Test & Reliability

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Impact of current density, accumulated injected charge and temperature on bipolar degradation in 4H-SiC PiN diodes

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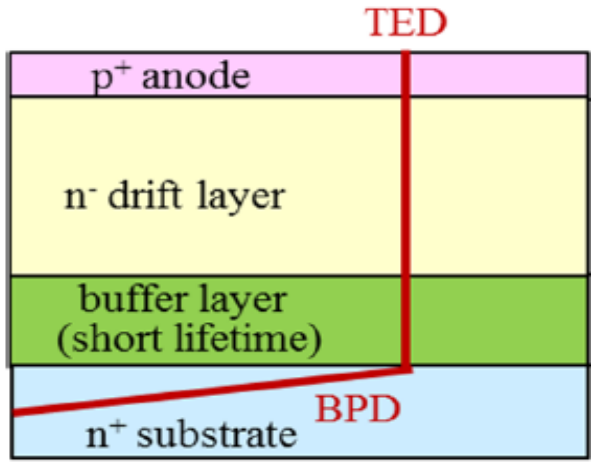
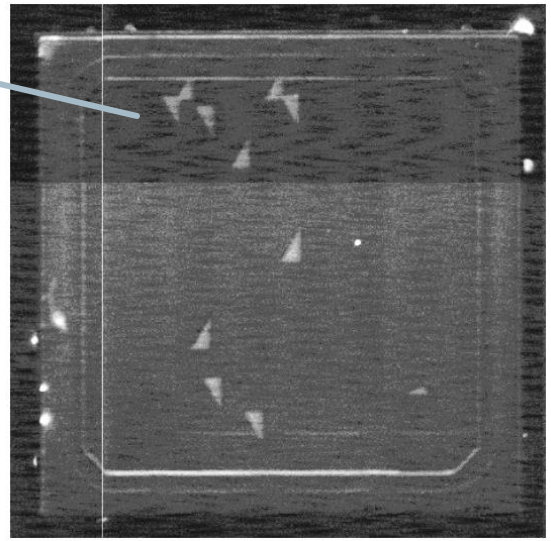
Introduction

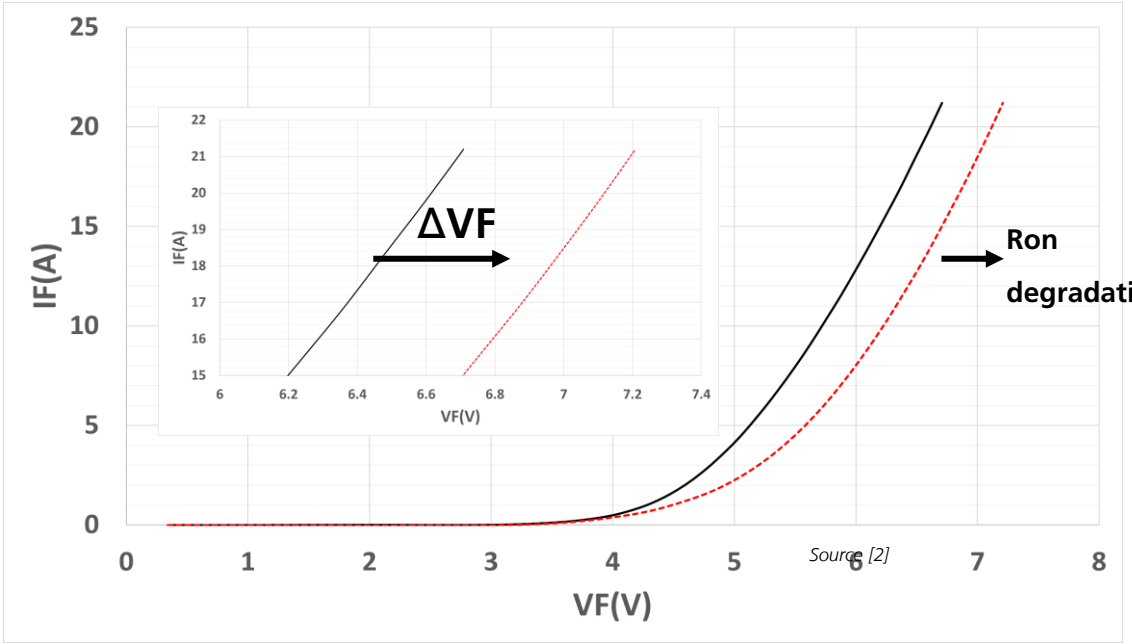
Bipolar Degradation



Source [1]



Source [2]

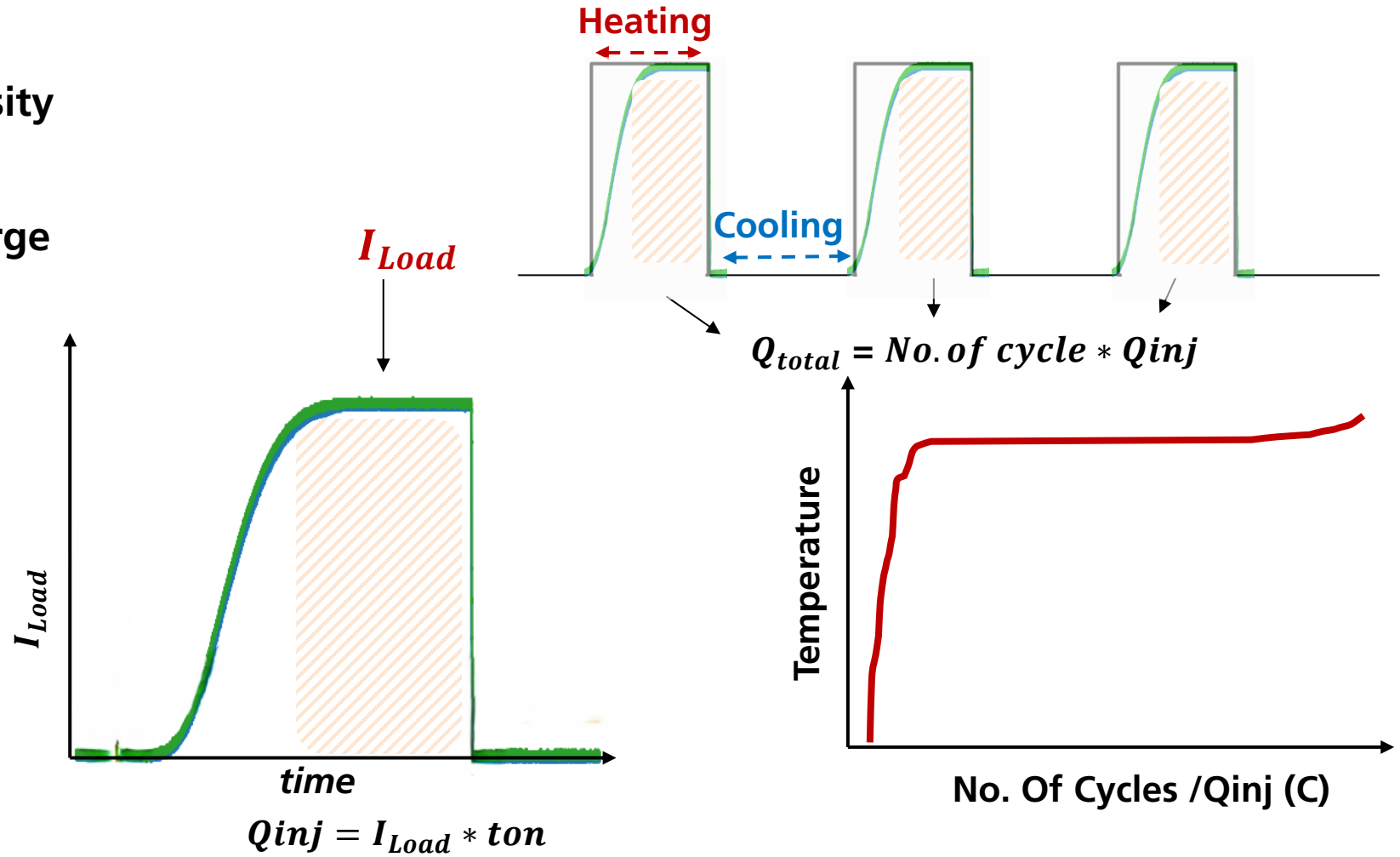


- **Bipolar Degradation (BD) :**
  Bipolar currents -> Stacking faults (SSFs) expansion ->
  Resistance increase -> Forward Voltage degradation

Targets of this study

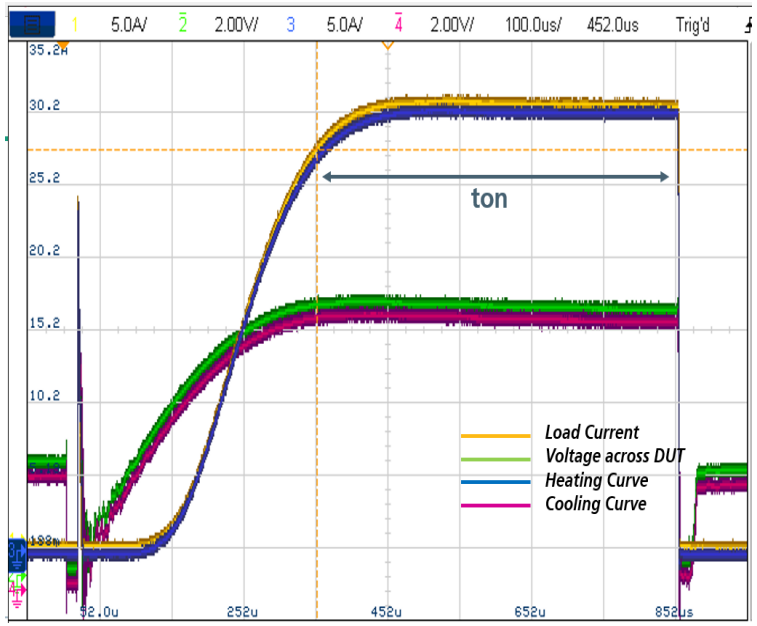
Impact of Temperature, Current density and Injected Charge

- **Current density**
- **Temperature**
- **Injected charge**

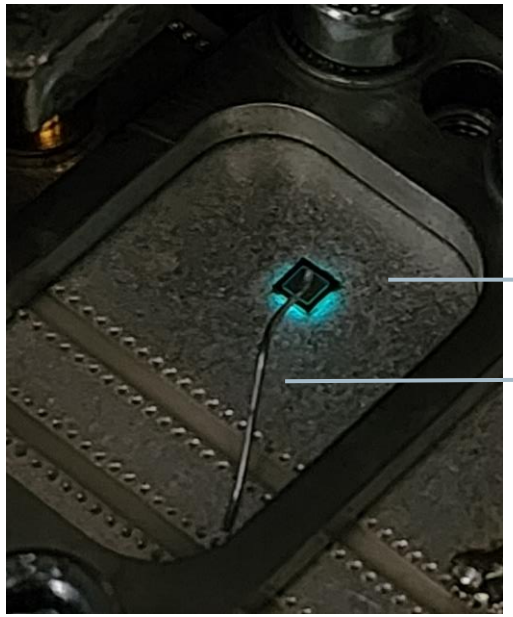


Test Setup
Original Setup

- Two-point measurement
- Bond-Wire (BW) aging
- Significant increase of VF
- Not possible to compare in-situ



Pulse Shape - PCmsec

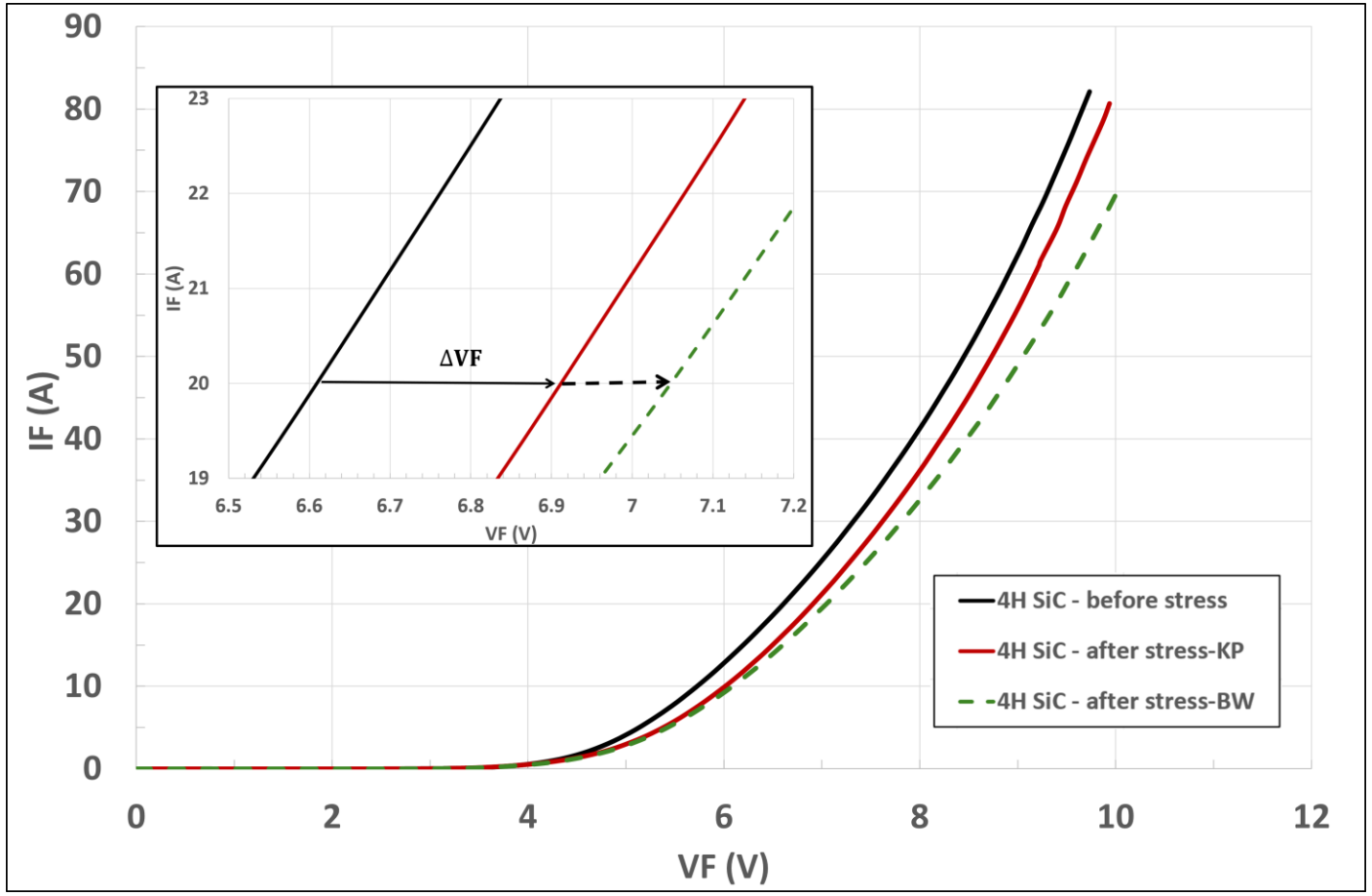


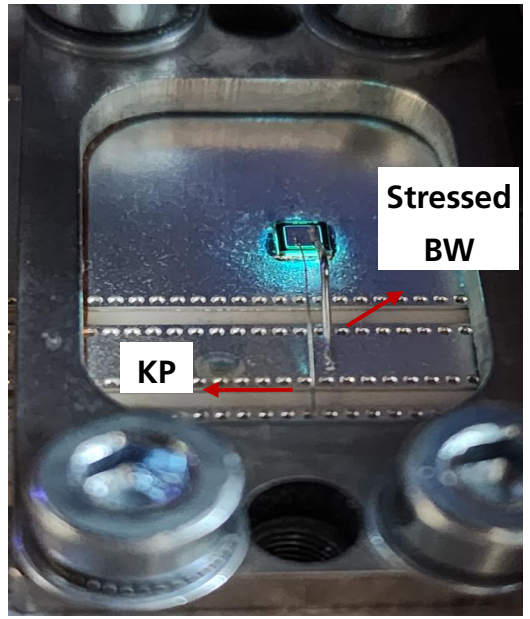
DUT mount with direct cooling

Improved Setup

Kelvin-Probe implementation

- The measurements including the BW led to a significant error in the forward voltage measurement.
- Solution: Introduced Kelvin–Probe measurement.

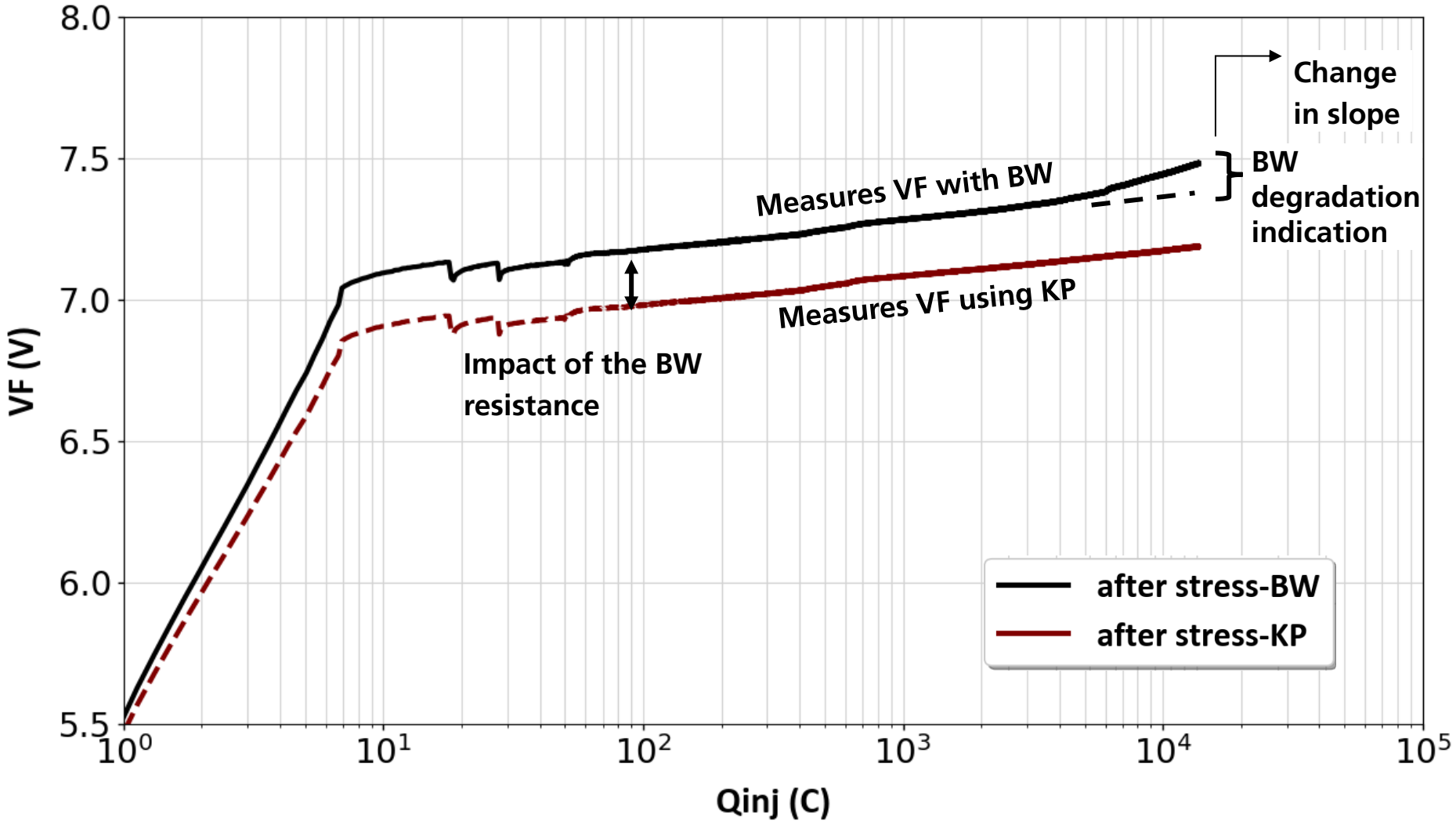




Characteristic features of the measurement curves

Impact of Bond-Wire Resistance

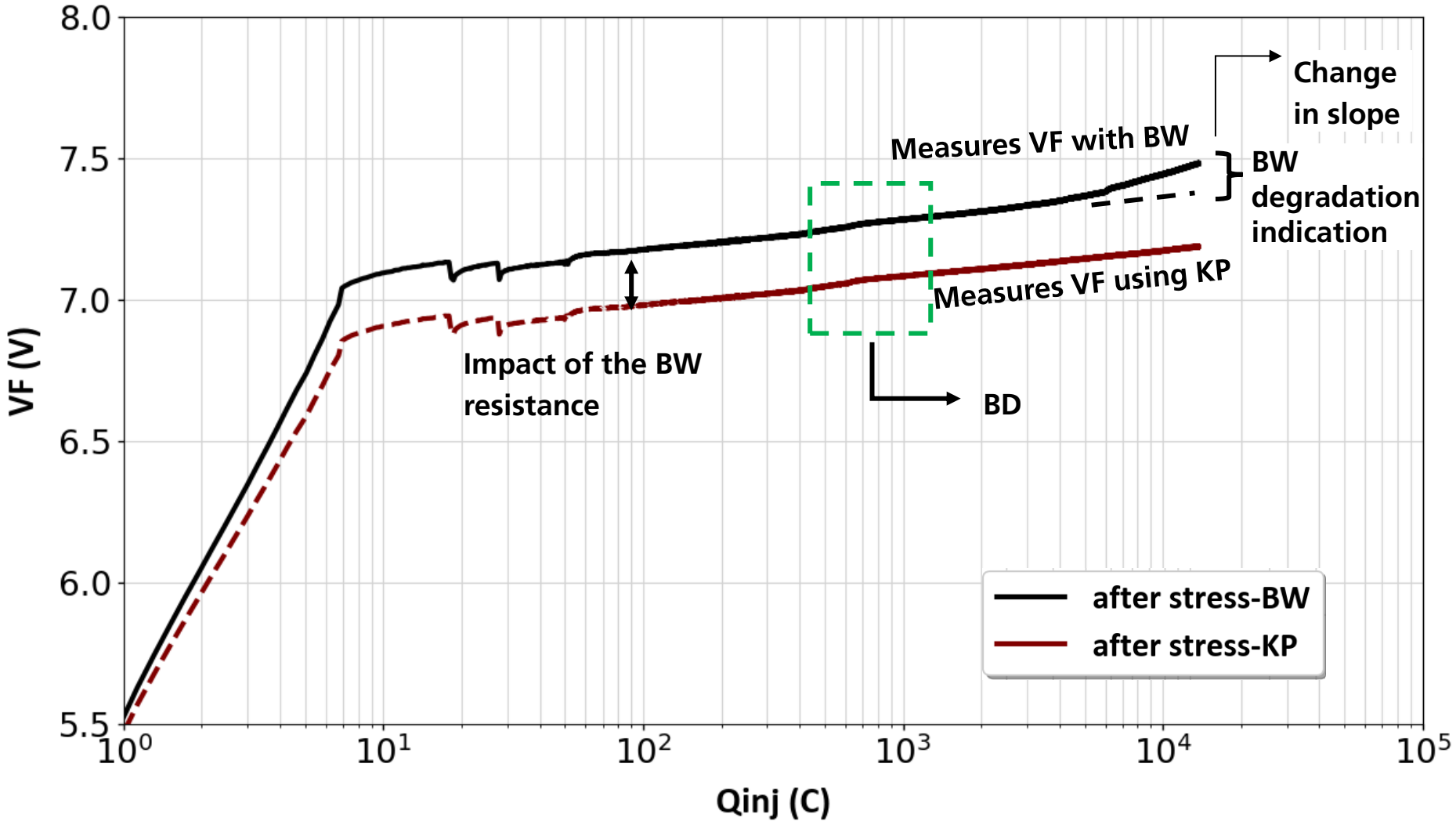
- Accurate VF measurement
- Ability to differentiate BW degradation from BD, **In-Situ**



Characteristic features of the measurement curves

Signature of Bipolar Degradation

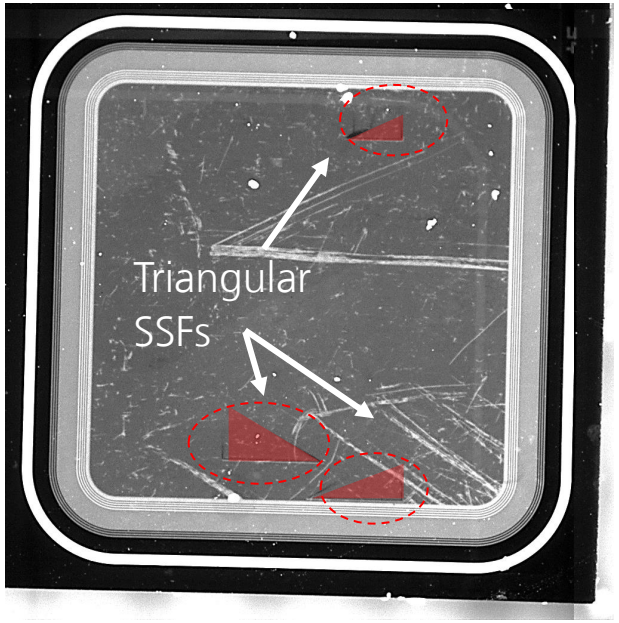
- **Skewness observed in curve**



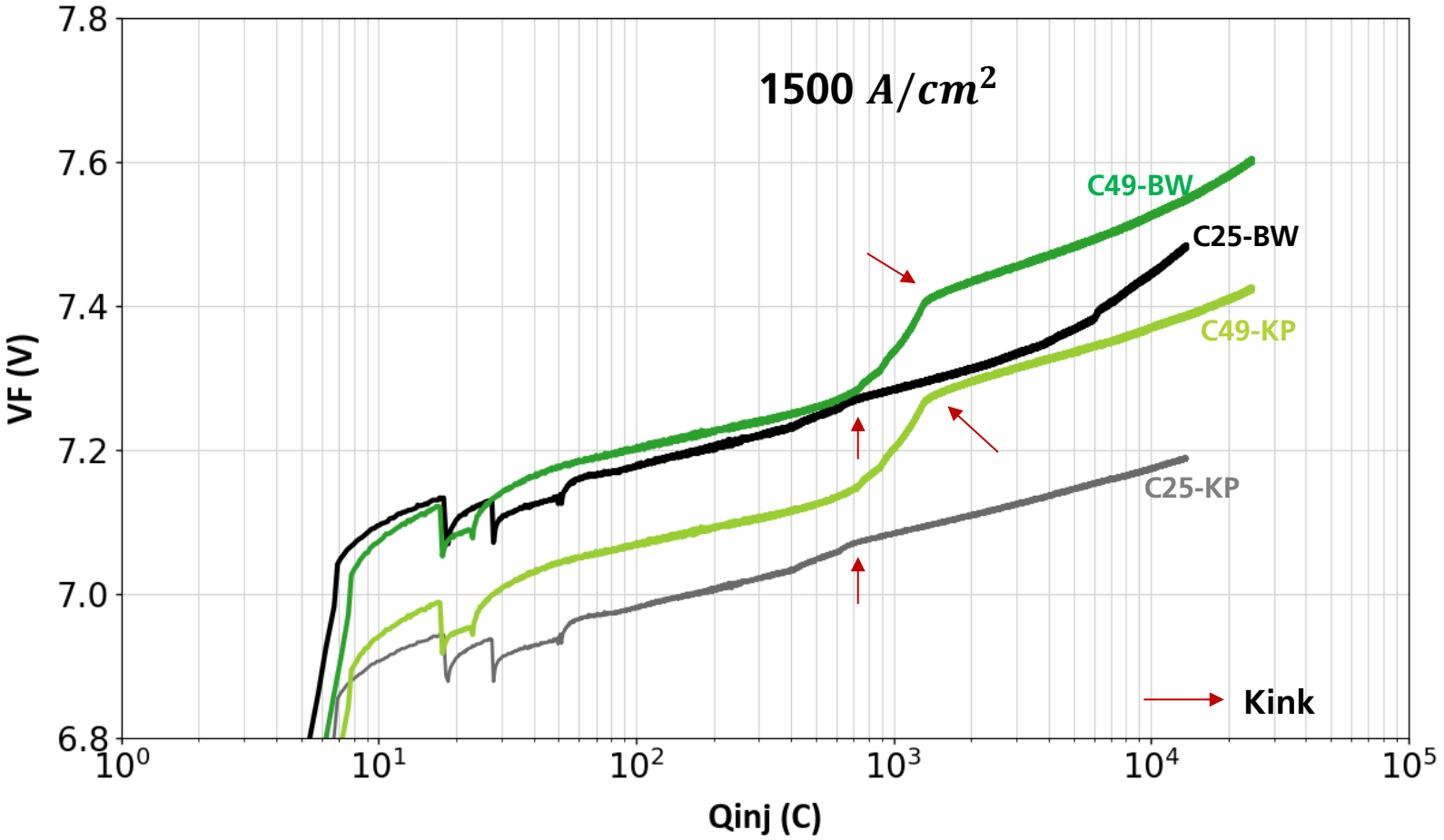
Characteristic features of the measurement curves

Signature of Bipolar Degradation

- Observed kink in the curve, a signature for bipolar degradation.



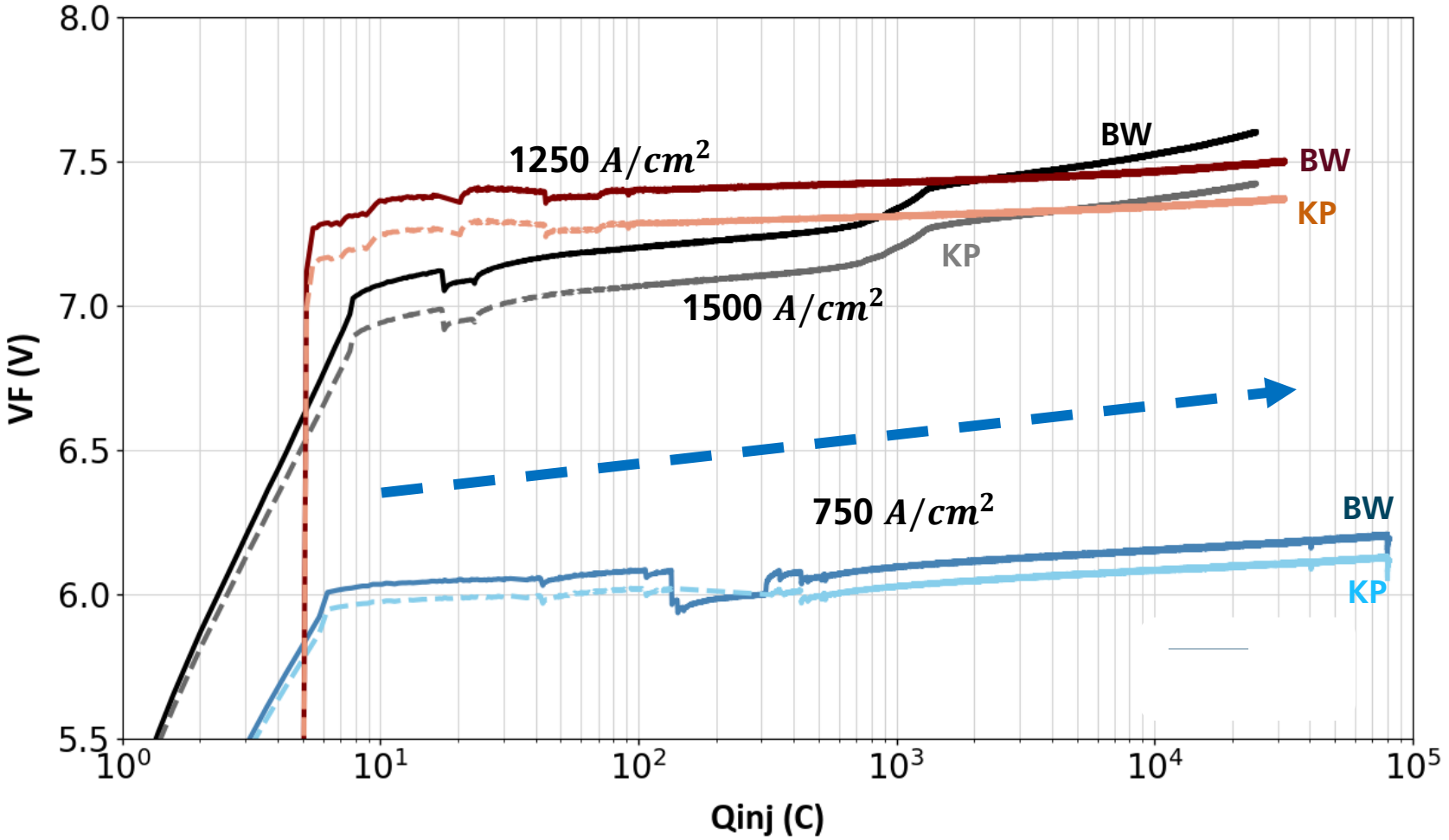
DUT C25 After stress- UV-PL image



Characteristic features of the measurement curves

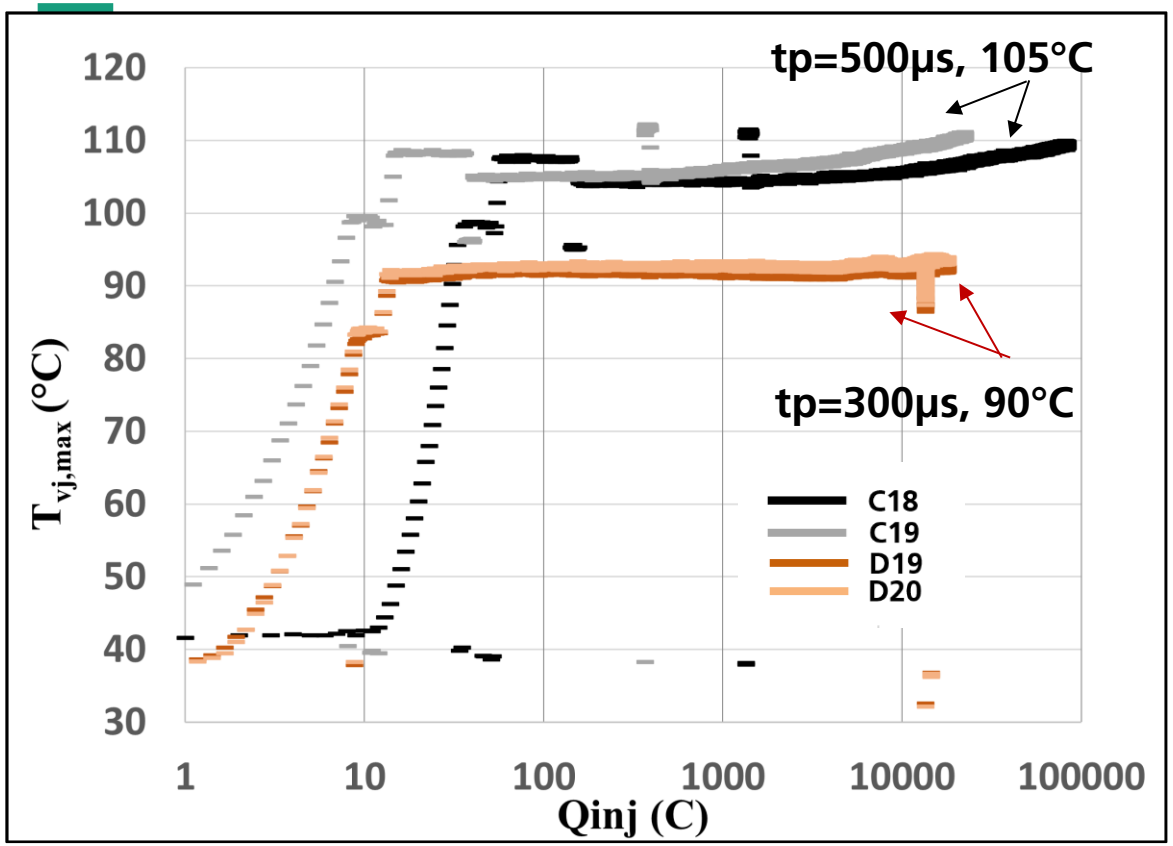
Systematic increase in VF

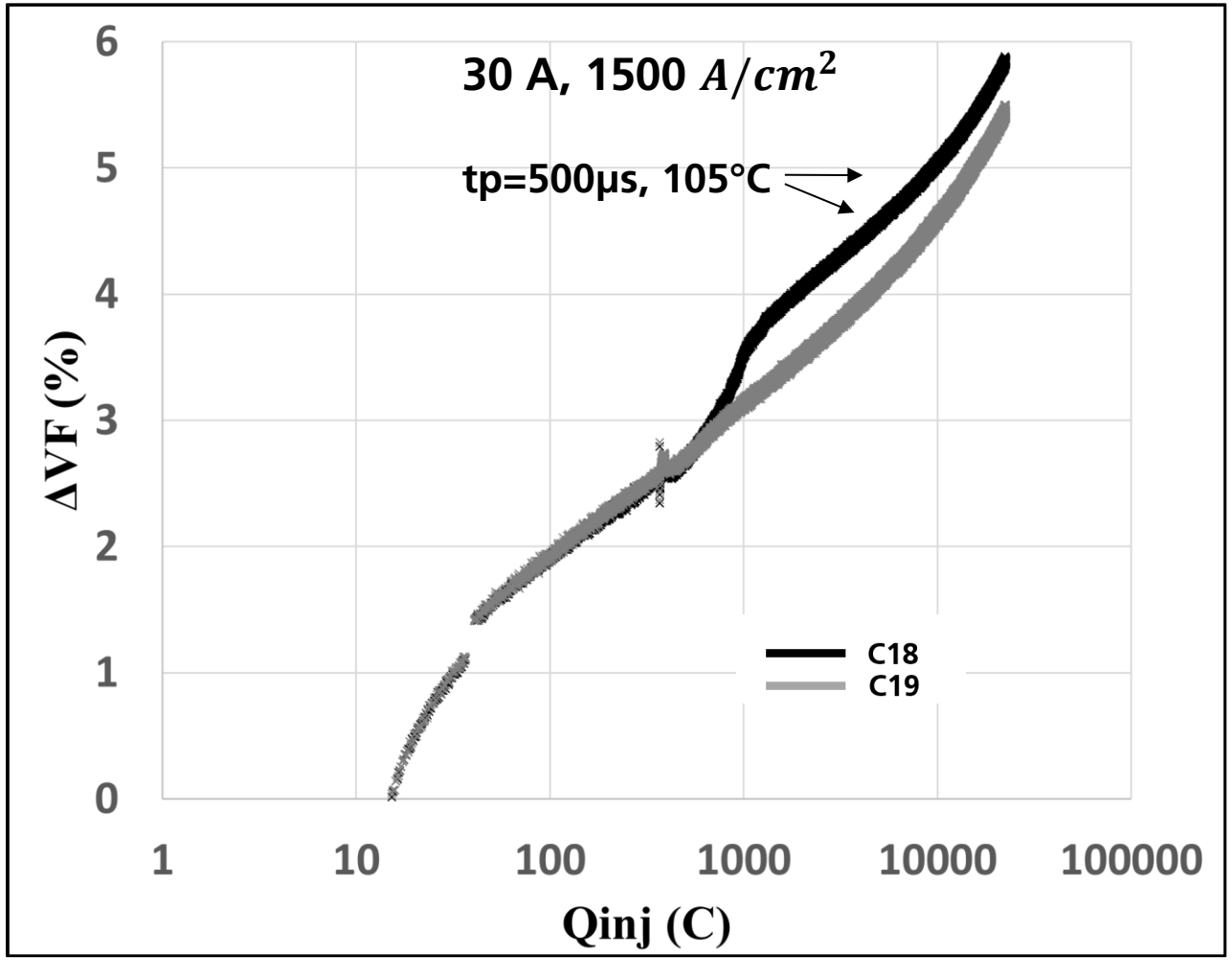
- Gradual increase in VF
- Present in all stress conditions
  - not Bond Wire degradation
  - not Bipolar Degradation



Impact of Temperature

Temperature control by Pulse Width variation

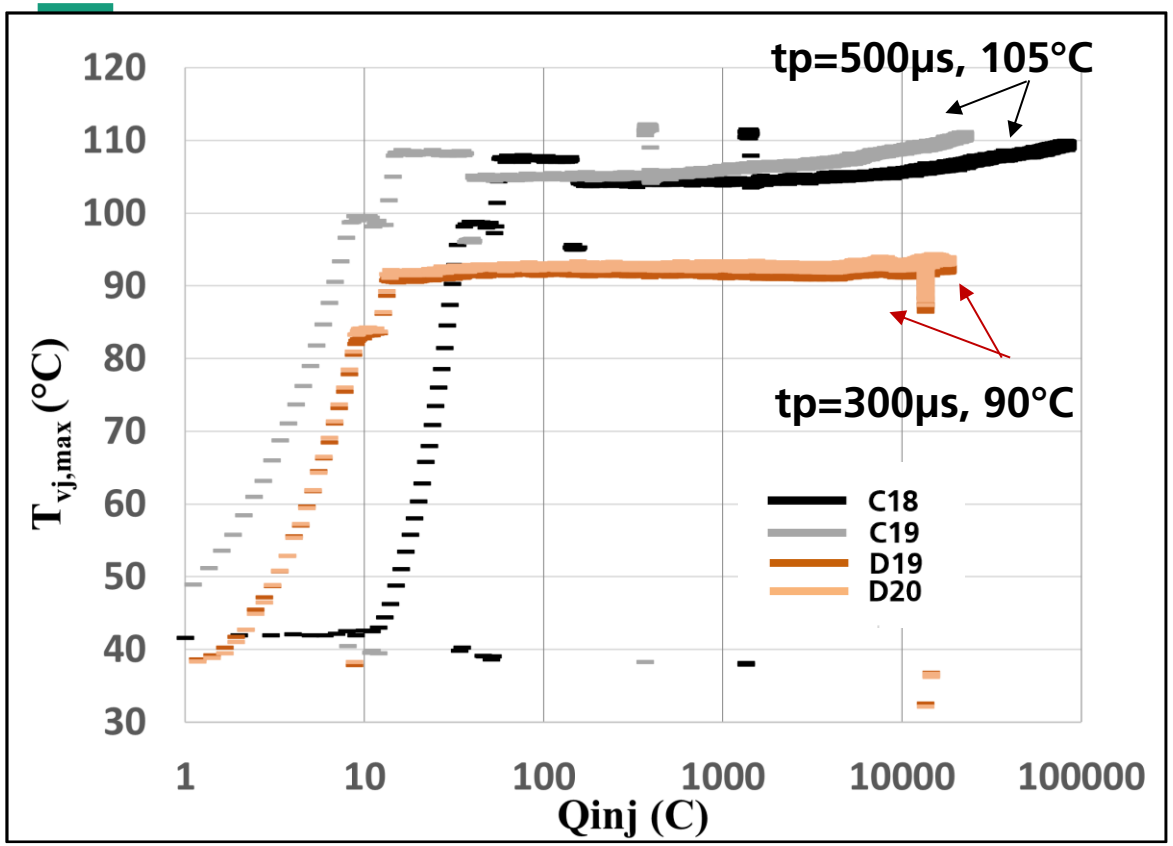


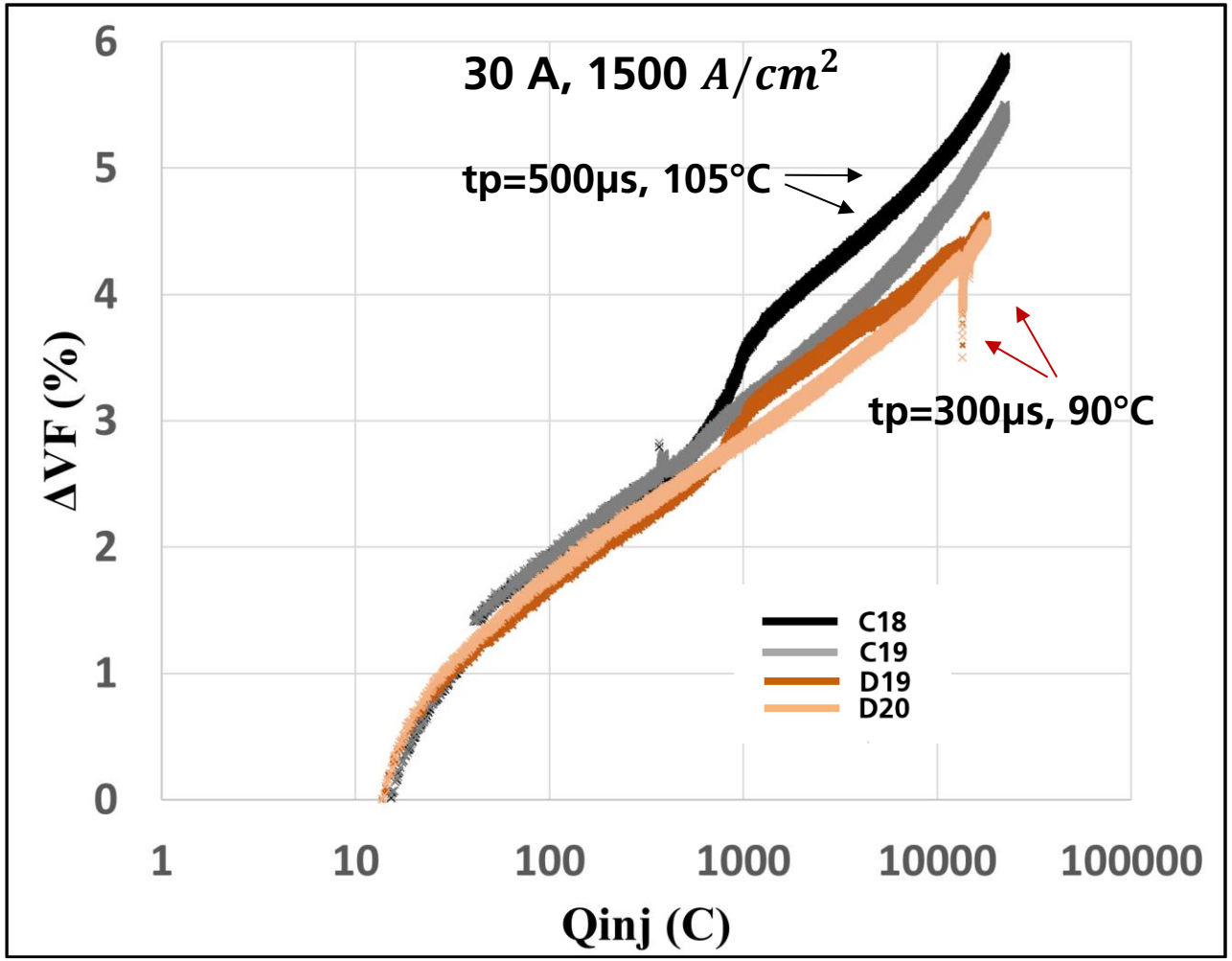


- Change in duration of the load current (I_L) influences the value of Tvj,max.

Impact of Temperature

Temperature control by Pulse Width variation



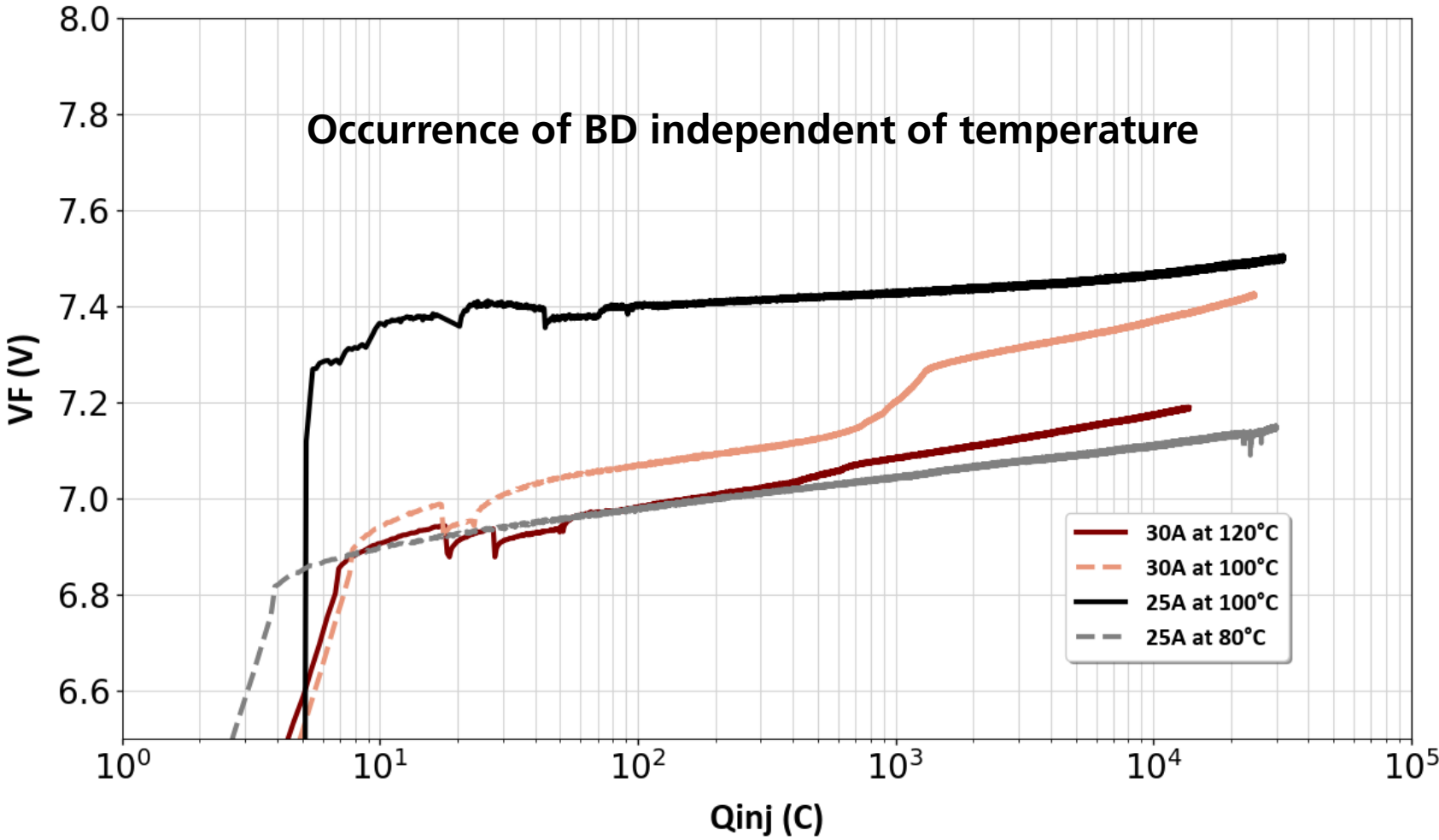


- **Temperature doesn't have a first order impact.**

Impact of Temperature

Temperature control by chiller

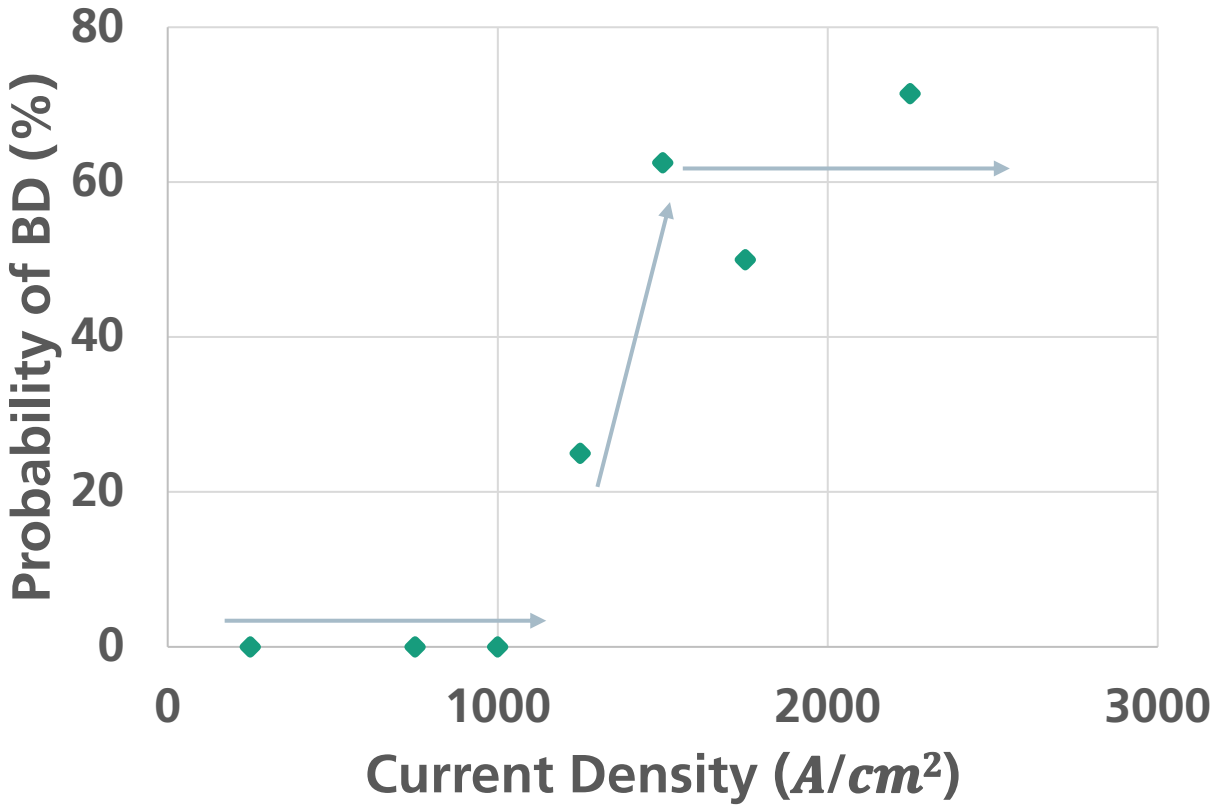
- Removes possible influence of Pulse Width
- Several DUTs -> same Pulse Width but at different Tvj,max,
- No direct consequence on Bipolar Degradation



- **Temperature doesn't have a first order impact.**

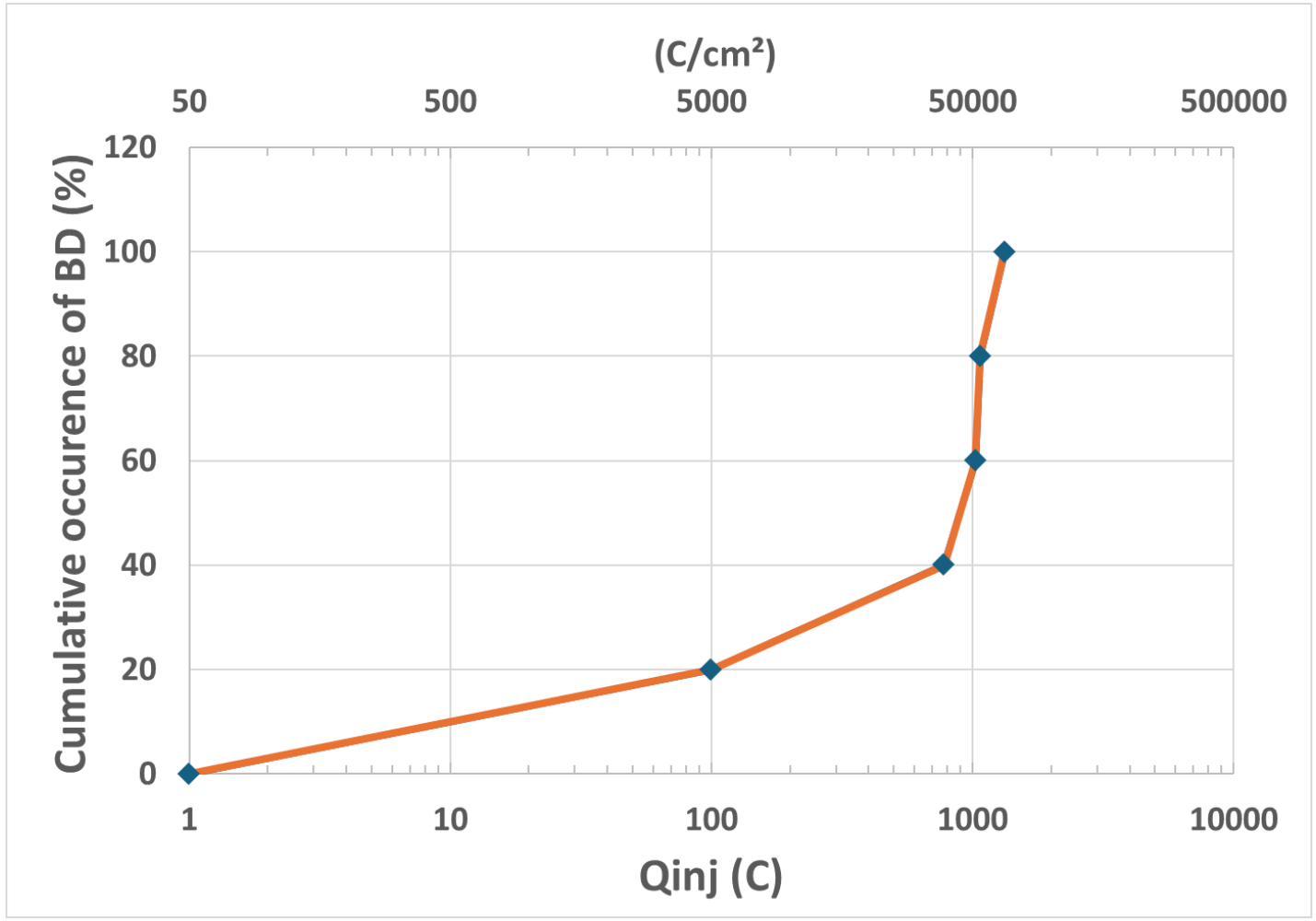
Impact of Current Density

Probability of occurence of Bipolar Degradation (BD)



- **BD observed above 1000 A/cm²~1500 A/cm²**

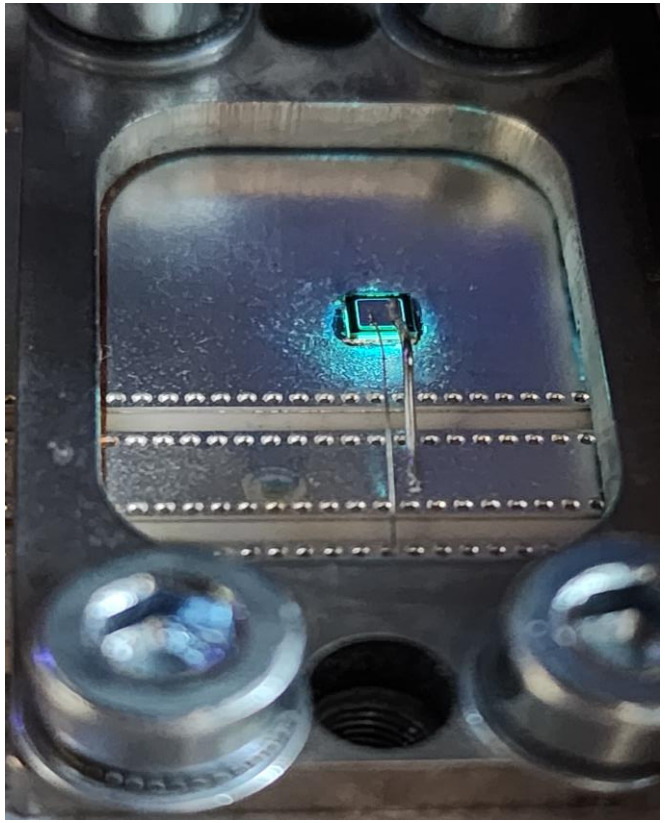
Impact of Injected Charge



- **When Bipolar Degradation occurs, it triggers around 50 kC/cm²**

Summary

- First study of Bipolar Degradation as a function of accumulated injected charge
- Introduction of In-situ KP measurements (ability to differentiate BD from BW degradation)
- Study of impact of Temperature, Stress current density and Injected charge without parameter interaction.



Conclusions

Temperature is not a first order parameter

Bipolar Degradation triggers above 1000A/cm^2

Critical injected charge was found to be around 50kC/cm^2

Outlook

Improvement on effective Pulse Width

Statistical observation for all parameters

UV Photoluminiscence

Test Bench improvement (PCB integration to test more DUTs at a time)

Image References

[1] Tsuchida, Hidekazu, et al. "Suppression of Bipolar Degradation in 4H-SiC Power Devices by Carrier Lifetime Control." *2019 IEEE International Electron Devices Meeting (IEDM)*. IEEE, 2019.

[2] Hatta, Naoki, et al. "Reduction of Forward Bias Degradation in 4H-SiC PiN Diodes Fabricated on 4H-SiC Bonded Substrates." *Key Engineering Materials* 948 (2023): 107-113.

References

[1] Bergman, J. Peder, et al. "Crystal defects as source of anomalous forward voltage increase of 4H-SiC diodes." Materials Science Forum. Vol. 353. 2001.

[2]Tsuchida, Hidekazu, et al. "Suppression of Bipolar Degradation in 4H-SiC Power Devices by Carrier Lifetime Control." *2019 IEEE International Electron Devices Meeting (IEDM)*. IEEE, 2019.

[3] Hatta, Naoki, et al. "Reduction of Forward Bias Degradation in 4H-SiC PiN Diodes Fabricated on 4H-SiC Bonded Substrates." *Key Engineering Materials* 948 (2023): 107-113.

[4] Omote, Kazuhiko. "Crystal defects in SiC wafers and a new X-ray topography system." The Rigaku Journal 29.1 (2013).

[5] Harada, Shunta, et al. "Suppression of stacking fault expansion in a 4H-SiC epitaxial layer by proton irradiation." Scientific Reports 12.1 (2022): 13542.

[6] Laha, S., et al. "Milliseconds Power Cycling (PCmsec) driving bipolar degradation in Silicon Carbide Power Devices." CIPS 2024; 13th International Conference on Integrated Power Electronics Systems. VDE, 2024.

[7] Brosselard, Pierre, et al. "The effect of the temperature on the Bipolar Degradation of 3.3 kV 4H-SiC PiN diodes." 2008 20th International Symposium on Power Semiconductor Devices and IC's. IEEE, 2008.

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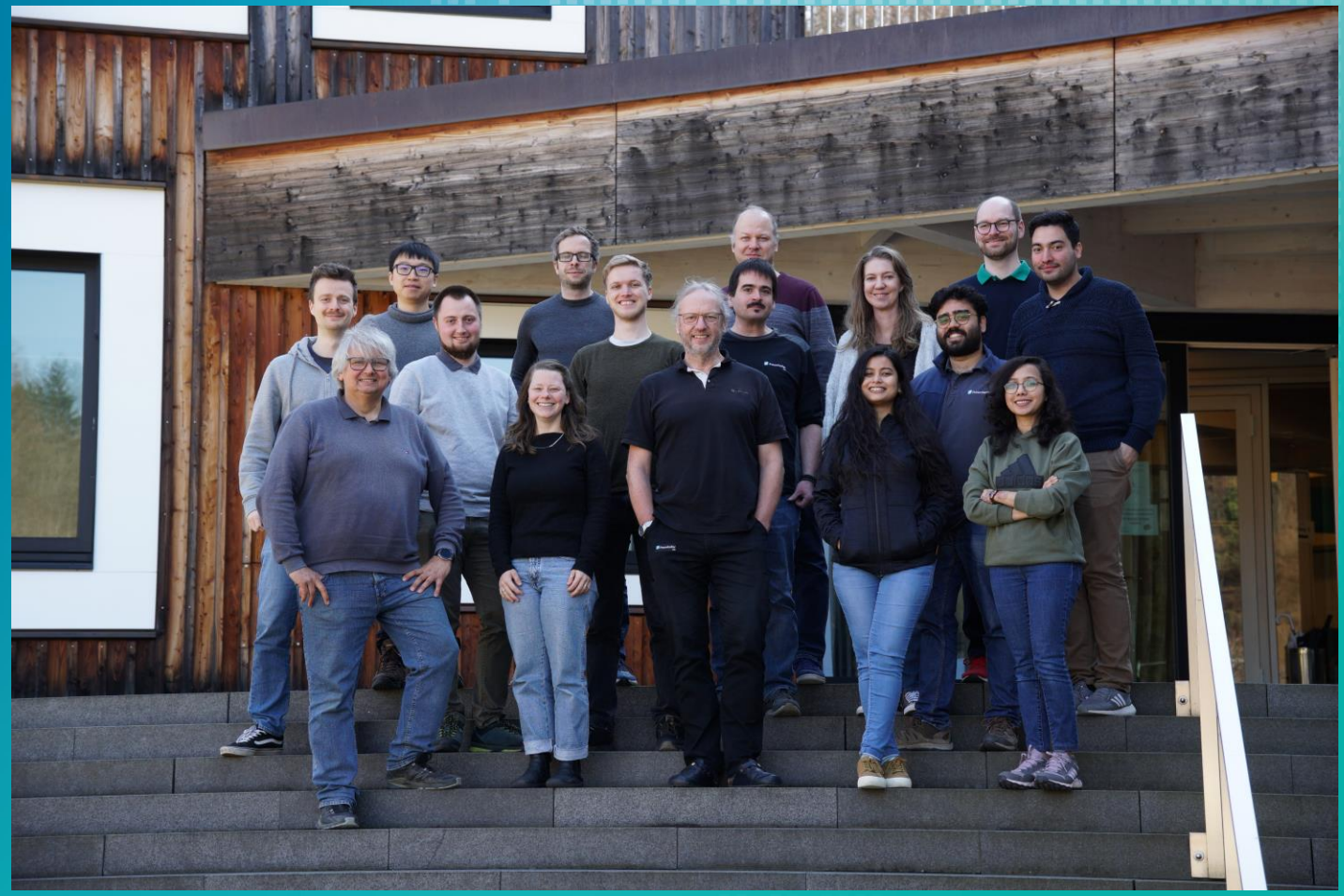
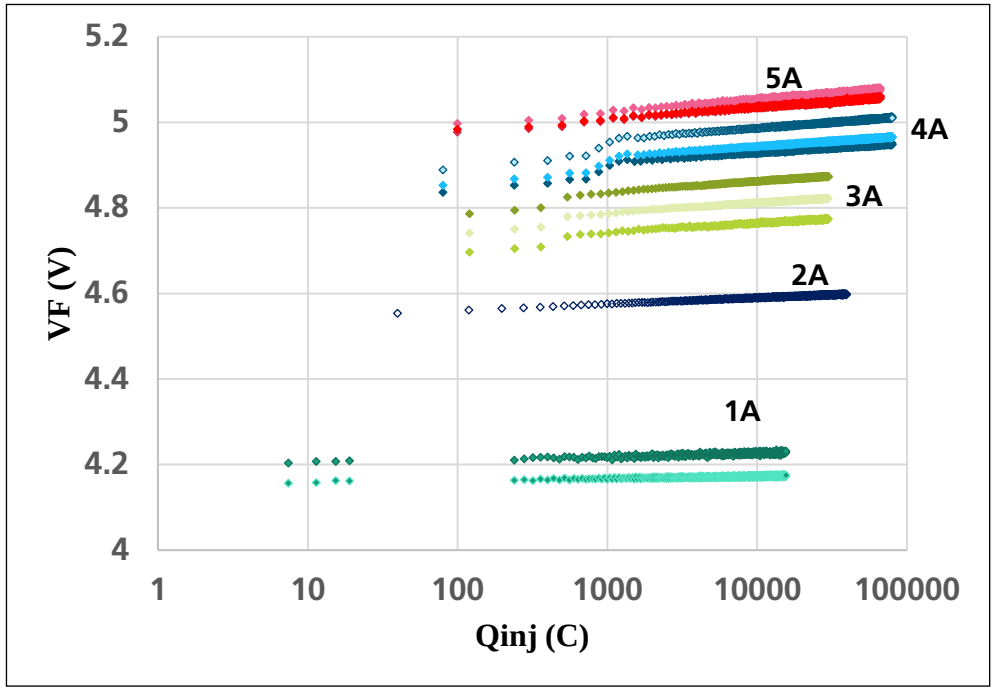
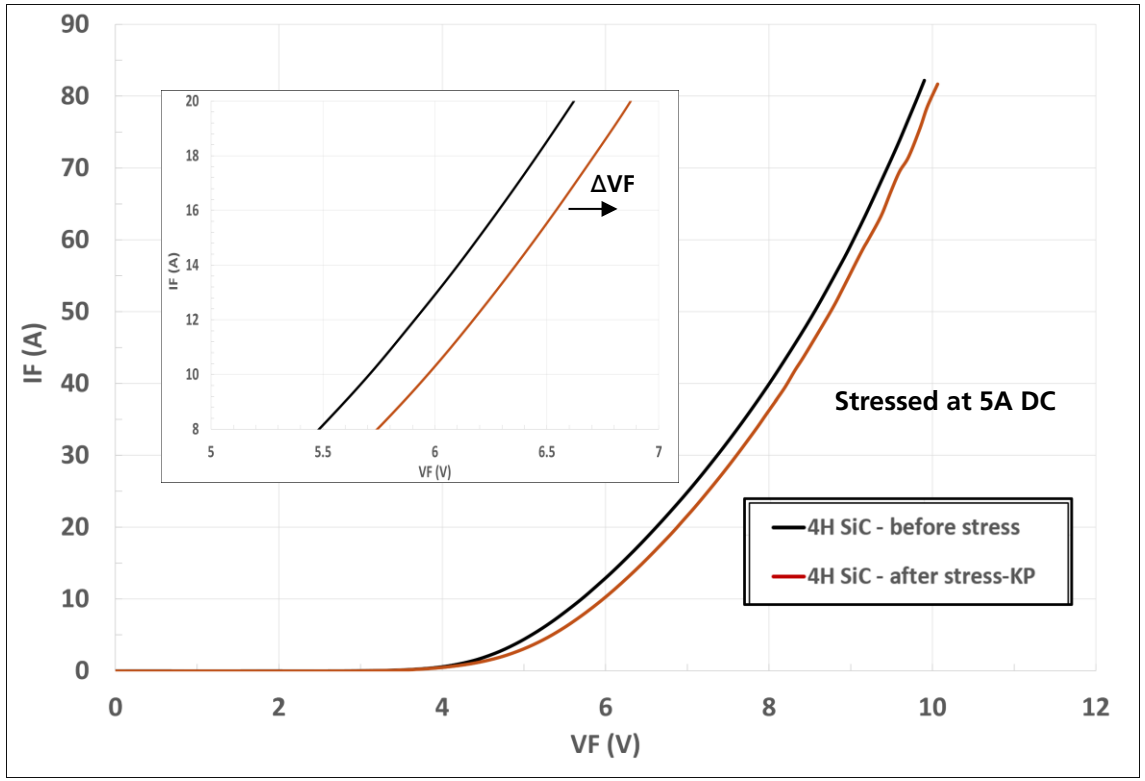


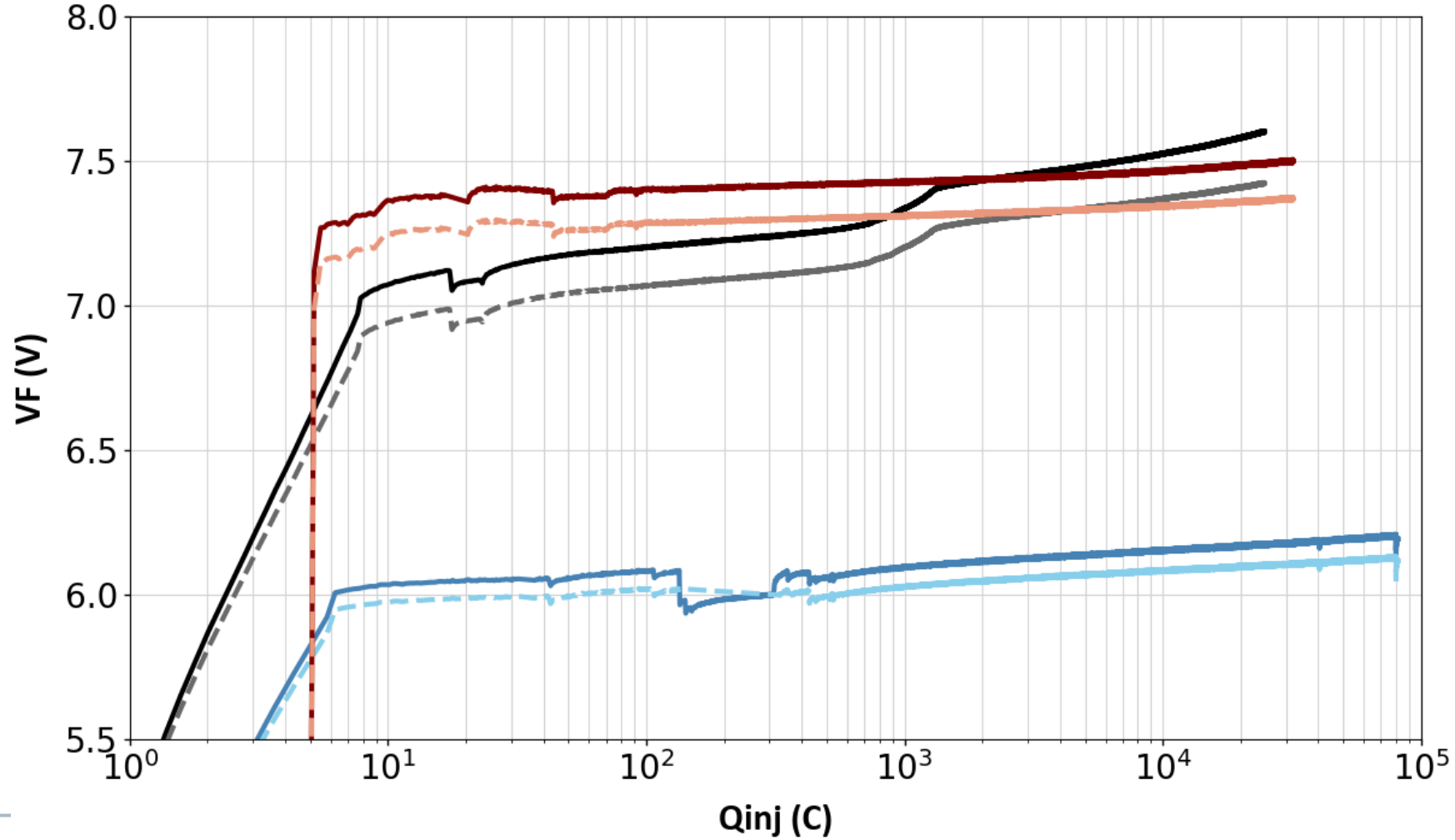
PC_{DC}





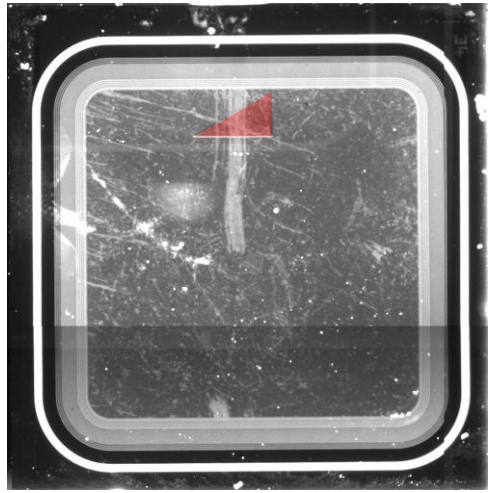
Results: Observed VF shift in the post characterization results.

Backup

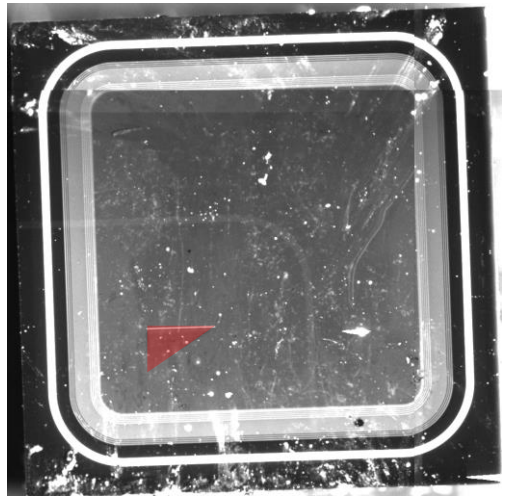


Photoluminiscence Results

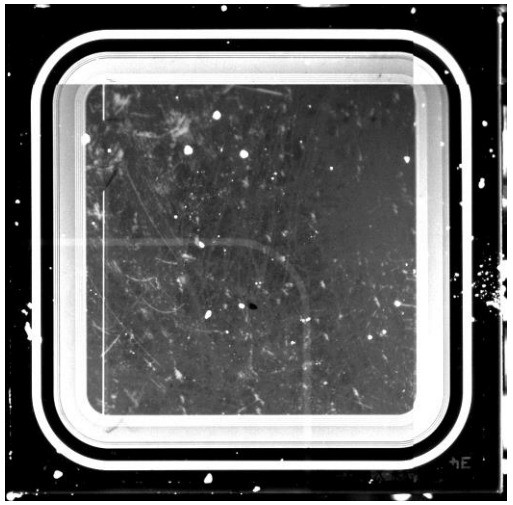
Stressed at 35A (1750 A/cm^2)



Stressed at 45 A (2250 A/cm^2)



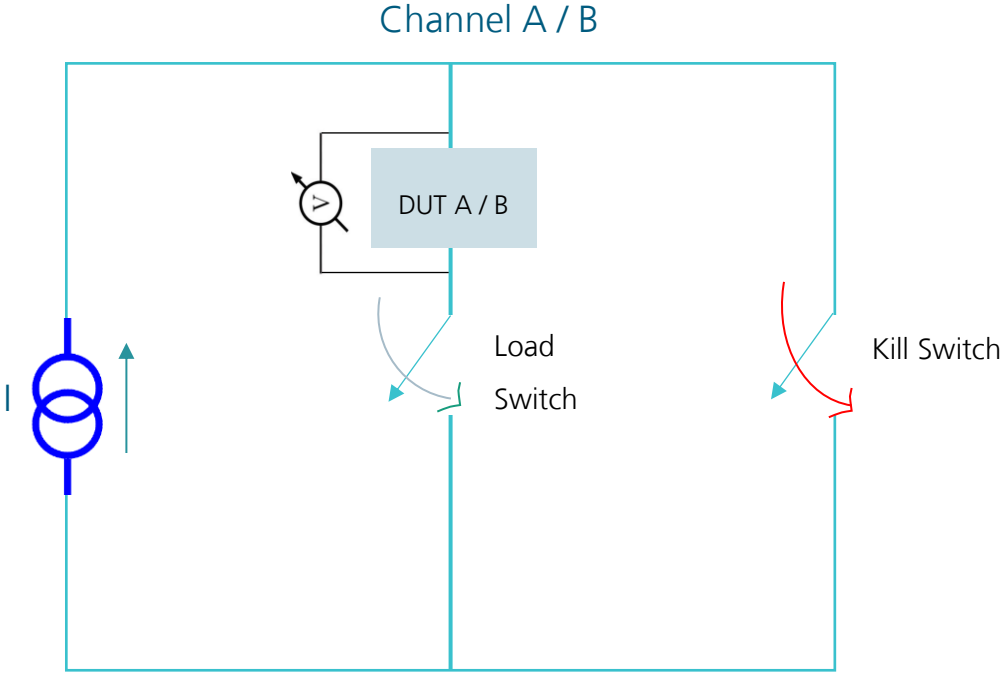
Stressed at 30A (1500 A/cm^2)

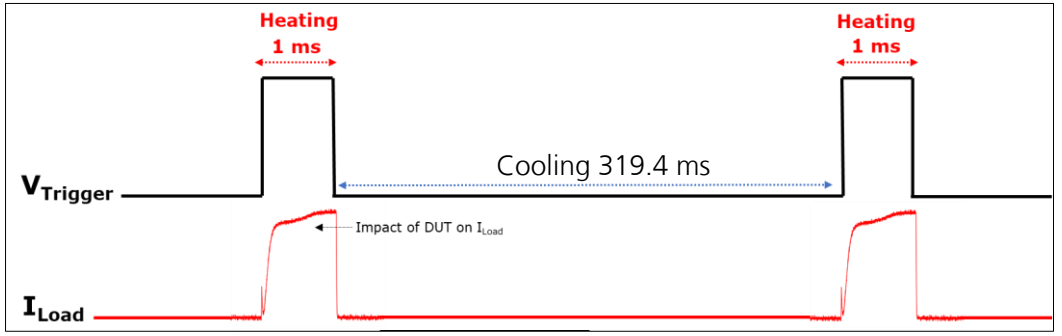


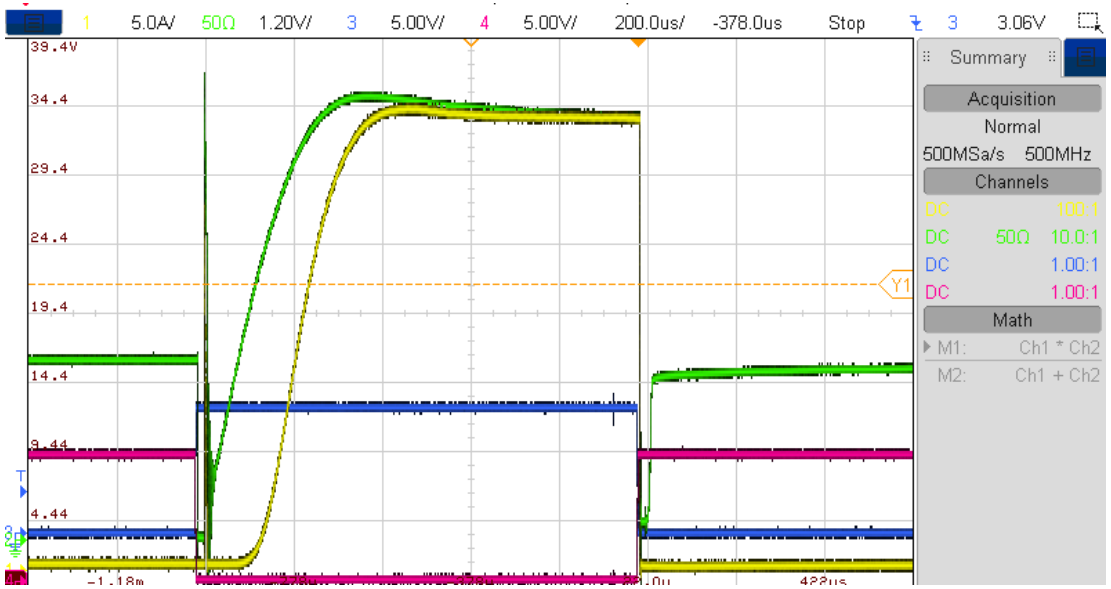
W08_C19

Conceptual design of experiment

Sweep test for very short pulsed PCmsec test







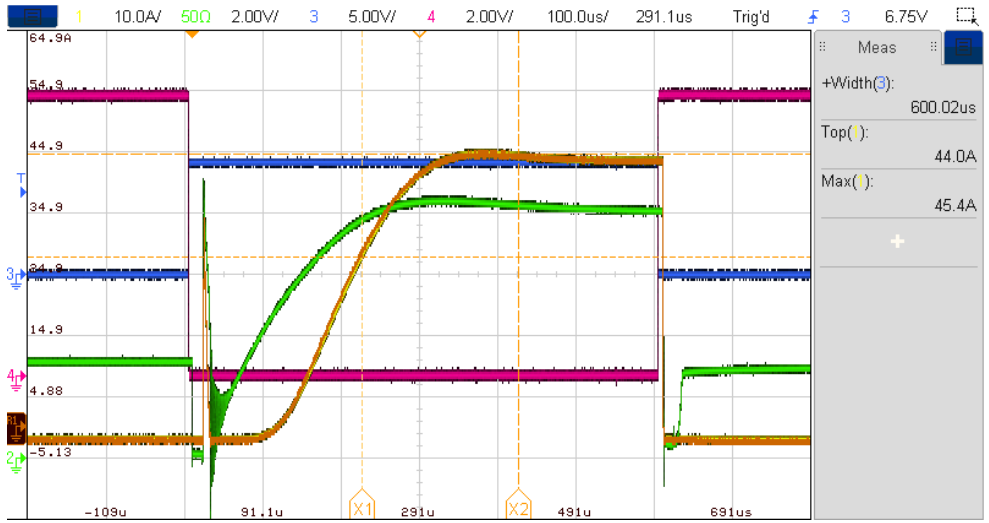
Load Current
Voltage across DUT
Heating Curve
Cooling Curve

- *Parameters : Load Current = 45 A (Coolant Temperature = 25 °C -28°C (Glycol + water))*
- *PC_{msec} parameters : t_{on} = 600µs and $t_{cooling/off}$ = 319.40 ms*

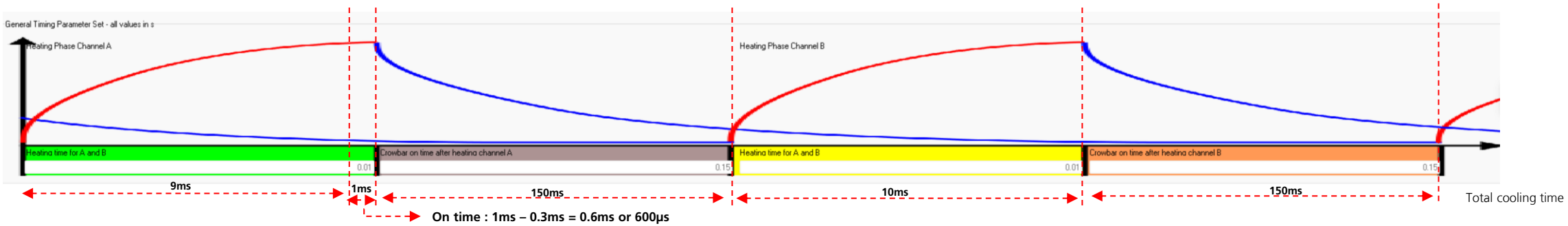
Pcmsec

45A, ~600k cycles

Current Pulse for W08



- ***Load Current***
- ***Voltage across DUT***
- ***Heating Curve***
- ***Cooling Curve***



- *Parameters : Load Current = 45 A (Coolant Temperature = 25 °C -28°C) (Glycol + water)*
- *PC_{msec} parameters : t_{on} = 600 µs and $t_{cooling/off}$ = 319.4 ms (150ms+150ms+10ms+0.4ms)*