Approach for AlGaN/GaN HEMT Power Amplifiers

- **Materials**: Undoped, polarization-induced 2DEG by OMVPE and MBE on sapphire and SiC
- **Layout**: .25 -.30 μm gates, 125 μm wide 50 μm pitch
- **Process:** Etch mesa, Ti/Al/Ti/Au 800° C ohmics, Ni Au gate, Si_3N_4 or AlN on surface
- **Tests:** I-V, f_t and class B power sweep
- **Physical theory/,modeling**: Polarization effects, dislocation charge, Monte Carlo V-E, low field mobility, device characteristics, temperature rise/impact on efficiency
- **Circuits:** cascode, monolithic broad-band amplifiers, balun combiners for class B/push-pull

Technology Highlights

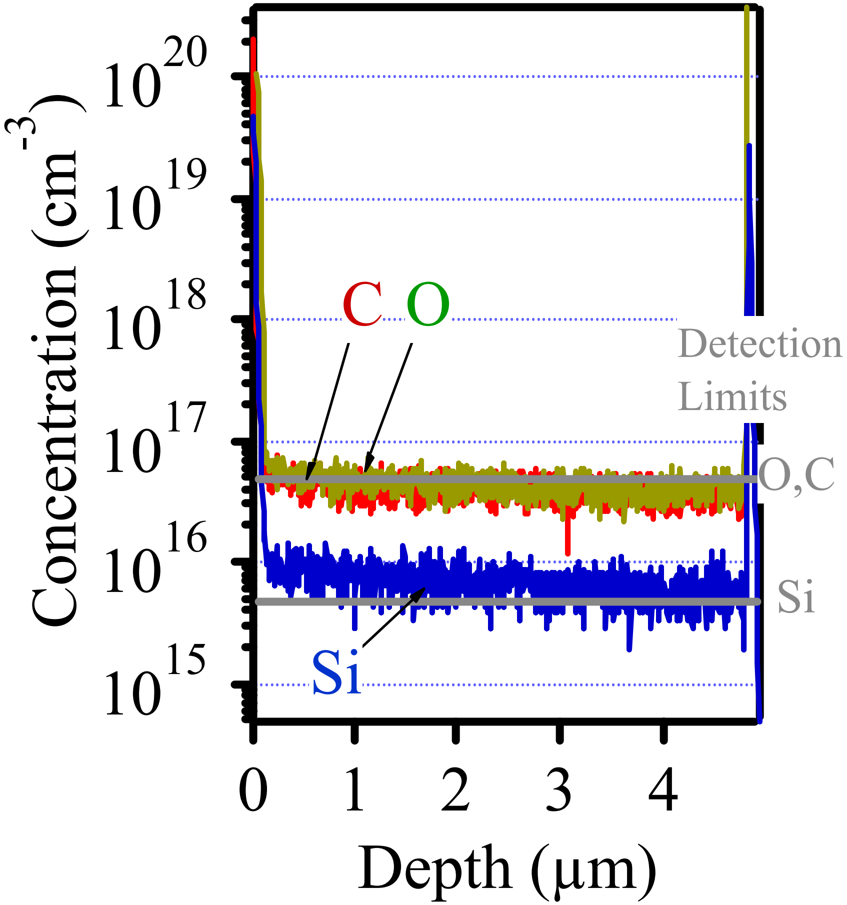
- 1. Obtained high quality $Al_{.3}Ga_{.7}N/GaN$ structures with
- > $1 \times 10^{13}/cm^2$ 2DEG, and ~ 300 $\Omega/\square$
- 2. Achieved undoped GaN buffer/channel with 10^7 - 10^8 Ω cm resistivity
- 3. Obtained .3-.5 Ω-mm ohmic contact resistance
- 4. Alleviated the current slump/DC to RF dispersion
- a) using Si_3N_4 or AlN coating of exposed semiconductor to stabilize
- surface charge
- b) using AlN sub buffer layer on SiC substrate
- 5. Determined frequency/breakdown voltage limits dependence on gate length
- 6. Obtained CW operation of small periphery devices at 11 W/mm,
- and obtained 10 W for 1.5 mm periphery
- 7. Achieved baluns with < .5 db insertion loss at x-band
- 8. Initial reliability study with stresses from gate current, drain
- voltage, and RF drive

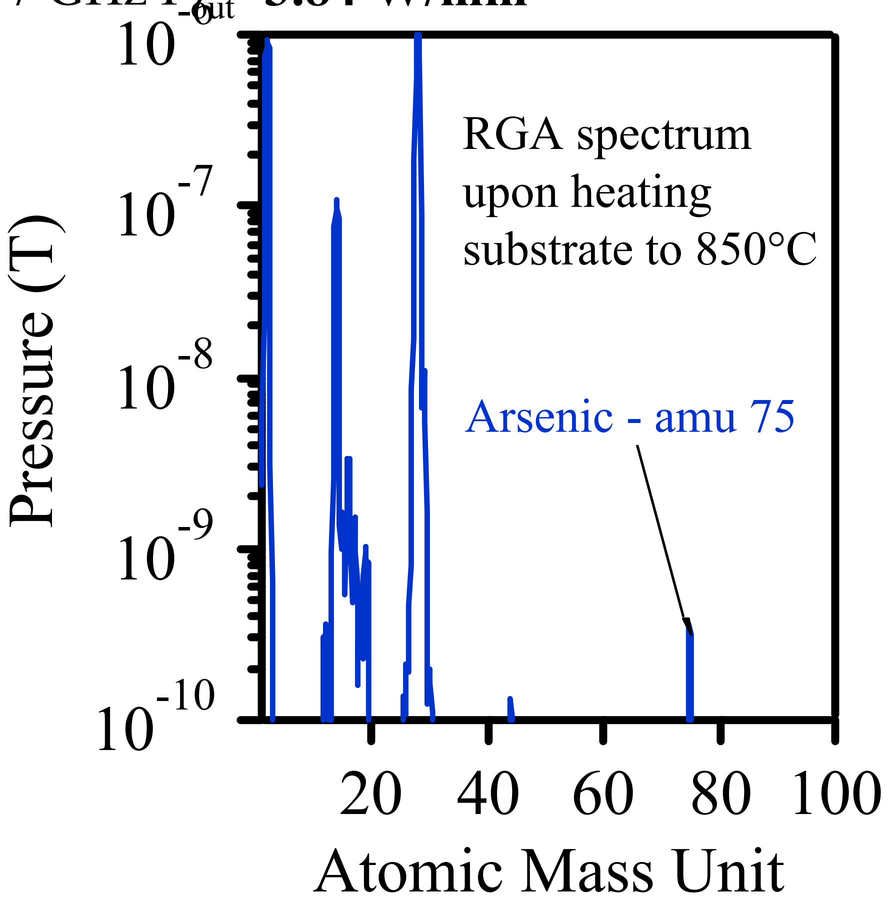
Modeling Highlights

1. GaN electron velocity vs. electric field with temperature change
2. Charging of threading dislocations/input on bulk mobility
3. 2DEG mobility variation with 2DEG sheet density
4. Gate leakage current with Al fraction, temperature
5. Device current-voltage characteristics/experimental verification
6. Rise in channel temperature with self heating/layout variation
7. Rise in knee voltage with temperature/input on drain efficiency

SIMS of GaN MBE HFET on Sapphire and MBE RGA

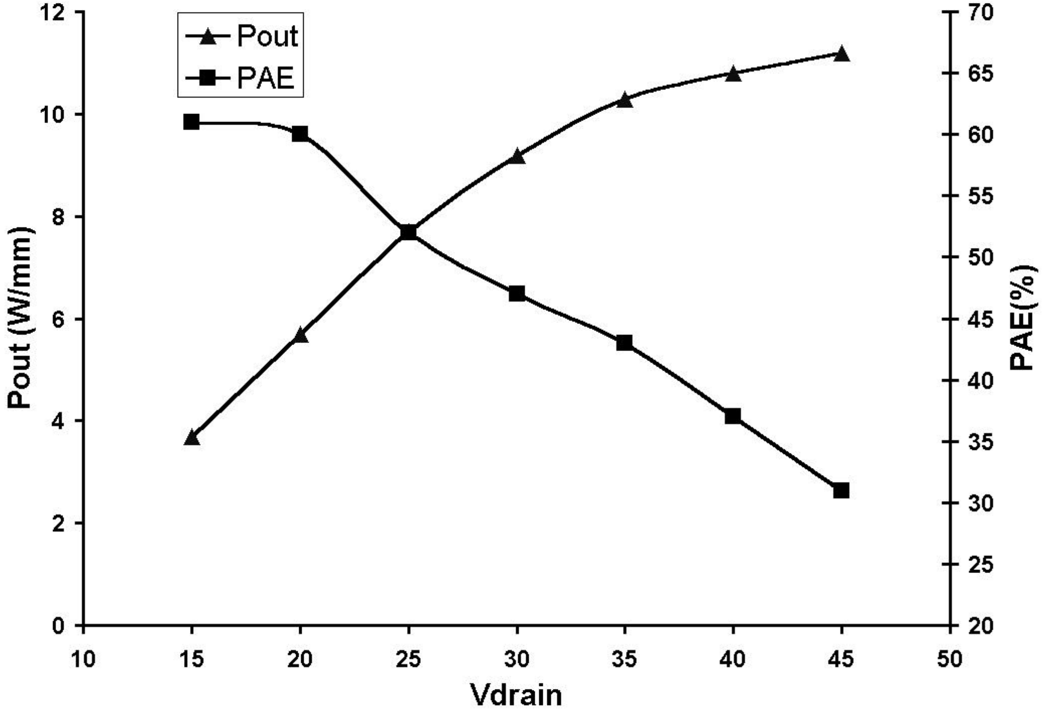
μ = 1478 cm^2/Vsec n=8.8x10^{12} cm^{-2} 7 GHz P_{out}=**3.84 W/mm**





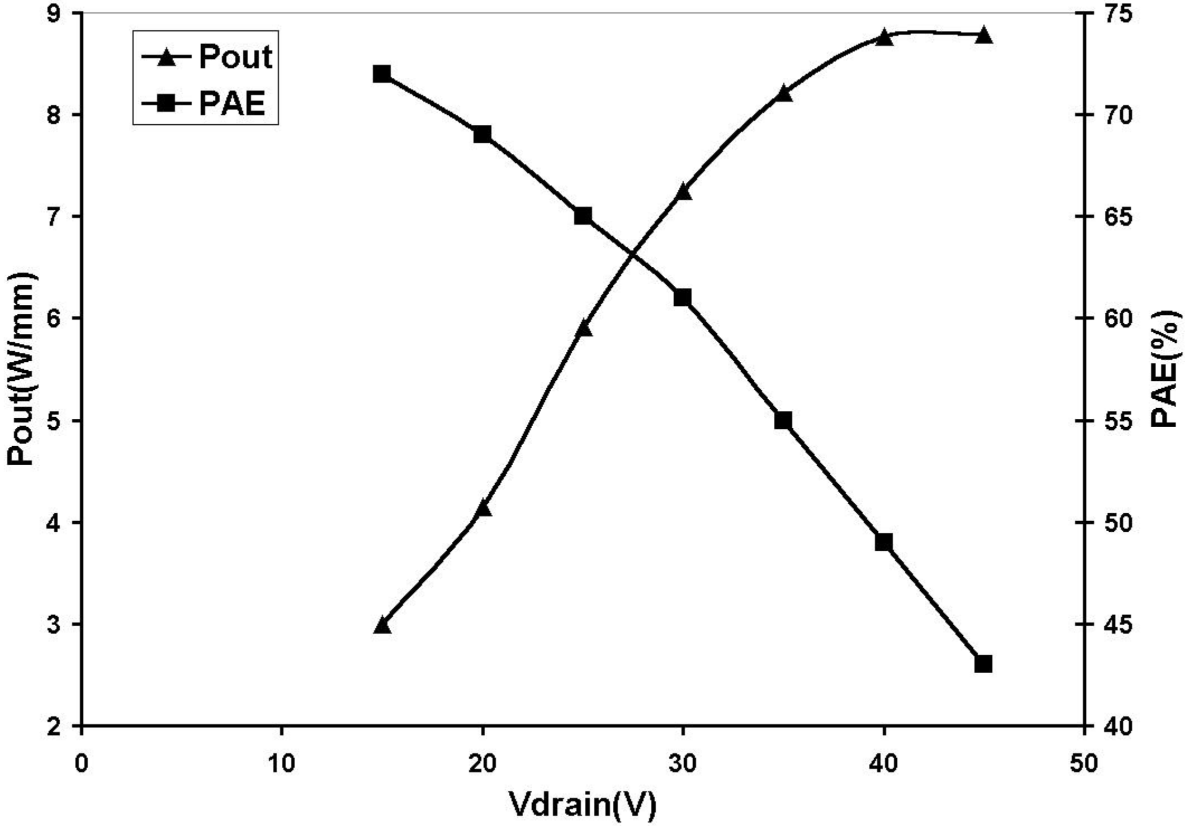
Unintentional impurities in GaN HFETs are at, or below, the SIMS detection limit despite the presence of Arsenic in the MBE machine

High Power, Broadband, Linear, Solid State Amplifier



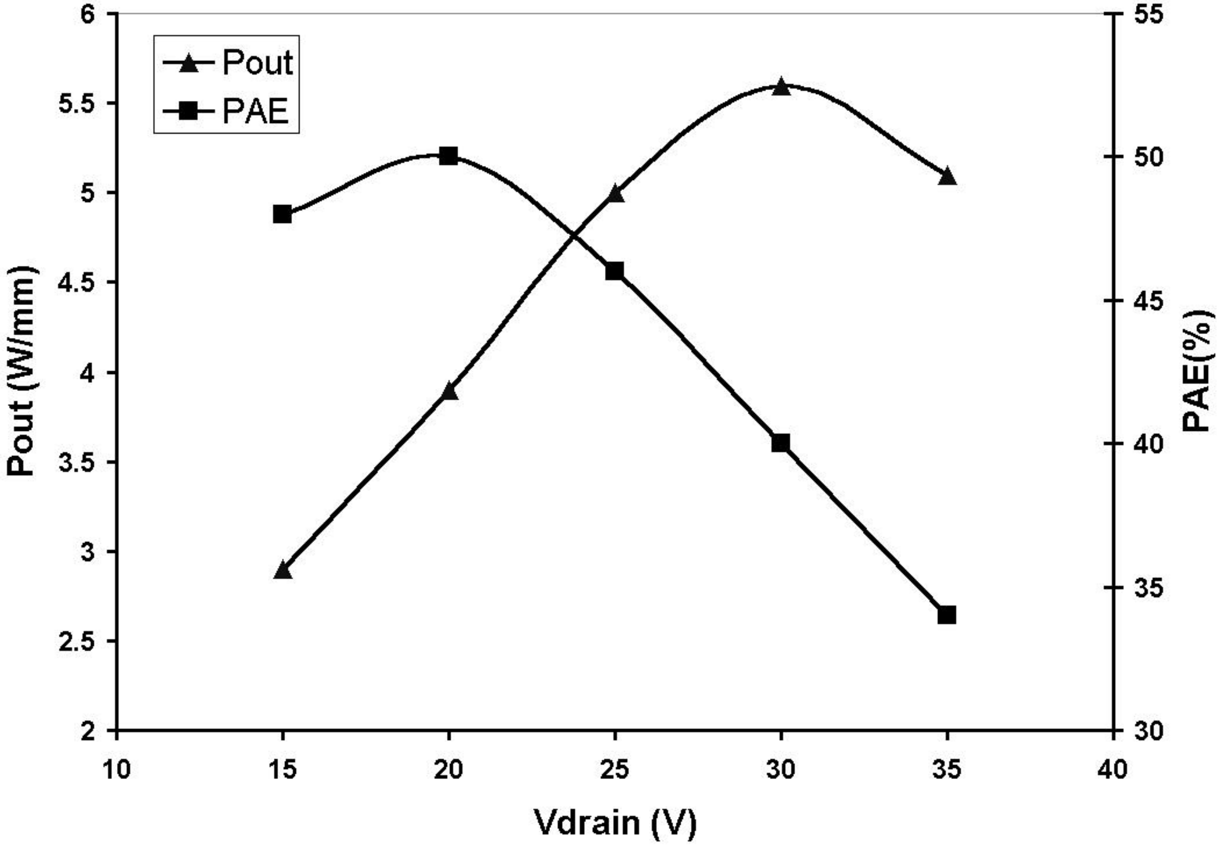
P_{out} and PAE measured on 100 µm T- device at 10 GHz

High Power, Broadband, Linear, Solid State Amplifier



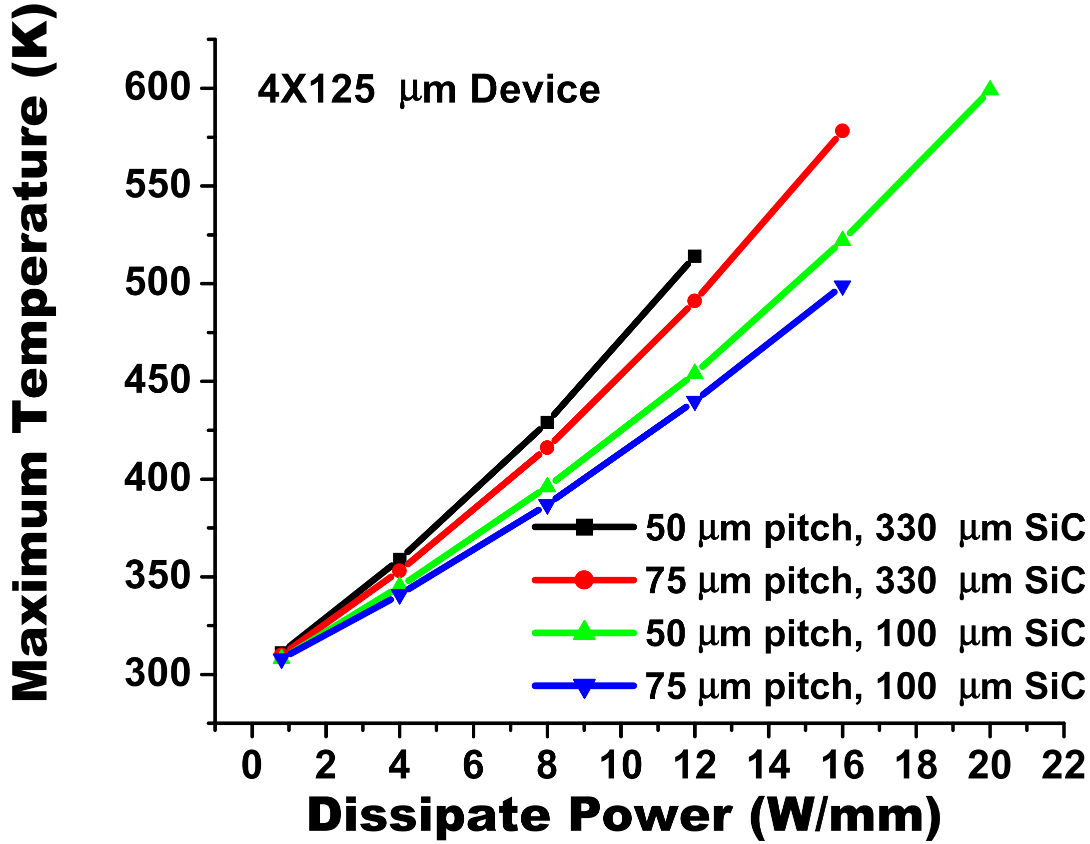
P_{out} and PAE measured on 200 µm (2X100 µm) U - device at 10 GHz

High Power, Broadband, Linear, Solid State Amplifier



P_{out} and PAE measured on 1.5mm (12X125 µm) device at 10 GHz

Thermal Simulation



- 4 gate finger device with 125µm width and 2µm width active region
- 1 µm buffer layer

Analysis of the effect of self-heating of HEMT bonded to 5°C heat sink

- **1.5 mm device, 12 x 125 µm channels, 50 µm pitch**
- **Obtained 10 W, 40% η_{PA} at 32 V_{ds}, class B**
- **Simulation of channel temperature for 15 W dissipation yields 545°K**
- **Sheet resistance is raised by ~ 2.9:1**
- **Knee voltage rises ~ 2.2:1, being 10 V at 545°K**
- **Class B efficiency is halved with 10 V_K and 30 V_{ds}**

NOTE: The efficiency is the same value for 12.6 W heat dissipation when chips on stainless steel anvil.

Technology Transfers to Industry

- **Raytheon**
- **GE/CRD**
- **BAE/Sanders**
- **Triquint**
- **Northrop Grumman**
- **Teledyne**
- **RF Nitro Communications Inc.**

- **Information Distribution**
  - **Evolving web page**
  - **Conference proceedings**
  - **publications**

HEMT Process Using PECVD Si_3N_4 Passivation

Process HEMT's by Standard Process

- Cl_2 ECR etch for mesa isolation
- Deposit/anneal Ti/Al/Ti/Au ohmics (800°C for .5-1 minute)
- Deposit Ni/Au mushroom gate

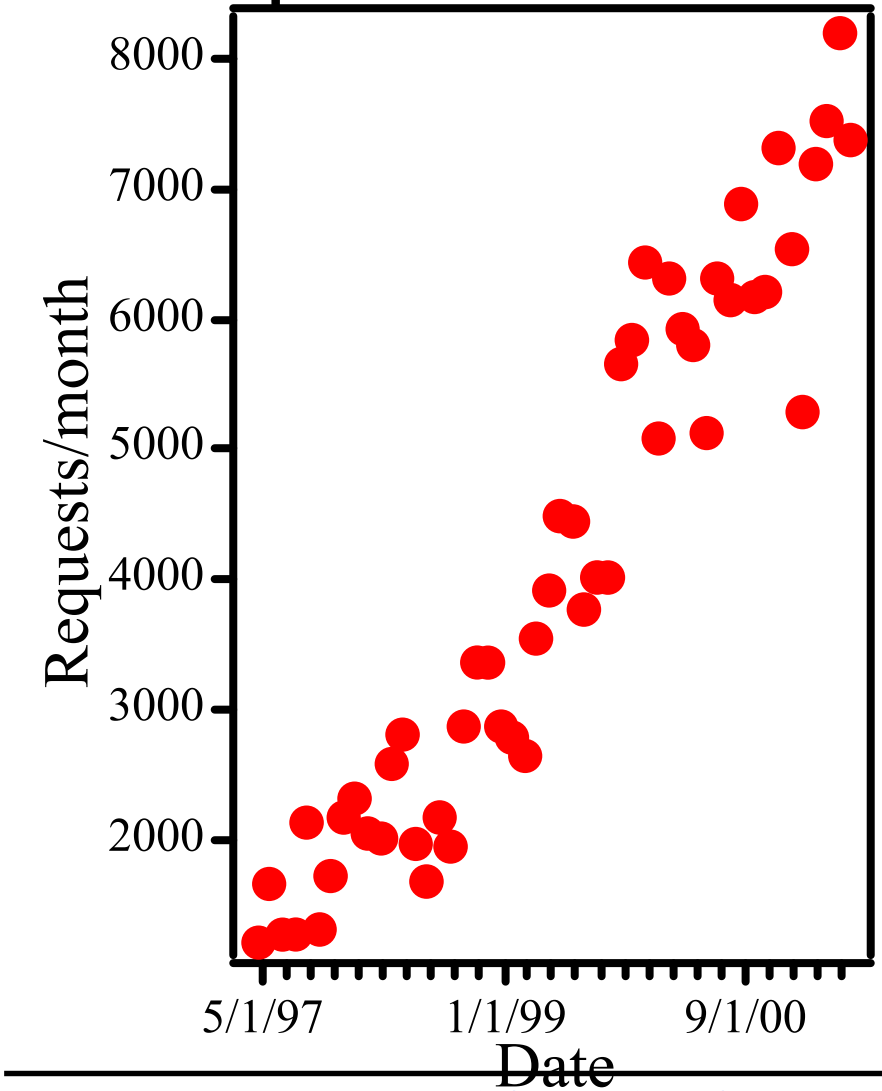
Si_3N_4 Passivation (Ion/Plasma Equipment, Inc.)

- Solvents, D.I., 30 sec. of 30:1 buffered HF
- Silane (18 SCCM) and NH_3 (60.7 SCCM)
- 550 m Torr, 50 Watts RF
- 160 Å/min., $\eta = 1.96 - 2.04$

RIE Etch windows to metal pads (Applied Materials)

- $CHF_3/0_2$; 30 SCCM/.7 SCCM
- 30 m, Torr, . 25 W/cm^2
- 400 Å/min

Dissemination of Cornell-team MURI Reports via the World Wide Web



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Summary

- The largest technology problems have been solved
- The key physical HEMTeffects have been modeled
- State-of-the-art power HEMT’s have been achieved
- These HEMT’s show short-term reliability
- The limits of power and efficiency are understood
- Cascode HEMT’s and baluns for push-pull power amplifiers have been fabricated
- AlGaN/GaN HEMT’s yield results equivalent to those predicted