

# Performance and Applications of GaN MMICs

Professor Jonathan Scott

&

Professor Anthony Parker

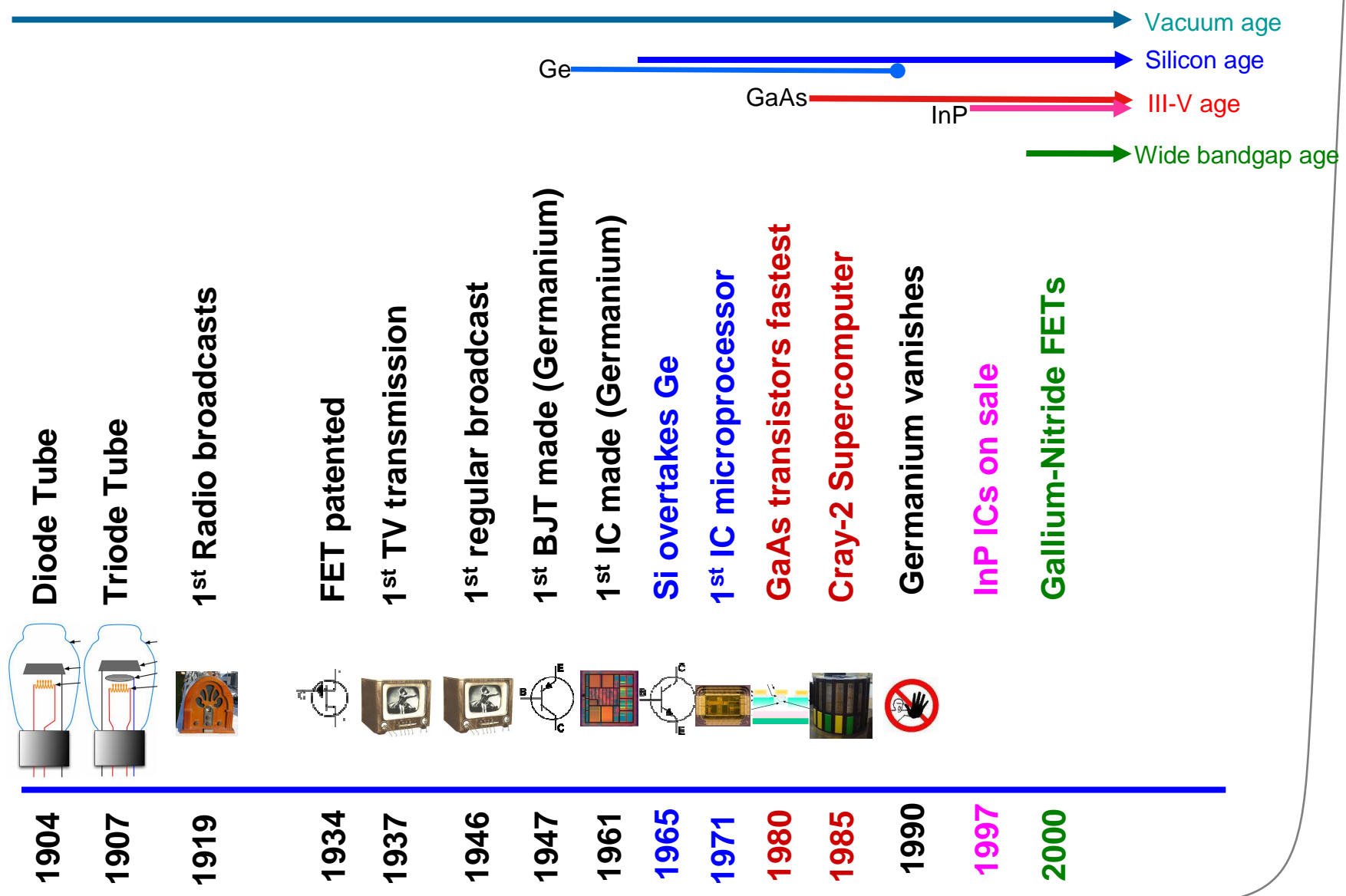


THE UNIVERSITY OF  
**WAIKATO**  
*Te Whare Wānanga o Waikato*

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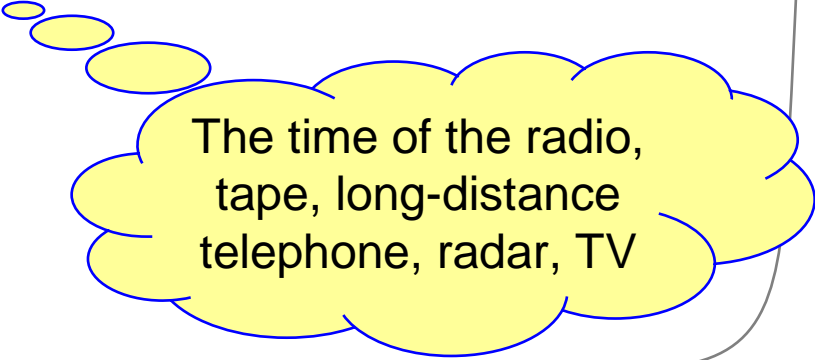
- “Invited paper”  $\Rightarrow$  license to ramble?
- Contents: Not a memory dump
- You will learn something important
  - If not, come and see me after, I need to meet you
- There is a single, important take-home...

# The History of Active Devices



# The History of Active Devices

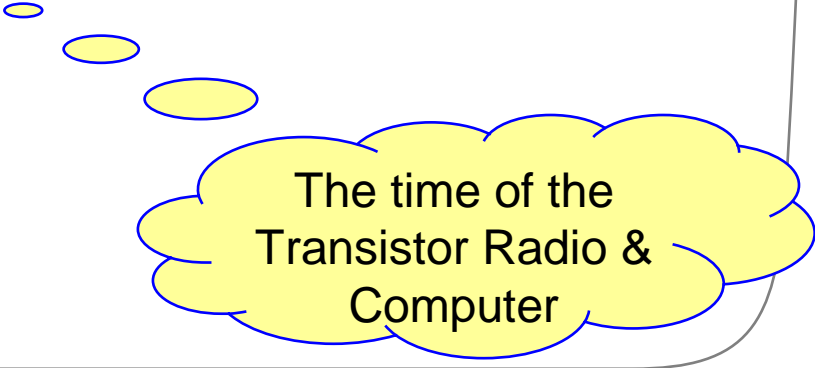
- Vacuum tube held sway for 50 years
- Easy physics, macro construction, open field
- FET patented mid-way, but not built
- Enabled
  - Radio communication
  - Broadcast entertainment
  - Sensitive measurement
  - Proportional industrial control



The time of the radio,  
tape, long-distance  
telephone, radar, TV

# The History of Active Devices

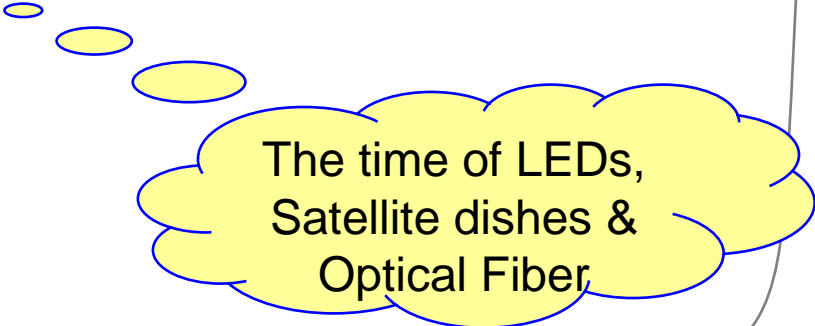
- BJT in Germanium: 1947
- Germanium vanished in 40 years
- Silicon beats Germanium in 1960s
- “Group IV” Motivation:
  - Robustness
  - Size
  - Power consumption
  - ~~• Cost~~
  - ~~• Integration~~



The time of the  
Transistor Radio &  
Computer

# The History of Active Devices

- “Group IV” will hold sway for >>50 years
- Why? Bonus of photolithographic manufacture
  - Integration (matching, cost)
  - Scalability
- 1980: LEDs common, GaAs FETs fast
- Motivation:
  - Faster
  - Visible emission
  - Integration of passives



The time of LEDs,  
Satellite dishes &  
Optical Fiber

# The History of Active Devices

- GaAs FET joined by InP HBT, et al
- “III-V” will hold sway for... only 40 years?
- 2000: GaN FETs appear
- Motivation:
  - 10x Frequency-x-Power over GaAs
  - Thermal >> GaAs
  - Breakdown >> Silicon

# Current State of Active Devices

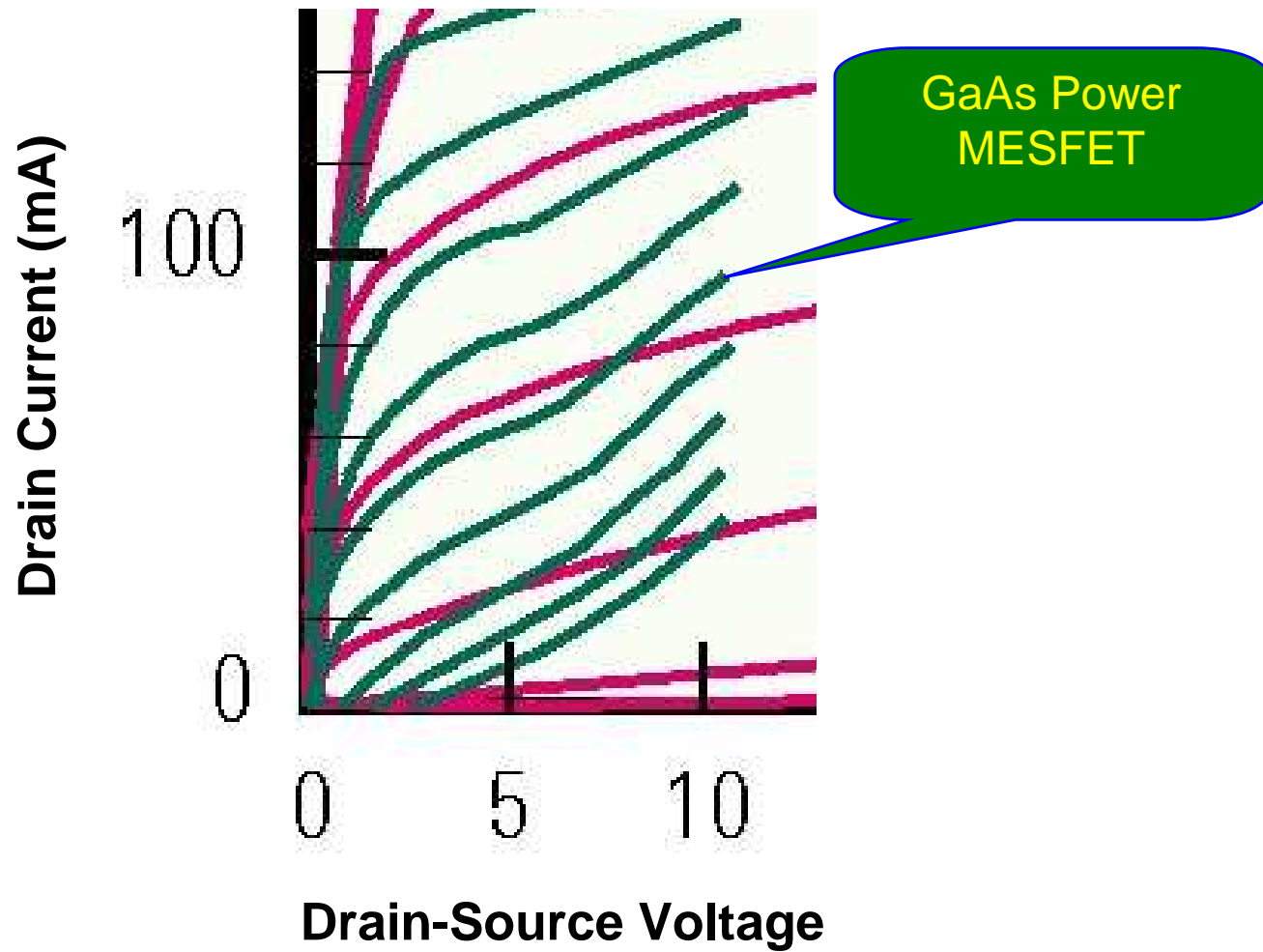
- Rapidity of GaN's rise...
  - 50 years for tubes;
  - 20 years for IV
  - 20 years for III-V (harder chemistry)
  - 10 for wide-bandgap
- Why?
  - Infrastructure courtesy lighting
  - Business model courtesy III-V



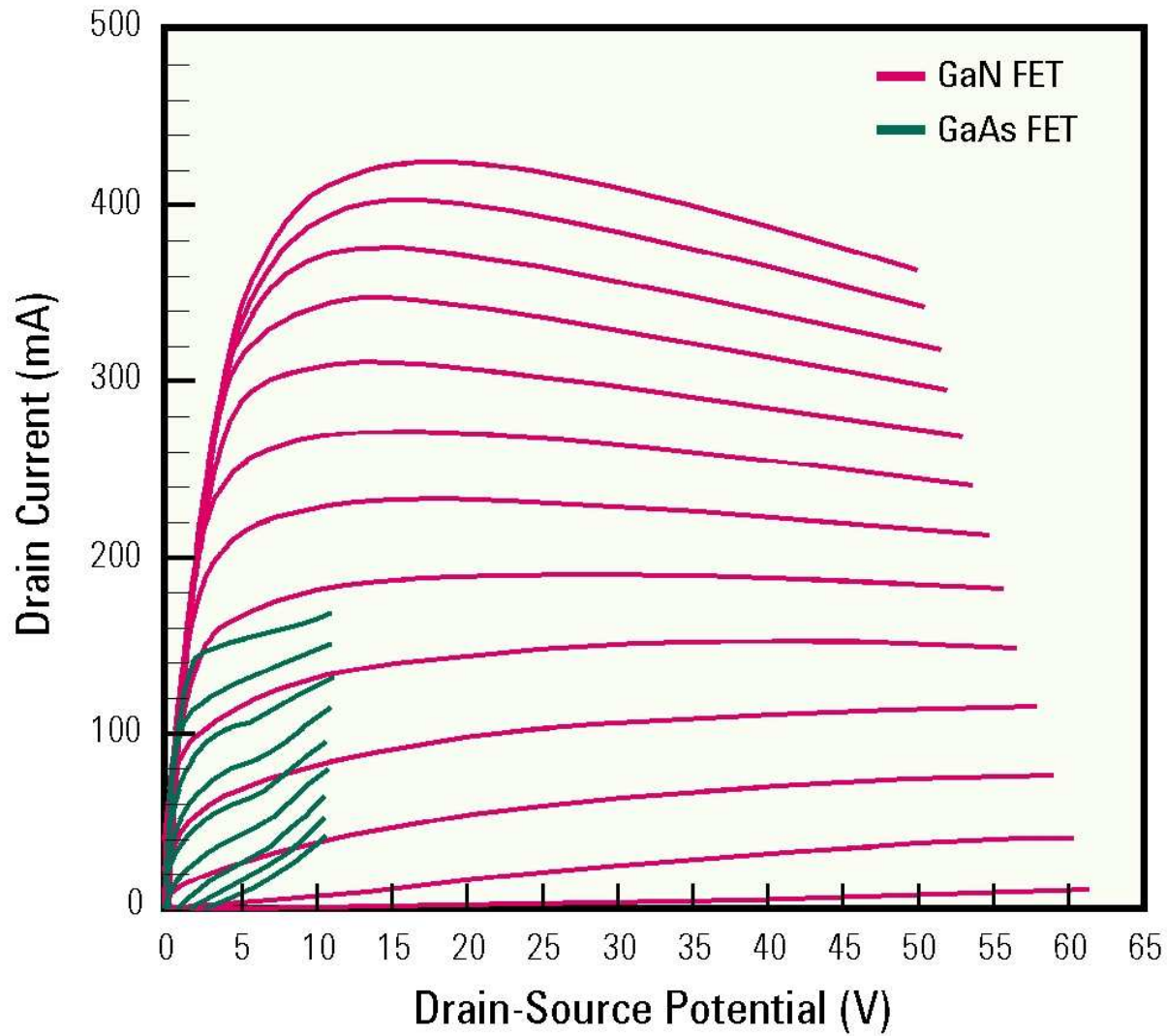
# History $\Rightarrow$ Prediction

- Perhaps 20 more years in III-V (GaAs & friends)
- Then Si & WB (GaN?) will dominate
- Why?
  - RED LEDs boosted GaAs, White LEDs boost GaN even more
  - GaN offers so much over GaAs
- Not convinced?
- HDVD to flashlight to garden lights depend on GaN, but GaN was unhead-of 10 years ago
- GaAs took longer, delivered less

# How good is GaN?

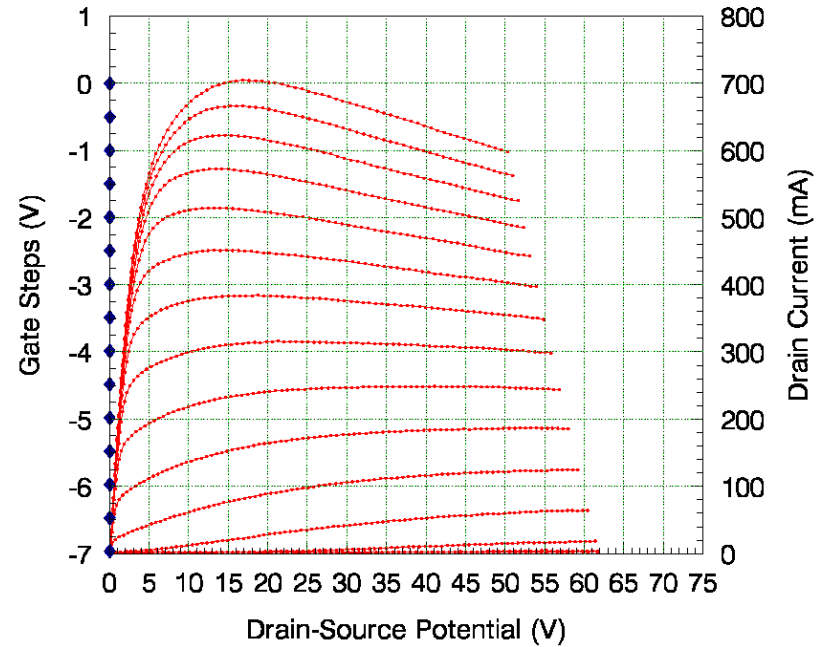
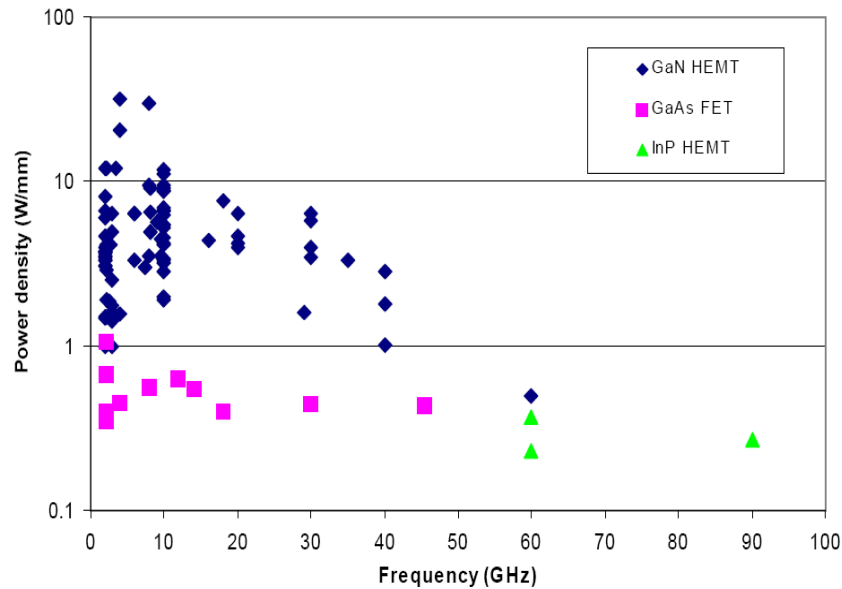


# GaN was this good... 3 years ago



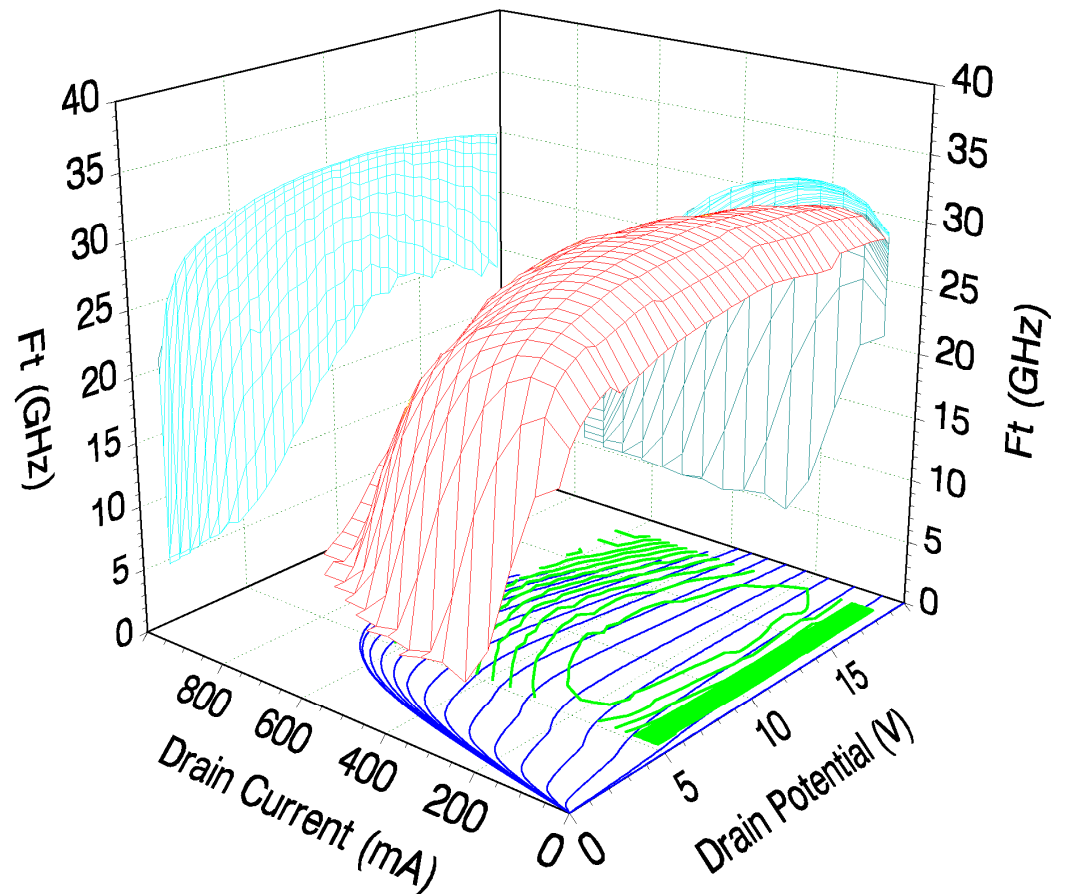
# Drain Characteristics – 1mm device

- Clean characteristics
- Modest dispersion
- Good  $g_m$
- Stunning power density



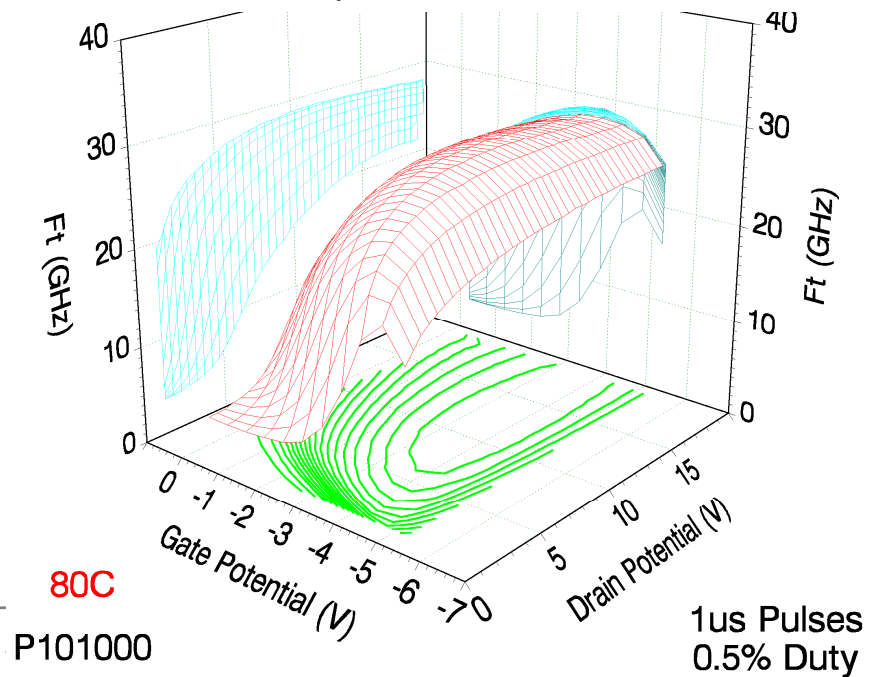
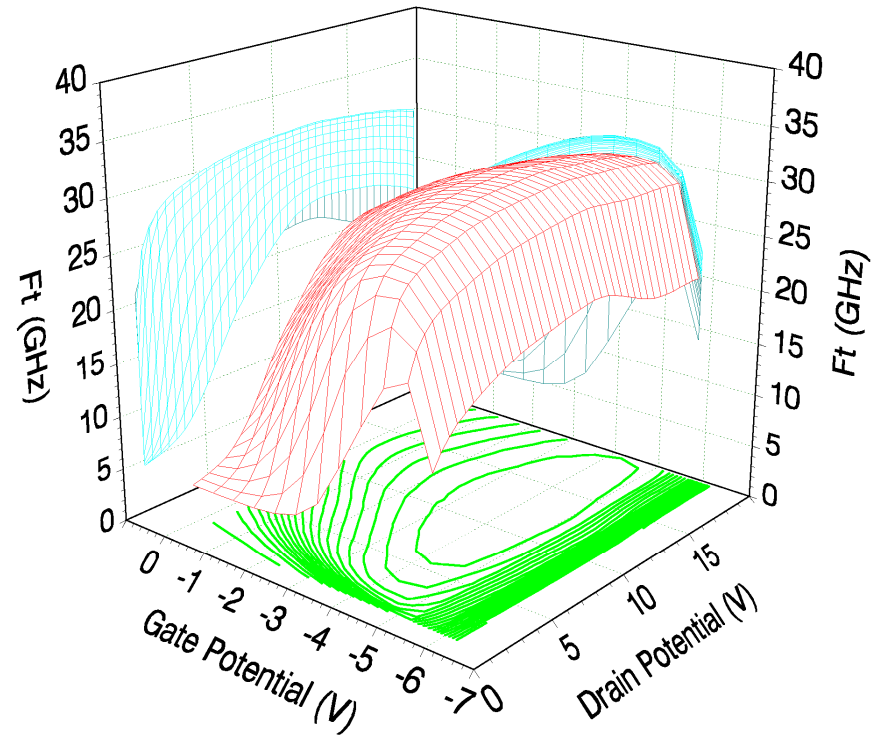
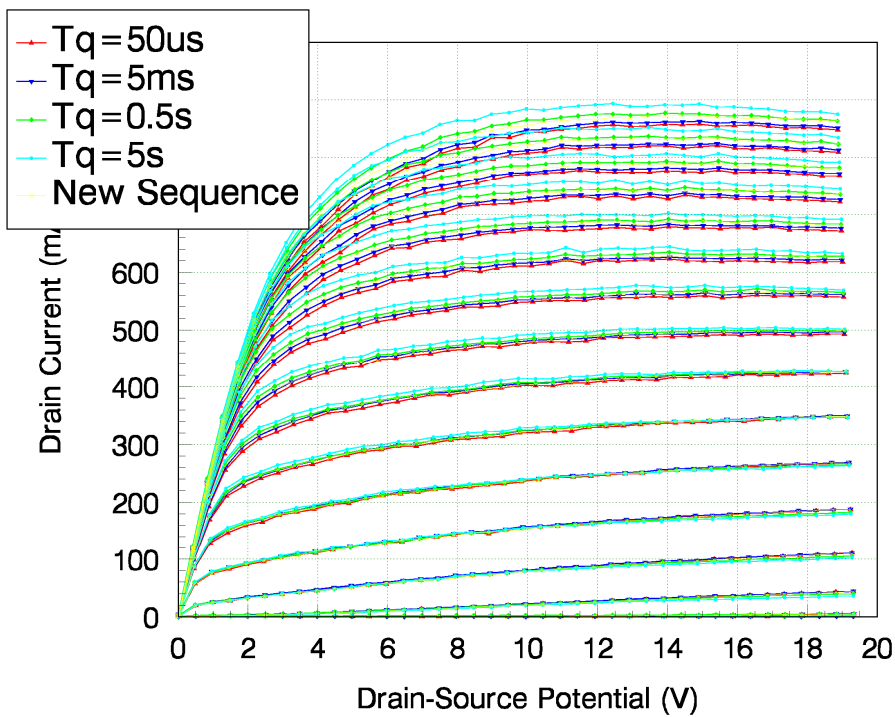
# Powerful and Fast

- Broad  $f_t$  peak
- This is a GaN-on-Si device
  - GaN on SiC better



# Robust

- Modest thermal effects
- No trapping (in modulation bandwidth)

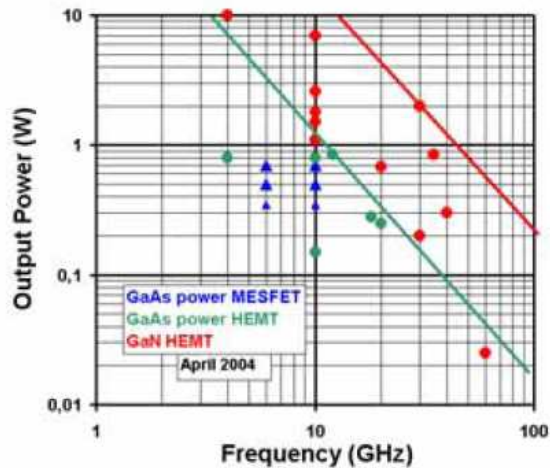


# Power-Bandwidth

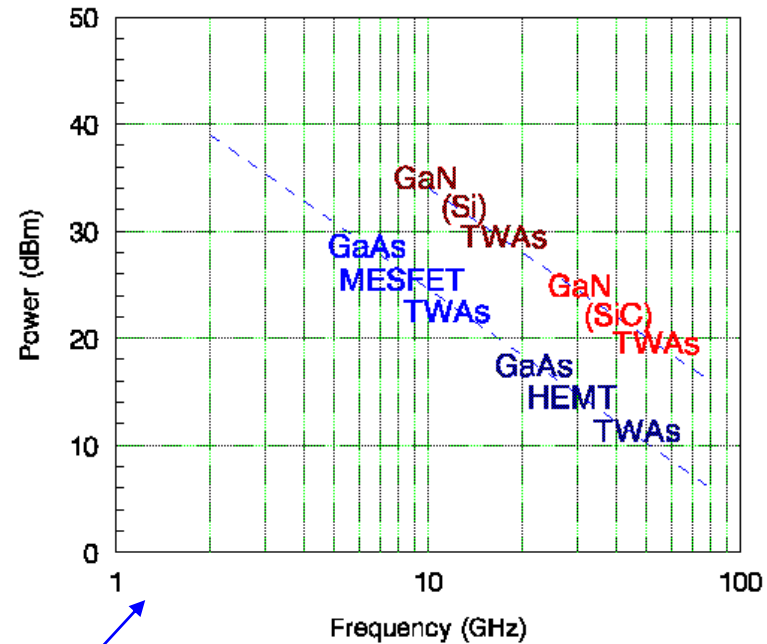
- Compare broadband amplifier (TWA) performance
- Theory:  $P_{\text{tuned}} \rightarrow \infty$

Actually silicon will not achieve base station performance at 5GHz

A factor of 20 improvement using GaN instead of GaAs



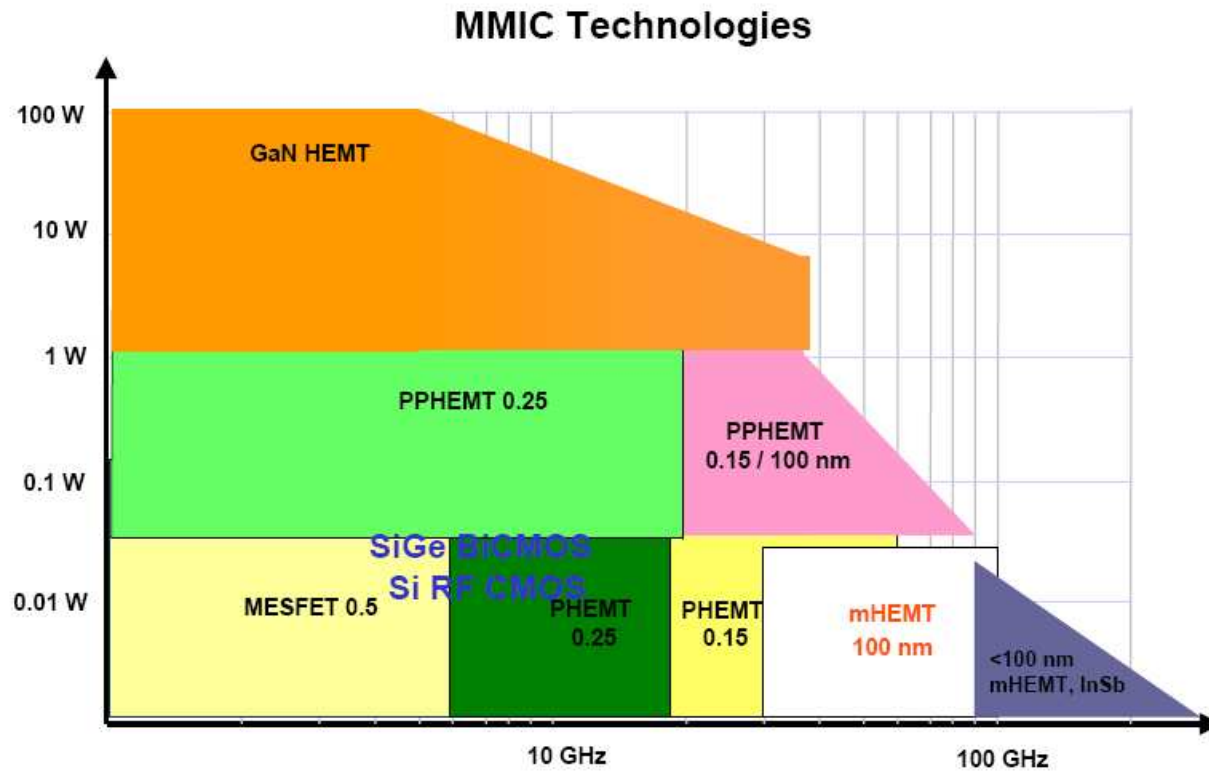
ESA



Agilent

# Power-Bandwidth

- Compare MMIC Technologies






# Applications-Mainline

- A few “No-brainer” applications
- PAs above 2GHz (devices already on sale)
- Radar (old, small-but-price-inelastic market)
  - Includes TWA replacement
- Sensors (operates at  $>320\text{C}$ , with only lowered  $g_m$ )

# Novel Application #1

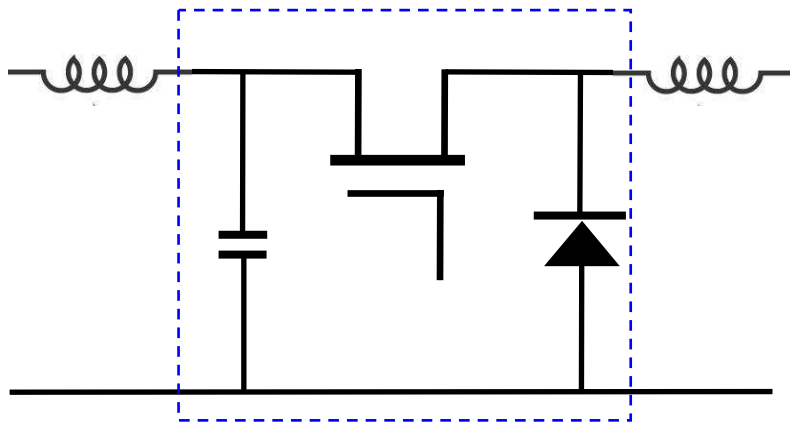
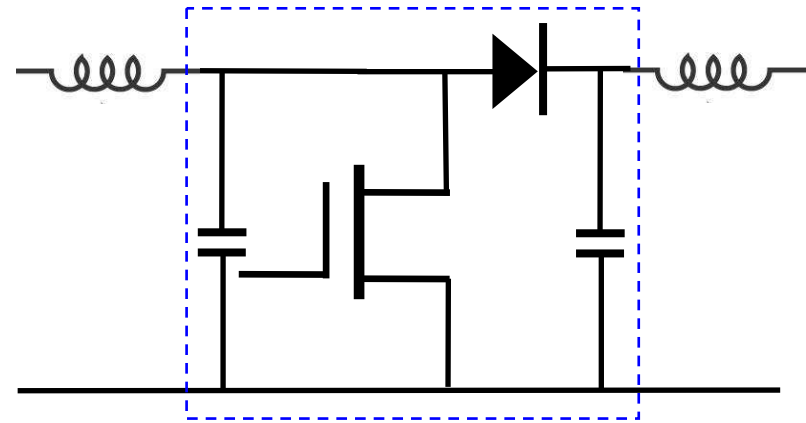
- MMIC SMPS
- Power conversion with  $10^8$  Hz-plus switching speed
- Acknowledged to be beyond silicon
- Some reports so far, but no use of passives yet
- 42V to 12V conversion on-chip?



GaN just moving  
from devices to  
MMICs

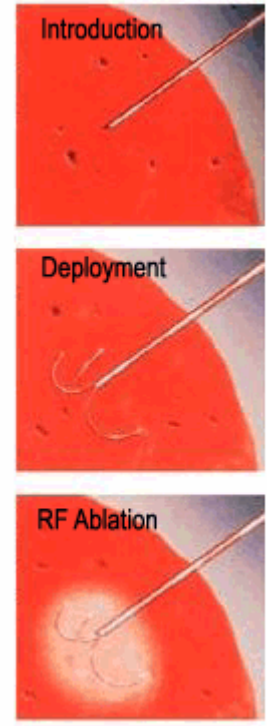
# Novel Application #1

- Boost with L in wires
- Buck with L in wires
- Resonant with L on-chip



# Novel Application #2

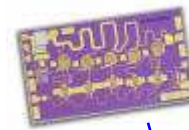
- Medical diathermy/ablation
- RF heating and thermal ablation commonplace
- Replace “pack+umbilical+probe” with MMIC probe



plus

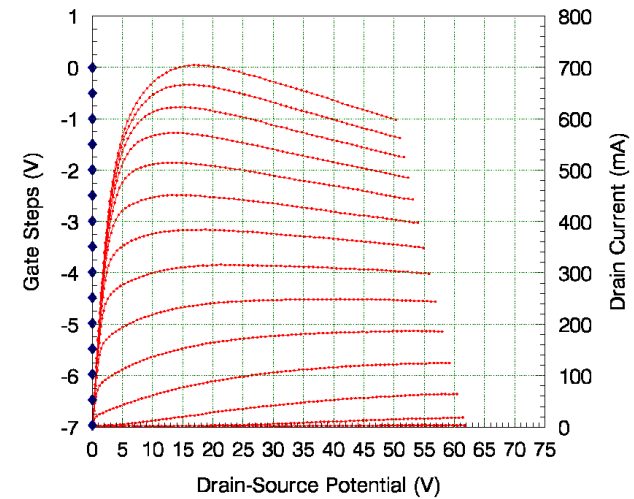


or

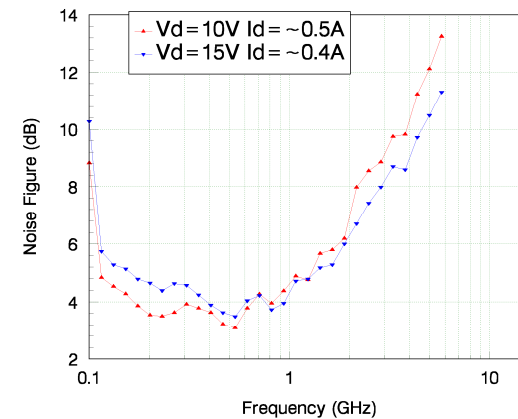


# Novel Application #3

- Dynamic range:  $V_{\max} - V_{\text{Noise}}$
- Tubes good despite noise
- GaN FET noise is low
- High DR DRO
  - Resonators now good for HV
  - Carrier-related noise 10—20dB lower



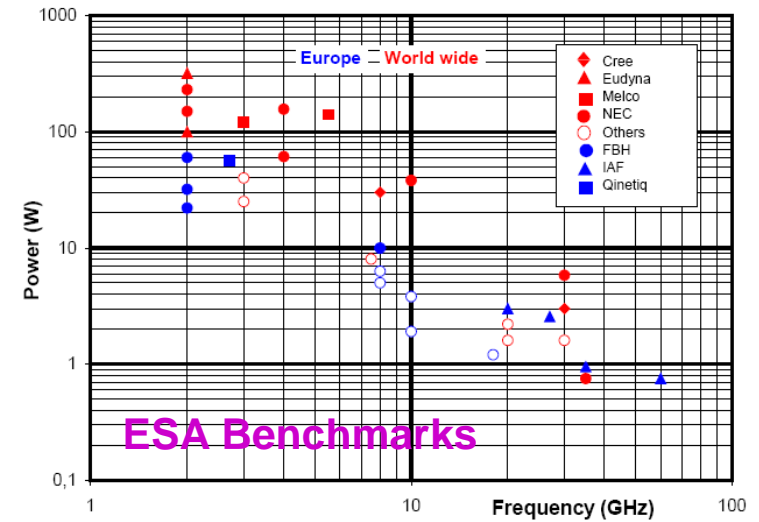
↑  
DR  
↓



# Foundry Offerings

- Indicator of technology maturity?
- Some foundries visible in 2004
  - DARPA requirement (no real interest)
  - Conspicuously unreliable or without foundation (offered!)
  - Qinetiq advertised but never returned calls
- 2007: Serious touting at IMS!
  - IMEC, uGaN, RSC/Teledyne...

**GaN foundry club:** here we narrow the field to BAE, Cree, Eudyna/Fujitsu, Fraunhofer, HRL, Nitronix, Northrop Grumman, Oki, Raytheon, RF Micro, Rockwell and TriQuint.



From  
Microwaves101.com  
(slightly out of date!)

# Some Publication Statistics

- IEEE IMS (2007)
  - 26 papers on GaN FET circuits
  - 18 on III-V (GaAs/InP HEMT/MESFET/HBT)
- IEEE Trans. Electron Devices & EDL (2006+)
  - 20% of CS transistor work GaN

# That Single Take Home Fact

- GaN is a major opportunity made for remote countries
  - Big impact (high value add proposition)
  - Wave breaking now (best time to start)
  - Foundry model is central (suits the antipodes)