CIPS 2026
14th International Conference on Integrated Power Electronics Systems

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Test & Reliability

Rijuta Bagchi

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

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[3)] Univ. Grenoble Alpes, CEA, Leti, France

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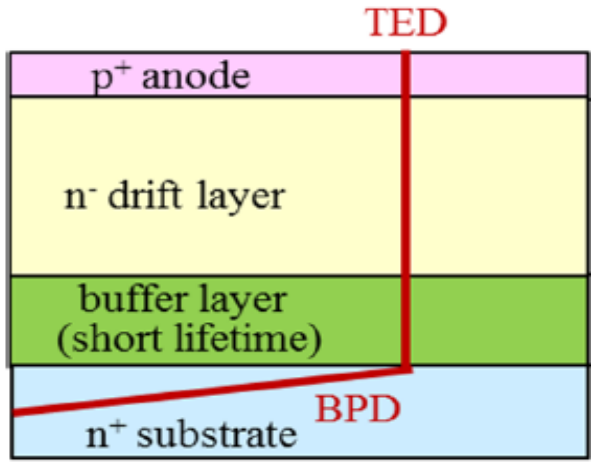
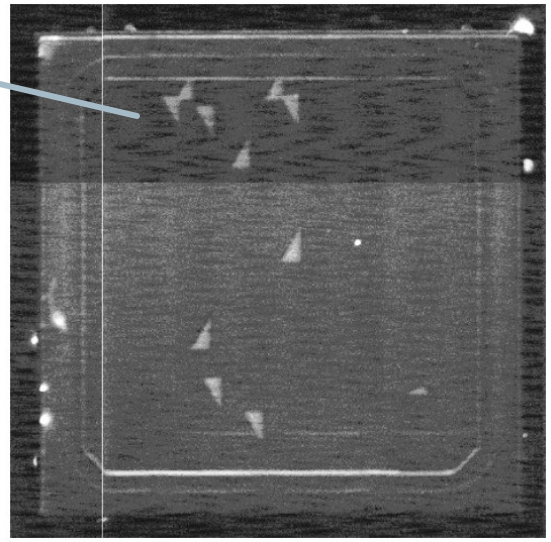
Introduction

Bipolar Degradation



Source [I]

Triangular SSFs



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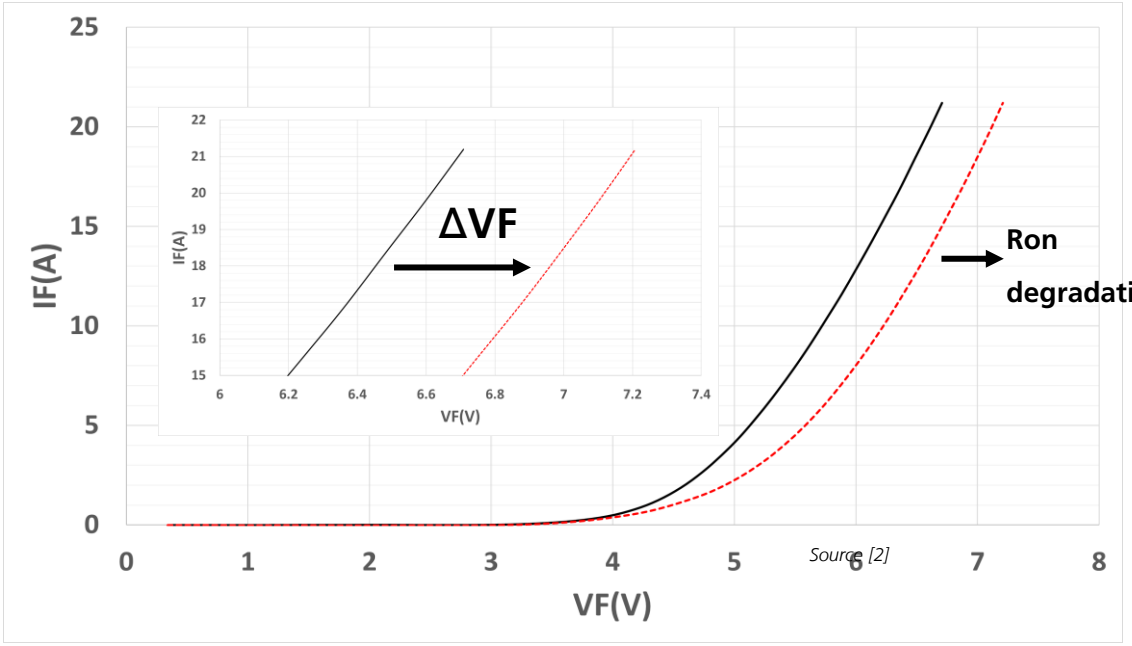

Source [2]

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

Source [III]

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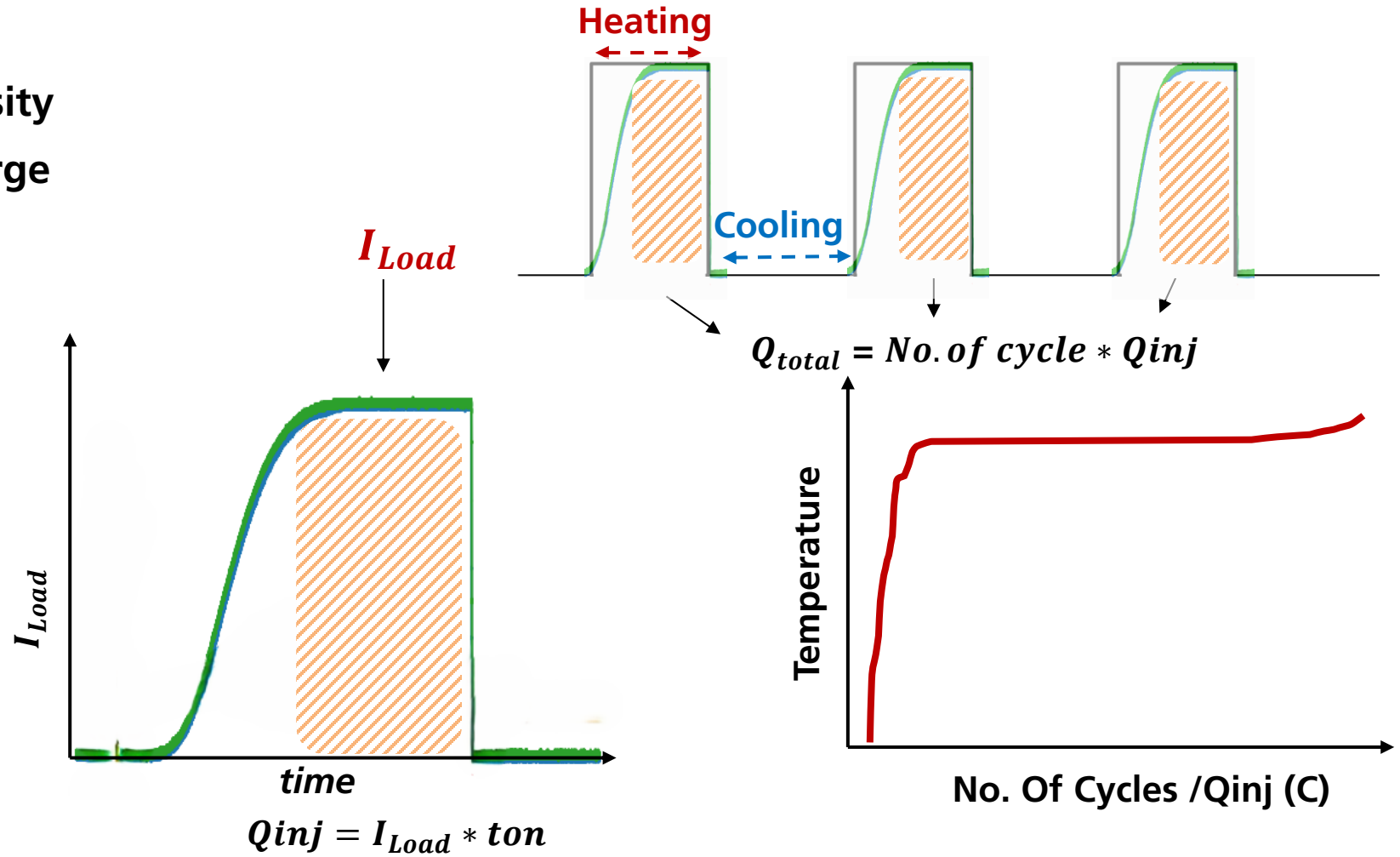
Targets of this study

Impact of Temperature, Current density and Injected Charge

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



Source [III]

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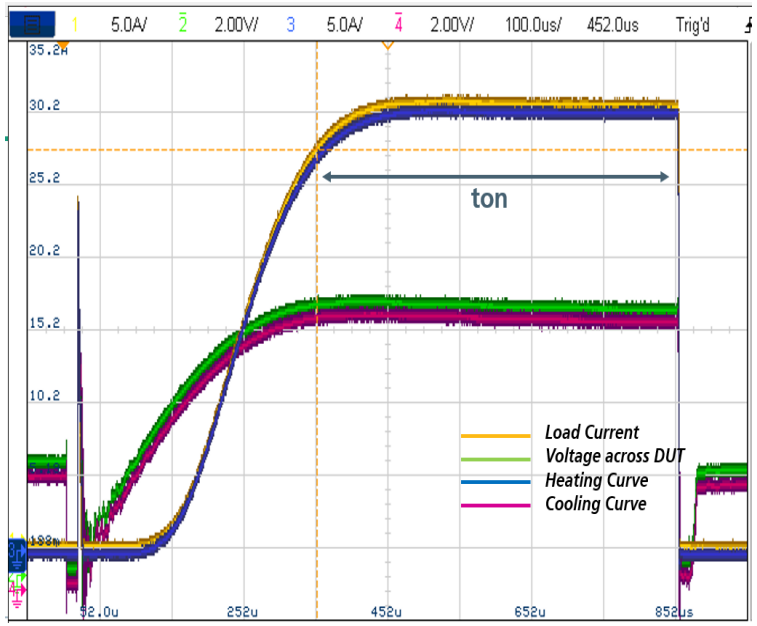
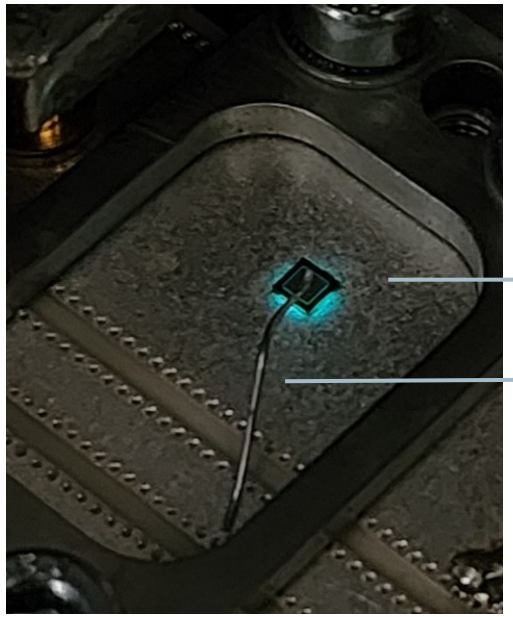
Test Setup

Original Setup

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



Pulse Shape - PCmsec



DUT mount with direct cooling

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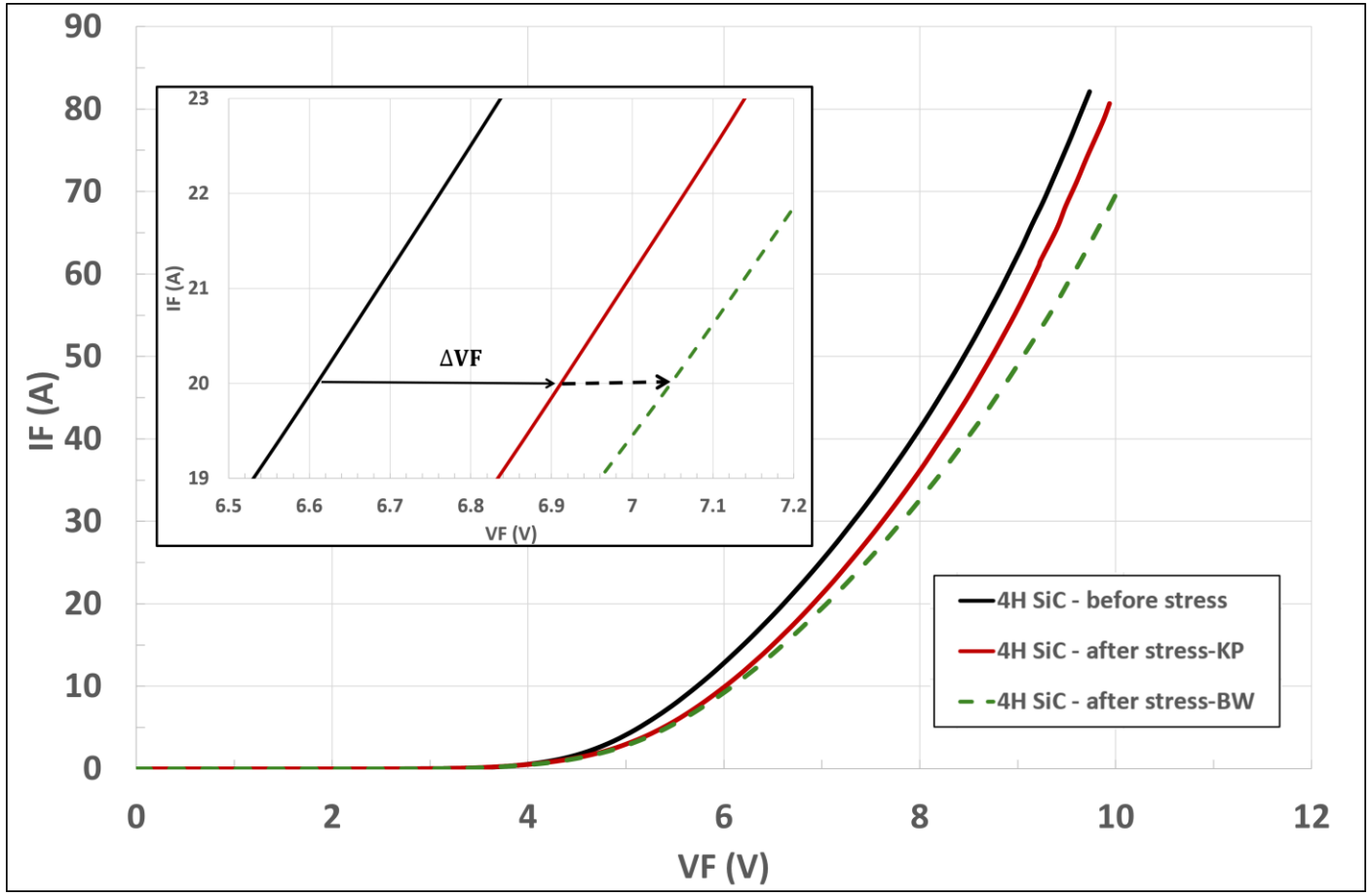
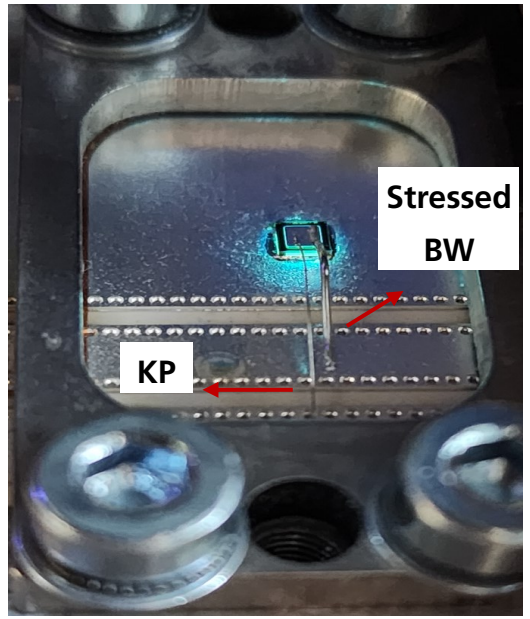
Improved Setup

Kelvin-Probe implementation

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





Source [III]

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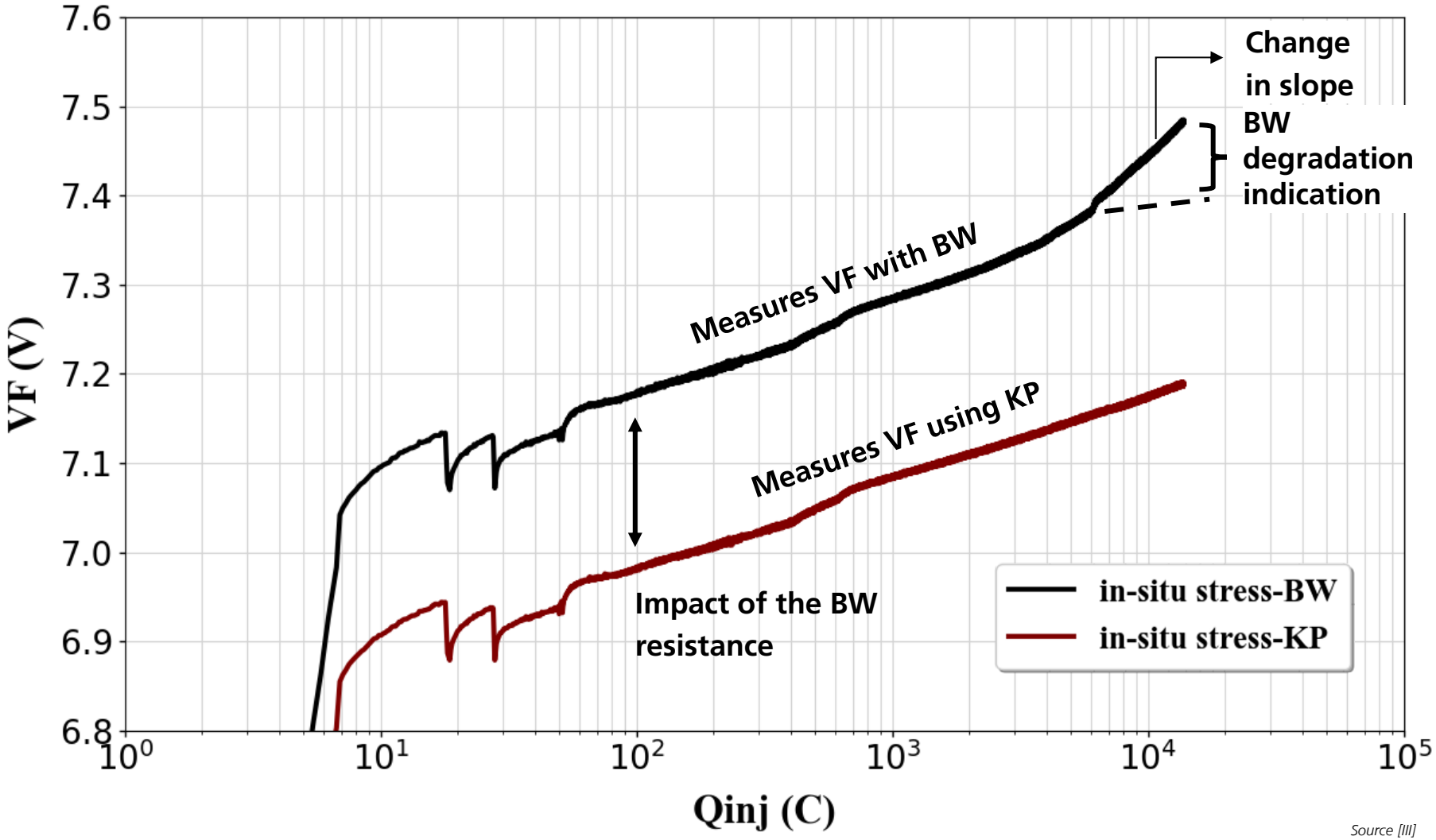
Characteristic features of the measurement curves

Impact of Bond-Wire Resistance

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



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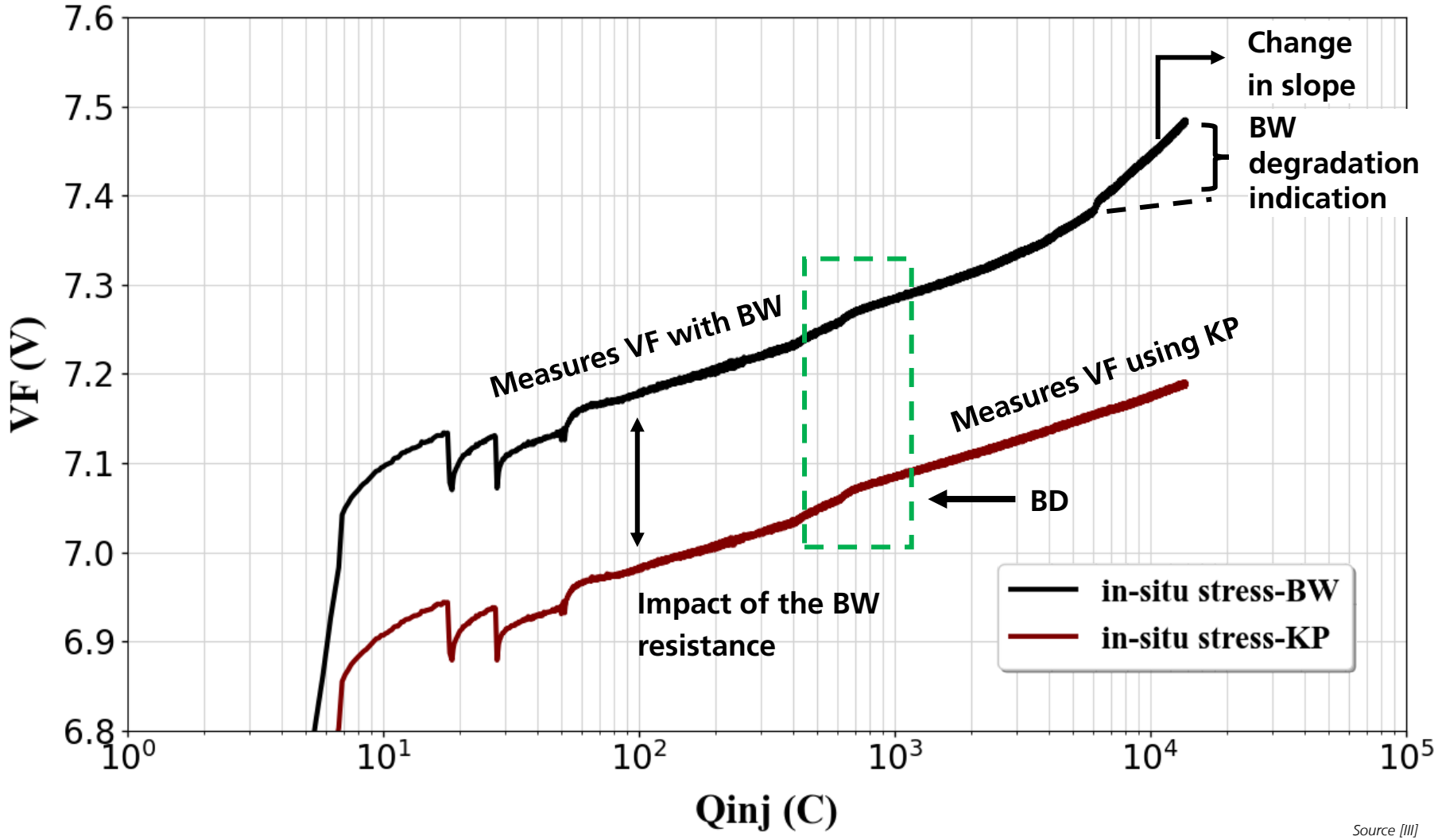
Characteristic features of the measurement curves

Signature of Bipolar Degradation

- **Skewness observed in curve**



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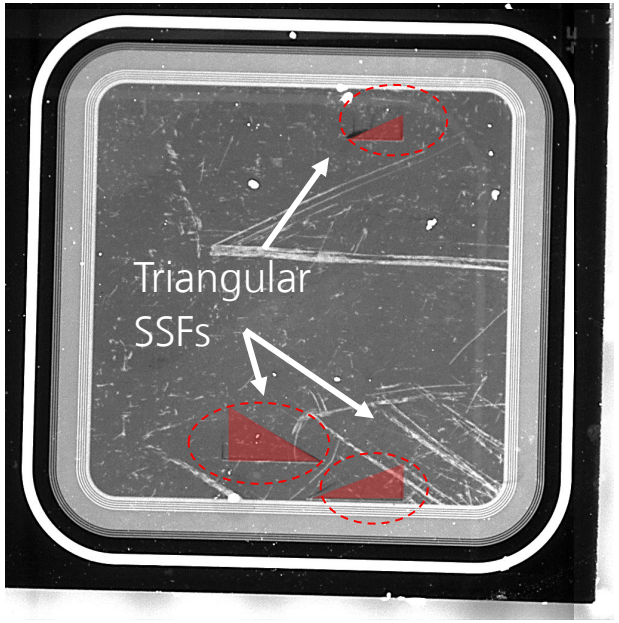
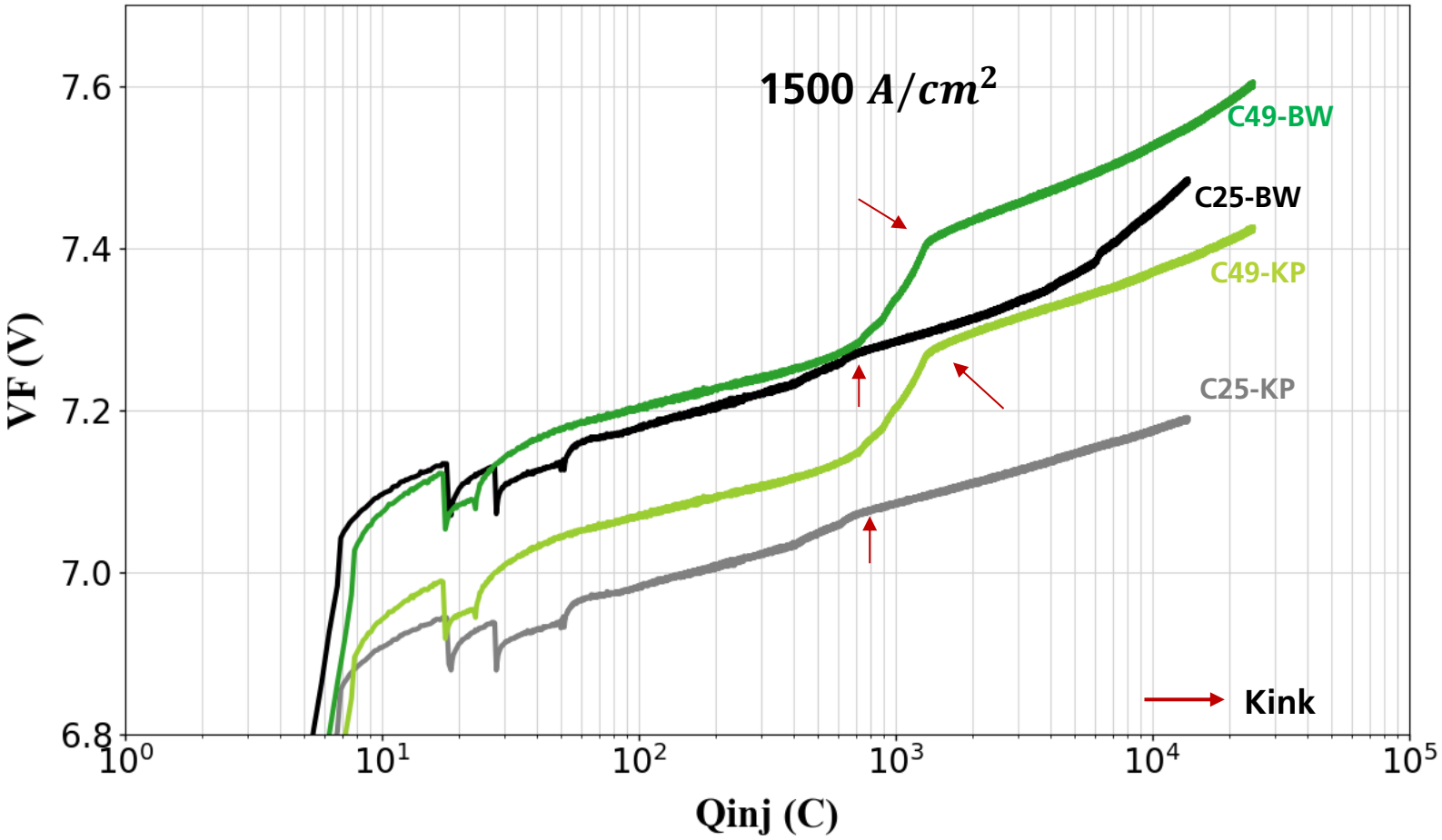
Characteristic features of the measurement curves

Signature of Bipolar Degradation

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



DUT C25 After stress- UV-PL image



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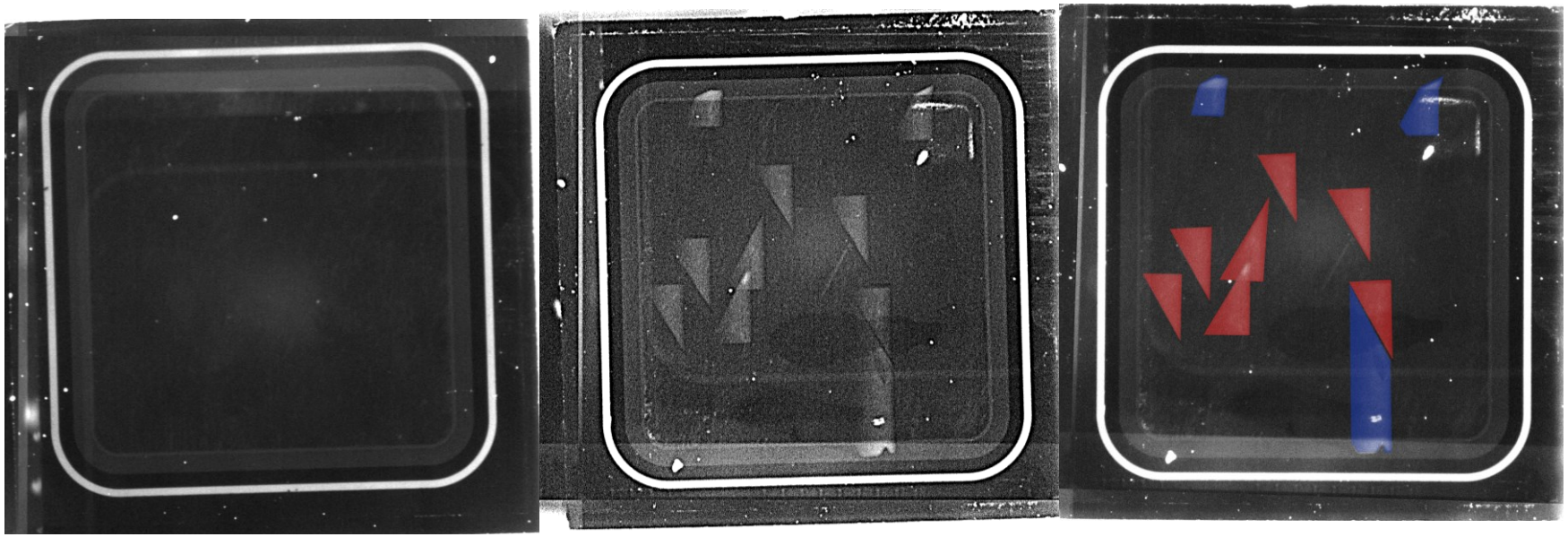
UV-Photoluminiscence (UV-PL) Analyses

Stacking Fault (SF) detection



(1)
no SFs

(2)
SFs detected

(3)
SFs detection by image processing

* UV-PL images (BP 420 nm) at current density 2250 A/cm^2 (45 A)

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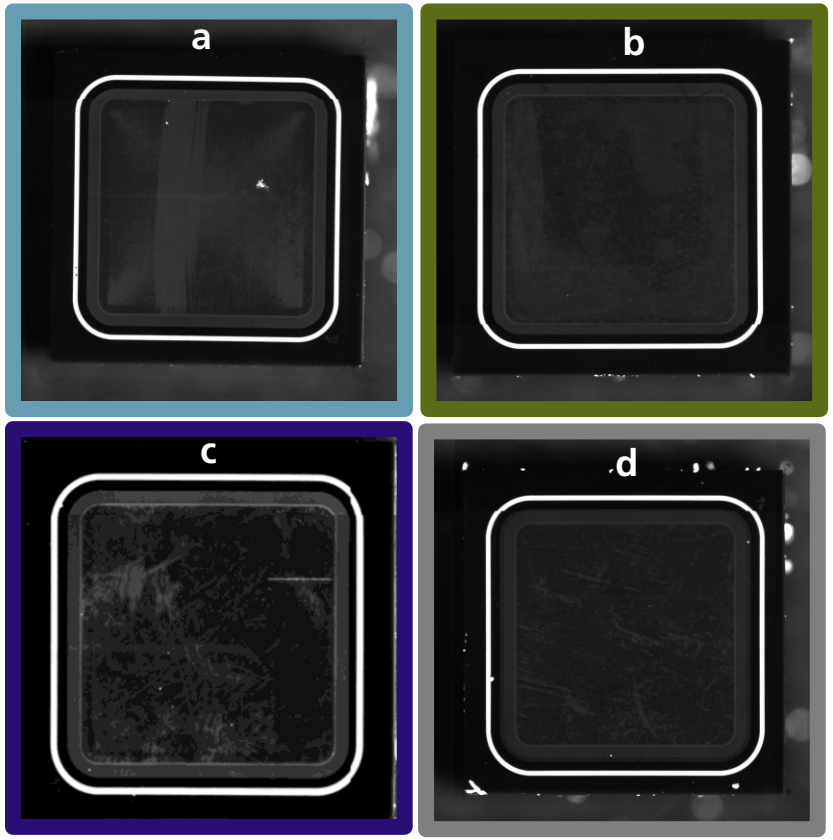
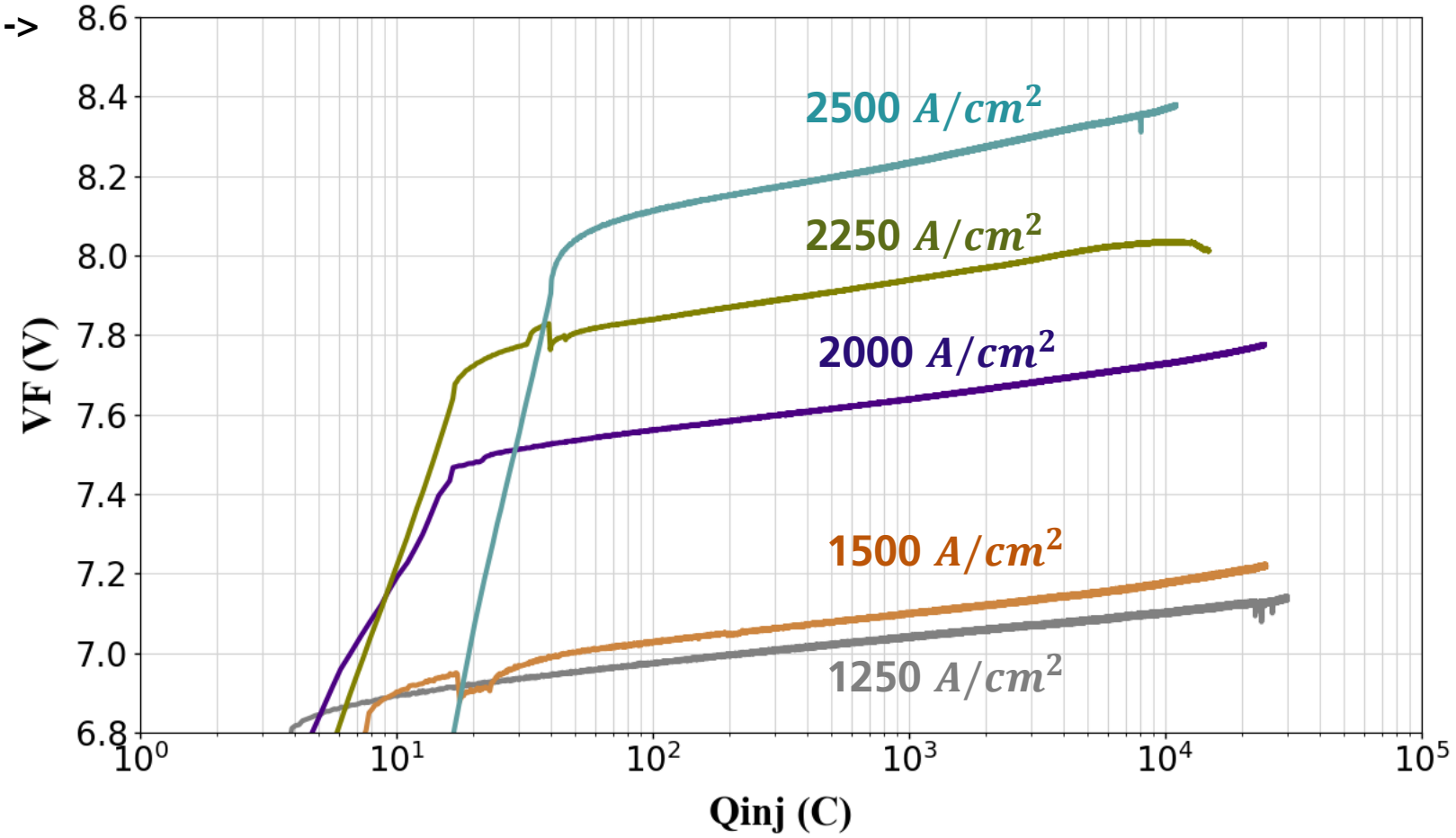
Impact of Current Density

VF-Kink as signature of Bipolar Degradation

- **VF-Characteristics that exhibit no kinks -> show no SFs**





** a) E15 (2500 A/cm²), b) E04 (2250 A/cm²), c) E08 (2000 A/cm²), d) C02 (1250 A/cm²)*

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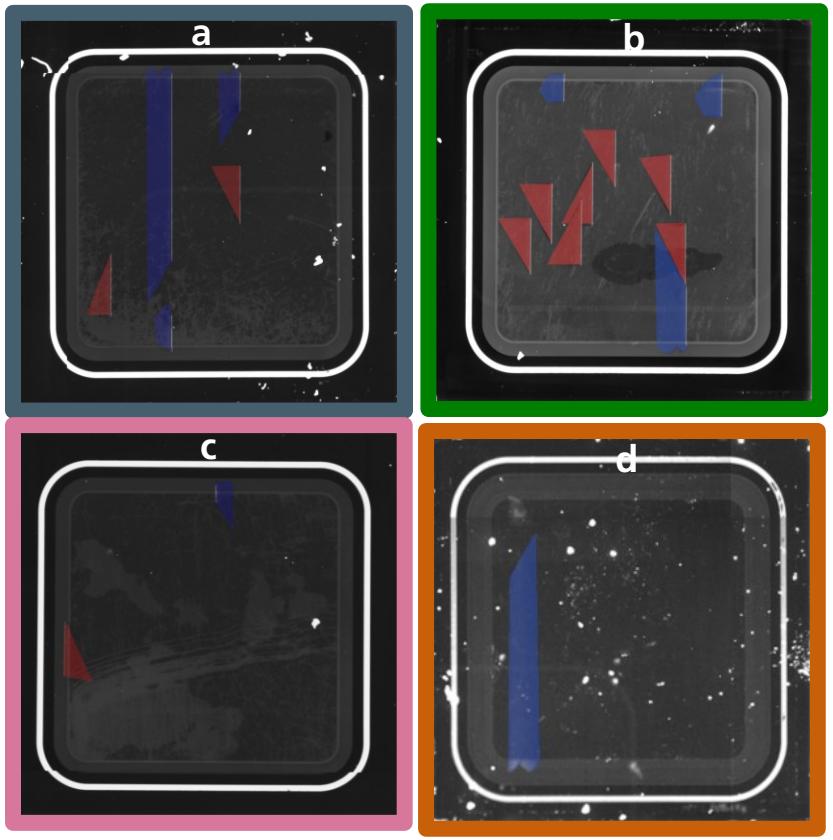
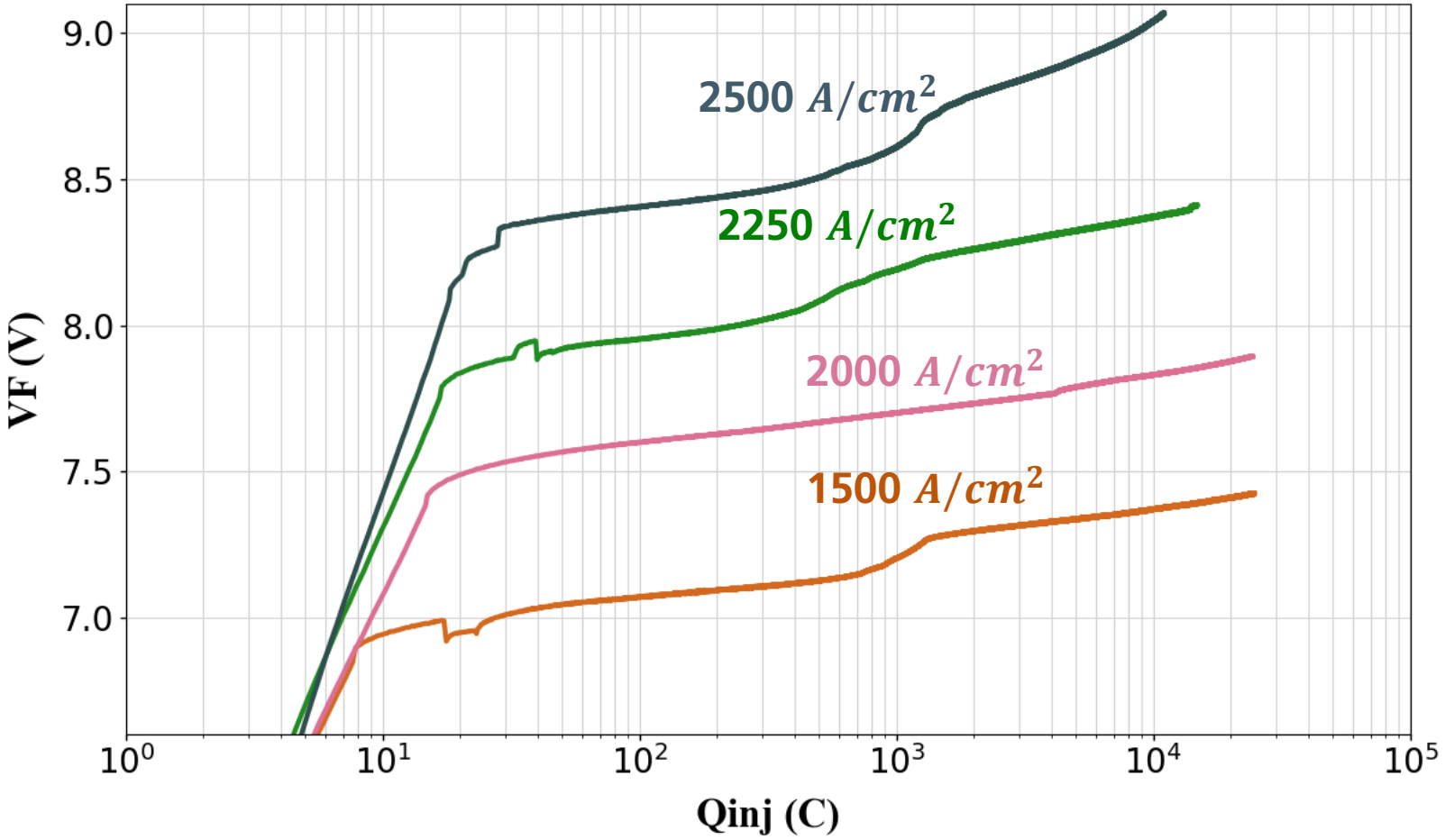
Impact of Current Density

Kink- Signature of Bipolar Degradation

- **VF-Characteristics that exhibit kinks -> show SFs**





** a) E13 (2500 A/cm²), b) E03 (2250 A/cm²), c) E12 (2000 A/cm²), d) C25 (1250 A/cm²)*

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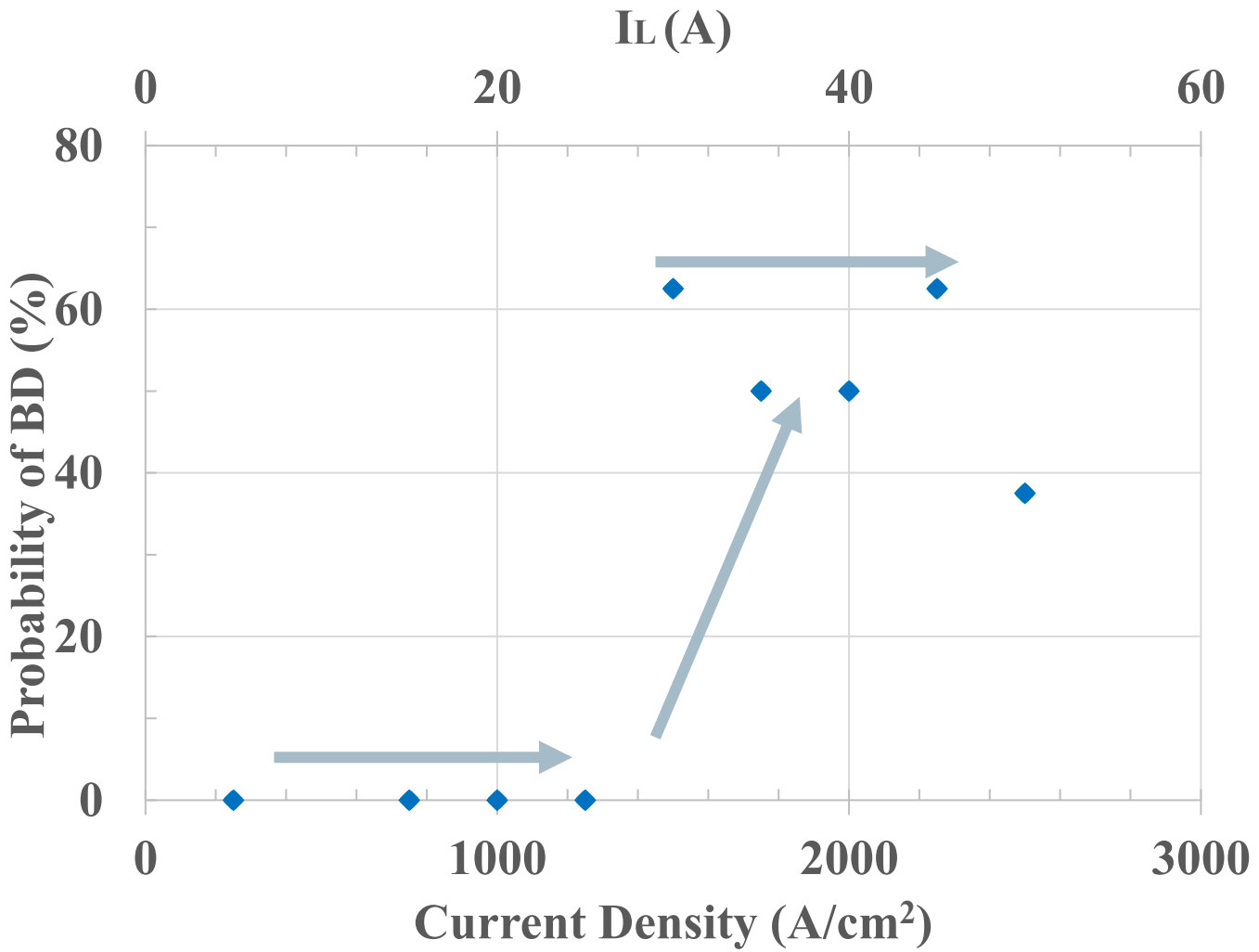
Impact of Current Density

Probability of occurence of Bipolar Degradation (BD)



- Percentage of devices exhibiting BD among all PIN diodes stressed at a given current density.
- At low current densities, probability remains zero.
- **BD observed above 1000 A/cm²~1500 A/cm²**

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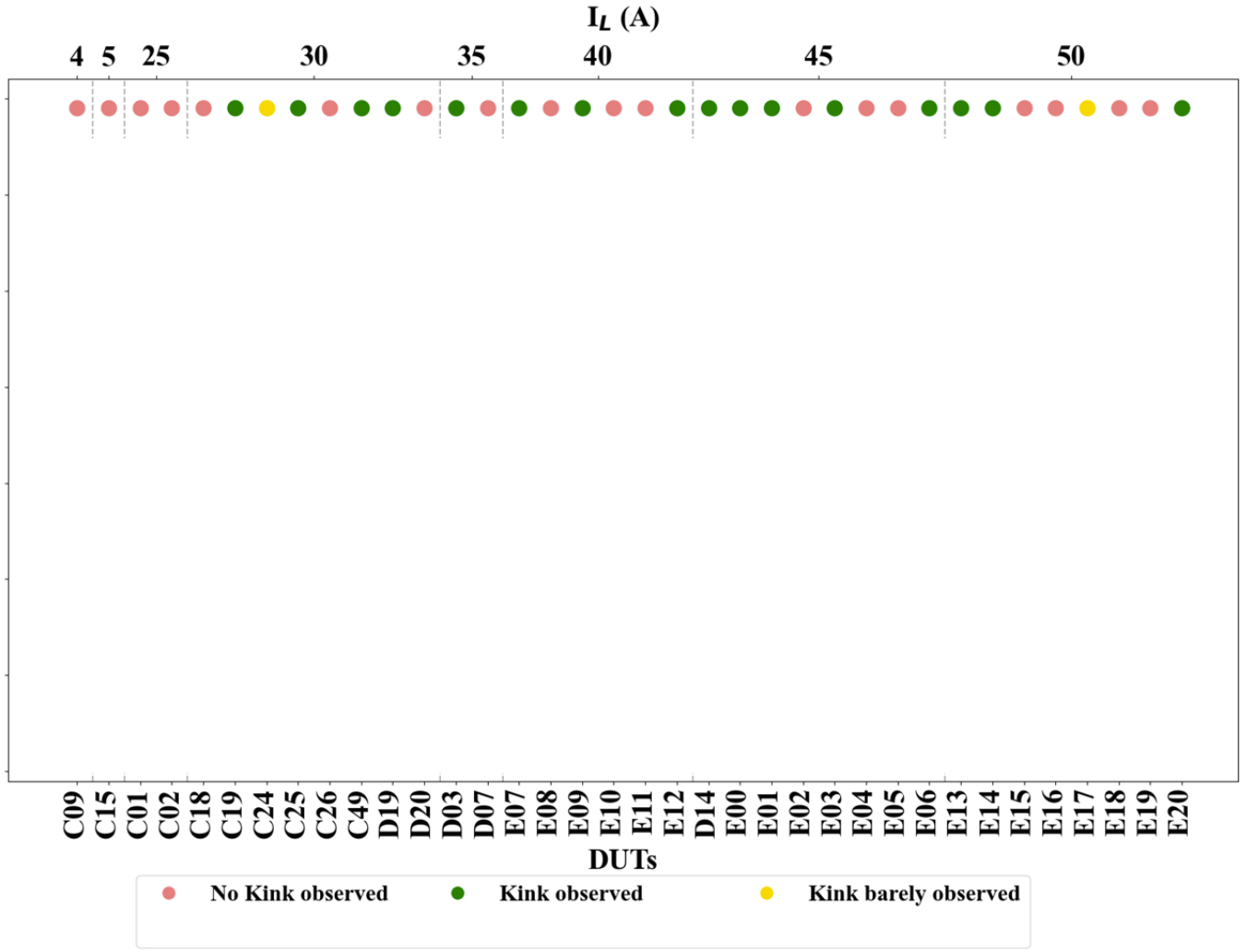
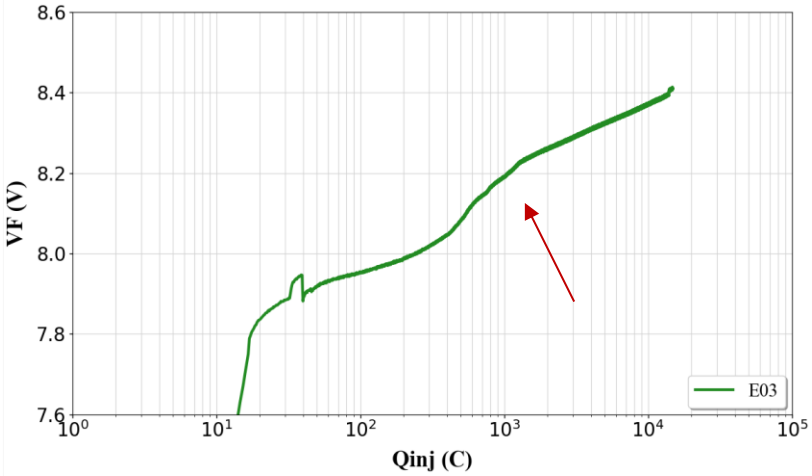
Impact of Current Density

VF-Kink as signature of Bipolar Degradation



Kink observation



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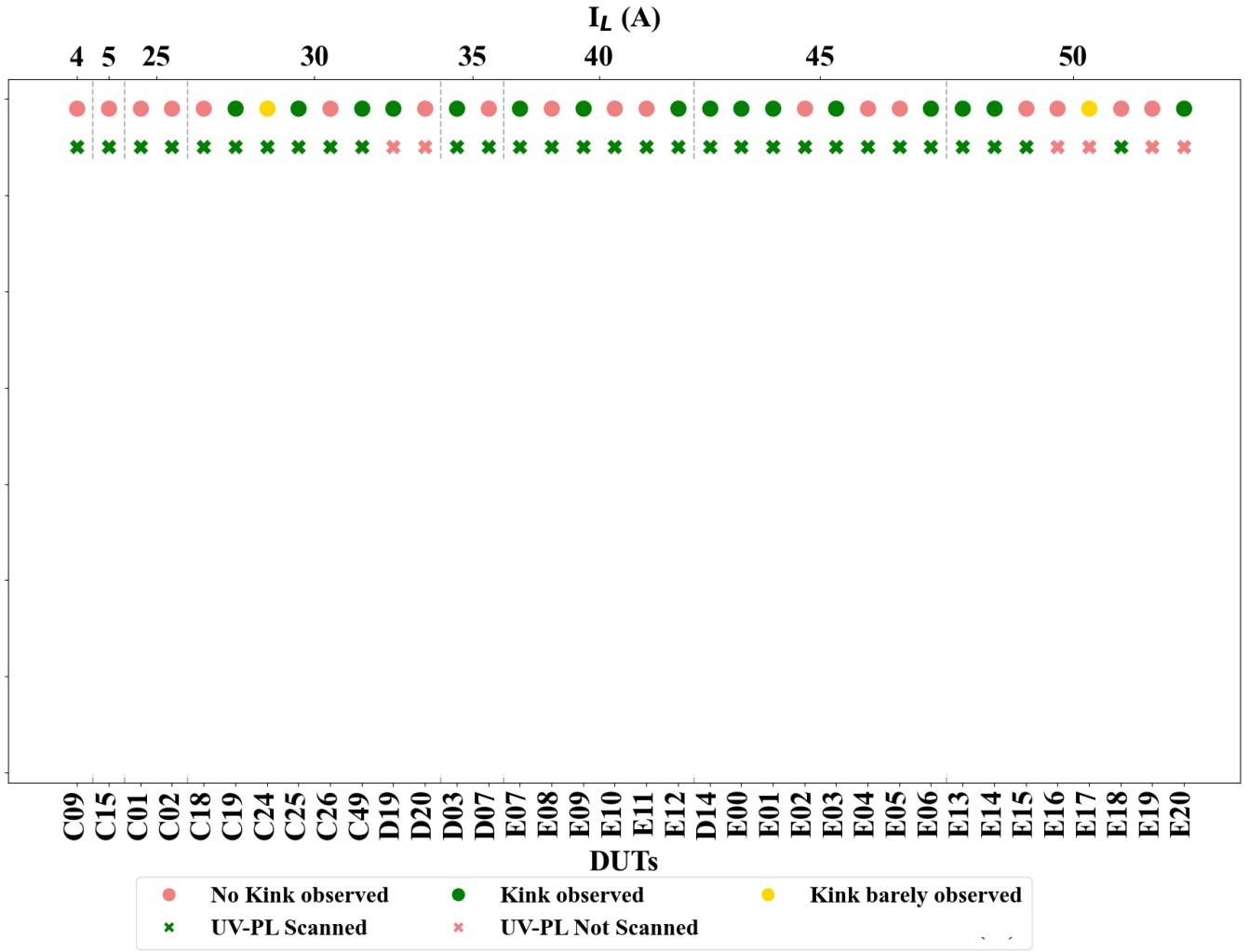
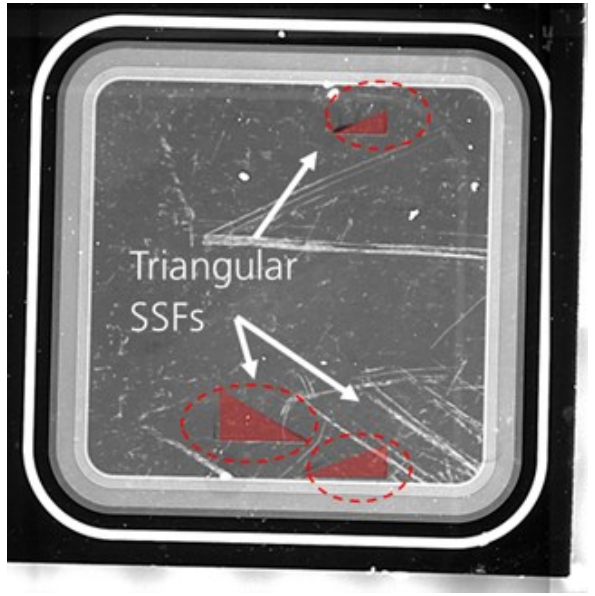
Impact of Current Density

UV-Photoluminescence validation for VF-kink



UV-PL scanned status



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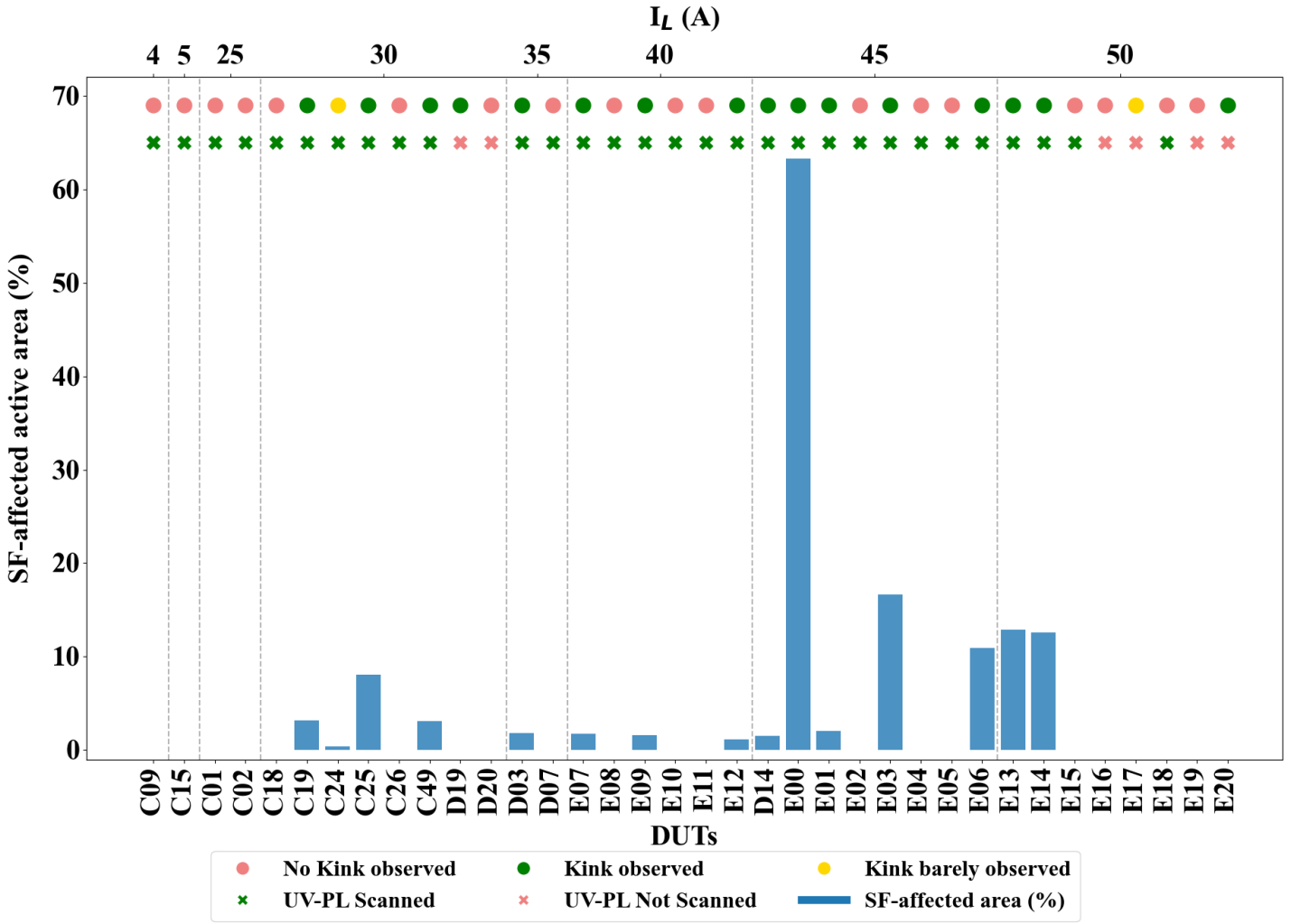
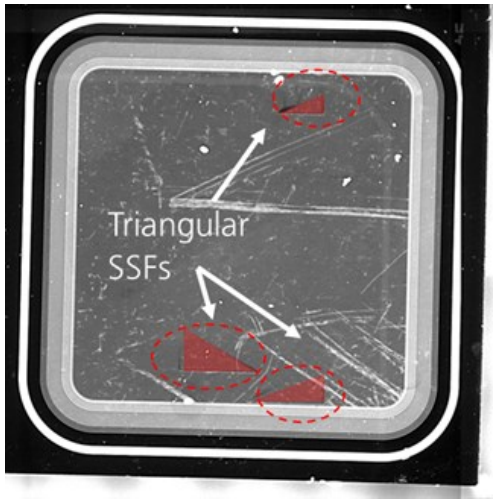
Impact of Current Density

UV-PL mapping of Stacking Fault-affected active area (%)





- **Zero degradation at ≤ 1250 A/cm², modest SF coverage (0.4–8%) at 1500-2000 A/cm²**

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Impact of Current Density

Stacking Fault degraded Active area Summary

Current Density (A/cm^2)	No. of DUTs UV-PL scanned	Mean SF-affected area (%)	Notes
≤ 1250	10	0	No degradation
1500	6	2.45	Low, scattered
1750	2	0.92	Minimal
2000	6	0.75	Minimal
2250	8	11.80	High
2500	4	6.37	Moderate

- **The severity of degradation is higher at elevated current densities (2250-2500 A/cm^2).**
  Demonstrates a clear trend of higher degradation at elevated current densities.

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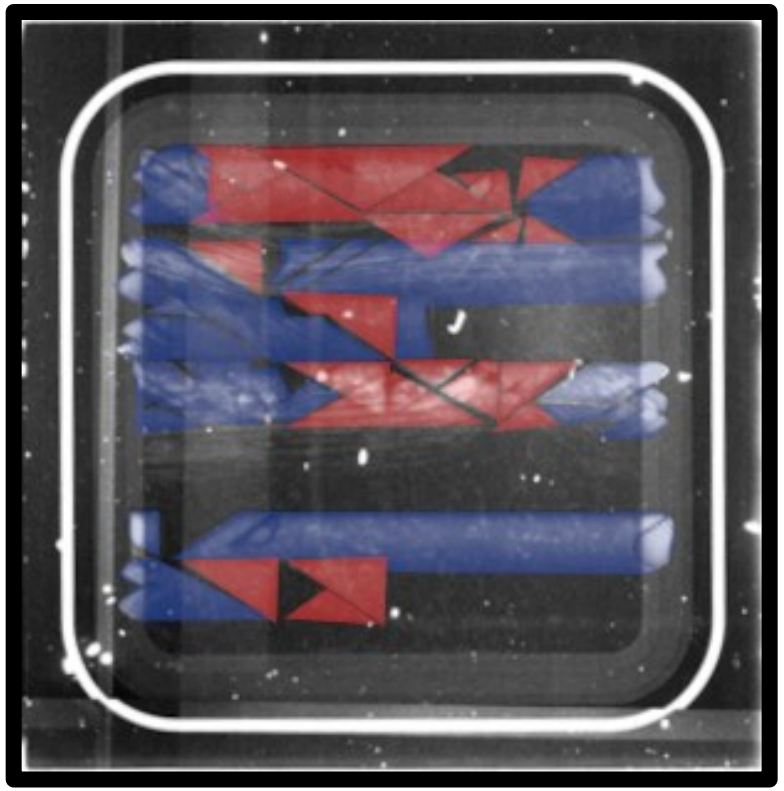
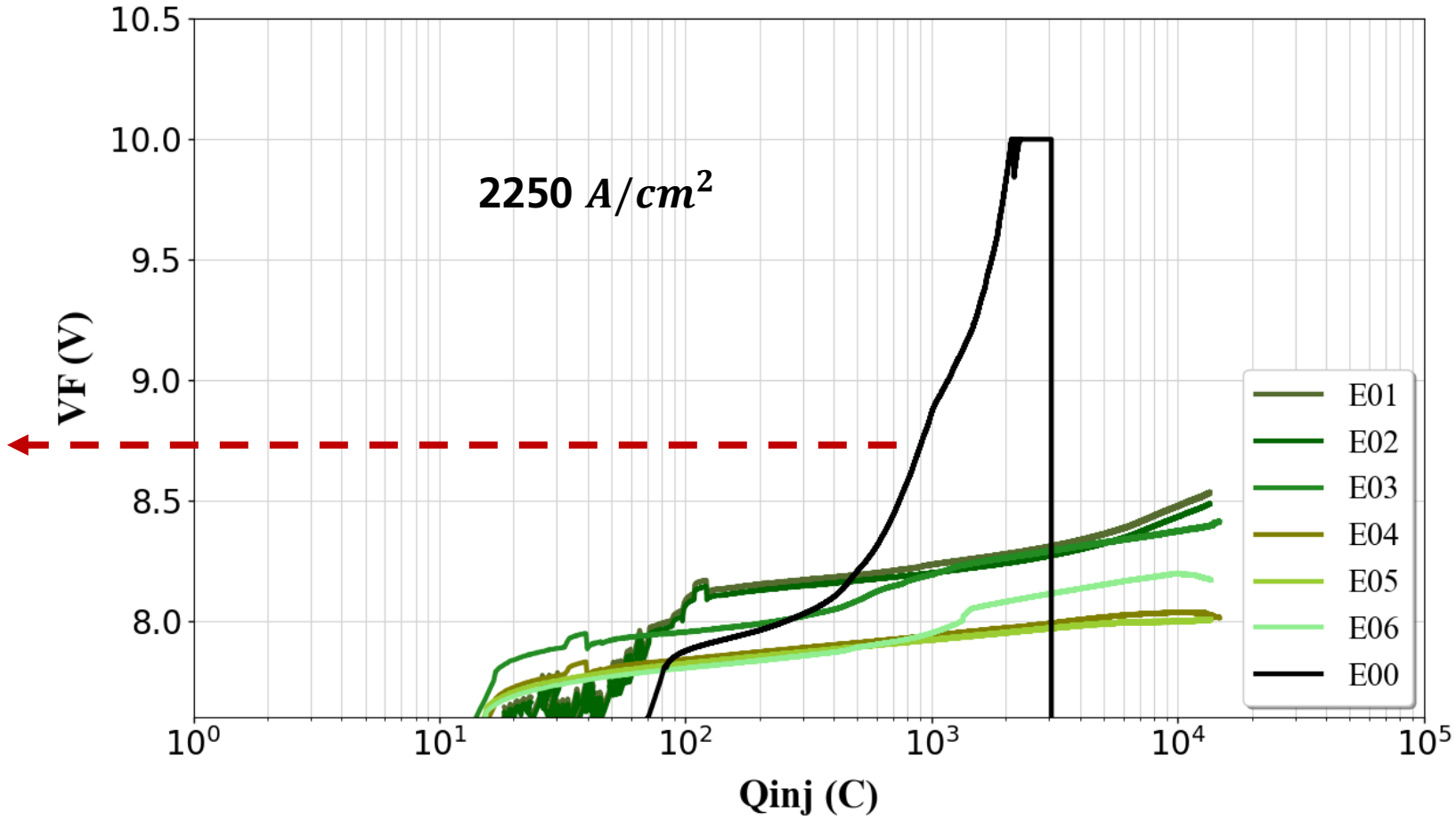
Impact of Current Density

Kink- Signature of Bipolar Degradation

- **SF Monster: 60% active area affected!**





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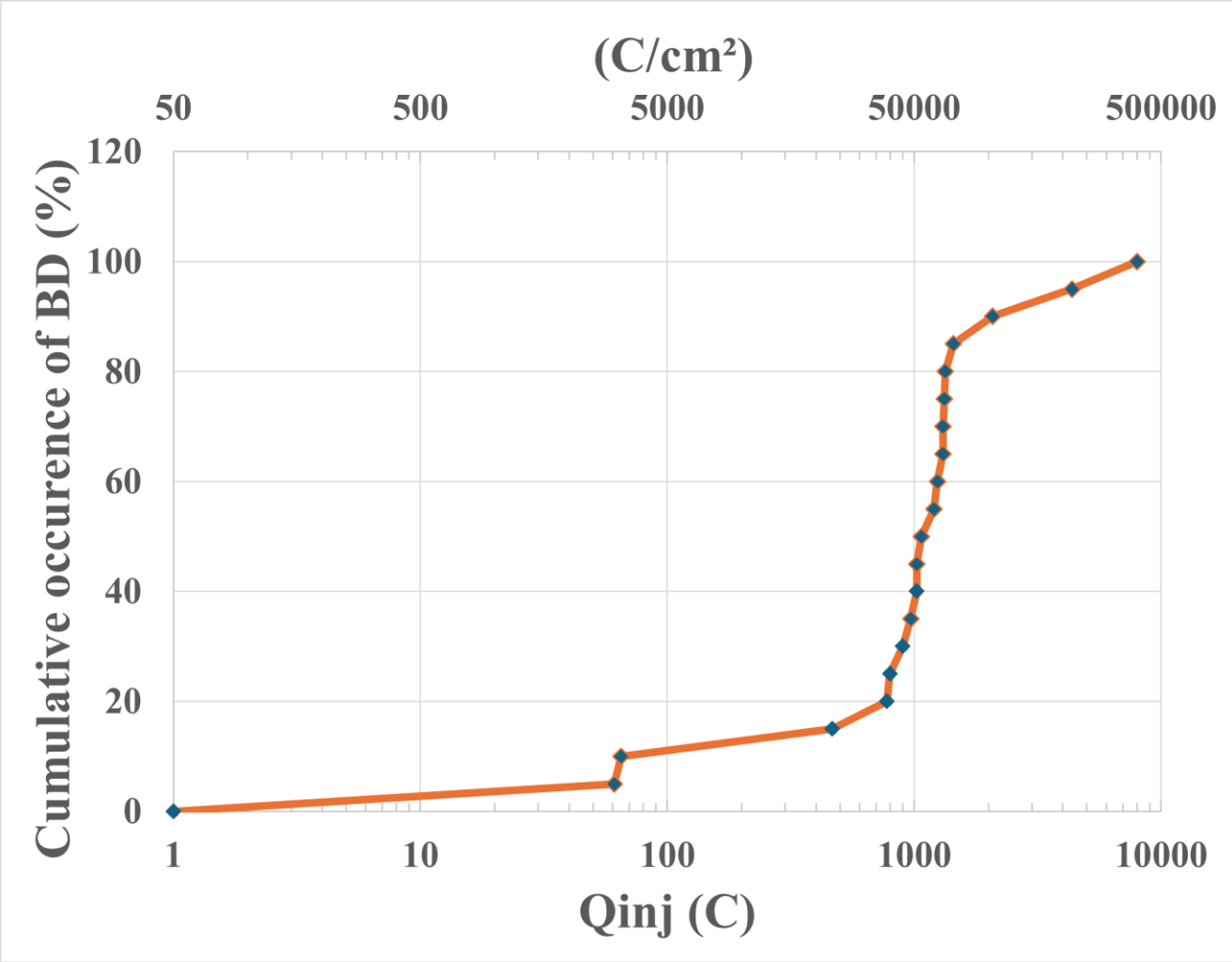
Impact of Injected Charge



- Percentage calculated over the population of devices exhibiting a kink, irrespective of the stress current density.
- **When Bipolar Degradation occurs, it triggers around 50 kC/cm²**

Source [III]

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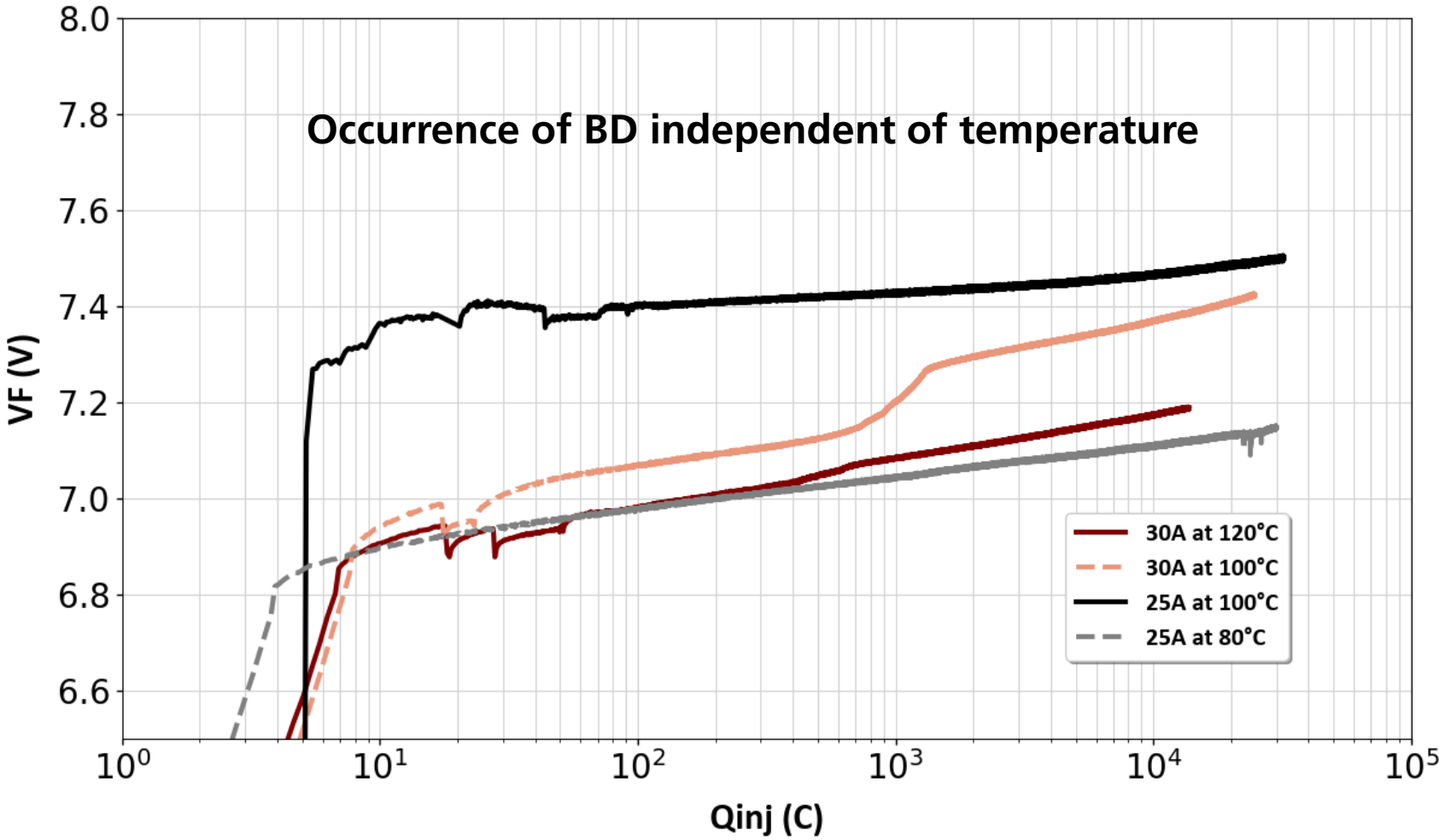
Impact of Temperature

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.**

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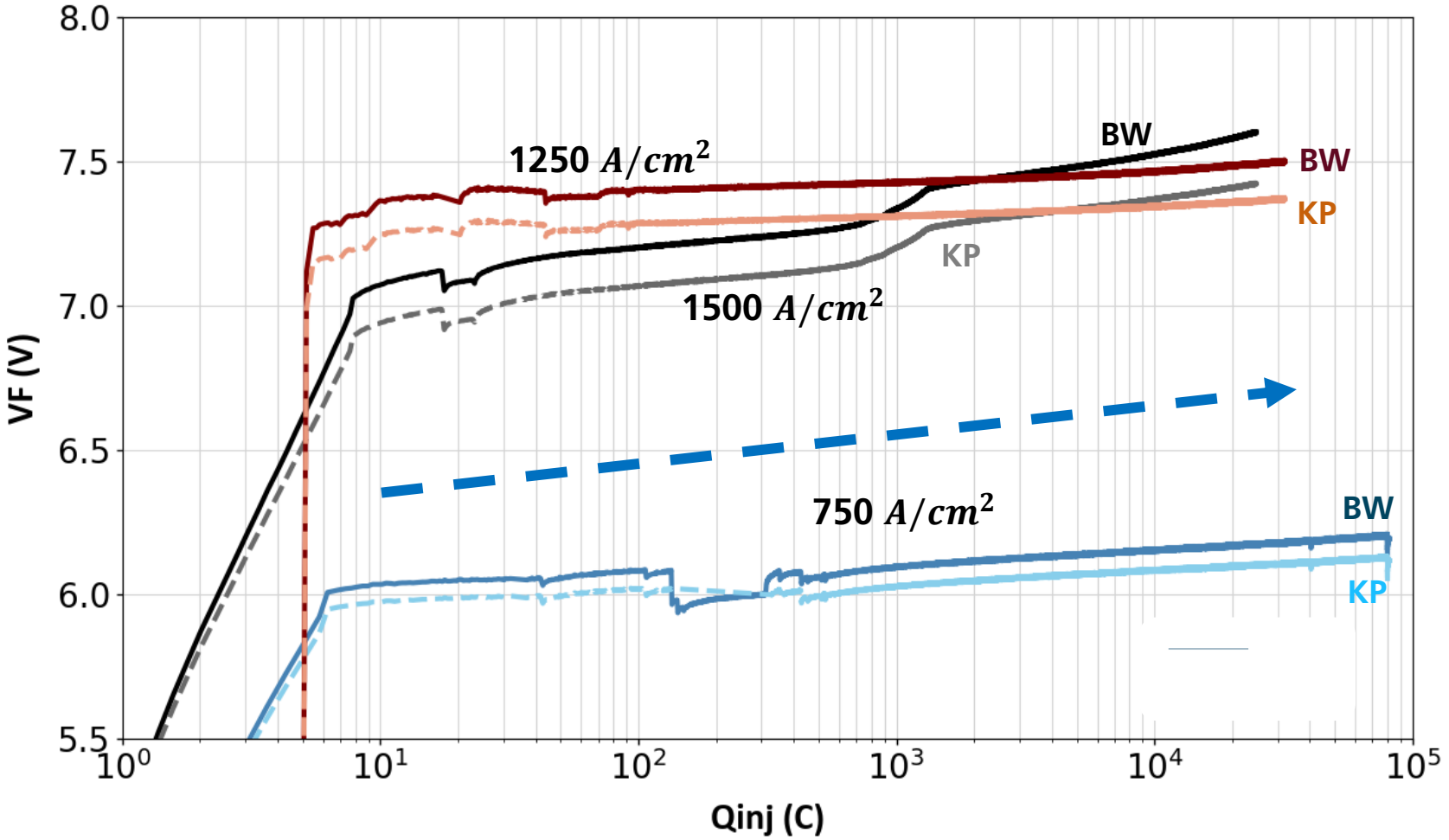
Characteristic features of the measurement curves

Systematic increase in VF

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



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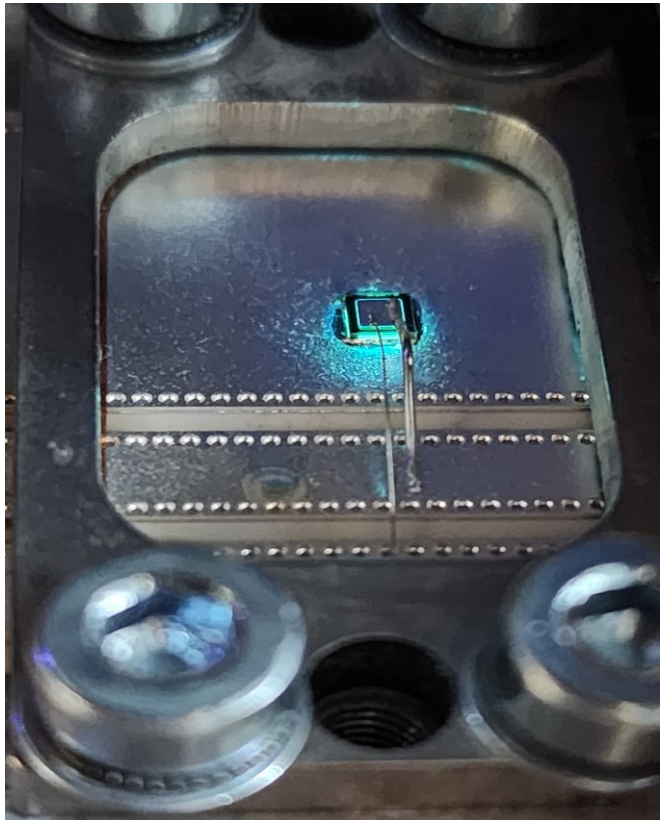
Summary

1. **Statistical evaluation of Bipolar Degradation**
2. **Introduction of In-situ KP measurements (ability to differentiate BD from BW degradation)**
3. **First study of Bipolar Degradation as a function of accumulated injected charge, leading to detection of Bipolar Degradation by electrical signature**
4. **Data suggest threshold regimes in current density (~1500 A/cm^2) and Injected charge density (50kC/cm^2)**
5. **Study of impact of Temperature, Stress current density and Injected charge without parameter interaction.**



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Conclusions

Developed a protocol to detect Bipolar degradation from electrical characteristics

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

Bipolar Degradation triggers at 1000-1500A/cm^2

Temperature is not a first order parameter

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Outlook

Improvement on effective Pulse Width

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



Implement the established method to different material, designs (engineered substrates)

To meet you all with latest findings in the next conference!

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Image and Slide References

[I] 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.

[II] 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.

[III] https://www.iisb.fraunhofer.de/content/dam/iisb2014/en/Documents/events/2025/icscrm_downloads/ICSCRM-2025-IISB_Session_Bagchi_Impact-of-current-density-accumulated-charge-temperature-on-bipolar-degregation-4H-SiC-pin-diodes.pdf

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[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.

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[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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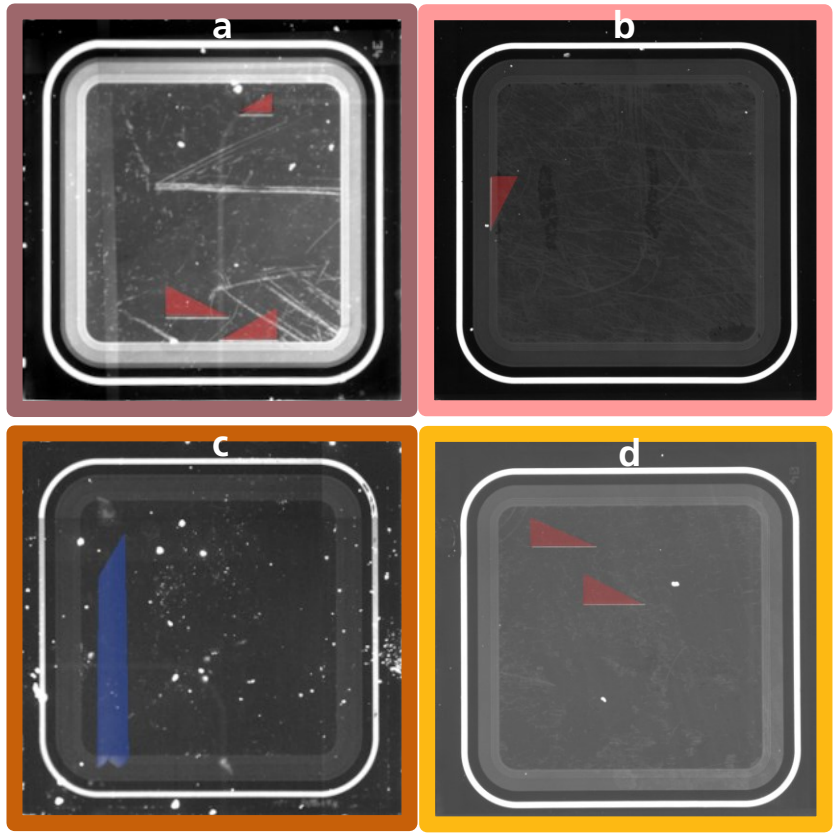
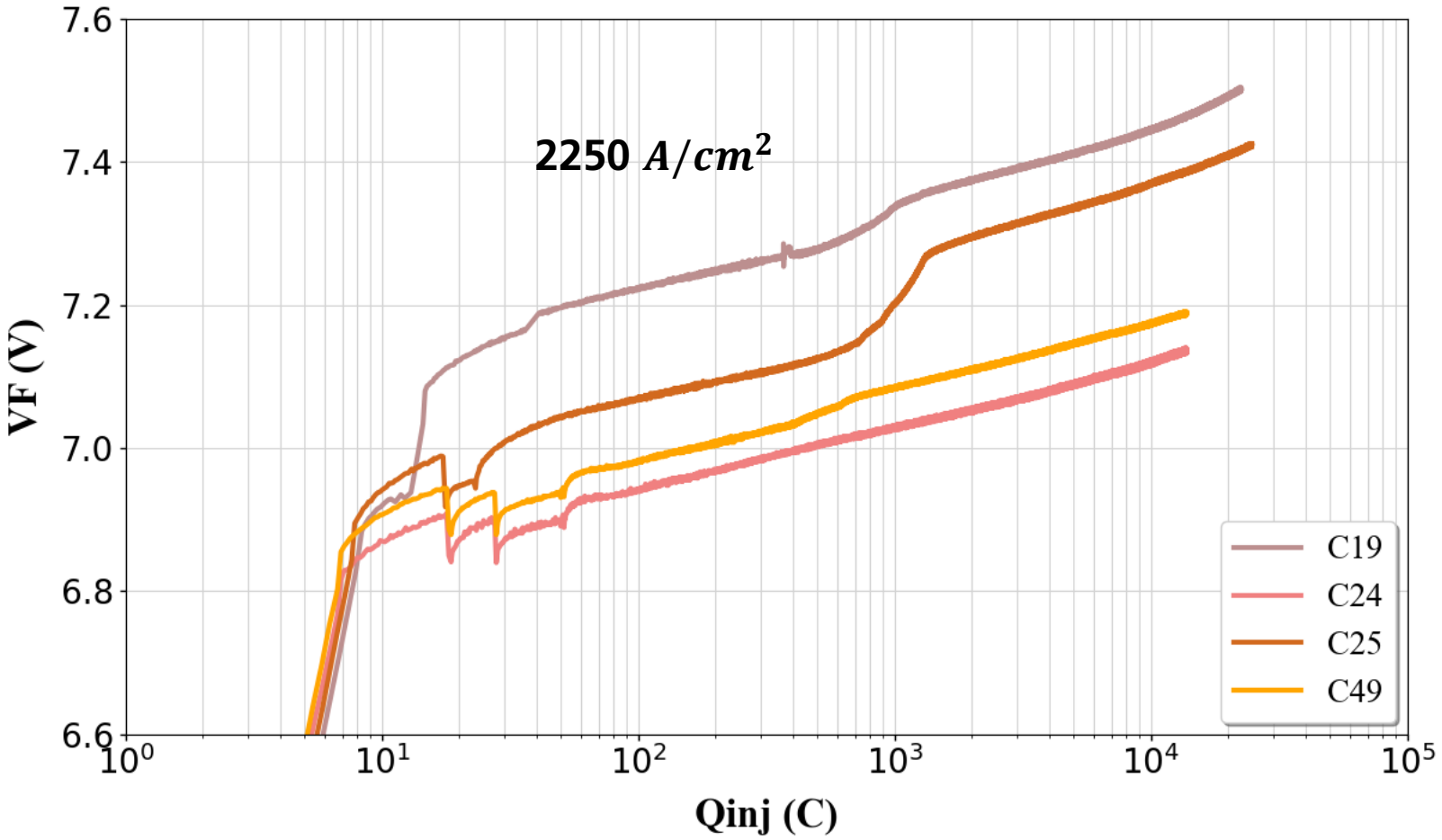
Kink- Signature of Bipolar Degradation

- **Curves that show kinks -> shows SFs**





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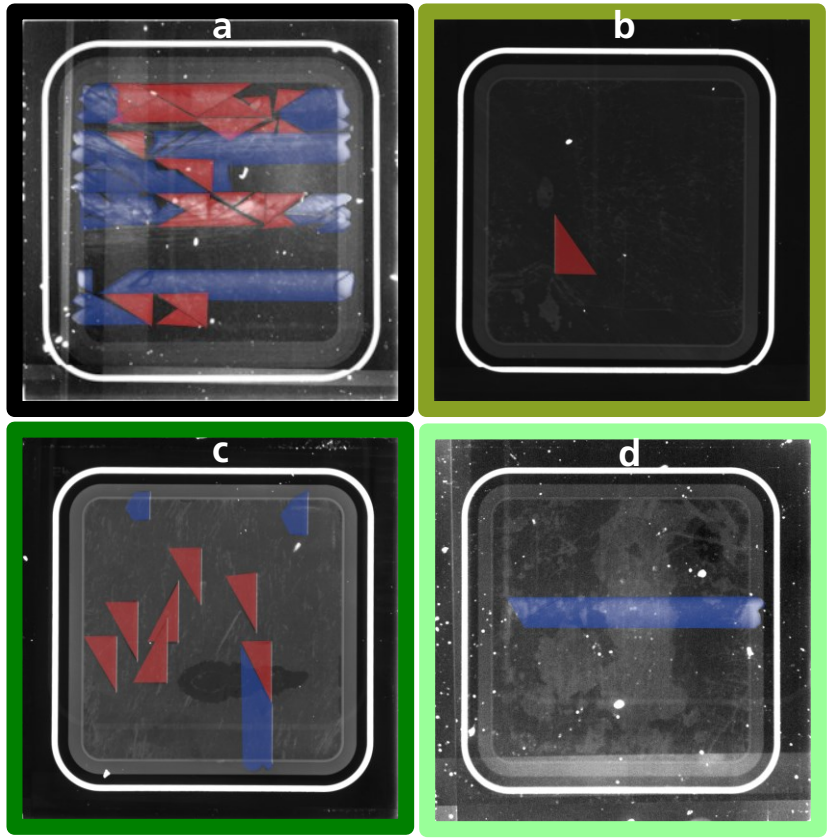
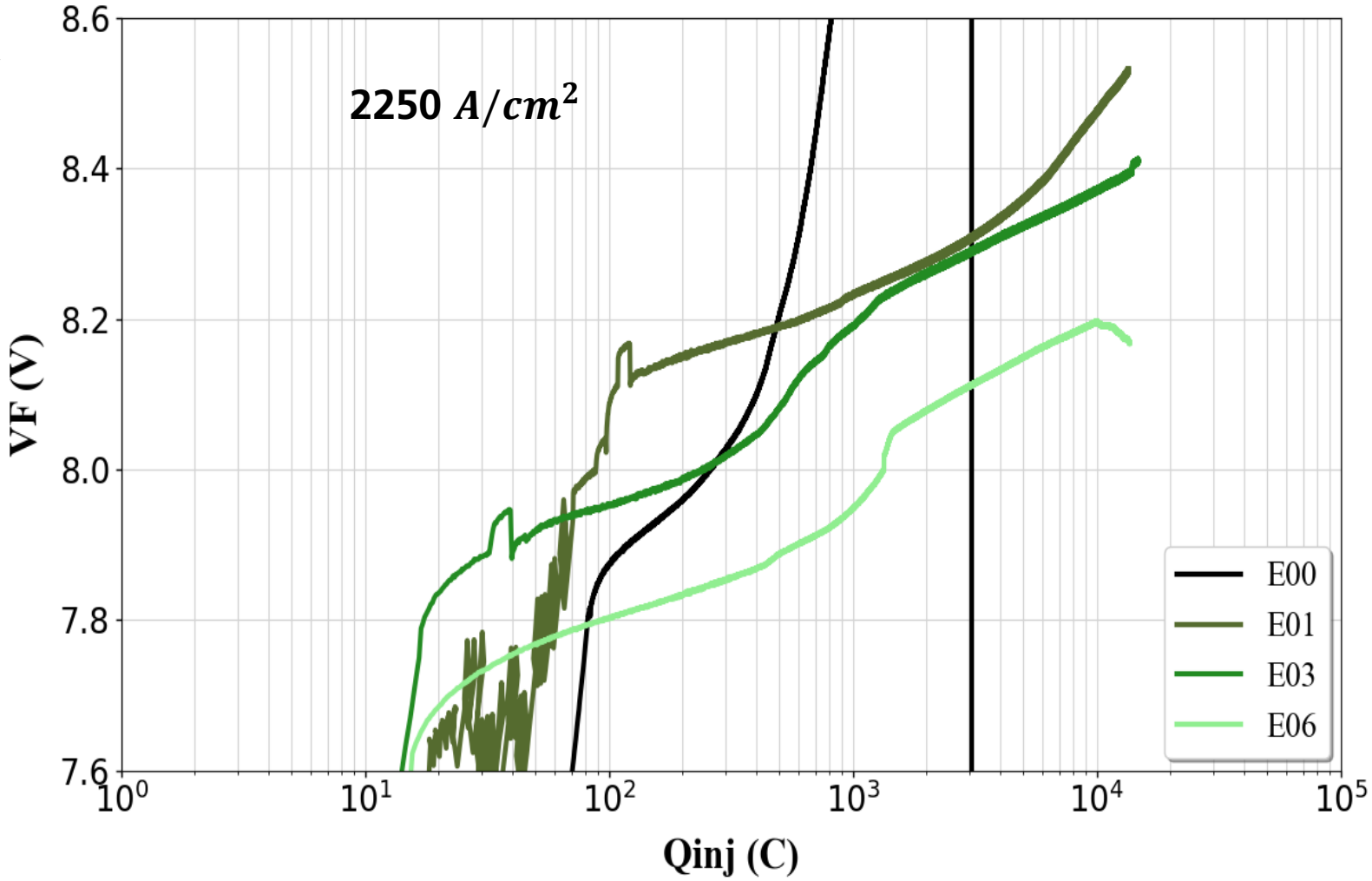
Impact of Current Density

Kink- Signature of Bipolar Degradation

- **Characteristics that exhibit kinks -> show SFs**





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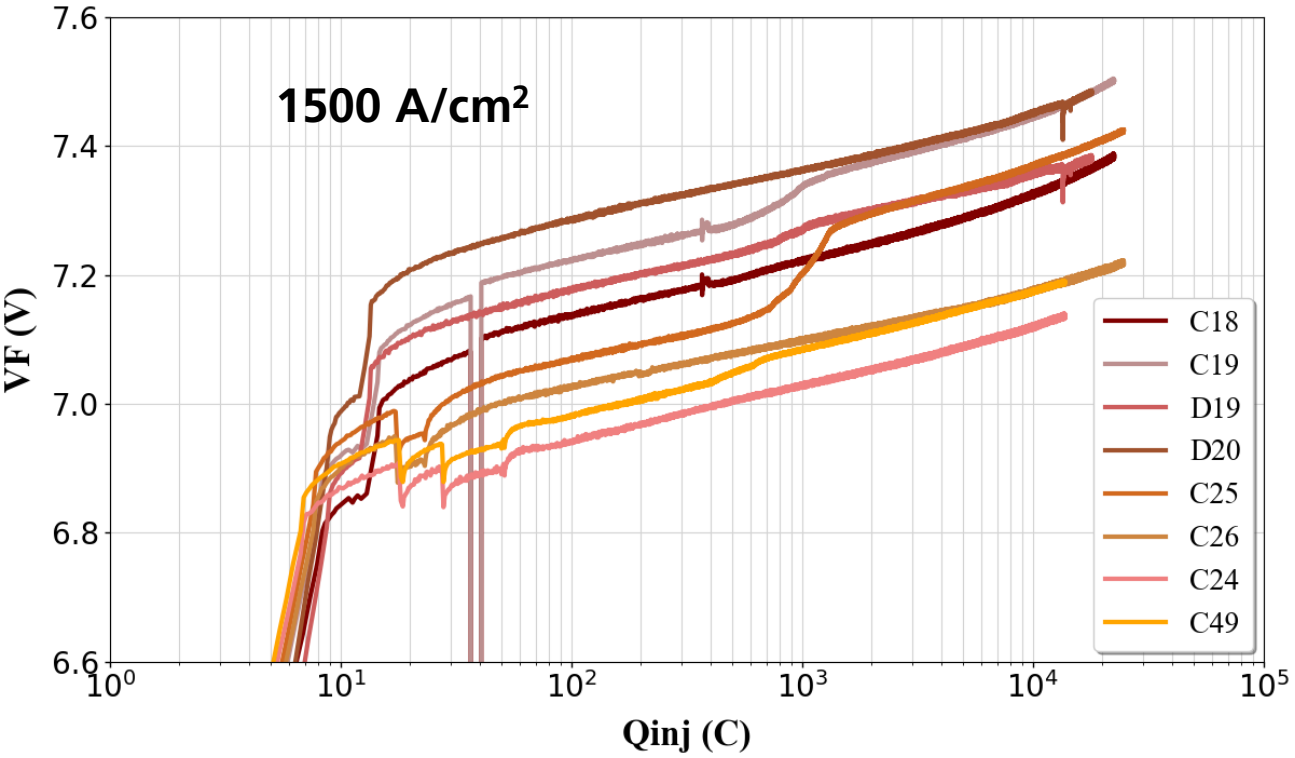
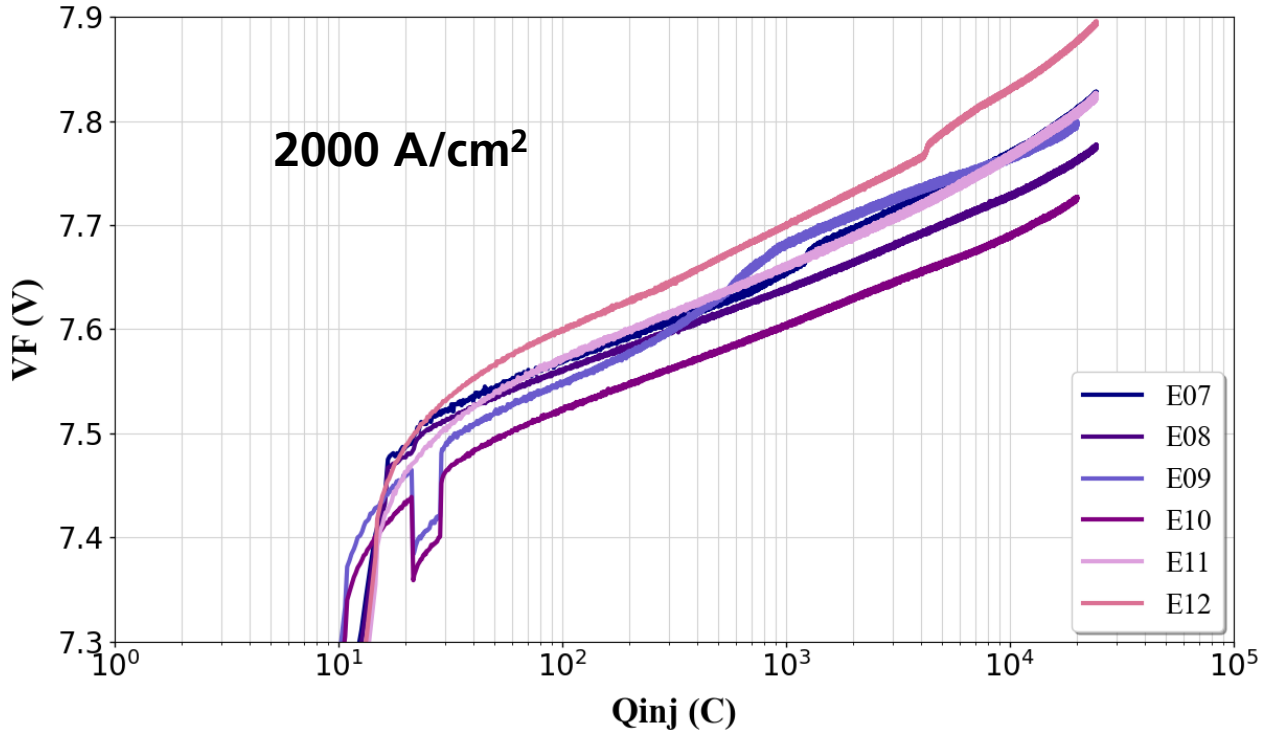
Impact of Current Density





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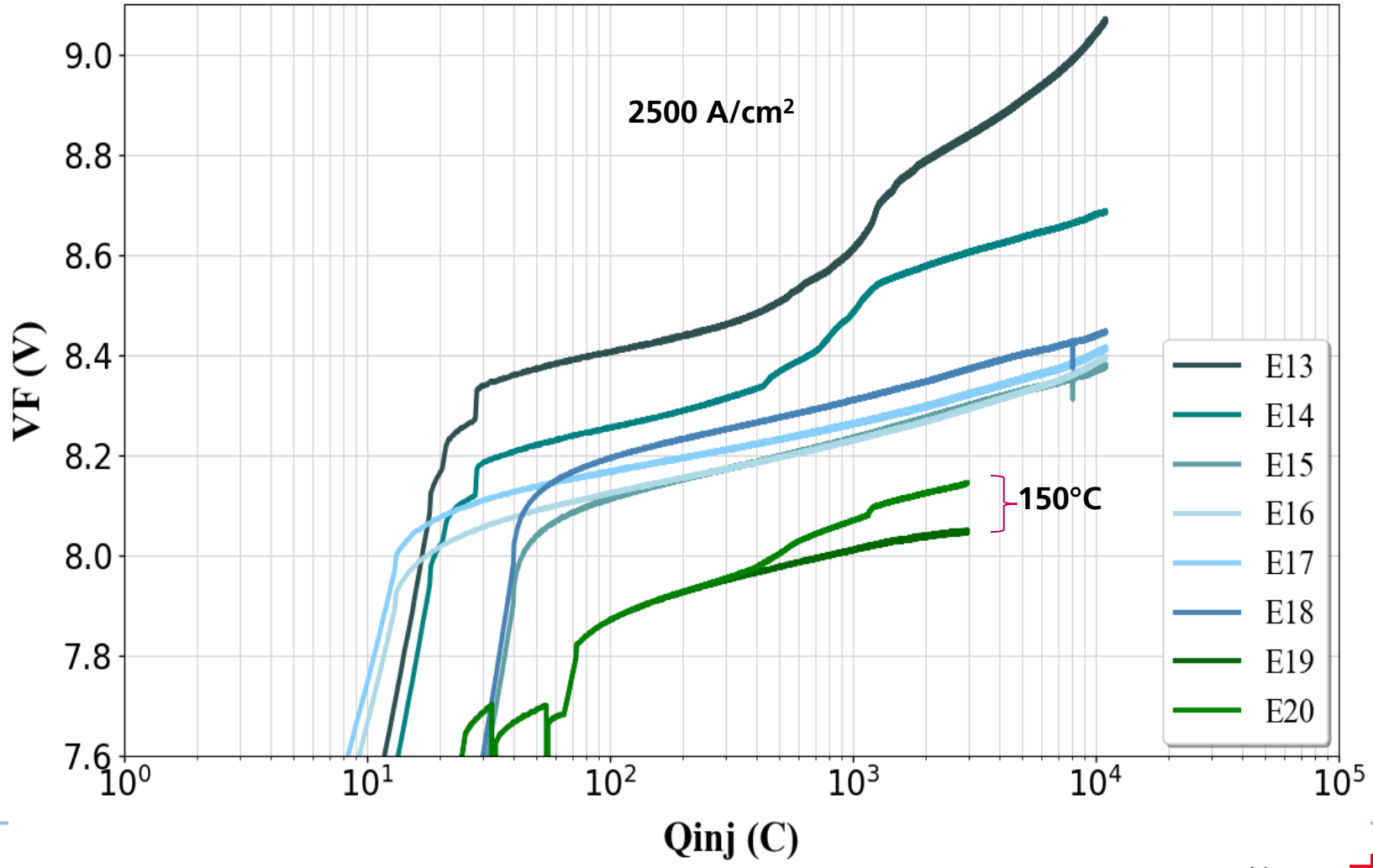
Impact of Temperature



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