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GaN-on-Si Reliability: A Comparative Study Between Process Platforms

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ROCS Workshop 2006
by

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Outline

- NRF1 Process Platform
  - Summary of NRF1 Process
  - NPT35050 Product Description
  - Comparison of NRF1 to Previous Process
- NRF1 Reliability Data
  - 3-temp DC Data
  - HTOL Data
  - RF Stress Data
  - VSWR Data
  - ESD Data
- Summary

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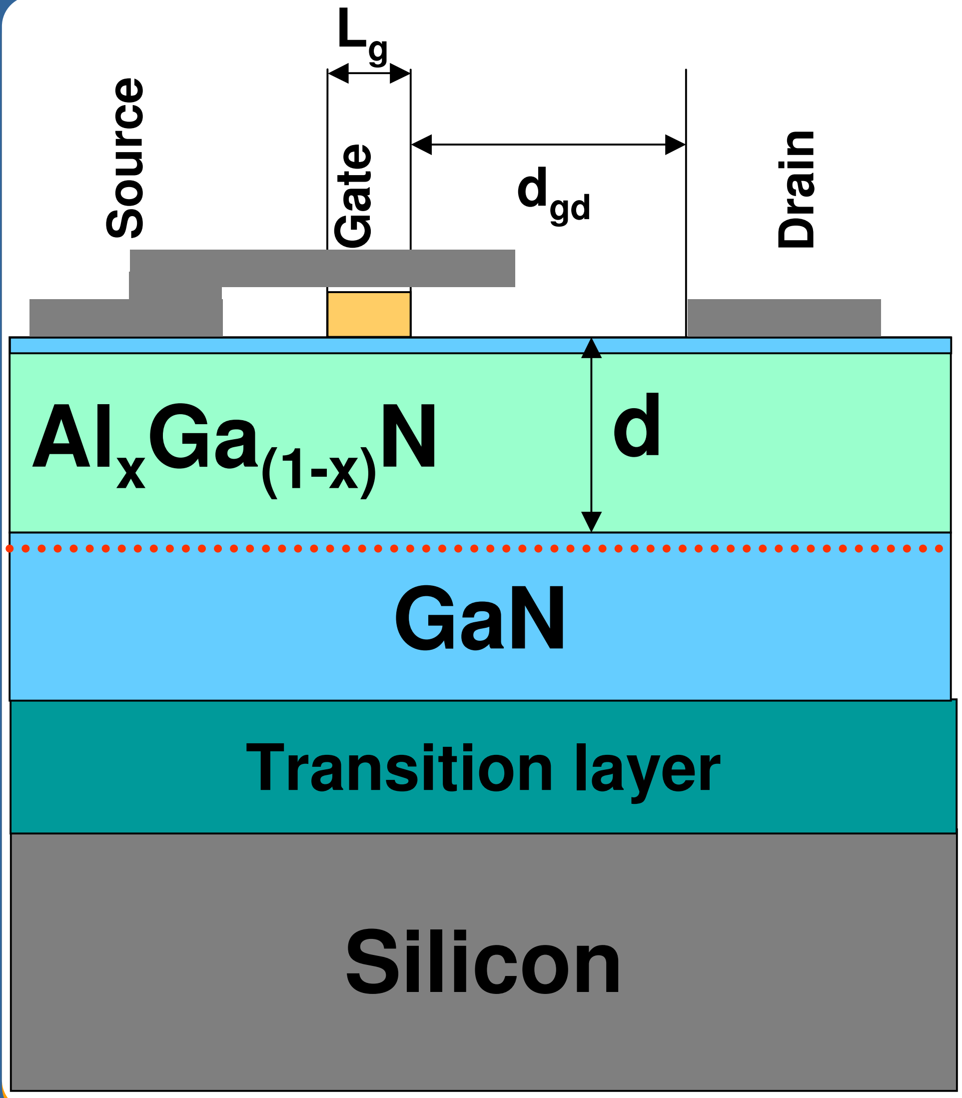
NRF1 Process Platform

NRF1 Technology Platform Attributes



- Gate Length (L_g) = .5 µm
- Gate-Drain Spacing (d_{gd}) =3 µm
- Gate-Pitch = 30 µm
- Unit gate width = 200 µm
- Source Field Plate employed
- Silicon wafer thinned to 6 mil
- Use 100mm (111) Float Zone Silicon for substrate

NRF1 Specification Limits

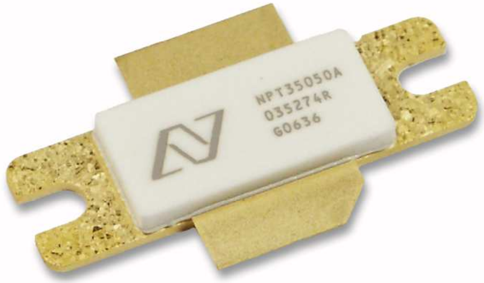
Parameter	Description	Units	LSL	TGT	USL
BVDG	Two Terminal Off-State Breakdown Voltage	V	135	160	-
BVDS	Three Terminal Off-State Breakdown Voltage	V	95	130	-
GMX	Maximum Extrinsic Transconductance	mS/mm	250	290	330
IDLK_100	Drain Leakage at V_{DS}=100V, V_{GS}=-8V	mA/mm	-	0.2	1.0
IDMAX	Maximum Open Channel Current	mA/mm	760	830	900
LOG_ISO	Isolation Leakage Current - LOG10	Log(A)	-	-9	-8
RC_TLM	Contact Resistance	Ohm mm	-	0.38	0.55
RDON	On Resistance	Ohm mm	2.4	3.0	3.6
RSH_CRBME	Epitaxial Layer Sheet Resistance	Ohm/sq	440	490	530
VP	Pinchoff Voltage	V	-1.50	-1.25	-1.00
NPSAT_W_MM	Saturated Output Power	W/mm	3.4	3.9	-
DEFF_MAX	Maximum Drain Efficiency	%	57	62.5	-

- Transitioned to new NRF1 technology in Oct. ‘05.
- To date >200 wafers have been processed with high yield versus specification limits above.
- Five high power RF products have been developed using this process platform.

NRF1 Based RF Products

WiMax Product Family

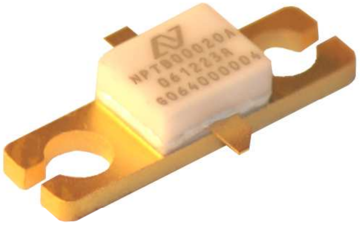
NPT35015



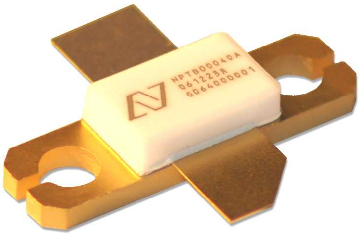
NPT35050*

NPT25015

Broadband Product Family



NPTB00025



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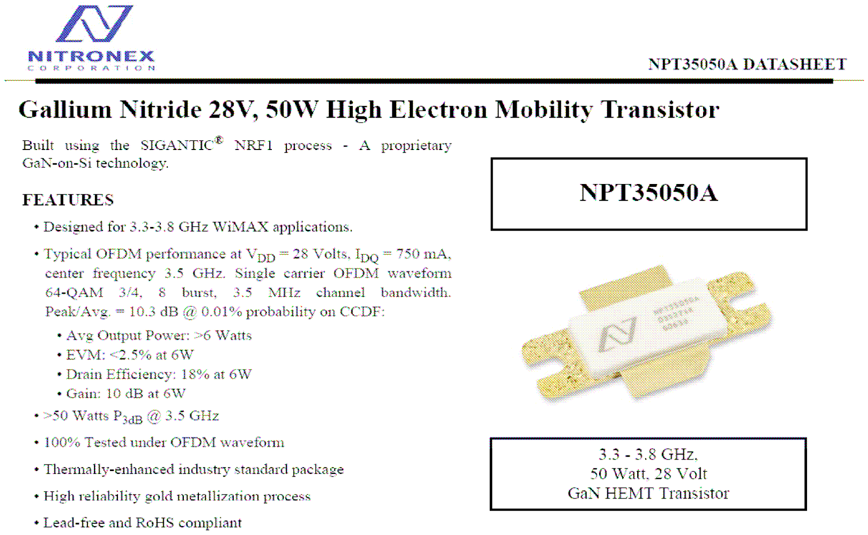
* NPT35050 used for process qual

NPT35050 Product



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NPT35050A DATASHEET

Gallium Nitride 28V, 50W High Electron Mobility Transistor

Built using the SIGANTIC® NRF1 process - A proprietary GaN-on-Si technology.

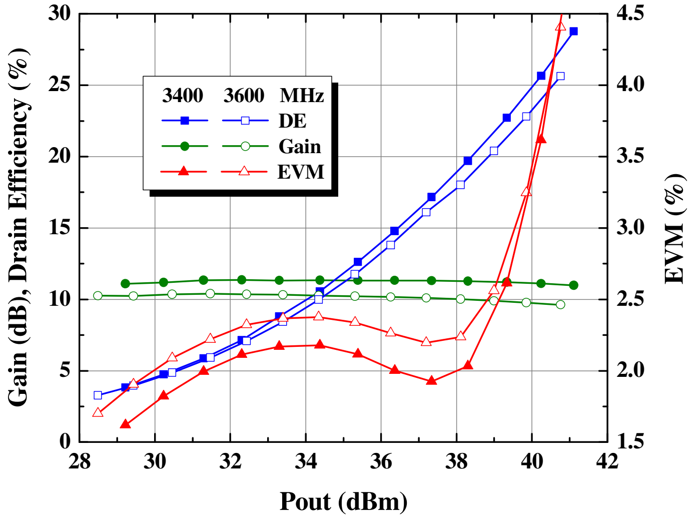
NPT35050A

FEATURES

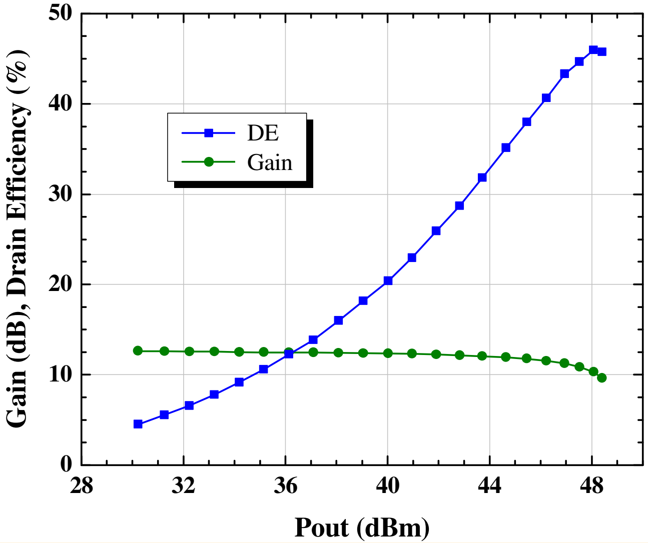
- Designed for 3.3-3.8 GHz WiMAX applications.
- Typical OFDM performance at V_{DD} = 28 Volts, I_{DQ} = 750 mA, center frequency 3.5 GHz. Single carrier OFDM waveform 64-QAM 3/4, 8 burst, 3.5 MHz channel bandwidth. Peak/Avg. = 10.3 dB @ 0.01% probability on CCDF:
  - Avg Output Power: >6 Watts
  - EVM: <2.5% at 6W
  - Drain Efficiency: 18% at 6W
  - Gain: 10 dB at 6W
- >50 Watts P_{3dB} @ 3.5 GHz
- 100% Tested under OFDM waveform
- Thermally-enhanced industry standard package
- High reliability gold metallization process
- Lead-free and RoHS compliant

3.3 - 3.8 GHz,
50 Watt, 28 Volt
GaN HEMT Transistor

EVM Performance



CW Performance



Process Comparison

	PH7	NRF1
Epitaxial Commodity	01038-4	04001-0
Gate Length	0.7μm	0.5μm
Configuration	standard	source-plate
Gate Anneal	No	Yes
Encapsulation Process	SiNx 90/400nm	SiNx 90/400nm
Die Thickness	6mil	6mil

- Several key changes for NRF1 process versus previous generation, PH7 process.
  - PH7 reliability reported on at 2005 ROCS workshop.

NRF1 Process Qualification (Comparison to PH7)

Test Name	Test Standard	PH7 Sample Set	NRF1 Sample Set
DC-HTOL	JESD22-A108	30 Devices, 1000 hours	45 devices, 1000 hours
3-Temp DC	JEP118-B	10 Devices/Temp @ 260, 285, and 310°C	30 Devices/Temp @ 260, 285, and 310°C
RF-HTOL	JESD22-A101-A	8 Devices, 500 hours	6 Devices, 500 hours
ESD-HBM	M-750-1020	30	36
ESD-MM	M-750-1020	30	36
Thermal Impedance	–	10	36
Autoclave	JESD22-A102	10	45
VSWR	–	10	36
Temp. Cycling	JESD22-A104	--	45
Thermal Shock	M-750-1056	--	15
Solderability	JESD22-B102	--	4
Mech. Shock	M-883-2002	--	38
Vibration	M-883-2007	--	38
Const. Acceleration	M-883-2001	--	38
Moisture Res.	M-883-1004	--	38
Salt Atmosphere	M-883-1009	--	15
Solvent Res.	M-833-2015	--	15
Bond Strength	M-750-2037	--	15

- All PH7 reliability tests being repeated on NRF1 process with substantial increases in sample size (from 1.5x to 3x).
- Additionally 10 new tests being performed on NRF1 baseline.

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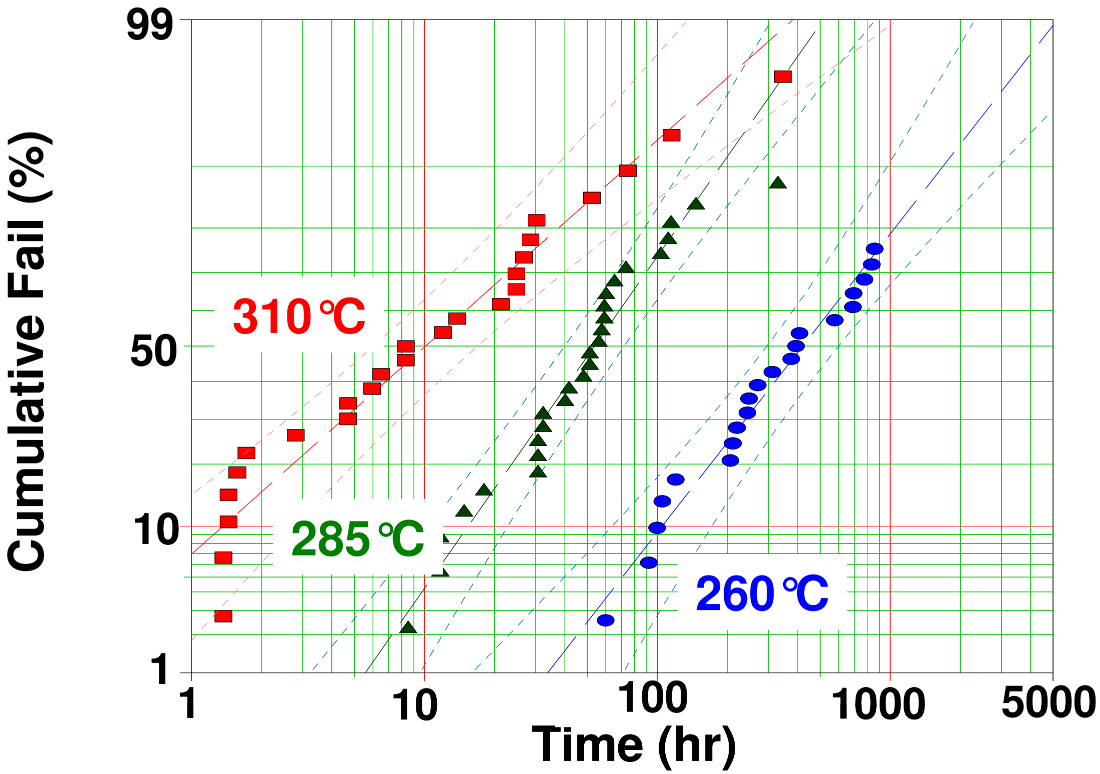
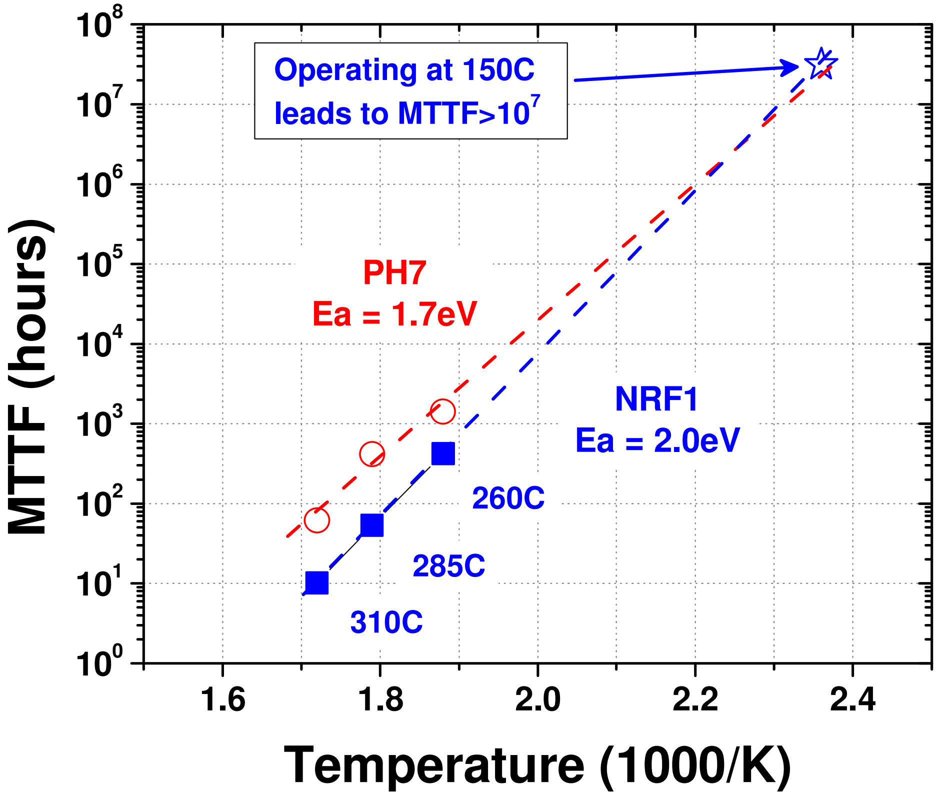
Reliability Data

3-Temperature DC LifeTest



- Data shown from 260℃, 285℃ and 310℃ life test with 30 devices per test group.
  - Failure defined as 15% drift in in-situ drain current.
- MTTF decreases with temperature as expected.

Arrhenius Plot of Activation Energy



Operating at 150C leads to MTTF>10^7

PH7

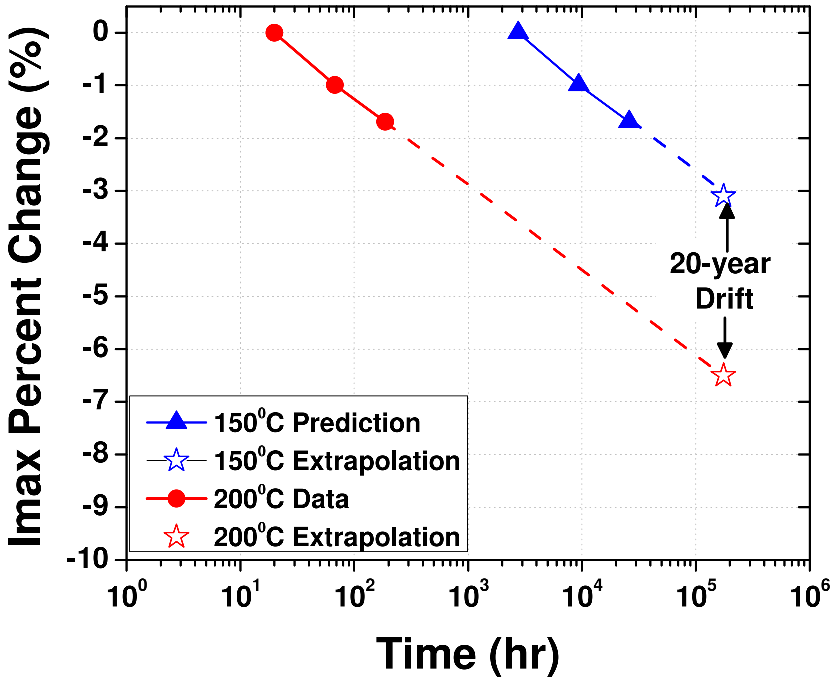
$y = 7E\text{-}14 * e^{20113x}$
R2 = 0.9967
Ea=1.7eV

NRF1

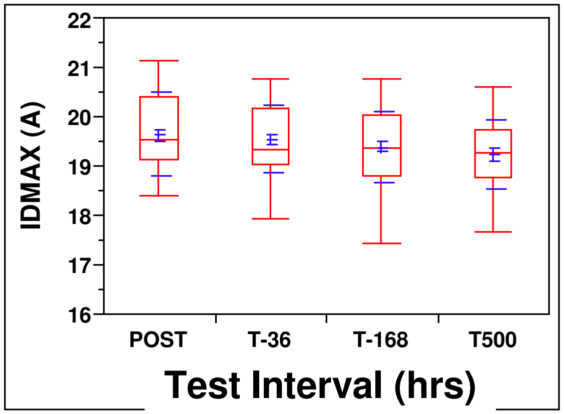
$y = 5E\text{-}17 * e^{23192x}$
R2 = 0.9988
Ea = 2.0eV

- NRF1 shows increased activation energy of 2.0eV versus 1.7eV for PH7.
- Both technologies show MTTF >10^7 hours at T_J=150℃.

20-Year Operating Life Extrapolation: Idss

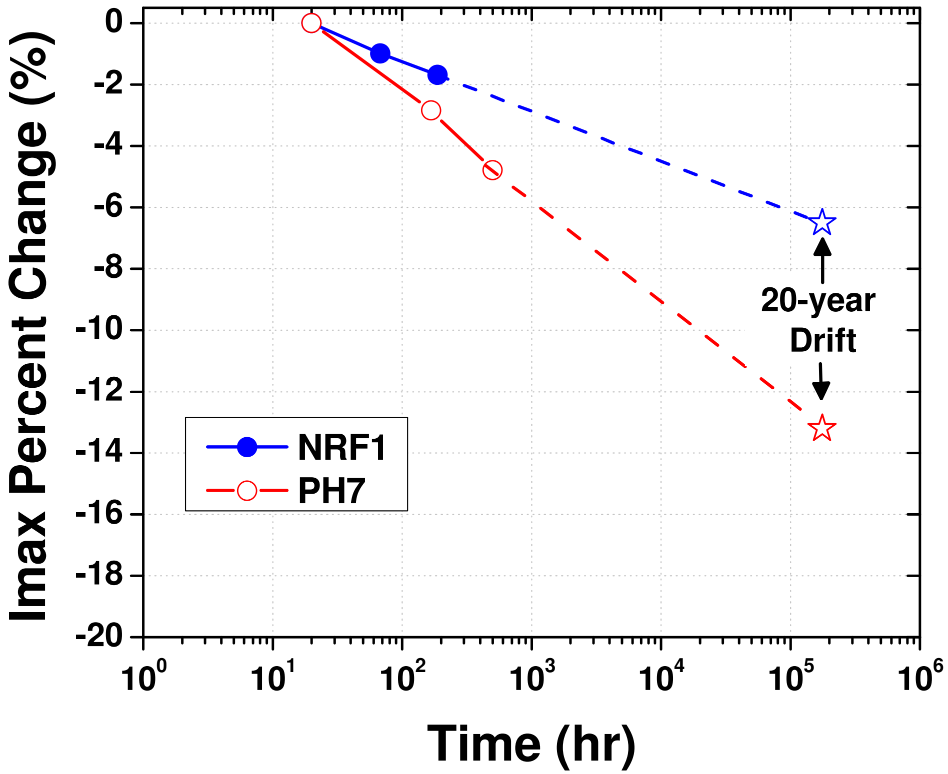


- Log fit to data yields 20 year drift <7% at stress temperature of 200℃.
- After applying acceleration factor, drift is ~3% at use temperature of 150℃.
  - Assumes E_a of 2.0 eV.



- Data consistent with drift predictions from previous 5 HTOL tests.
  - To date over 200 devices and 200,000 device hours of DC-HTOL

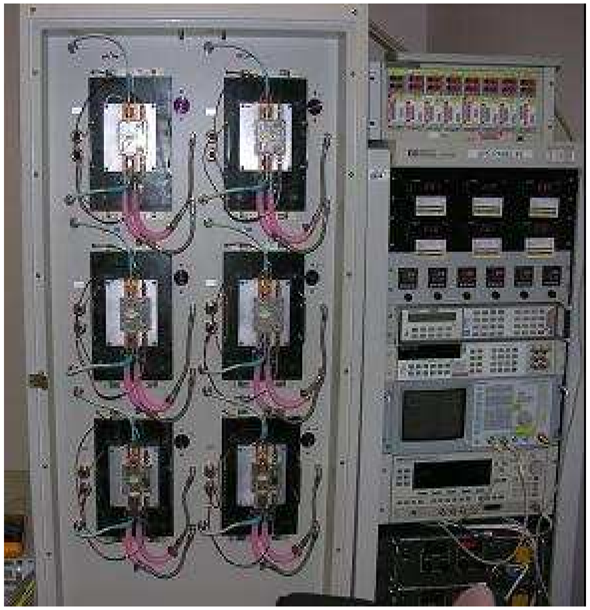
DC-HTOL Comparison @ T_J = 200°C



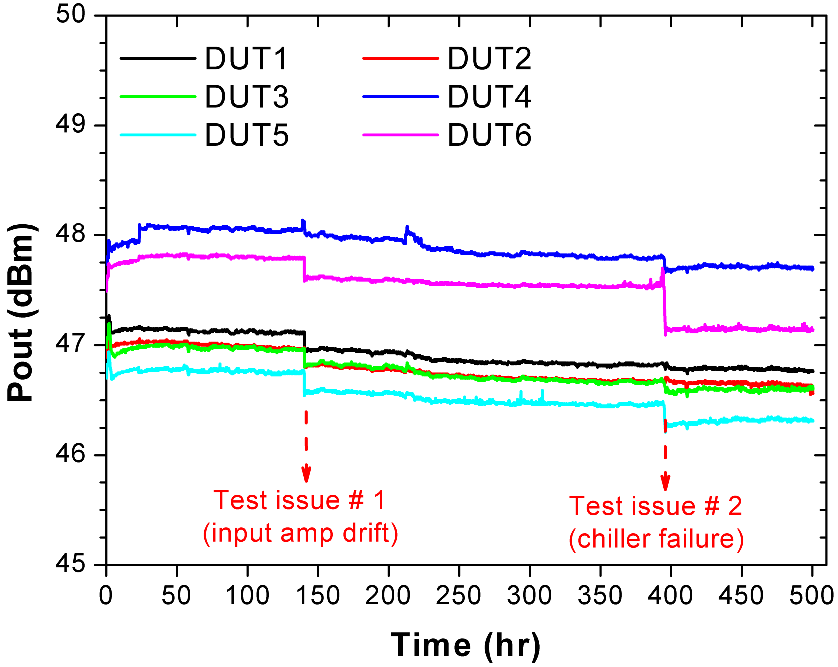
- NRF1 shows 50% improvement in 20-year drift rate when compared to previous PH7 technology.
- Confirms process improvement from implementation of gate anneal shown last year.

RF-HTOL Results

RF Lifetest System @ NSWC Crane

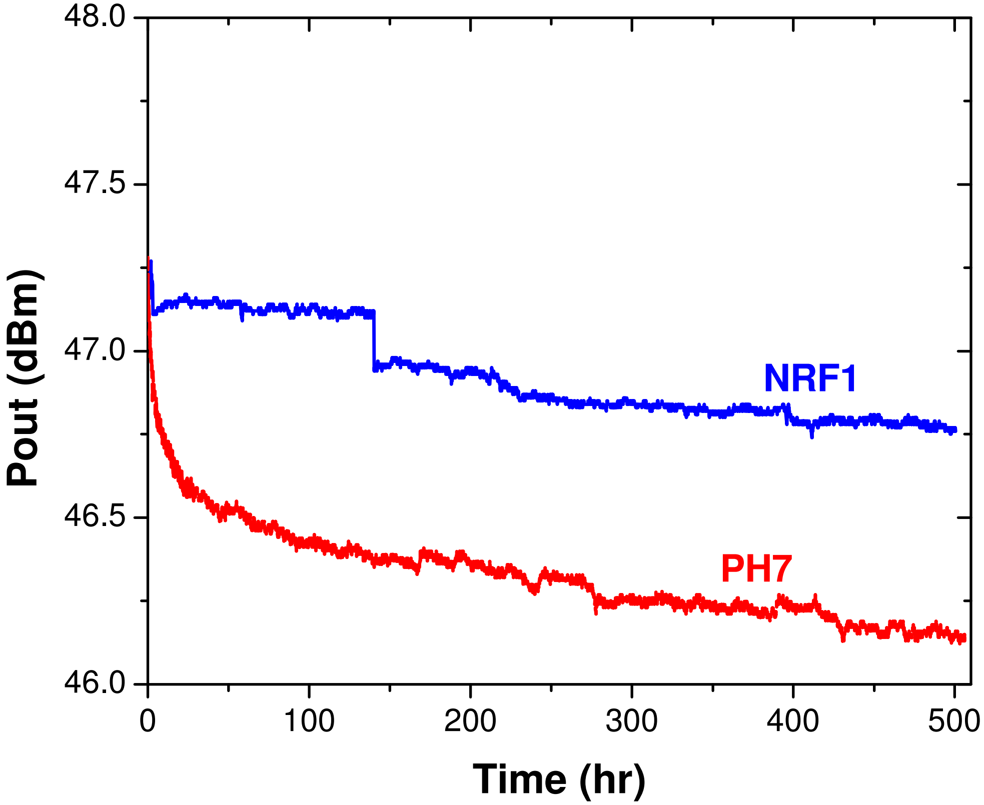


In-Situ Psat drift



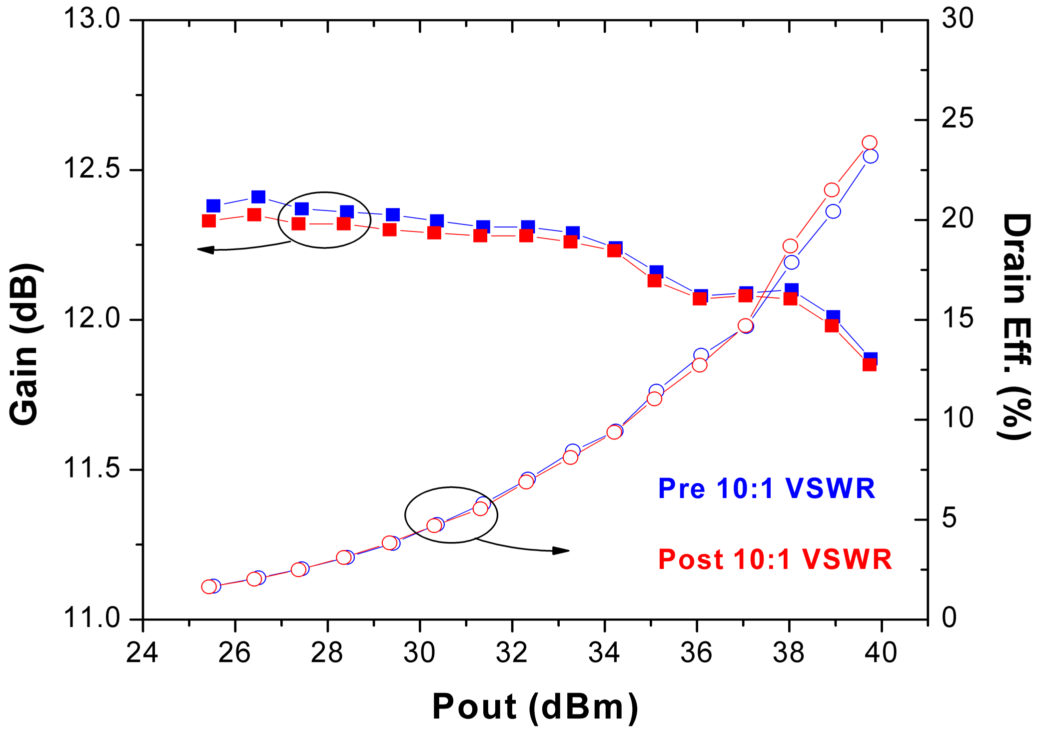
- RF-HTOL testing performed on 6 devices.
  - Freq = 2.14GHz, Pout = 3dB compression (~47dBm), Tj = 200℃.
- 2 Test issues:
  - 130 hours input amp drift
  - 390 hours chiller fail (caused Tj upto 400C for 10-20min) all devices recover within 0.2dB except DUT 6, 0.5dB drift.

RF-HTOL Comparison



- NRF1 technology shows less drift under RF-HTOL conditions, consistent with prediction from DC-HTOL.

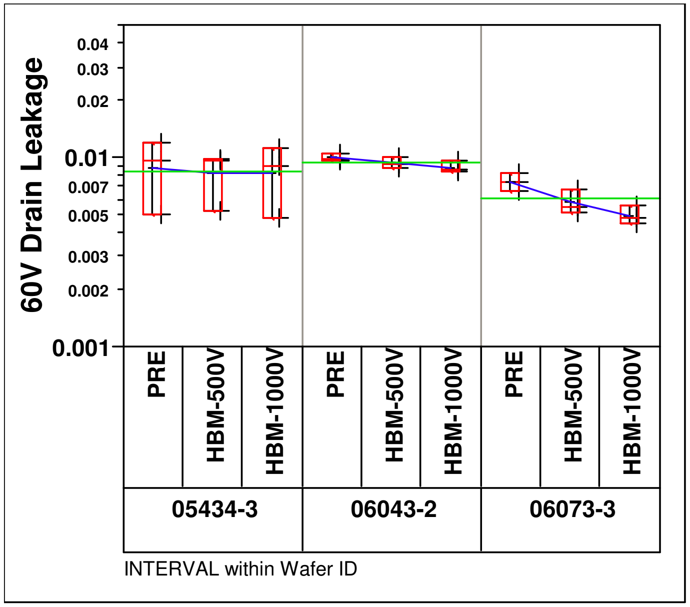
VSWR Robustness Testing



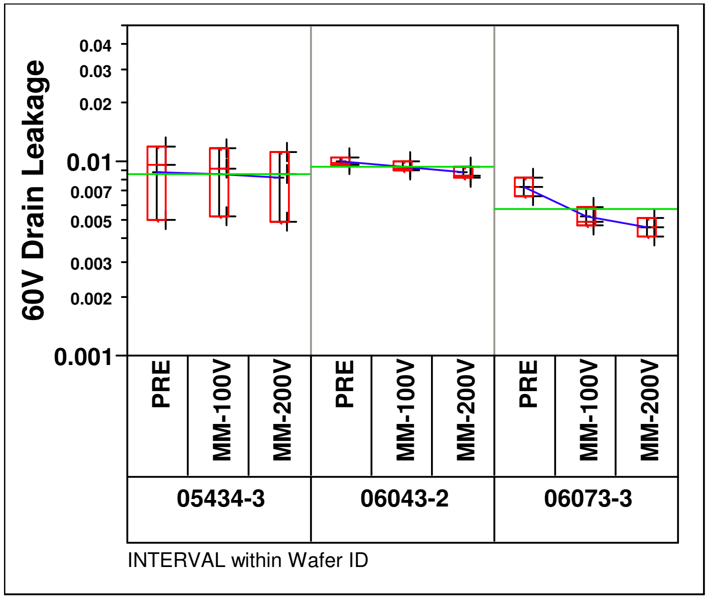
- 5 devices stressed with 10:1 VSWR mismatch on output of device.
  - Output power of 38dBm under OFDM signal.
  - Line Stretcher used to rotate through all angles.
- Typical power sweep shows no degradation in performance.
- Similar to results seen on PH7.

ESD Results

Human Body Model (HBM)



Machine Model (MM)



- For each voltage, all pin combinations were stressed with 3 pulses according to JESD22-A114 and A115.
- Testing across 3 different process and assembly lots (3 DUTs/lot).
  - HBM: No failures at 1000V → class 1C.
  - MM: No failures at 200V → class M3.
- Similar performance to that seen on PH7.

Summary

- NRF1 process developed and released to production.
  - NRF1 incorporated several key changes over predecessor technology, including shorter gate length, modified epitaxial design, and inclusion of gate anneal and source field plate.
- Extensive reliability testing performed on NRF1 process and compared to previous PH7 version of technology.
- NRF1 shows equivalent robustness as demonstrated by ESD and VSWR testing.
- NRF1 shows significantly improved drift phenomenon, ~50%, as demonstrated by DC-HTOL, RF-HTOL, and 3-temp DC.
- The improved reliability performance, coupled with the improved electrical performance and consistency, make NRF1 a viable commercial GaN technology platform.

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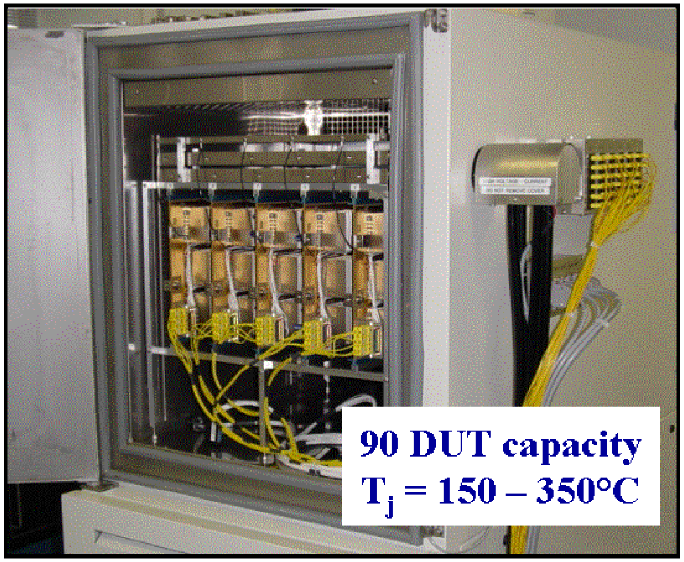
THANK YOU

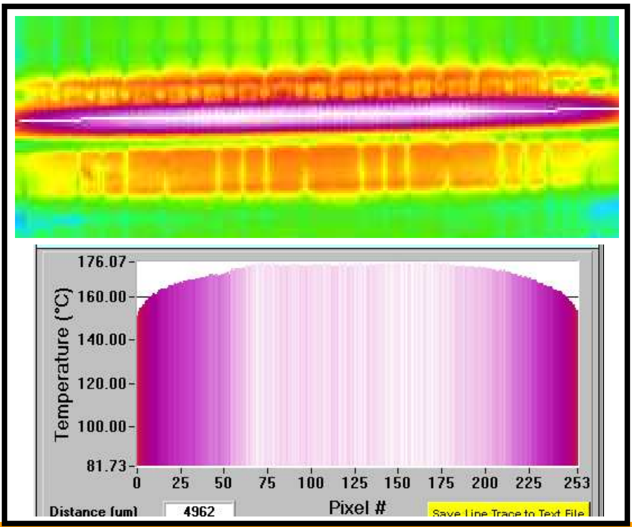
Nitronex's 3-Temp DC Life Test Station Designed For GaN

- Bias at V_{ds} = 28V and 2.34A, Fixed V_g, vary T_{amb} to achieve T_j.
- T_j range: 260, 285, and 310℃
- 25-30 devices per temperature
- Thermal imaging performed to verify T_j.
  - Thermal resistance of 2.3 C/W used for T_{case} setting.
  - T_j Std dev = 5℃ (less than 3%)
- 20hr Burn-in prior to life test.
- Stress times as follows:
  - 260C → 750hrs
  - 285C → 1000hrs
  - 310C → 500hrs



90 DUT capacity

T_j = 150 – 350°C



Distance (um) 4962

Operating DC Life Test System

- Bias at V_{ds} = 28V and 2.34A
- Tbase=30C by water cooling
- Tj = 200C

- 100 test positions
- Manages On/Off, tracks hours
- Monitors current to each device
- Controls mount surface temperature
- Stores all data to database
- Failsafe - alerts on alarm conditions

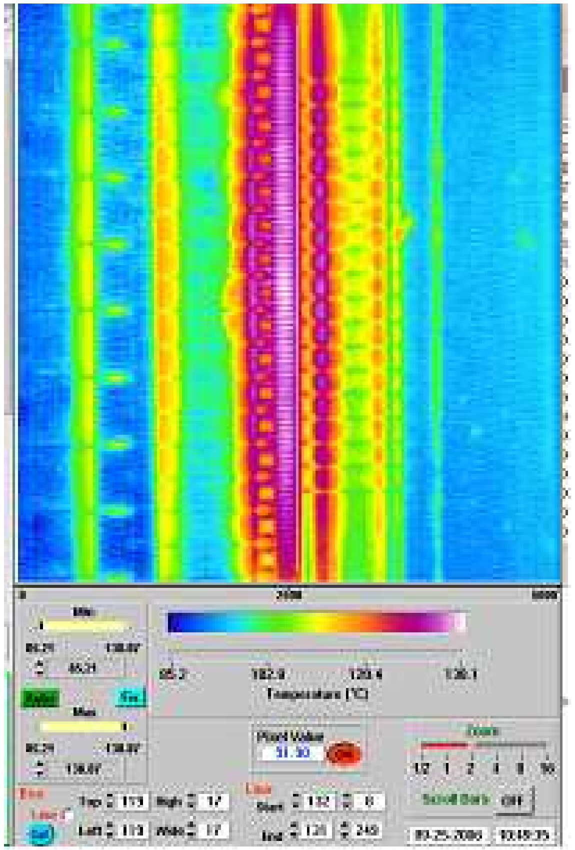
Historic Test Runs

(across process generation)

Completion Date	Device Size	No. Wafers	No. Devices	Stress Time	Device Hours
Q2 2003	2mm	3	18	2,000 hrs	36,000 hrs
Q1 2004	16mm	5	50	1,500 hrs	75,000 hrs
Q2 2004	16mm	2	10	1,000 hrs	10,000 hrs
Q4 2004	36mm	2	20	1,000 hrs	20,000 hrs
Q1 2005	36mm	5	30	1,000 hrs	30,000 hrs

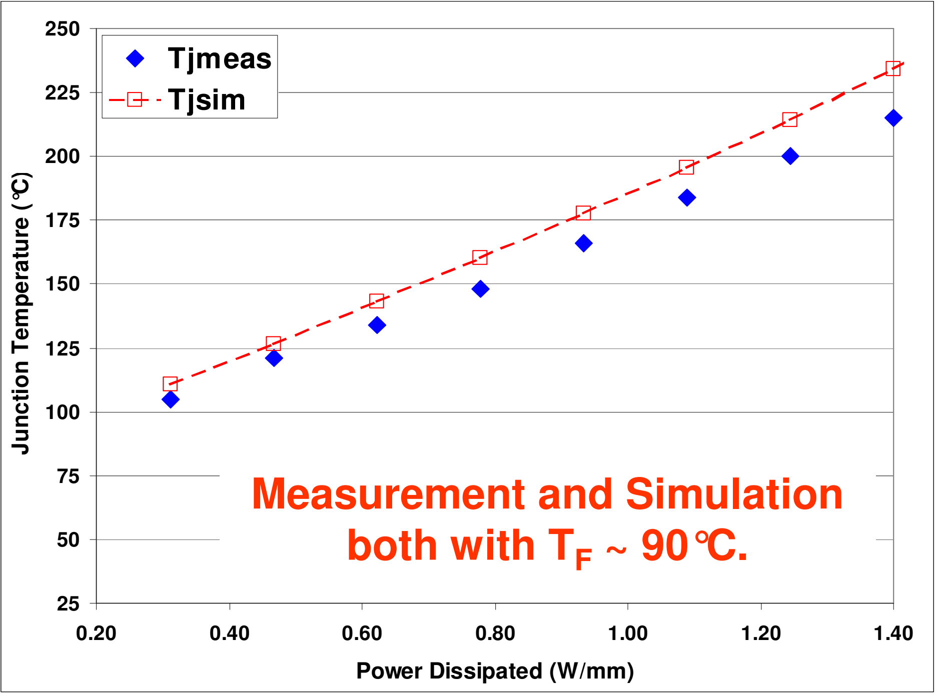
Thermal Imaging

DUT	T_{case} (°C)	$T_{junction}$ (°C)	R_{TH} (°C/W)	Pass/Fail
1	88.50	142.00	1.95	PASS
2	89.80	143.00	1.95	PASS
3	88.90	137.00	1.76	PASS
4	88.10	134.00	1.68	PASS
5	88.60	141.00	1.92	PASS
6	88.00	137.00	1.79	PASS
7	88.20	136.00	1.75	PASS
8	88.20	141.00	1.93	PASS
AVG	**88.54**	**138.88**	**1.84**	
STD DEV	**0.59**	**3.27**	**0.11**	

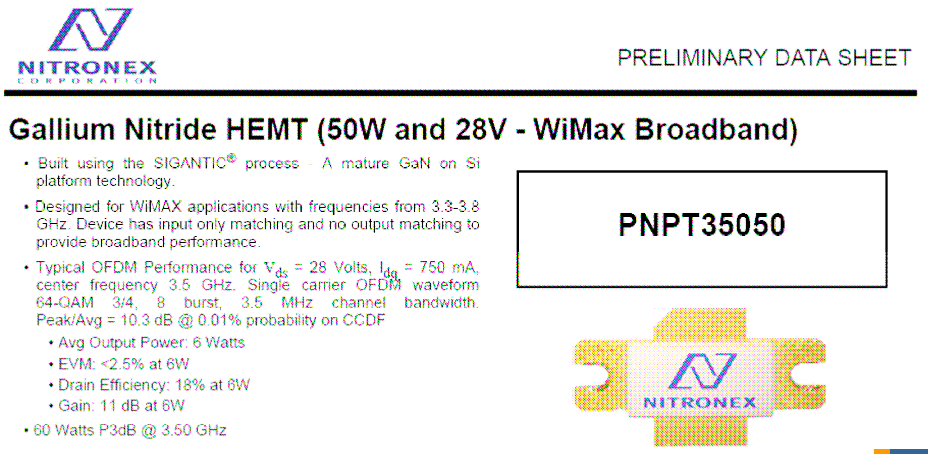


- Devices biased at Vds=28V and Ids=975mA.
  - Equivalent to Pout=6W and DE=18%.
- All devices pass spec sheet value of 1.95°C/W.

Nitronex Current Products: NPT35050 Thermal Evaluation



Measurement and Simulation both with T_F ~ 90°C.



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PRELIMINARY DATA SHEET

Gallium Nitride HEMT (50W and 28V - WiMax Broadband)

- Built using the SIGANTIC® process - A mature GaN on Si platform technology.
- Designed for WiMAX applications with frequencies from 3.3-3.8 GHz. Device has input only matching and no output matching to provide broadband performance.
- Typical OFDM Performance for V_{ds} = 28 Volts, I_{dq} = 750 mA, center frequency 3.5 GHz. Single carrier OFDM waveform 64-QAM 3/4, 8 burst, 3.5 MHz channel bandwidth. Peak/Avg = 10.3 dB @ 0.01% probability on CCDF
  - Avg Output Power: 6 Watts
  - EVM: <2.5% at 6W
  - Drain Efficiency: 18% at 6W
  - Gain: 11 dB at 6W
- 60 Watts P3dB @ 3.50 GHz

PNPT35050

36mm Device

- Device designed to operate under backed off conditions with Vd=28V.
- Specified operating power is 6W and efficiency is 18%. This implies power dissipation of 0.75W/mm.
- Tjmax of ~150°C is maintained at worst case flange temperature specification of 90°C.