are grown with repeated cycles of precursor doses and purging stages shown in Figure 1. The film growth is self limiting and based on surface reactions, which allows for the atomic scale control of the deposition. For the oxides grown in this project, two precursors are used: one for the oxide and one for the other element (Al or Hf). In order to improve the oxidation of the thin film, some of the depositions were aided by oxygen plasma. An alternative oxygen-providing precursor used was water. The other precursors for Al_2O_3 and HfO_2 were tri-methyl aluminum and tetrakis(ethylmethylamino) hafnium respectively.

Oxide thin films were deposited on silicon wafers, including HfO_2 with plasma, Al_2O_3 with plasma, and Al_2O_3 with water. The films were grown with varying parameters of temperature, plasma power, and pressure. The temperatures ranged from 100°C to 300°C in increments of 50°C and were controlled through a table heater within the growth chamber. The plasma power was directly controlled through the tool software and ranged from 100W to 300W in increments of 50W. The last parameter of pressure was controlled by the precursor and purging gas flows of the chamber. The pressure ranged from 100 mTorr to 500 mTorr in increments of 100 mTorr. Each film was grown for 300 cycles and nominally 300 Å thick.

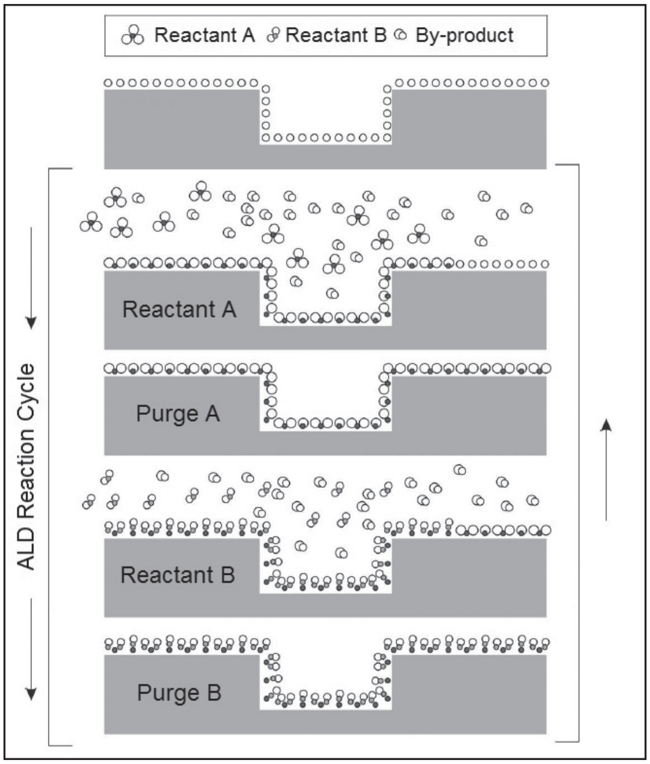


Figure 1: Basic ALD growth cycle.

Capacitors were fabricated to test the electrical properties of the oxide thin films. Capacitors were fabricated by depositing metal contacts with radii of 340 μm, consisting of a layer titanium and platinum 200 Å and 1000 Å in thickness respectively. The dielectric constants of the thin films were determined by measuring the capacitance, using known values for the film thickness and contact area. In addition, the leakage current was measured for a voltage sweep ranging from -20 V to 20 V.

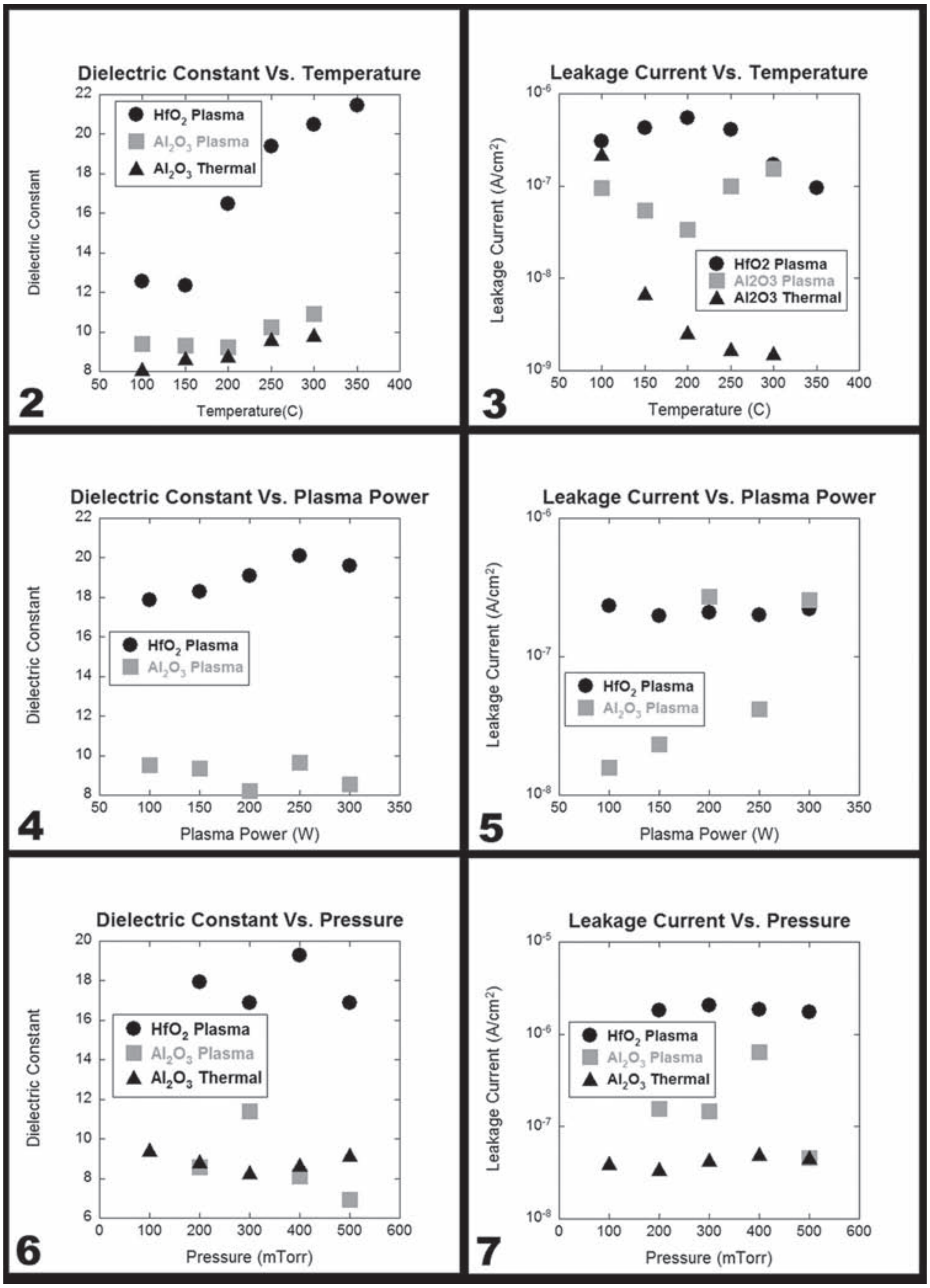
The optimal growth parameters for HfO_2 were found to be 300°C at 250W using the default pressure, but both the plasma power and pressures were found to have little effect on the electrical properties of the films. For Al_2O_3 with plasma, the optimal parameters were 250°C at 100W at 300 mTorr.

With Al_2O_3, the pressure had little effect as well. However, higher plasma powers had significantly higher leakage current in the films. This was likely due to a larger amount of reflected power as the plasma power increased. Finally, for Al_2O_3 with water, the optimal parameters were 300°C at default pressure. Again, pressure did not have a significant effect on film growth. Results of the experiment are summarized in Figures 2 to 7.

Summary Results and Future Work:

Initial work on the effects of annealing was begun with anneals at 400°C and 500°C for 30 minutes with oxygen gas. In addition, literature was found indicating that an anneal can decrease leakage current by orders of magnitude, but experiments have only been run for HfO_2 grown with water and anneals using forming (N_2/H_2) gas. No conclusive results have been found currently for HfO_2 with plasma or thermally grown Al_2O_3. In addition, initial zinc oxide thin film transistors will be created using the optimal parameters for the films.

Future work will apply results of the study to improved zinc oxide and zinc telluride thin film transistors. Applications of these may be used for low power electronic displays and potentially in flexible electronics.



Acknowledgements:

I would like to thank my mentors Jeffrey Siddiqui and Emine Cagin for training and teaching me during this REU as well as my advisor Jamie Phillips. I would also like to thank Sandrine Martin, Brandon Lucas, and the staff of the Lurie Nanofabrication Facility for their assistance and coordination of the program. Finally, I would like to thank the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program and National Science Foundation for funding this program.

References:

[1] P.Carcia, R. McLean, and M.Reilly; "High-performance ZnO thin-film transistors on gate dielectrics grown by atomic layer deposition"; Applied Physics Letters, 88, 123509 (2006).

[2] Ritala, M. and M. Leskelä; "Atomic layer epitaxy - a valuable tool for nanotechnology?"; Nanotechnology, 10, 19-24 (1999).

[3] Puurunen, R.; "Surface chemistry of ALD: A case study for C_3H_9Al/water process"; Journal of Applied Physics, 97, 121301 (2005).

Figures 2 through 7: 2. Dielectric constant data for temperature variance; 3. Leakage data for temperature variance; 4. Dielectric constant data for plasma power variance; 5. Leakage data for plasma power variance; 6. Dielectric constant data for pressure variance; 7. Leakage data for pressure variance.