# Advancing GaN Power Device Technology:

# Theoretical Insights into Reliability, Switching Behavior, and Device-Level Design Optimization

*Samaneh Sharbati, Associate professor,*
*University of Southern Denmark*

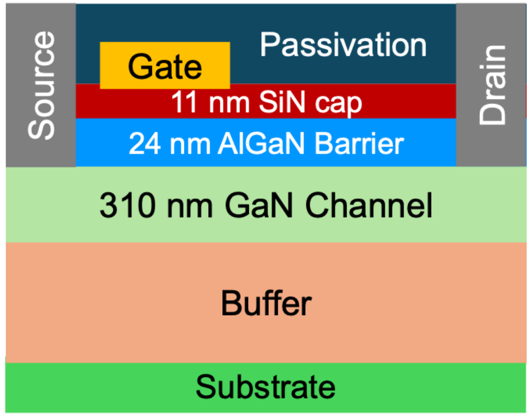
**Bodo‘s Wide Bandgap Event 2025**

*Making WBG Designs Happen*

**GaN**

# Outline

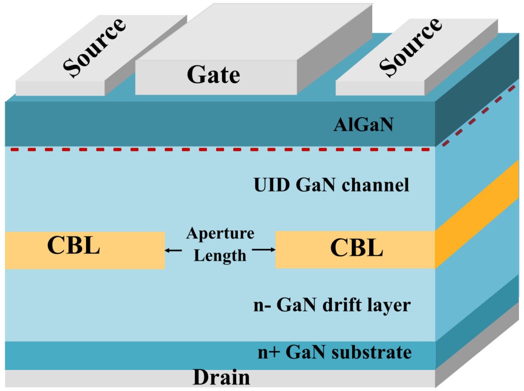
➢ **GaN MISHEMT**




**Breakdown voltage > 650 V**

**Intrinsic failure mechanisms:** Current collapse, Dynamic Ron

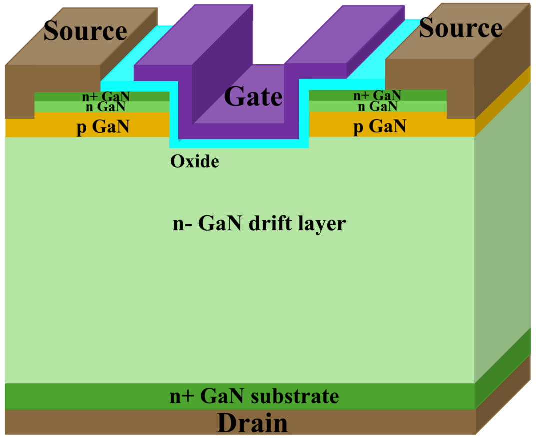
➢ **CAVET**




**Static &Dynamic characteristic**

**Application prospective**

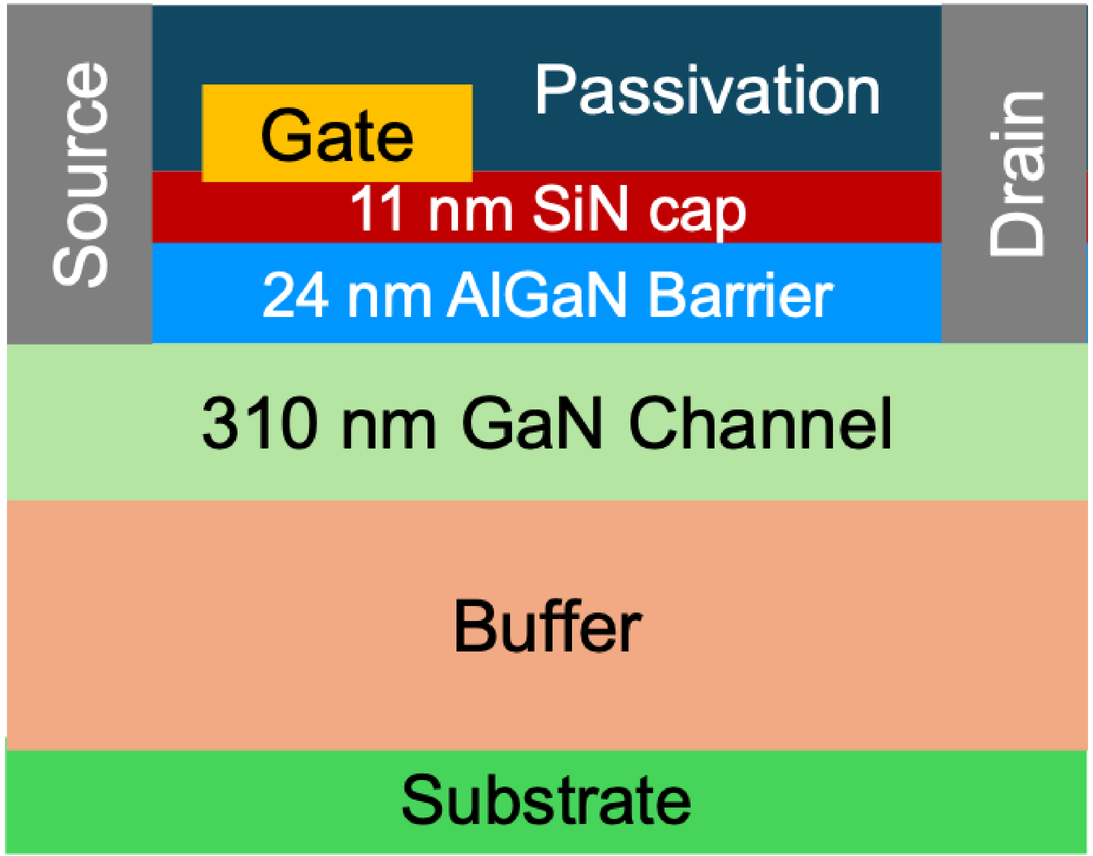
➢ **Trench MOSFET**




**static and dynamic optimization, Switching loss, Power loss**

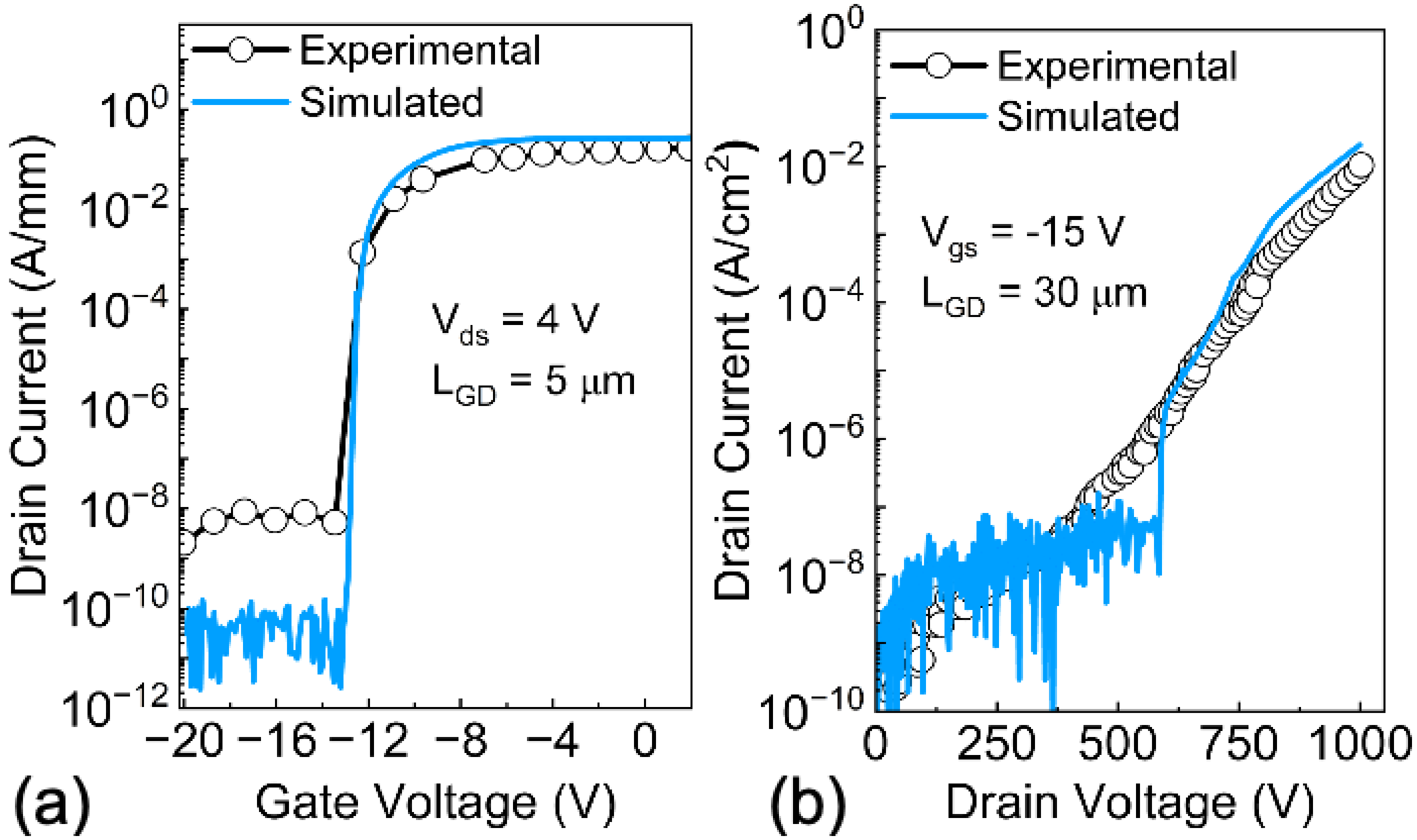
**Advanced Design**

# Improving Thermal and Electrical Performance of AlGaN/GaN MISHEMTs through Buffer Engineering



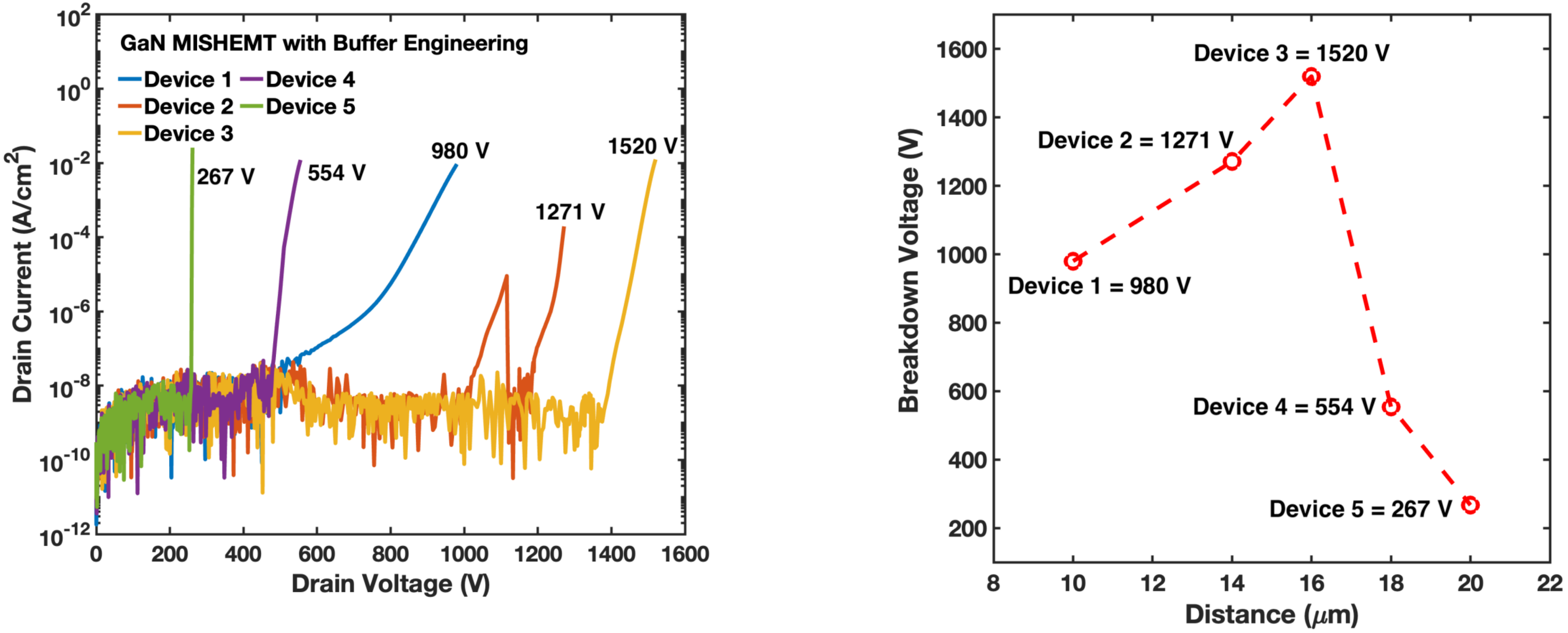

Cross-sectional schematic of GaN MISHEMT.

# Calibration of the Fabricated GaN MISHEMT with SiN-stack



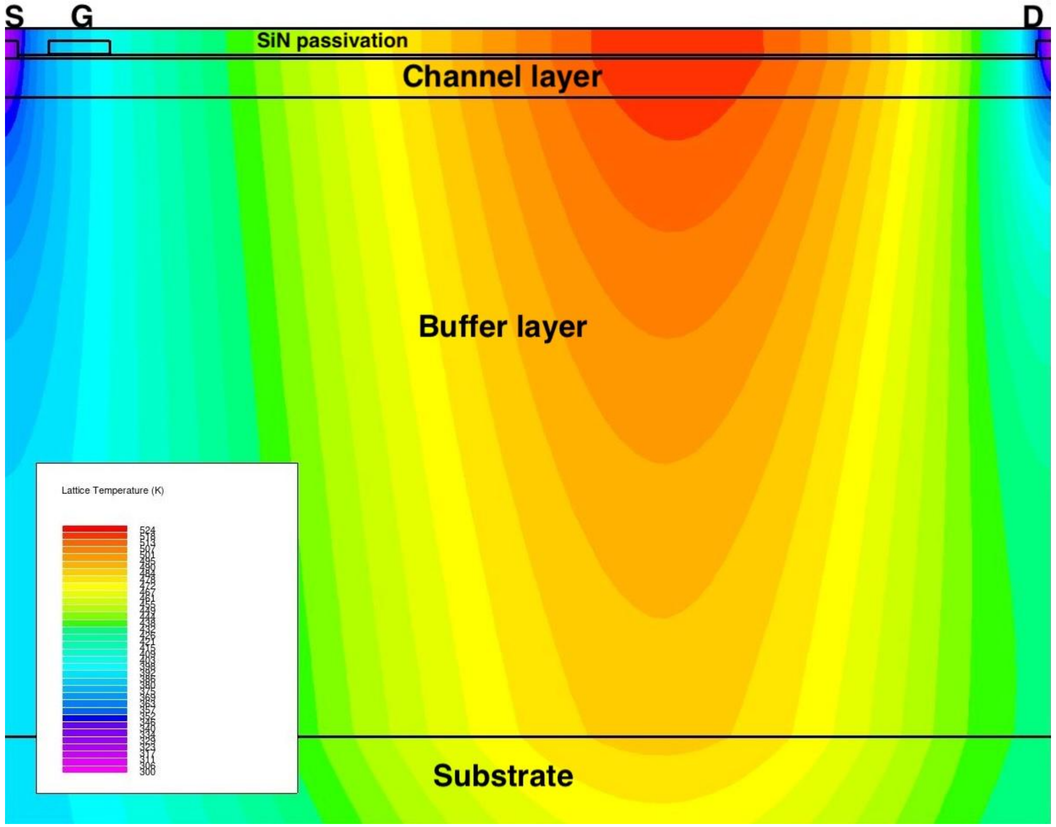

Calibrated (a) DC transfer characteristics at gate-drain distance of 5 μm , and (b) Off-state breakdown voltage at gate-drain distance of 30 μm of fabricated GaN MISHEMT device

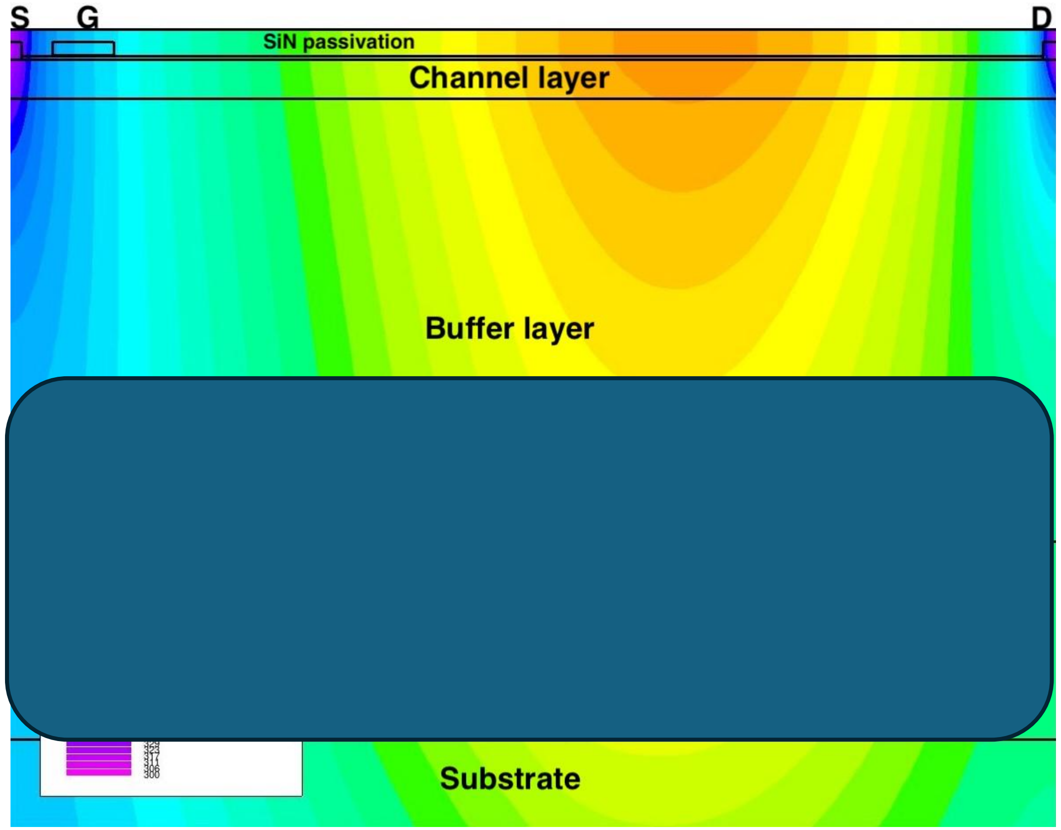
# Breakdown Voltage analysis of different devices

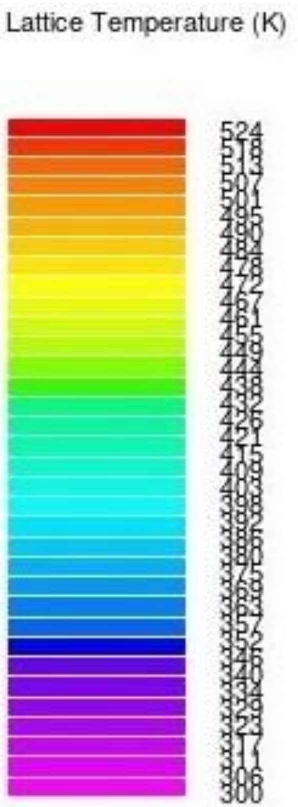



Breakdown Voltage analysis of different devices

# Normalized Self-heating Effect at 524 K

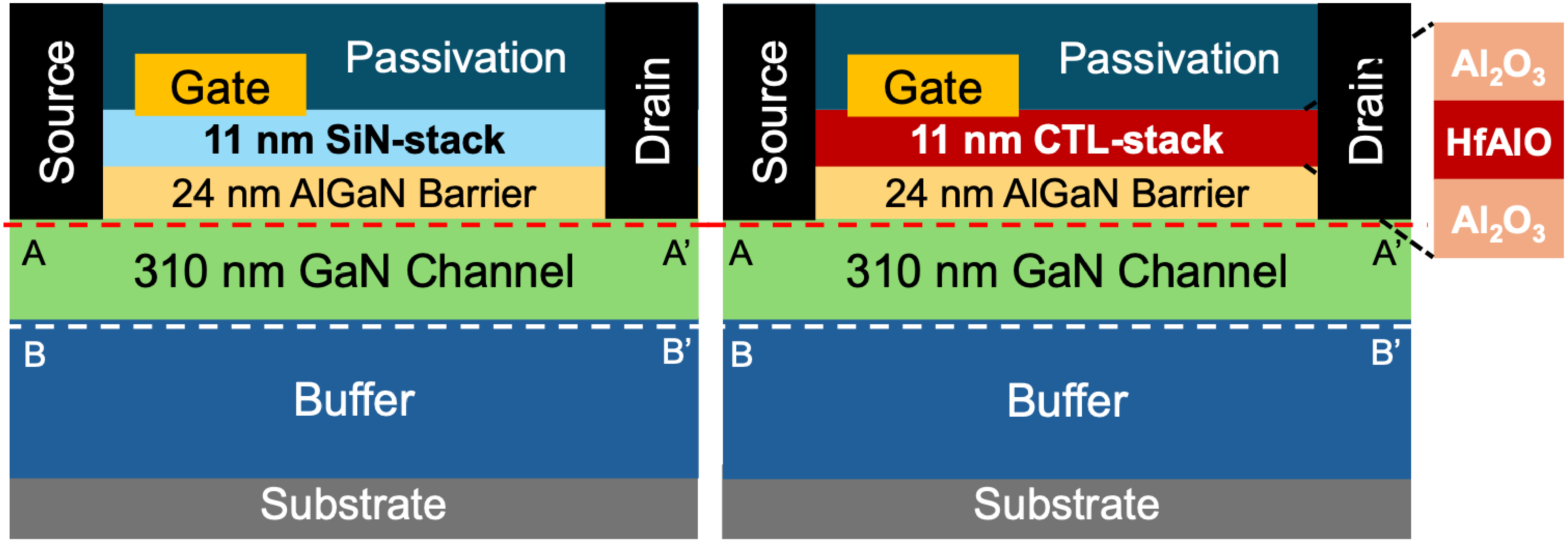


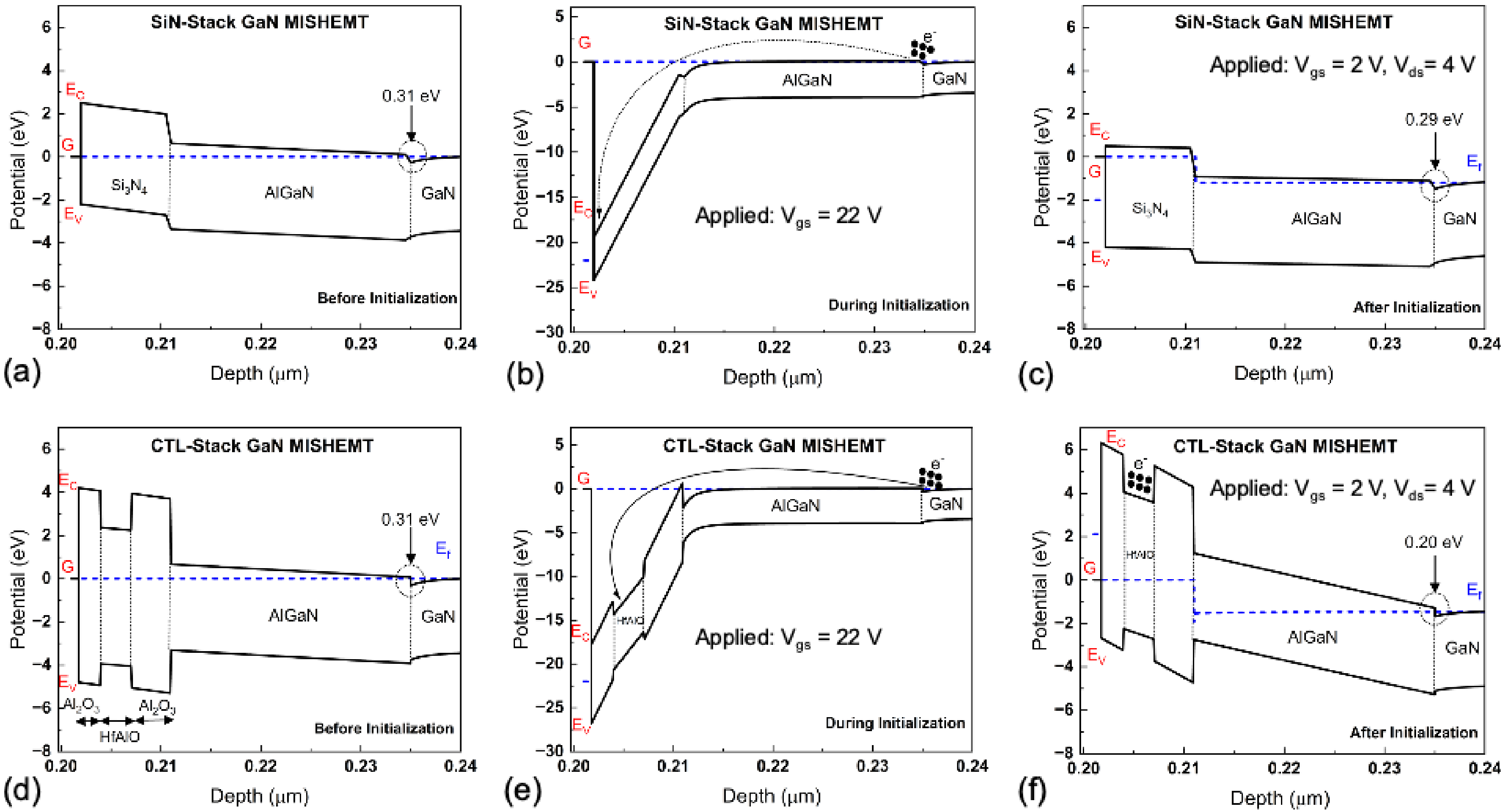

Normalized Self-heating Effect at 524 K

# Mitigation of Current Collapse and Dynamic RON in GaN MISHEMTs Using a Quantum-Well-Engineered Al2O3/HfAlO/Al2O3 Charge-Trapping Layer



# Schematic Band Diagram of GaN MISHEMTs

SDU Centre for Industrial Electronics CIE




Simulated schematic band diagram at the gate region of the GaN MISHEMT with SiN-stack (a) before, (b) during, and (c) after initialization process, and the GaN MISHEMT with CTL-stack (d) before, (e) during, and (f) after initialization process, respectively.

# I-V Characteristics of GaN MISHEMTs

SDU Centre for Industrial Electronics

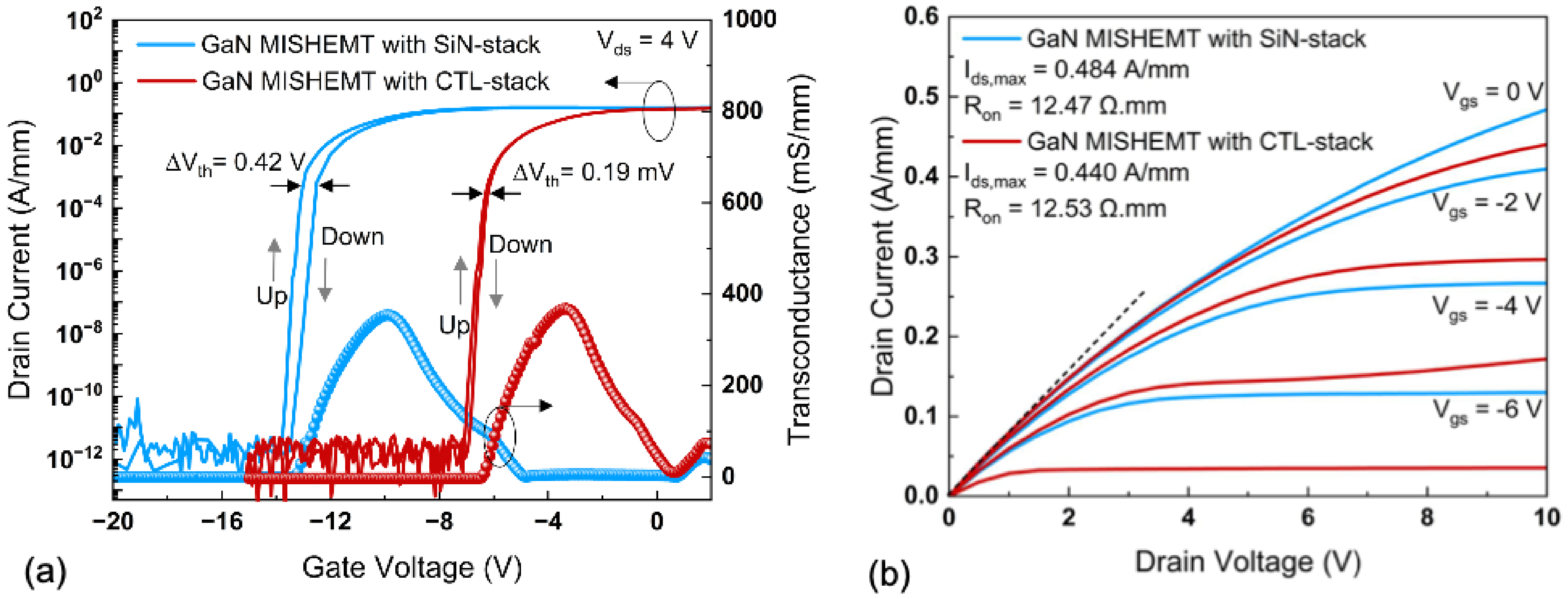
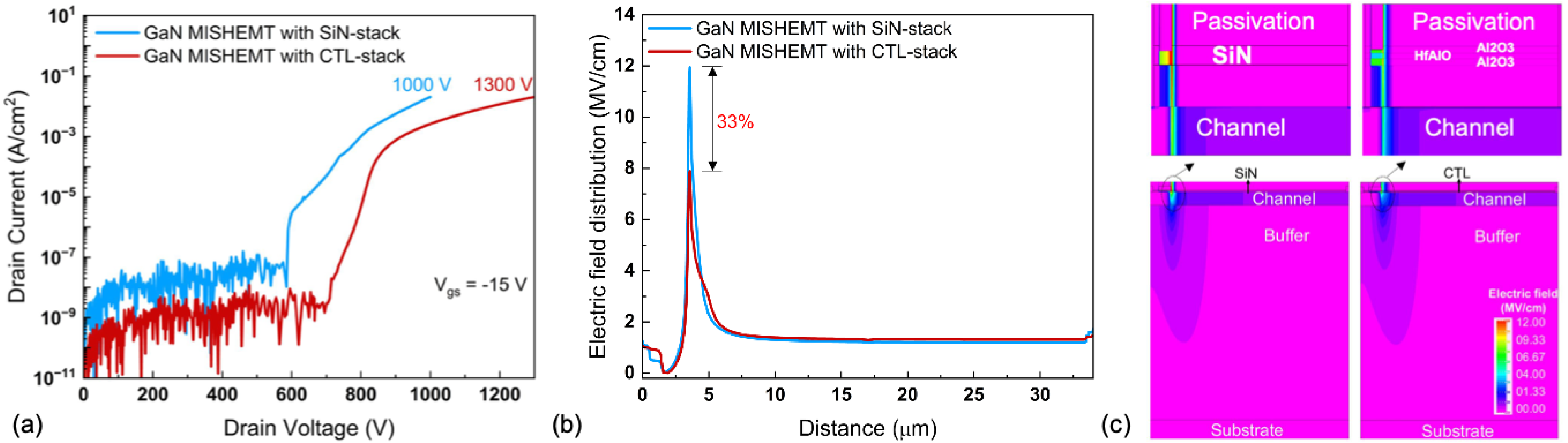


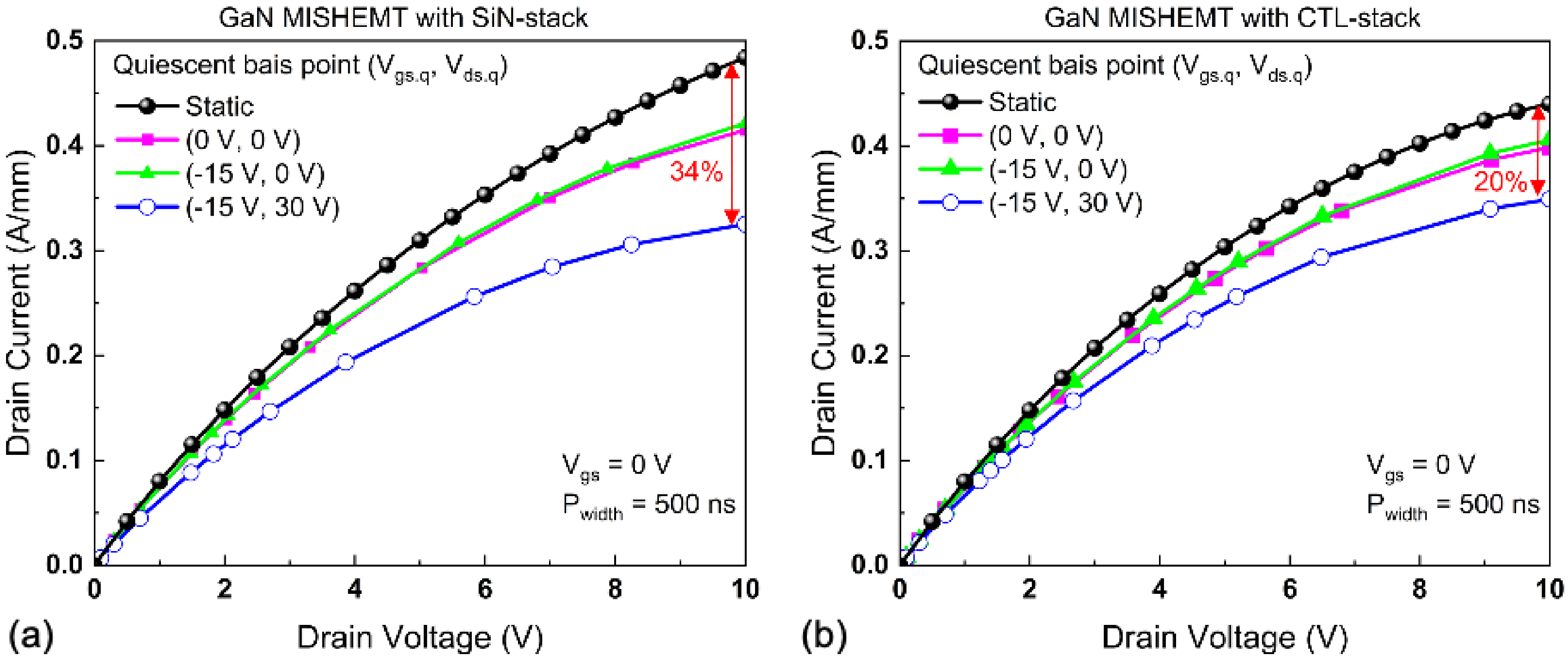

Fig. 4. (a) Dual sweep transfer characteristics, and (b) output characteristics of the devices.

# Breakdown Characteristics of GaN MISHEMTs



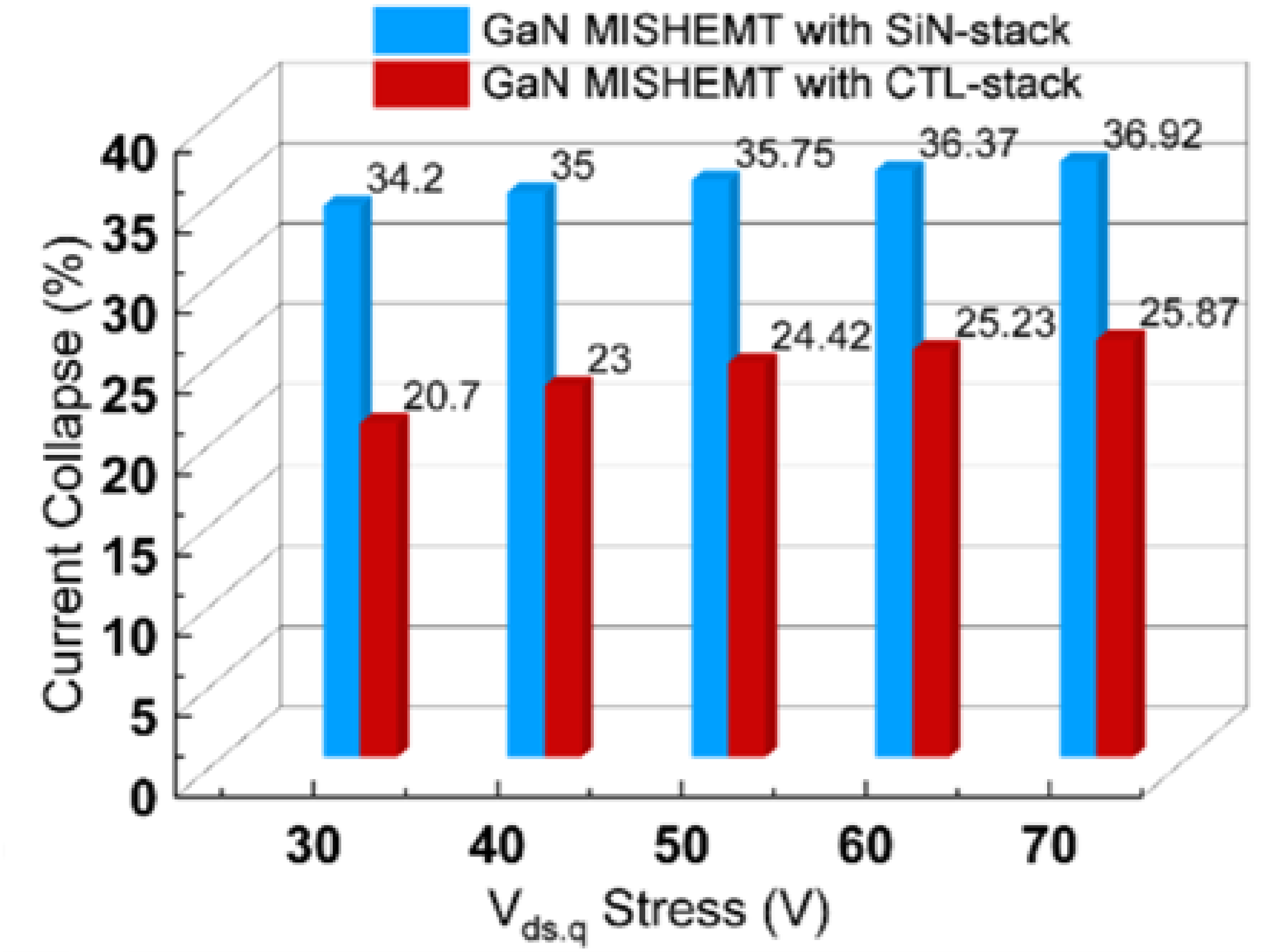

(a) Breakdown voltage characteristics at Vgs = -15 V, (b) electric-field distribution at Vds of 500 V, and (c) comparison of the computed electric field distribution of the MISHEMT devices.

# Current Collapse Characterization of GaN MISHEMTs

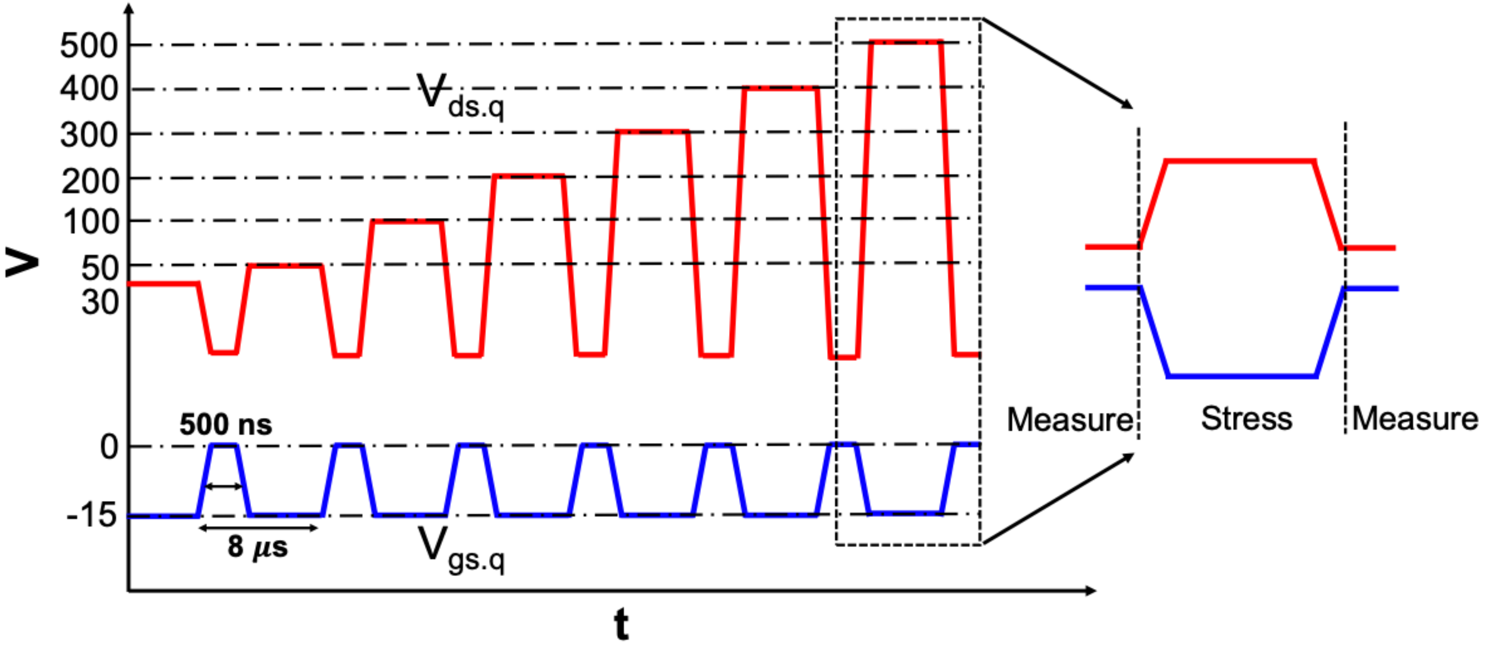



Pulsed I–V characteristics of GaN MISHEMT with (a) SiN-stack and (b) CTL-stack device and (c) Current collapse ratio at Vgs = 0 V, Vds= 10 V with different quiescent bias over static bias.

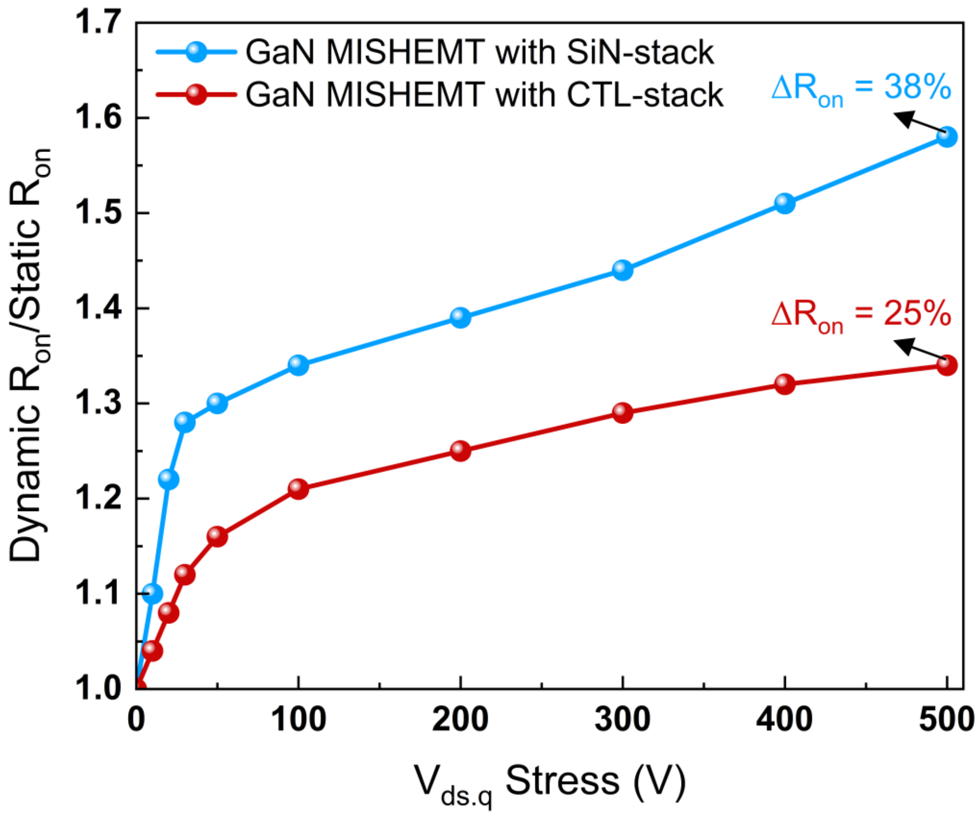
# Dependency of Current Collapse Effect



# Dynamic Ron Characterization of GaN MISHEMTs

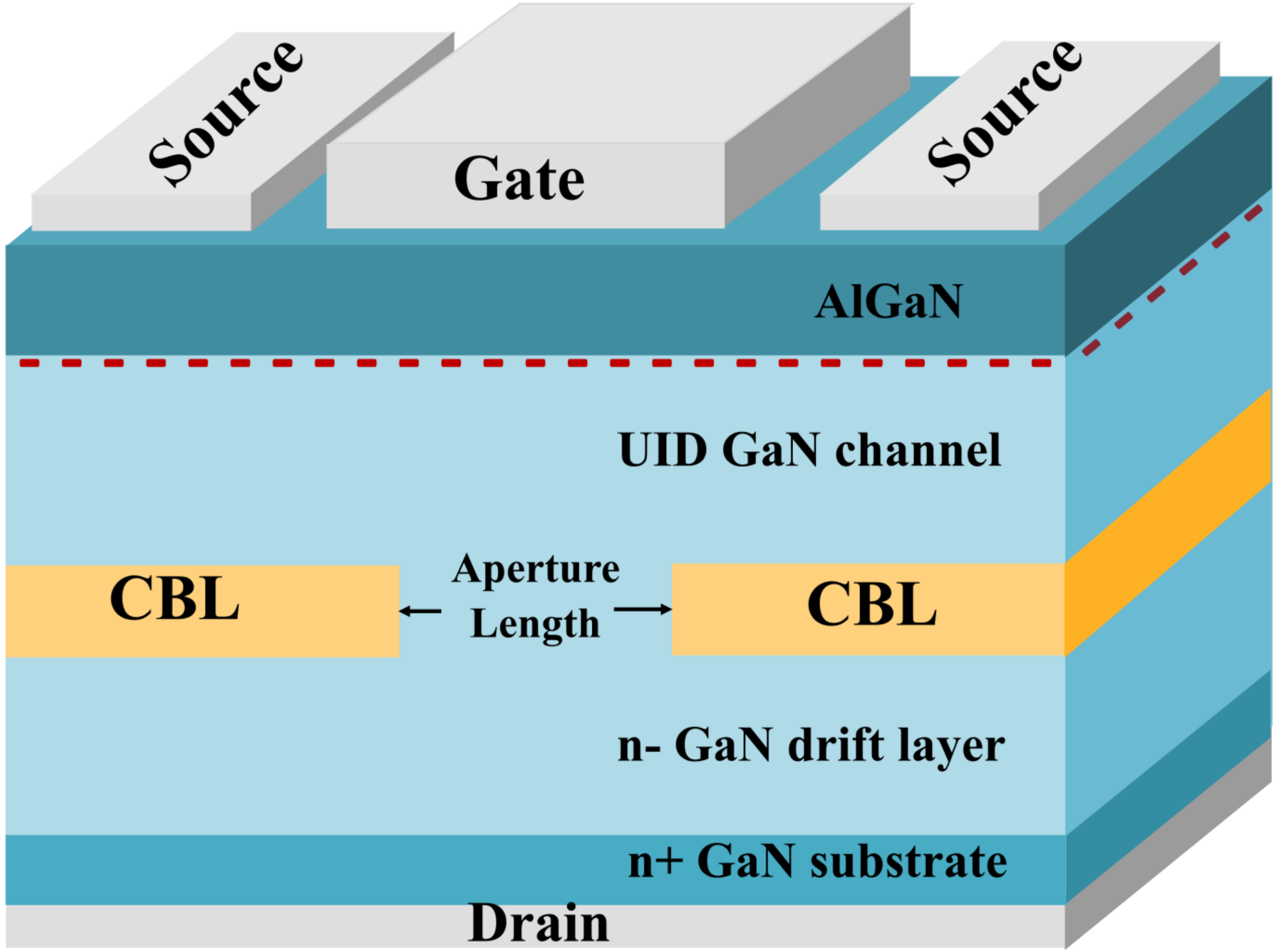



Timing diagram depicting describing the measure-stress-measure cycle.




Dynamic RON degradation of both devices.

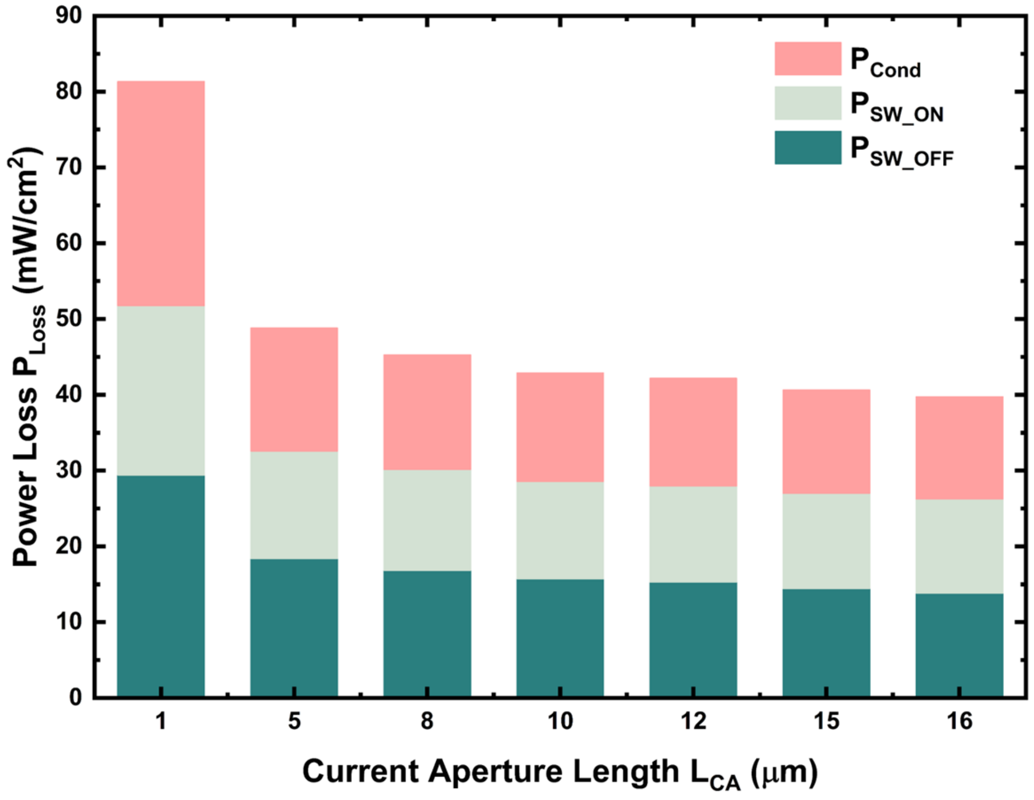
# Current Aperture Vertical Electron Transistor (CAVET)




**Conventional CAVET Structure**

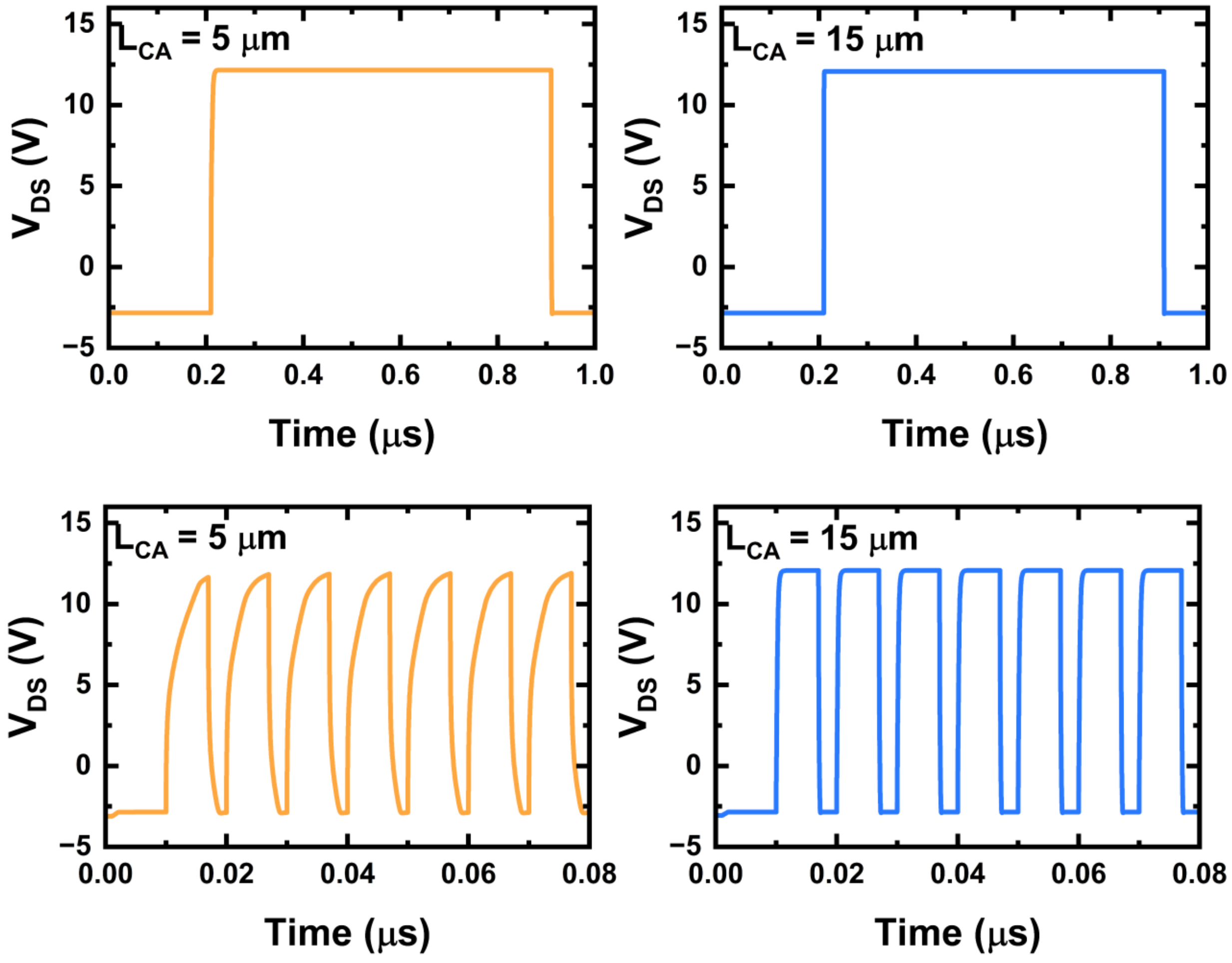
**By optimizing aperture length**

- The turn-on and turn-off power losses decreased by 53% and 45%.
- Total loss is reduced almost by half.



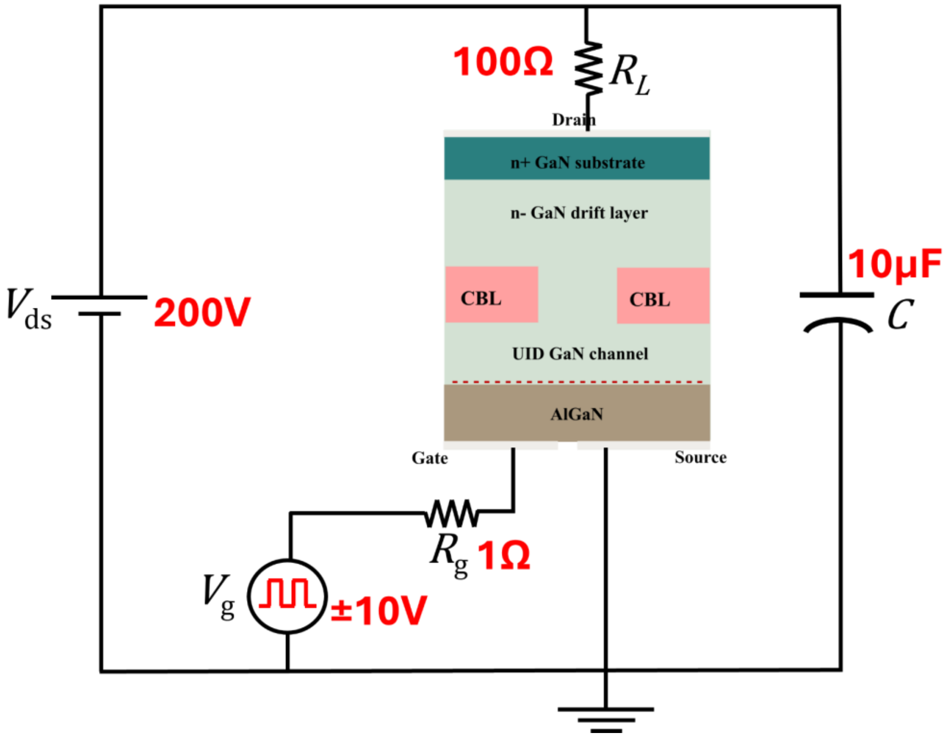
# Applications (Oscillator)

SDU Centre for Industrial Electronics cie



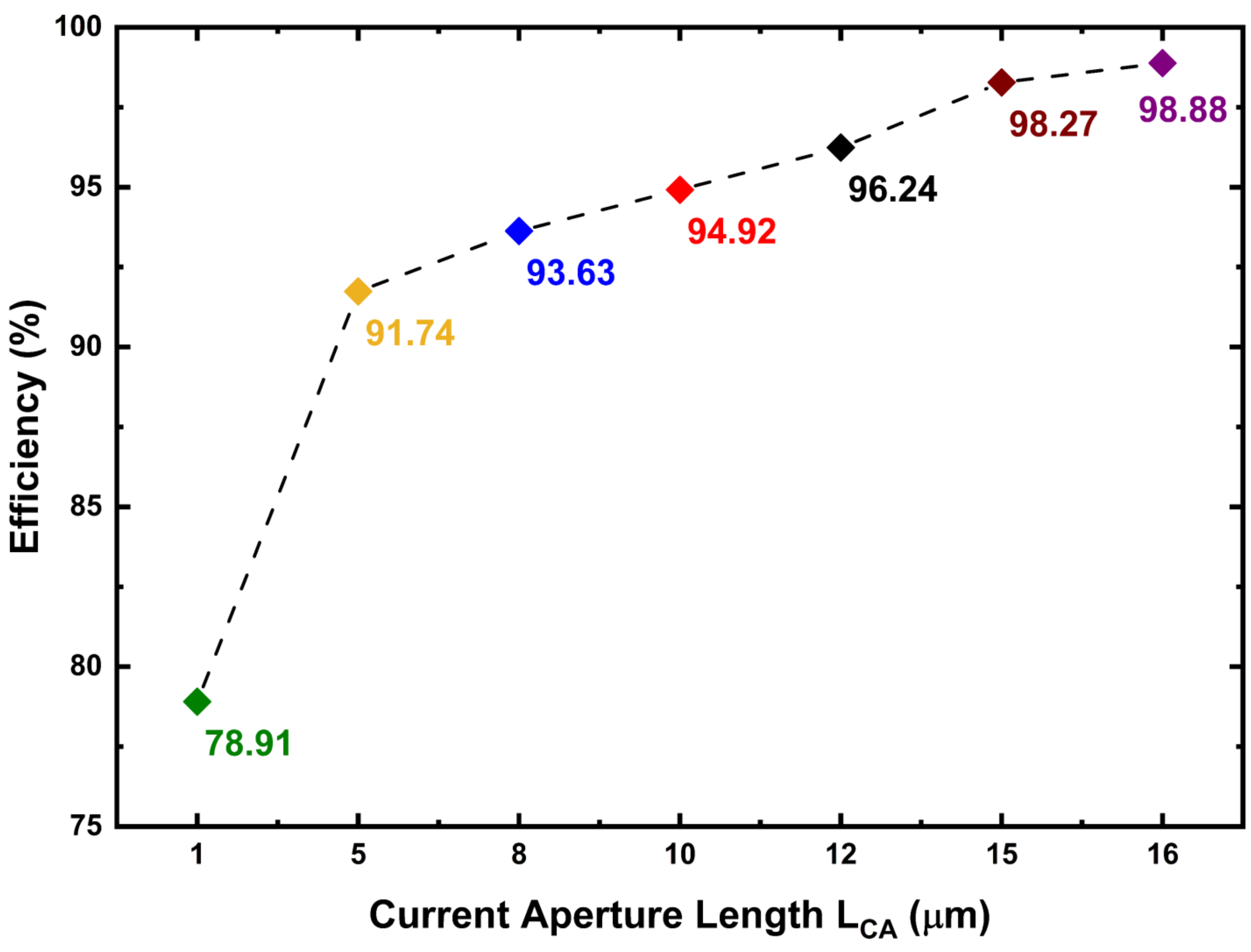

Typical waveforms of CAVET in the rectangular-wave oscillator circuit at switching frequencies of 1 MHz and 100 MHz.

- The output waveform of the oscillator remains sharp for larger aperture length at higher frequencies.

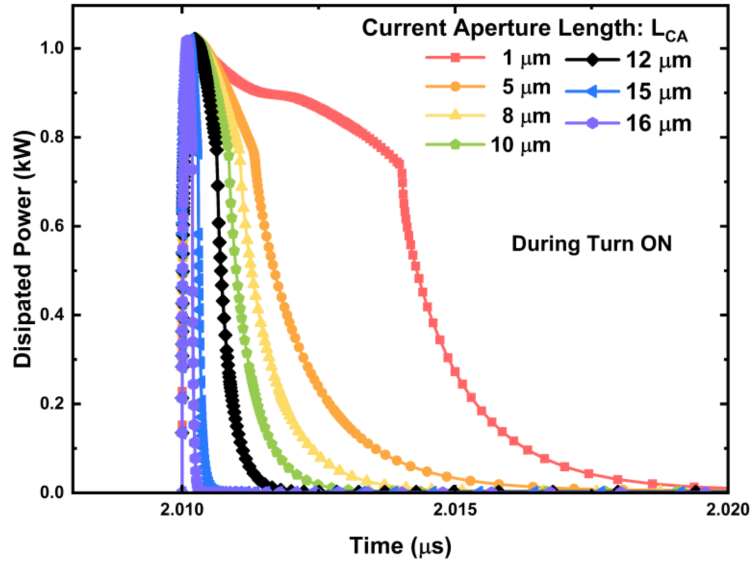


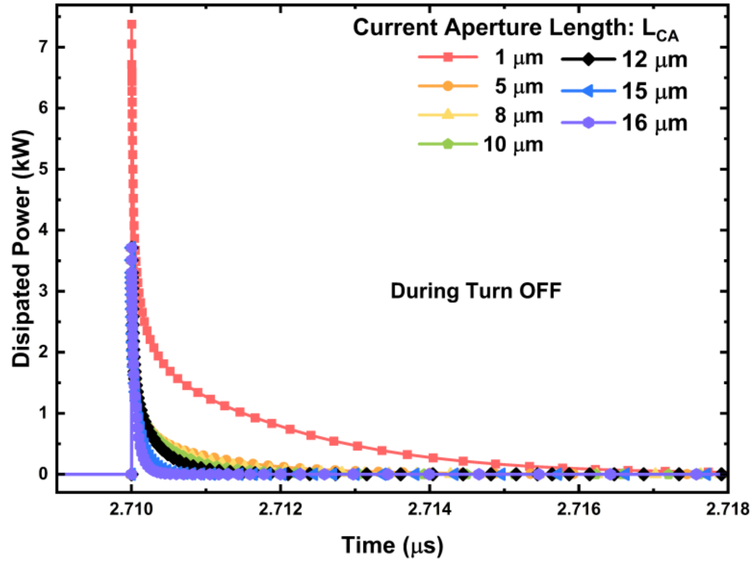

Schematic circuit diagram of a rectangular-wave oscillator circuit

# Applications (DC-DC Boost Converter)



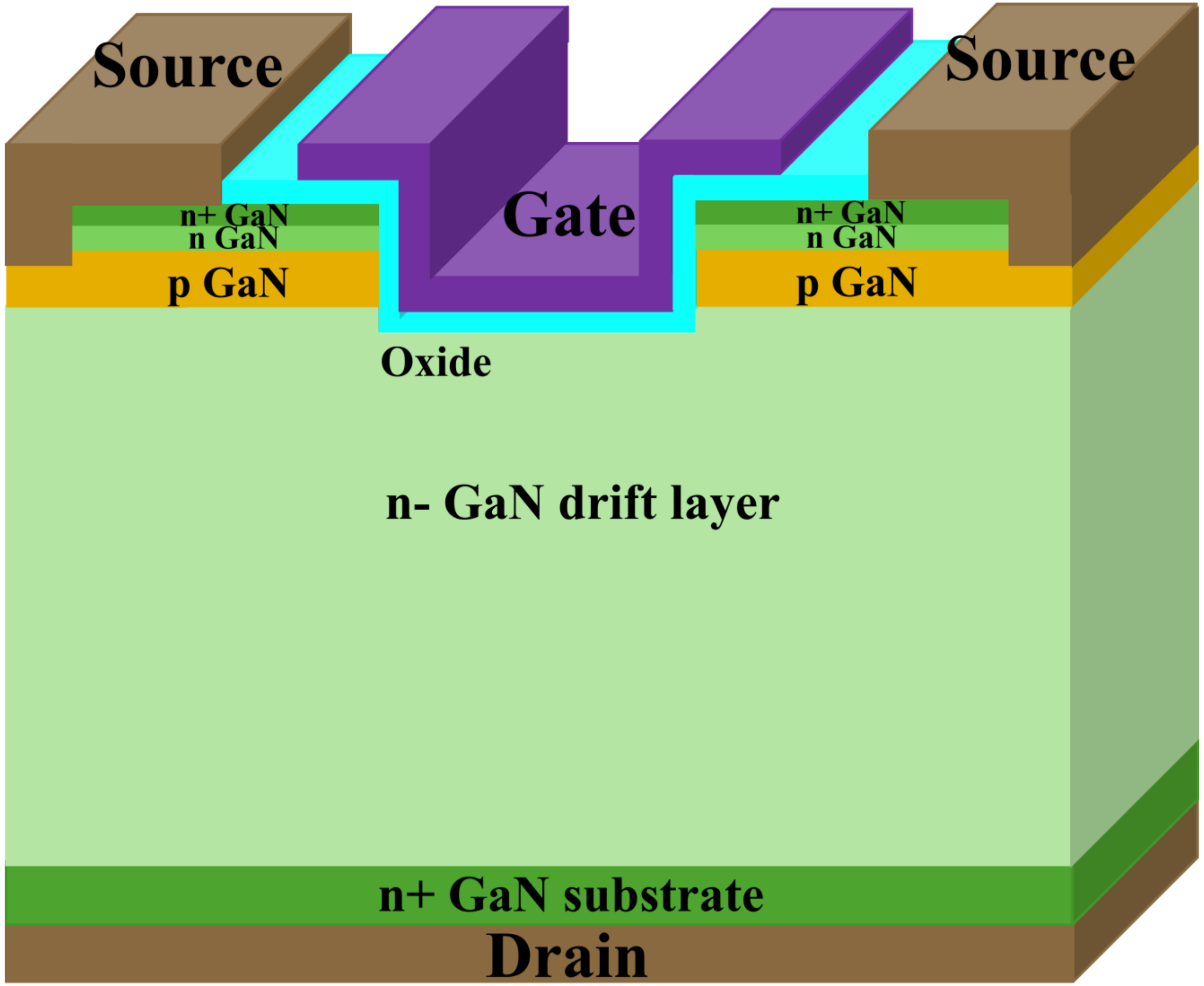

Efficiency of DC-DC Boost Converter Circuit with CAVET switch.




The dissipated power during the turn-on and off in the DC-DC Boost Converter.

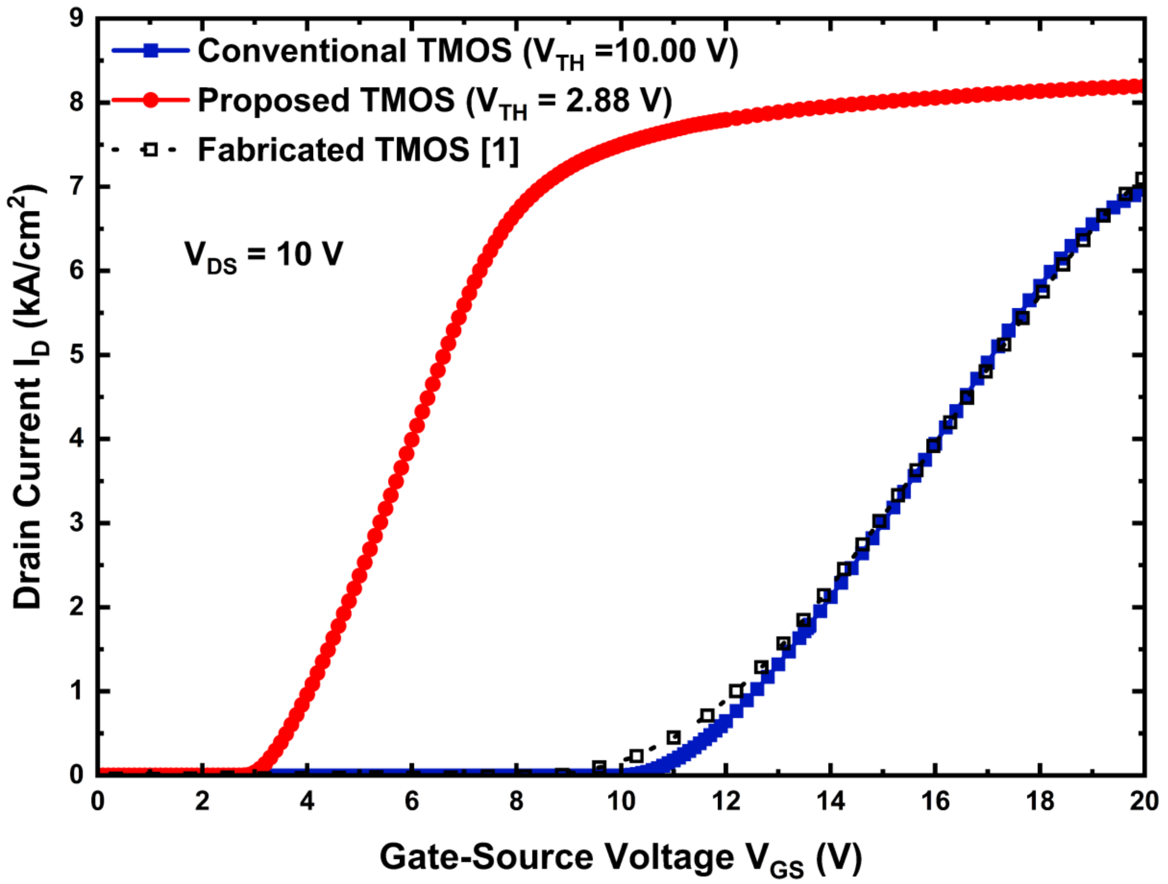
# Vertical GaN TMOS

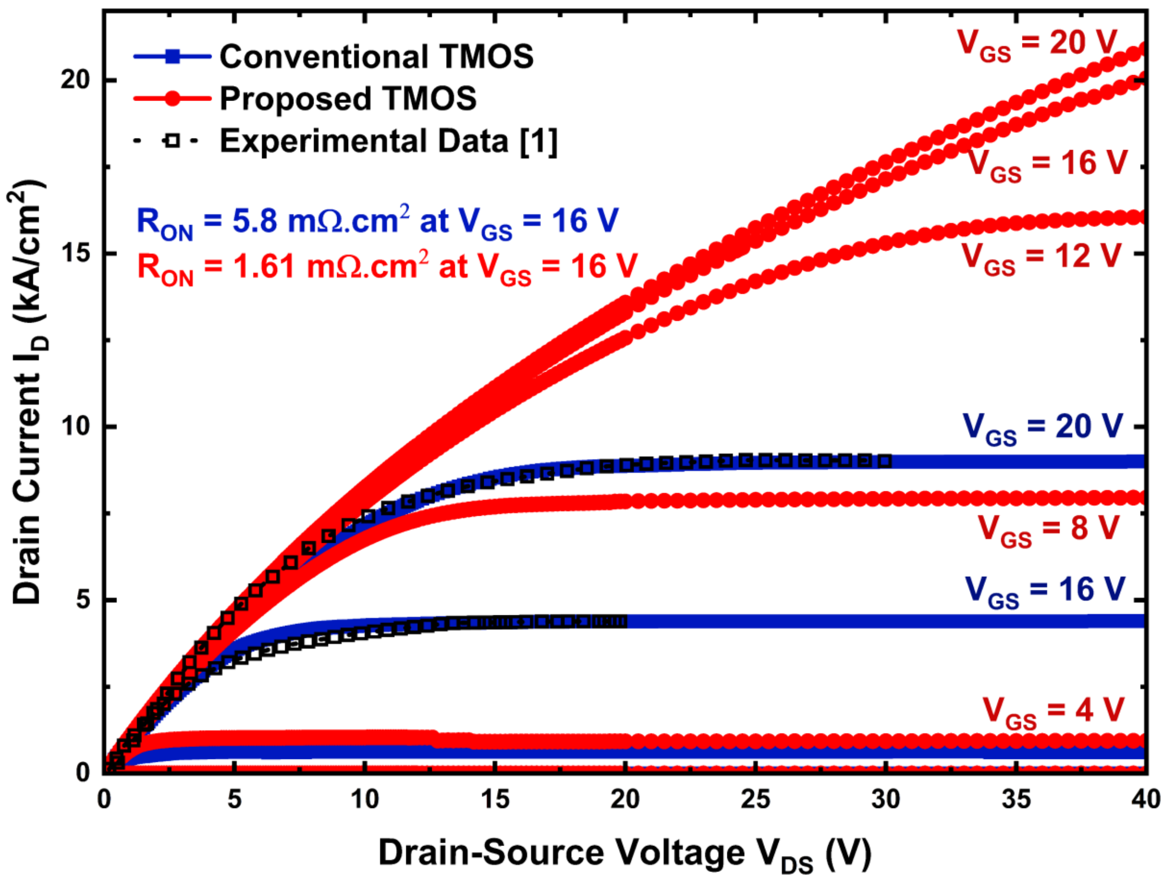



**Conventional Vertical GaN TMOS Structure**

[1] M. Kamiński, A. Taube, J. Tarenko, O. Sadowski, E. Brzozowski, J. Wierzbicka, M. Zadura, M. Ekielski, K. Kosiel, and J. Jankowska-Śliwińska, "Vertical GaN Trench-MOSFETs Fabricated on Ammonothermally Grown Bulk GaN Substrates," physica status solidi (a), pp. 2400077, 2023.

# Proposed TMOS (Static Characteristics)



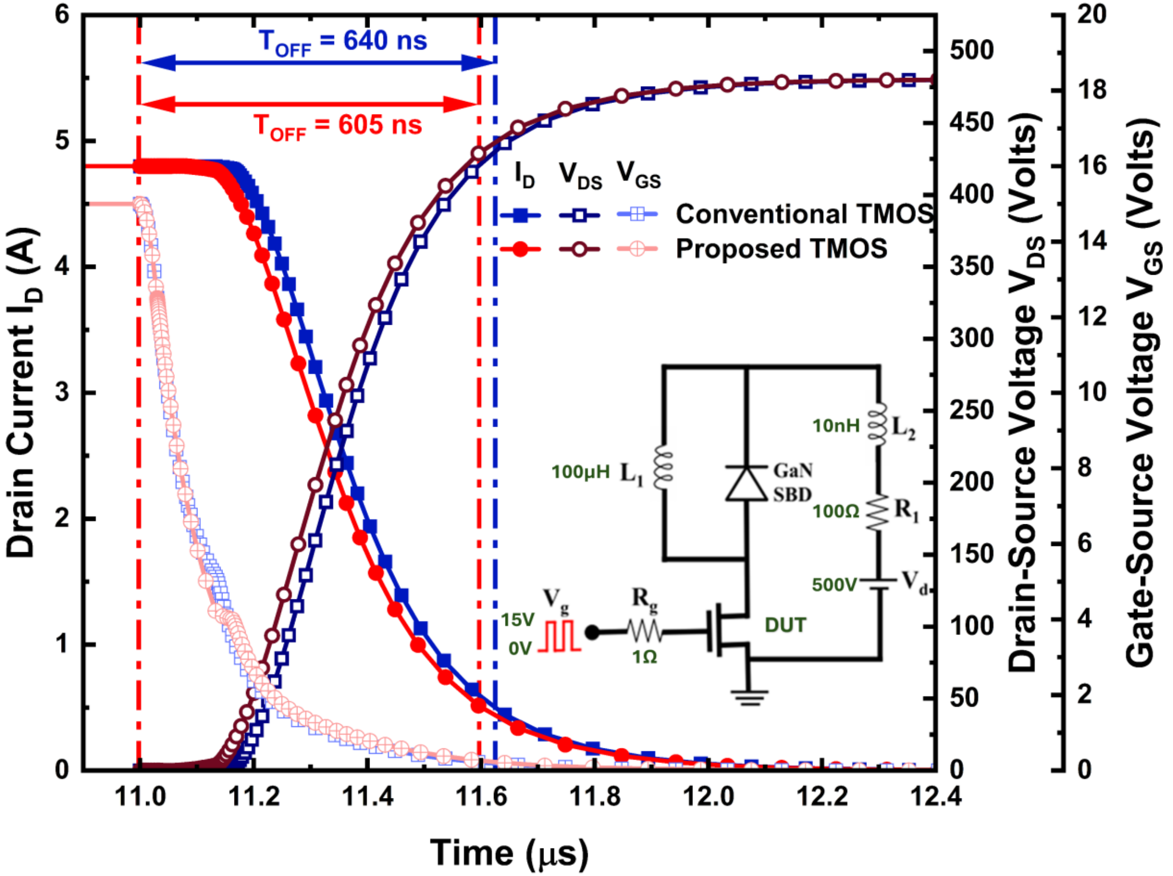



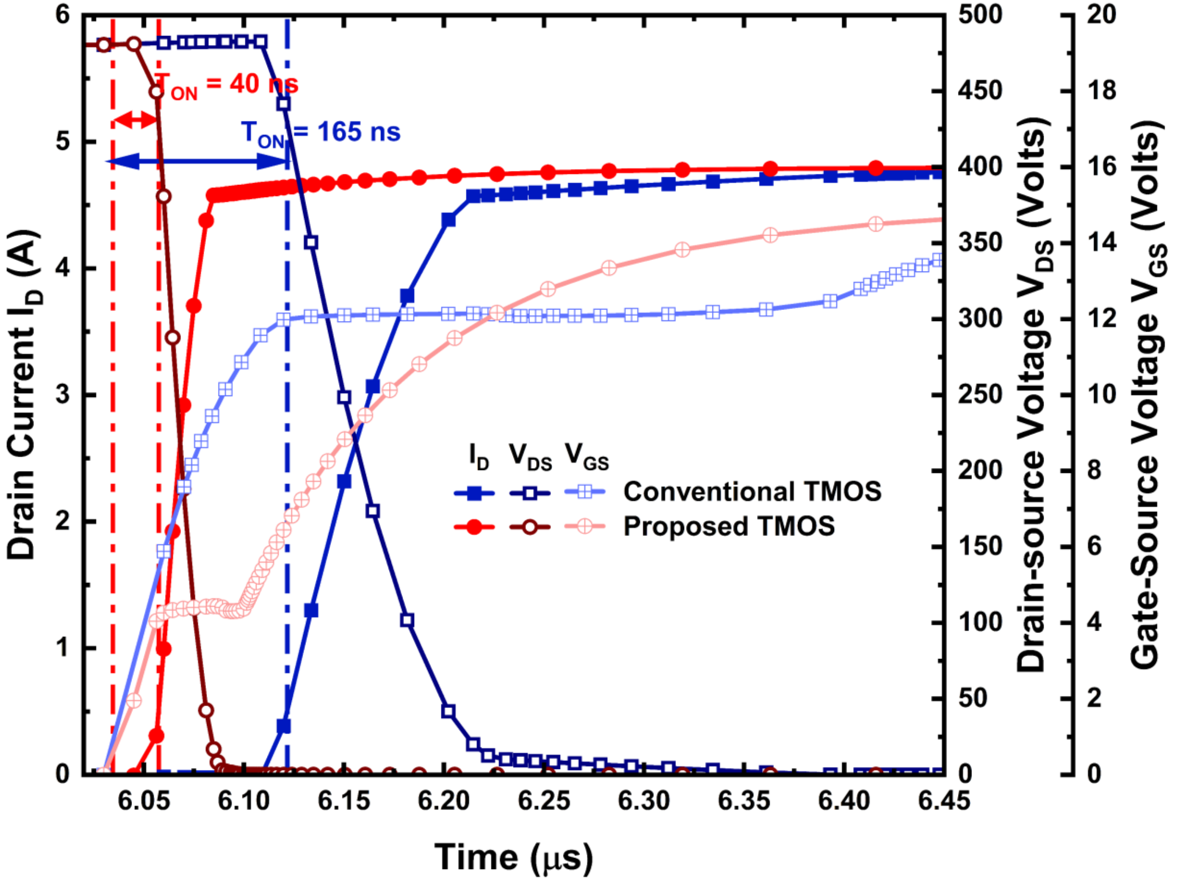

- **The threshold voltage of the proposed device is 2.88 V (72% lower than the conventional).**

- **The output current is 2 times higher than that of the conventional device.**
- **The on-state resistance is 70% lower than the conventional TMOS.**

[1] M. Kamiński, A. Taube, J. Tarenko, O. Sadowski, E. Brzozowski, J. Wierzbicka, M. Zadura, M. Ekielski, K. Kosiel, and J. Jankowska-Śliwińska, "Vertical GaN Trench-MOSFETs Fabricated on Ammonothermally Grown Bulk GaN Substrates," physica status solidi (a), pp. 2400077, 2023.

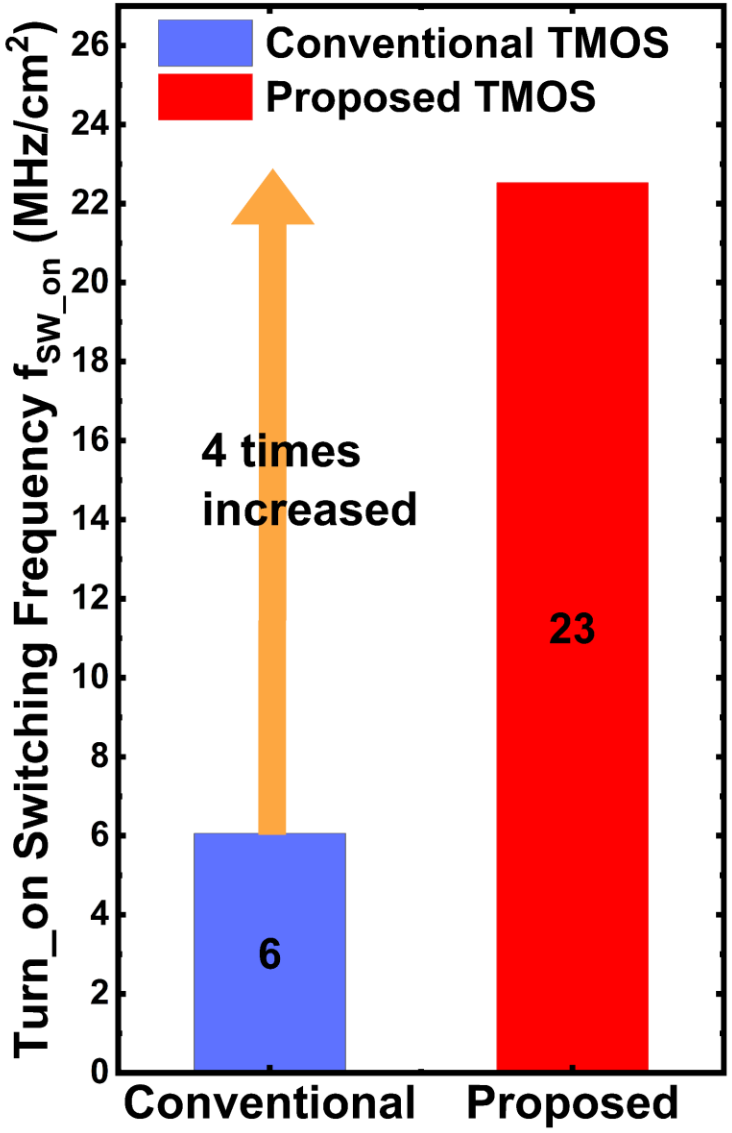
# Proposed TMOS (Switching Characteristics)

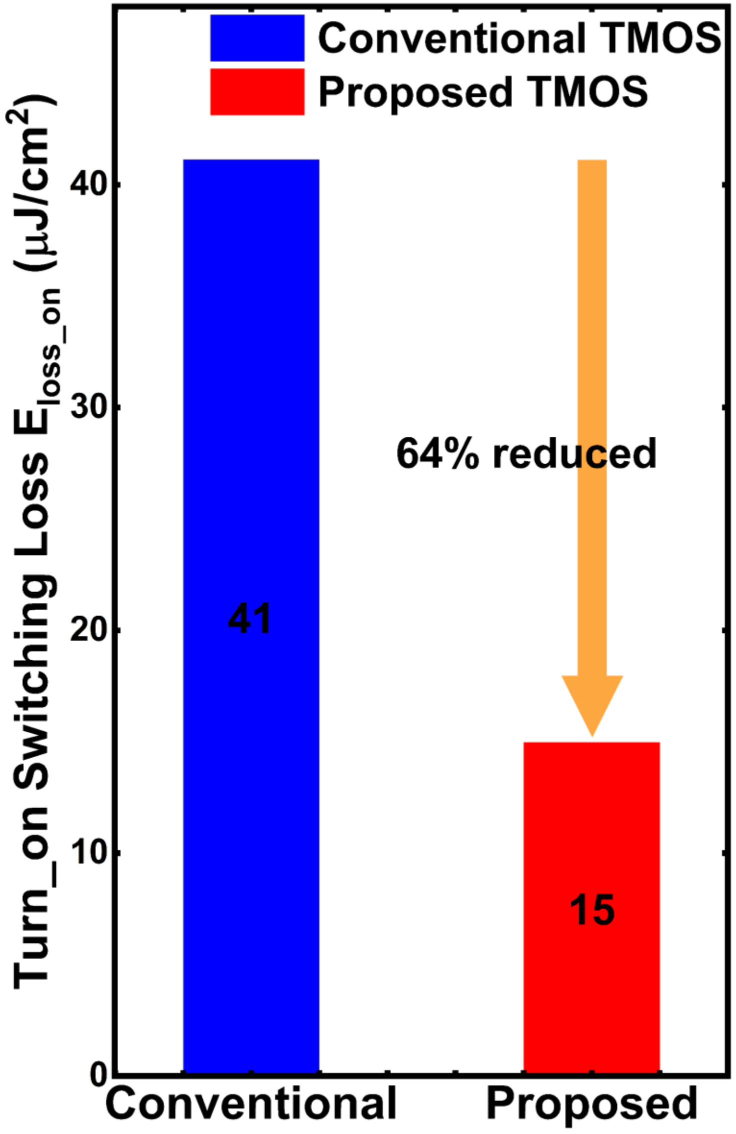



- **Turn-off time is 35 ns lower than the conventional TMOS**
- **Turn-on time decreases more than 4 times.**

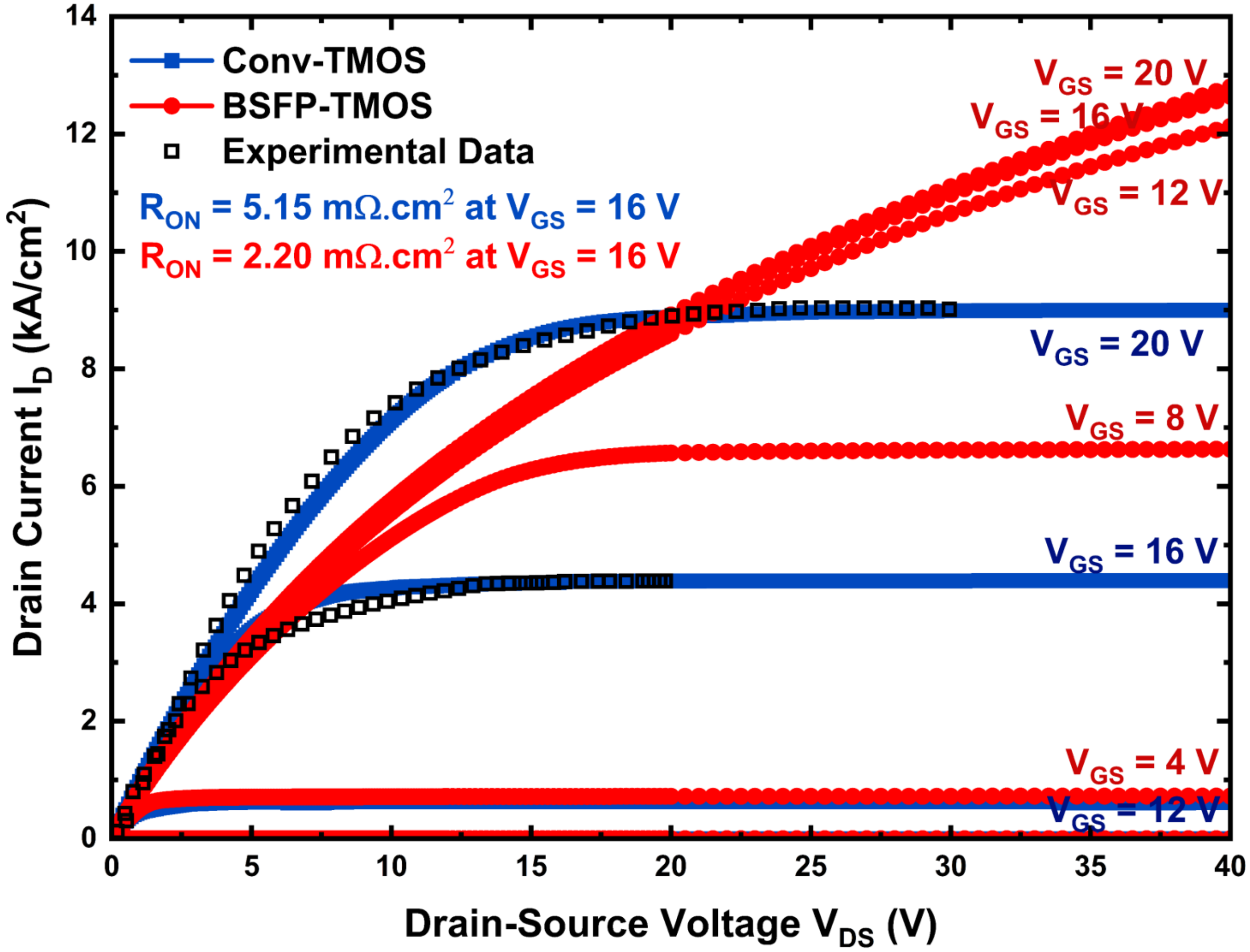
# Proposed TMOS (Switching Characteristics)




- The turn-on switching frequency is four times higher than the conventional TMOS.
- The turn-on switching loss is reduced by 64%.

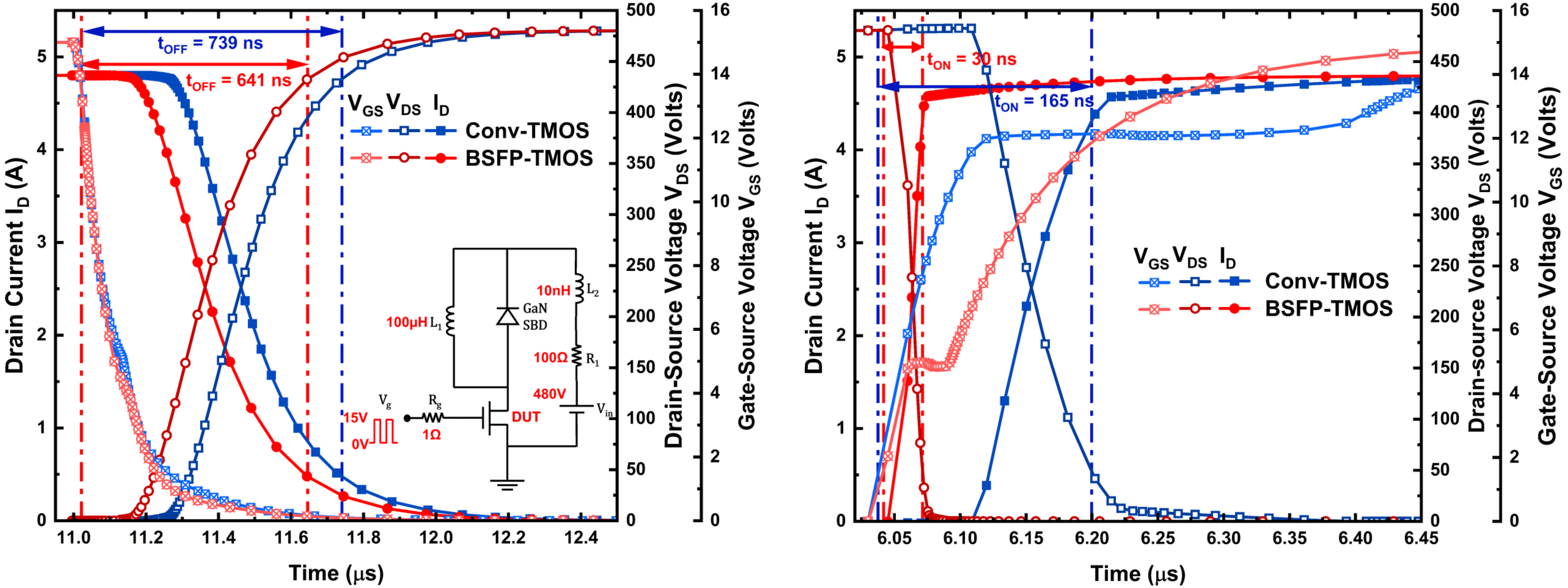
# Advanced Design for TMOS




Output Characteristics

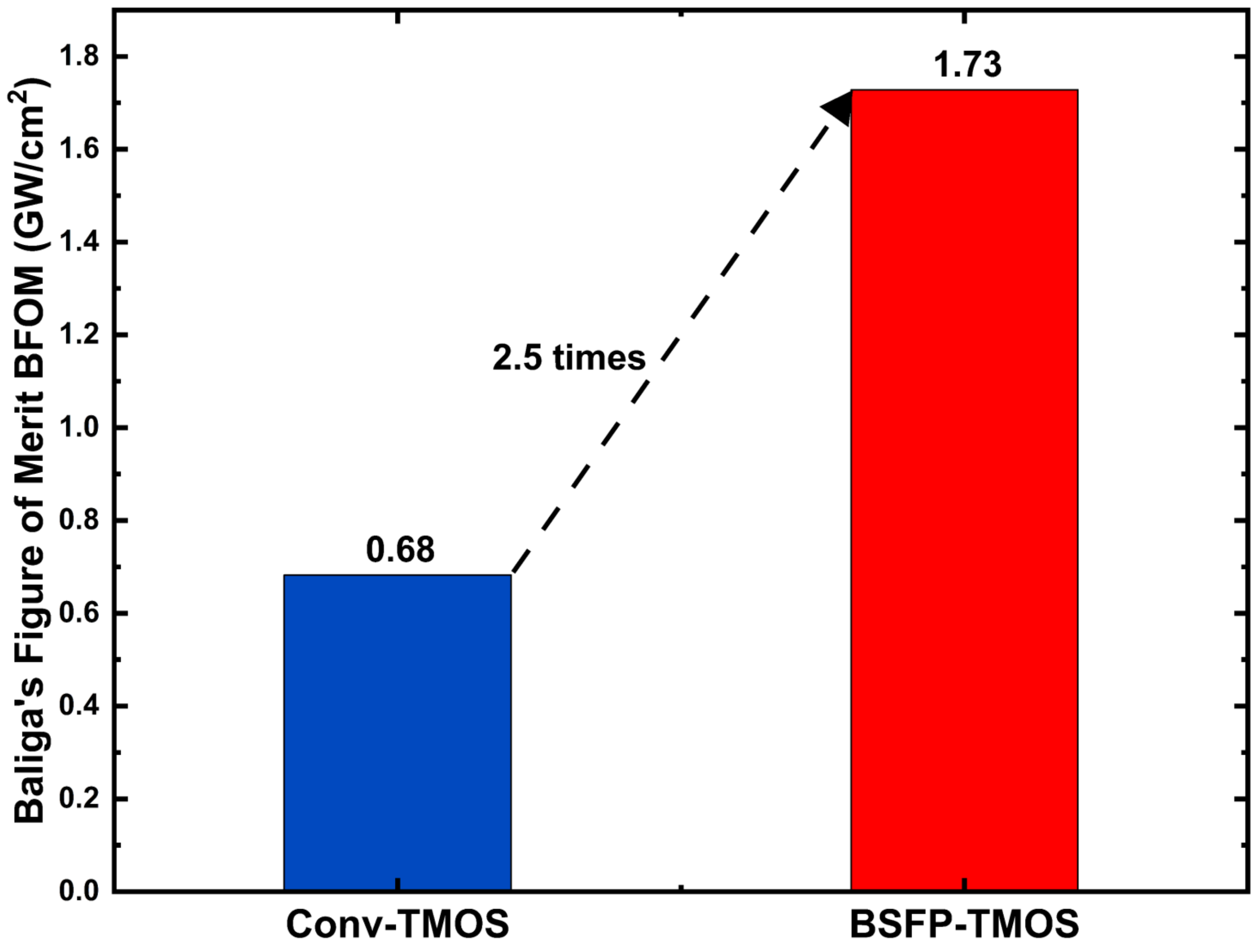
- **The output current increases from 9 kA/cm² to 13 kA/cm².**
- **The on-state resistance is 60% lower than the conventional TMOS.**

# Advanced Design for TMOS (Switching Characteristics)




- Turn-off time is 98 ns lower than the conventional TMOS
- Turn-on time decreases more than 5 times.

# Advanced Design for TMOS (Figure of Merits)




- **Baliga Figure of Merit increases by approximately 3 times.**


THANK YOU!