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Dynamic On-Resistance Characterization of GaN HEMTs under High Temperature Using Multigroup Double Pulse Test

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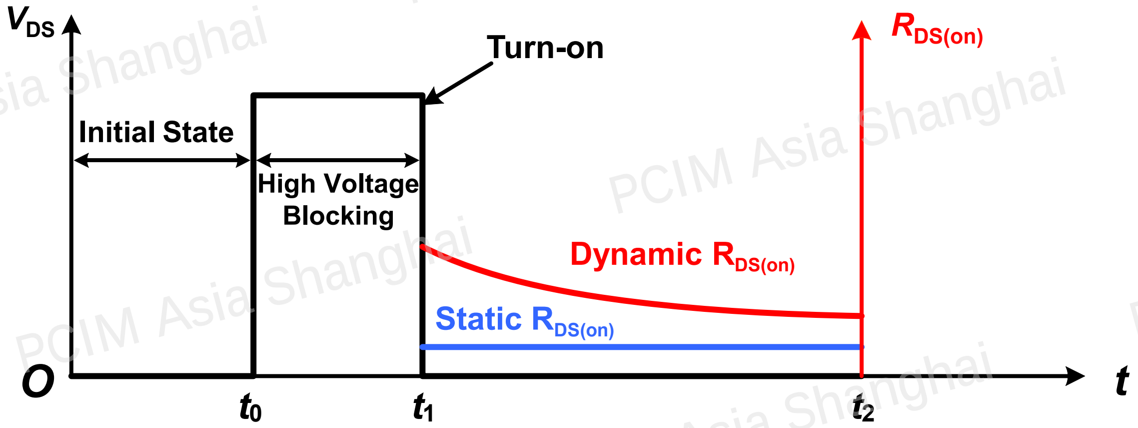
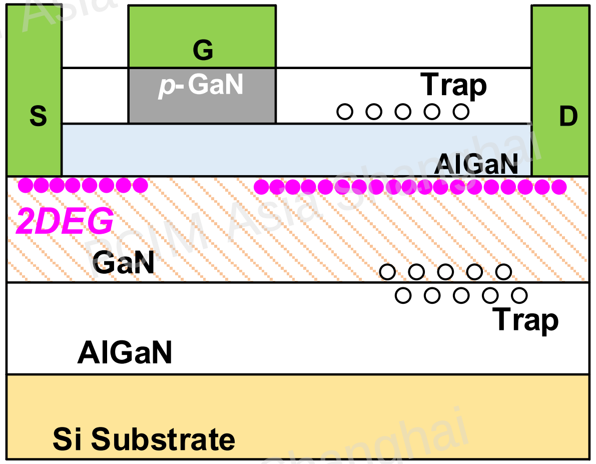
Various Factors may Affect GaN Devices' R_{ON}[1]



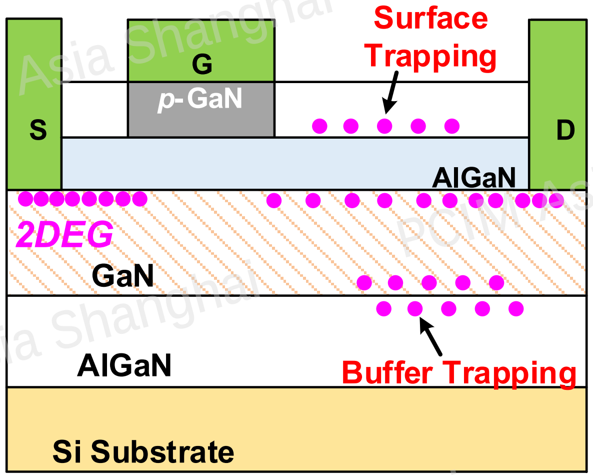
Dynamic R_{ON} $\propto$

- OFF-state drain bias voltage
- Load current
- Junction temperature
- ......

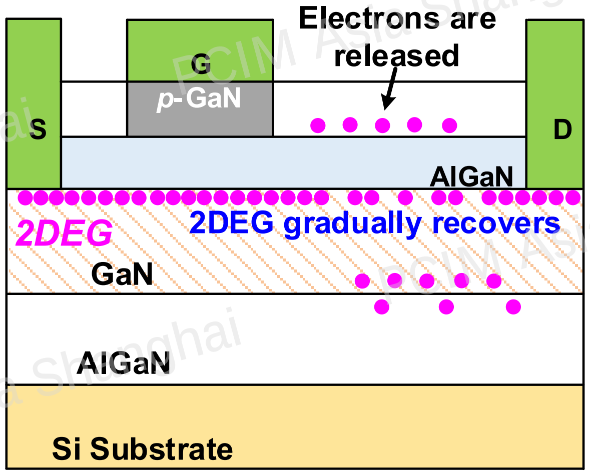
0 ~ t_0: Initial State



t_0 ~ t_1: High Voltage Blocking



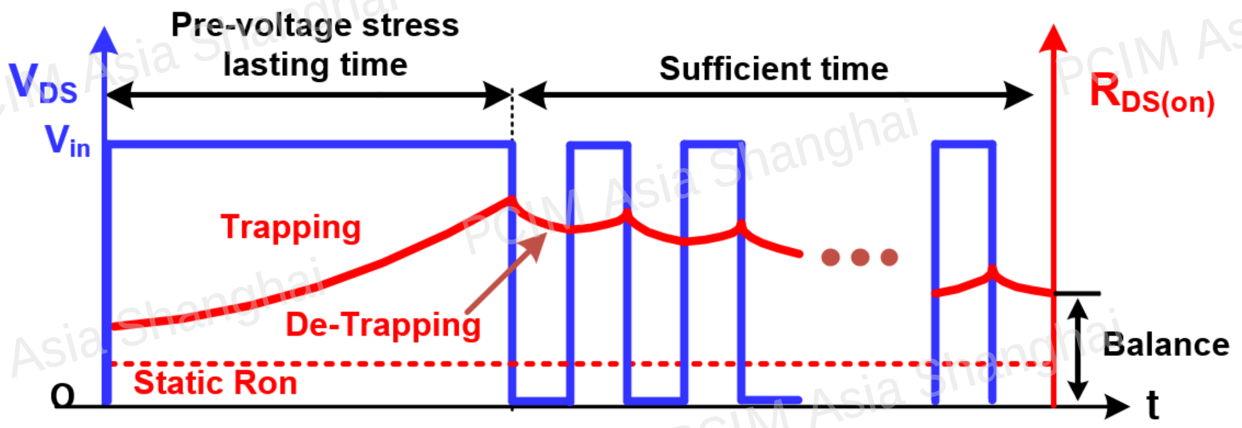
t_1 ~ t_2: After Device Turn-on



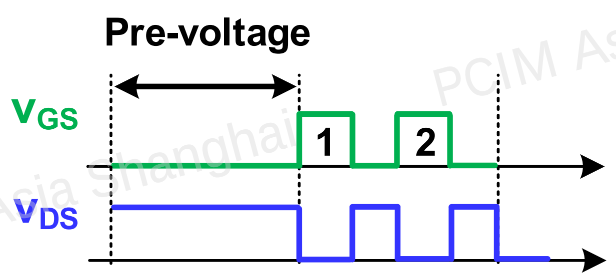
[1] S. Yang, S. Han, K. Sheng, and K. J. Chen, "Dynamic On-Resistance in GaN Power Devices: Mechanisms, Characterizations, and Modeling," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 7, no. 3, pp. 1425–1439, Sep. 2019

Pre-Voltage Stress' s Interference can' t be Eliminated in DPT

➢ V_{DS} bias effect in continuous pulse [2]



■ DPT may not relied



□ DPT can't ignore the pre-voltage.

□ Exclude influence of bias V_{DS}

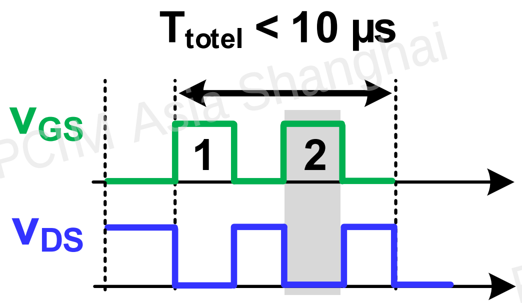
□ Simulate real power converter

➢ Consider Multi-pulse Test (MPT) for dynamic $R_{DS(on)}$ evaluating.

[2] K. Li, P. L. Evans, C. M. Johnson, A. Videt, and N. Idir, "A GaN-HEMT Compact Model Including Dynamic RDSon Effect for Power Electronics Converters,".

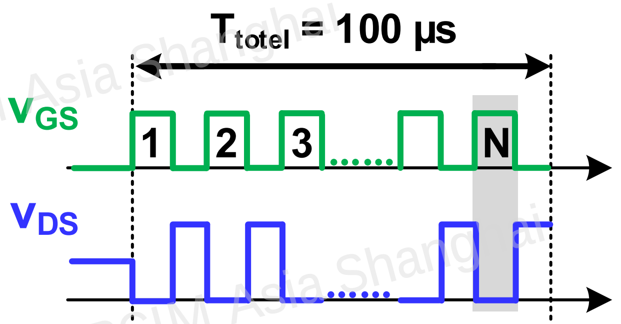
Multi-group Double Pulse Test is Selected

- **Double Pulse Test (DPT)**



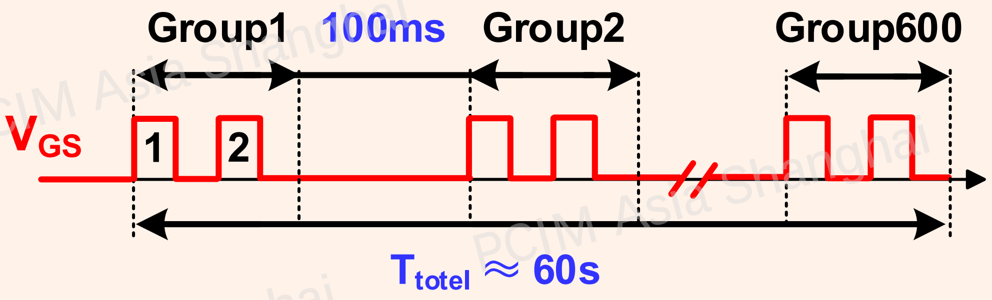
- ☐ **No self-heating.**
- ☐ **Pre-voltage influence.**

- **Multi-pulse Test (MPT)**



- ☐ **Steady state.**
- ☐ **Self-heating.**

- **Multi-group double pulse test (MGDPT) [3]**

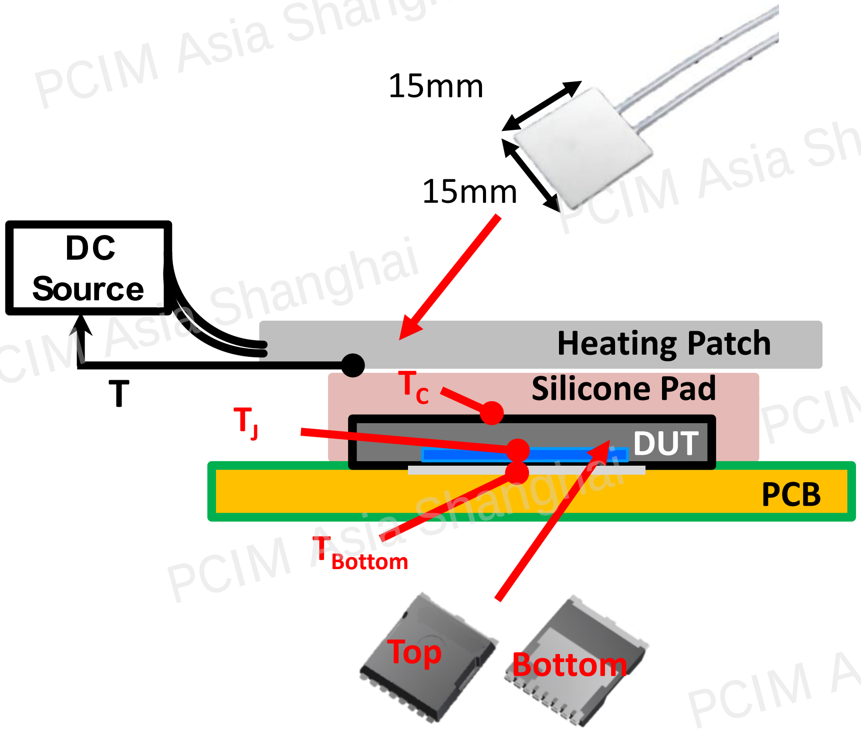


- ☐ **Sufficient off-state pulse width for heat dissipation.**
- ☐ **Sufficient total time for reaching the steady state.**

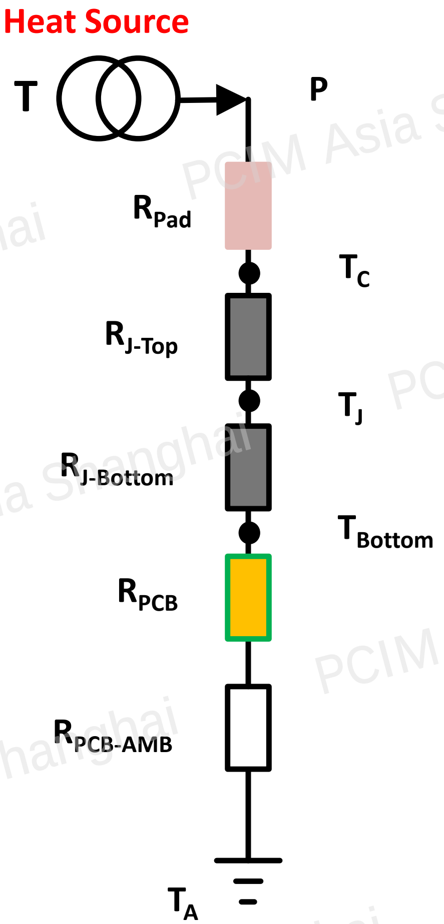
[3] "Dynamic on-resistance test method for GaN high electron mobility transistor (HEMT) in hard-switching circuits", Version 1.0, CASAS 005-2022.

Heating Scheme :
T_J can be Approximated by T_{Bottom} under Condition $R_{J\text{-}Top} >> R_{J\text{-}Bottom}$

■ Heating Scheme



■ Thermal Resistance Model



$$\frac{T_C - T_A}{T_J - T_A} = \frac{R_{PCB} + R_{PCB-AMB} + R_{J\text{-}Top} + R_{J\text{-}Bottom}}{R_{PCB} + R_{PCB-AMB} + R_{J\text{-}Bottom}}$$

$$T_J = \frac{R_{PCB} + R_{PCB-AMB} + R_{J\text{-}Bottom}}{R_{PCB} + R_{PCB-AMB} + R_{J\text{-}Top} + R_{J\text{-}Bottom}} T_C + \left(1 - \frac{R_{PCB} + R_{PCB-AMB} + R_{J\text{-}Bottom}}{R_{PCB} + R_{PCB-AMB} + R_{J\text{-}Top} + R_{J\text{-}Bottom}}\right) T_A$$

$$T_J = \gamma T_C + \delta$$

T_{Bottom} can be measured in offline mode

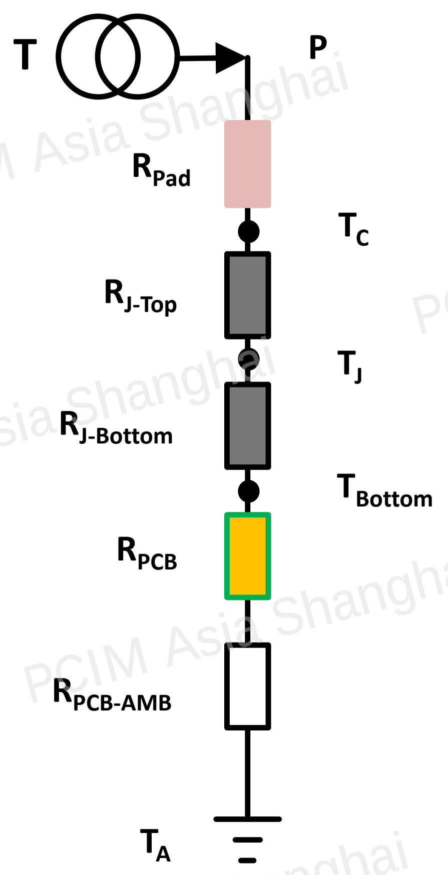
$$T_J \approx T_{Bottom}$$ [4]

$$T_{Bottom} = \alpha T_C + \beta$$

[4]R. Hou, Y. Shen, H. Zhao, H. Hu, J. Lu and T. Long, "Power Loss Characterization and Modeling for GaN-Based Hard- Switching Half-Bridges Considering Dynamic on-State Resistance," in IEEE Transactions on Transportation Electrification, vol. 6, no. 2, pp. 540-553, June 2020.

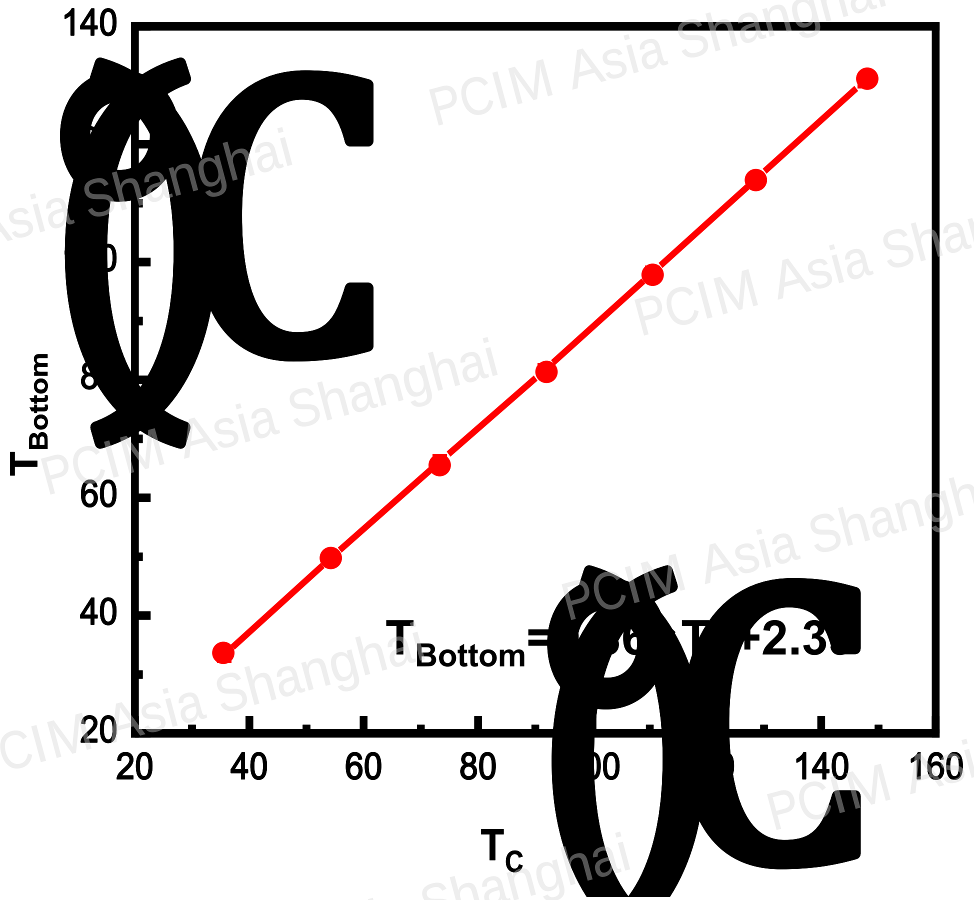
Heating Scheme :
T_J can be Calculated by T_{Top} through Mathematical Relationships

- **Thermal Resistance Model**



$T_{Bottom}=\alpha T_C+\beta$

- **The Relationship between T_{Bottom} and T_{top}** **(Offline Measurement)**

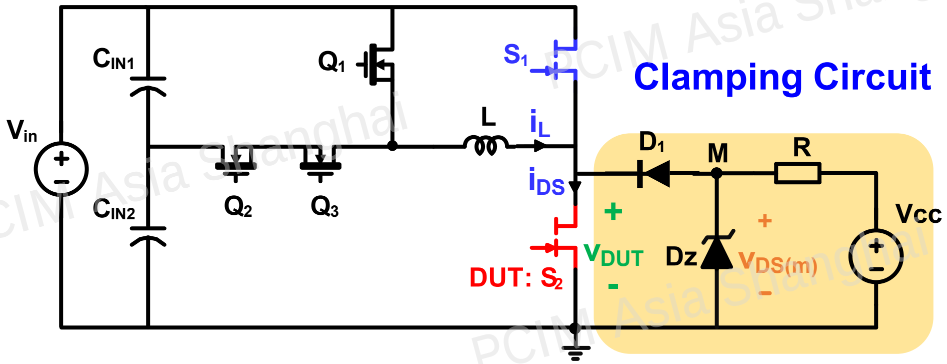


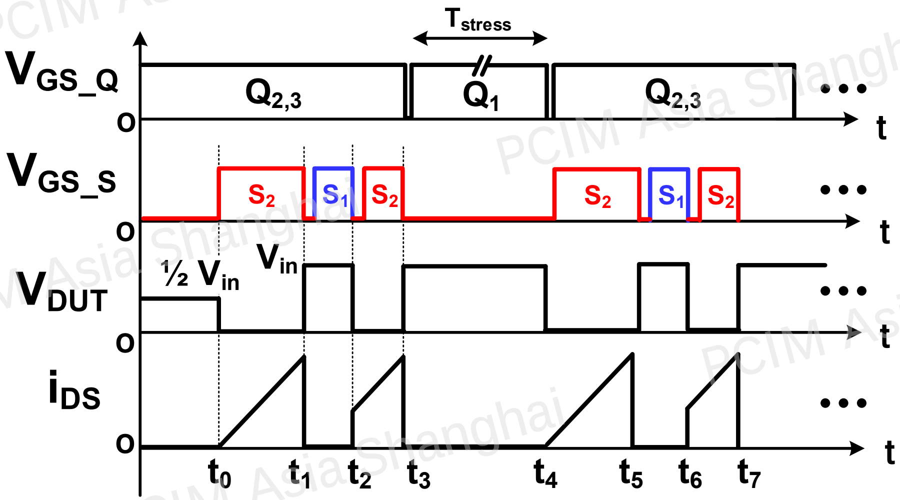
$T_J \approx T_{Bottom}$

$T_J=0.86\times T_C+2.39$

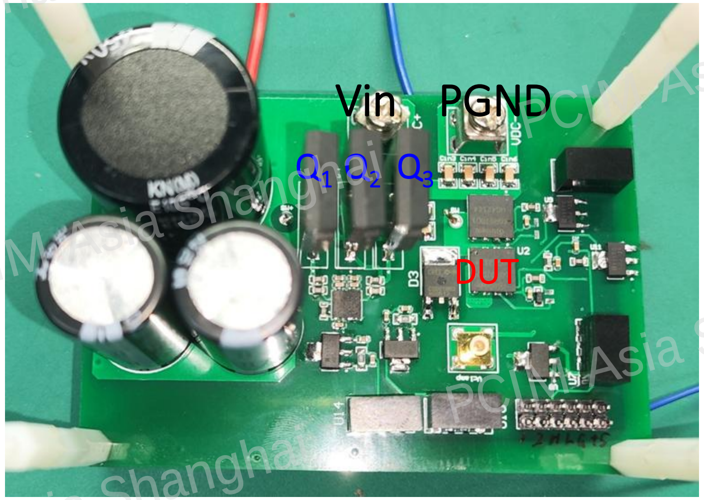
Complete Test Bench

■ Stress-Controlled Test Bench[5]

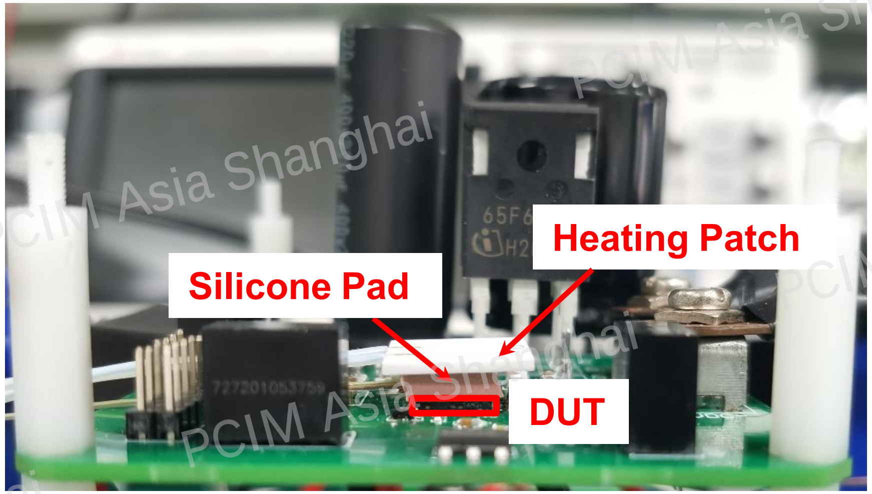




■ Bird View



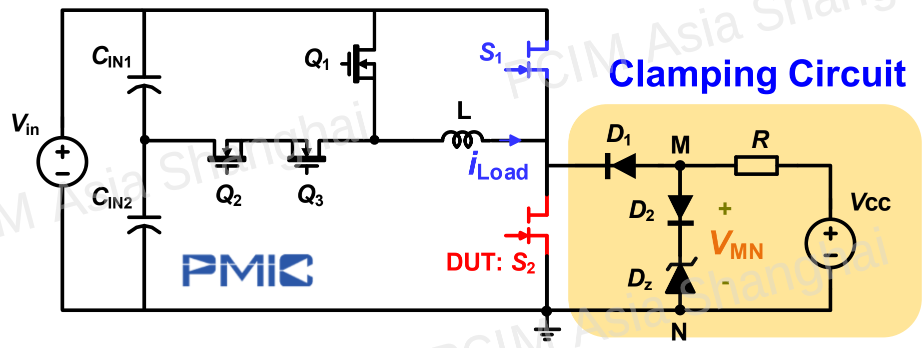
■ Side View

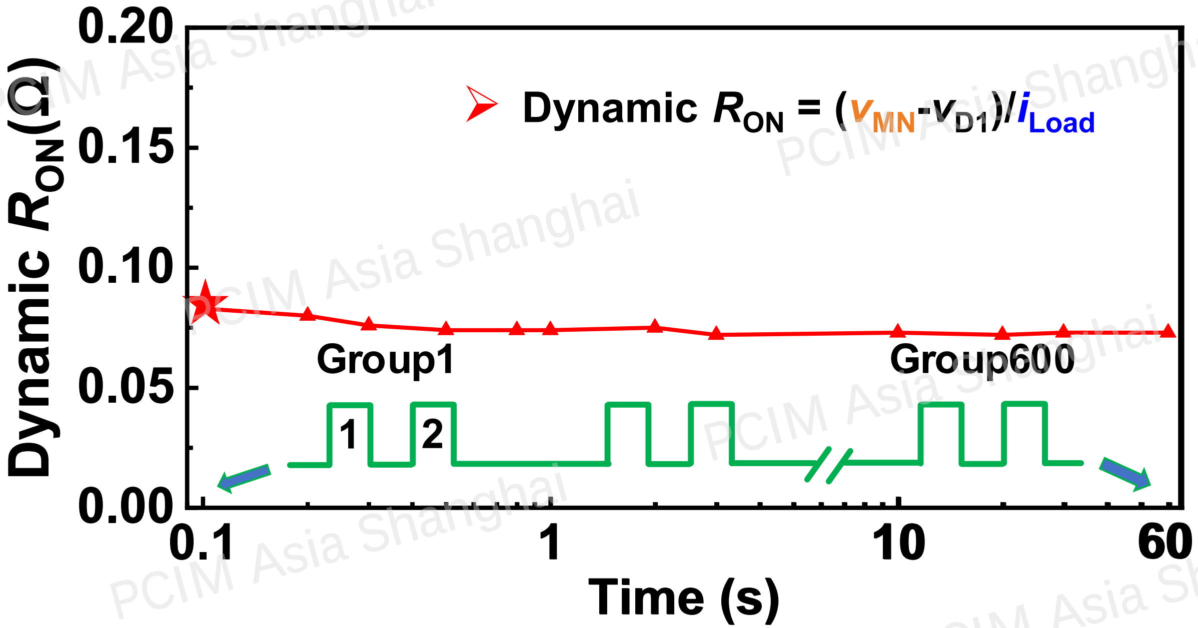


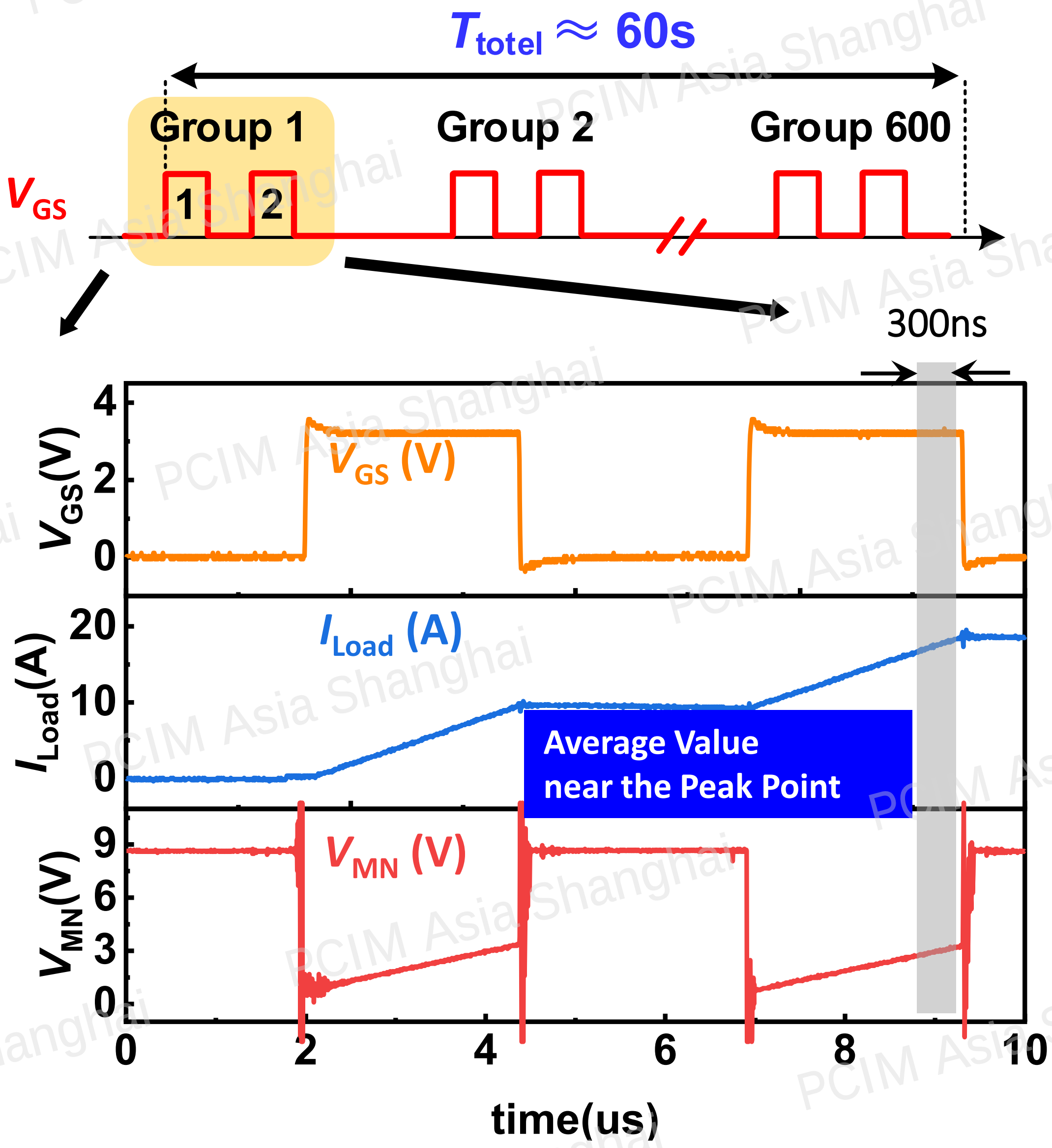
[5] Z. Xie, X. Wu, Z. Dong, J. Sun, K. Sheng and K. J. Chen, "Dynamic On-Resistance Characterization of GaN Power HEMTs Under Forward/Reverse Conduction Using Multigroup Double Pulse Test," in IEEE Transactions on Power Electronics, vol. 39, no. 2, pp. 1963-1967, Feb. 2024.

Data Processing Methods: Average Value near the Peak Current Point

Test Bench







Key Parameters of the Devices Under Test

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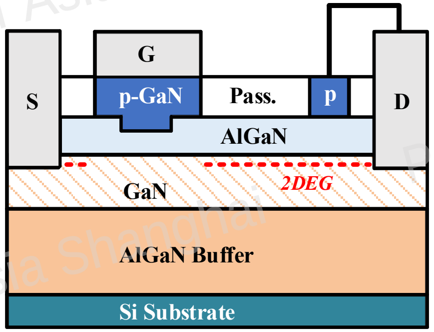
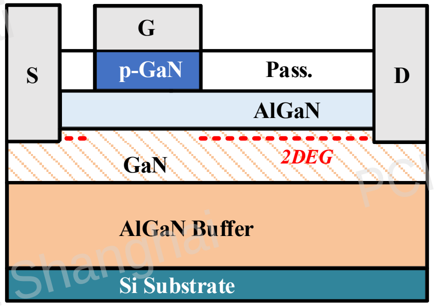
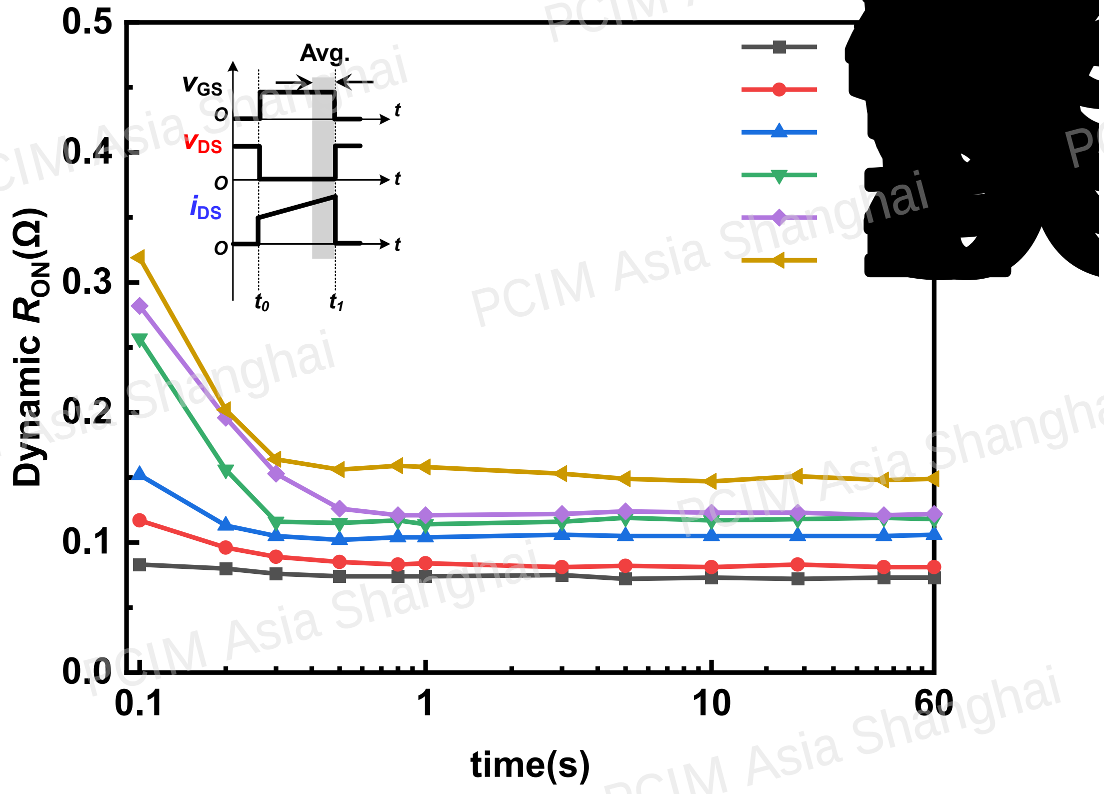
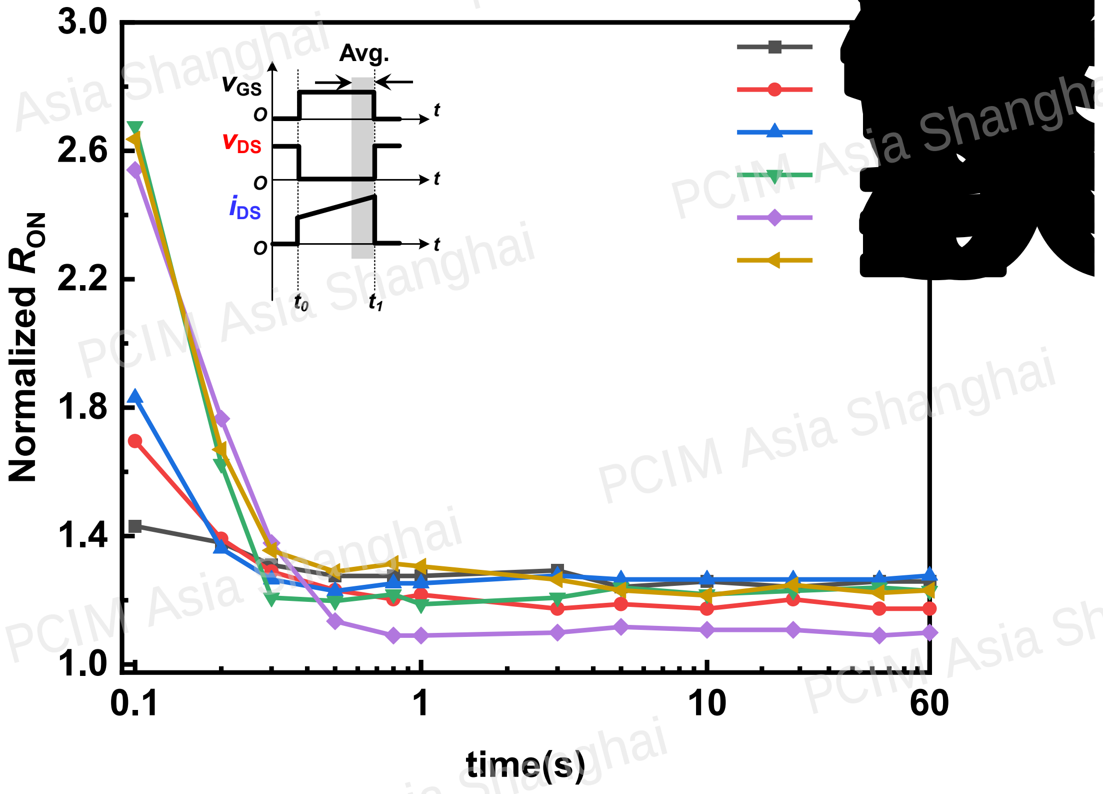
Parameters	Device A	Device B
Brand	Infineon	Innoscience
Voltage/Current Rating	600V/31A	700V/17A
Static R_{ON}	55mΩ	106mΩ
Gate metal/p-GaN contact	Ohmic contact	Schottky contact
Structure	**HD-GIT** 	**E-mode *p*-GaN** 

Normalized R_{ON} (T_J) = Dynamic R_{ON} (T_J) /Static R_{ON} (T_J)

- **Device A （HD-GIT）** **(55mΩ)** **@[redacted]%I_{MAX},I_{GS}=5.7mA,V_{DS}=400V,HS**

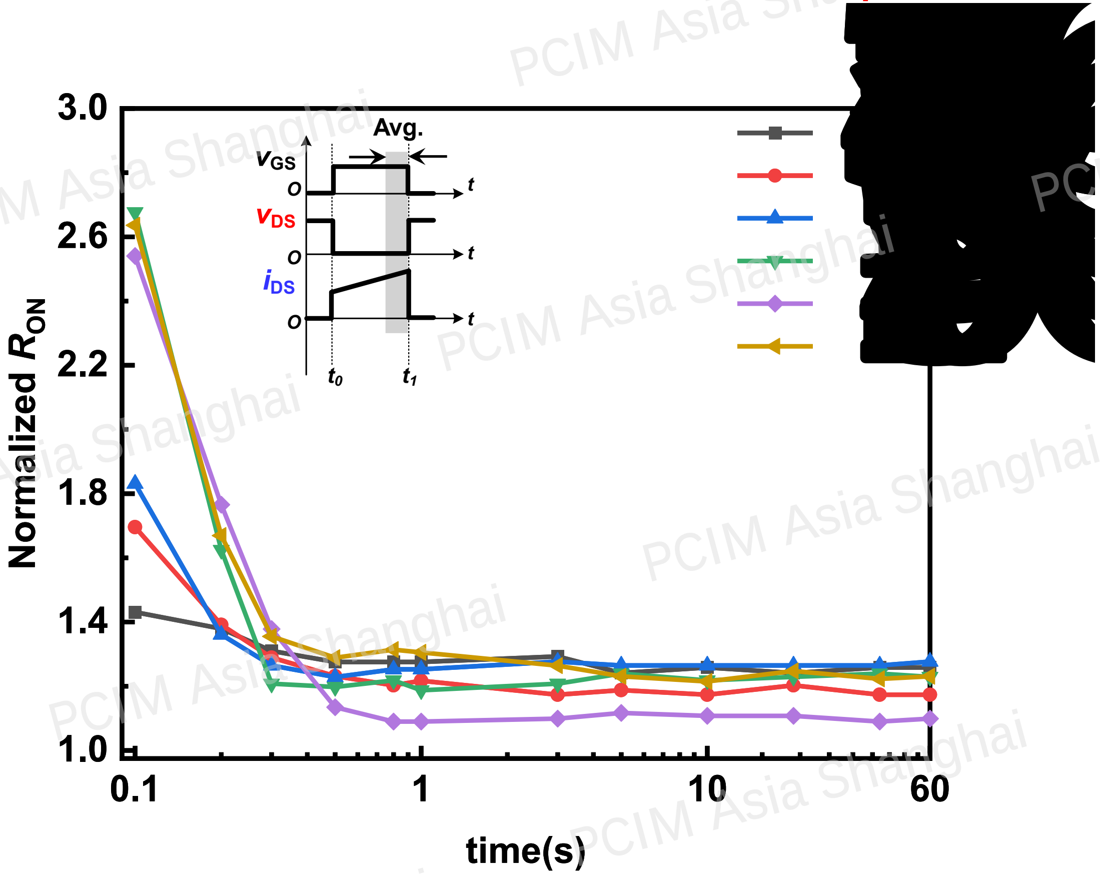


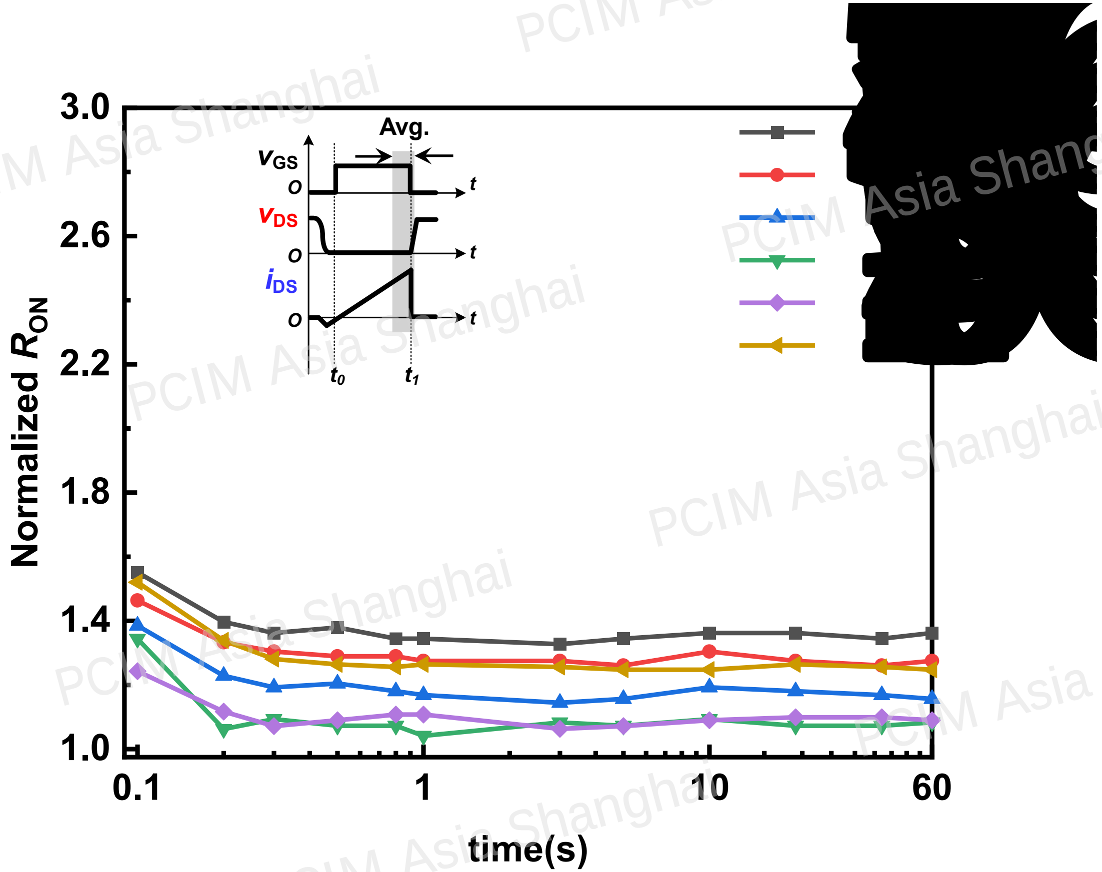


➢ **Normalized R_{ON} does not exhibit a gradual increase with rising T_J.**

Multi-group DPT Results of Device A@ Different T_J

- **Device A（HD-GIT）** **(55mΩ)** **@I_{peak}=70%I_{MAX}, I_{GS}=5.7mA,V_{DS}=400V**

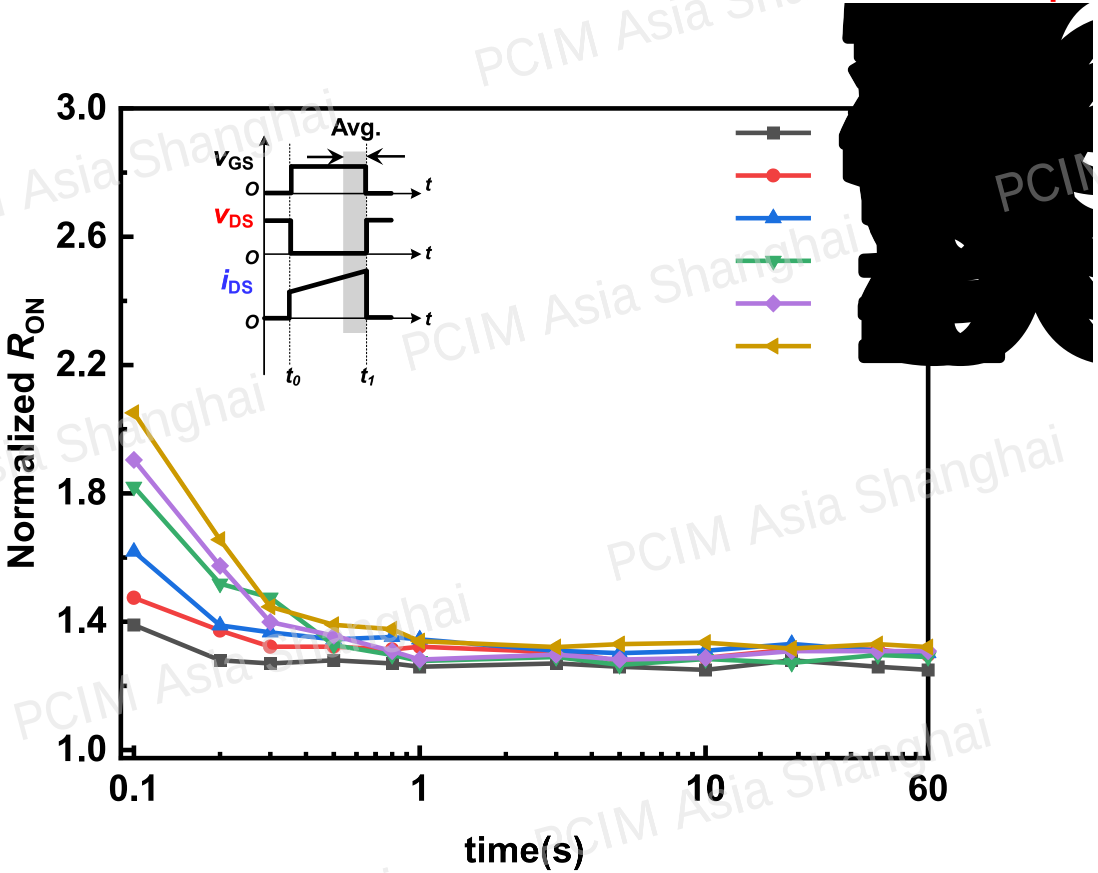


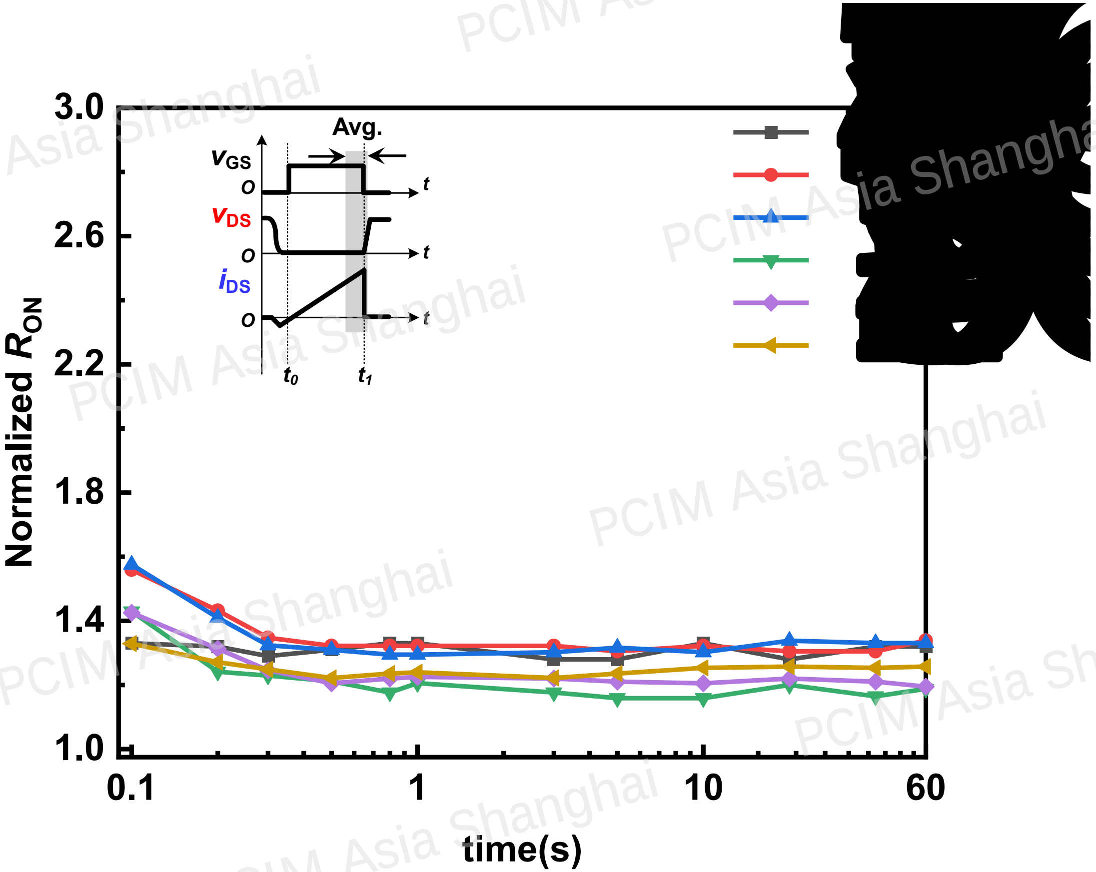


➢ **The recovery of the dynamic R_{ON} is more pronounced under HS for Devive A @ high T_J.**

Multi-group DPT Results of Device B@ Different T_j

- **Device B (E-mode p-GaN)** (106mΩ) @I_{peak}=70%I_{MAX},V_{GS}=6V,V_{DS}=400V

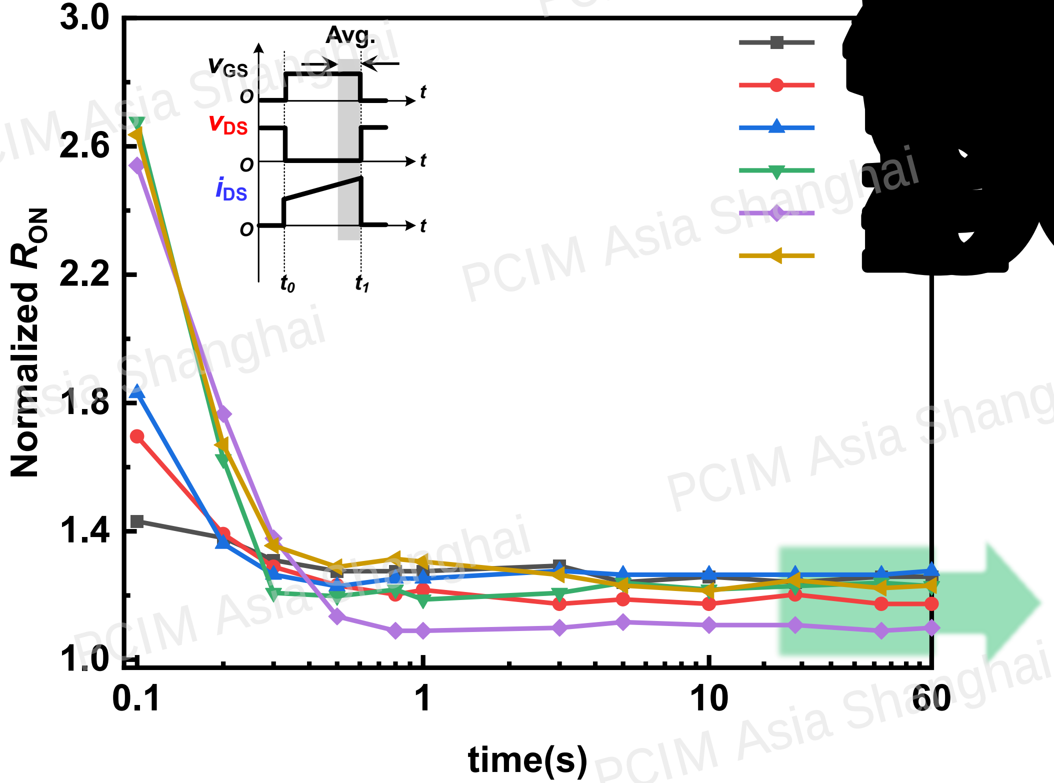


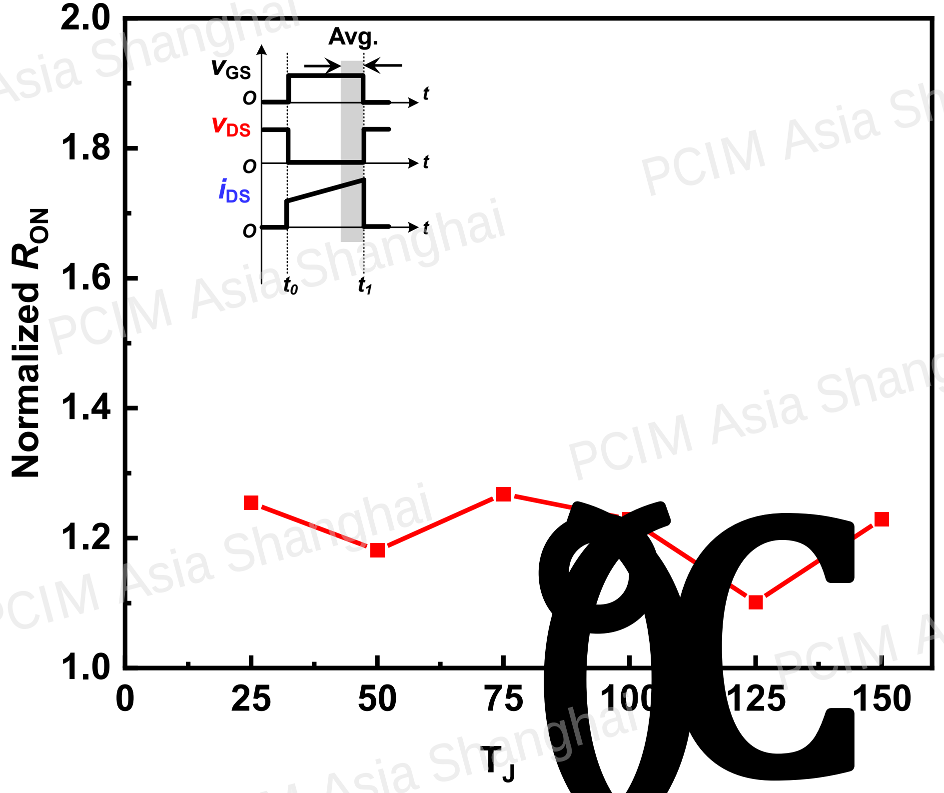


➢ The recovery of the dynamic R_{ON} is more evident under HS for Devive B.

The Average R_{ON} over 40-60s Represents the R_{ON} @ this T_J

■ **Device A (HD-GIT)** (55mΩ) @I_{peak}=70%I_{MAX}, I_{GS}=5.7mA,V_{DS}=400V,HS





➢ The normalized R_{ON} exhibits a minimum value around T_J = 125 °C under HS for DeviveA.

Normalized R_{ON} vs. T_J Curves for Device A and Device B

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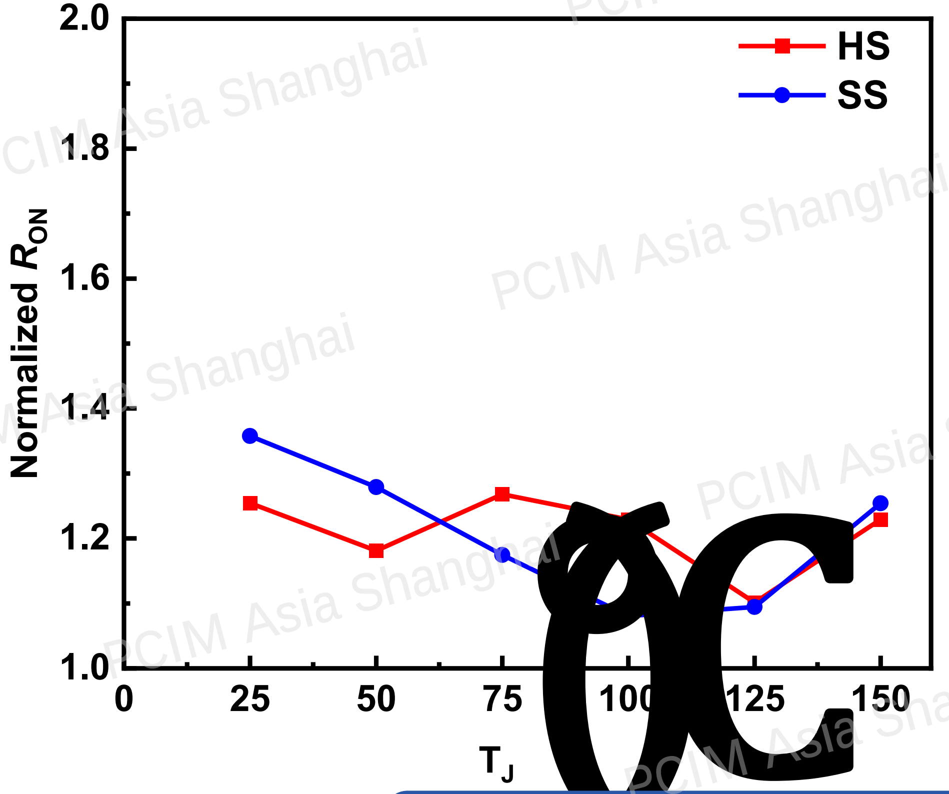
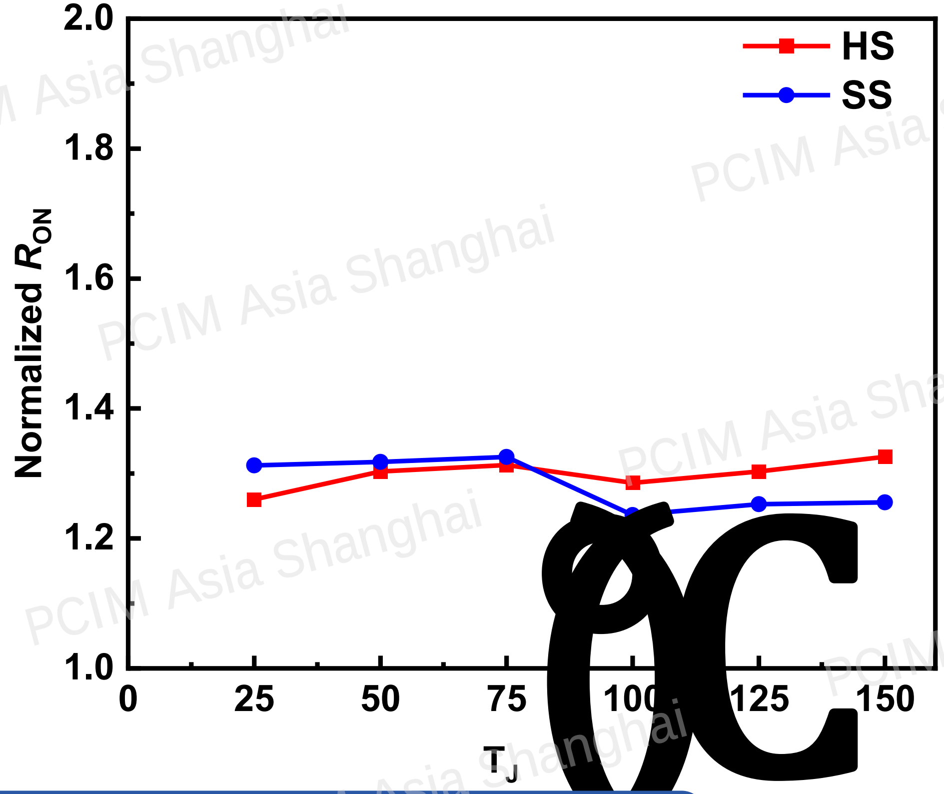
➢ @I_{peak}=70%I_{MAX}，V_{DS}=400V

■ Device A（HD-GIT） (55mΩ)



■ Device B（E-mode p-GaN） (106mΩ)



➢ The normalized R_{ON} exhibits a minimum value for DeviveA.
➢ The normalized R_{ON} shows no such minimum for DeviveB.

GaN Devices Operate at Different V_{DS} : R_{ON} Behaves Differently @Different V_{DS}

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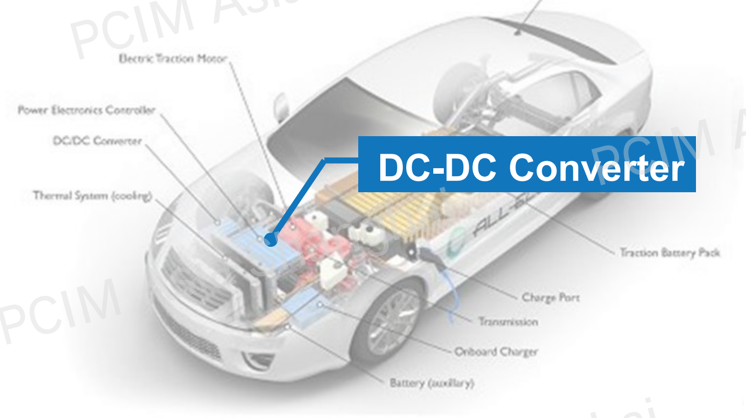
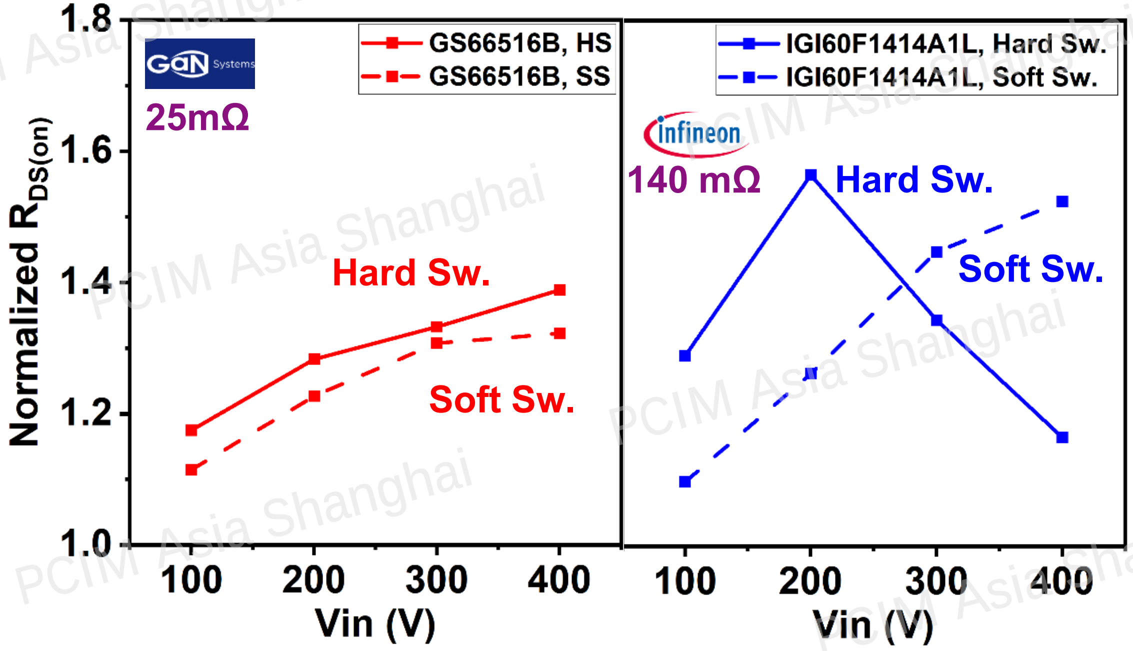
■ Pure-Electric Vehicle（EV）



> ➢ Devices Operate @ Different V_{DS}

■ Double Pulse Test (DPT) with Different V_{DS}[5]

@T_J=25℃



> ➢ $R_{DS(on)}$ changes with different V_{DS}

[5] R. Li, X. Wu, S. Yang, and K. Sheng, “Dynamic on-State Resistance Test and Evaluation of GaN Power Devices Under Hard- and Soft-Switching Conditions by Double and Multiple Pulses,” IEEE Trans. Power Electron., vol. 34, no. 2, pp. 1044–1053, Feb. 2019

MGDPT Results of HD-GIT Device : R-T_J characteristics vary with V_{DS}

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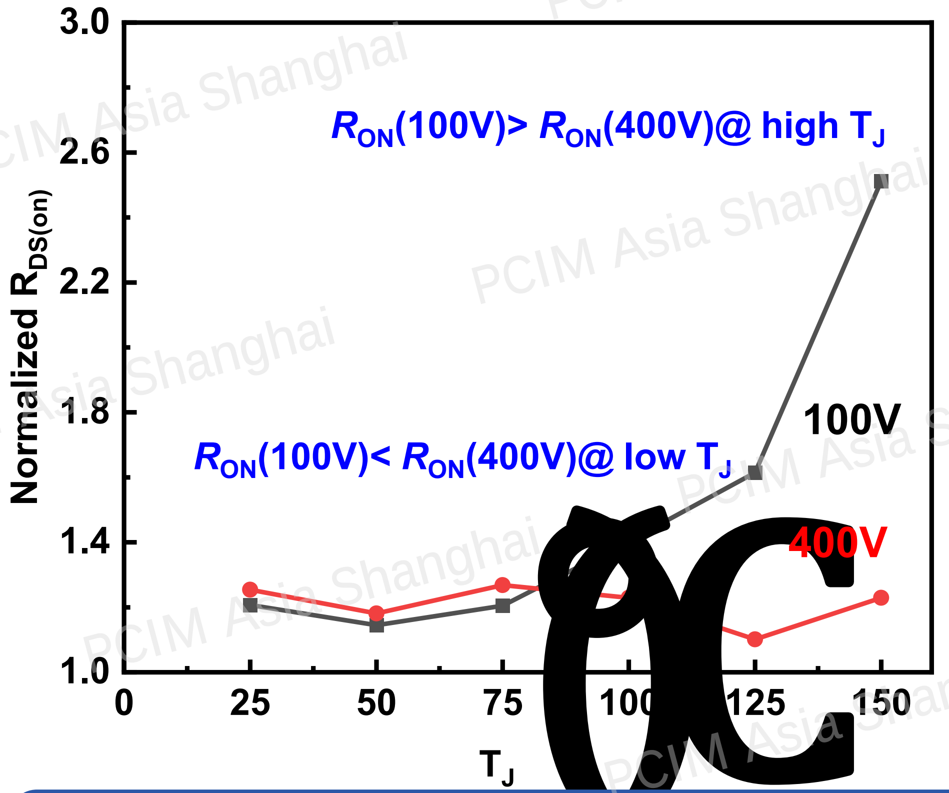
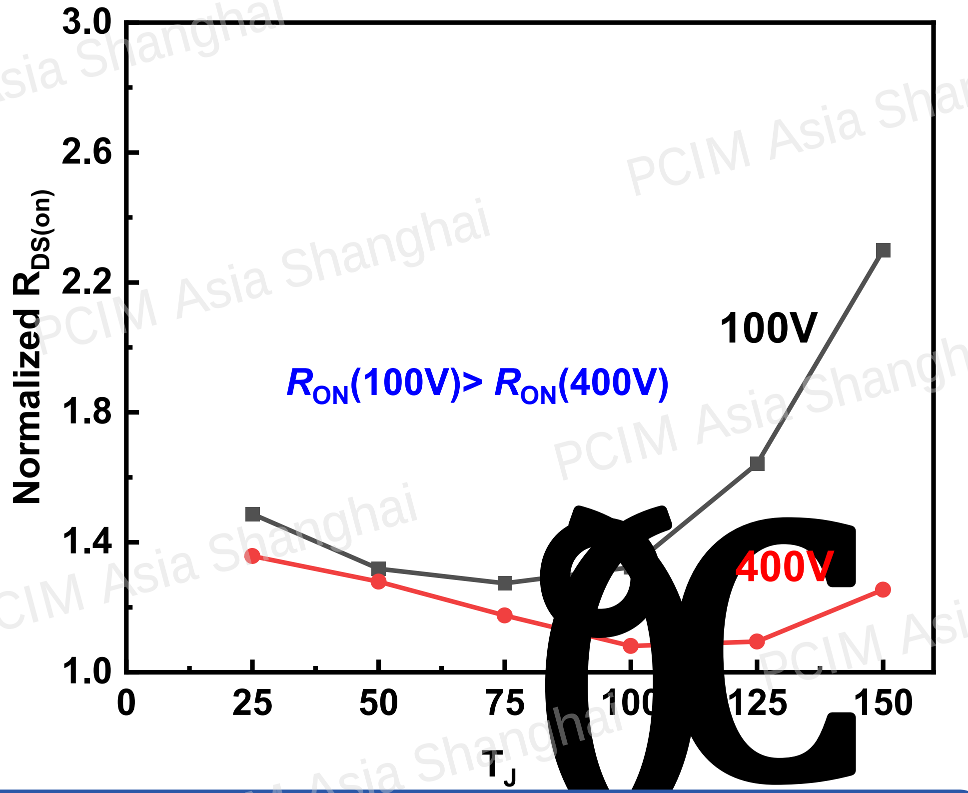
- **HD-GIT Device (106mΩ)** @ I_{peak}=70%I_{MAX} (25℃) ; I_{GS}=5.7mA

t_{stress}=100ms

■ Normalized $R_{DS(on)}$ vs. T_J @ HS



■ Normalized $R_{DS(on)}$ vs. T_J @ SS



- Dynamic R_{ON} (100V)> Dynamic R_{ON} (400V) @low T_J but Dynamic R_{ON} (100V) < Dynamic R_{ON} (400V) @high T_J with HS;
- Dynamic R_{ON}(100V) exceeds Dynamic R_{ON}(400V) with SS.

MGDPT Results of E-mode p-GaN Device : R-T_J characteristics vary with V_{DS}

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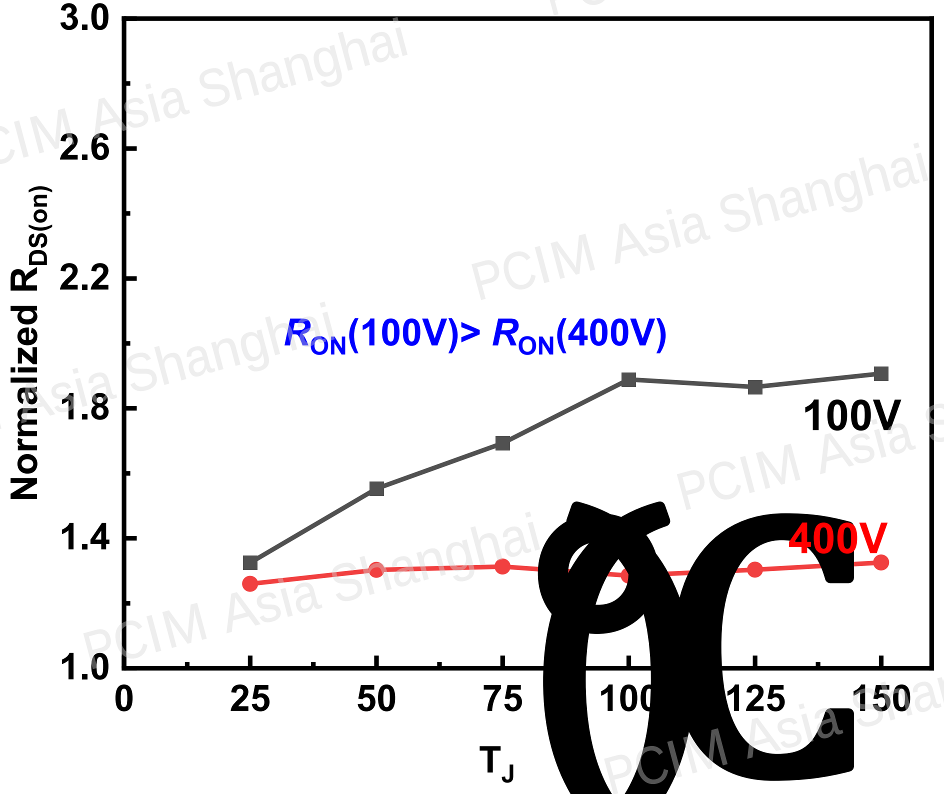
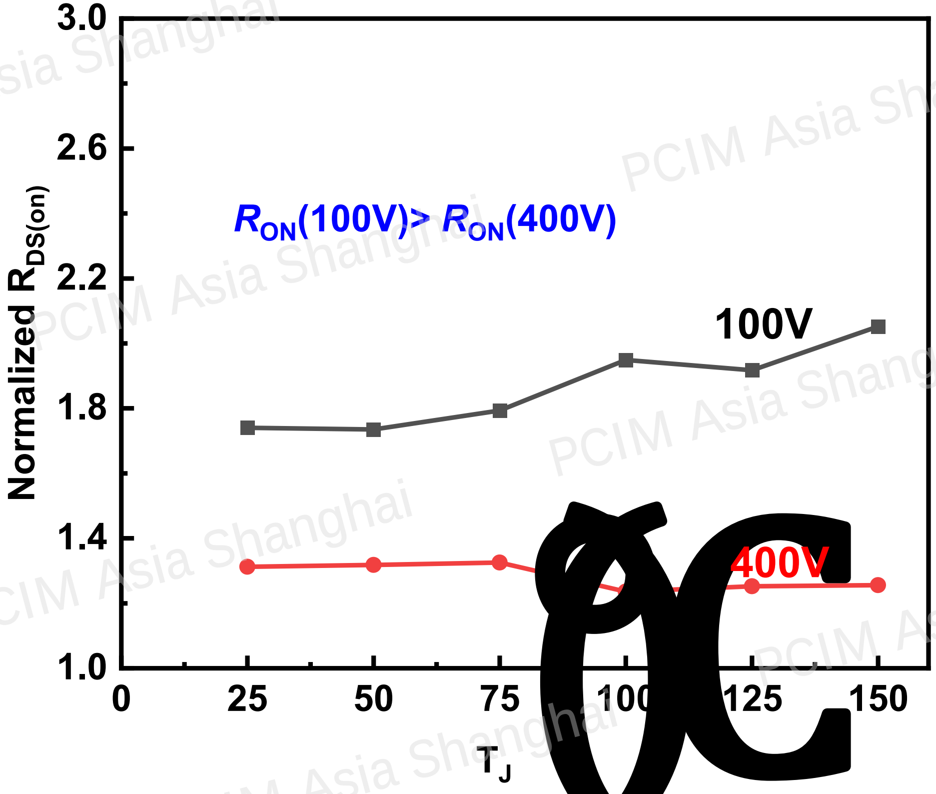
- **E-mode p-GaN Device** (106mΩ) @ I_{peak}=70%I_{MAX} (25℃) ; V_{GS}=6V t_{stress}=100ms

■ Normalized $R_{DS(on)}$ vs. T_J @ HS



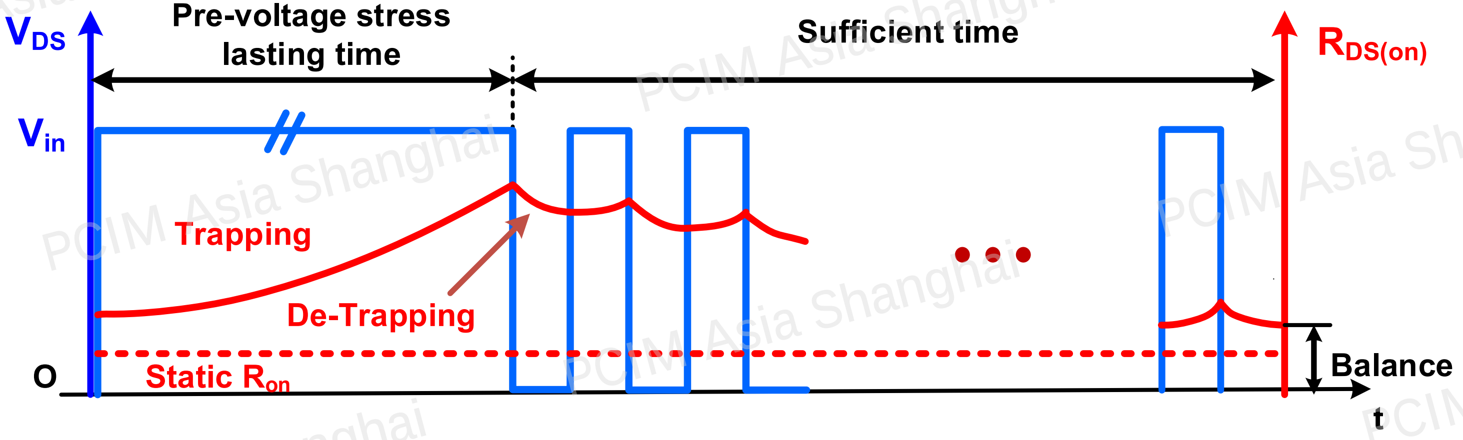
■ Normalized $R_{DS(on)}$ vs. T_J @ SS



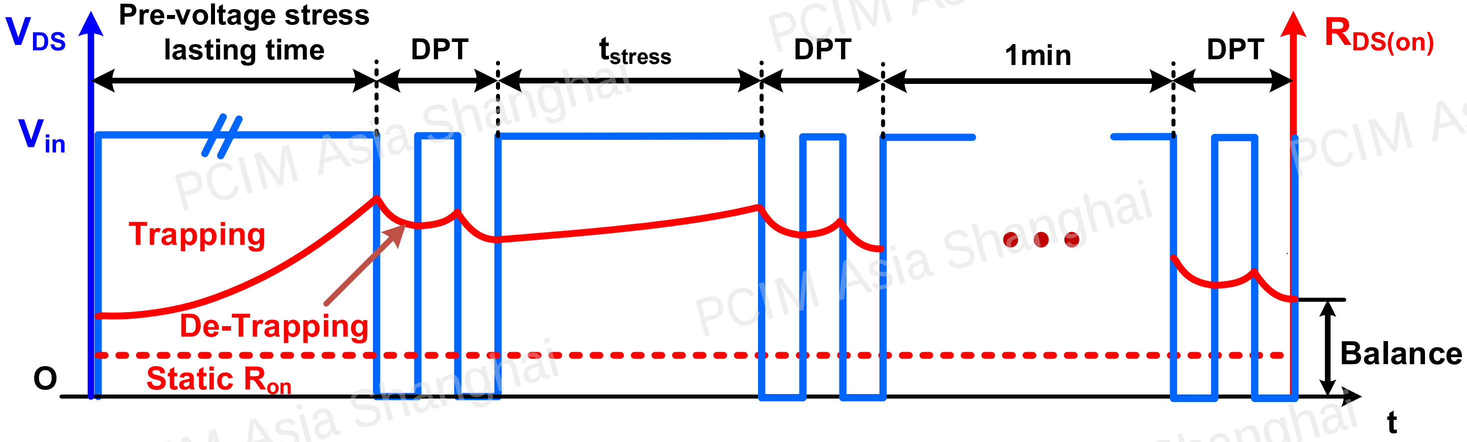
➢ Dynamic R_{ON} @ V_{DS}=100V exceeds Dynamic R_{ON} @ V_{DS}= 400V with HS &SS.

t_{stress} may Have an Significant Impact on Dynamic R_{ON}

- V_{DS} bias effect in continuous pulse [5]



- V_{DS} bias effect in MGDPT



Long period of t_{stress} may have an impact on Trapping and De-Trapping @ high T_J

$R_{ON,\ Measured} \overset{?}{\vee} R_{ON,\ actual}$

[5] K. Li, P. L. Evans, C. M. Johnson, A. Videt, and N. Idir, "A GaN-HEMT Compact Model Including Dynamic RDSon Effect for Power Electronics Converters,".

R_{ON} of HD-GIT Device vs. t_{stress}@V_{DS}=100V& V_{DS}=400V

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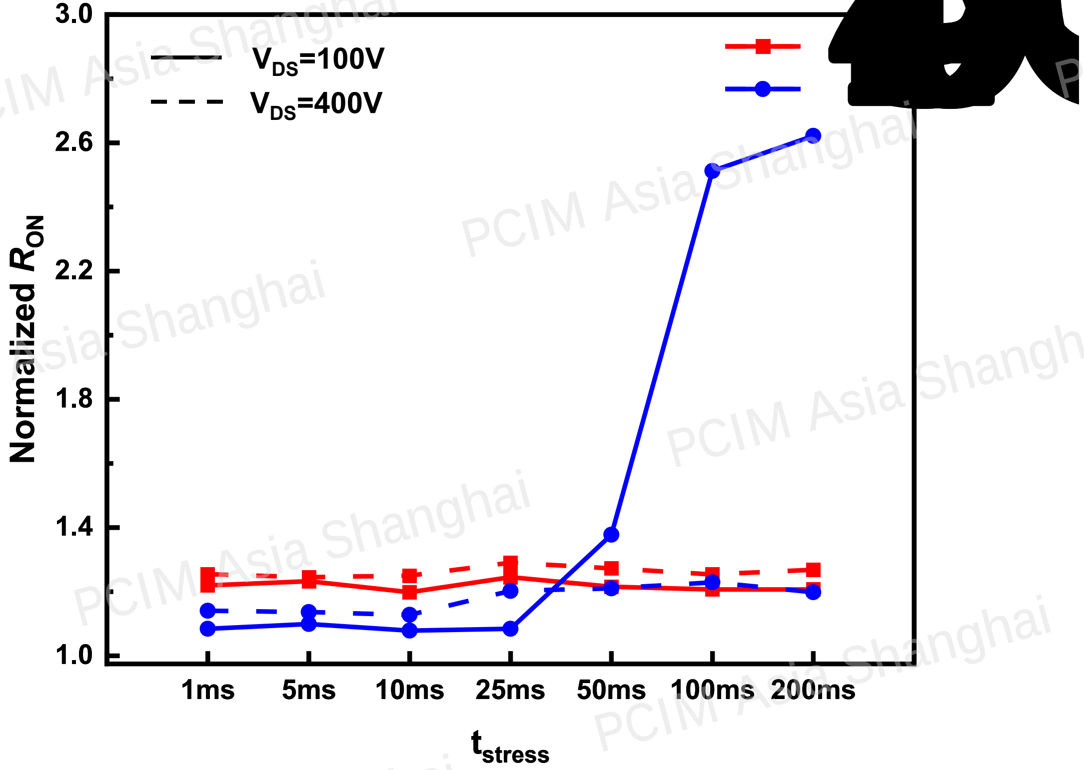
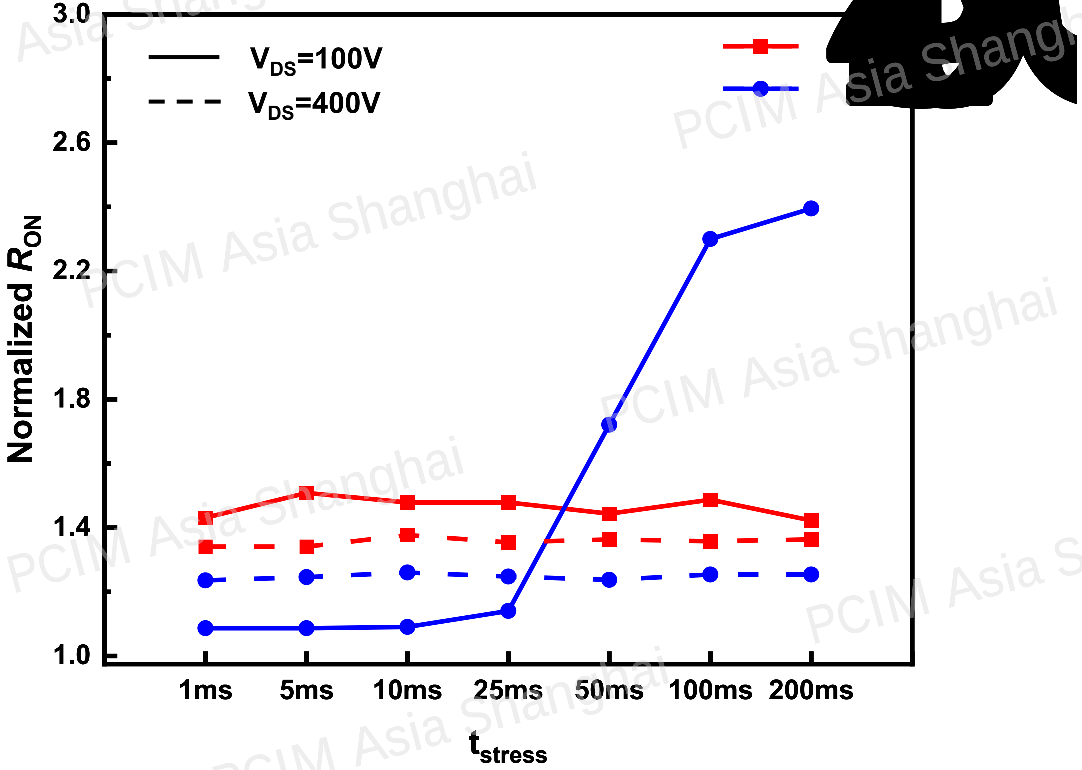
- **HD-GIT Device (106mΩ) @I_{peak}=70%I_{MAX}, I_{GS}=5.7mA**

- **Normalized $R_{DS(on)}$ vs. t_{stress} @ H[redacted]**



- **Normalized $R_{DS(on)}$ vs. t_{stress}@ SS[redacted]**



➢ The dynamic R_{ON} of Device A decreases with reduced t_{stress} under conditions of high T_J and low V_{DS}.

R_{ON} of E-mode p-GaN Device vs. t_{stress}@V_{DS}=100V& V_{DS}=400V

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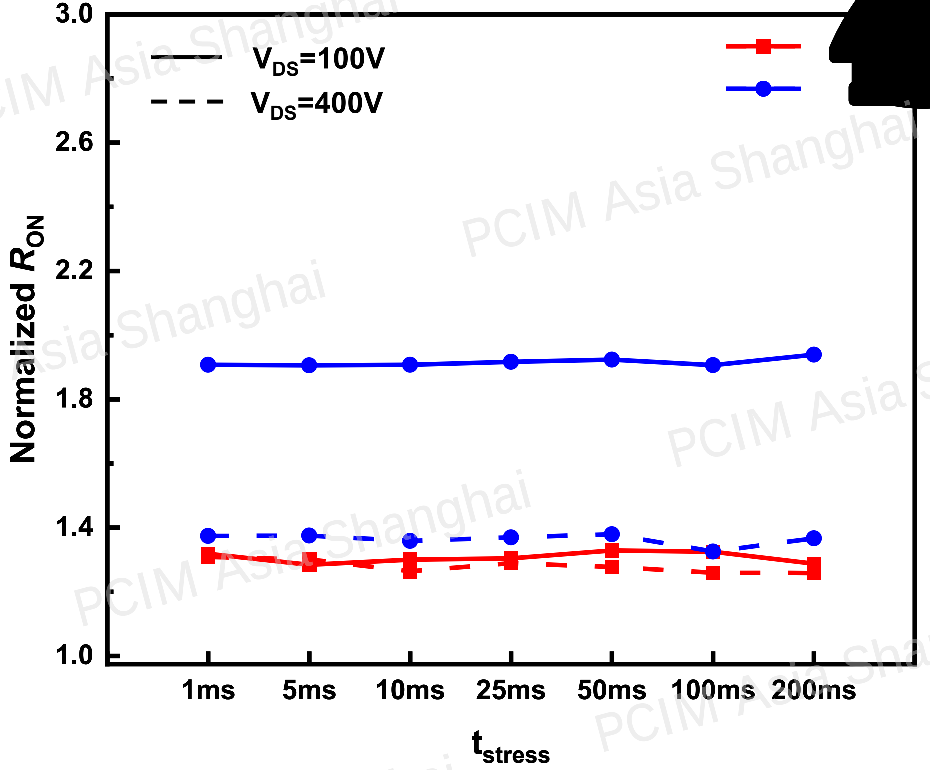
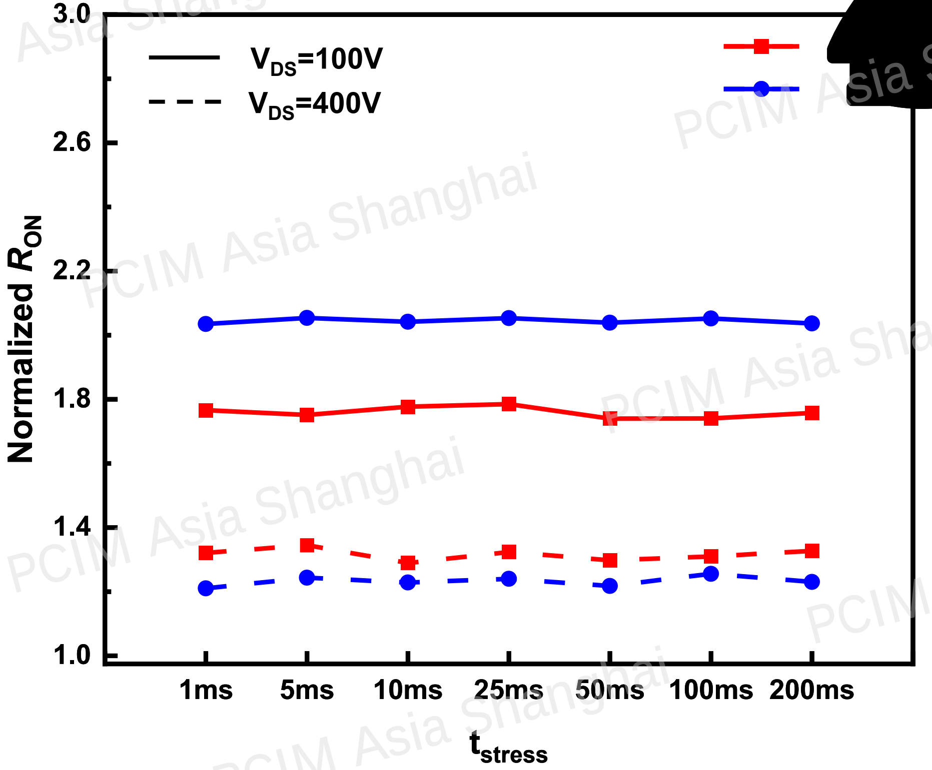
- E-mode p-GaN Device (106mΩ) @I_{peak}=70%I_{MAX}, V_{GS}=6V

- Normalized $R_{DS(on)}$ vs. t_{stress} @ H[redacted]



- Normalized $R_{DS(on)}$ vs. t_{stress}@ SS[redacted]



➢ The dynamic R_{ON} of Device B shows no significant variation with changes in t_{stress}.

Conclusion

- 1.The dynamic on-resistance of both GaN device types demonstrates a gradual recovery over time.
- 2.The two devices exhibit distinct behaviors in response to increasing junction temperature: the HD-GIT device shows a minimum value in its normalized on-resistance, whereas the E-mode p–GaN device exhibits no discernible minimum.
- 3.Under conditions of high junction temperature and low V_{DS}, the dynamic on-resistance of the HD-GIT device decreases with reduced t_{stress}, while that of the E-mode p–GaN device remains largely unaffected by t_{stress}.

Thank you for your time and attention!