Encapsulation for IGZO Thin Film Transistors

Julia Okvath, Advisor: Dr. Karl Hirschman

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

I. Project Goal

Goal: To investigate the effectiveness of several materials as encapsulation to improve thermal stability in Indium-Gallium-Zinc Oxide TFTs.

An effective encapsulation material:

- Behaves like a hermetic seal
- Does not degrade standard device operation
- Shows resistance to thermal stress testing

II. Motivation

TFTs are used in LCD display technologies and can be made of a-Si:H (low mobility), poly-Si (higher mobility but expensive), or IGZO.

IGZO benefits:

- Higher mobility than a-Si
- Less expensive than poly-Si
- Compatible with existing process lines

Thermal Stability Challenge:

- TFTs show threshold voltage shift after thermal stress testing

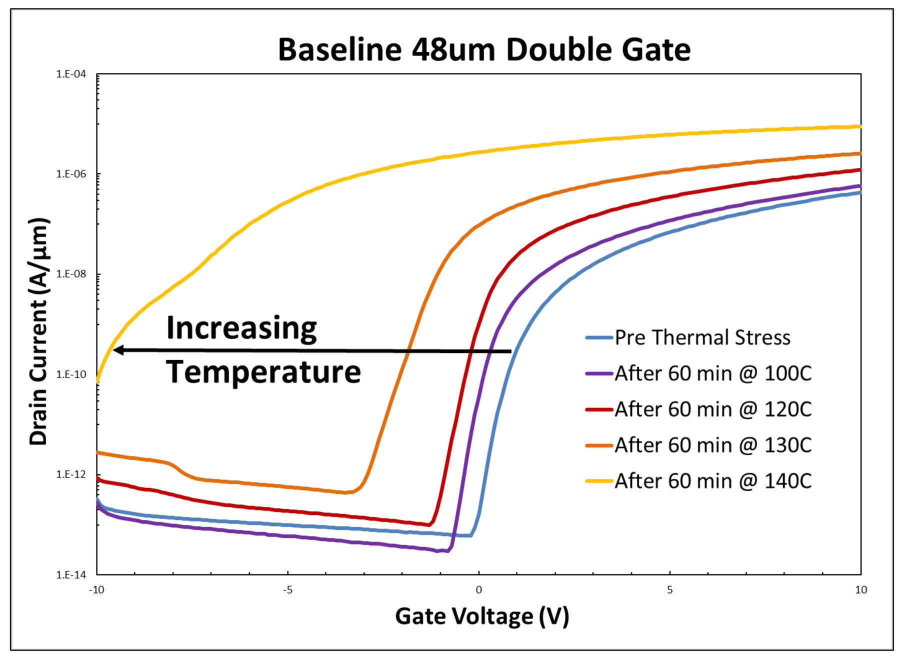

Fig. 1: Double gate (DG) TFT subjected to various elevated temperatures for 60 minutes each.

III. Hypothesis for Thermal Instability

- PECVD SiO_2 readily adsorbs moisture present in the room ambient
- During thermal stress, the absorbed water reacts with IGZO surface/bulk, raising the electron concentration (donor effect)
- For DG devices, H_2O in oxide reacts with Al to form Al_2O_3 which liberates monatomic hydrogen and a larger V_T shift is observed
- The same mechanism is operative during sintering of Si-MOS devices resulting in interface traps passivation [1]

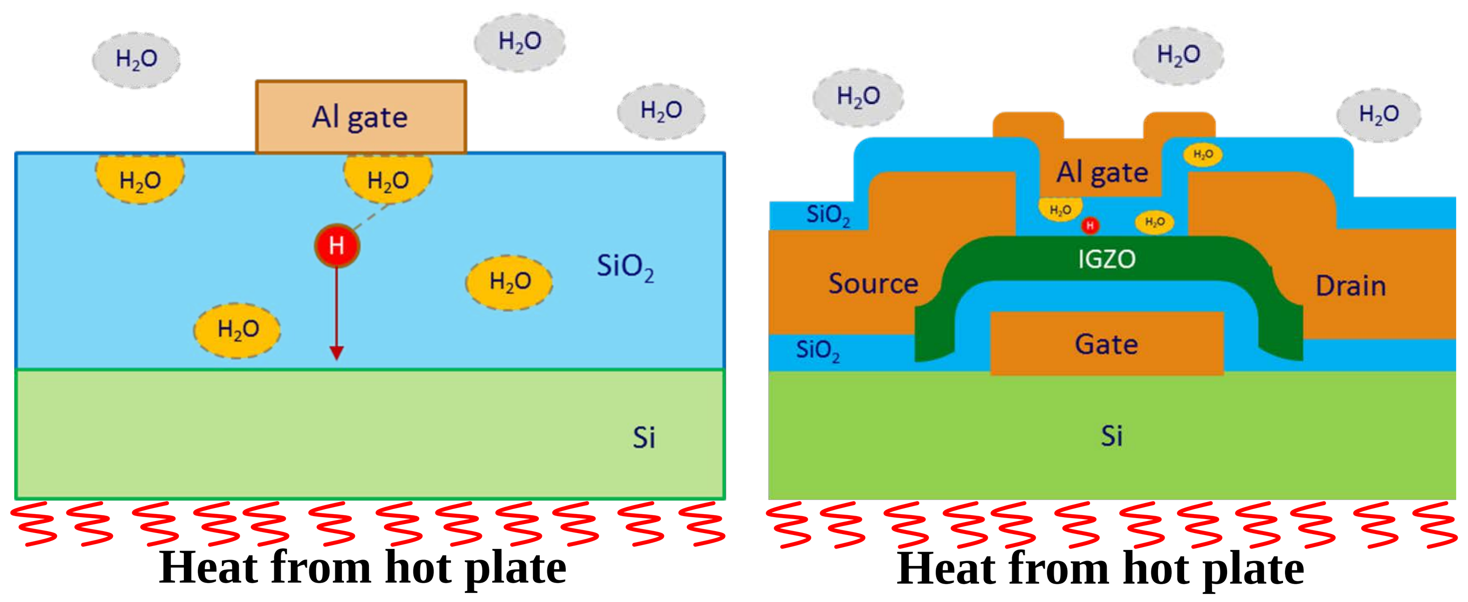

Fig. 2: H_2O reacting with Al to liberate hydrogen which diffuses to the Si of the capacitor (left) and to the IGZO channel of the TFT (right)

IV. Proposed Solution

Use an atomic-layer deposited (ALD) material to act as an encapsulation layer/barrier to the water vapors present in the ambient.

Proposed ALD materials:

- Aluminum oxide (Al_2O_3)
- Hafnium dioxide (HfO_2)
- Titanium dioxide (TiO_2)
- Nano-laminate (Al_2O_3 / HfO_2)

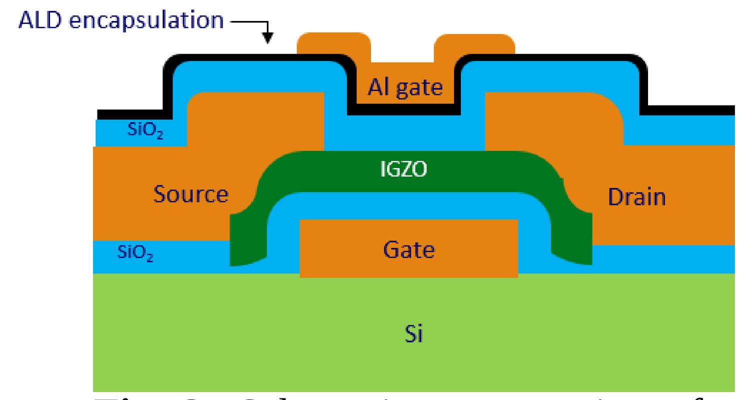

Fig. 3: Schematic cross-section of DG TFT with ALD encapsulation

Nano-laminate: alternating 5nm layers of two or more ALD materials. This is used to decrease the chance of defects in the ALD film which decreases the probability of ambient H_2O diffusing into the IGZO.

V. I-V Characteristics

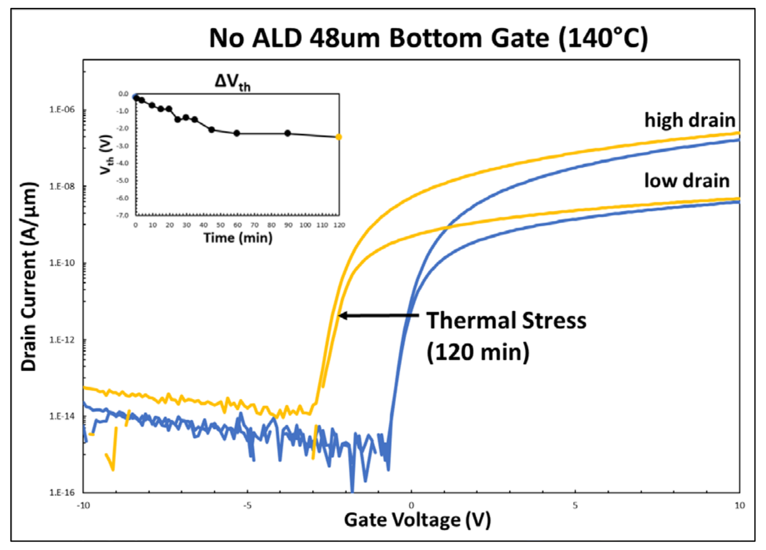

Fig. 4: Bottom gate (BG) device without ALD encapsulation, subjected to 140˚C for 120min.

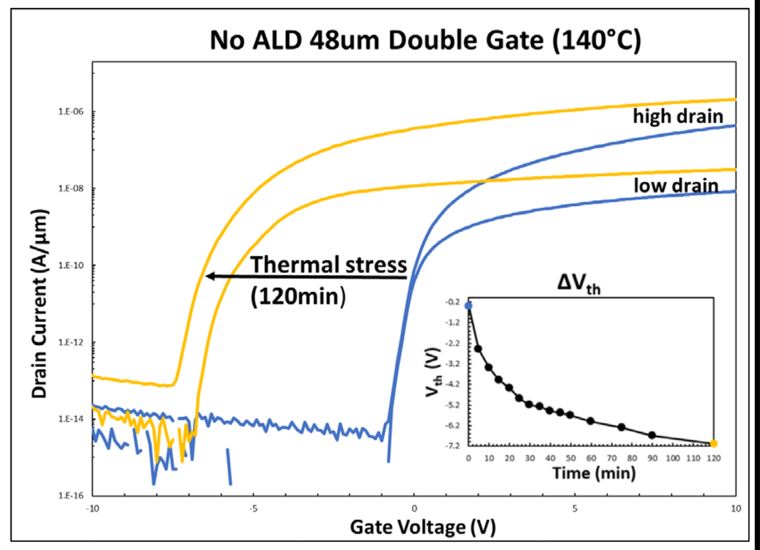

Fig. 5: DG device without ALD encapsulation, subjected to 140˚C for 120 min.

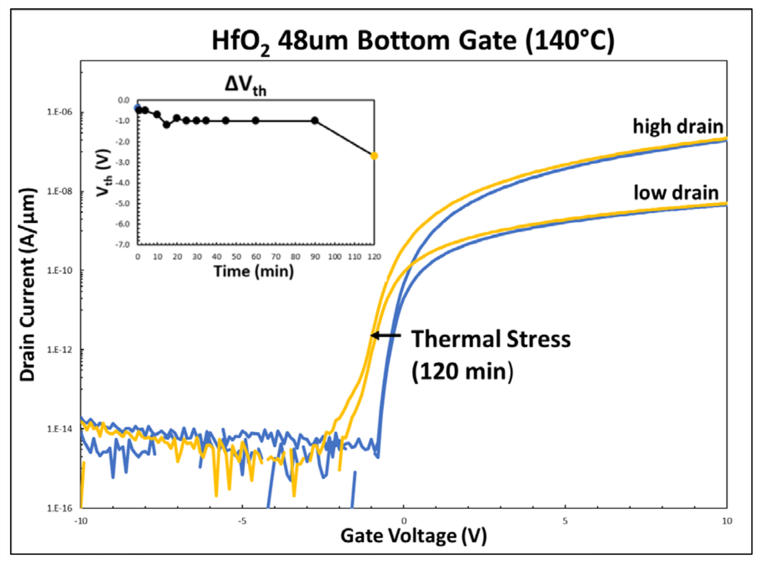

Fig. 6: BG device encapsulated using ALD-HfO_2, subjected to 140°C for 120 min.

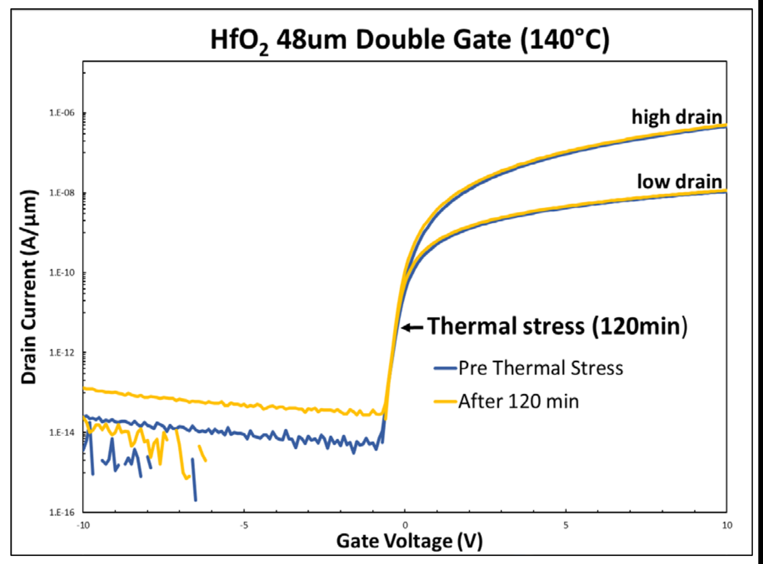

Fig. 7: DG device encapsulated using ALD-HfO_2, subjected to 140˚C for 120 min.

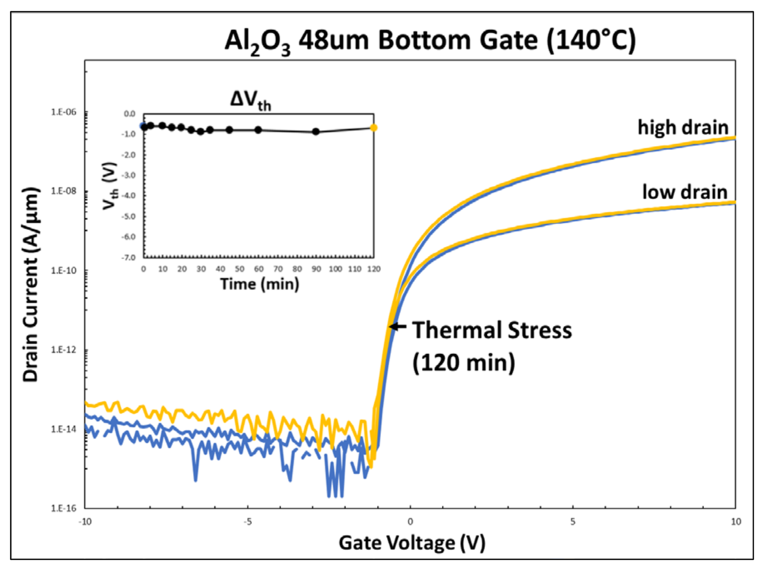

Fig. 8: BG device encapsulated using ALD-Al_2O_3, subjected to 140˚C for 120 min.

Figures 4-8 show that the addition of an encapsulation layer significantly improves the thermal stability of IGZO TFTs. This effect can be seen in both BG and DG devices however, DG HfO_2 devices seem to show slightly better stability.

V. I-V Characteristics (con't)

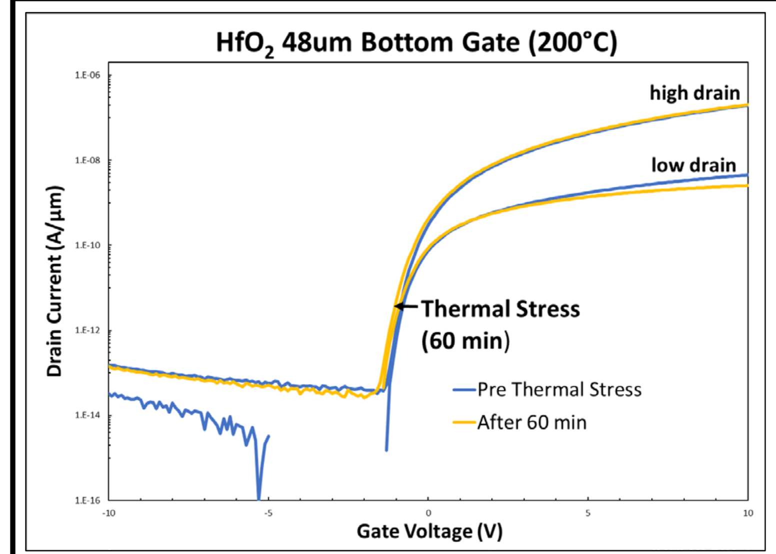

Fig. 9: BG device encapsulated using HfO_2, subjected to 200°C for 60 min.

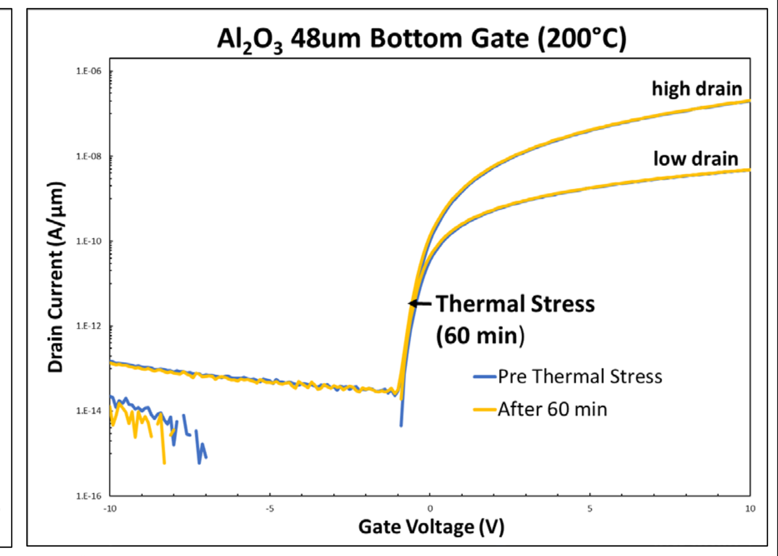

Fig. 10: BG device encapsulated using Al_2O_3, subjected to 200˚C for 60 min.

Figures 9 and 10 show that encapsulated bottom gate devices remain thermally stable even after subjected to 200°C for 60 minutes. However, when double gate devices are exposed to the same heat treatment, all devices become conductive (the channel is shorted). This occurs whether or not the DG devices are encapsulated.

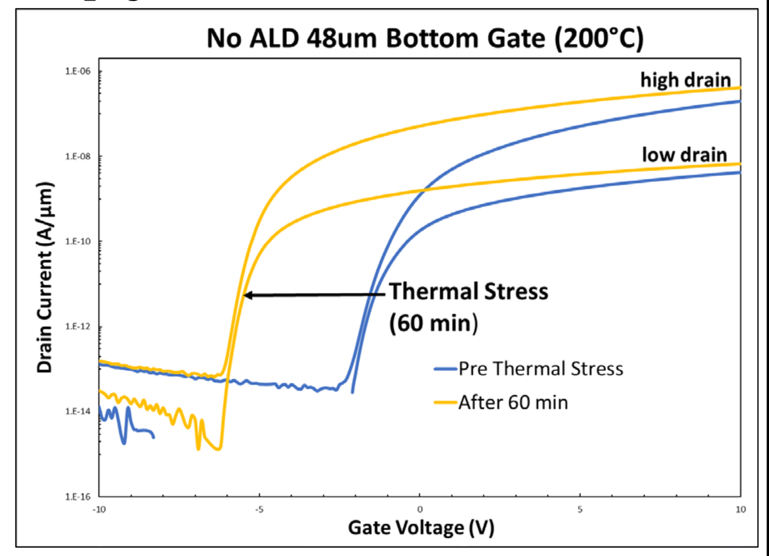

Fig. 11: BG device without ALD encapsulation, subjected to 200˚C for 60 min.

VI. Conclusions

Bottom gate devices without encapsulation exhibit a shift of about 2 V under a thermal stress for 120 min at 140°C. After encapsulation the shift is reduced to about 0.5 V. Double gate devices without any encapsulation show a shift of 7 V at 140°C after 120 min while devices with encapsulation show no apparent shift. When subjected to 200°C for 60 min, encapsulated bottom gate devices show a minimal voltage shift while devices without encapsulation show a shift of about 4 V. All double gate devices subjected to 200°C for 60 min become conductive (*i.e.* resistors). This study confirms the hypothesis that the water incorporation in TEOS oxide is responsible for instability after thermal treatment. ALD deposited Al_2O_3 and HfO_2 films are excellent barriers to moisture and application of these films over the fabricated devices demonstrate significant improvement in stability.

Future Work

- DG Al_2O_3 device testing
- TiO_2/Nano-laminate encapsulation

References

[1]B. E. Deal, E. L. MacKenna, and P. L. Castro, "Characteristics of Fast Surface States Associated with SiO2-Si and Si3N 4-SiO2-Si Structures," Journal of the Electrochemical Society, vol. 116, no. 7, pp. 997–1005, 1969

Acknowledgements

- Dr. Karl Hirschman
- Prashant Ganesh, Tarun Mudgal, Harithshanmaa Sethupathi, Muhammad Salahuddin Kabir
- Patricia Meller, Peter Morici, John Nash and the SMFL staff
- Corning Inc.