Status of: 'Guidelines for Space Qualification of GaN HEMT Technology'

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Background

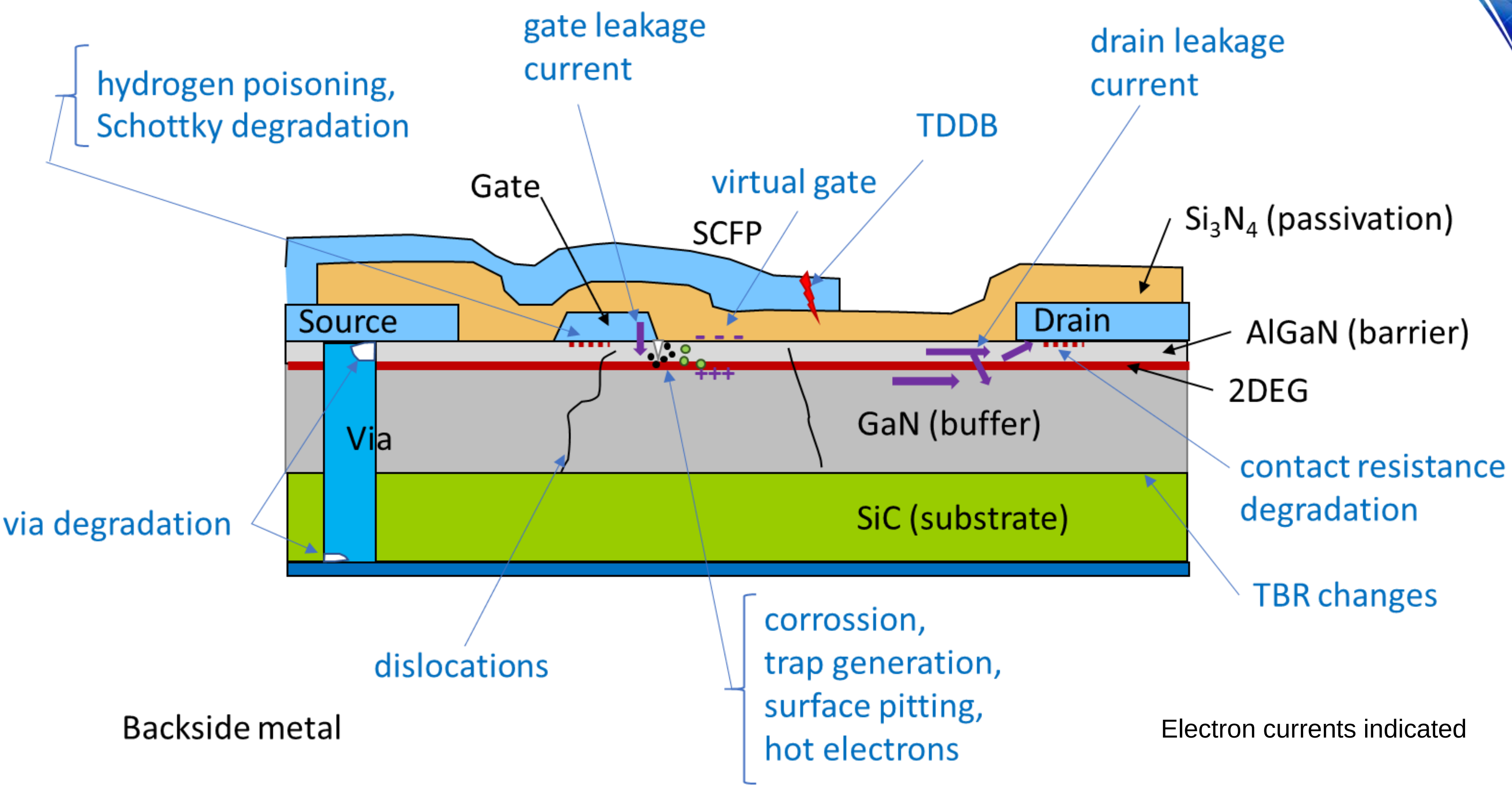
Status of space qual of GaN RF/Microwave HEMT technology

- GaN RF/microwave HEMTs and MMICs are beginning to find their way into Class A and B space missions
  - *GaN HEMT advantages*
    - High power density -- Watts/mm of gate length
    - High voltage capability – eases RF matching
    - Radiation hard -- >10Mrad
  - *GaN HEMT issues*
    - Trapping phenomena causes new problems
    - Current collapse, pulse-to-pulse instability, low frequency noise etc.
    - Piezoelectric effects at high voltage may generate even more traps
- No official GaN government standards presently exist for qualification in space
  - *Existing standards cover Si, GaAs devices*
- Aerospace TOR (Tech. Operating Report) is an attempt to fill this gap
  - *Weekly working group meetings held from 8/19 – 12/19*
  - *100 participants from GaN fabs, aerospace firms, industry, government*
  - *Previous draft document received numerous comments*

Please request TOR TOR-2018-00691 "Guidelines for Space Qualification of GaN HEMT Technologies" J. Scarpulla, C. Gee

Failure Mechanisms in GaN HEMTs

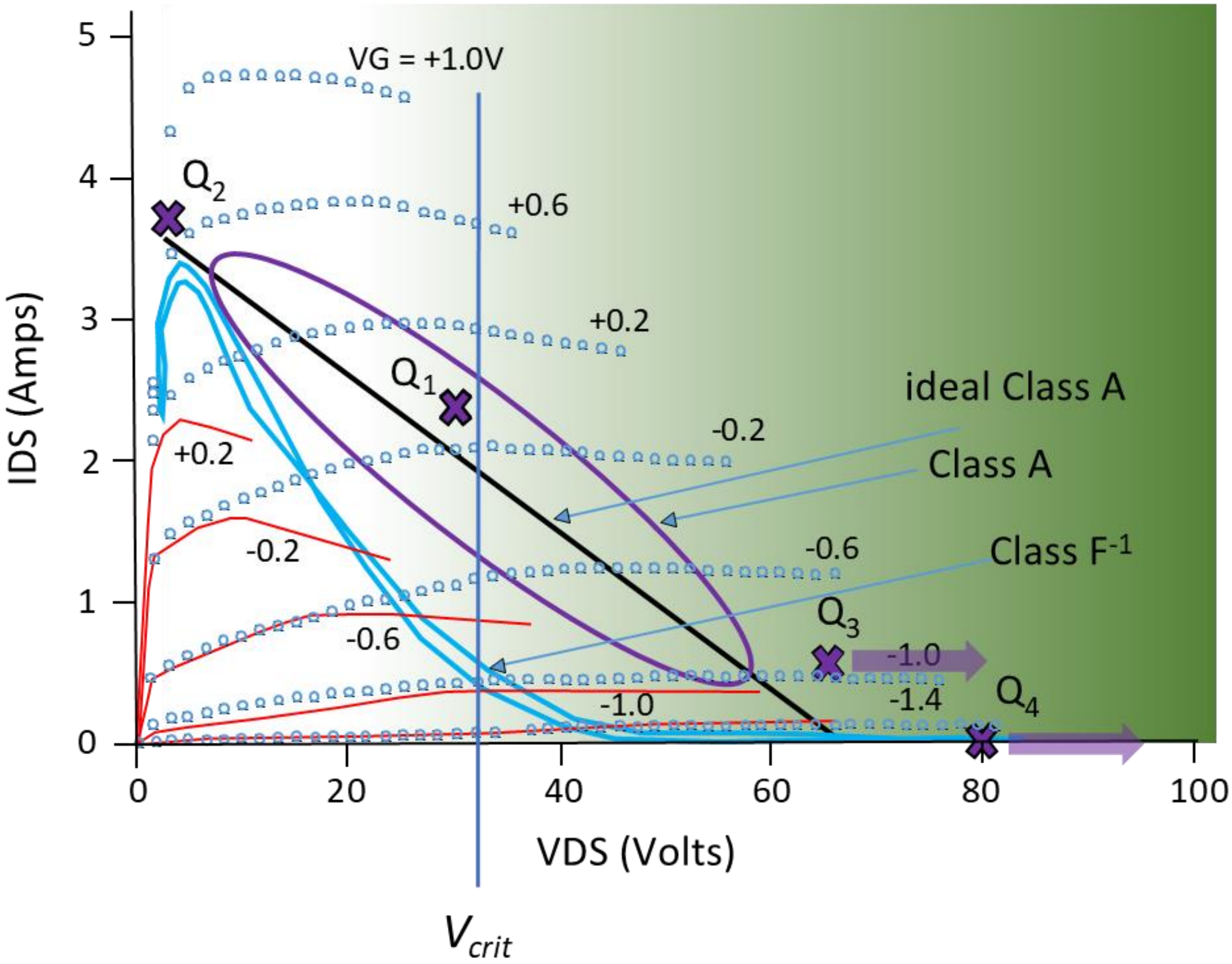
Understanding of the failure modes guides qual testing



Different failure modes operate in different electrical regimes

The IV Plane

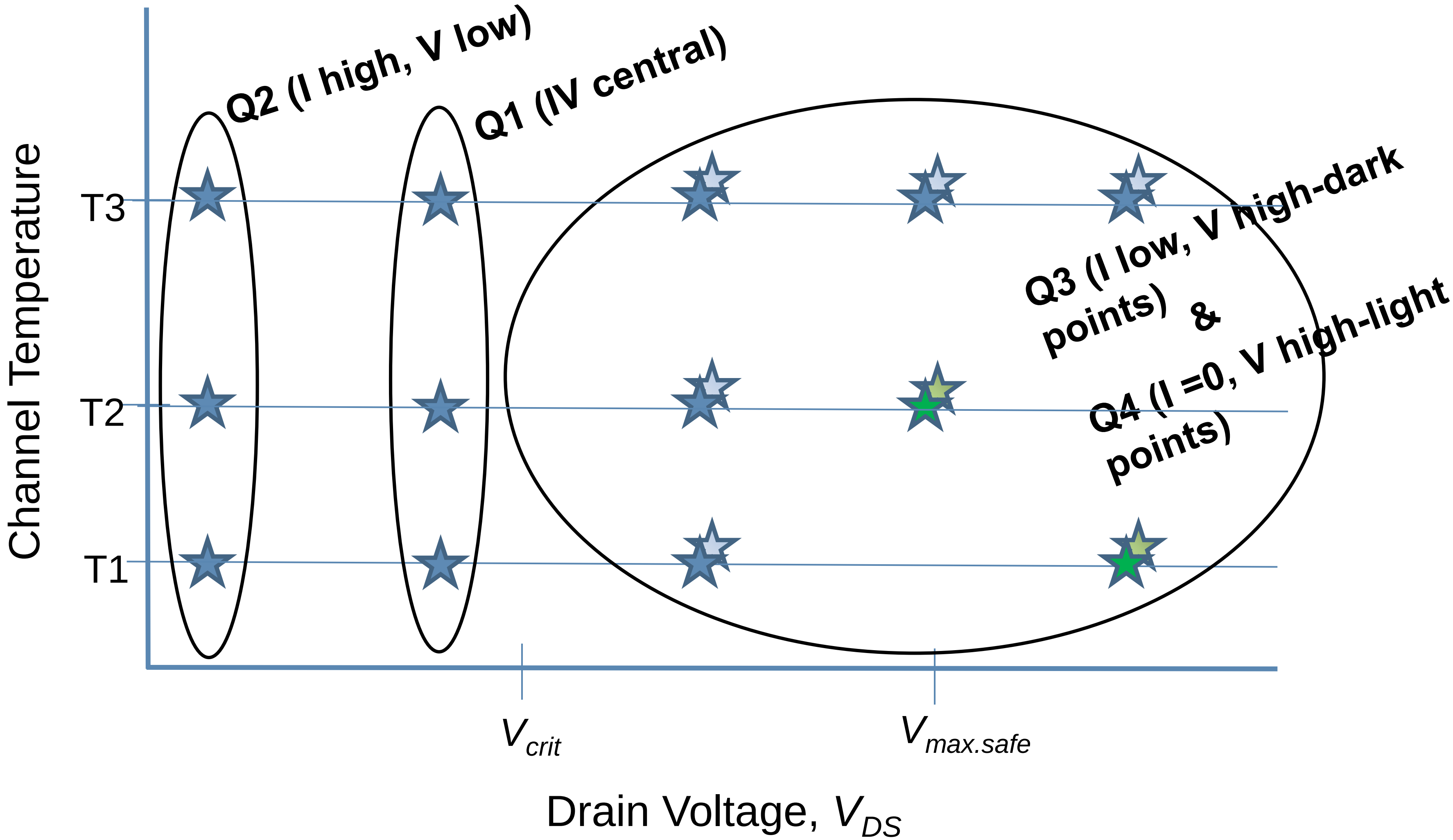
Recommendations for accelerated life testing (ALT)



The "DC vs. RF" question – can DC rel testing be sufficient for an RF device?

DC Reliability Testing Scheme

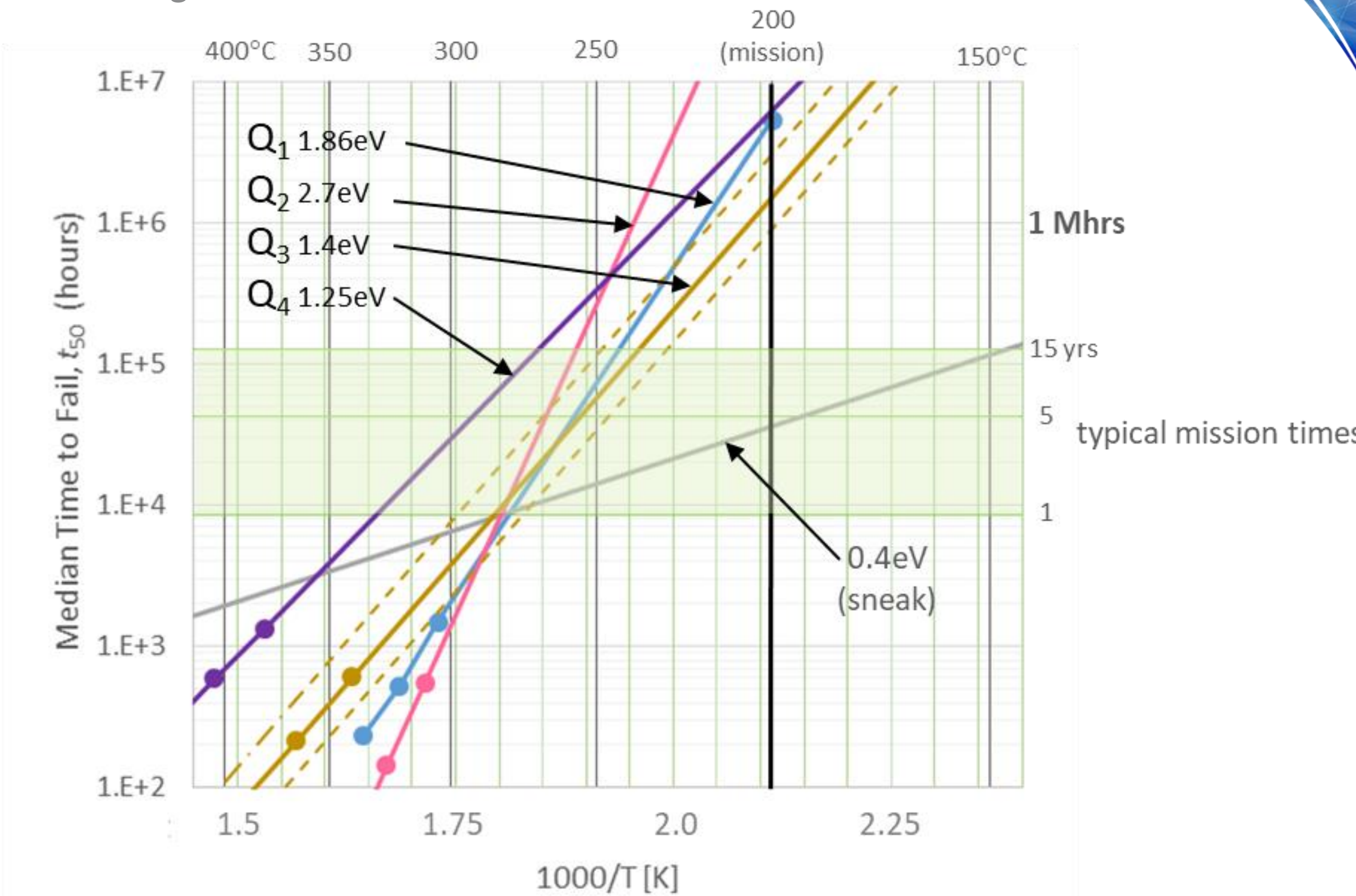
including temperature and voltage accelerants (2-dimensional problem)



Optimum test plan includes all four "Q-points"

Multiple Q-points at different temperatures

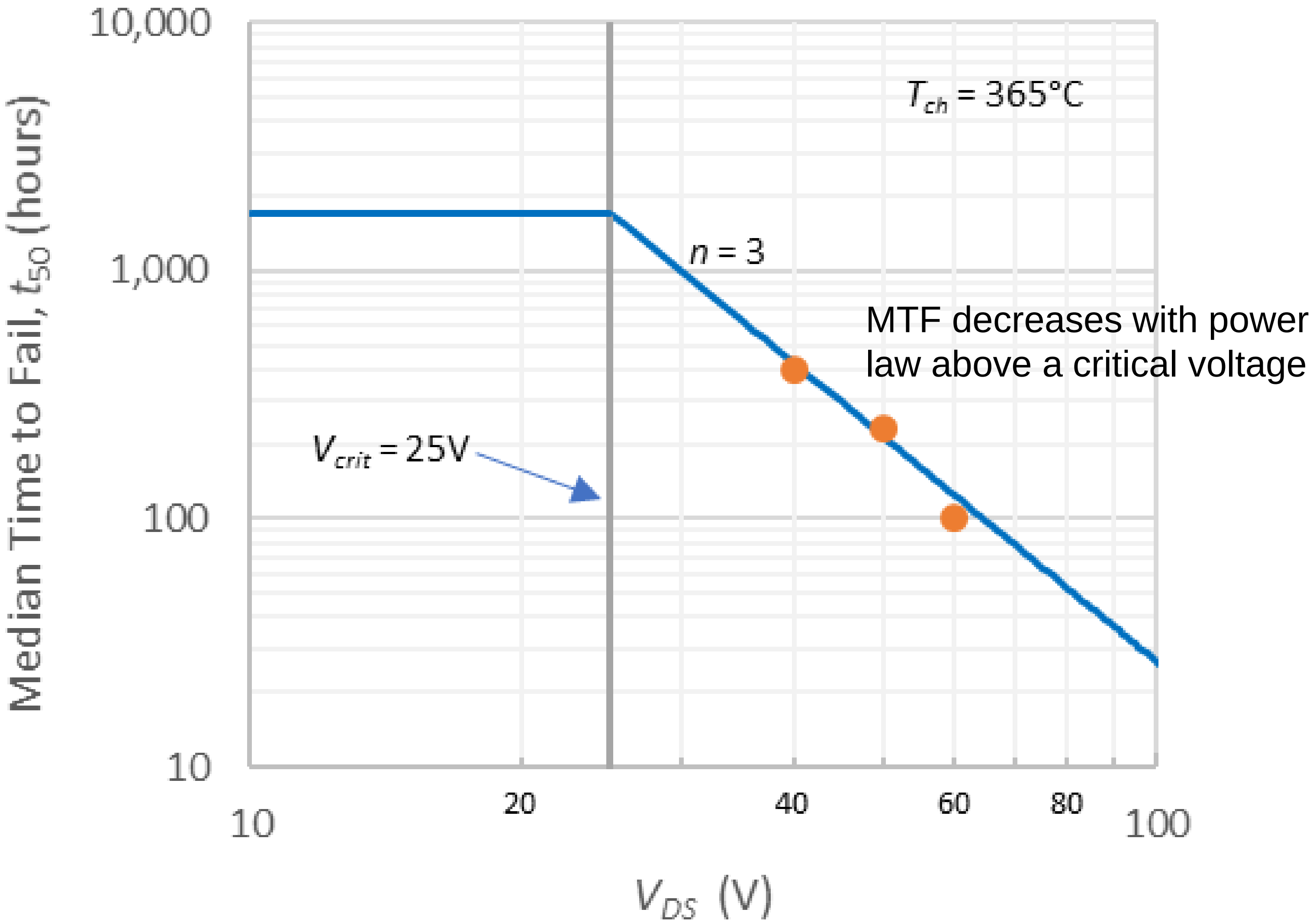
Activation energies differ



Arrhenius plots emphasize temperature acceleration …. What about voltage acceleration?

Q4 (off state) Voltage accelerated test

(at constant accelerated temperature)

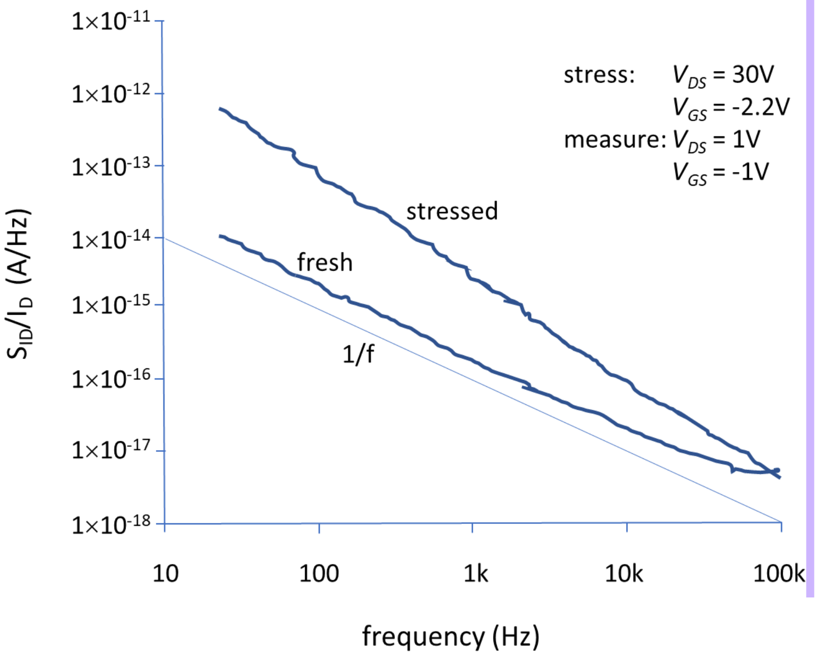


Not all HEMTs exhibit a voltage dependence of accelerated failure time

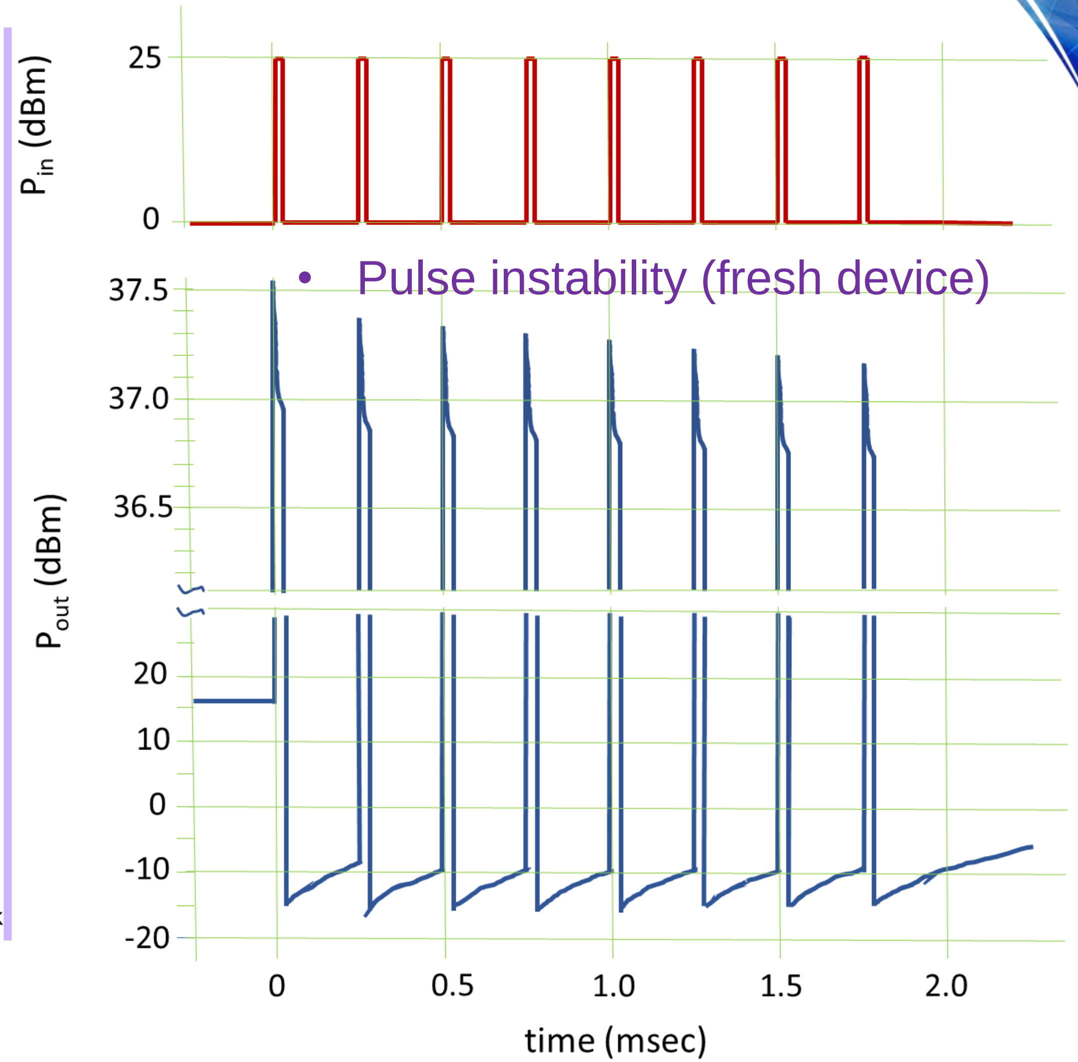
Why traps are important

Trapping causes noise, pulse distortion and instability

- Low frequency noise increase after 1,000 hr stress



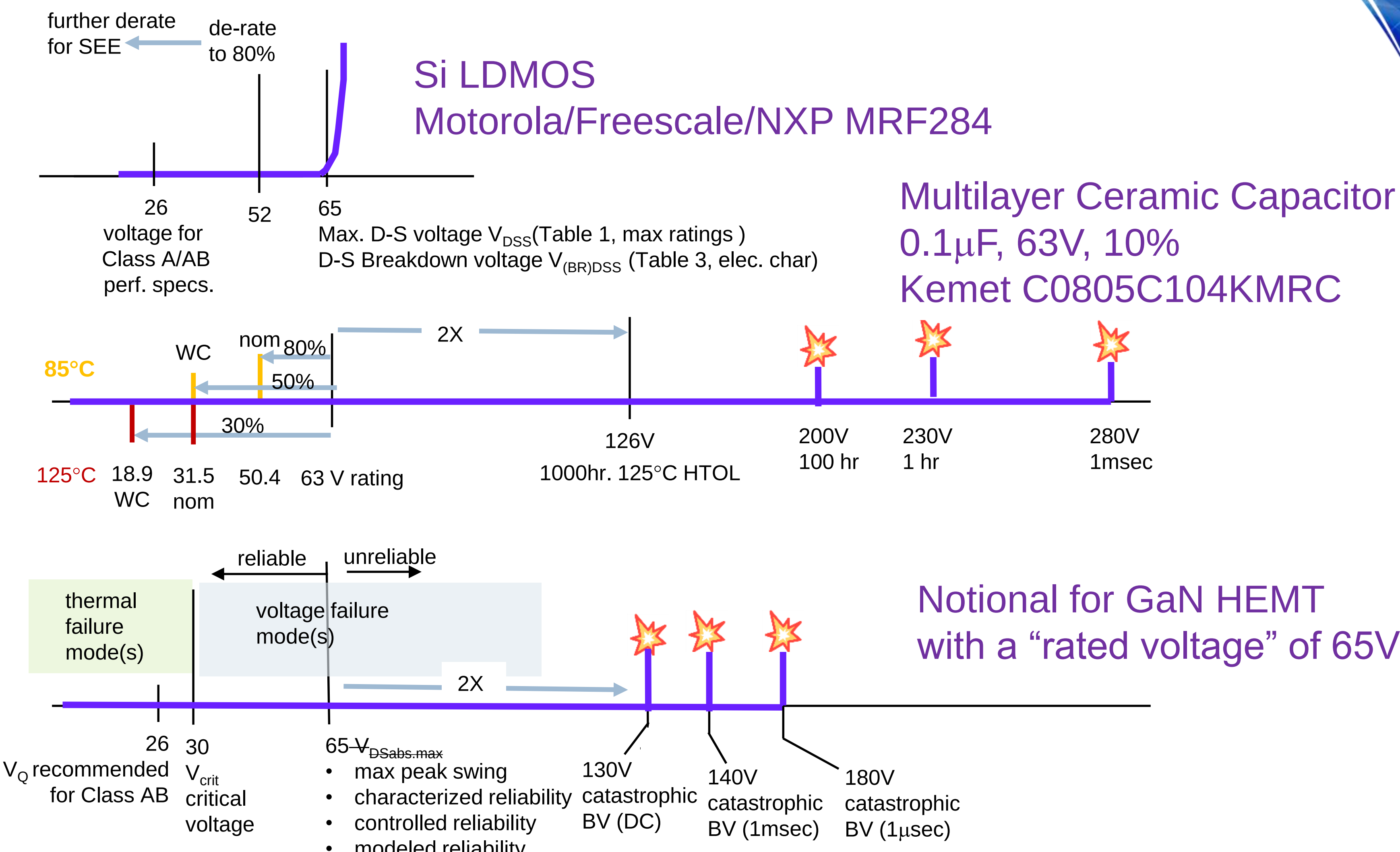
- Pulse instability (fresh device)



Worsening of trapping with mission aging, stress, radiation is unknown

Rating (and de-rating) Approaches

for familiar device types vs. a GaN HEMT



- ***GaN devices more resemble ceramic than silicon***
- ***Vabs.max is an unfortunate, overused and imprecise term for GaN !!***

Ref.: derating rules come from TOR-2006(8583)-5236 rev. B, “Technical Requirements for Electronic Parts, Materials, and Processes Used in Space Vehicles” March 6, 2013

Recommended RF GaN HEMT Ratings Sheet

Maximum Ratings[1]	Symbol	Rating	units	
Maximum channel temperature	T_{max}	250	°C	T_{max}
Maximum Safe Drain-Source Voltage[2]	$V_{DSmax.safe}$	70	V	T_{max}
Maximum Safe Drain Current per unit gate width	$I_{Dmax.safe}$	850	mA/mm	T_{max}
Maximum Safe Reverse Gate-Source Voltage	$V_{GRmax.safe}$	-12	V	$V_{DS} = V_{DSmax,safe}, T_{max}$
Maximum Safe Gate Current per finger[3]	$I_{gmax.safe}$	2	mA	electromigration limit
Maximum Safe RF Input Power[4]	$P_{in.max.safe}$	28	dBm	CW, input return loss < 15dB
Maximum Safe RF Dissipated Power	$P_{diss.max.safe}$	33	W	CW

[1]Operation within these maximum ratings meets the reliability goal of 0.2% failures in 15 years with 90% confidence
[2]DC or pulsing above $V_{DSmax.safe}$ reduces reliability and risks immediate or delayed catastrophic breakdown
[3]DC or average RF gate current
[4]for full recovery of performance within 1 sec after exposure

Supplementary Rating	Symbol	Rating	units	
Channel-to-Baseplate Thermal Resistance	θ_{CB}	1.5	°C/W	specified at T_{max}
Critical Voltage[5]	V_{crit}	25	V	specified at T_{max}
Recommended Quiescent Voltage[6]	V_Q	35	V	
Recommended Quiescent Current[6]	I_Q	180	mA/mm	
Burnout Drain-Gate Voltage[7]	$V_{DG(BO)}$	140	V	1 msec DC pulse, T = 25°C
Burnout RF Input Power [7]	$P_{in(BO)}$	32	dBm	1 msec RF pulse, T = 25°C

[5]Operation above V_{crit} incurs performance degradations still within EOL limits if max safe ratings are obeyed.
[6]For typical class AB operation with compression less than 3dB
[7]Catastrophic burnout ensues within 1 msec of application of this applied condition

More Recommendations & Test Protocols

Topics to consider for space qualification of GaN

- Robustness
  - *SOA (safe operating area)*
  - *Gate burnout*
  - *RF burnout*
  - *ESD*
  - *Temperature cycling*
  - *Power cycling*
  - *Off-state voltage screening*
- Intrinsic Reliability
  - *DC lifetesting (4 Q-points)*
  - *RF lifetesting*
  - *Step stressing*
  - *TLYF (Test Like You Fly)*
  - *Thin film resistors*
  - *Electromigration*
- Environmental Effects
  - *Moisture sensitivity*
  - *Hydrogen sensitivity*
  - *Air Sensitivity*
- Extrinsic Defects
  - *MIMCAPs*
  - *Gate Defects*
  - *Airbridge Defects*
  - *Backside Via defects*
- Mechanical
  - *Backside metal adhesion*
  - *Bondpull tests*
  - *Die shear tests*
  - *Step Coverage*
  - *Low Frequency Oscillations*
- Radiation Effects
  - *Total Ionizing Dose*
  - *Dose Rate*
  - *Singe Event Effects SEE, SEB*
  - *Displacement Damage*
  - *GaN dosimetry, LET*
- Ratings and Derating
  - *Reliability, burnout and SEB considerations*

Guidelines are provided on these topics and more

Conclusion

- A peer-reviewed and vetted space qualification methodology for GaN power HEMTs and MMICs is in press
- TOR-2018-00691 “Guidelines for Space Qualification of GaN HEMT Technologies” J. Scarpulla, C. Gee
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- THANK YOU!