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Dynamic High Temperature Operating Life Tests for GaN Hybrid-Drain-embedded GITs – Demonstration of Highly Reliable Operations

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Outline

Demonstration of Highly Reliable Operations by Panasonic's 600V GaN Power Transistors

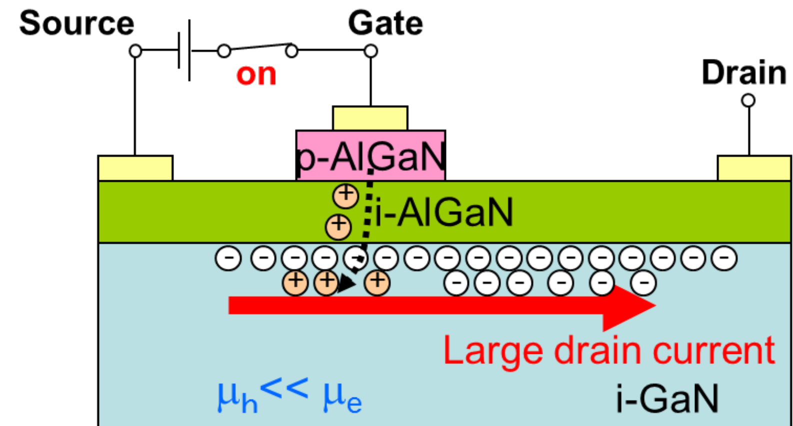
- **GaN Hybrid-Drain-Embedded GIT (HD-GIT) and Its Reliability**
- **Dynamic High Temperature Operating Life (D-HTOL) Test for HD-GIT**
- **Estimation of D-HTOL Lifetime for Totem-pole PFC using HD-GITs**

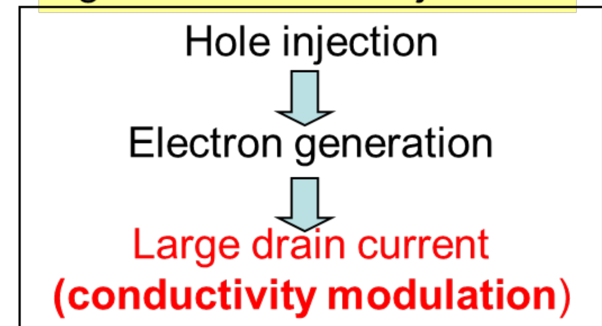
Panasonic's 600V Gate Injection Transistor (GIT)

- Normally-off operation with low on-state resistance is achieved by a new Gate Injection Transistor (GIT).
- Low cost fabrication is possible on large diameter Si substrate.

Photo of GaN on 6-inch Si

Operating principle of GIT





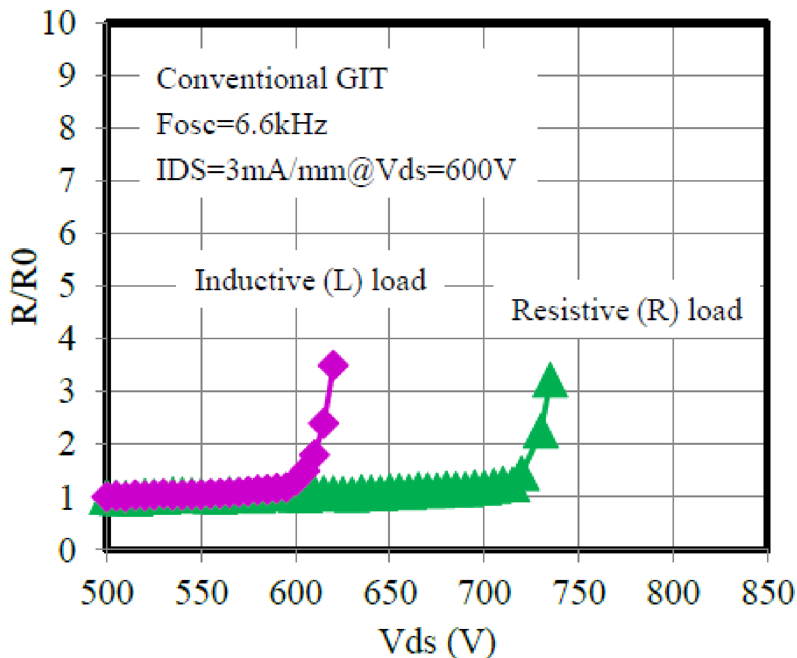
Available Specifications

Threshold Voltage Vth : +1.2V	Rating Drain Current: 26A
On-state Resistance Ron: 55mΩ	Blocking Voltage: 600V

Impact of Switching Locus on Current Collapse

- Significant increase of dynamic R_{on} is observed in GITs at high drain voltages under inductive load switching.
- Current collapse of the GIT needs to be suppressed even by the inductive load switching with severe biasing conditions.

Dynamic Ron of Conventional GITs Under Multi-pulsed Switching



Evaluation Circuit and Switching Locus

	Evaluation Circuit	Switching Locus
Resistive load	R, Vds, GaN, Ids	Turn off, Turn on, Ids (A), Vds (V)
Inductive load	R, L, GaN	Semi-on state, Turn on, Turn off, Ids (A), Vds (V)

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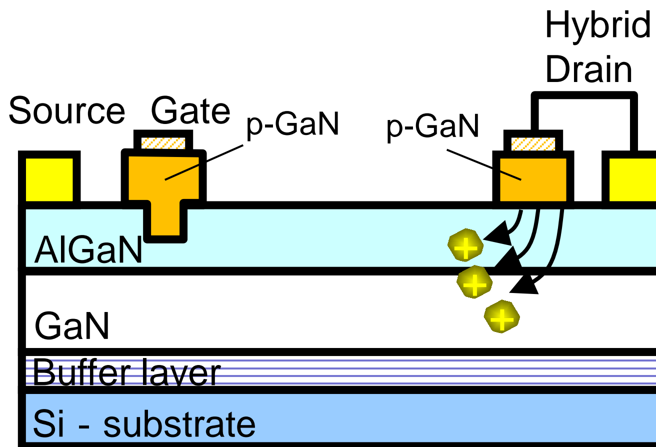
HD-GIT for Current-Collapse-Free Operations

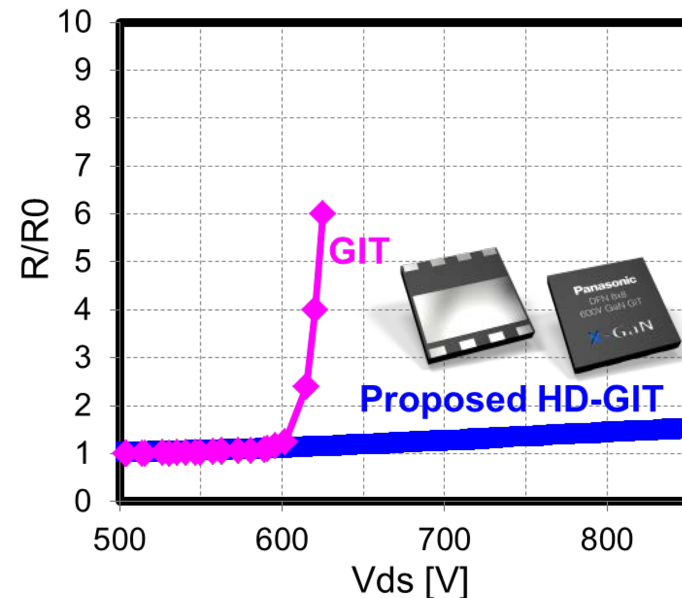
HD-GIT : Hybrid-Drain-embedded Gate Injection Transistor

- **HD-GIT has additional p-GaN at the drain to inject holes and to completely suppress the current collapse.**
- **Recessed-gate with thick AlGaN layer reduces the on-state resistance maintaining the normally-off operation.**

Schematic cross section of HD-GIT



Dynamic R_{on} normalized by DC values (R/R0) under inductive load switching



Reliability of HD-GIT Under JEDEC Standard Tests

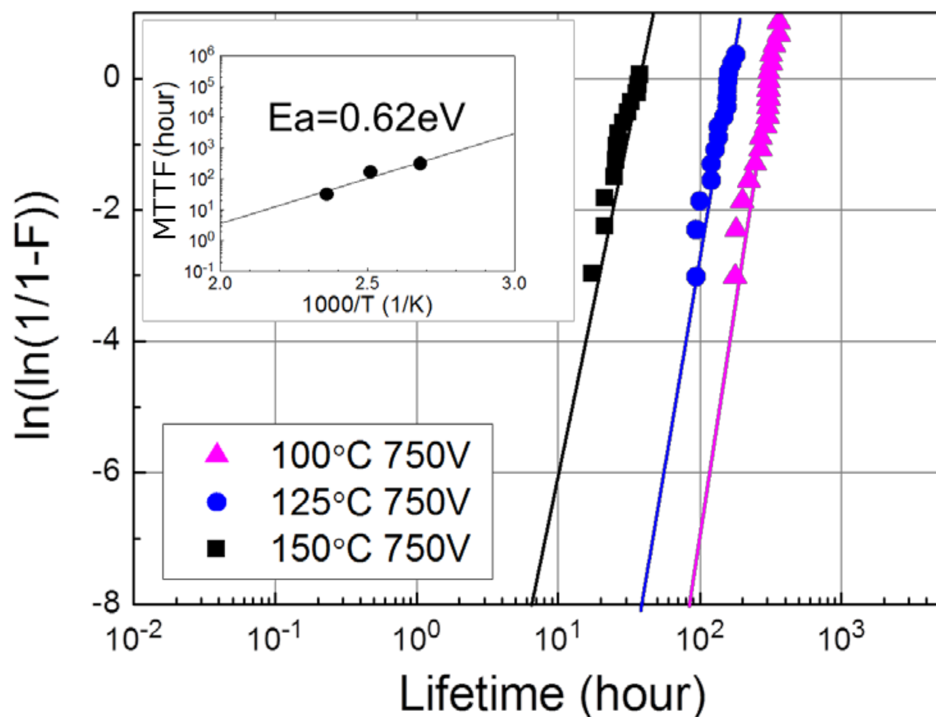
- **HD-GIT passes all of the reliability test standards by JEDEC that have been originally specified for Si power transistors.**

	Test Item	Test Condition	JEDEC Standard	Quantity	Result
1	HTRB	Ta=150℃, Vds=480V, t=1000h	JESD22-A108	77 x 3lot	Pass
2	H3TRB	Ta=85℃, RH=85%, Vds=480V, t=1000h	JESD22-A101	77 x 3lot	Pass
3	DC HTGS (Forward)	Tj=150℃, Vgs=4.0V, t=1000h	JESD22-A108	77 x 3lot	Pass
4	DC HTGS (Reverse)	Tj=150℃, Vgs=-12V, t=1000h	JESD22-A108	77 x 3lot	Pass
5	AC HTGS	Continues pulses applied to VGS (max/min=7.7V/-7.2V), 1000h, Tj=150℃	N/A	5 x 1lot	Pass
6	HTS	Ta=150℃, t=1000h	JESD22-A103	77 x 3lot	Pass
7	TC	Ta=-55℃～150℃, 1000cyc, 30min each	JESD22-A104	77 x 3lot	Pass
8	IOL	Ta=25℃, ⊿Tj=100℃, 12500cyc	JESD22-A105	6 x 1lot	Pass
9	ESD (HBM,CDM)	HBM:C=100pF, R=1.5kohm, ±2000V, CDM: ±2000V	JS-001/JS-002	3 x 3lot	Pass

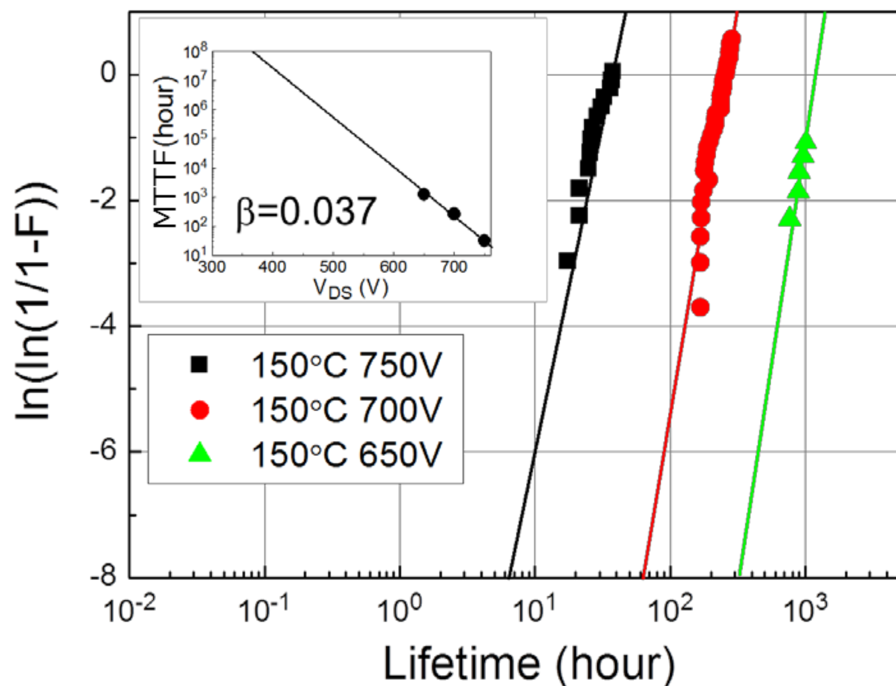
Long Lifetime of HD-GITs Under HTRB Tests

- **Extracted lifetime of high temperature reverse blocking (HTRB) tests at 480V/80℃ (80% de-rated from maximum rated blocking voltage) is over 1000 years.**

Weibull plot for various temperatures



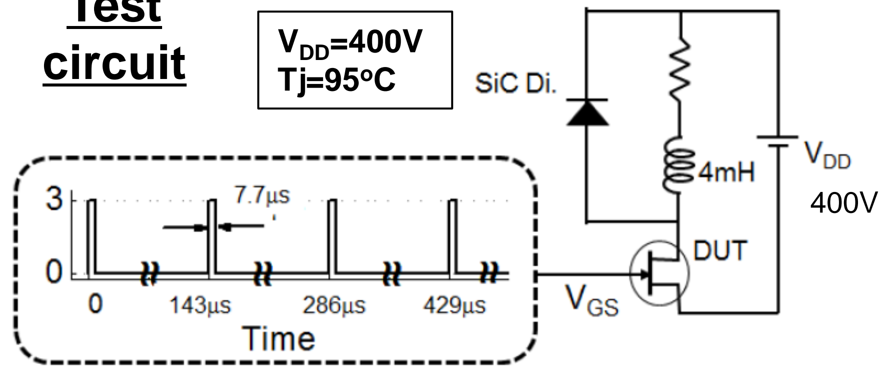
Weibull plot for various drain voltage



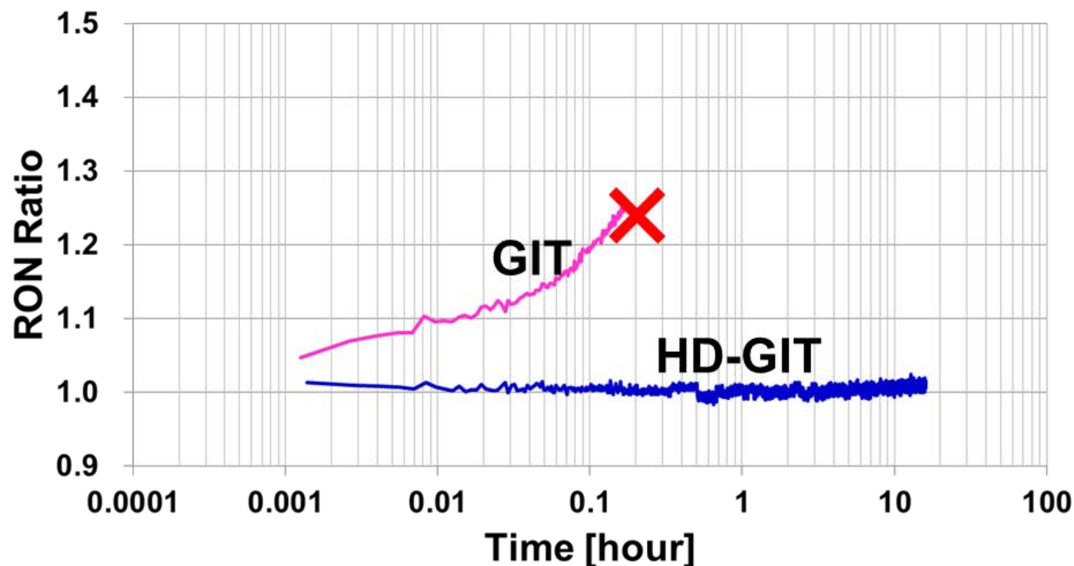
Long Lifetime of HD-GIT Under D-HTOL Tests

- Long **lifetime of 3600h** is demonstrated by HD-GITs under inductive-load switching reliability tests called as **Dynamic High Temperature Operating Life (D-HTOL)** test.

Test circuit

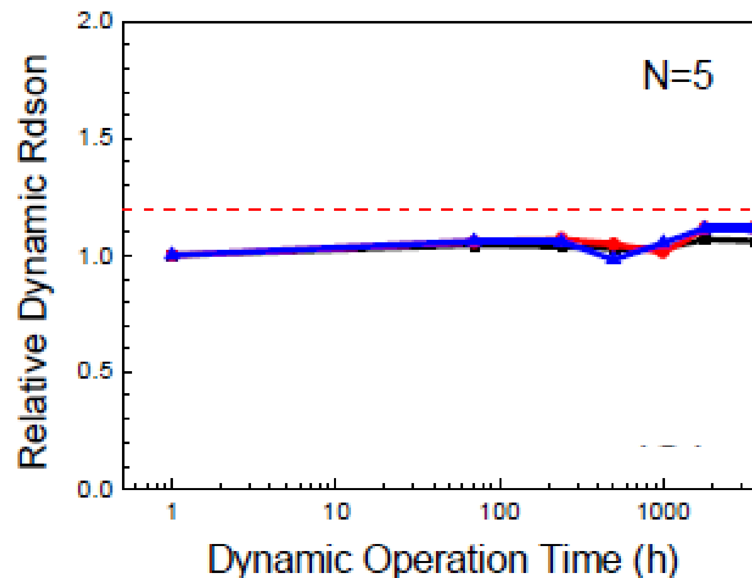


Typical switching reliability test results for HD-GITs and conventional GITs



D-HTOL test results

Dynamic Ron

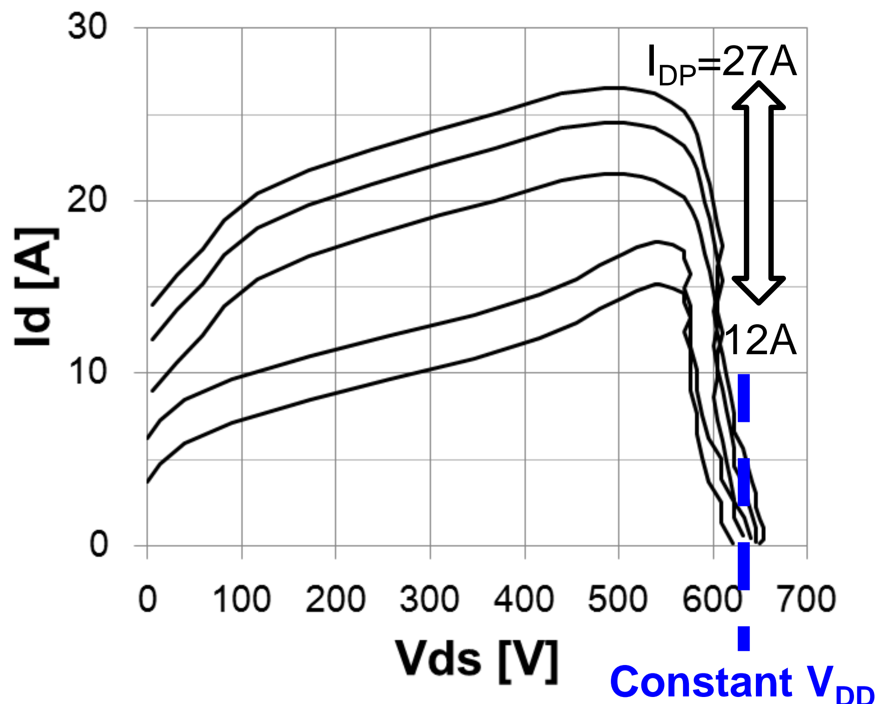


Variation of Current / Voltage Stress in D-HTOL Test

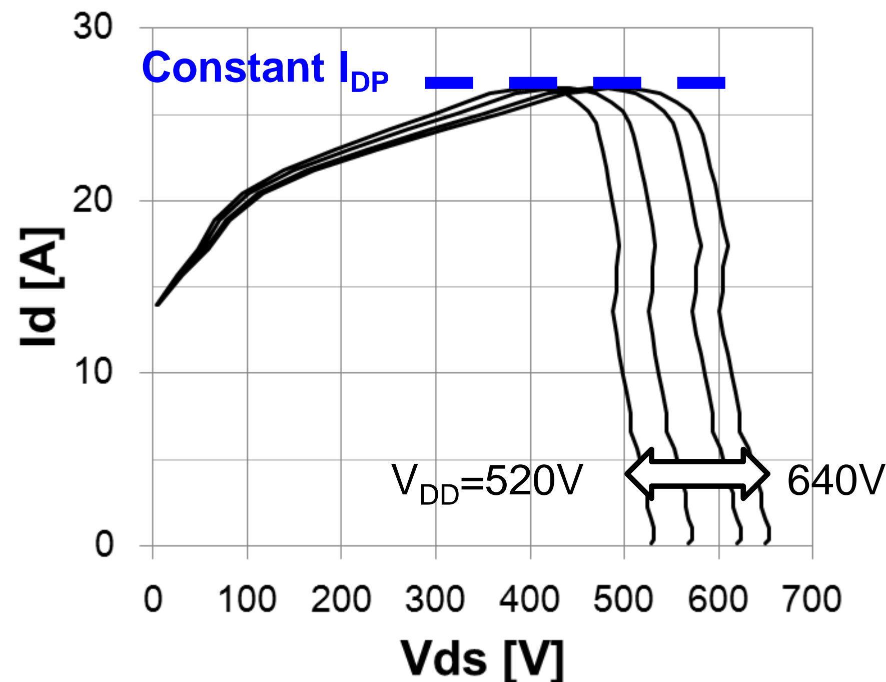
- Applied **current and voltage** as the acceleration parameters **can be independently varied** by adjusting the circuit parameters (L, R) of D-HTOL test circuit.

Variation of switching locus by adjusting circuit parameters

Variation of current with constant voltage

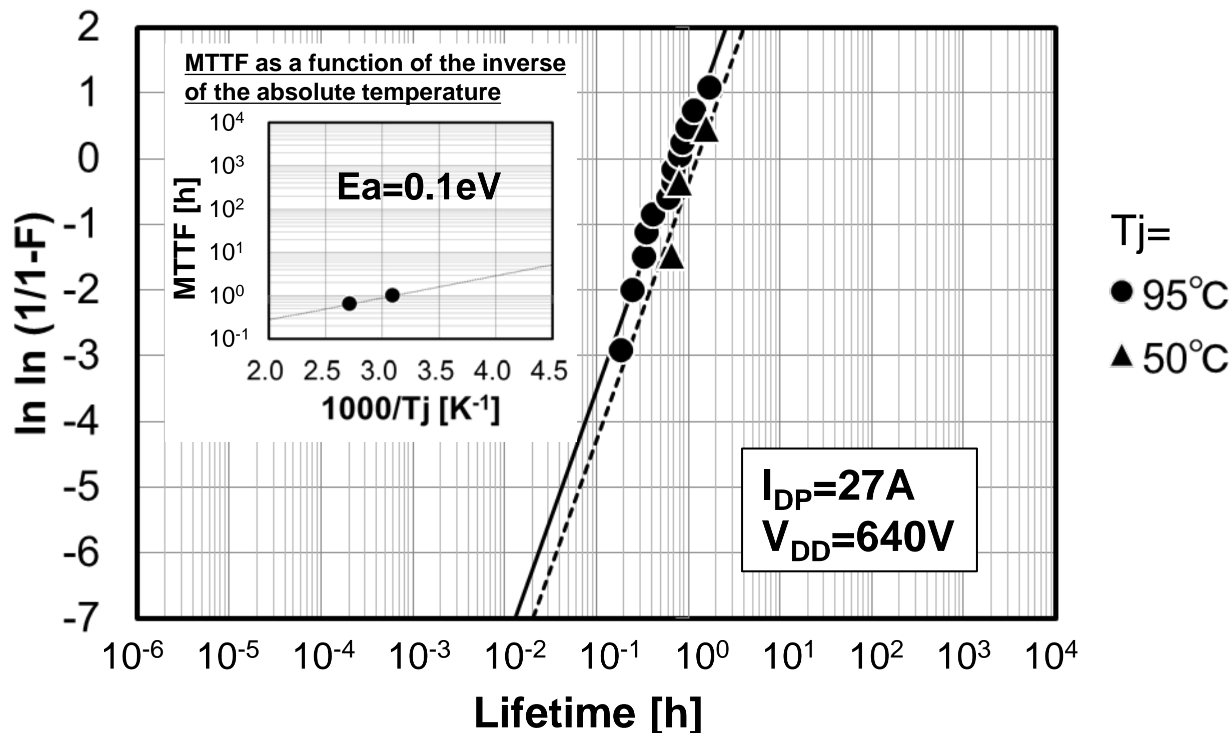


Variation of voltage with constant current



D-HTOL Test Accelerated by Temperature

- **Increase of the junction temperature does not affect the lifetime of D-HTOL test for HD-GIT.**



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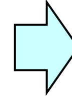
D-HTOL Test Accelerated by Drain Current / Voltage

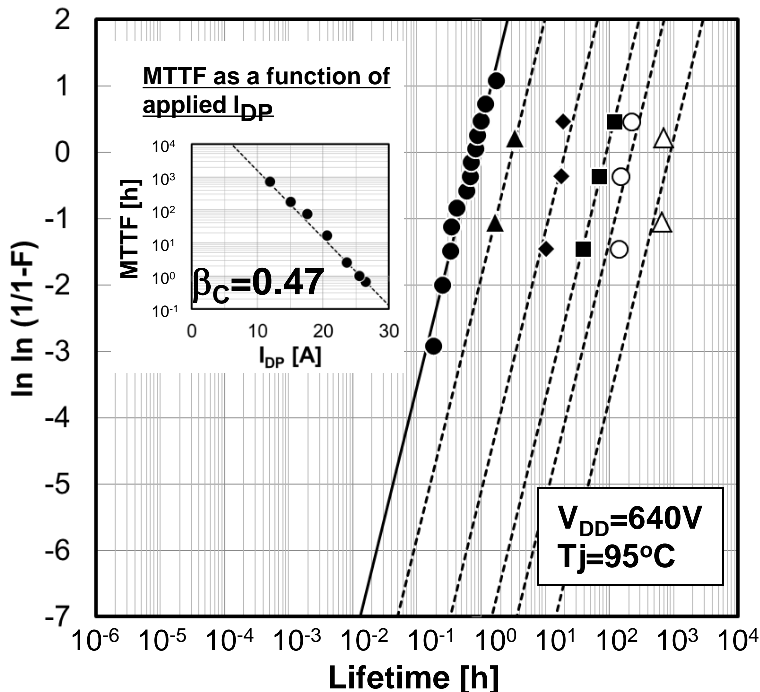
- Increase of drain current /voltage shorten the lifetime of D-HTOL.
  - I_{DP} acceleration factor : β_C=0.47
  - V_{DD} acceleration factor : β_V=0.039



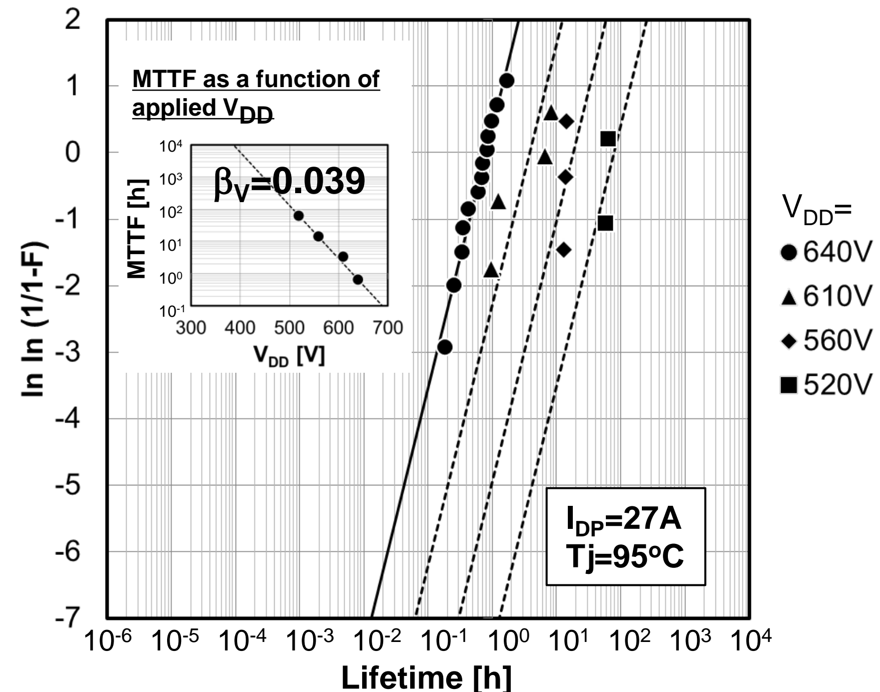
Lifetime of D-HTOL

$$\tau = A \cdot e^{-(\beta_V \cdot V_{DD} + \beta_C \cdot I_{DP})}$$

Weibull plot for various peak drain current



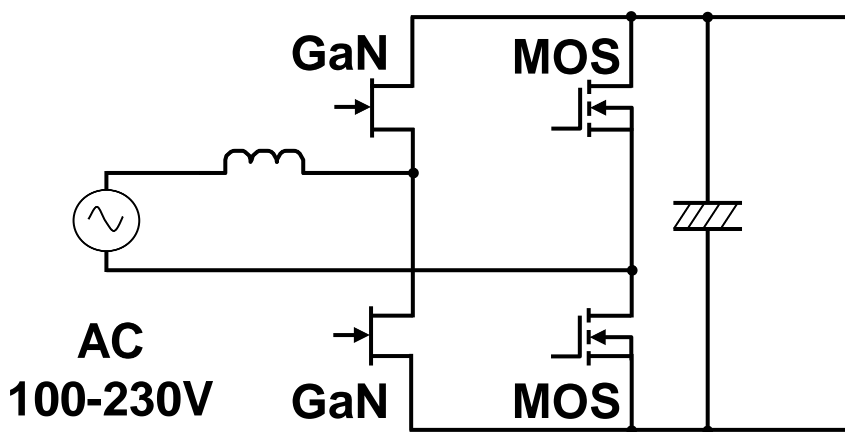
Weibull plot for various drain voltage



Estimation of D-HTOL Lifetime for Totem-pole PFC

- **Totem-pole PFC with GaN HD-GITs is considered for the estimation of D-HTOL lifetime in practical switching systems.**
- **The measured lifetime of D-HTOL for HD-GITs at various drain current/voltage is used for the estimation.**

Circuit Diagram of Totem-pole PFC with GaN devices



Operating conditions considered for estimation of D-HTOL lifetime

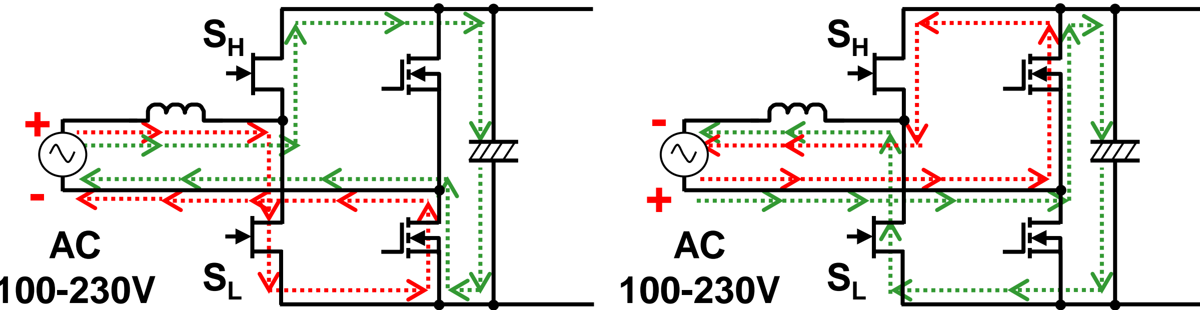
Item	Value
Output power	3kW
Input / Output Voltage	207V(AC 60Hz) / 400V
Frequency	45kHz
Target efficiency	98.5%

Operating Principle of Totem-pole PFC

- Two operating half-cycles exist in the operation.
- **Forward operations of GaN HD-GITs** during the two half-cycles **only need to be considered** for the estimation of the lifetime.

Current paths and switching waveforms of Totem-pole PFC

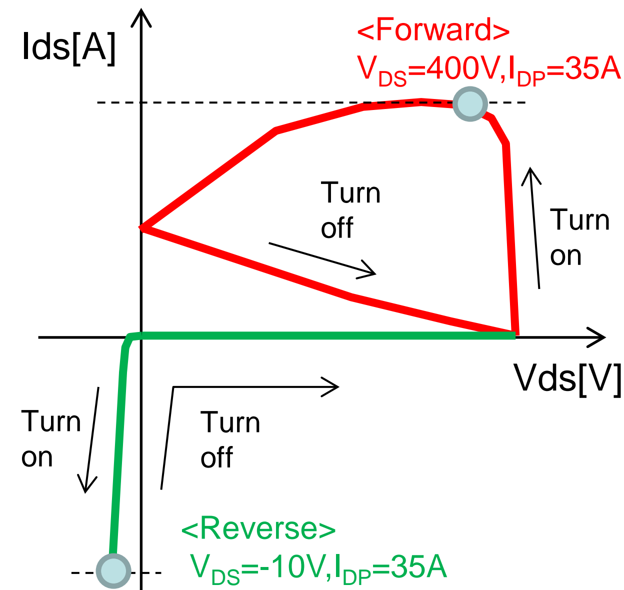
Positive half cycle *Negative half cycle*



Charge energy to Inductor
Deliver energy to Capacitor

	Positive half cycle	Negative half cycle
H-side (S_H)	Reverse (Diode) Ids	Forward (Switch) Ids
L-side (S_L)	Forward (Switch) Ids	Reverse (Diode) Ids

Current-voltage locus



Magnitude of operating stress

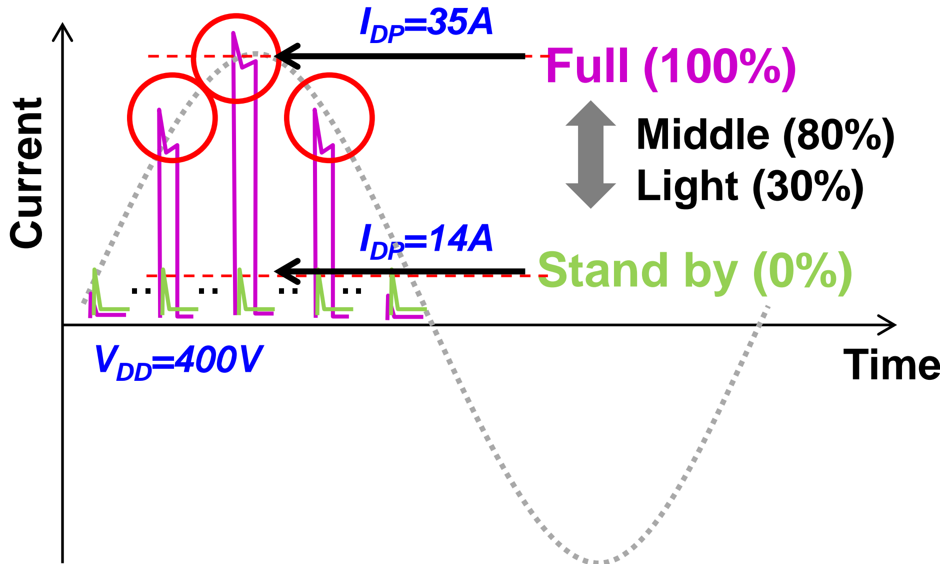
Reverse		Forward
-10V/35A	<<<<<	**400V/35A**

Reduction of Lifetime by PFC Operation

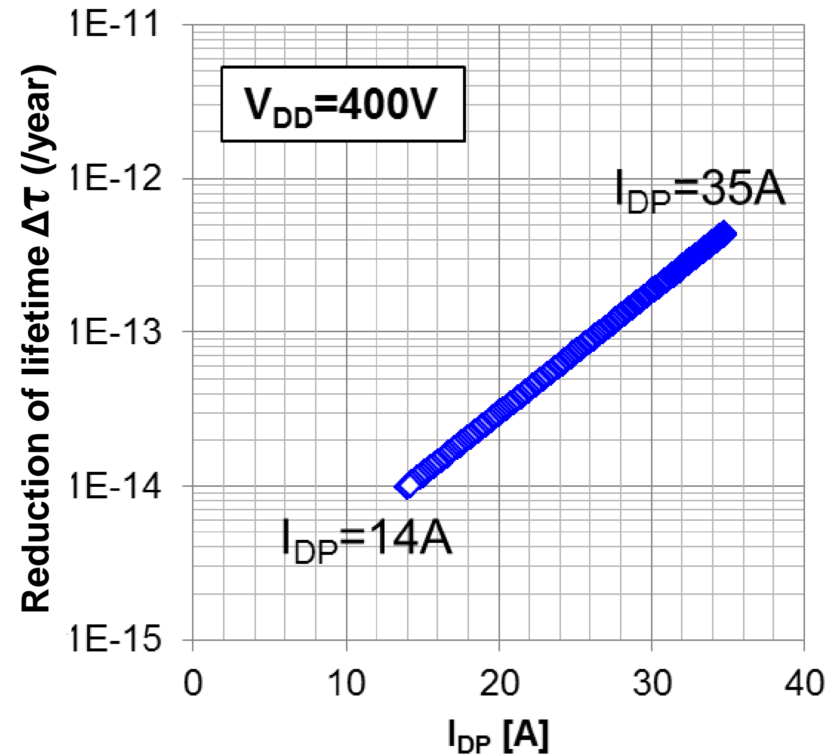
Extraction steps for reduction of the lifetime

- **Reduction of lifetime by a single current pulse Δτ is calculated by measured D-HTOL results dependent on V_{DD} and I_{DP}.**
- **ΣΔτ = 1 indicates that the device reaches catastrophic failure.**

Switching waveforms of totem-pole PFC for various load current



Extracted reduction of lifetime



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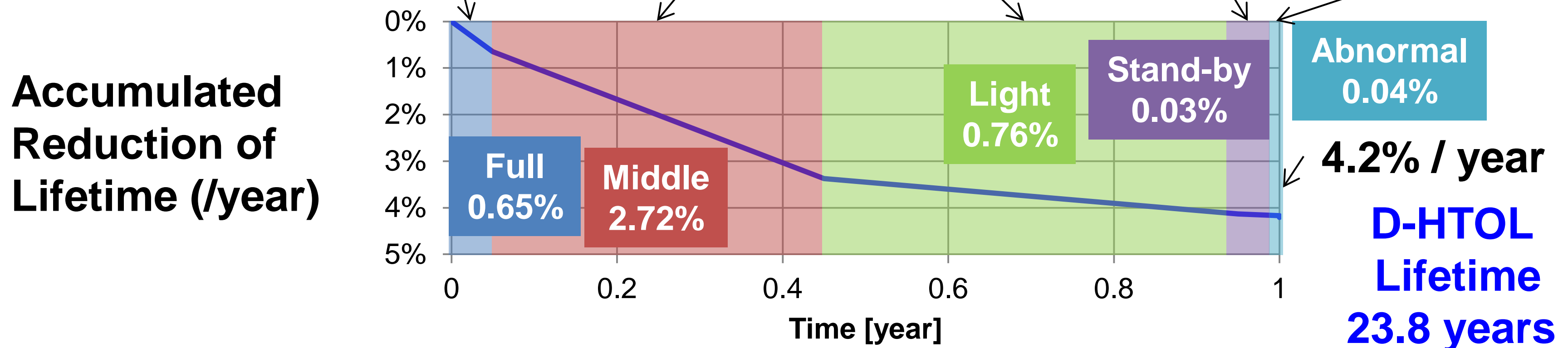
D-HTOL Lifetime for Totem-Pole PFC with HD-GITs

- **D-HTOL lifetime of totem-pole PFC is estimated to be 23.8 years (=1/0.042) considering the load conditions and the operating fraction.**

Reduction of D-HTOL Lifetime Depending on Load Conditions

Load Condition	Full 100% Load	Middle 80% Load	Light 30% Load	Stand-by 0% Load	Abnormal 200% Load
Operating Waveform (Half cycle)	V_{DD}=400V, I_{DP} 14A..35A..14A	V_{DD}=400V, I_{DP} 14A..31A..14A	V_{DD}=400V, I_{DP} 14A..20A..14A	V_{DD}=400V, I_{DP} 14A..14A..14A	V_{DD}=500V, I_{DP} 14A..56A..14A
Operating fraction	5%	40%	50%	5%	0.0002%



Summary

Demonstration of Highly Reliable Operations by Panasonic's 600V GaN Power Transistors

- **GaN HD-GIT free from current collapse passes all of the reliability test standards by JEDEC.**
- **HD-GIT exhibits long lifetime under switching reliability tests called as D-HTOL with inductive load.**
- **Acceleration factors for the D-HTOL by drain current/voltage are extracted for the estimation of lifetime in practical switching system.**
- **D-HTOL lifetime for totem-pole PFC using GaN HD-GITs are estimated to be as long as 24 years.**

Acknowledgements

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