Atmospheric neutron testing of GaN power devices

Mario Sacristan Barbero (SY-STI-BMI R2E)
Ruben Garcia Alia (SY-STI-BMI R2E)
Maria Kastriotou (ChipIR)
Carlo Cazzaniga (ChipIR)

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Outline

- Radiation effects on Power Transistors.
  - SEE and Cumulative effects in Si MOSFETs.
  - SEB in Si MOSFETs.
  - Why Wide Band-Gap devices?
  - Previous testing of SiC and GaN.
- Neutron testing of GaN HEMTs at ChipIR.
  - Test setup and DUTs.
  - Destructive and partially destructive SEE.
  - Cumulative effects.
- Conclusions and future work.

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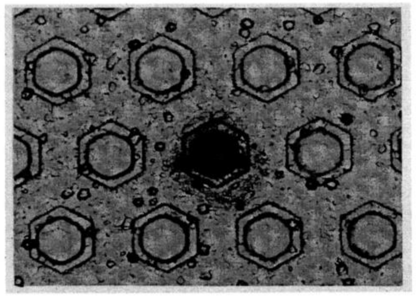
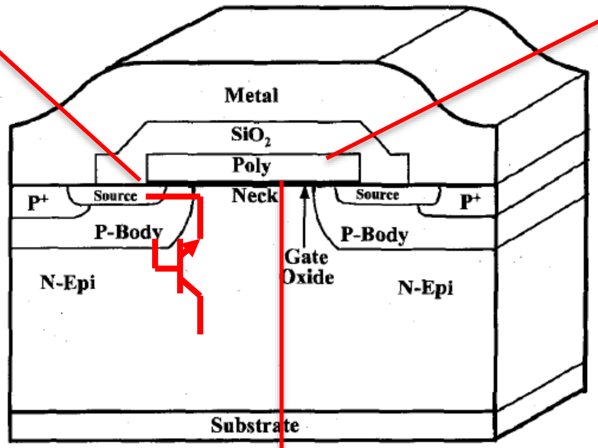
PRELIMINARY

SEE and Cumulative effects in Si MOSFETs.

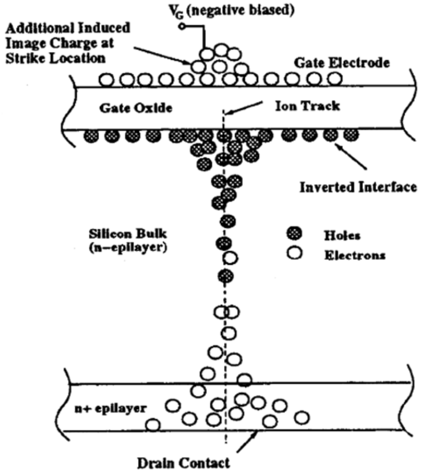
Single Event Burnout (SEB): due to the parasitic bipolar transistor, a regenerative current can be stablished leading to burnout (not typical of PMOS).



E.G. Stassinopoulos et al. IEEE TNS 39(6), 1992

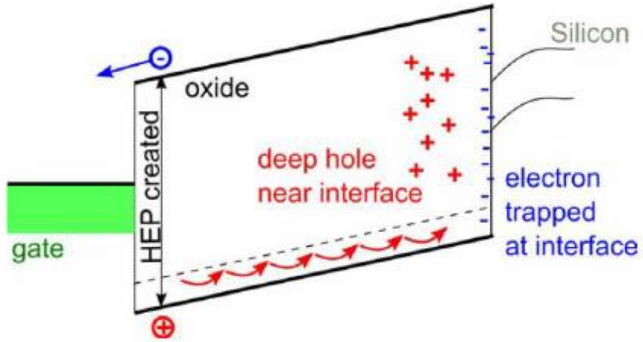


Single Event Gate Rupture (SEGR): induced charges close to the oxide can generate electric field exceeding the breakdown limit.



F.W. Sexton, IEEE TNS 50(3), 2003

Leakage current increase: decrease of the sub-threshold slope, increasing the current for $V_g = 0$.

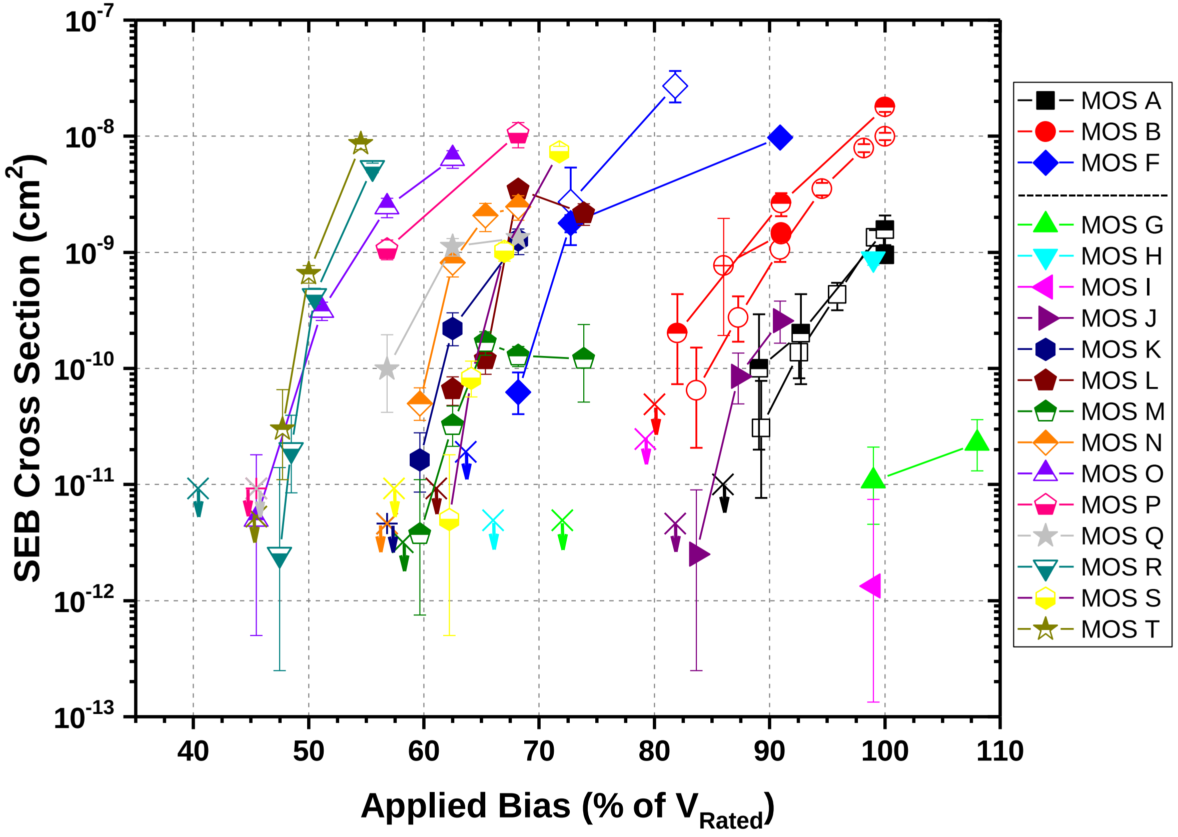


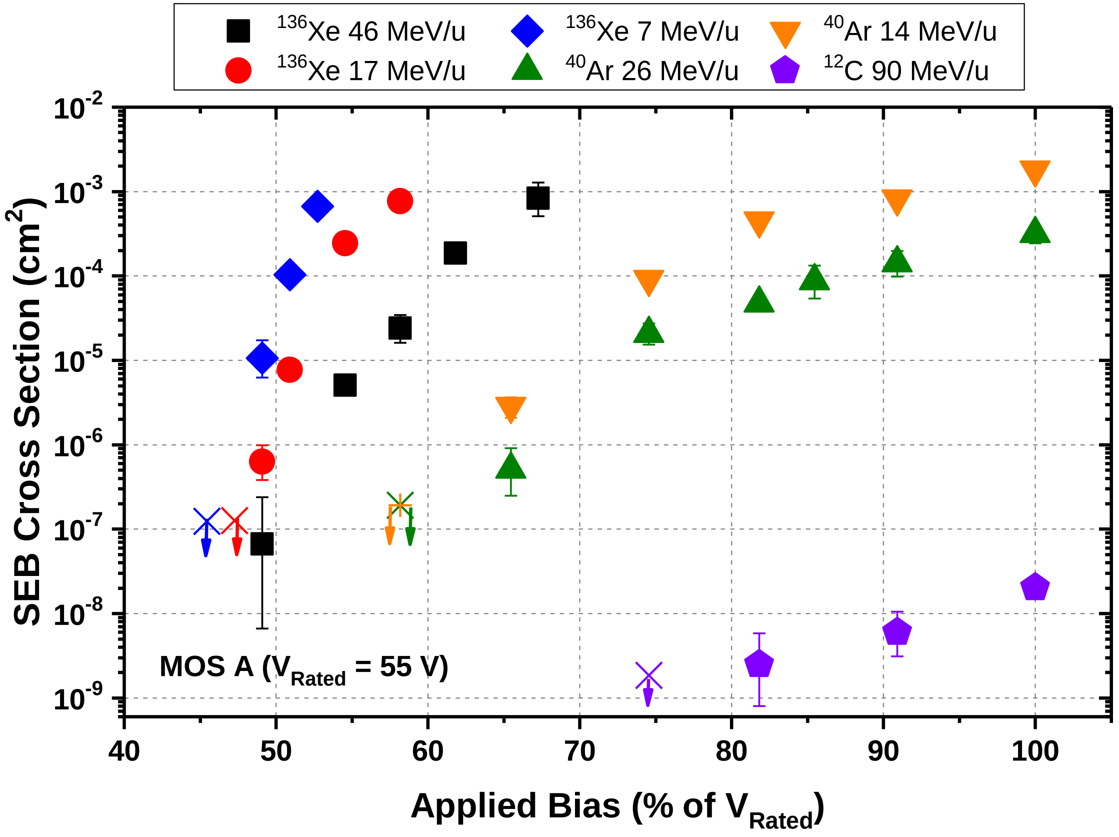
Threshold voltage shift: due to the trapped interface charges, threshold voltage is reduced, hence easier to turn ON.

Displacement Damage is less relevant in MOSFET than in bipolar technology due to its majority carrier technology, for typical fluences of LHC tunnel. At fluences higher than 10^{14} p cm^{-2} displacement damage increases R_{on} due to impurities in the channel.

SEB in Si MOSFETs

Test of several COTS MOSFETs at same energies and different LET

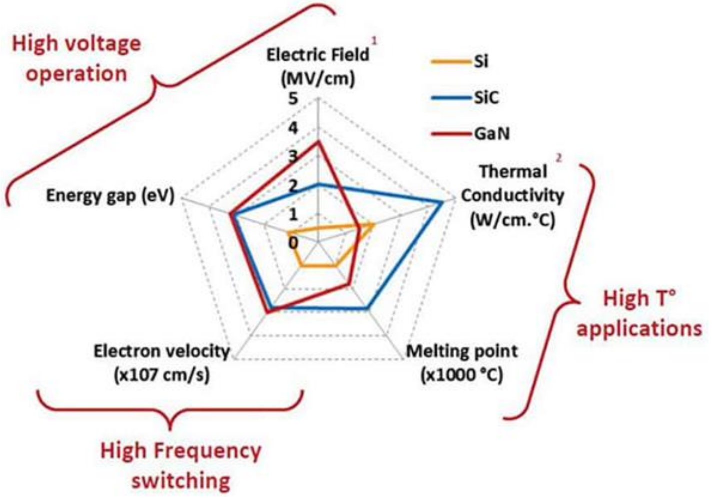


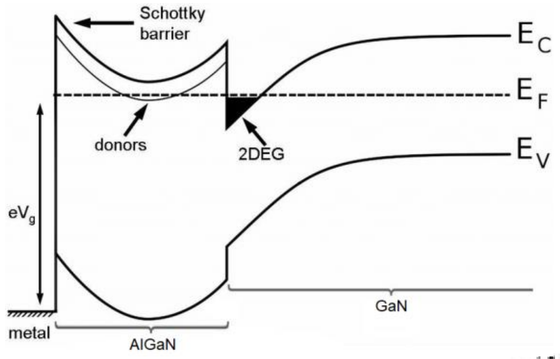


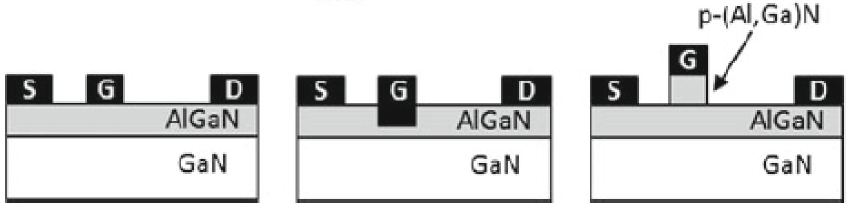
2020, P. Fernández-Martínez

Why Wide Band-Gap devices?

- Wide band-gap semiconductors (SiC, GaN) allow devices to operate at **higher voltages, temperatures and frequencies.**
- Wider band-gap implies **less generated carriers** and higher field and temperature limits **reduce microscopic cumulative damages.**
- **SiC MOSFETs** have proved enhanced **tolerance against SEE** and **less TID** susceptibility.
- **GaN HEMTs** rely on **a high mobility 2DEG electron channel** generated in the AlGaN/GaN heterojunction, instead of a MOS capacitors at MOSFETs, therefore:
  - **SEE tolerance**: wide band-gap semiconductor, lack of parasitic bipolar.
  - **TID tolerance**: no oxide layers.
  - **DD tolerance**: majority carrier technology.







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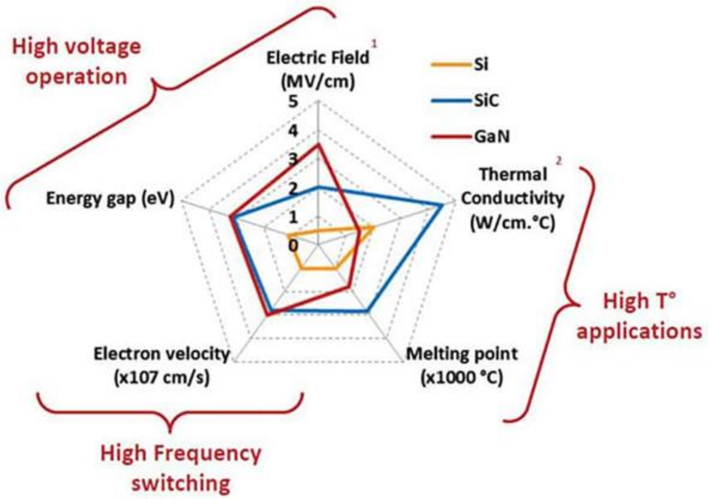
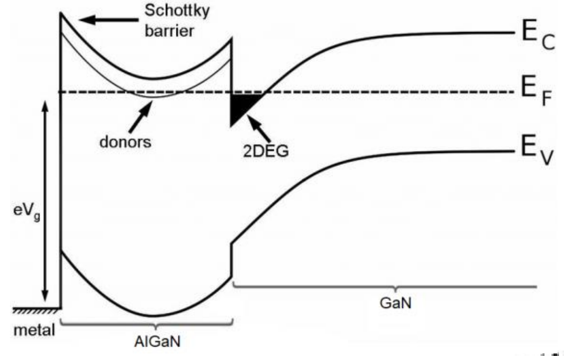
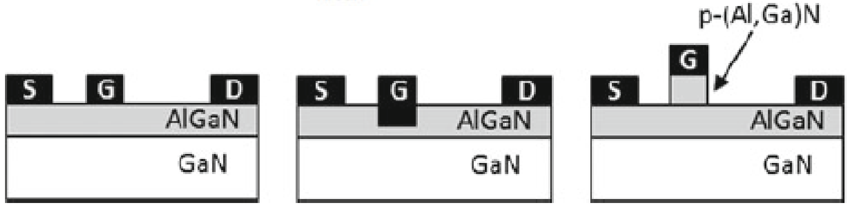
TO BE VERIFIED







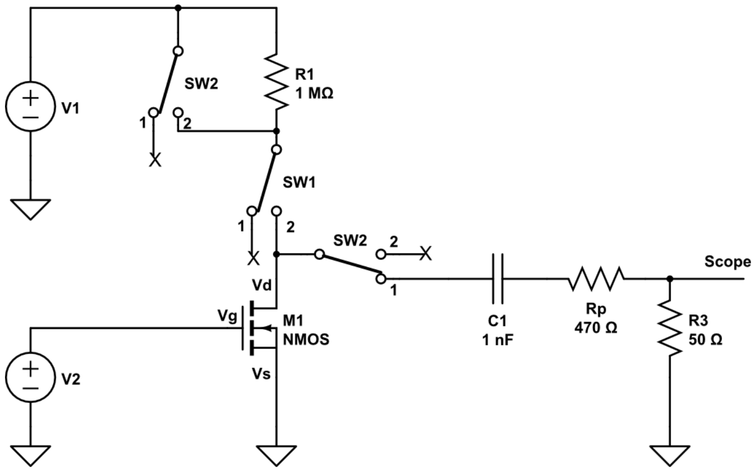
Previous testing of SiC and GaN

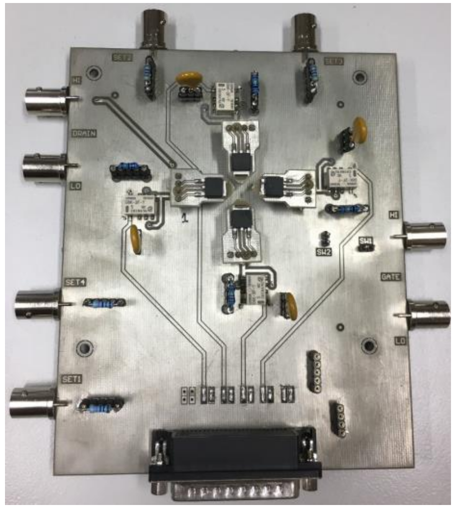
- **CERN**: Extensive work by C. Martinella with SiC MOSFET concerning SEB and SELC (see previous presentation).
- SiC MOSFETs at **RADSAGA**:
  - CHARM: SEB cross section for CREE C3M0120090D at 3.1e-10 cm^2 @850V. Fluence 2e9 n/cm^2.
  - ChipIR: SEB cross section for CREE C3M0120090D at 4.5e-11 cm^2 @750V. Fluence 2e11 n/cm^2.
- Further studies suggest **TID damages are still present.**

  S. Gerardin, 2013, "Radiation performance of new semiconductor power devices for the LHC experiment upgrades"
- GaN HEMTs at **RADSAGA**:
  - GANIL: SEBs detected at 83 and 100% $V_{ds,max}$, 12 PGA26E19BA DUTs. Fluence 3e6 i/cm^2.
  - CHARM: No events up to 2e9 n/cm^2, 20 EPC2012 DUTs and 20 PGA26E19BA DUTs.
  - ChipIR: No events up to 1.5e11 n/cm^2, 48 PGA26E19BA DUTs.

Test setup and DUTs at ChipIR

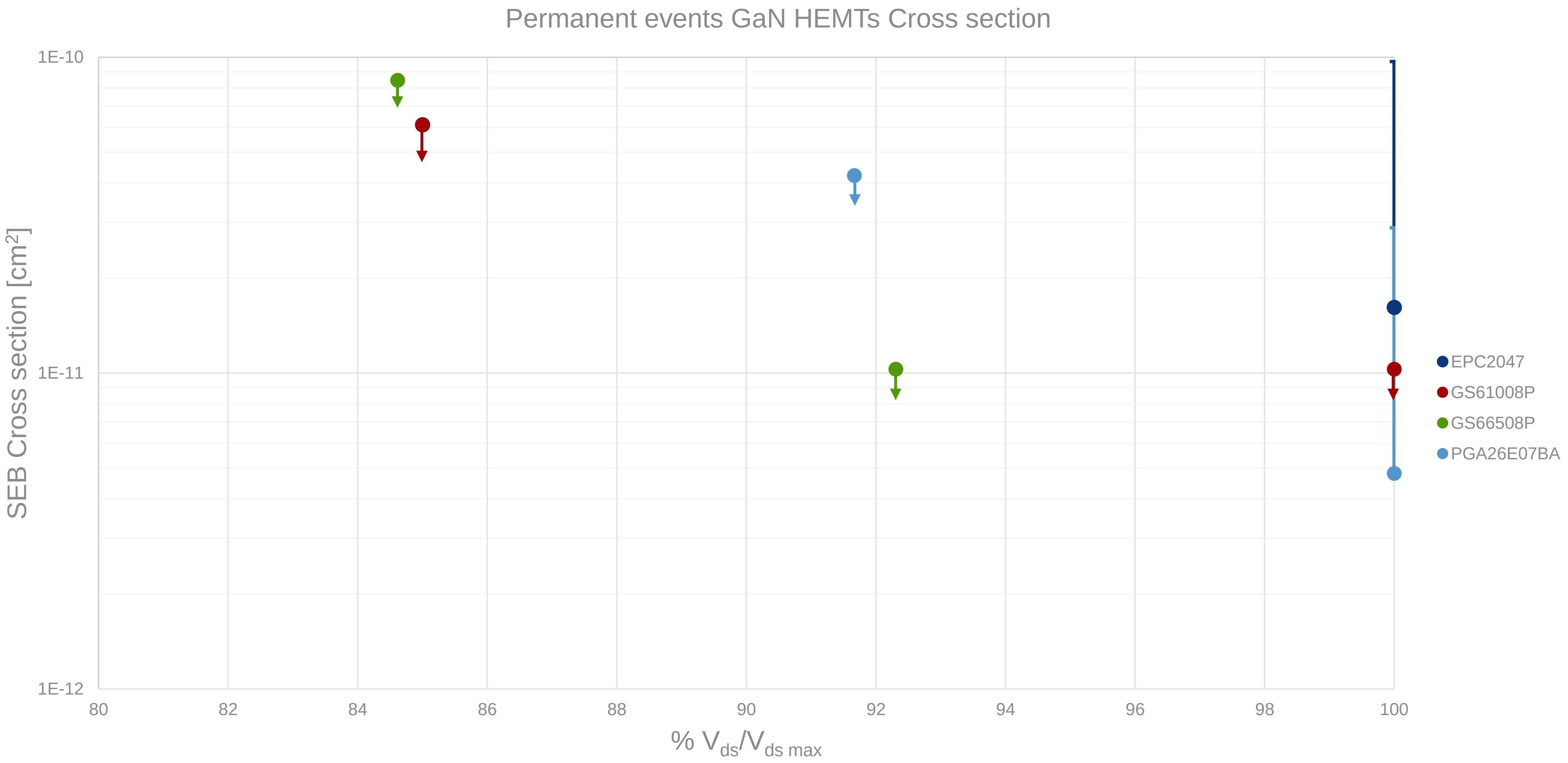
- **4 references** tested (100V and 600V). x2 DUTs of each reference.
- Irradiation board provides **protective system in case of destructive event** and device **characterisation of I-V curves**.
- DUTs **monitored in two ways**: drain/gate total current consumption and drain transients monitored via oscilloscope.
- Test performed remotely with the on-site assistance of our colleagues Maria Kastriotou and Carlo Cazzaniga from ChipIR.





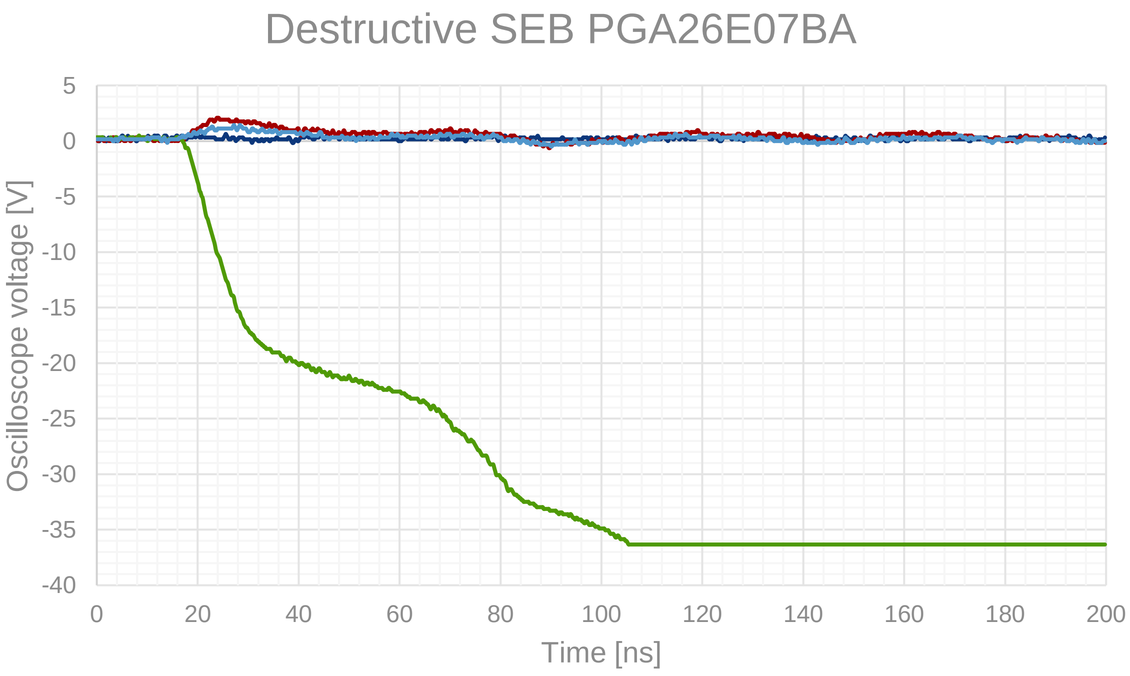
Reference	Technology	$V_{ds,max}$ [V]	$V_{ds,test}$ [V]
EPC2045	GaN HEMT	100	100
GS61008P	GaN HEMT	100	100
PGA26E07BA	GaN HEMT	600	600
GS66508P	GaN HEMT	650	600

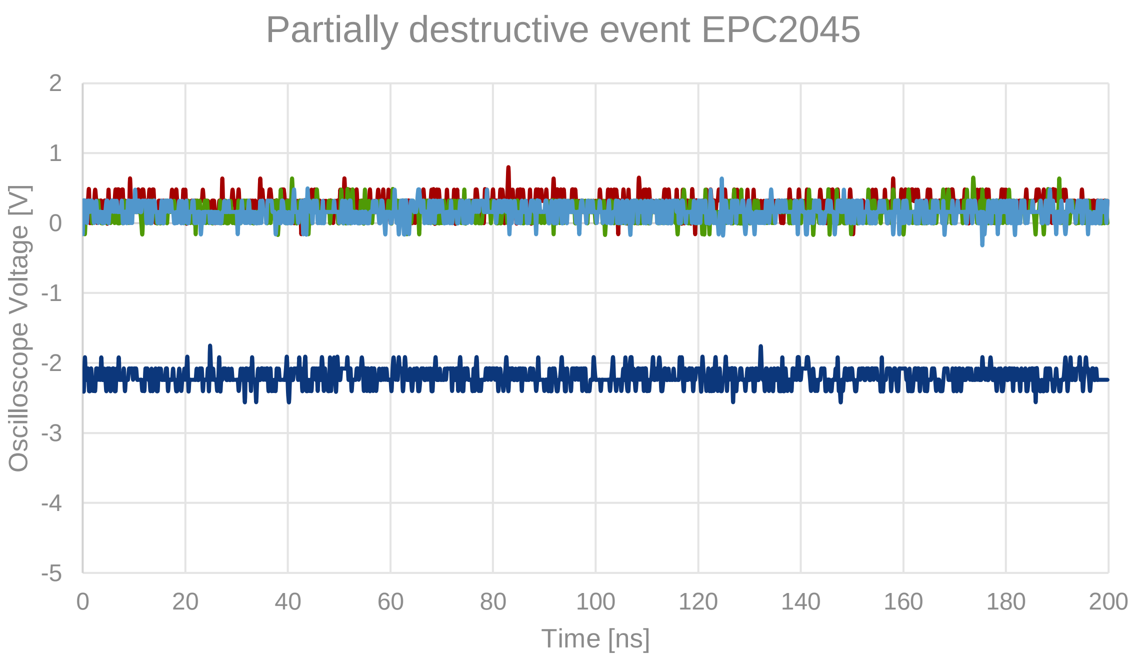
Destructive and partially destructive SEE



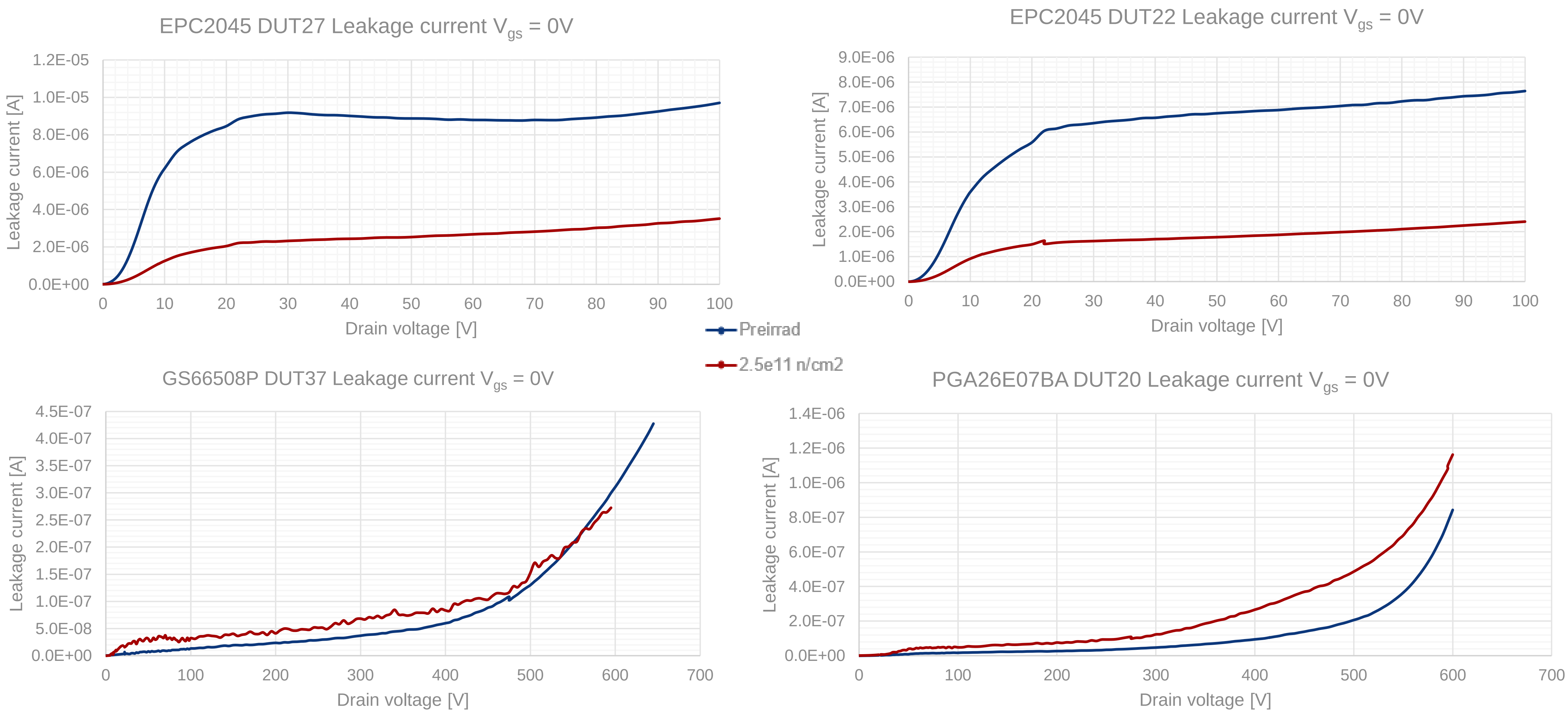
Destructive and partially destructive SEE

- 600V PGA26E07BA, one destructive event detected. Effect is the short-circuit of drain and source. No gate damage. GS66508P no events.
- 100V EPC2045, two partially destructive events, due to leakage current increase by two orders of magnitude. No gate damage. GS61008P no events.





Cumulative effects. Leakage current.



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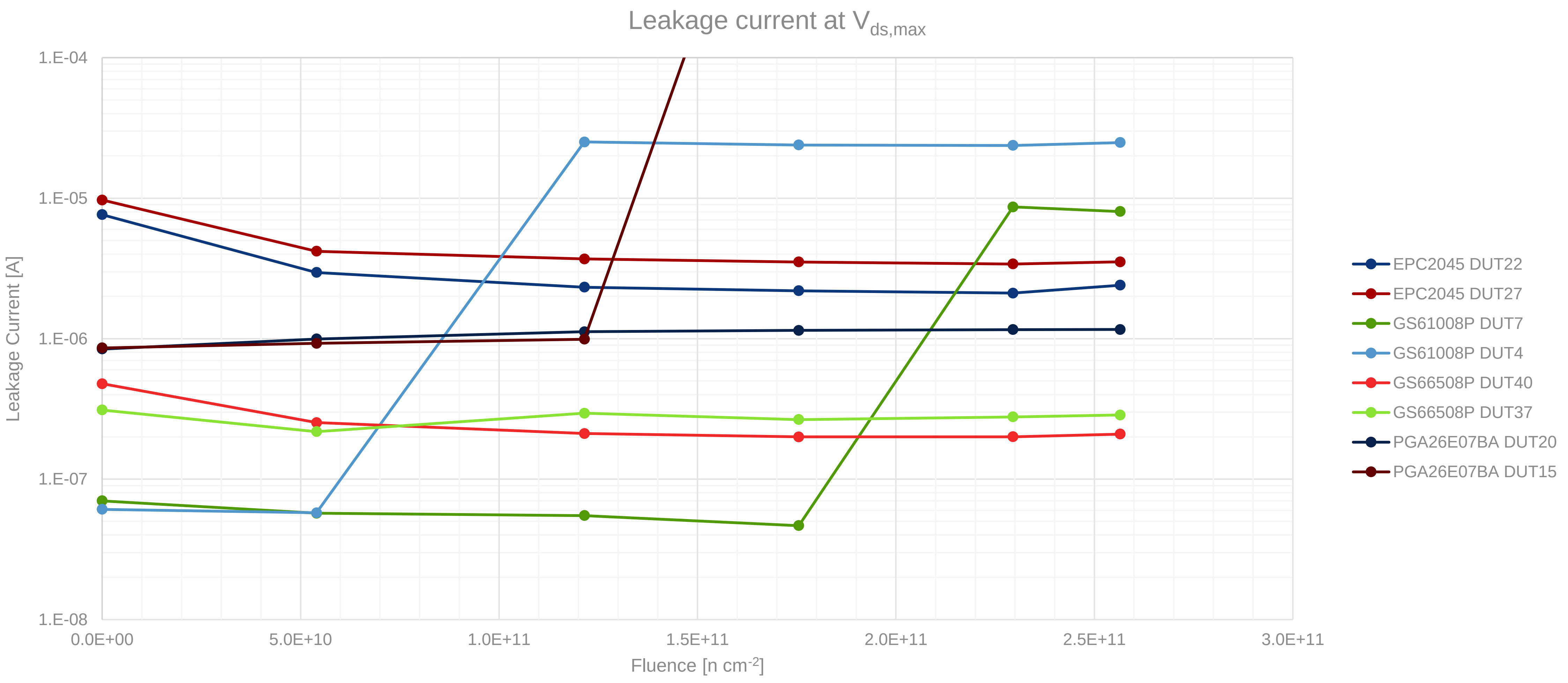

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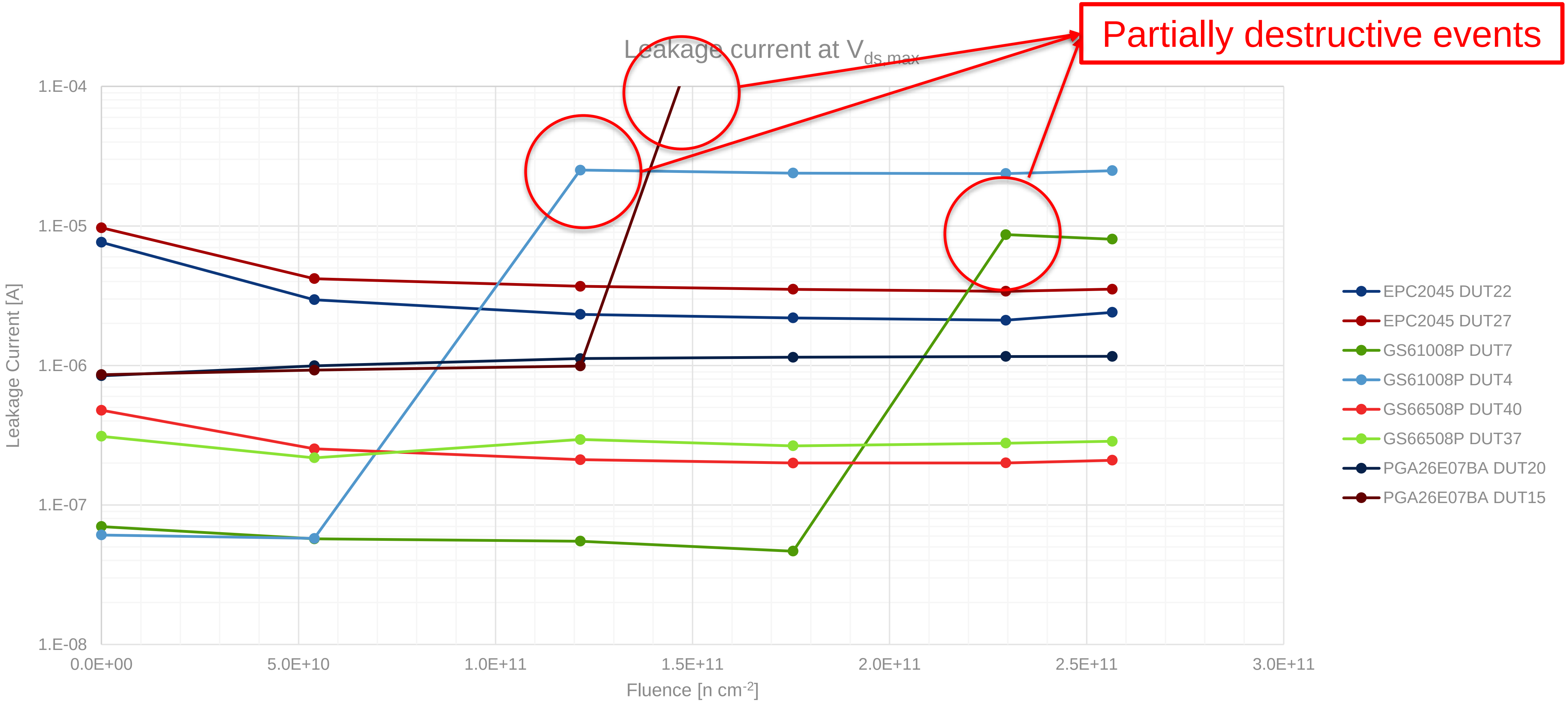
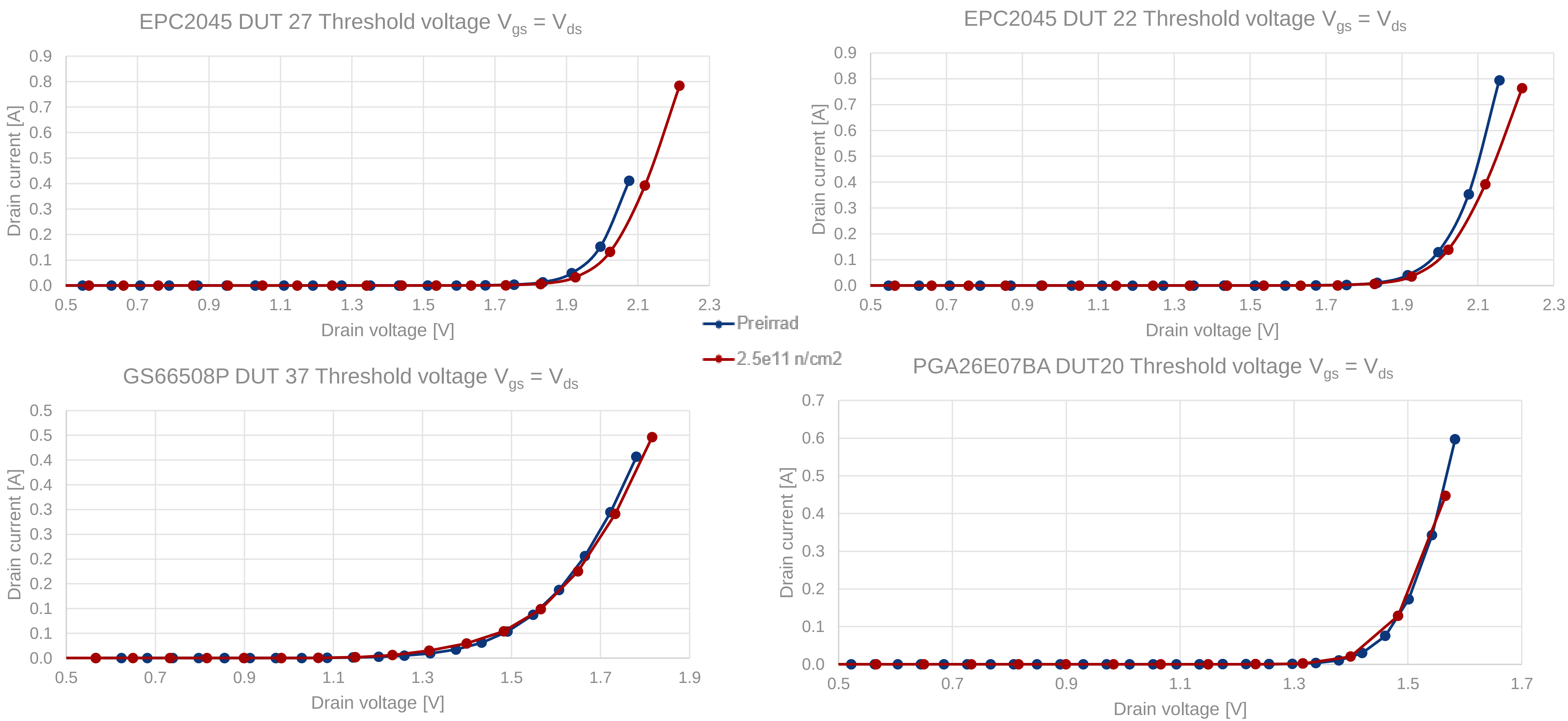


Cumulative effects. Threshold voltage.



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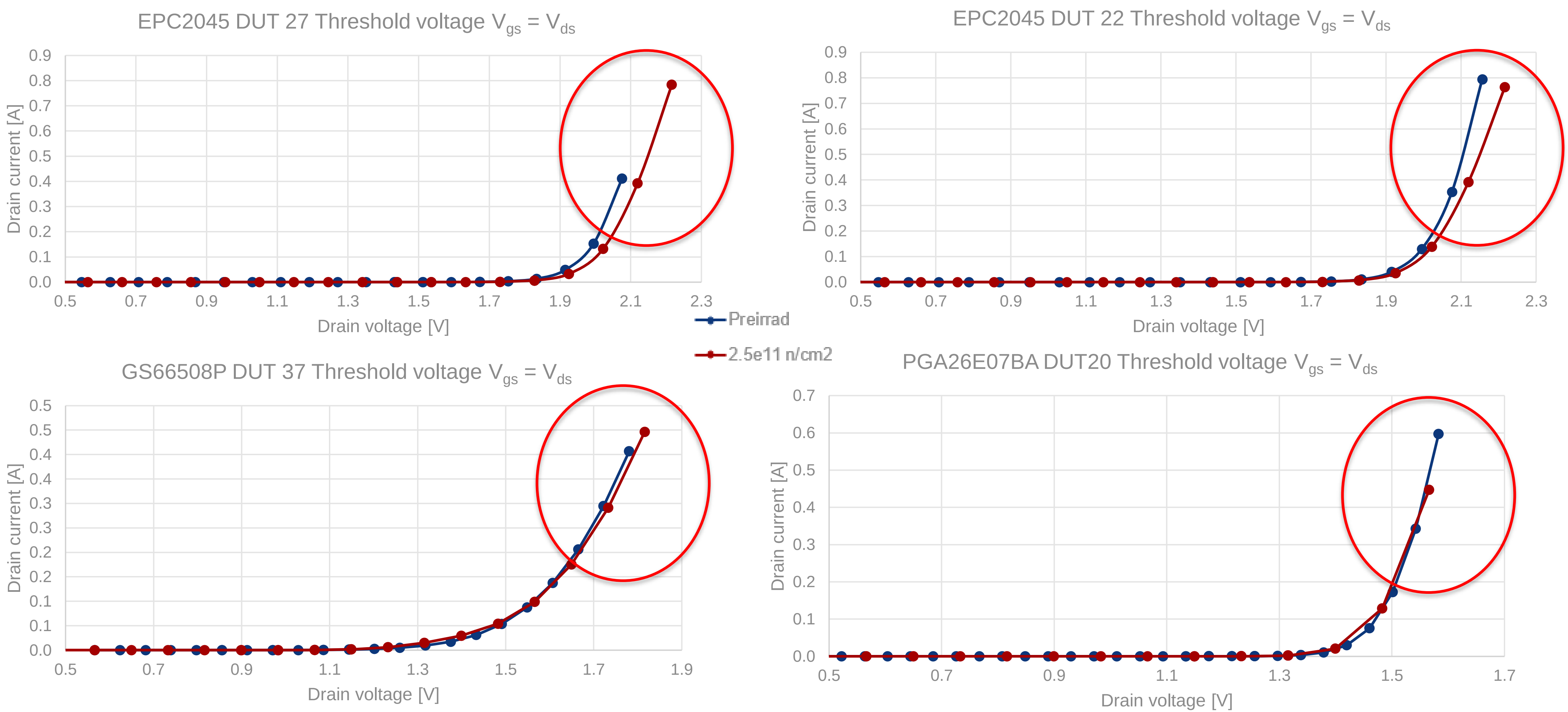

Conclusions and future work

- **GaN HEMTs** (x4@100V and x4@600V) have been tested in ChipIR up to **2.5e11 n cm^{-2} s^{-1}**.
- No destructive events observed in 100V devices. One destructive events in 600V devices one, setting **cross sections in the order of 1e-11 cm^2** at 100% V_{ds}.
- Cumulative damage by neutrons is very limited, with a slight **decrease in leakage current, no effect on the threshold voltage** and a **decrease in transconductance** for large gate voltages.
- **Further testing SEE** with protons/heavy ions and **TID** with gamma rays.
- Characterisation of the devices to **check room temperature annealing**.
- Need to **correlate radiation effects with existing technologies** for substrates and gate structures of GaN HEMTs.
- **Special acknowledgments to Maria Kastriotou and Carlo Cazzaniga** from ChipIR without whom the campaign would not have been possible.

Thank you for your attention!

mario.sacristan.barbero@cern.ch

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