Physics Based Models of eGaN® Device Failure Mechanisms

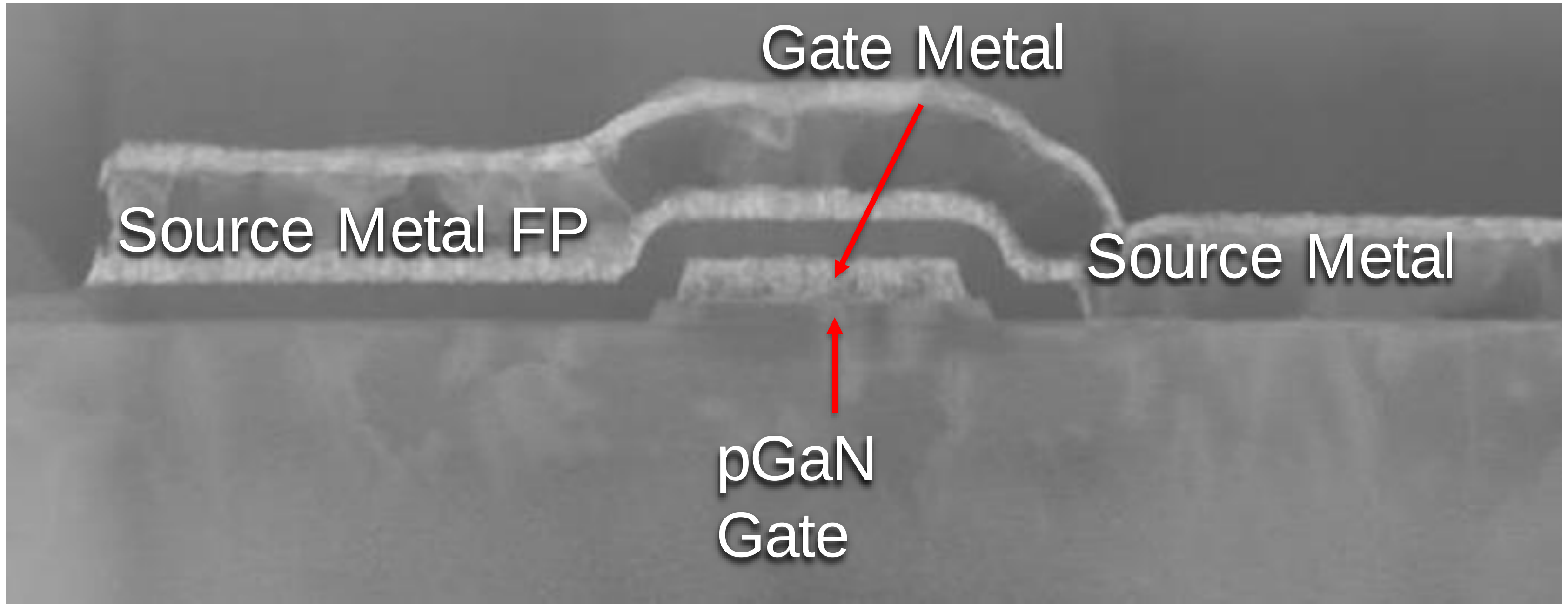
Reliability Reports and Methodology

Stressor	Device/ Package	Test Method	Instrinsic Failure Mechanism	EPC Test Results
Voltage	Device	HTGB	Dielectric failure (TDDB)	Phase 12 Report
			Threshold Shift	
		HTRB	Threshold Shift	
			$R_{DS(on)}$ Shift	
		ESD	Dielectric rupture	[2,3,6,7,8,9,10]
Current	Device	DC Current (EM)	Electromigration	In Progress
			Thermomigration	In Progress
Current + Voltage (Power)	Device	SOA	Thermal Runaway	Phase 12 Report
		Short Circuit	Thermal Runaway	
Voltage Rising/Falling	Device	Hard-switching reliability	$R_{DS(on)}$ Shift	
Current Rising/Falling	Device	Pulsed Current (Lidar reliability)	None found	
Temperature	Package	HTS	None found	[6,7,8,9]
Humidity	Package	MSL1	None found	[3,4,5,6,7,8,9,10]
		H3TRB	None found	[1,2,3,4,5,6,7,8,9,10]
		AC	None found	[4,5,6,7,8,9]
		Solderability	Solder corrosion	Phase 12 Report
		uHAST	Dentrite Formation/Corrosion	[10]
Mechanical/ Thermo-mechanical	Package	TC	Solder Fatigue	Phase 12 Report
		IOL	Solder Fatigue	
		Bending force test	Delamination	
		Bending Force Test	Solder Strength	
		Bending Force Test	Piezoelectric Effects	
		Die shear	Solder Strength	
		Package force	Film Cracking	

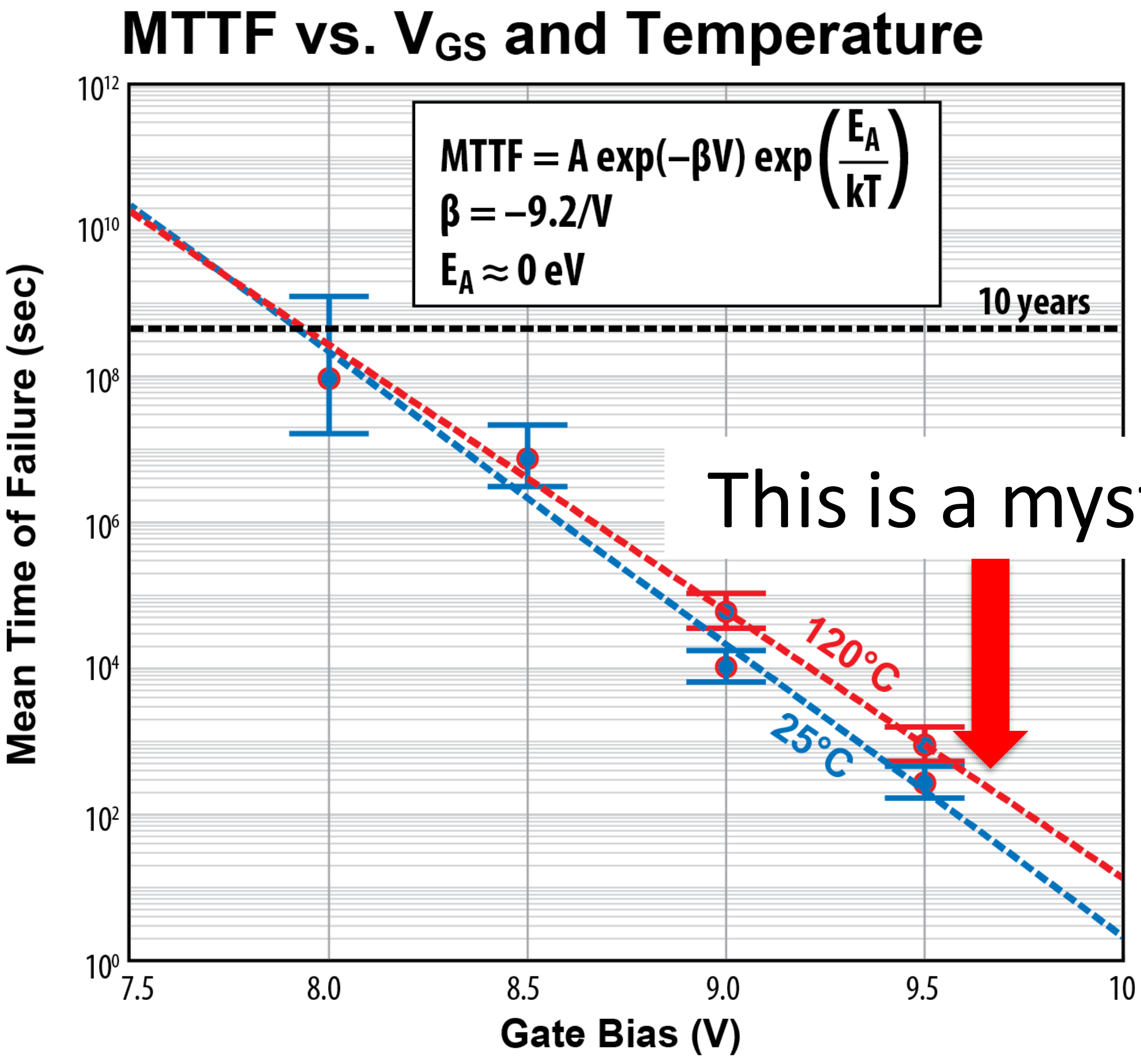
Stress – Voltage

Gate-Source

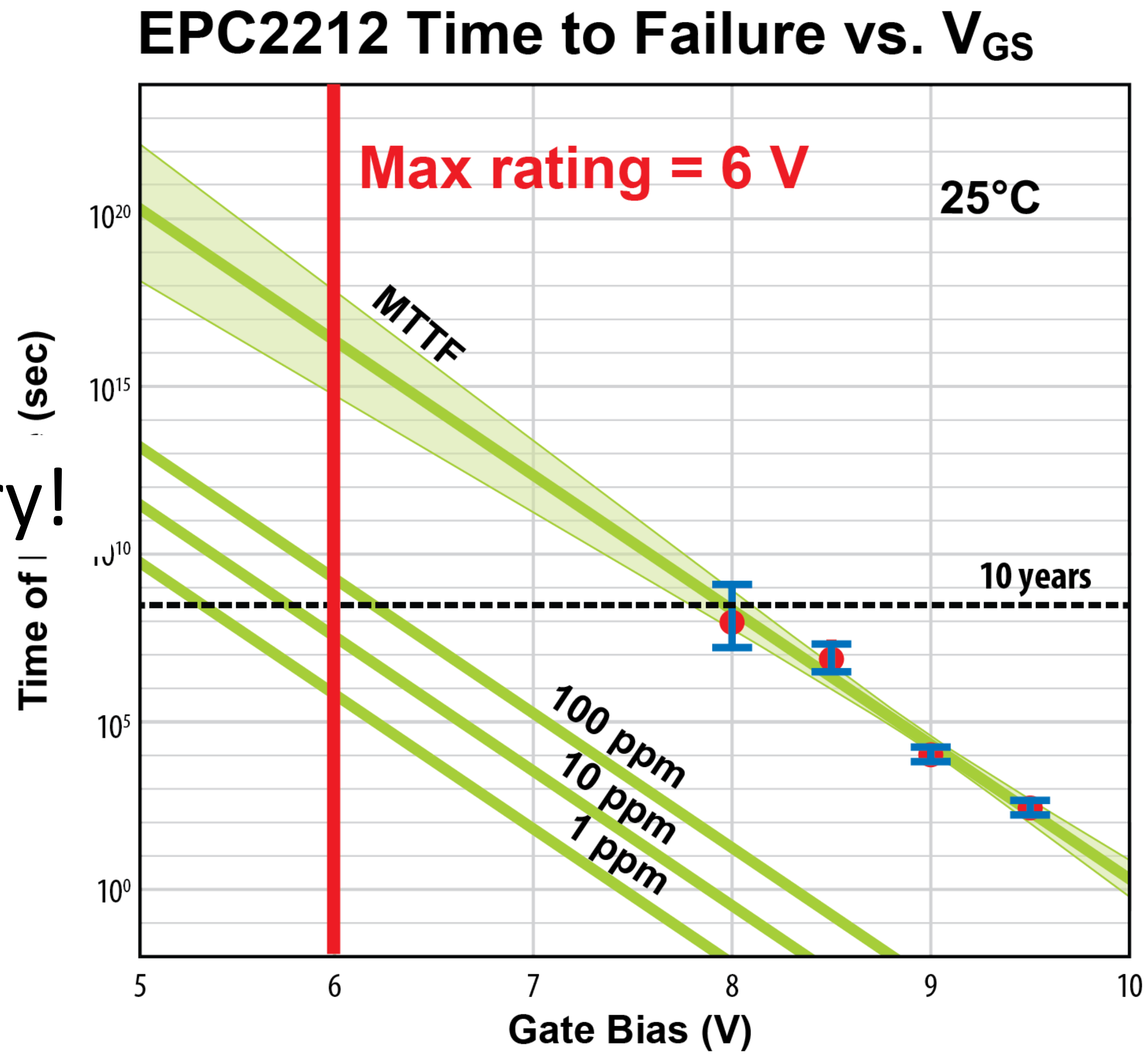
Gate-Source Voltage Stress



Gate Acceleration: Time to Failure

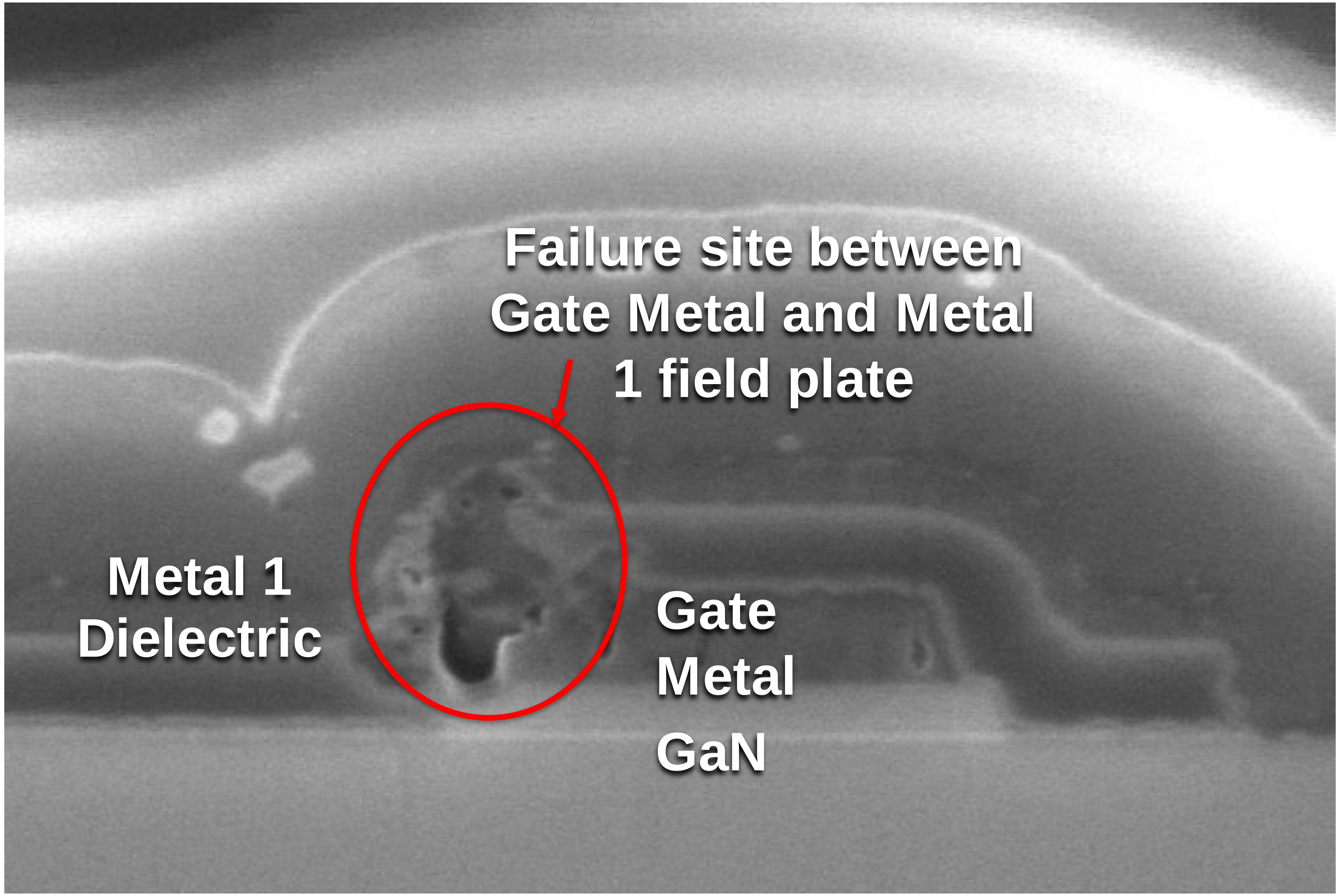


This is a mystery!

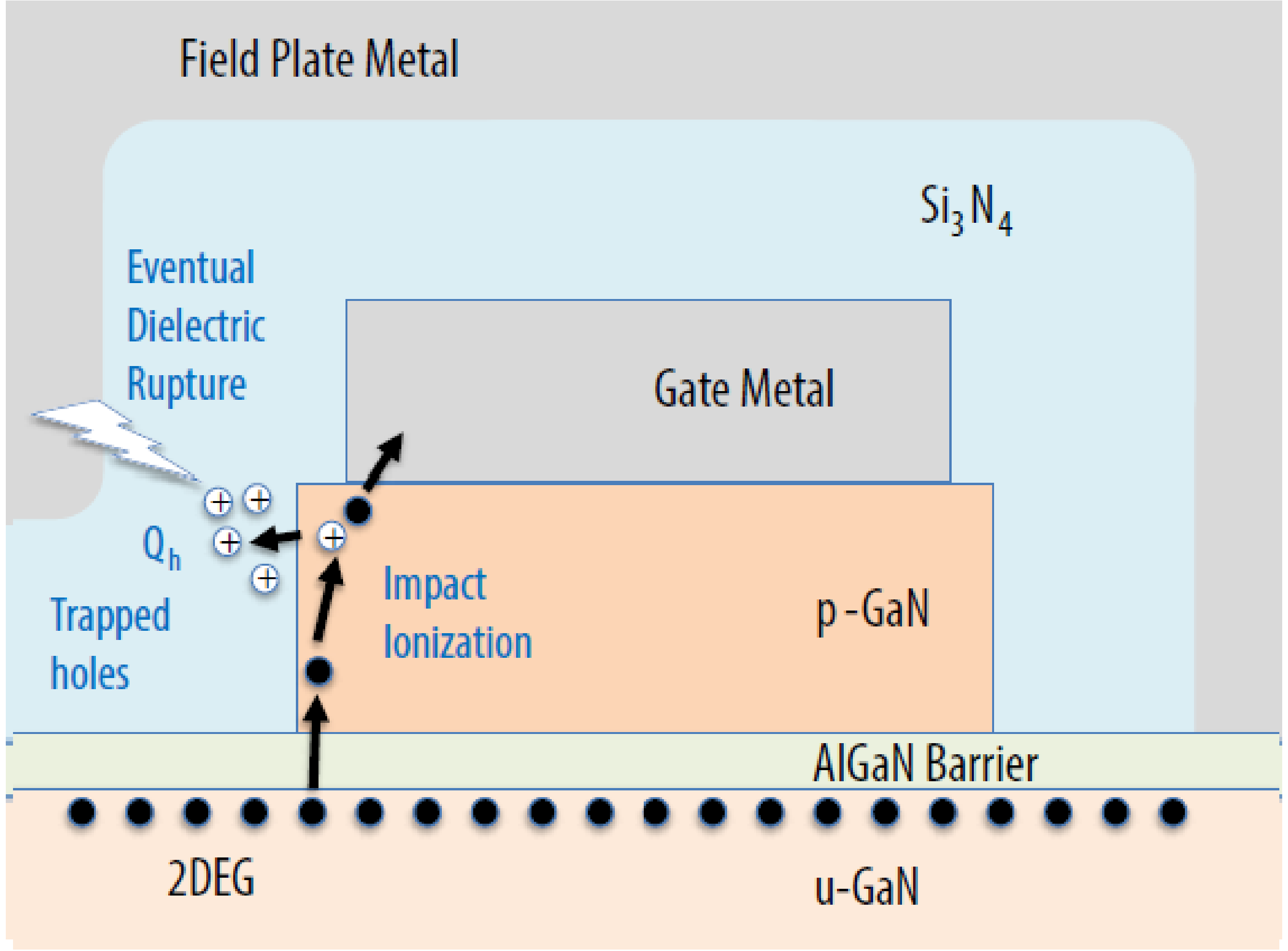


EPC has tested certain part types to 3000 hours

Gate Failures Not in GaN



Impact Ionization Mechanism



Impact Ionization Model Development

$$G = \alpha_n \frac{|J_n|}{q} + \alpha_p \frac{|J_p|}{q}$$

$$G \approx \alpha_n \frac{|J_n|}{q} \qquad J_n >> J_p$$

Ref	a_n(1/cm)	b_n(V/cm)	m
Ji et al.[12]	2.10E+09	3.70E+07	1
Ozbek [13]	9.20E+05	1.70E+07	1
Cao et al. [8]	4.48E+08	3.40E+07	1
Ooi et al. [15]	7.32E+07	7.16E+06	1.9

$$\alpha_n = a_n e^{-(b_n/F)^m}$$

$$a_n(T) = a_{n;0}(1 - c\Delta T)$$

$c = 6.5x10^{-3}\ K^{-1}$

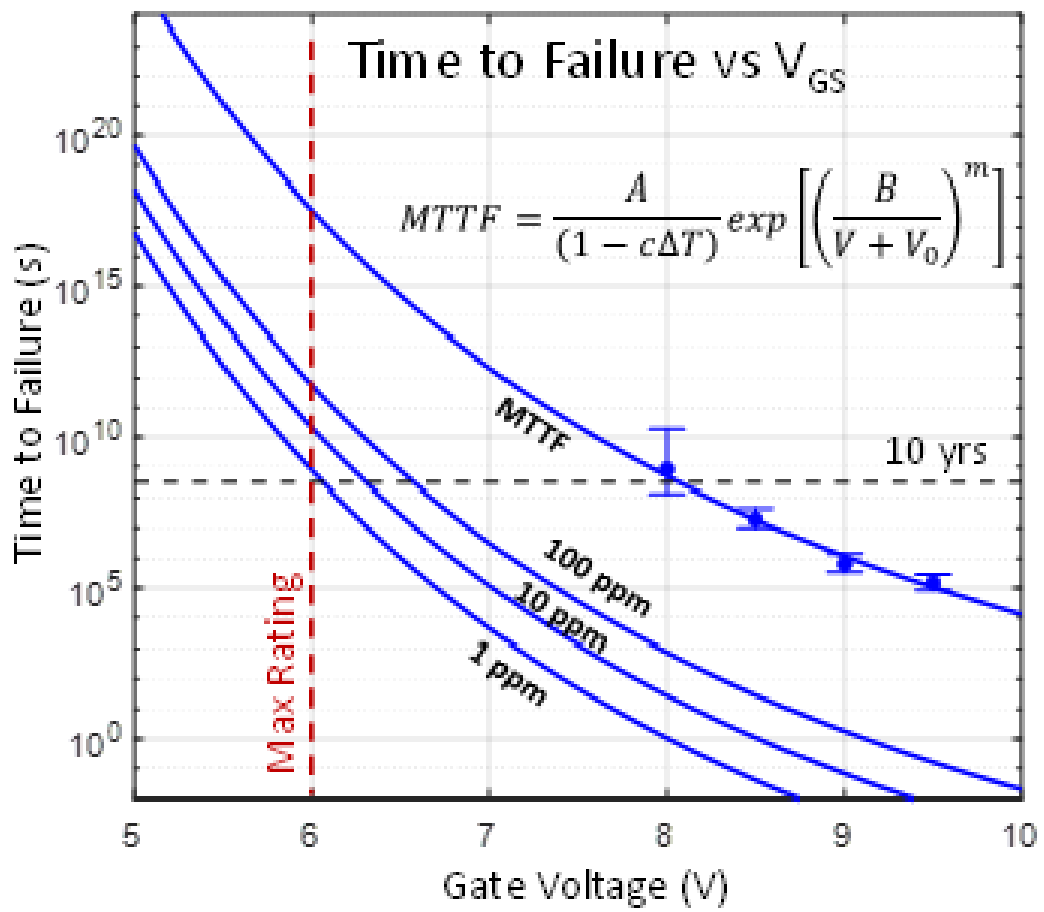
$$MTTF \propto \frac{Q_c}{G}$$

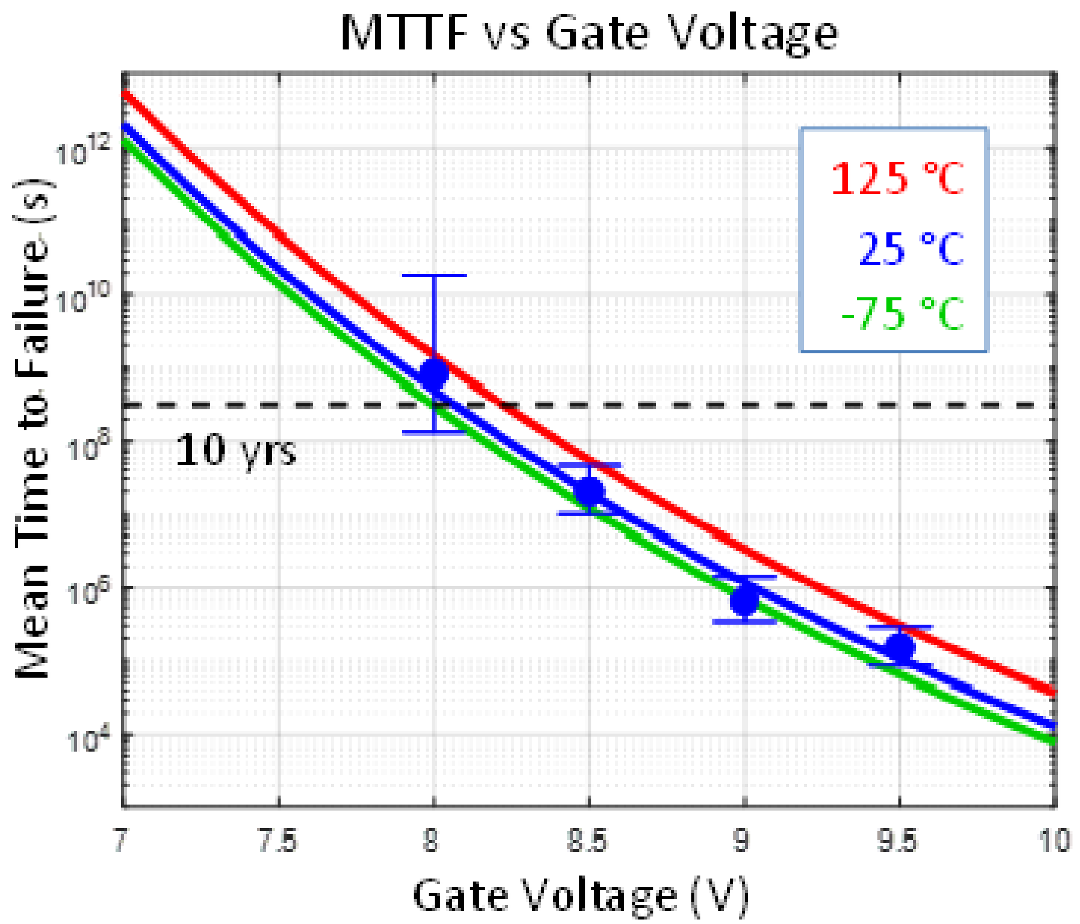
$$MTTF \propto \frac{Q_c}{G} = \frac{qQ_c}{\alpha_n J_n} = \frac{qQ_c}{J_n a_{n,0}(1-c\Delta T)} exp\left[\left(\frac{b_n}{F}\right)^m\right]$$

$$MTTF = \frac{Q_c}{G} = \frac{qQ_c}{\alpha_n J_n} = \frac{A}{(1-c\Delta T)} exp\left[\left(\frac{B}{V+V_0}\right)^m\right]$$

$m = 1.9$
$V_0 = 1.0\ V$
$B = 57.0\ V$
$A = 1.7x10^{-6}\ s$
$c = 6.5x10^{-3}\ K^{-1}$

Theory vs. Experimental Results





$$MTTF(V_{GS}, \Delta T) = \frac{A}{(1 - c\Delta T)} exp\left[\left(\frac{B}{V_{GS} + V_0}\right)^m\right]$$

$m = 1.9$

$V_0 = 1.0\ V$

$B = 57.0\ V$

$A = 1.7x10^{-6}\ s$

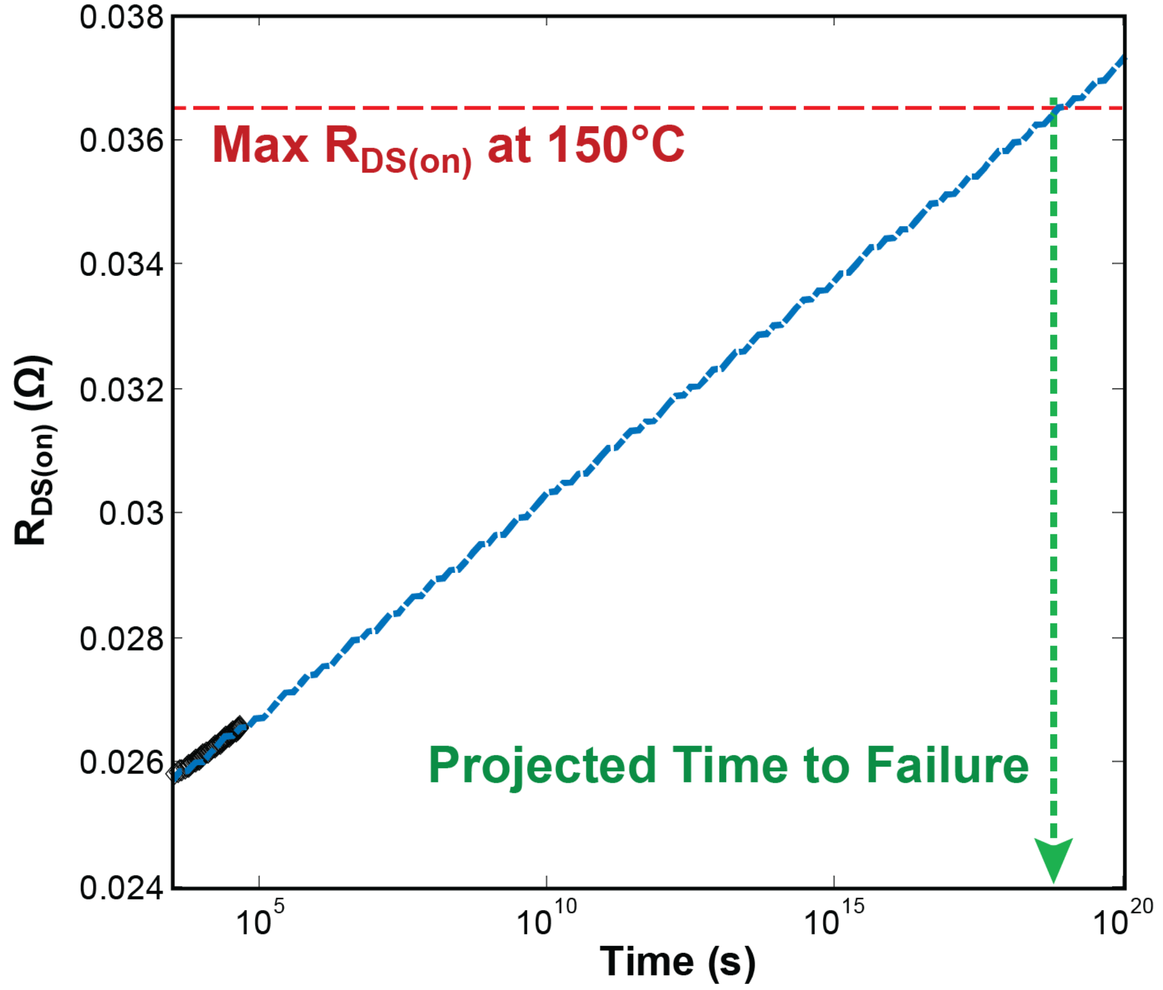
$c = 6.5x10^{-3}\ K^{-1}$

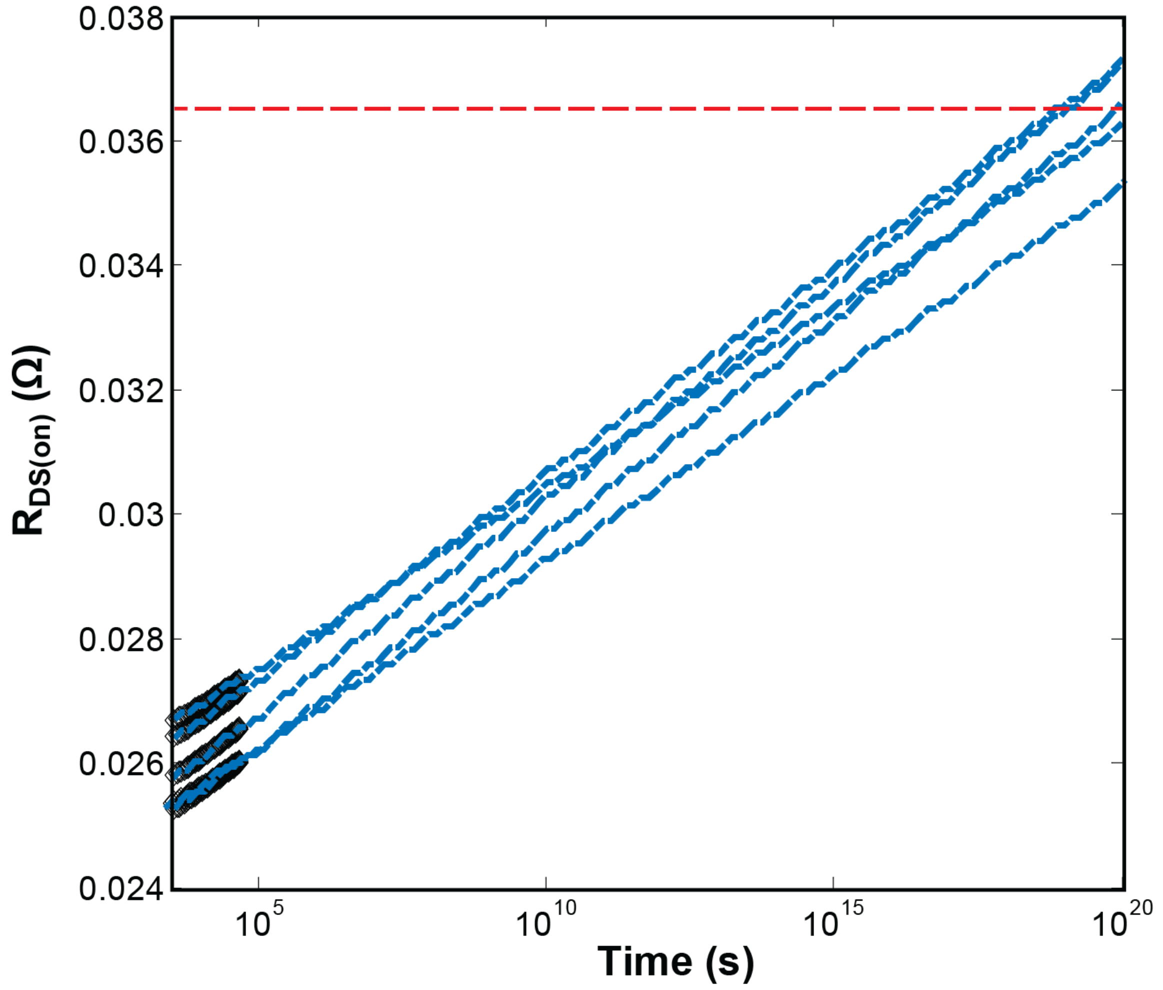
Stress – Voltage

Drain-Source

Characterizing $R_{DS(on)}$ Shift in Time

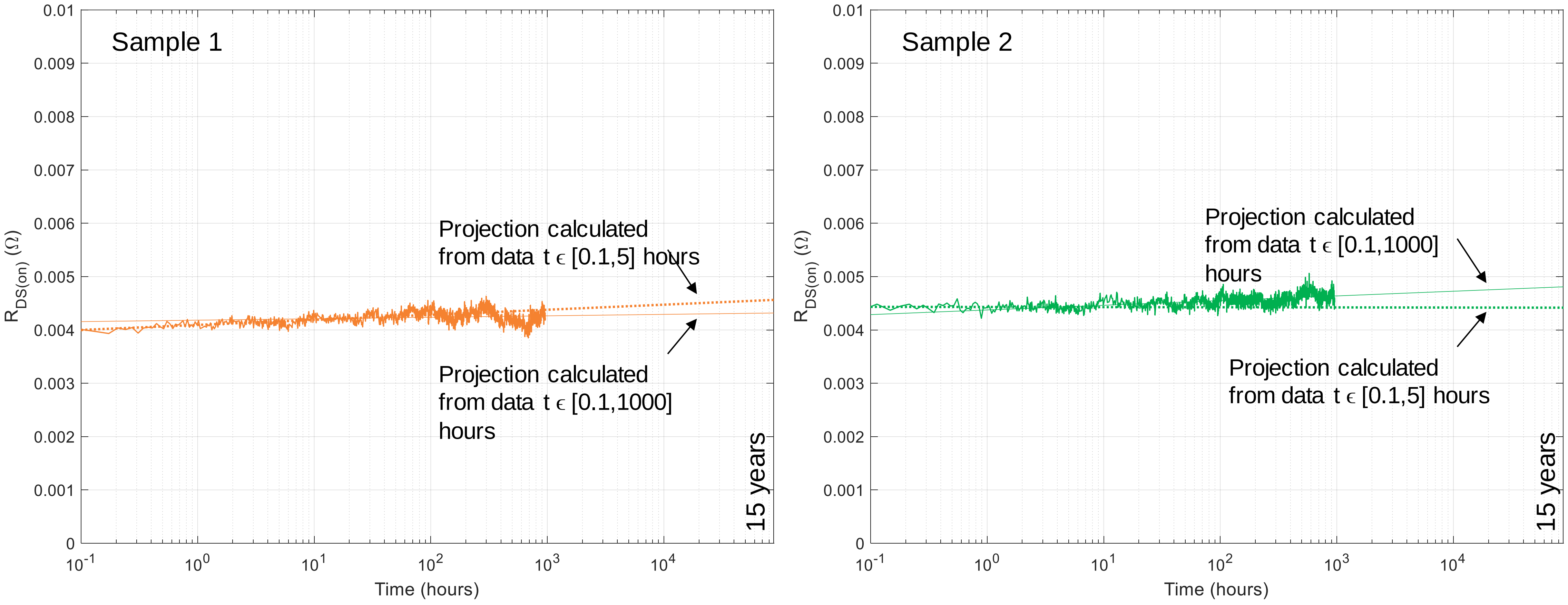
120 V overstress at 150°C (100 V Rated Device)



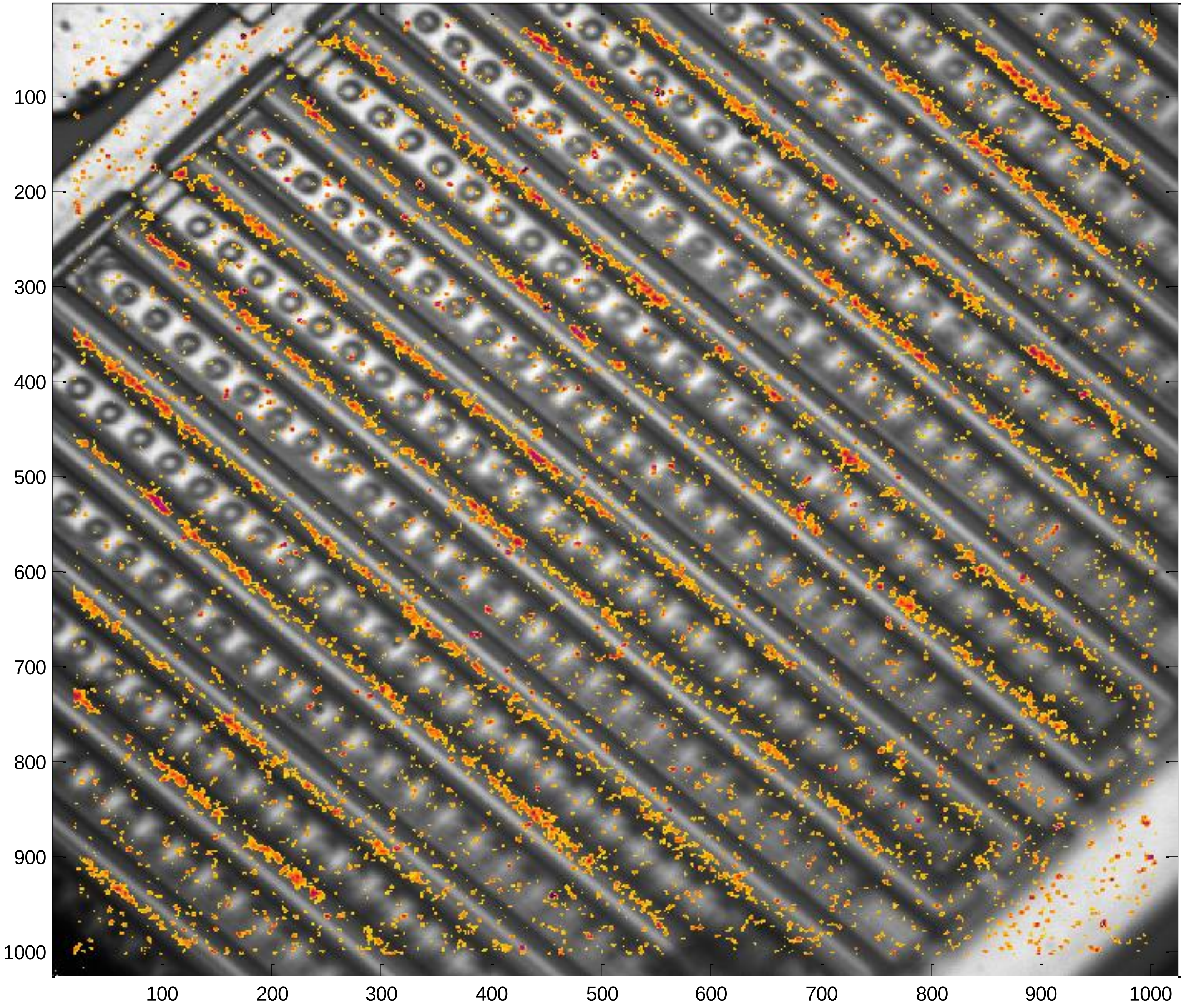


$$R(t) = R_0 (\alpha + \beta \ln[t])$$

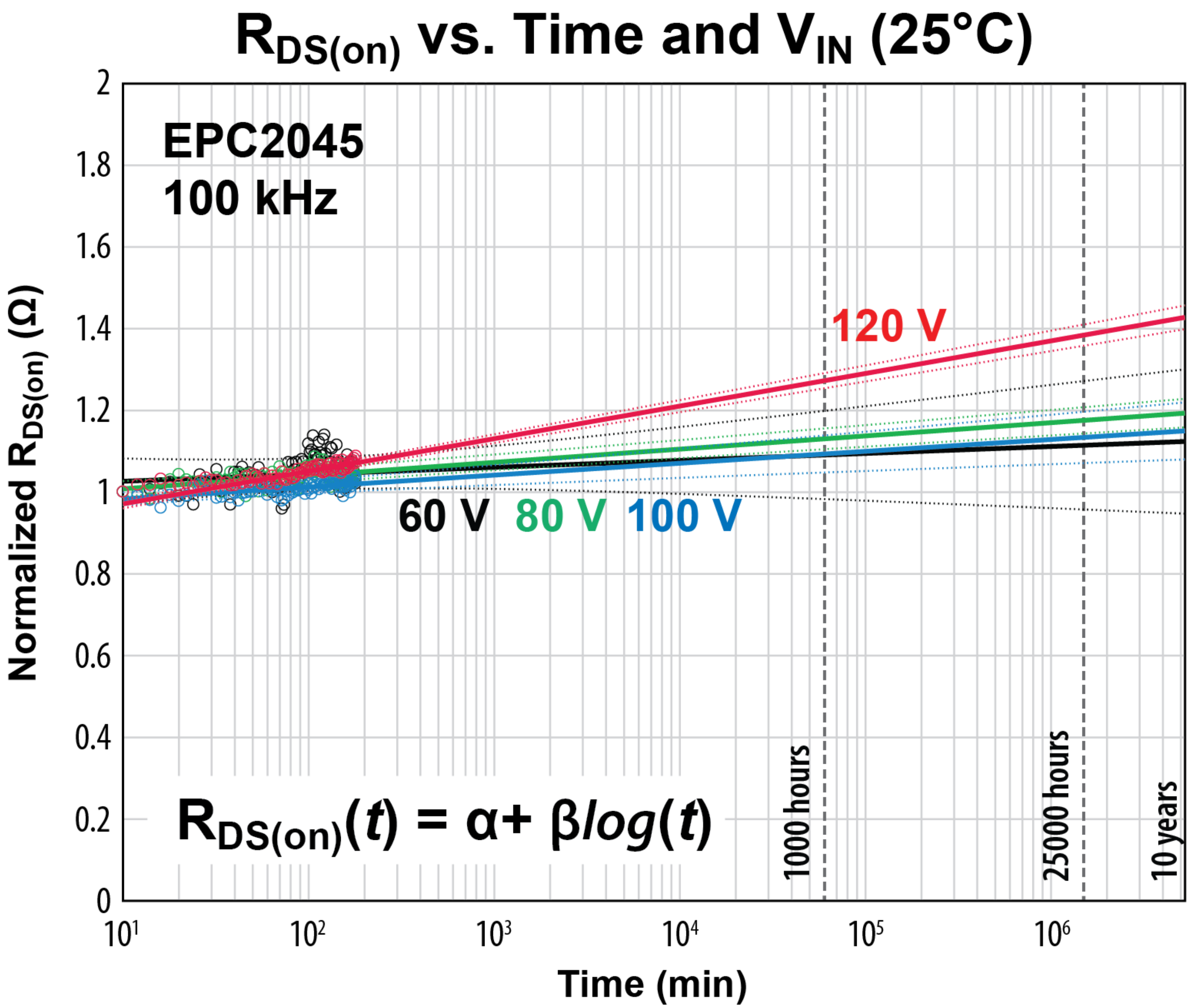
$R_{DS(on)}$ Projection Analysis

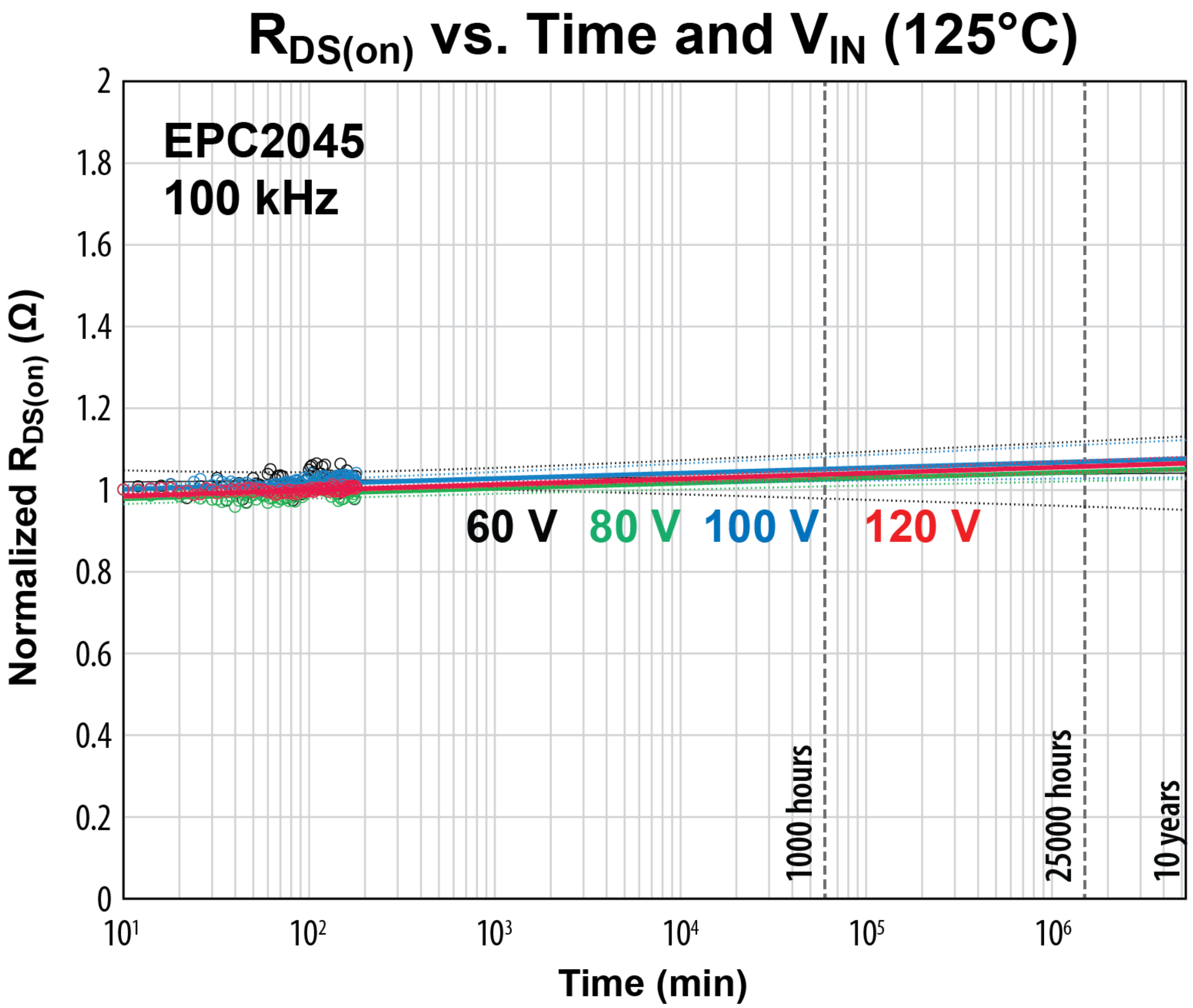


Physics of $R_{DS(on)}$ Shift – Hot Carrier Emission

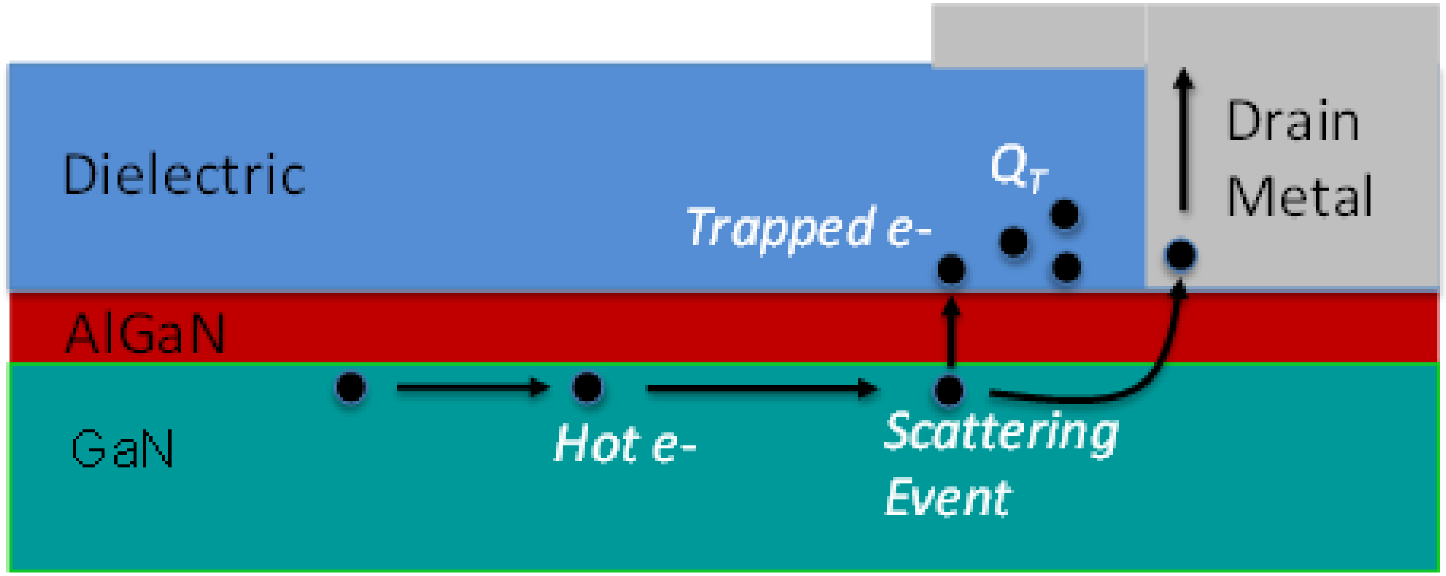


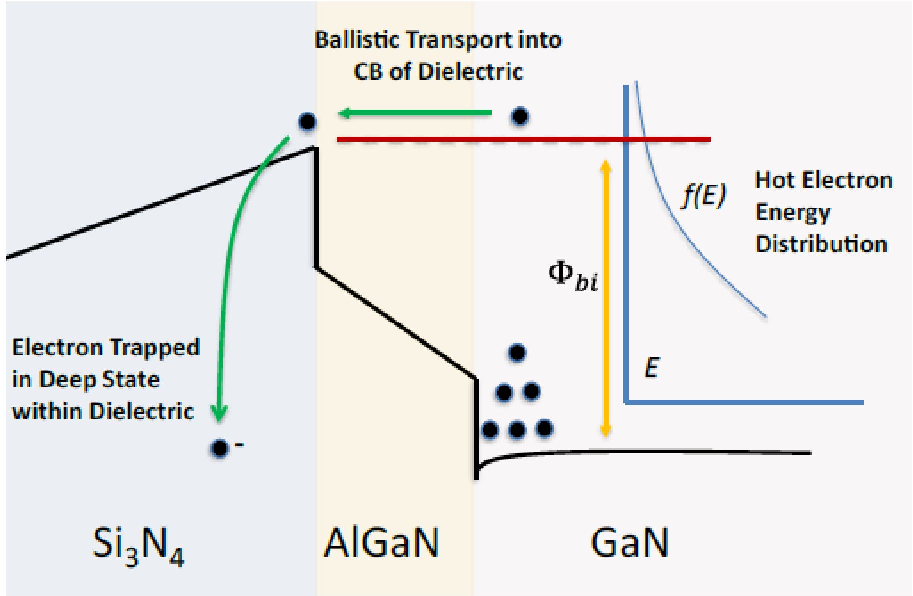
Hard-Switching: Effect of V_{IN}





Hot Carrier Trapping Mechanism





Hot Carrier Trapping Model

$$f(E)dE \propto Ee^{-E/qF\lambda}dE \qquad \frac{dQ_S}{dt} = A\int_{\Phi_{bi}+\beta Q_S}^{\infty} f(E)dE = A\int_{\Phi_{bi}+\beta Q_S}^{\infty} Ee^{-E/qF\lambda}dE \qquad \frac{dQ_S}{dt} = B\exp\left(-\frac{\beta Q_S}{qF\lambda}\right)$$

$$Q_S(t) = \frac{qF\lambda}{\beta}\log\left(1+\frac{B\beta}{qF\lambda}t\right) \qquad R(t) = R_0 + \frac{C}{Q_P - Q_S} = R_0 + \frac{C}{Q_P - \frac{qF\lambda}{\beta}\log\left(1+\frac{B\beta}{qF\lambda}t\right)}$$

$$R(t) \approx R_0 + \frac{C}{Q_P}\left[1+\frac{qF\lambda}{Q_P\beta}\log\left(1+\frac{B\beta}{qF\lambda}t\right)\right] \qquad \tau_{LO} \propto exp\left(\frac{\hbar\omega_{LO}}{kT}\right) \quad \lambda = v_{th}\tau_{LO} \propto A\sqrt{kT}exp\left(\frac{\hbar\omega_{LO}}{kT}\right)$$

$$\frac{\Delta R}{R} = \frac{R(t)-R(0)}{R(0)} \approx a + bF\exp\left(\frac{\hbar\omega_{LO}}{kT}\right)\sqrt{T}\log(t)$$

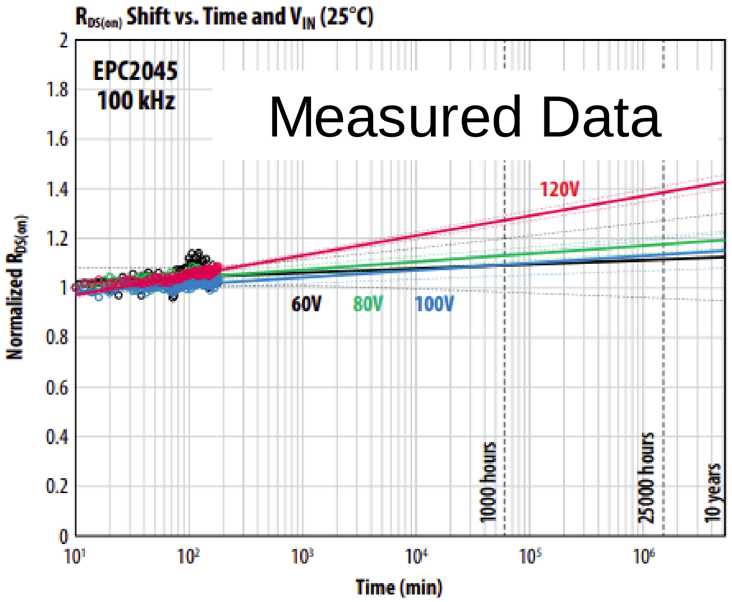
Putting it All Together – Hot Carrier Trapping Model

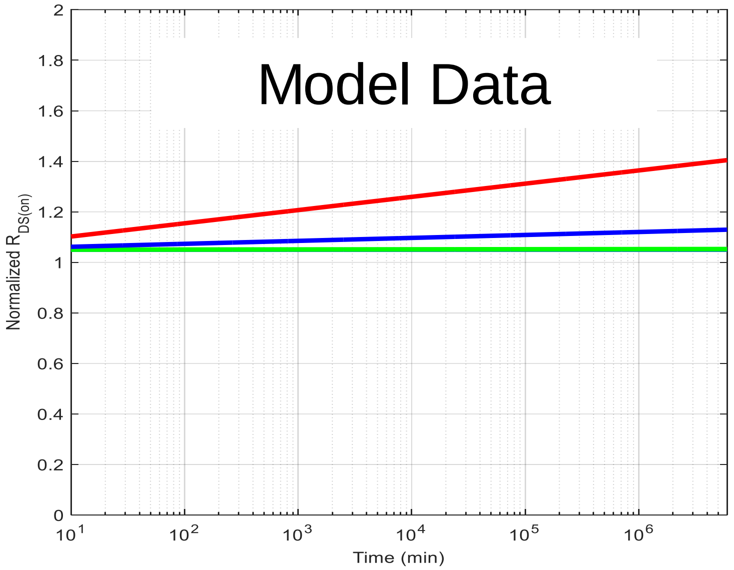
$$\frac{\Delta R}{R} = \frac{R(t) - R(0)}{R(0)} \approx a + bF\exp\left(\frac{\hbar\omega_{LO}}{kT}\right)\sqrt{T}\log(t)$$

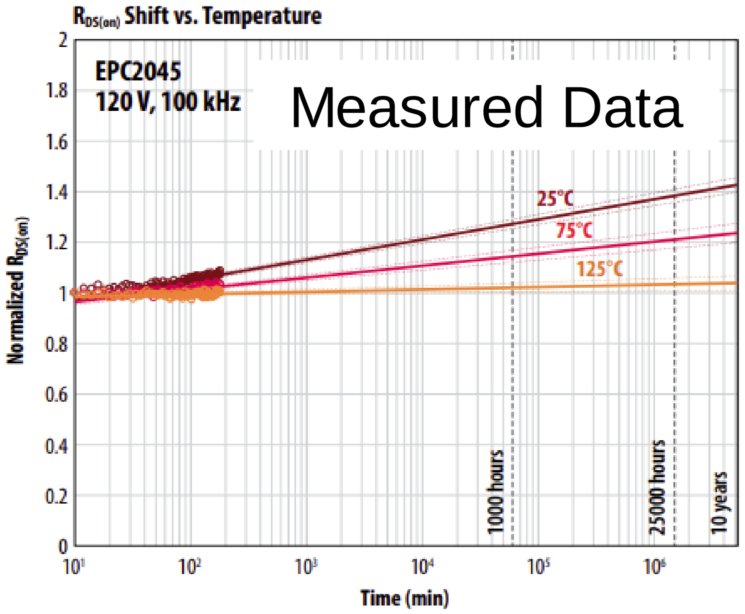
$$= a + b\left[\frac{V_{DS}}{1 + exp[-\alpha(V_{DS} - V_{FD})]}\right]^2 exp\left(\frac{2\hbar\omega_{LO}}{kT_l}\right)\log(t)$$

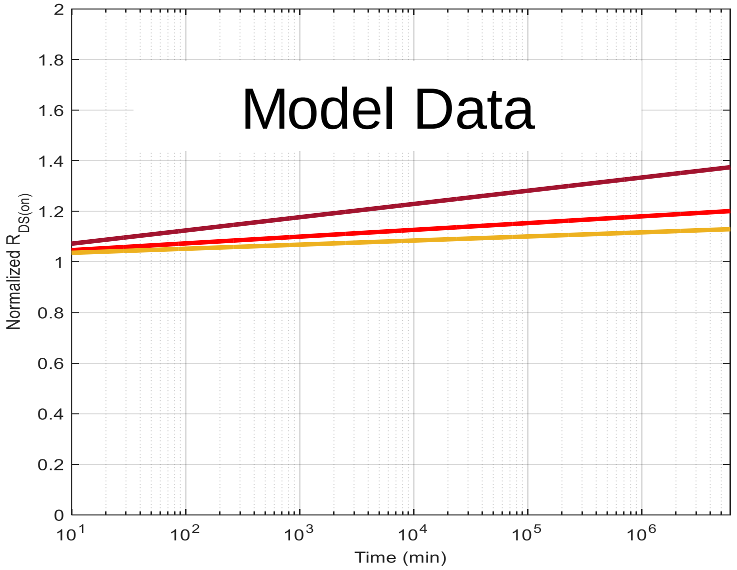
a = 0.02 (unitless)
b = 1.9E-8 (V^{-2})
$\hbar\omega_{LO}$ = 92 meV
V_{FD} = 100V (appropriate for Gen5 100V products only)
α = 0.1 (V^{-1})
t = time in min

Model vs Measurement









Stress – Thermo Mechanical

Thermo-Mechanical Stress

-40˚C to 125˚C Temperature Cycling results for EPC2053

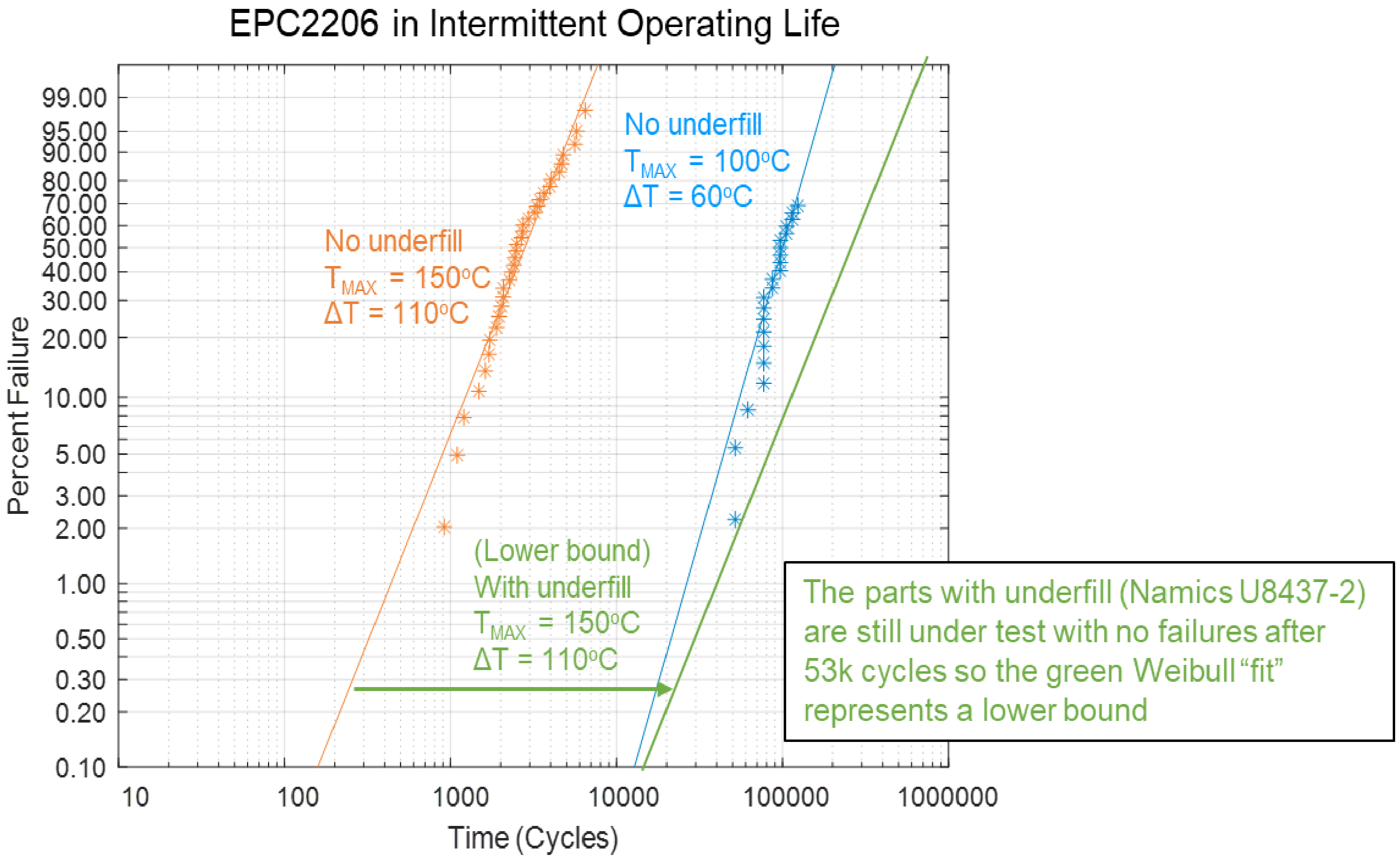
Product/DOE	EPC2053										
Stress condition: -40℃ to 125℃	Status	300 cycles	550 cycles	850 cycles	1000 cycles	1250 cycles	1550 cycles	1750 cycles	1950 cycles	2150 cycles	2450 cycles
No Underfill	Completed	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	2/32 fails	3/32 fails	3/32 fails	3/32 fails
Henkels UF1137_H	On-going	0/40 fail	0/40 fail	0/40 fail	0/40 fail	0/40 fail					
Masterbond EP3UF_M	On-going	1/40 fails	7/40 fails	15/40 fails	25/40 fails	39/40 fails					
MC7685-UFS	Completed	0/32 fail	0/32 fail	0/32 fail	1/32 fails	17/32 fails	32/32 fails	32/32 fails			
MC7885-UF	Completed	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	1/32 fails	1/32 fails	1/32 fails
Namics 8410-406B	Completed	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail
Namics U8437-2_N	Completed	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail	0/32 fail
	On-going	0/40 fail	0/40 fail	0/40 fail	0/40 fail	0/40 fail					

-55˚C to 155˚C Temperature Cycling results for EPC2053

Product/DOE		EPC2053				
Stress condition: -55C to 150C	Status	300 cycles	600 cycles	900 cycles	1100 cycles	1300 cycles
No Underfill	Completed	0/16 fail	0/16 fail	0/16 fail	0/16 fail	1/16 fails
Henkels UF1137_H	On-going	0/20 fail	0/20 fail	0/20 fail	0/20 fail	
Masterbond EP3UF_M	On-going	5/20 fails	15/20 fails			
MC7685-UFS	Completed	1/16 fails	9/16 fails	13/16 fails		
MC7885-UF	Completed	2/16 fails	1/16 fails	7/16 fails		
Namics 8410-406B	Completed	0/16 fail	0/16 fail	0/16 fail	0/16 fail	0/16 fail
Namics U8437-2_N	Completed	0/16 fail	0/16 fail	0/16 fail	0/16 fail	0/16 fail

Thermo-Mechanical Stress

Intermittent Operating Life – EPC2206

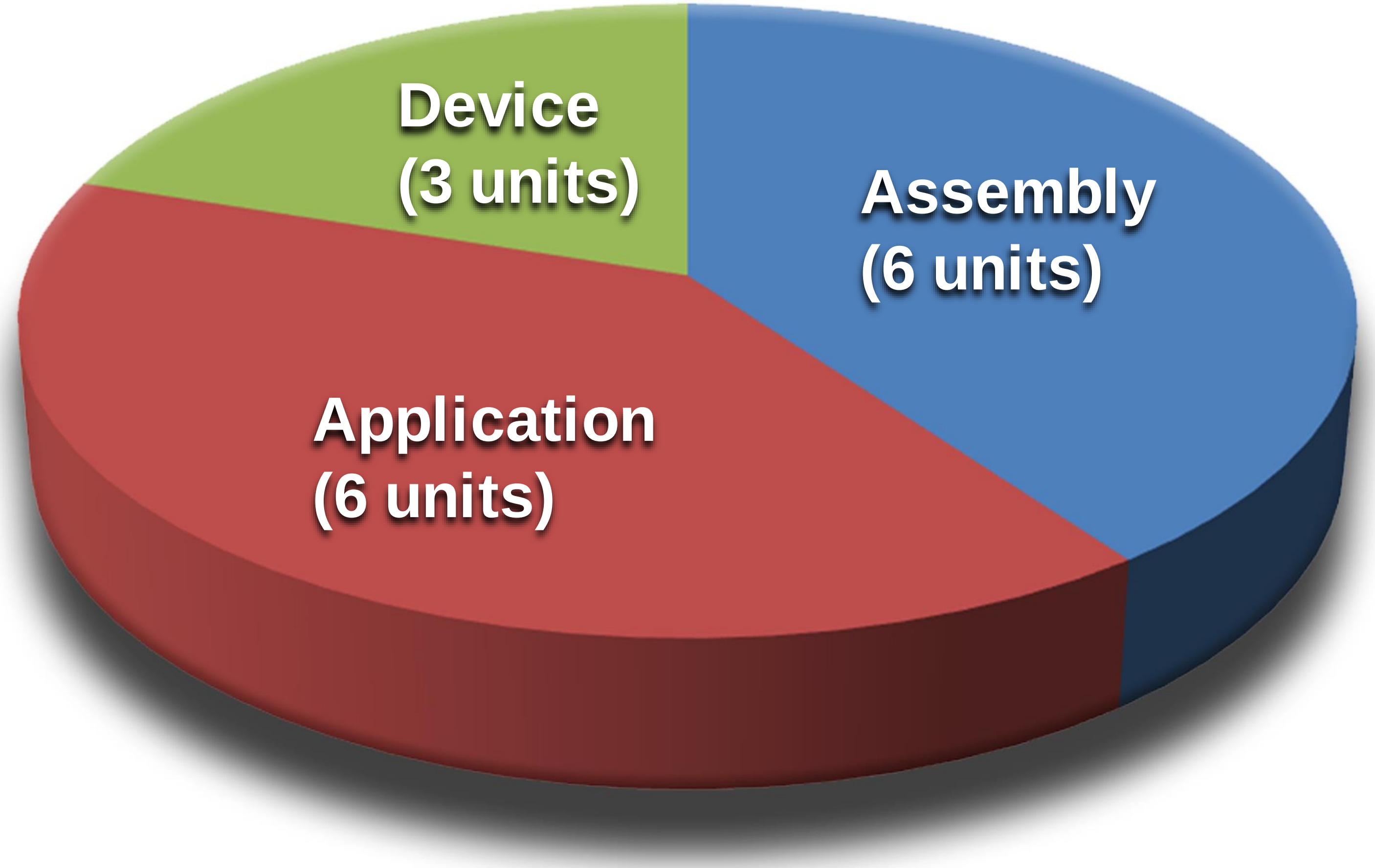


Results

eGaN FET Reliability

Field Failures by Category

1/1/2017– 12/31/2020

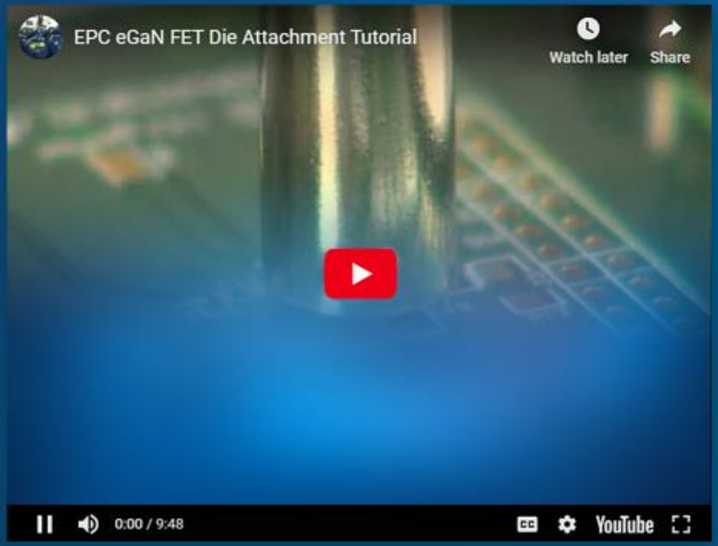


Proven Reliability – 226 billion device hours in the field since January 1, 2017 with only 3 device failures.

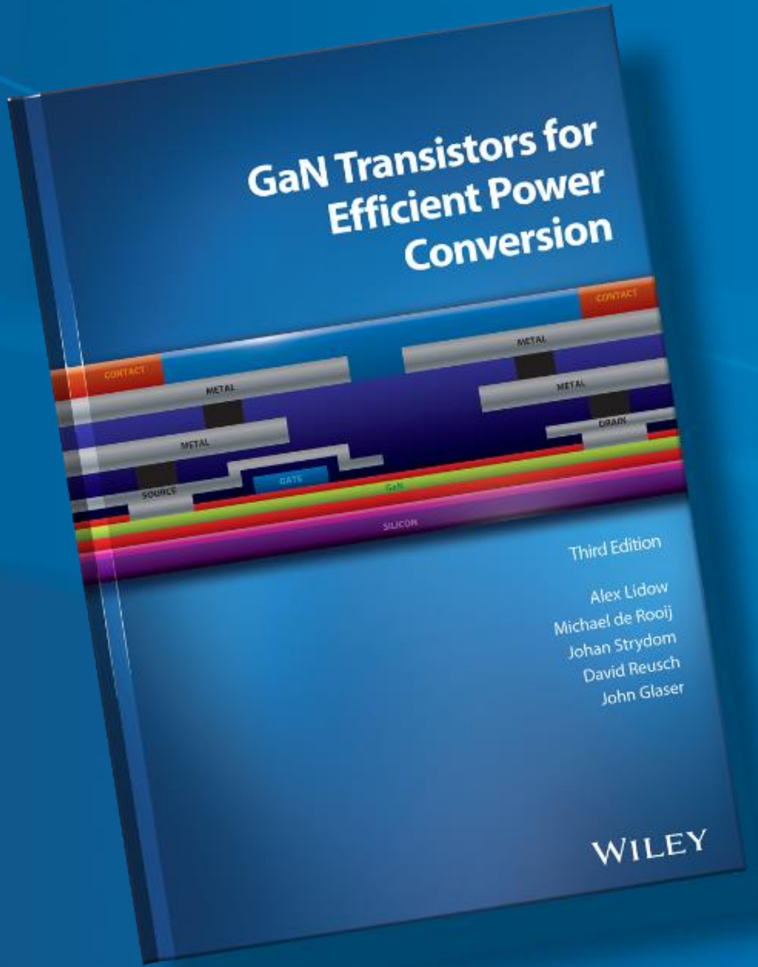
Conclusions

- Traditional MOSFET qualification testing needs to be modified for GaN.
- Modifications need to be based on a deep knowledge of intrinsic failure mechanisms.
- By characterizing intrinsic failure mechanisms over all stress conditions, users can have confidence in lifetime predictions for a given mission profile.

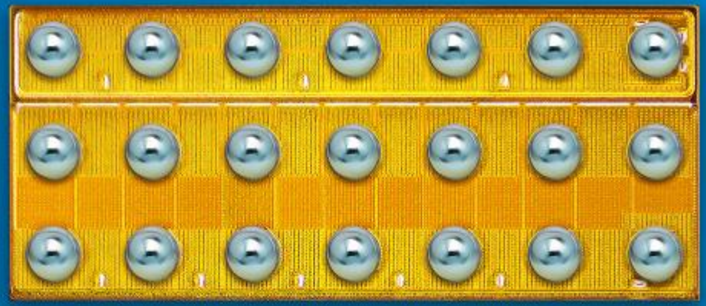
EPC
EFFICIENT POWER CONVERSION



How To GaN Video Series

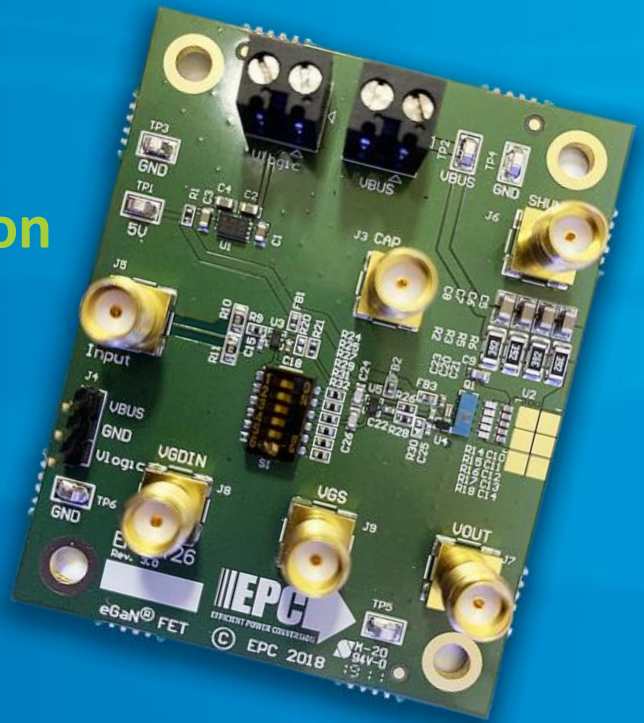


3rd Edition Textbook



eGaN® FETs and ICs

Evaluation Kits



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