Preliminary Results from Phase II of the Wide Bandgap Semiconductor for RF Applications (WBGS-RF) Program

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CS MANTECH April 25, 2006

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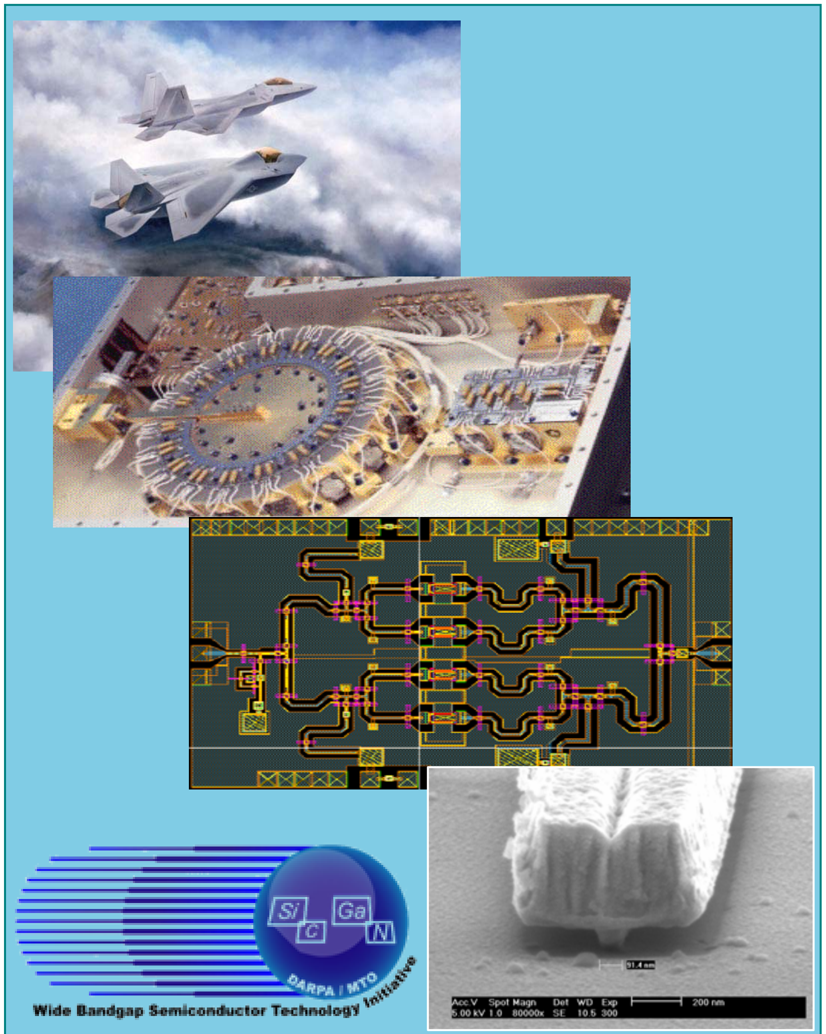
Wide Bandgap Semiconductor for RF Applications (WBGS-RF)



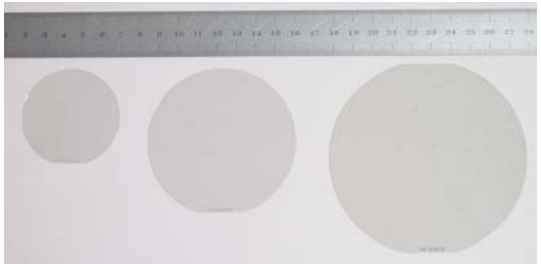
Goal

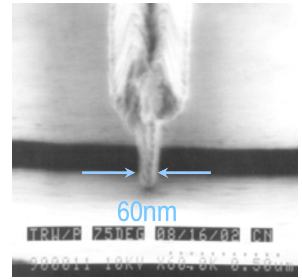
- Exploit the materials properties of wide band-gap semi-conductors to achieve reliable, high performance devices and MMICs with
  - higher power
  - higher efficiency & bandwidth
  - superior thermal performance
- Achieve rapid insertion into DoD RF systems

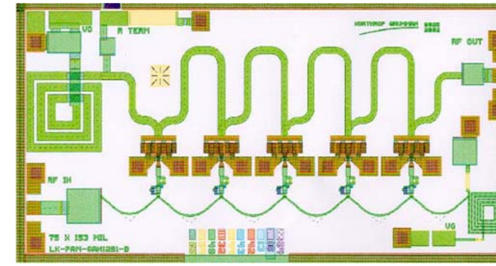
Technical Challenges

- Reliable devices (≥ 10^6 hrs)
- High operation frequency (≥40GHz)
- High bandwidth (≥ 1 decade)
- High RF yields (≥ 50%)
- Thermal management (~ 1 KW/cm^2)

WBGS-RF Program Plan







Phase I results
- High quality SI SiC substrates
- Highly uniform GaN epitaxy, both MBE and MOCVD

36 mo. Device Demos
- X-band discrete
- Q-band discrete

Objective Demos
- X-band T/R module
- Broadband SSPA
- Q-band SSPA

18 mo. Device PoC
- X-band discrete
- Q-band discrete

48 mo. Circuit Demos
- X-band PA MMIC
- X-band LNA MMIC
- Broadband PA MMIC
- Q-band PA MMIC

WBG Semiconductor Materials

Phase I (24 months)

BAA01-035

Device Technologies

Electronic Integration and Circuit Technologies

Phase II (36 months)

Phase III (24 months)

BAA04-19

3/05

Today

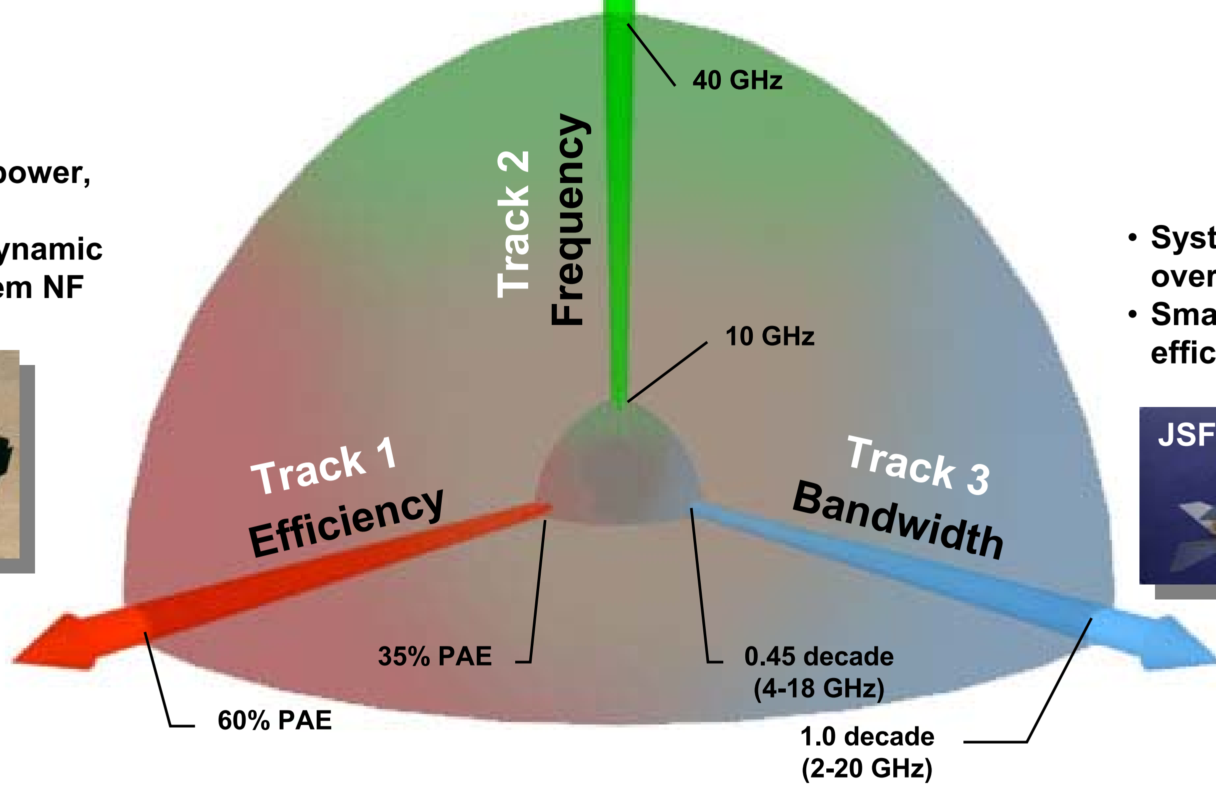
Three Tracks Aligned with Technical Challenges and Potential Applications

- Reduced system size, weight, cost
- Manufacturable

Track	PAE (%)	f (GHz)	BW
(1) X-Band T/R Module	60	8-12	1.5X
(2) Q-band HPA	40	>40	1.1X
(3) Wide-band HPA	30	2 – 20	10X

- Transmit: higher power, reduced cooling
- Receive: higher dynamic range, lower system NF

- Systems that operate over wider bands
- Smaller, lighter, more efficient



Phase II & III Metrics and Goals

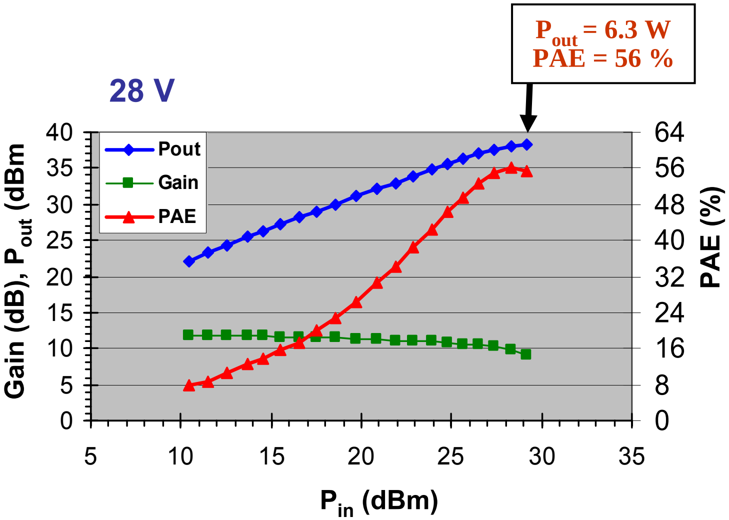
Type / Integration Level / Track (Band)	Unit	Phase II						Phase III					
		18 month◊ Milestone Device			36 month GNG Device			48 month GNG MMIC			60 month Goal Module		
		X	Q	WB	X	Q	WB	X	Q	WB	X	Q	WB
Drain Bias	V	28	25	28	40	28	40	48	28	48	48	28	48
Cell Size	µm	1250	500	400	1250	500	1250						
Operating Frequency	GHz	8-12	>40	8-12	8-12	>40	8-12	8-12	>40	2-20	8-12	>40	2-20
Output Power*	W	6.3	1.26	2.63	7.94	1.58	7.94	15	4	15	60	20	100
Power Density*	W/mm	5.0	2.5	6.6	6.4	3.2	6.4						
Power Added Efficiency	%	55	27	60	60	35	60	55	37	30	35	30	20
Gain at Power	dB	10	7	10	12	8	12	16	7.5	9	18-20	13	30
RF Yield‡	%	50	20	50	50	50	50	50	50	50			
Output Power Uniformity†	dB	1.5	1.5	1.5	1	1	1	1	1.5	1			
PAE Uniformity†	% pts	6	6	6	3	3	3	3	6	3			
Small Signal Gain Uniformity†	dB	1.5	1.5	1.5	1	1	1	1	1.5	1			
LNA Survivability	W										50		
Long Term Performance**	hrs	1.E+05	1.E+04	1.E+05	1.E+05	1.E+05	1.E+05	1.E+05	1.E+05	1.E+05	1.E+06	1.E+06	1.E+06

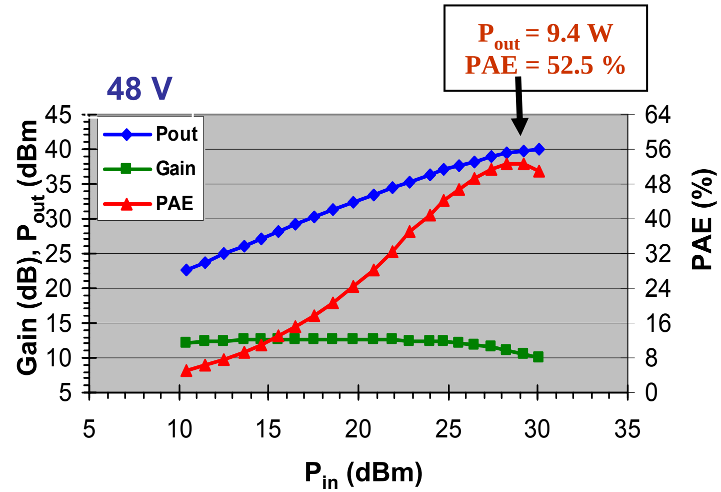
* Measured at compression corresponding to maximum PAE
† Uniformity defined as the standard deviation in measured values from 100 devices/MMICs on all validation wafers
‡ The fraction of devices from all validation wafers meeting or exceeding all relevant GNG requirements
** Failure is defined as a 1 dB decrease in output power compared with its level at the time that testing commences

◊ Revised 06/05

Track 1 (X-Band) Progress

		Phase II		
		Today	18 month	36 month
Type	Unit	Status	Milestone	GNG
Integration Level		Device	Device	Device
Track (Band)		X	X	X
Drain Bias	V		28	40
Cell Size	µm		1250	1250
Operating Frequency	GHz		10	10
Output Power*	W		6.3	7.94
Power Density*	W/mm		5.0	6.4
Power Added Efficiency	%		55	60
Gain at Power	dB		10	12
RF Yield‡	%		50	50
Output Power Uniformity†	dB		1.5	1
PAE Uniformity†	% pts		6	3
Small Signal Gain Uniformity†	dB		1.5	1
LNA Survivability	W			
Long Term Performance**	hrs		1.E+05	1.E+05





10 GHz; 1.25-mm periphery; 0. 5-um L_g,

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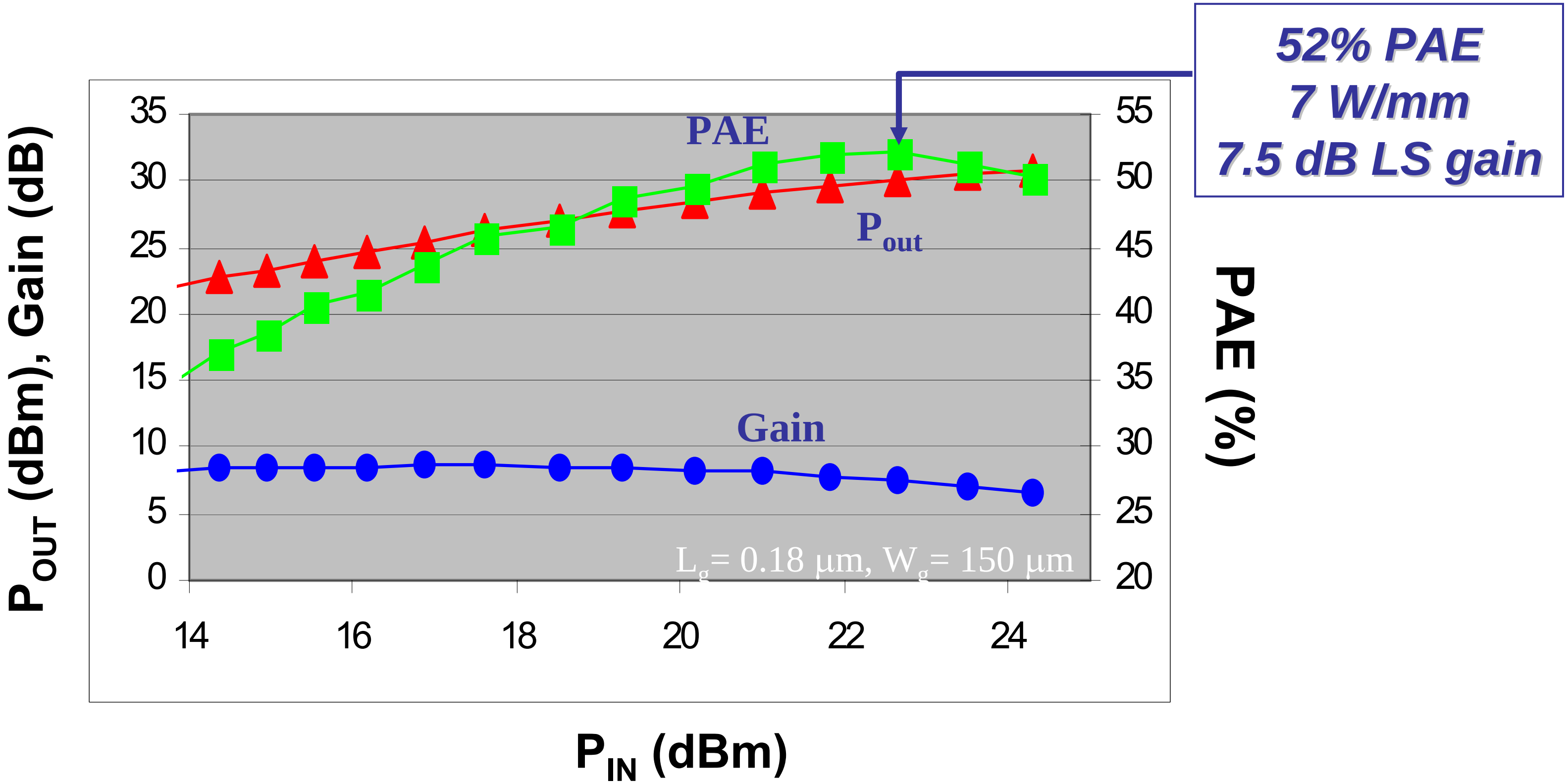
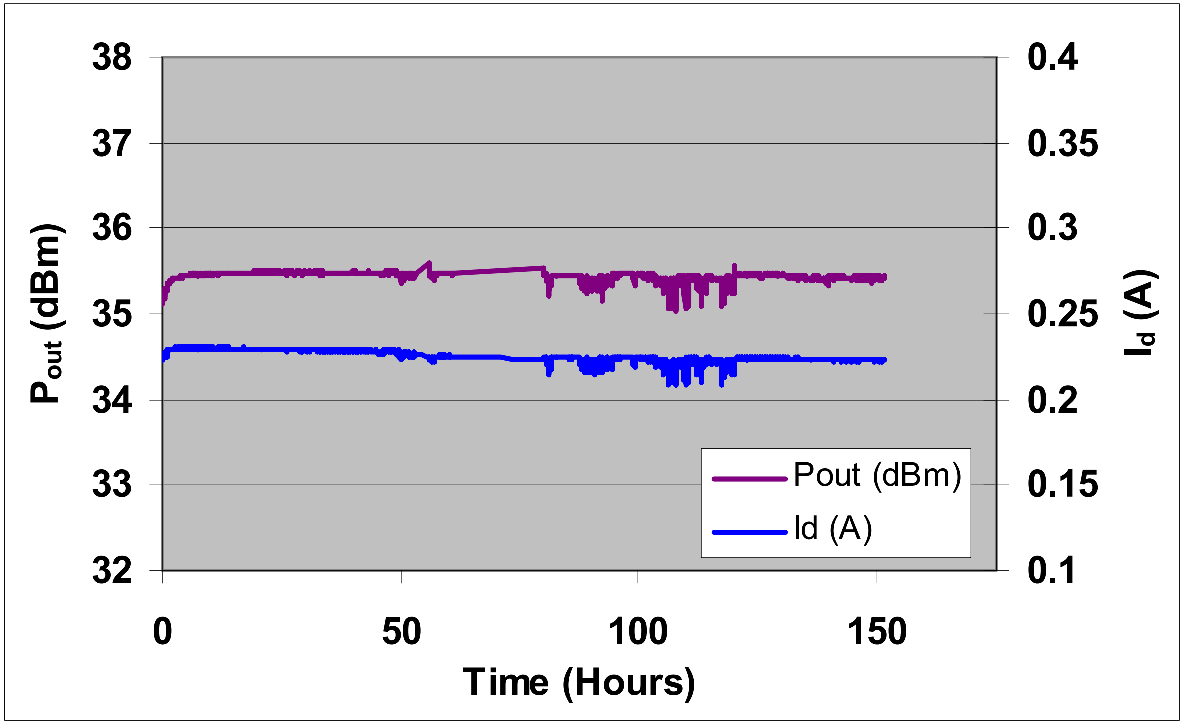
InGaN Back-Barrier Improves Device PAE at High Frequency



- InGaN back-barrier HEMT at 35 GHz
- Control device (no InGaN) showed ~ 40% PAE

Highest PAE reported for a GaN HEMT at 35 GHz

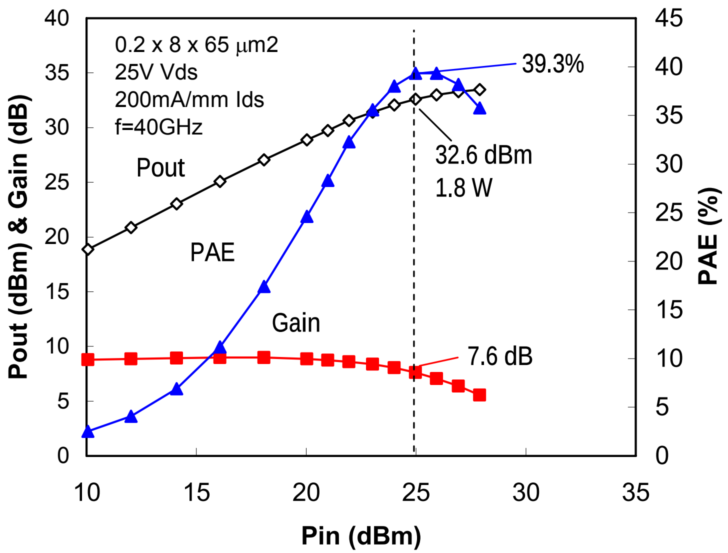
Some Encouraging Early Reliability Results



- 1.25-mm HEMT
- V_{DS} = 28 V
- 4 GHz
- T_{CHAN} ~ 250°C; T_{BASE} = 165°C
- 3.5 Watt (2.8 W/mm) and 51% PAE (at 250°C)

Track 2 (Q-Band) Progress

		Phase II		
		Today	18 month	36 month
Type	Unit	Status	Milestone	GNG
Integration Level		Device	Device	Device
Track (Band)		Q	Q	Q
Drain Bias	V	25	25	28
Cell Size	µm	500	500	500
Operating Frequency	GHz	40	>40	>40
Output Power*	W	1.42	1.26	1.58
Power Density*	W/mm	2.8	2.5	3.2
Power Added Efficiency	%	30.6	27	35
Gain at Power	dB	7.6	7	8
RF Yield‡	%	>50	20	50
Output Power Uniformity†	dB	0.12	1.5	1
PAE Uniformity†	% pts	1.8	6	3
Small Signal Gain Uniformity†	dB	0.5	1.5	1
LNA Survivability	W			
Long Term Performance**	hrs		1.E+04	1.E+05



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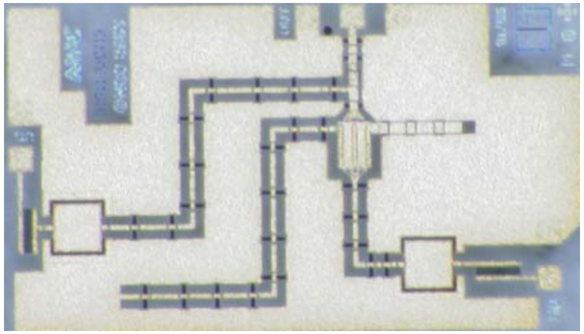
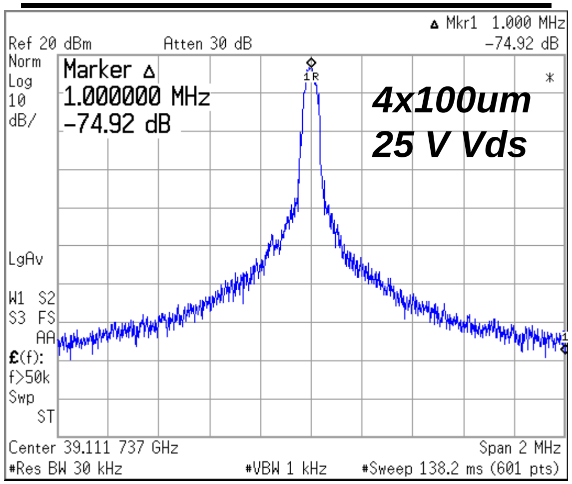
Low Phase Noise VCO

GaN VCO MMIC



Measured Performance

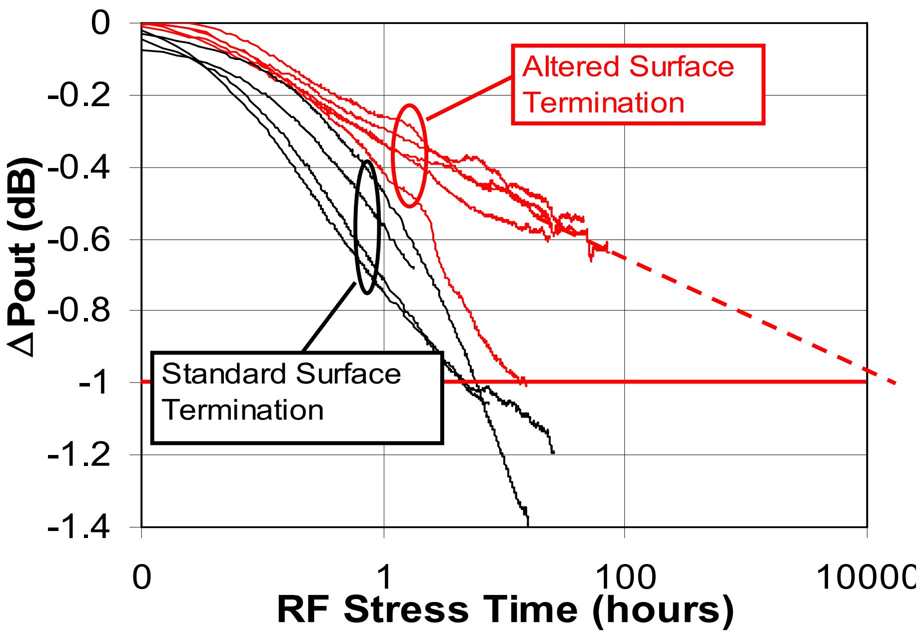


VCOs	Phase Noise at 100KHz Offset (dBc/Hz)	Phase Noise at 1MHz Offset (dBc/Hz)
38-GHz InP HBT VCO	-82	-108
38-GHz output frequency push-push GaAs HBT oscillator	-89	-107
33-GHz SiGe differential HBT VCO	-76	-99
39-GHz GaN VCO – This work	-92	-120

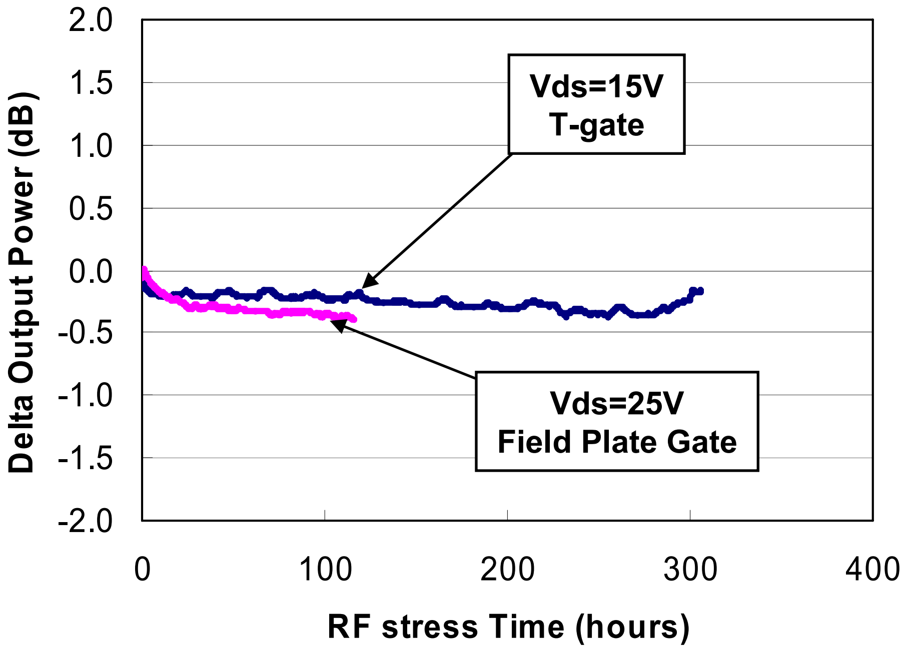
Demonstrated record 39 GHz VCO phase noise of -120 dBc/Hz

Some Encouraging Early Reliability Results

Material identified as key influence on device stability

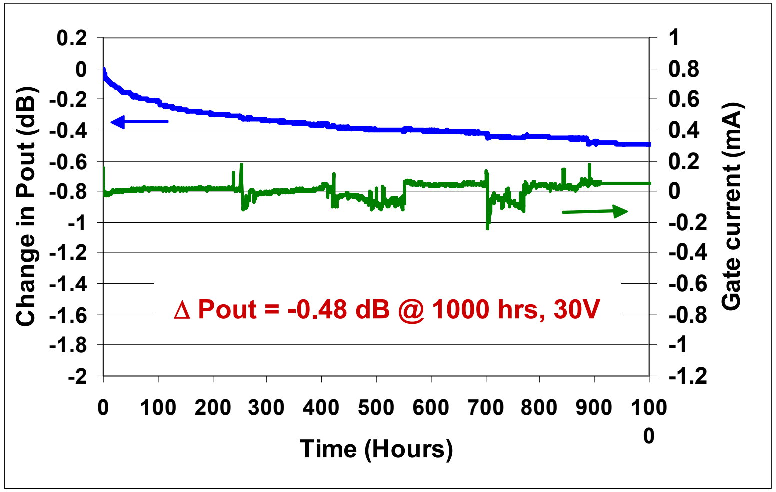


Long-Term RF Stability Tests Currently Underway



Track 3 (Wideband) Progress

Type	Unit	Today	18 month	36 month
		Phase II		
Type	Unit	Status	Milestone	GNG
Integration Level		Device	Device	Device
Track (Band)		WB	WB	WB
Drain Bias	V	30	28	40
Cell Size	µm	400	400	1250
Operating Frequency	GHz	10	10	10
Output Power*	W	2.27	2.63	7.94
Power Density*	W/mm	5.68	6.6	6.4
Power Added Efficiency	%	49.66	60	60
Gain at Power	dB	10.1	10	12
RF Yield‡	%		50	50
Output Power Uniformity†	dB	0.23	1.5	1
PAE Uniformity†	% pts	3.6	6	3
Small Signal Gain Uniformity†	dB	0.2	1.5	1
LNA Survivability	W			
Long Term Performance**	hrs		1.E+05	1.E+05



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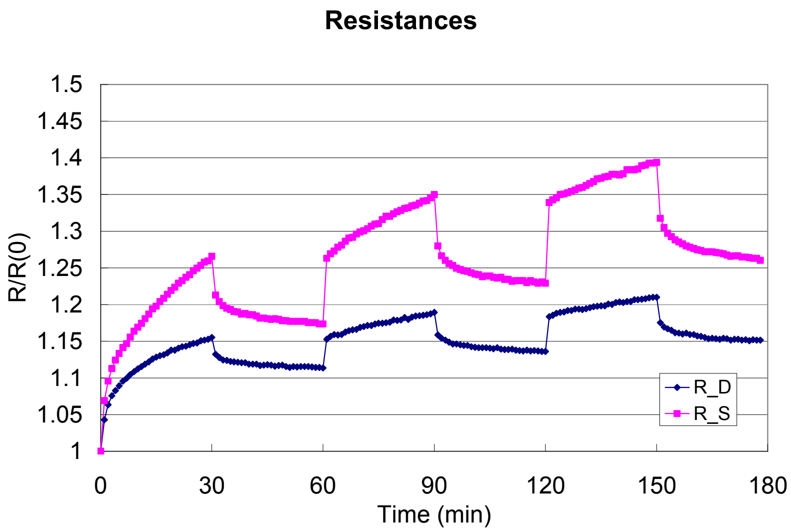
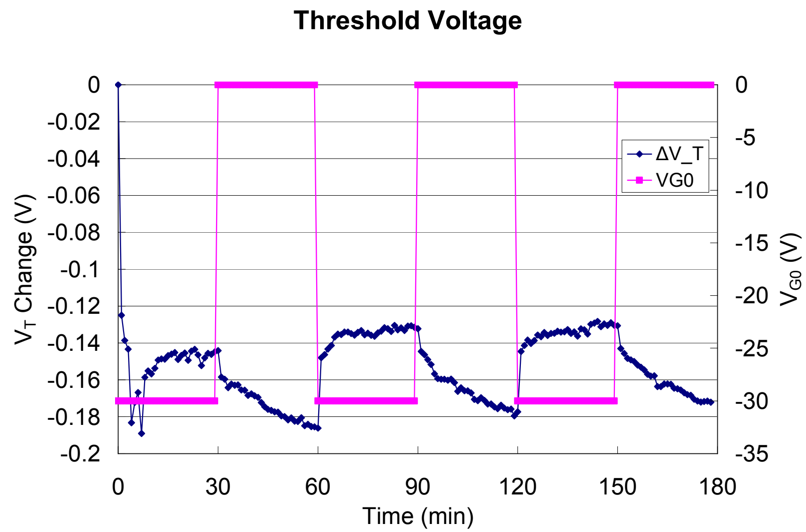
Understanding Physics of Failure

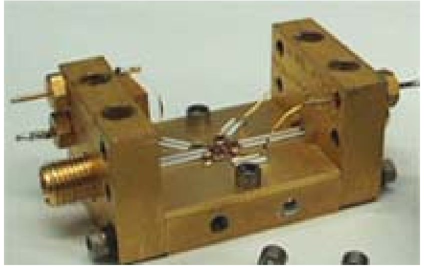




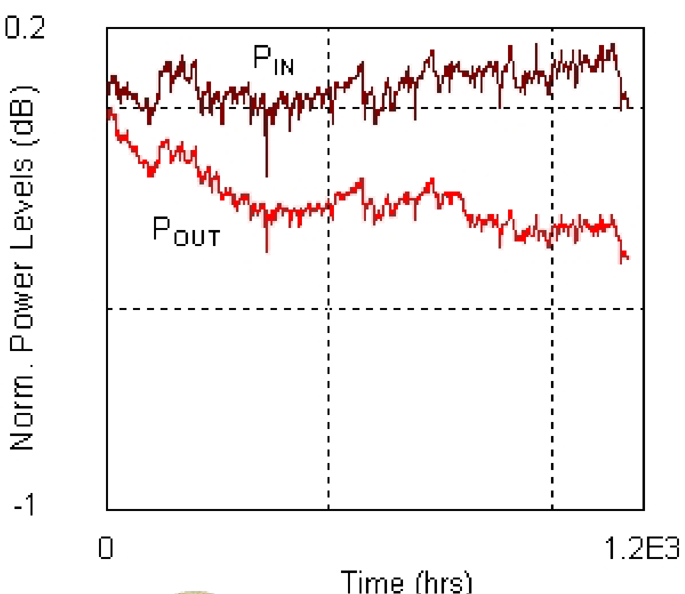
- **MIT is performing stress testing to understand the fundamental physics of failure**
- **Theories drive experiment plans and define reliability tests**

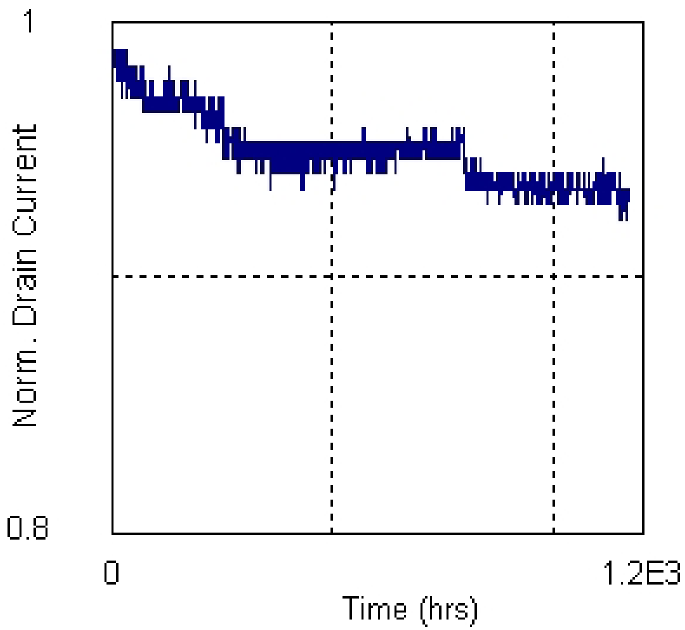
TriServices Labs Example: Fixtured RF Operational Life Test

- Discrete GaN HEMTs with hybrid matching, coaxial RF connections.
  - V_{DS} = 28V, I_{DQ} = 100 mA/mm, T_{CH} = 110 ºC.
  - P_{OUT} = 5.2 W/mm, PAE = 50.0%, P_{IN} = 2 dB compressed.



- 0.4 dB P_{OUT} degradation after 1200 hours.





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