Performance and Applications of GaN MMICs

Professor Jonathan Scott

&

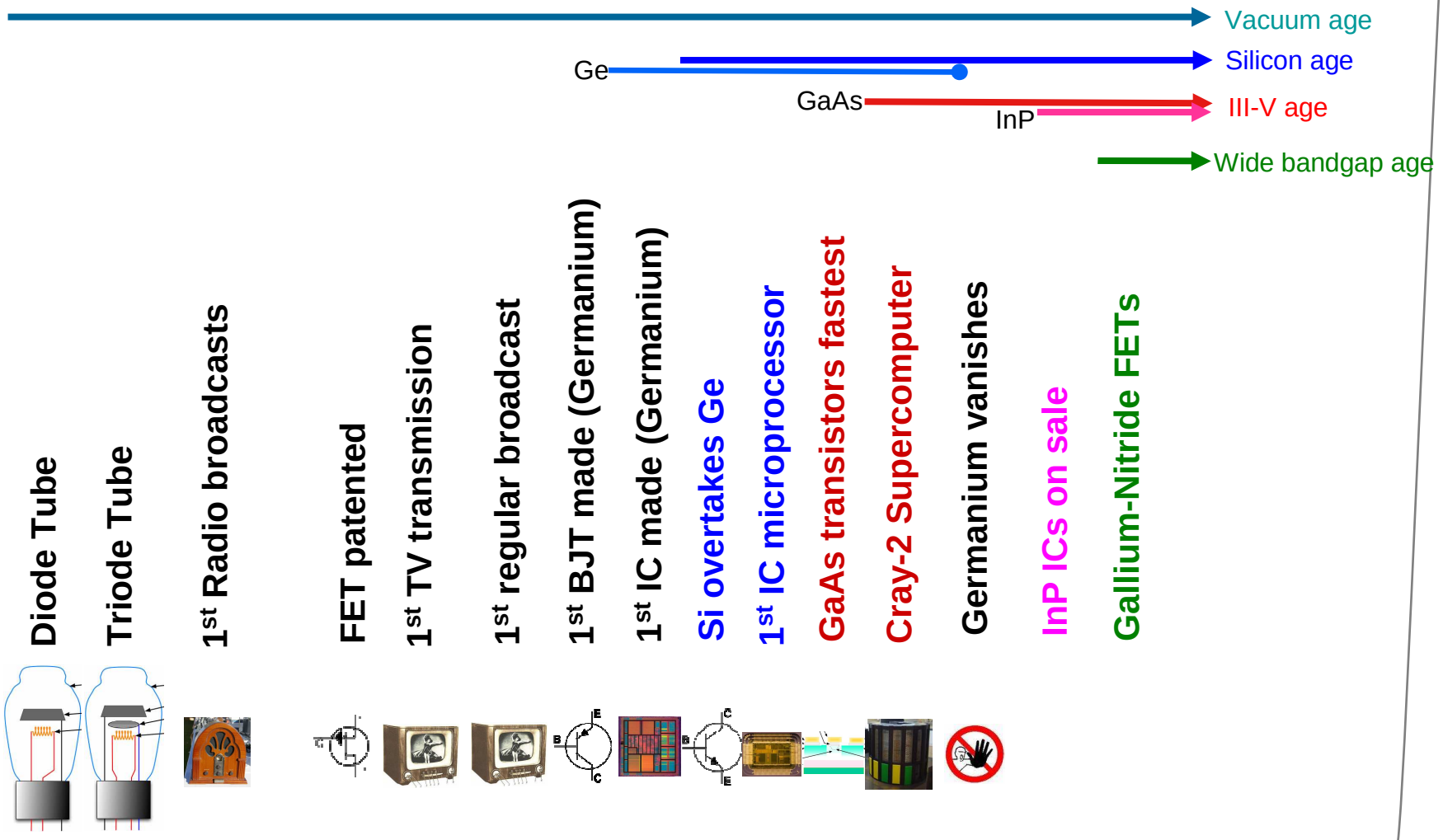
Professor Anthony Parker

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Contents

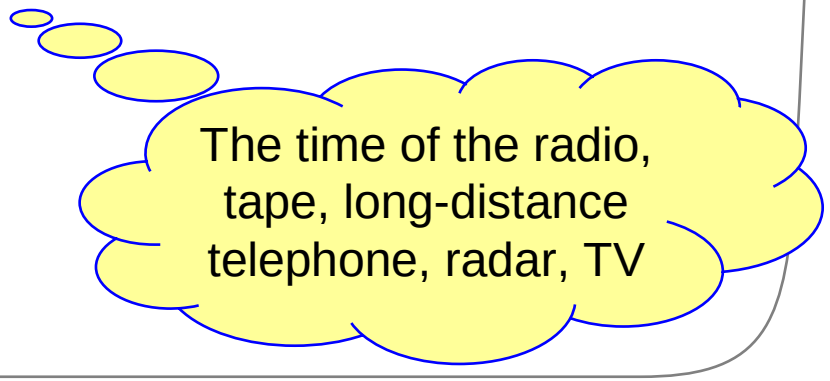
- "Invited paper" $\Rightarrow$ license to ramble?
- Contents: Not a memory dump
- You will learn something important
  - If not, come and see me after, I need to meet you
- There is a single, important take-home…

The History of Active Devices



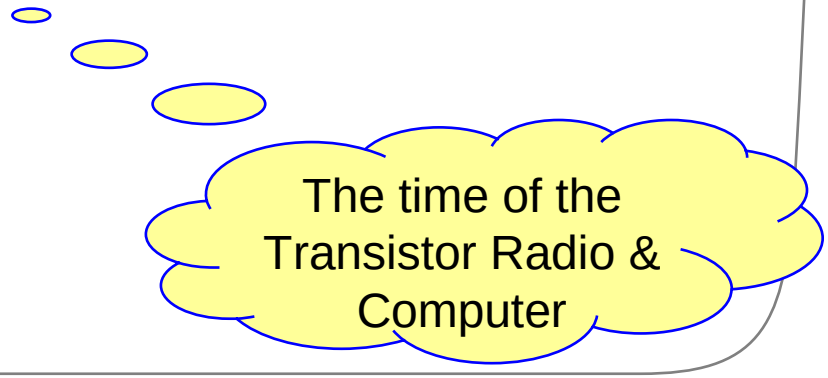
The History of Active Devices

- 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



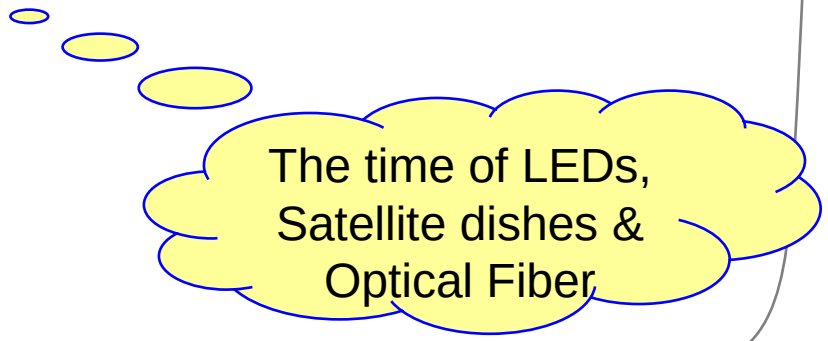
The History of Active Devices

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



The 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 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

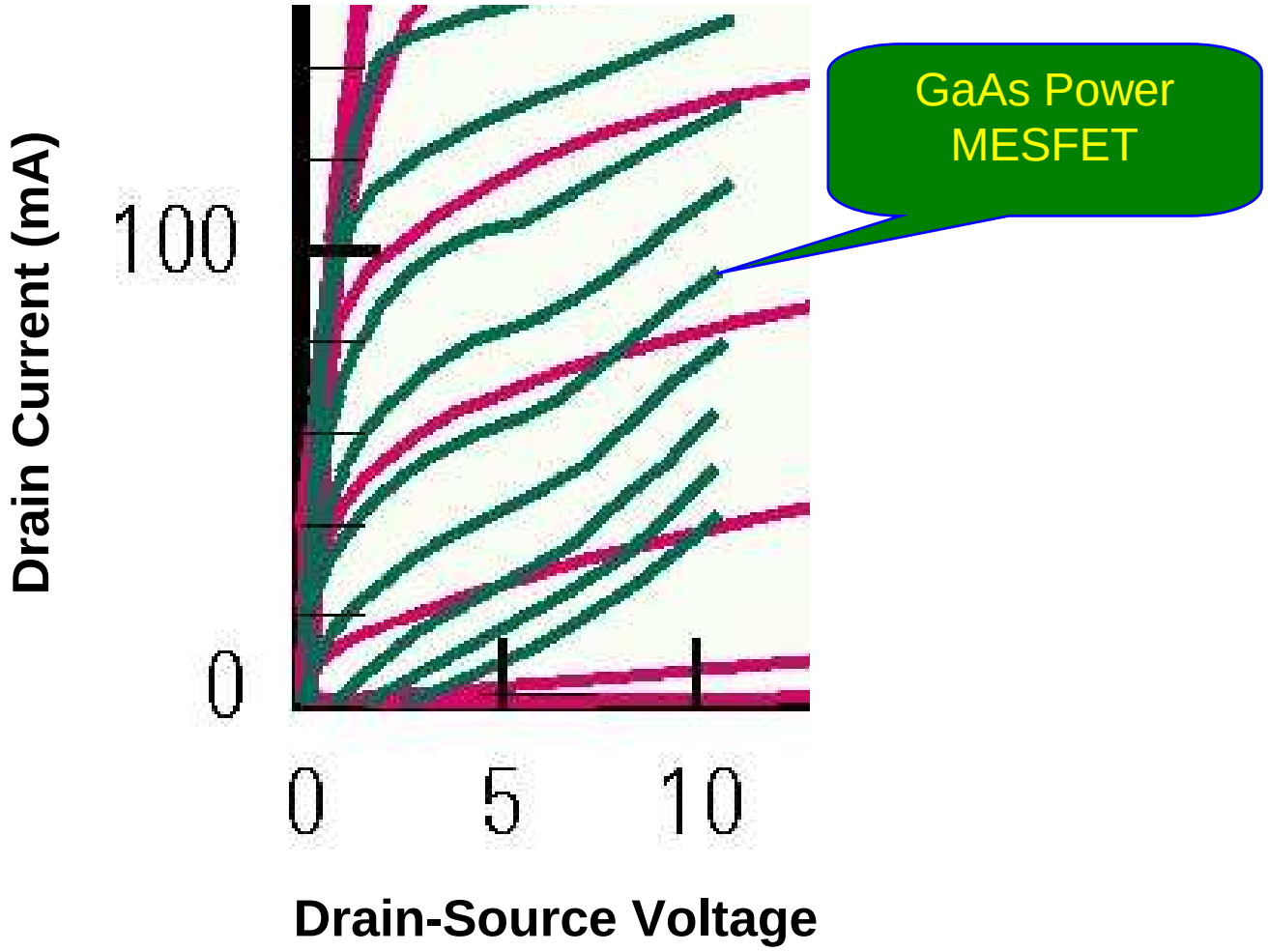
Current State of Active Devices

- 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

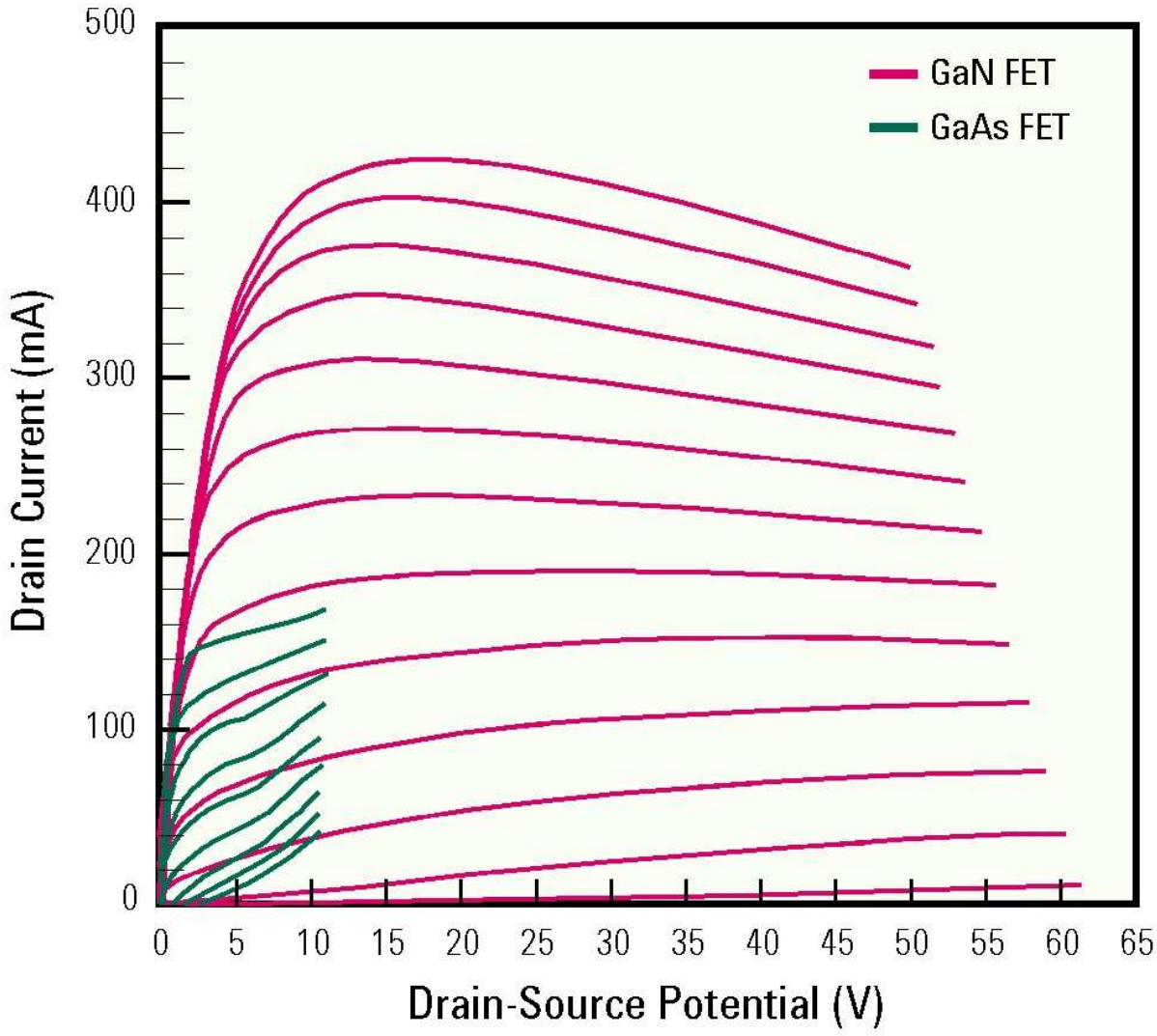
History ⇒ Prediction

- 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?



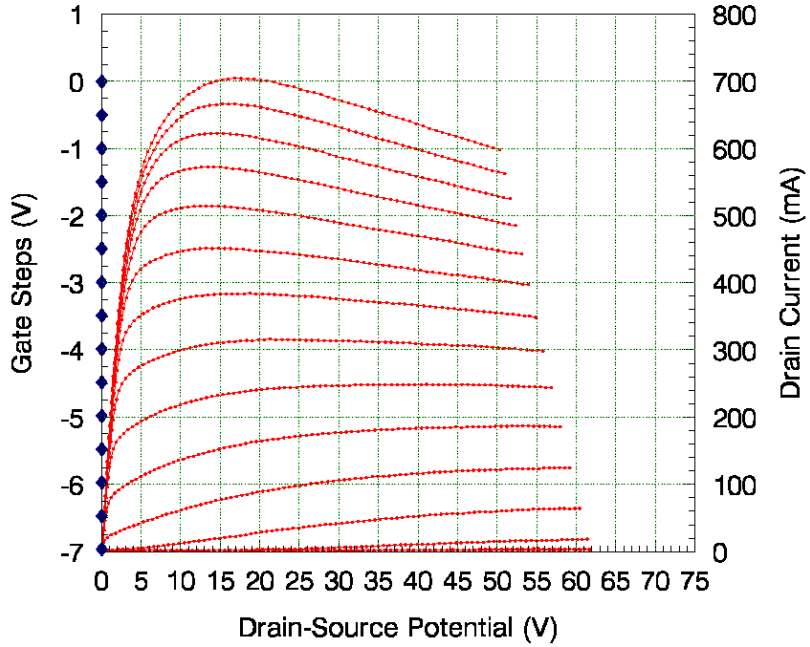
GaN was this good… 3 years ago

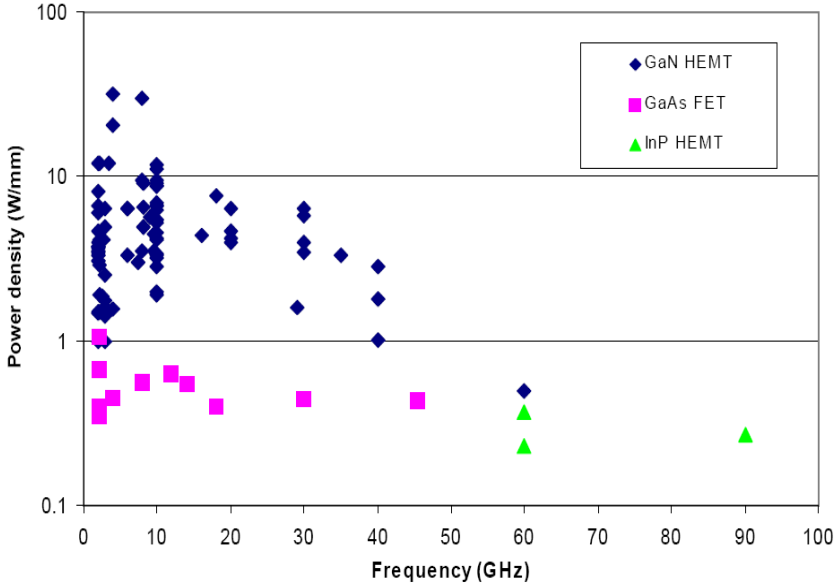


micro GaN GmbH

Drain Characteristics – 1mm device

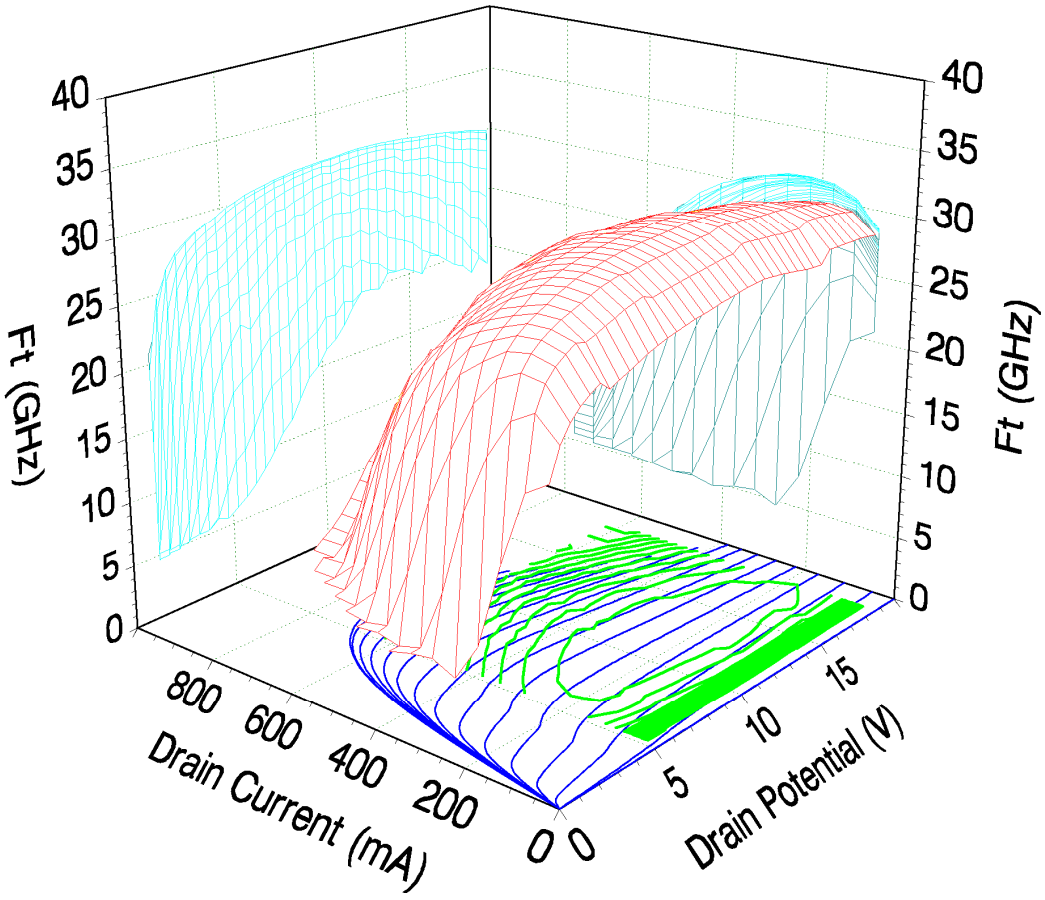
- Clean characteristics
- Modest dispersion
- Good g_m
- Stunning power density





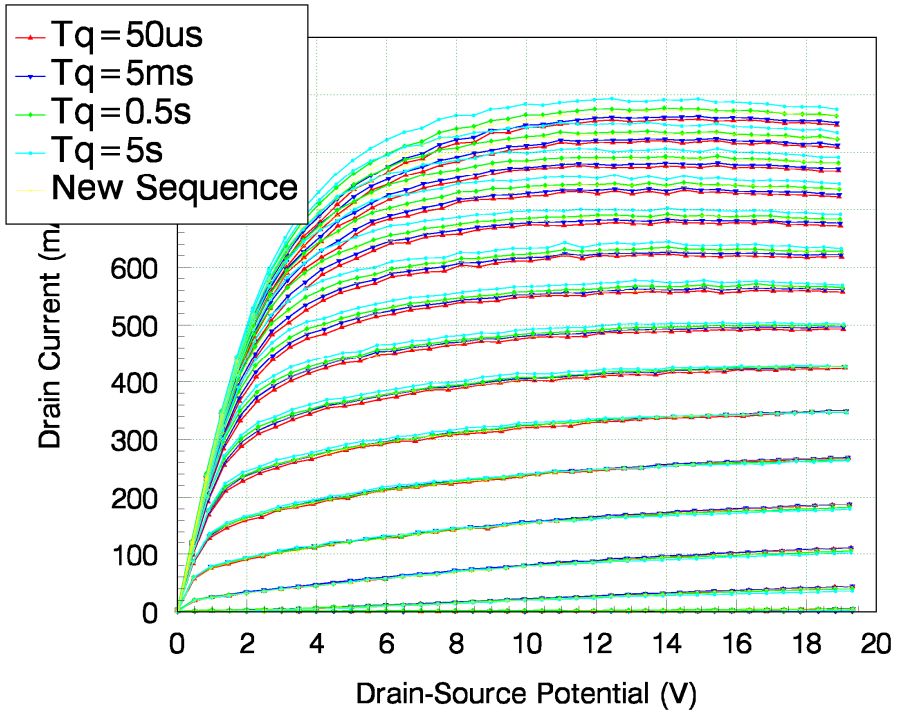
Powerful and Fast

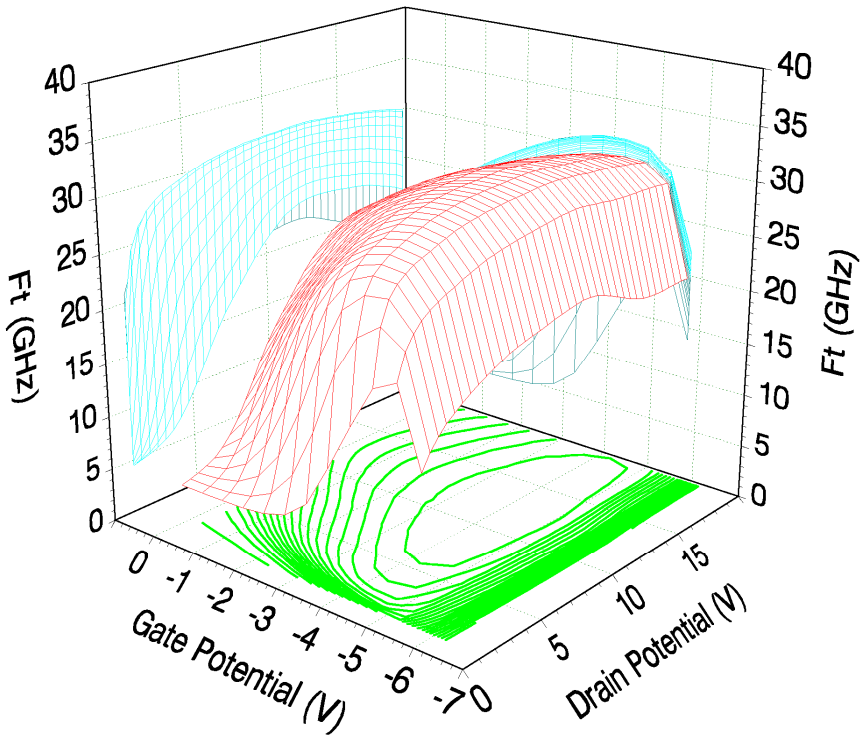
- Broad Ft peak
- This is a GaN-on-Si device
  - GaN on SiC better

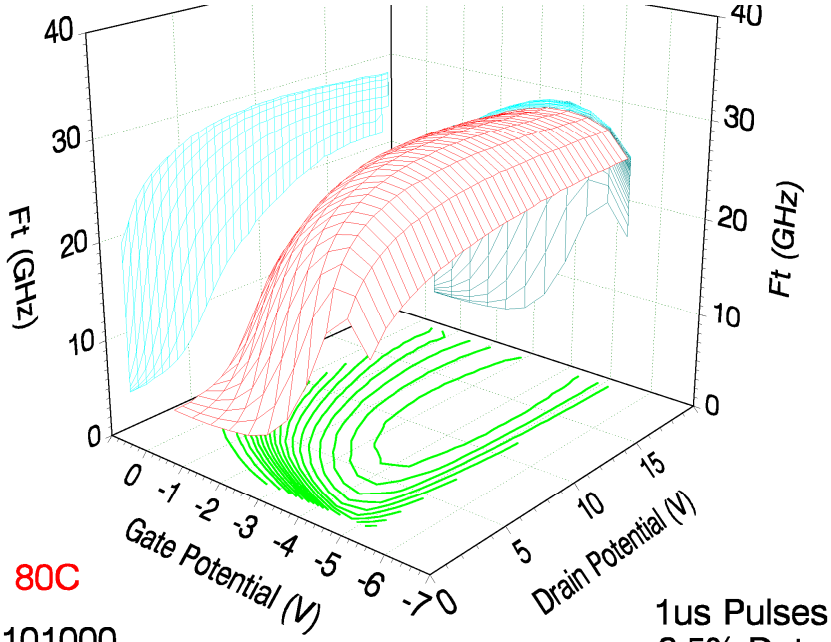


Robust

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







80C

P101000

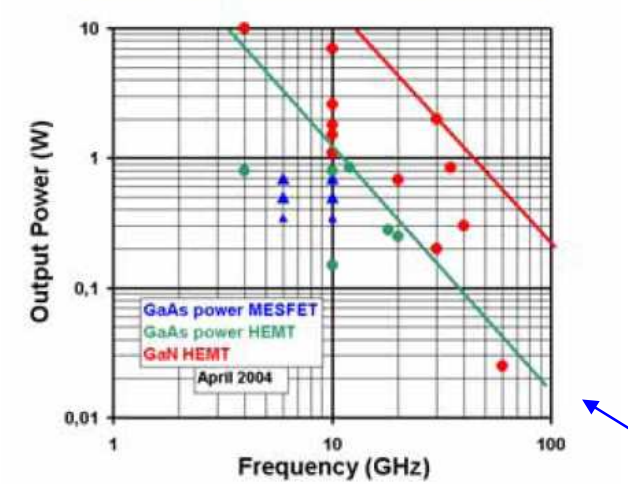
1us Pulses
0.5% Duty

Power-Bandwidth

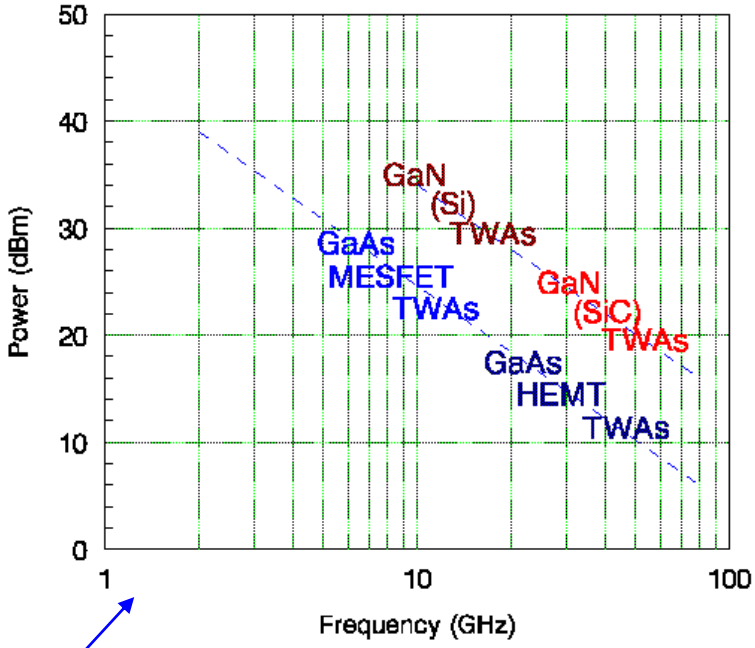
- Compare broadband amplifier (TWA) performance
- Theory: $P_{tuned} \rightarrow \infty$

Actually silicon will not achieve base station performance at 5GHz

A factor of 20 improvement using GaN instead of GaAs



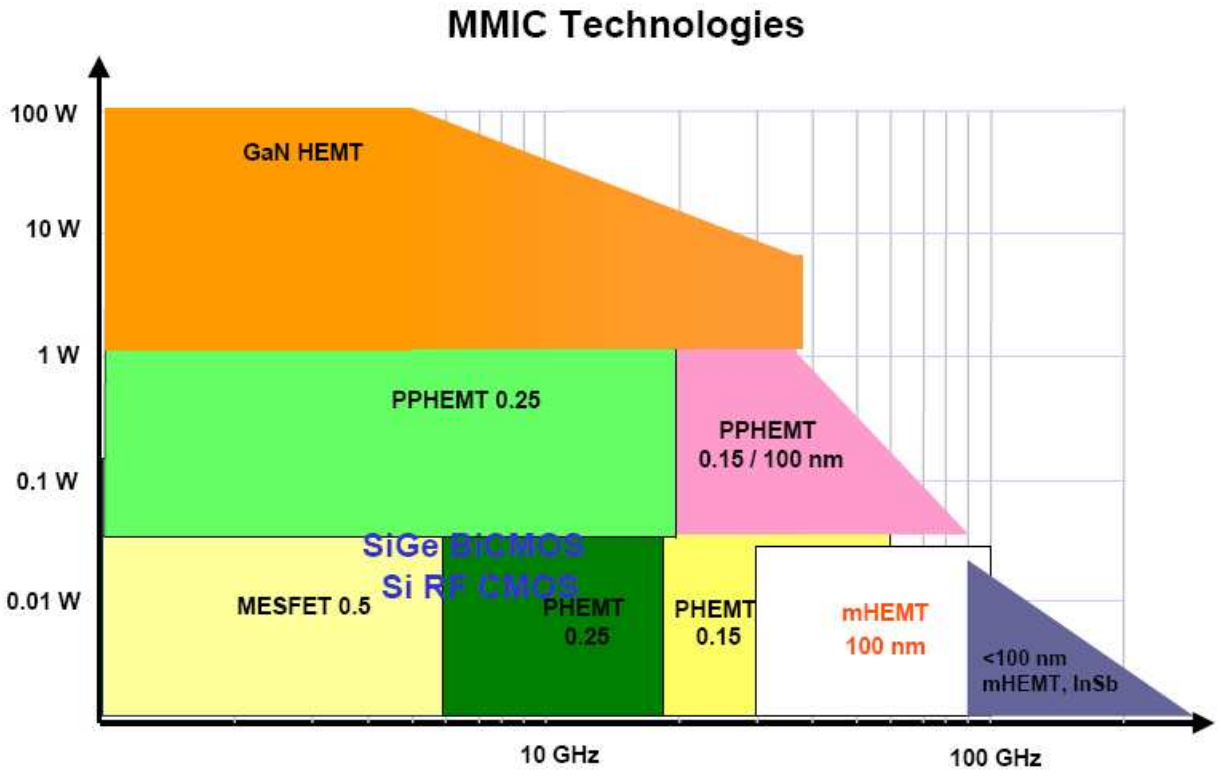
ESA



Agilent

Power-Bandwidth

- Compare MMIC Technologies



Applications-Mainline

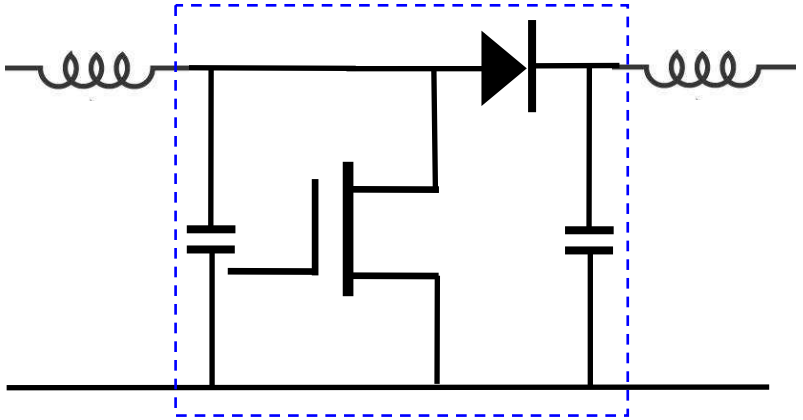
- A few “No-brainer” applications
- PAs above 2GHz (devices already on sale)
- Radar (old, small-but-price-inelastic market)
  - Includes TWA replacement
- Sensors (operates at >320C, with only lowered g_m)

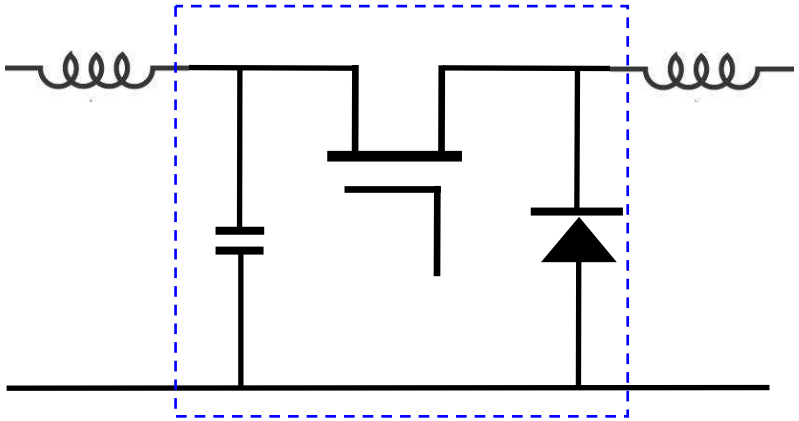
Novel Application #1

- 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?

Novel Application #1

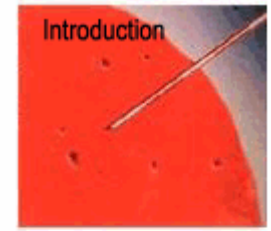
- Boost with L in wires
- Buck with L in wires
- Resonant with L on-chip

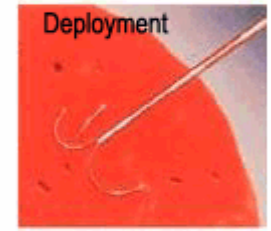


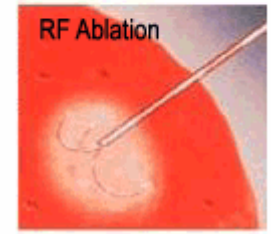


Novel Application #2

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

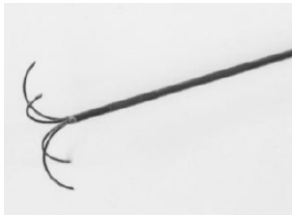


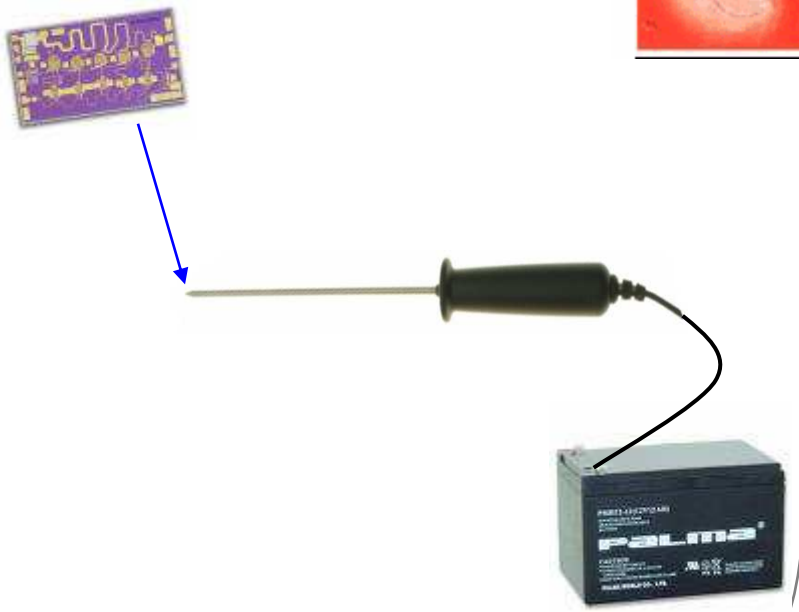




plus

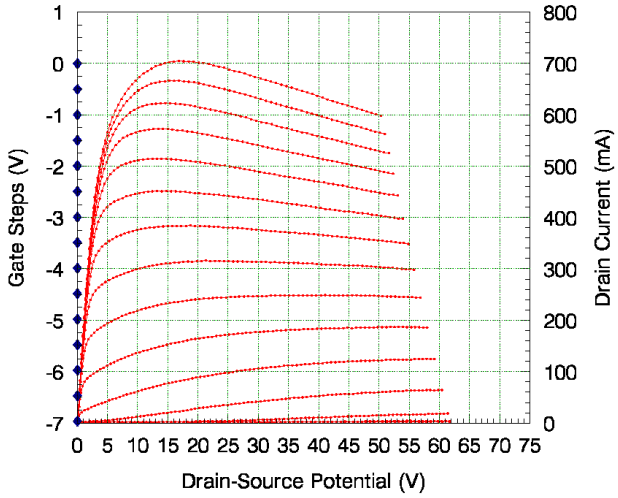
or



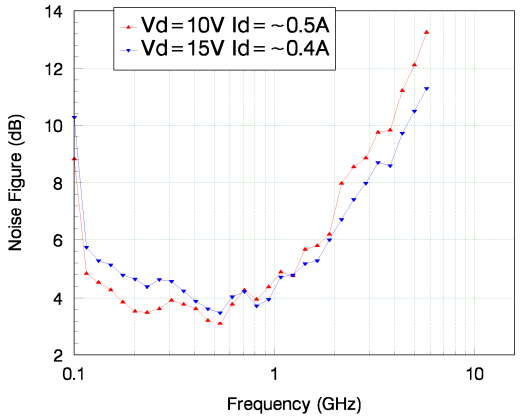


Novel Application #3

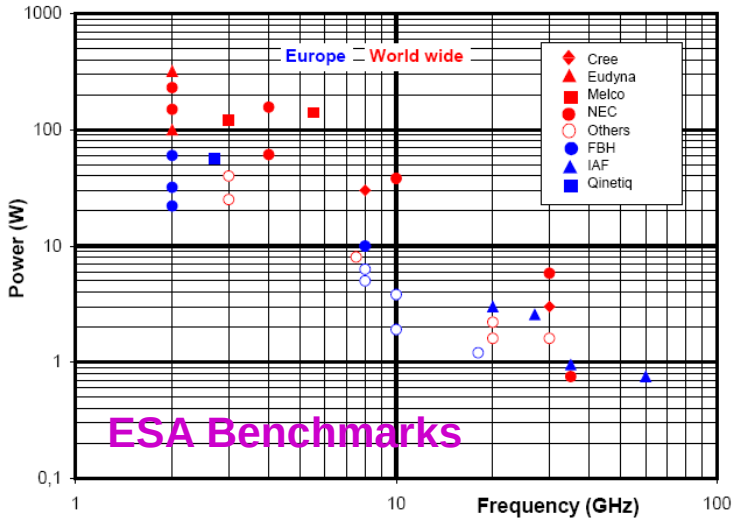
- Dynamic range: V_{max}-V_{Noise}
- Tubes good despite noise
- GaN FET noise is low
- High DR DRO
  - Resonators now good for HV
  - Carrier-related noise 10—20dB lower



↑
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…

From Microwaves101.com (slightly out of date!)

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.

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)