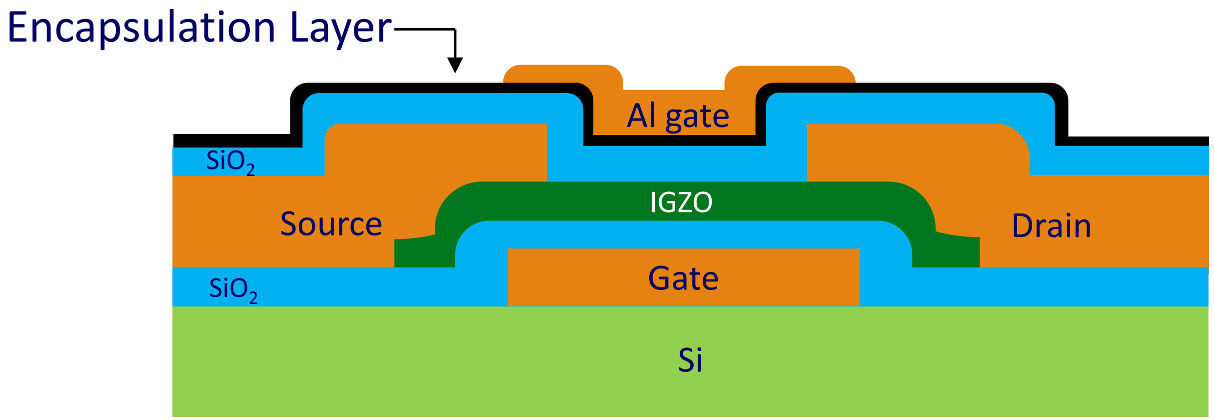
Encapsulation of Indium-Gallium-Zinc Oxide Thin Film Transistors



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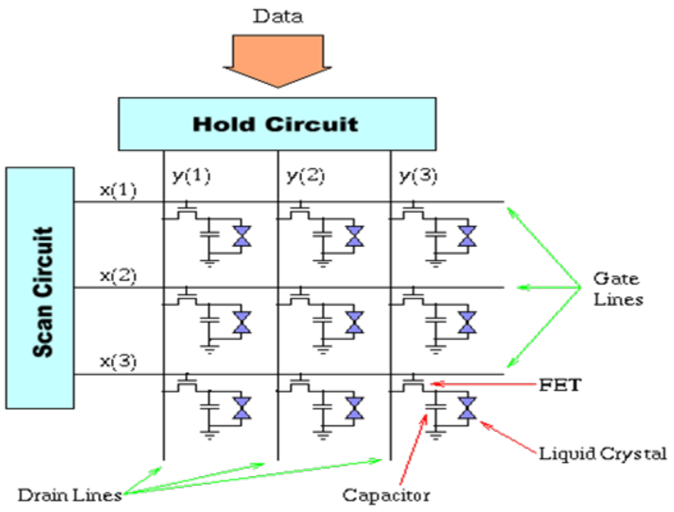
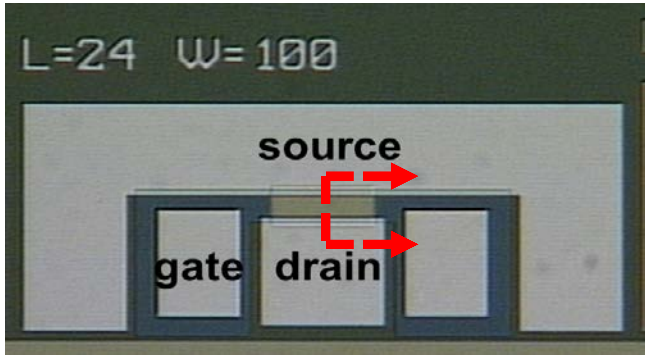
Outline

- Brief Introduction to IGZO TFTs
- Overview of Preliminary Results
- Hypothesis and Proposed Solution
- Experimental Outline
- Results and Analysis
- Conclusion/Future Work

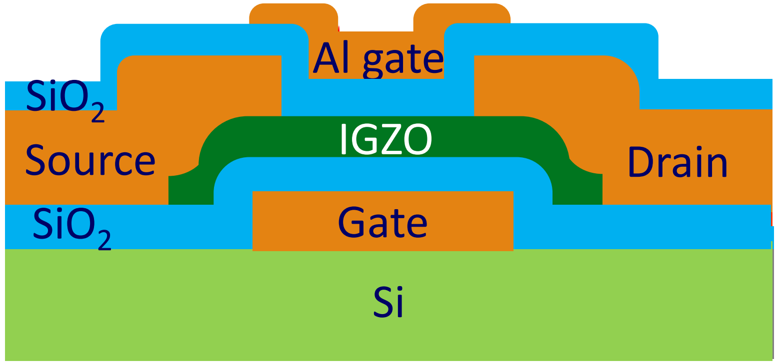
Introduction to IGZO TFTs



Top-down view of TFT



Double-gate cross-section



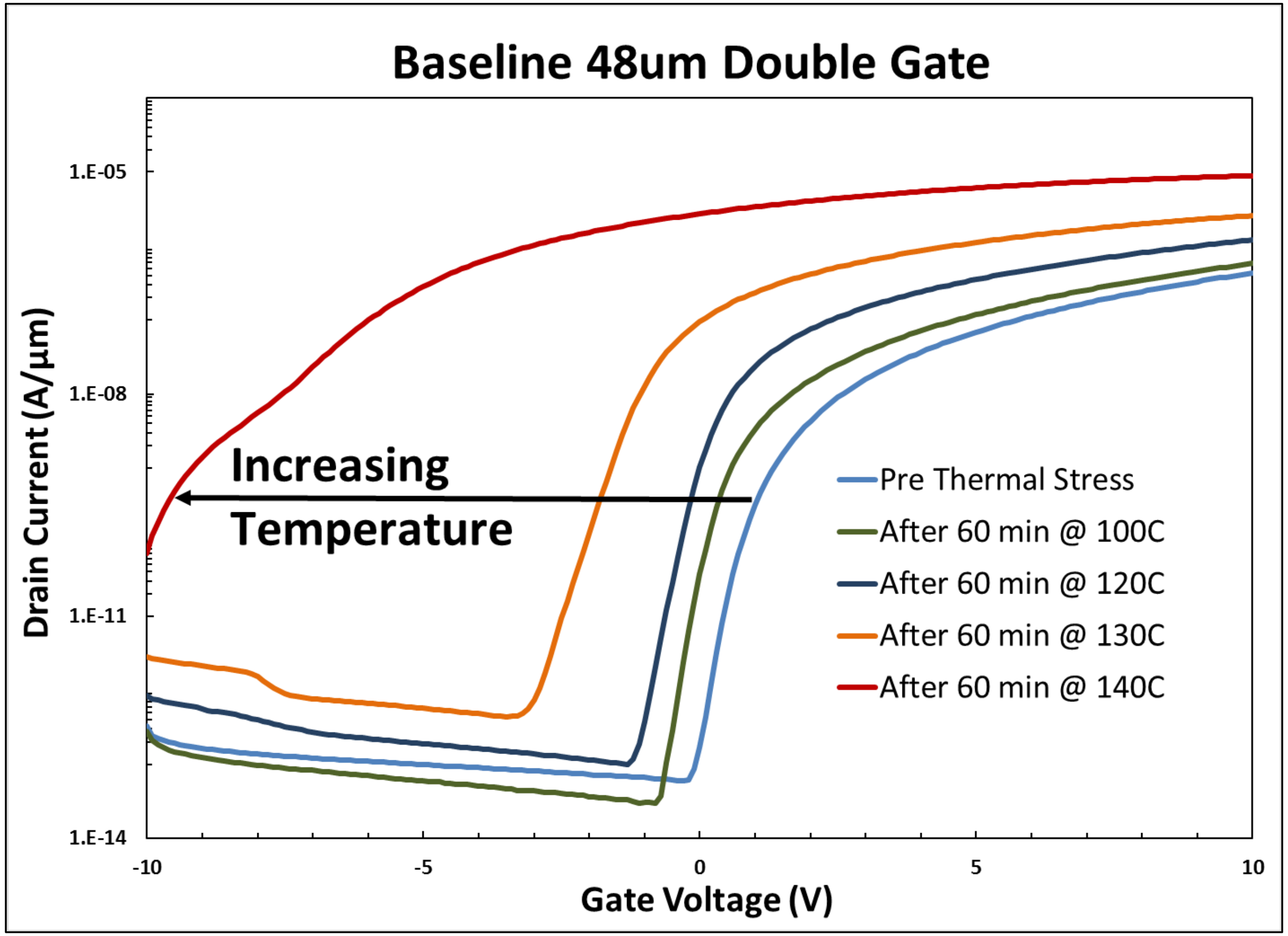
Possible Channel Materials:

- Amorphous silicon
  - Low mobility
- Polycrystalline Silicon
  - Higher mobility than a-Si
  - Expensive to manufacture
- Indium-Gallium-Zinc Oxide
  - Higher mobility than amorphous silicon
  - Less expensive to manufacture than polycrystalline Si [1]
  - Compatible with existing process lines

Preliminary Results: Thermal Instability

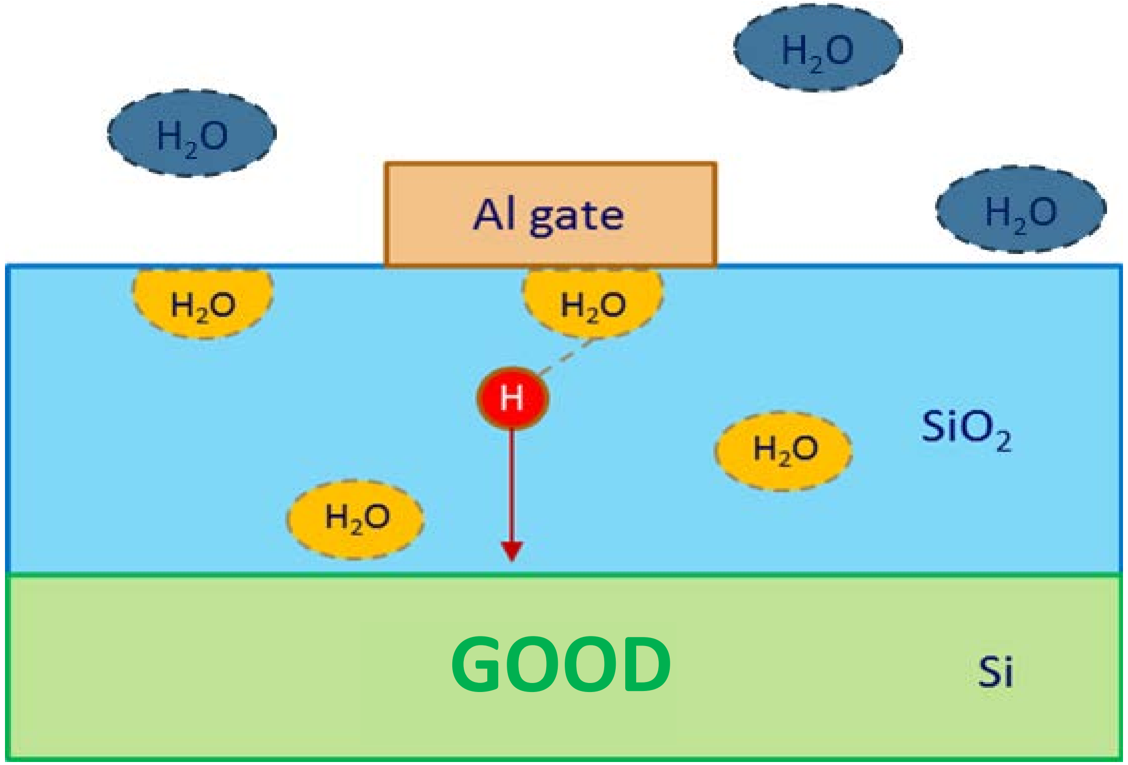
Problem:

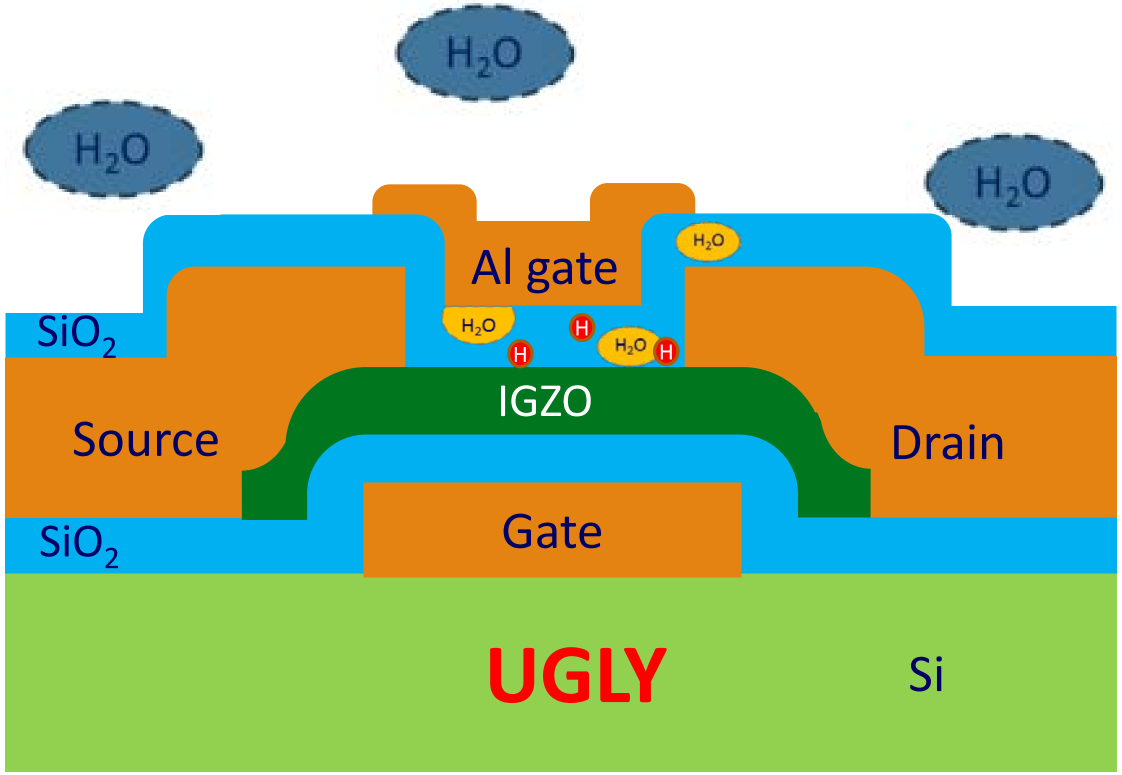
- Devices exhibit degradation when thermally stressed above 100°C.
- Back-end LCD/OLED integration utilizes processing temperatures above 100°C



Hypothesis for Device Instability

PECVD SiO_2 readily adsorbs moisture present in the room ambient. During the sintering process for Si-MOS devices, the absorbed water reacts with the metal gate which results in interface trap passivation [2]. However, this same mechanism will raise the electron concentration in the IGZO channel of a TFT.



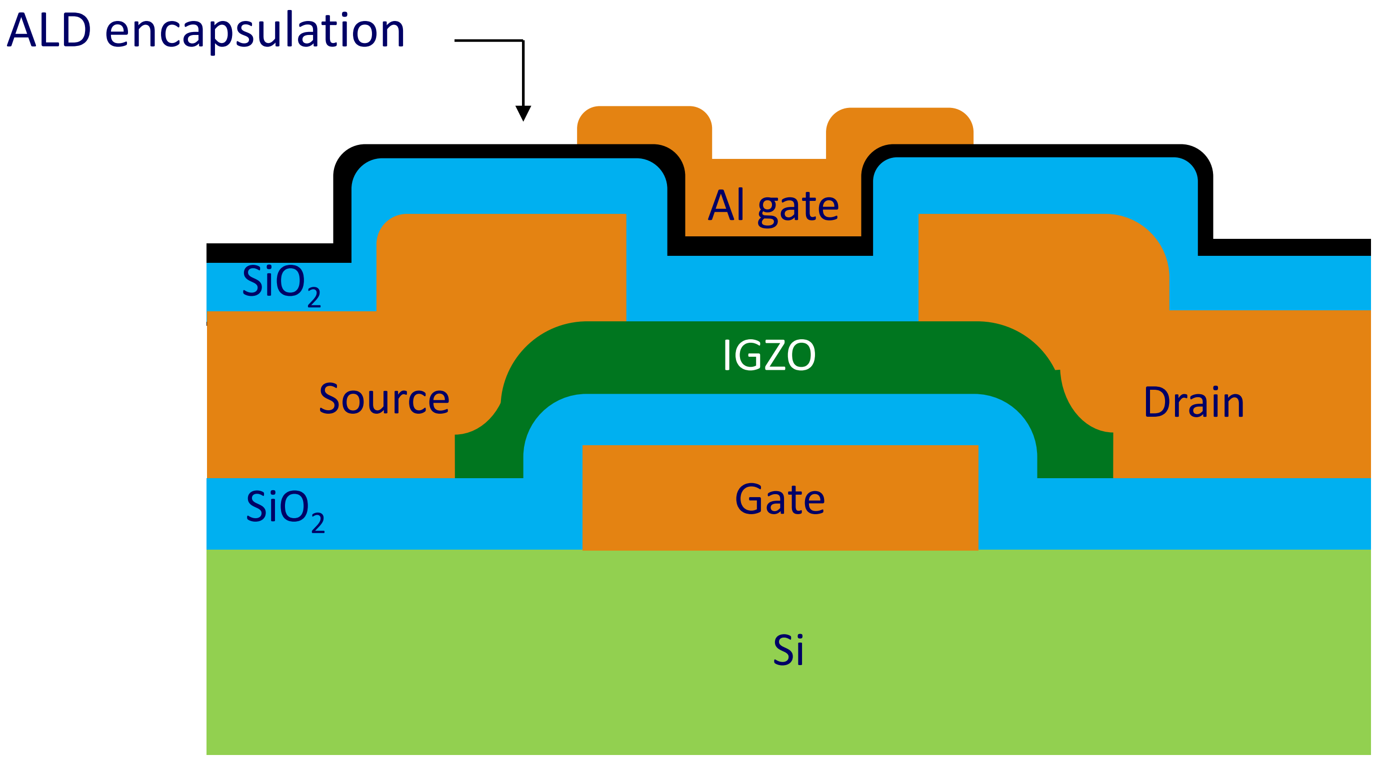


Proposed Solution

Solution: Use an atomic-layer deposited (ALD) material to act as an encapsulation layer/barrier to the water vapors present in the ambient [3], [4].

Proposed ALD Materials:

- Aluminum oxide (Al_2O_3)
- Hafnium dioxide (HfO_2)
- Titanium dioxide (TiO_2)



Experimental Outline

Device Type	Encapsulation
Bottom-gate	None (ref.)
Bottom-gate	15 nm HfO_2
Bottom-gate	15 nm Al_2O_3
Double-gate	None (ref.)
Double-gate	15 nm HfO_2
Double-gate	15 nm Al_2O_3

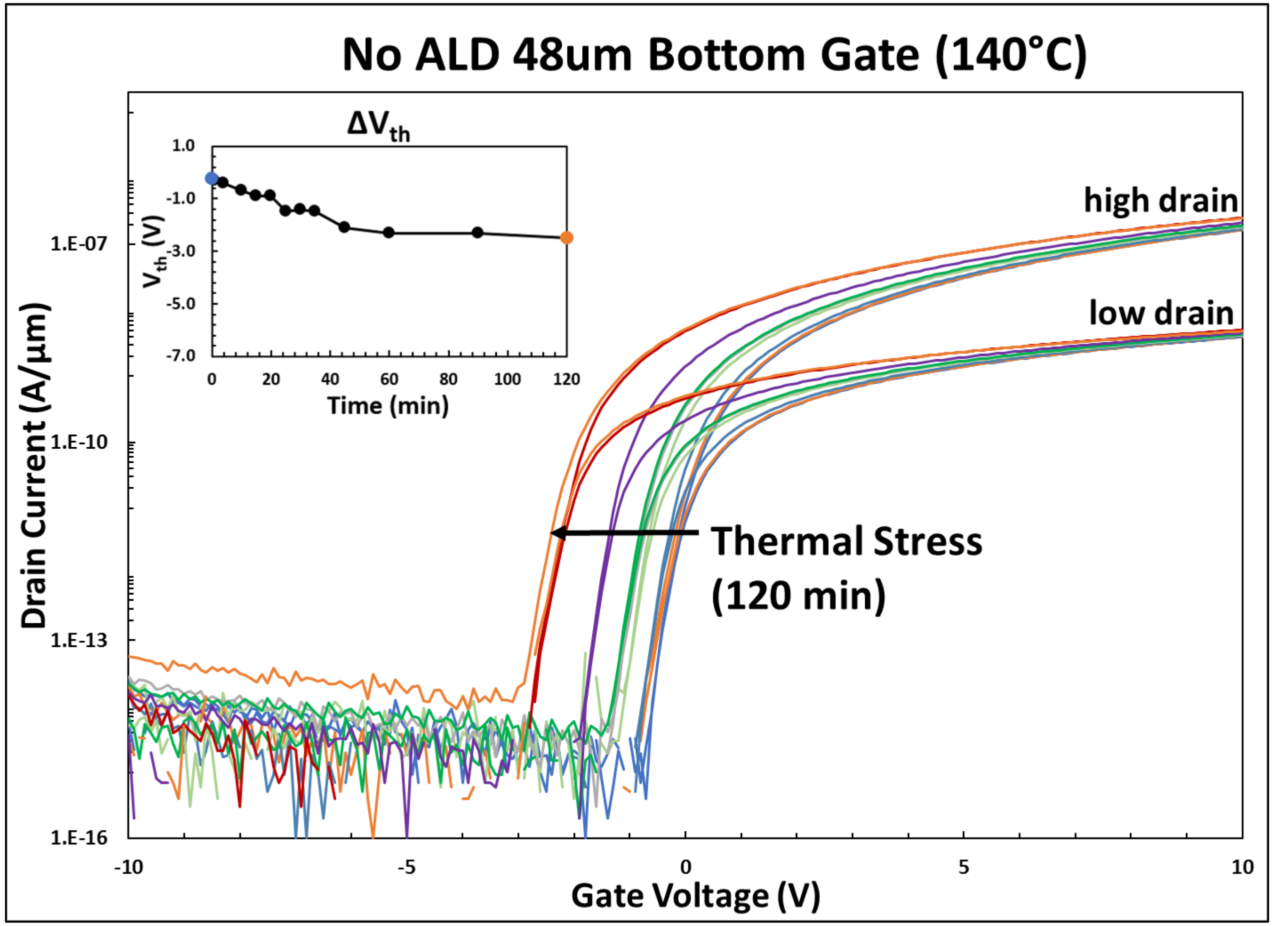
Thermal Experiments:

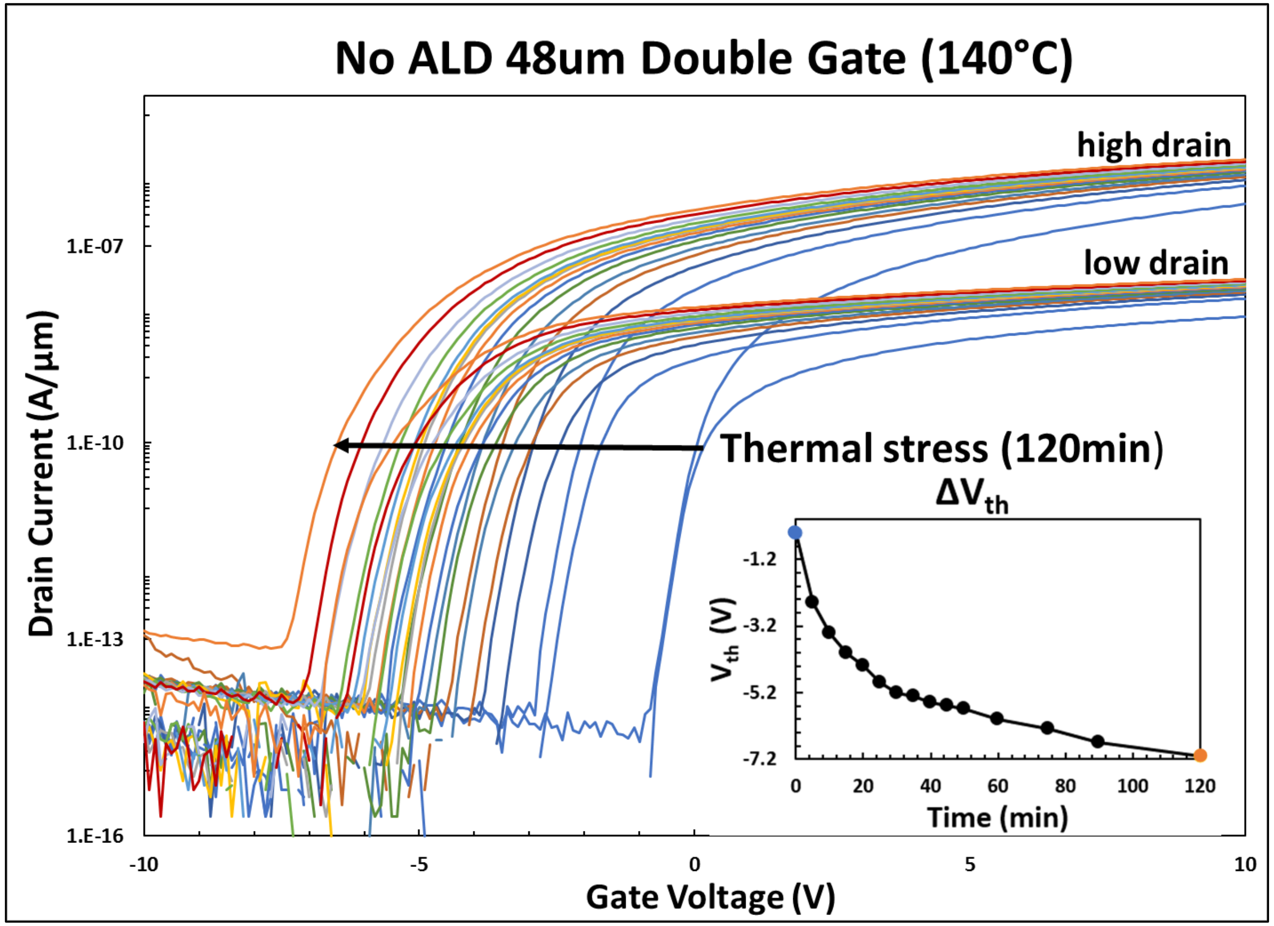
1. 140°C for a total of 120 minutes
2. 200°C for a total of 60 minutes

Processing details:

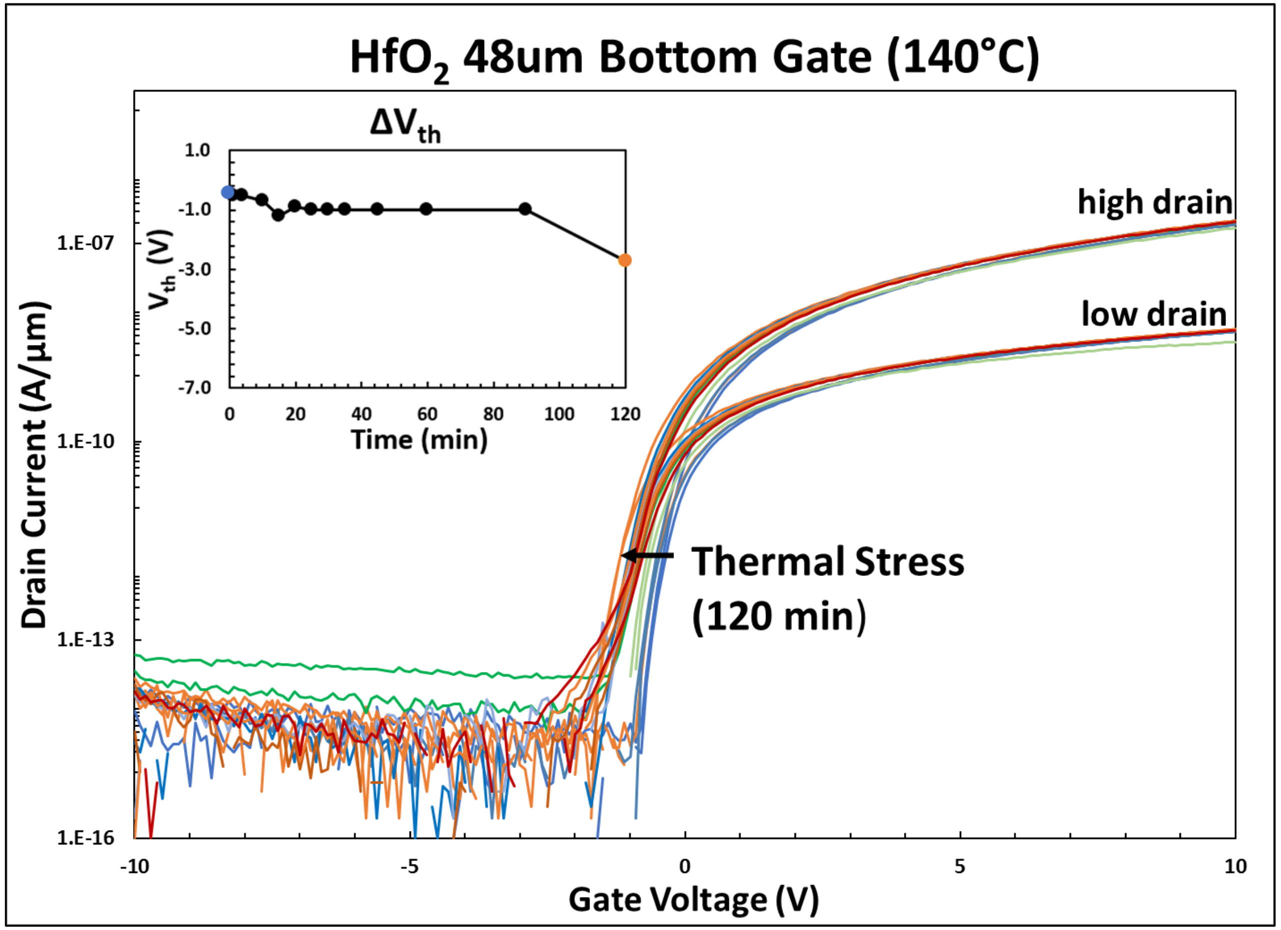
- PECVD SiO_2 passivation annealed at 400°C for 10 hours
- ALD materials immediately deposited at 200°C

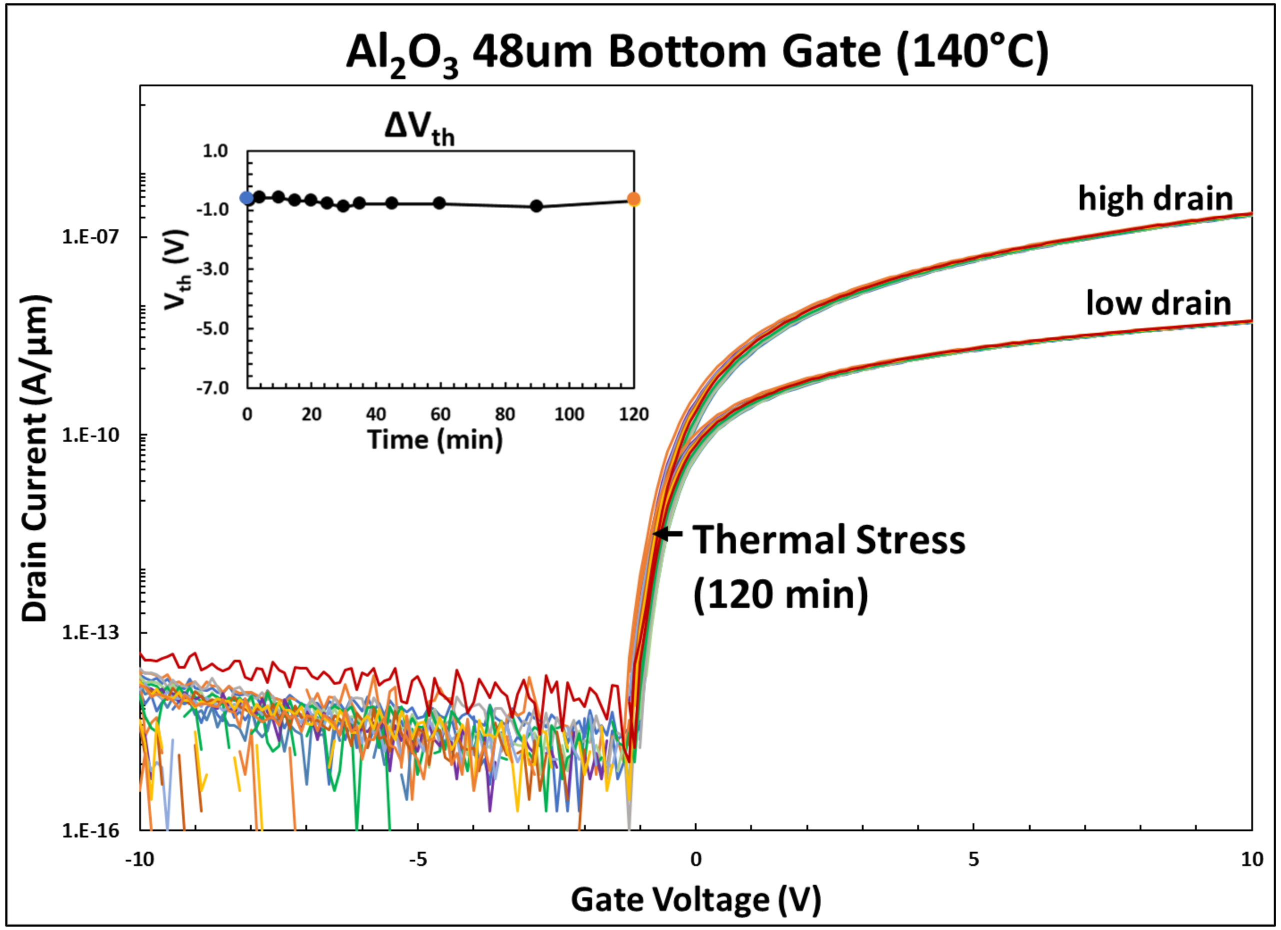
140°C Treatment: No Encapsulation (ref.)



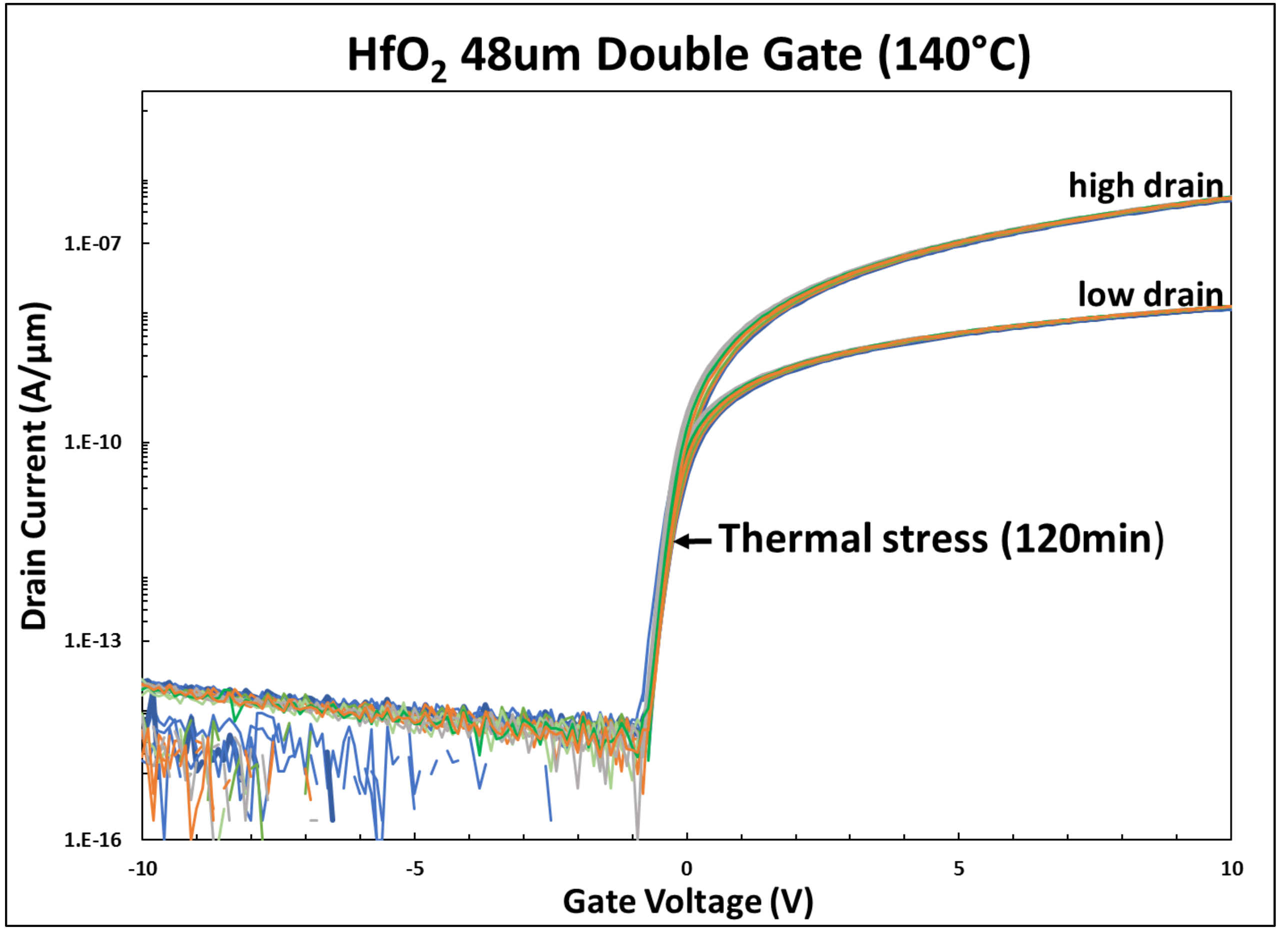


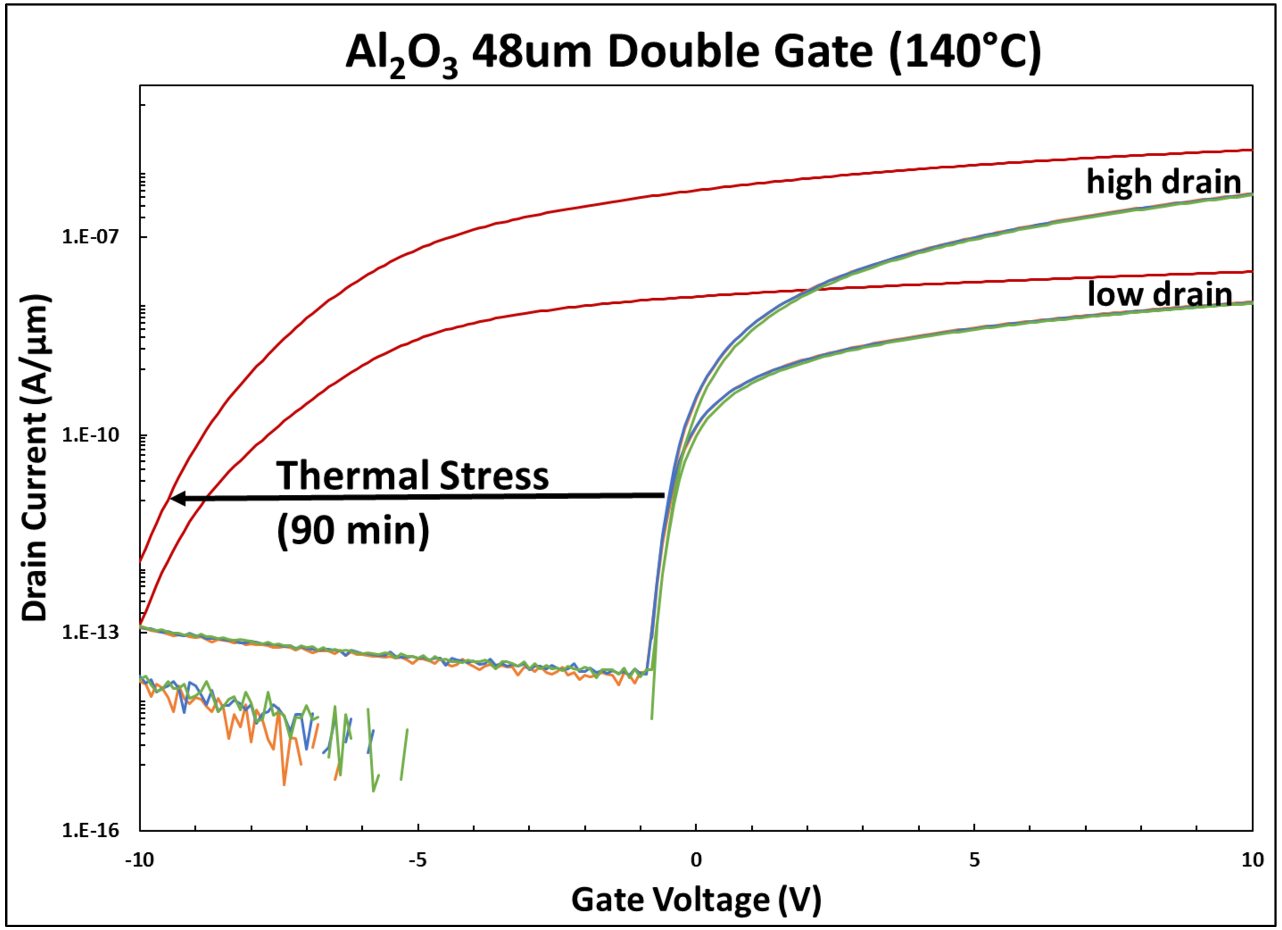
140°C Treatment: Bottom-gate Encapsulated



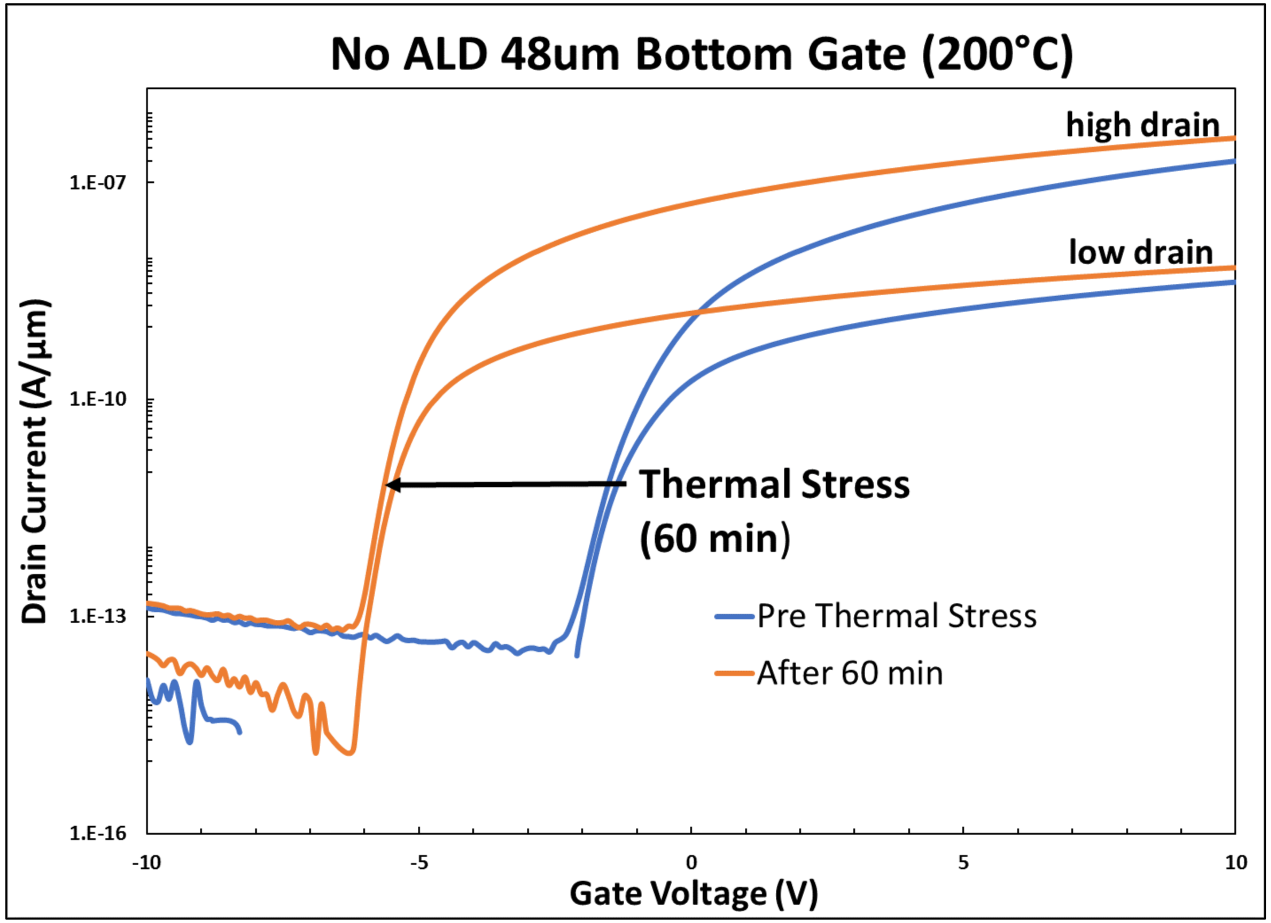


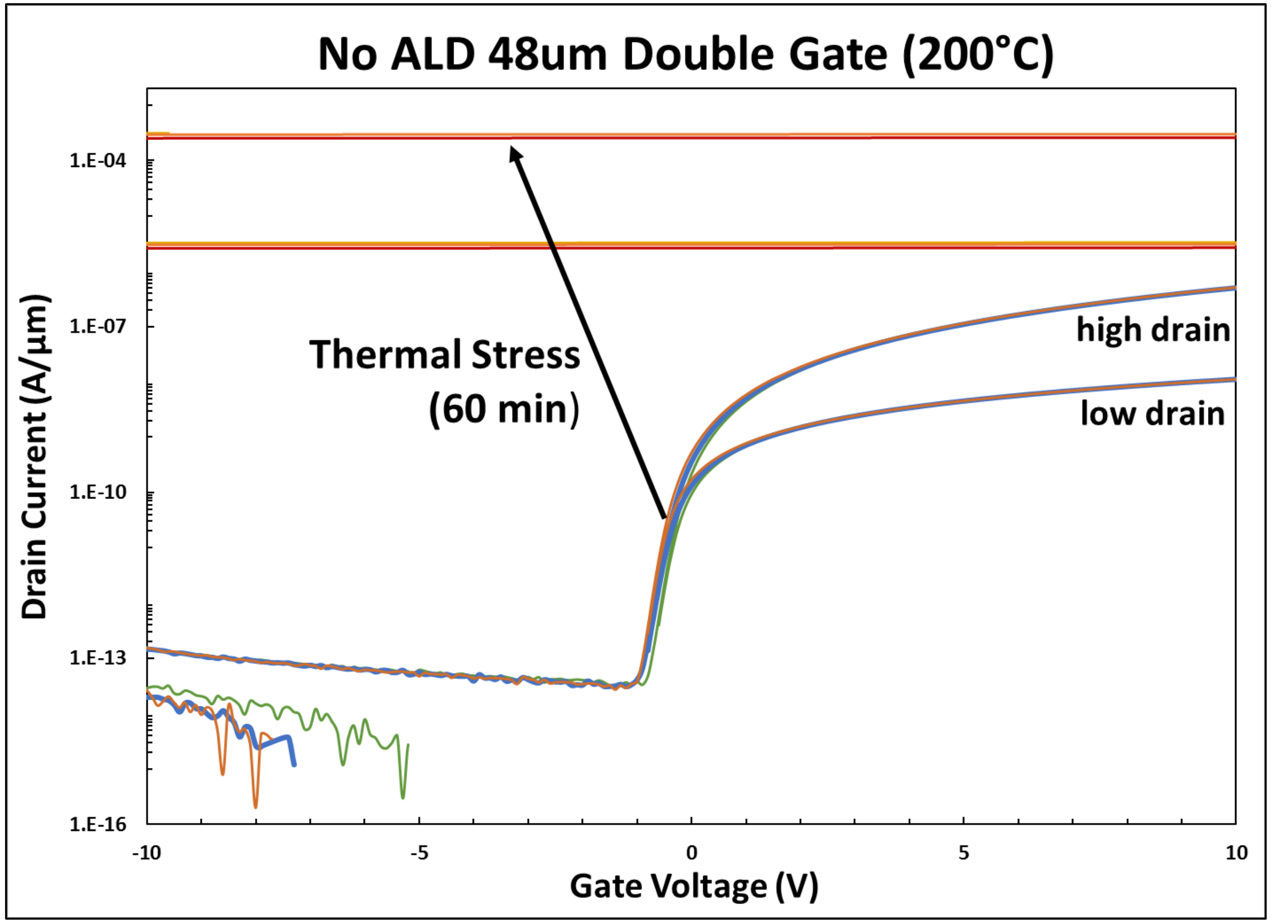
140°C Treatment: Double-gate Encapsulated



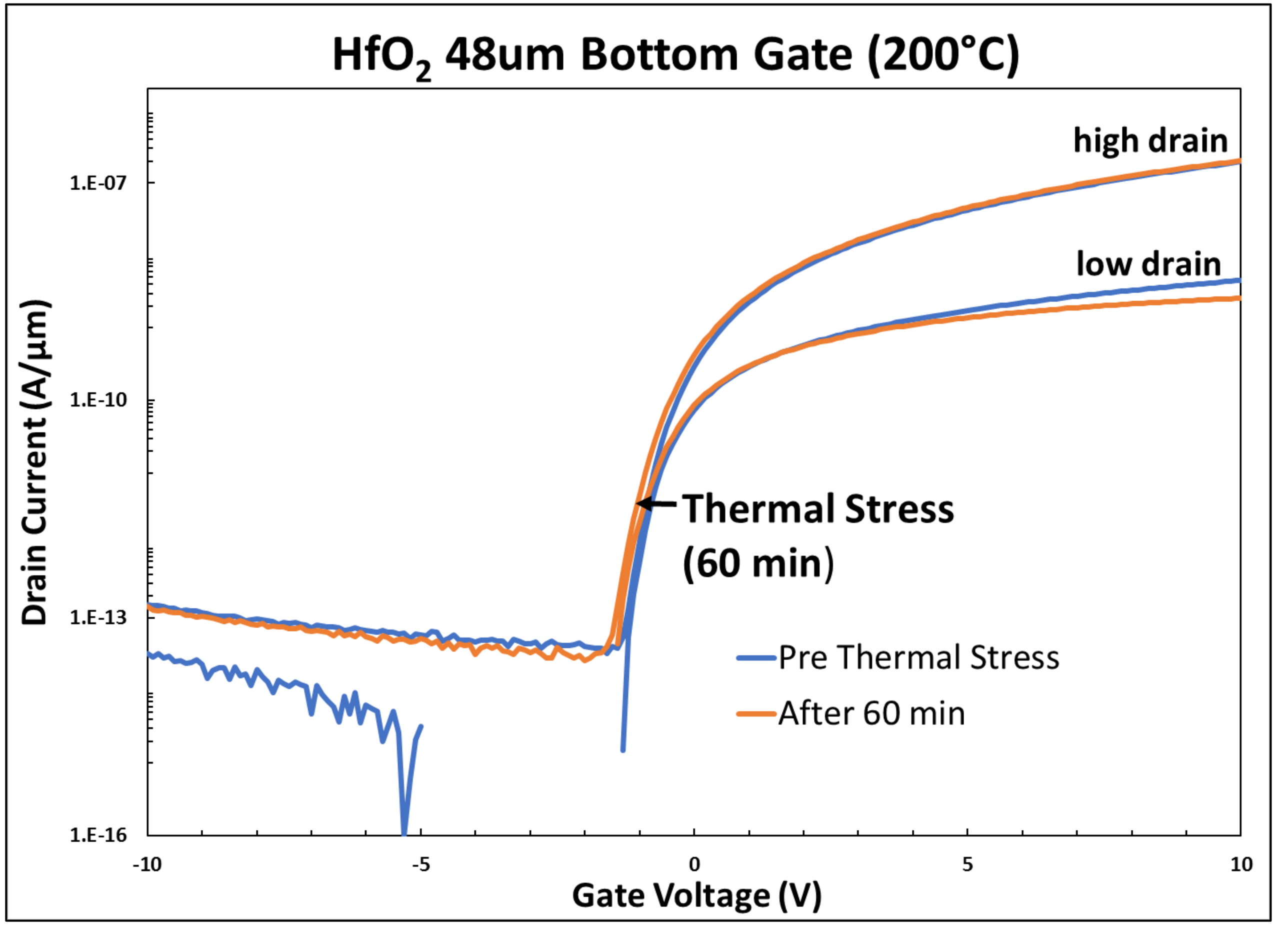


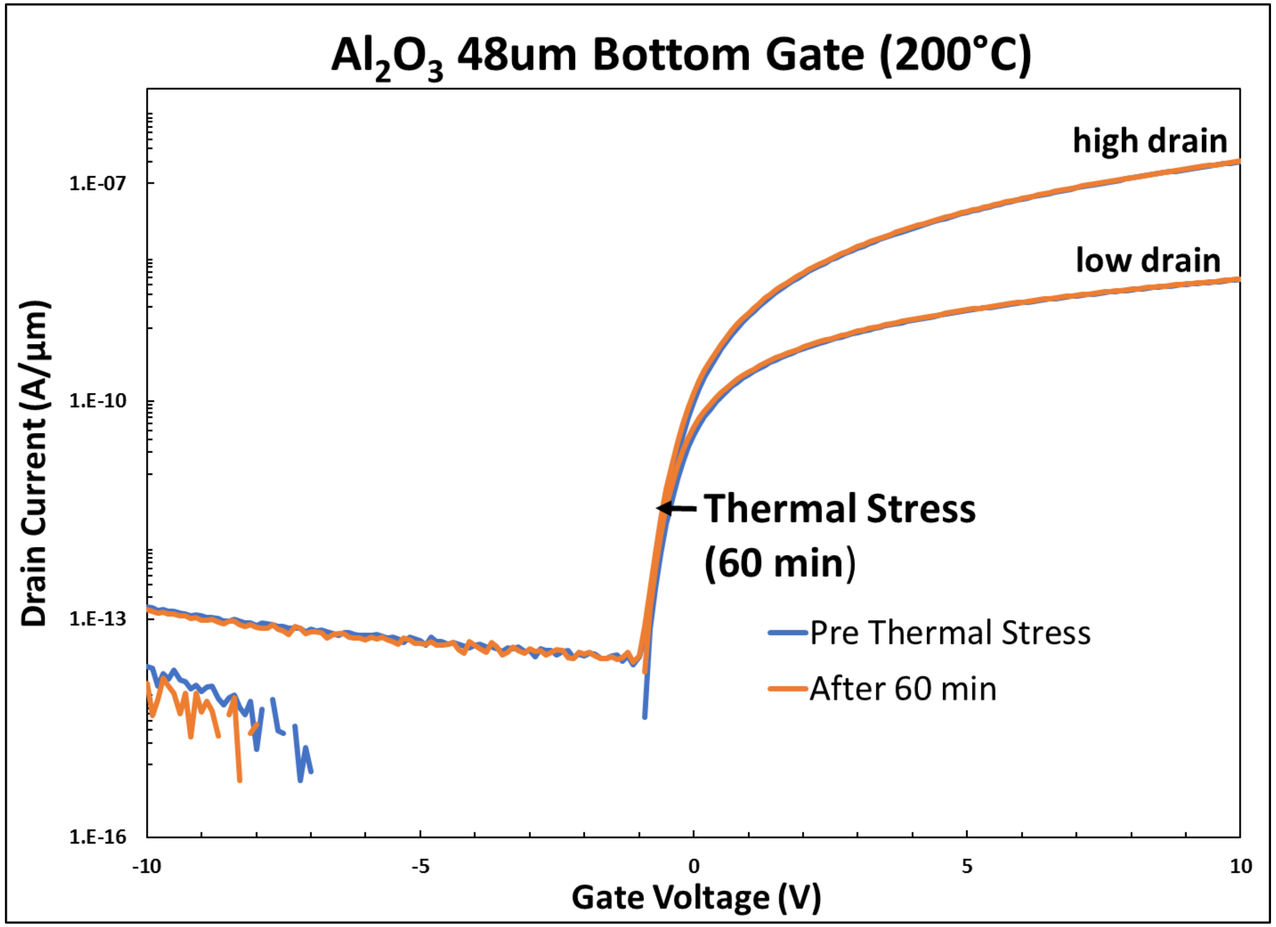
200°C Treatment: No Encapsulation (ref.)



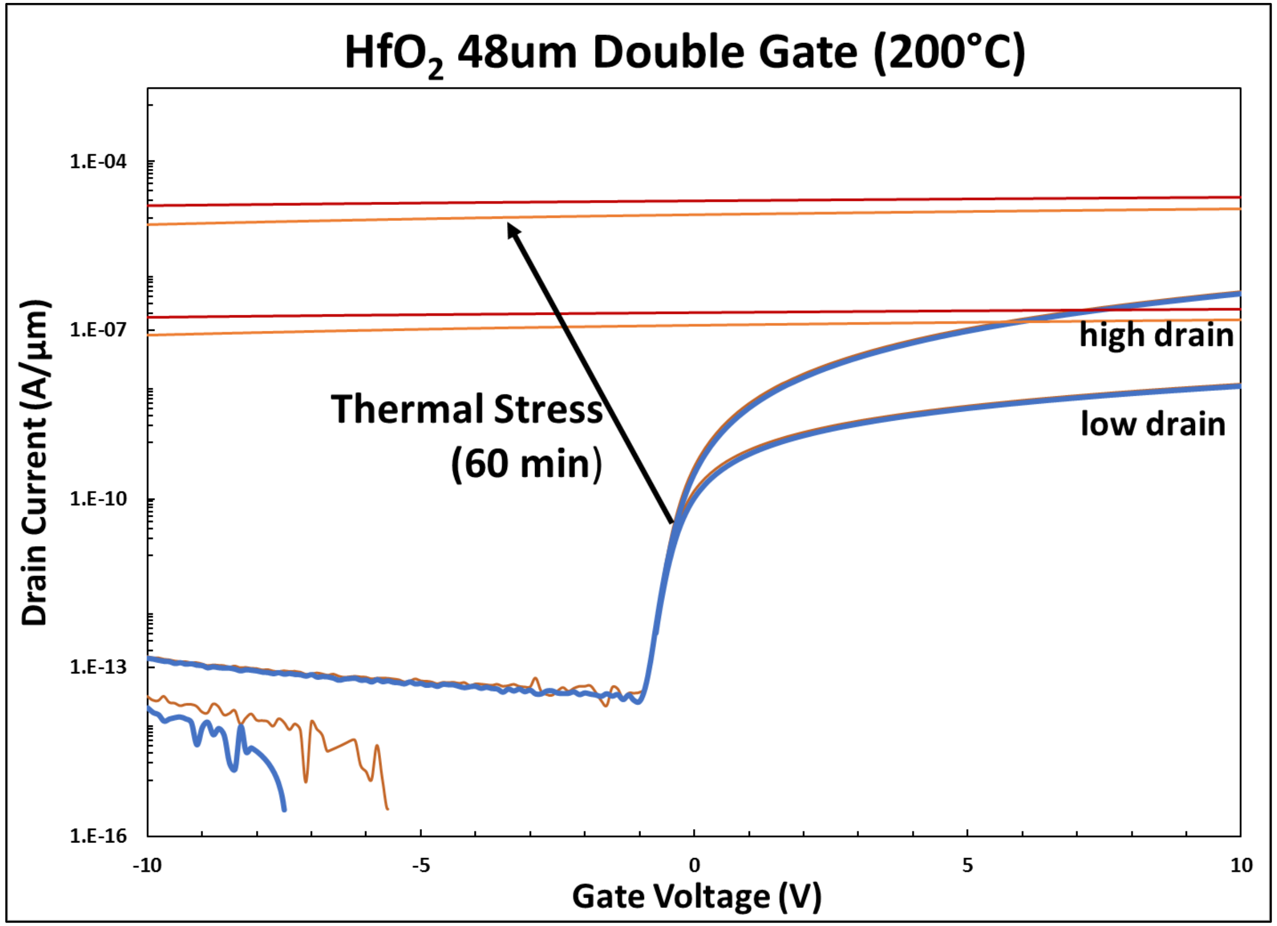


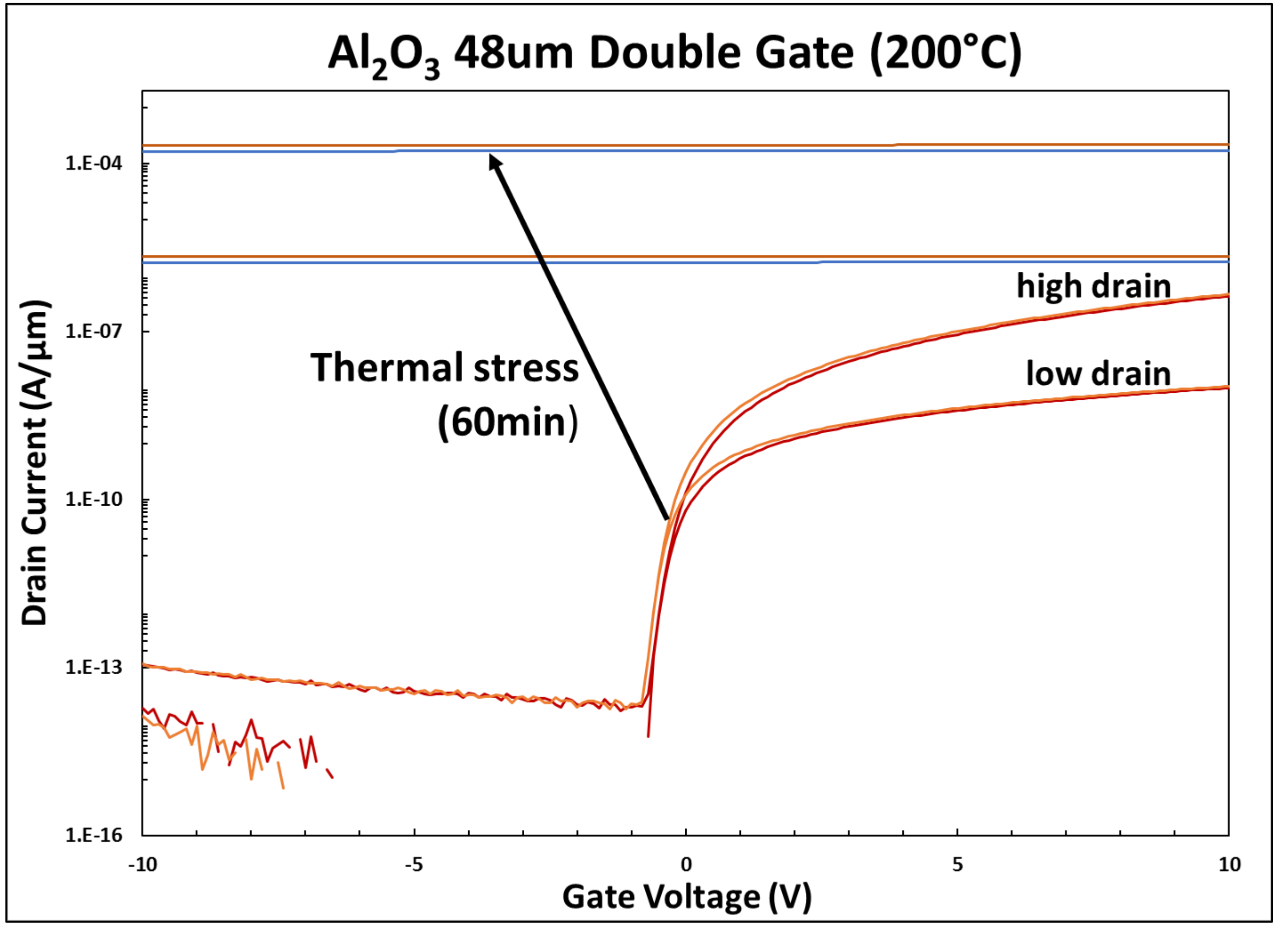
200°C Treatment: Bottom-gate Encapsulated





200°C Treatment: Double-gate Encapsulated





Summary of Results

Device Type	ALD	Voltage Shift after 140°C for 120min	Voltage Shift after 200°C for 60min	Thermally Stable?
Bottom-gate	No ALD/Reference	2 V	4 V	NO
Bottom-gate	15 nm HfO_2	~ 0.5 V	< 0.1 V	YES
Bottom-gate	15 nm Al_2O_3	No shift	< 0.1 V	YES
Double-gate	No ALD/Reference	7 V	Conductive	NO
Double-gate	15 nm HfO_2	No shift	Conductive	**Yes, At 140°C**
Double-gate	15 nm Al_2O_3	> 10 V	Conductive	NO

- Bottom-gate devices show thermal stability after being subjected to both 140°C and 200°C
- Double-gate devices are stable after being subjected to 140°C for 120 minutes

Conclusions

- Results support the hypothesis that water incorporation in PECVD SiO_2 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 on bottom-gate devices demonstrate significant improvement in stability.
- Double-gate devices show improvement at 140°C, however hydrogen liberation appears to render the devices conductive at 200°C.

Future Work:

- Fabricate and test alumina encapsulated double-gate devices
- Fabricate and test both bottom-gate and double-gate TiO_2 and Nano-laminate encapsulated devices

Acknowledgements

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- Corning Inc.

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[2] 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

[3] L. H. Kim, et al., "Optimization of Al2O3/TiO2 nanolaminate thin films prepared with different oxide ratios, for use in organic light-emitting diode encapsulation, via plasma-enhanced atomic layer deposition," Physical Chemistry Chemical Physics, vol. 18, pp. 1042-1049, Jan 2016.

[4] M. H. Tseng, et al., "Low-temperature gas-barrier films by atomic layer deposition for encapsulating organic light-emitting diodes," Nanotechnology, vol. 27, Jul 2016.