# “Impact of Commercialization of GaN based Power Devices on PV Solar Power Generation

**Tim McDonald**
**VP, Emerging Technologies Group**

International IOR Rectifier

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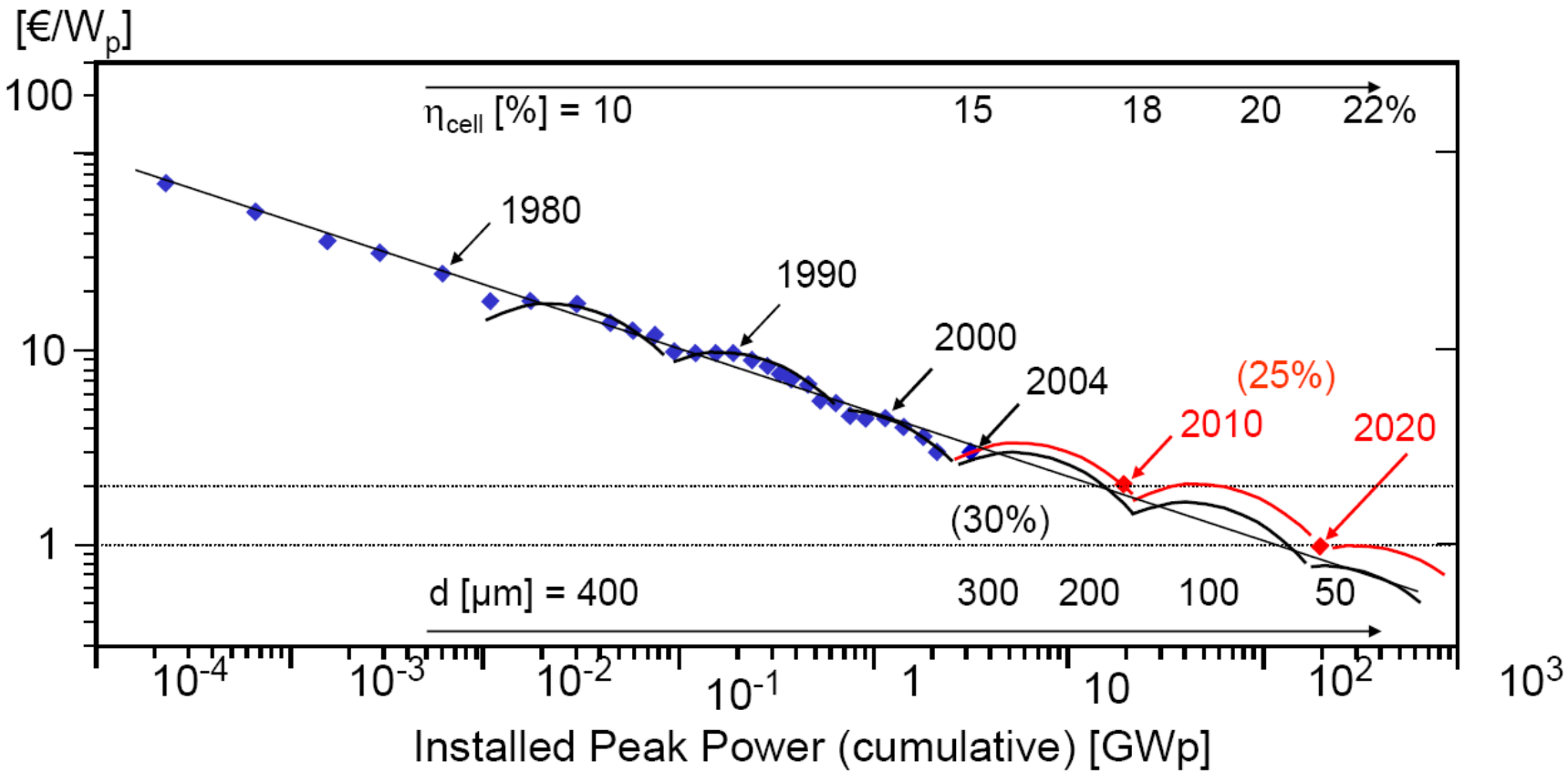
# Outline

- Why is GaN interesting to fabricate power devices for PV solar power generation?
- What is GaN? What do we refer to as “GaN based power devices”?
- What are the barriers to commercialization of GaN based power devices?
- How does IR’s GaNpowIR technology platform overcome these barriers?
- What benefit does GaN based power conversion make available to solar power generation?
- What is current performance of GaN based Power conversion for solar power generation?
- Barriers to Realizing the benefits: Opportunity for ARPA-e

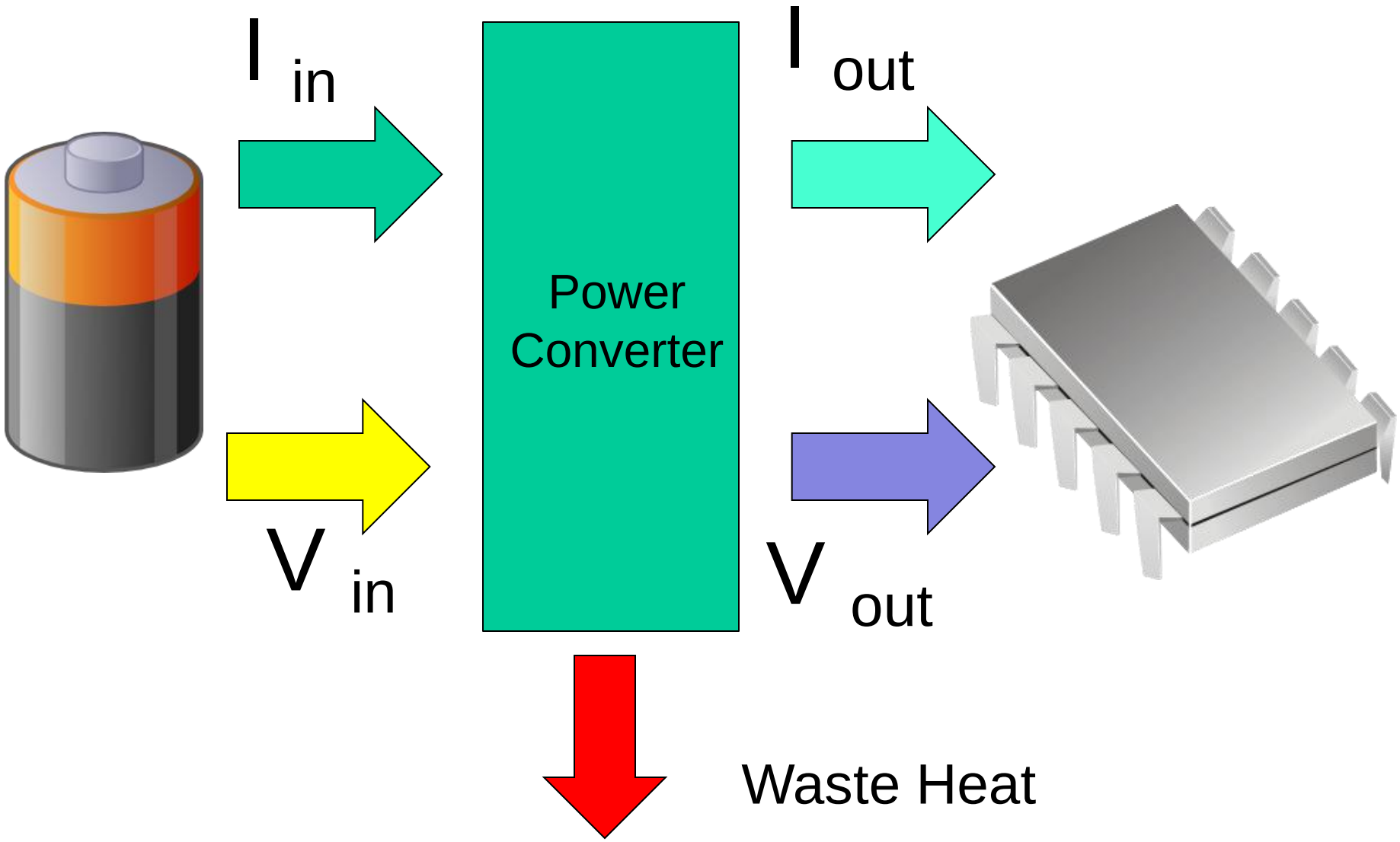
# Si PV Panel Cost Trend




Graph: G. Willeke, ISE

- Assuming a 3000€ cost per KW (total cost), and nominal power of 4KW, every 1% of efficiency improvement translates in 120€.
- Still better to spend more in power electronics than PV $m^2$

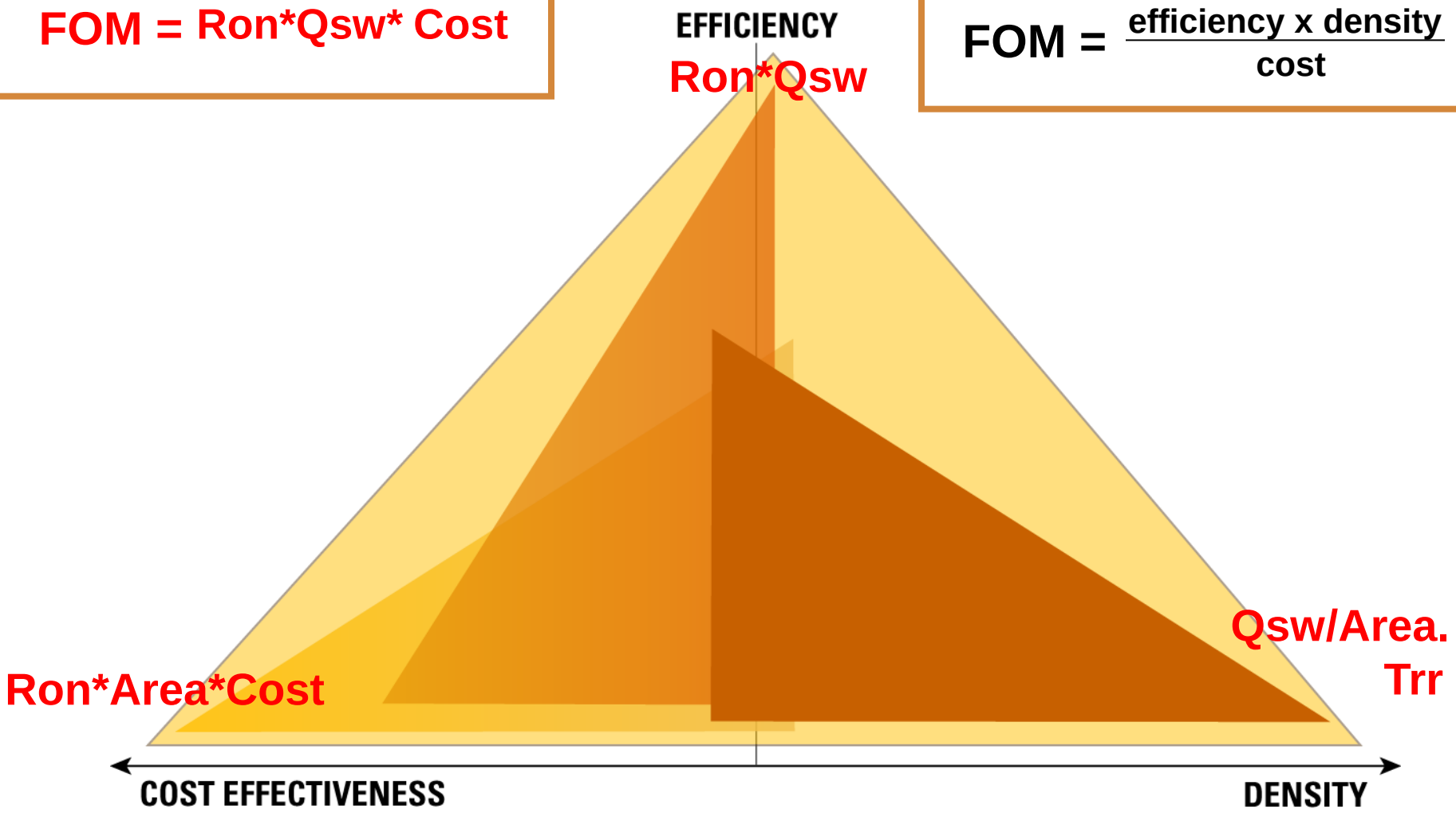
# Power Conversion Process



# Figure of Merit: Tradeoffs

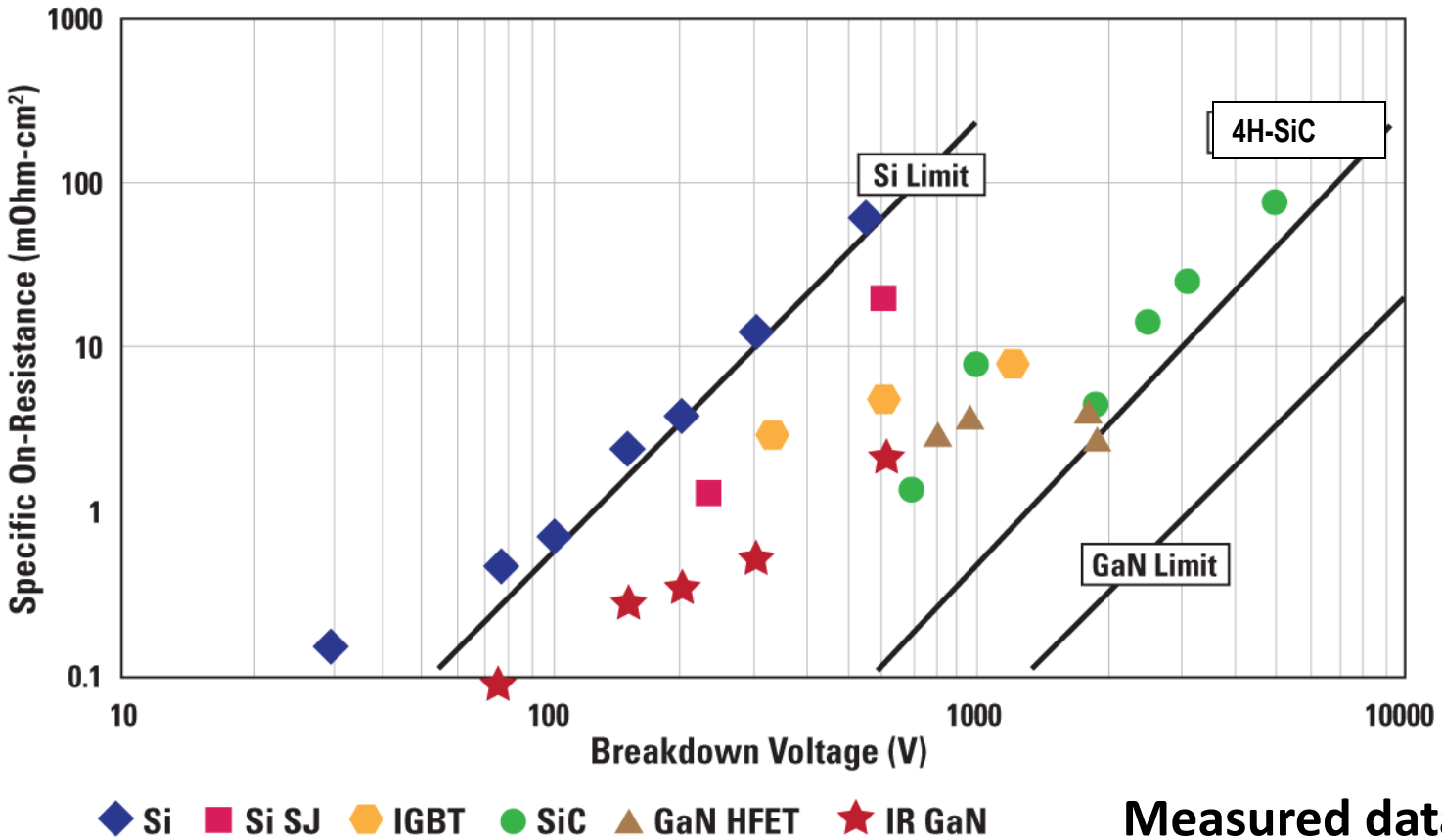
**FOM = Ron*Qsw* Cost**

$$\text{FOM} = \frac{\text{efficiency x density}}{\text{cost}}$$



# Dramatic Improvements in Power Device FOM

## Comparison of $R_{on}$ for Si, SiC, and GaN

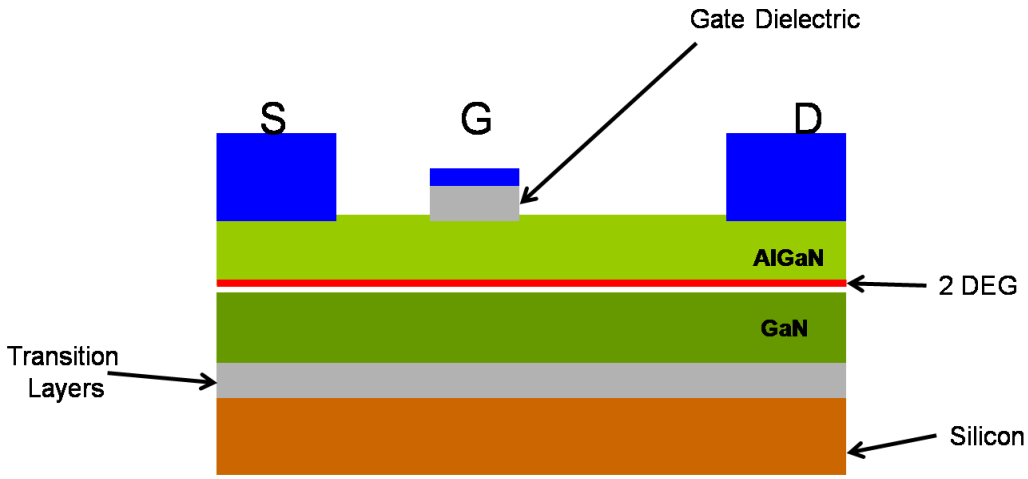


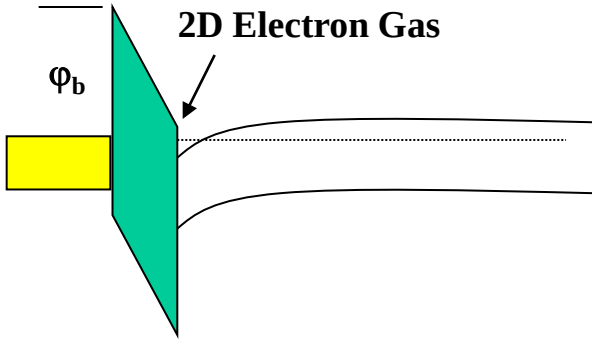

**Measured data**

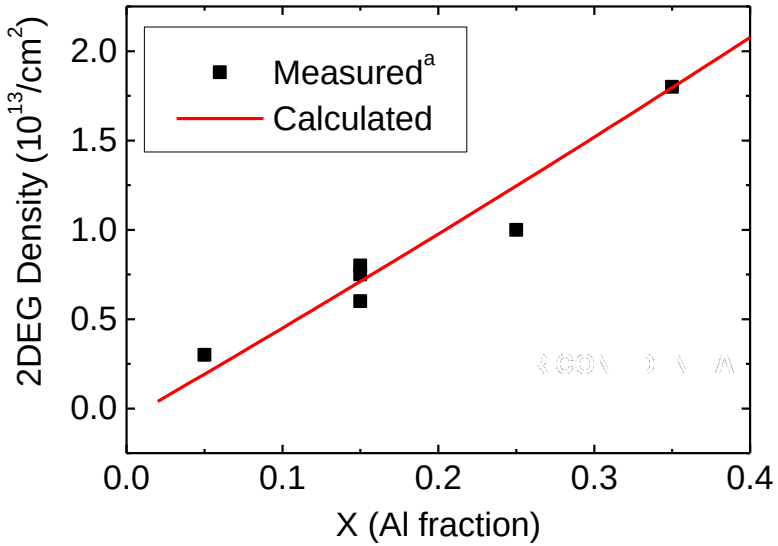
**Ecrit : Si = 20 V/µm , GaN = 300 V/ µm**

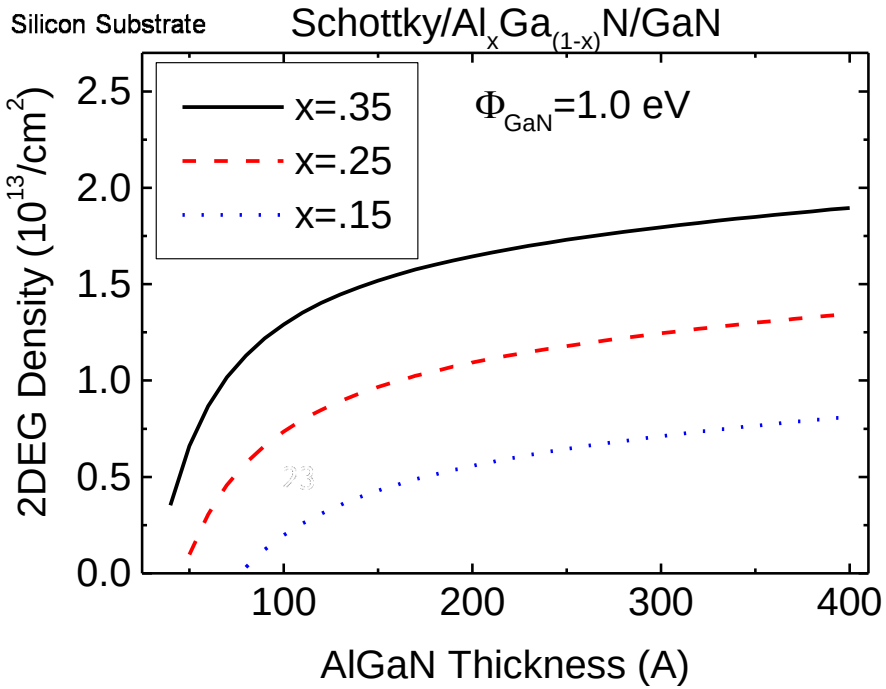
**Ref: N. Ikeda et.al. ISPSD 2008 p.289**

# HEMT-FET Structure



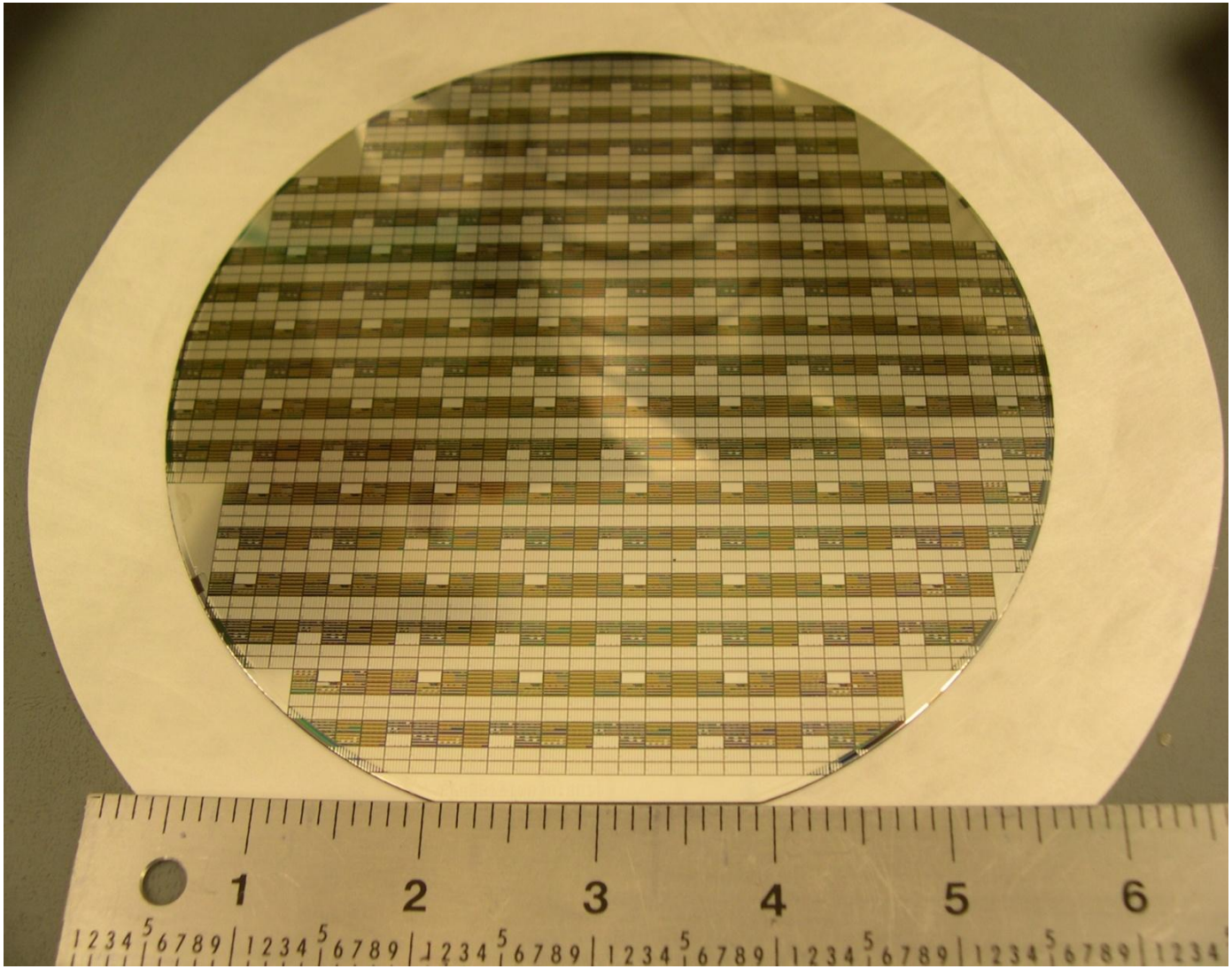

[a] J. Van Hove, SVTA & J. Redwing, ATMI

# Requirements for commercially viable GaN based power devices :

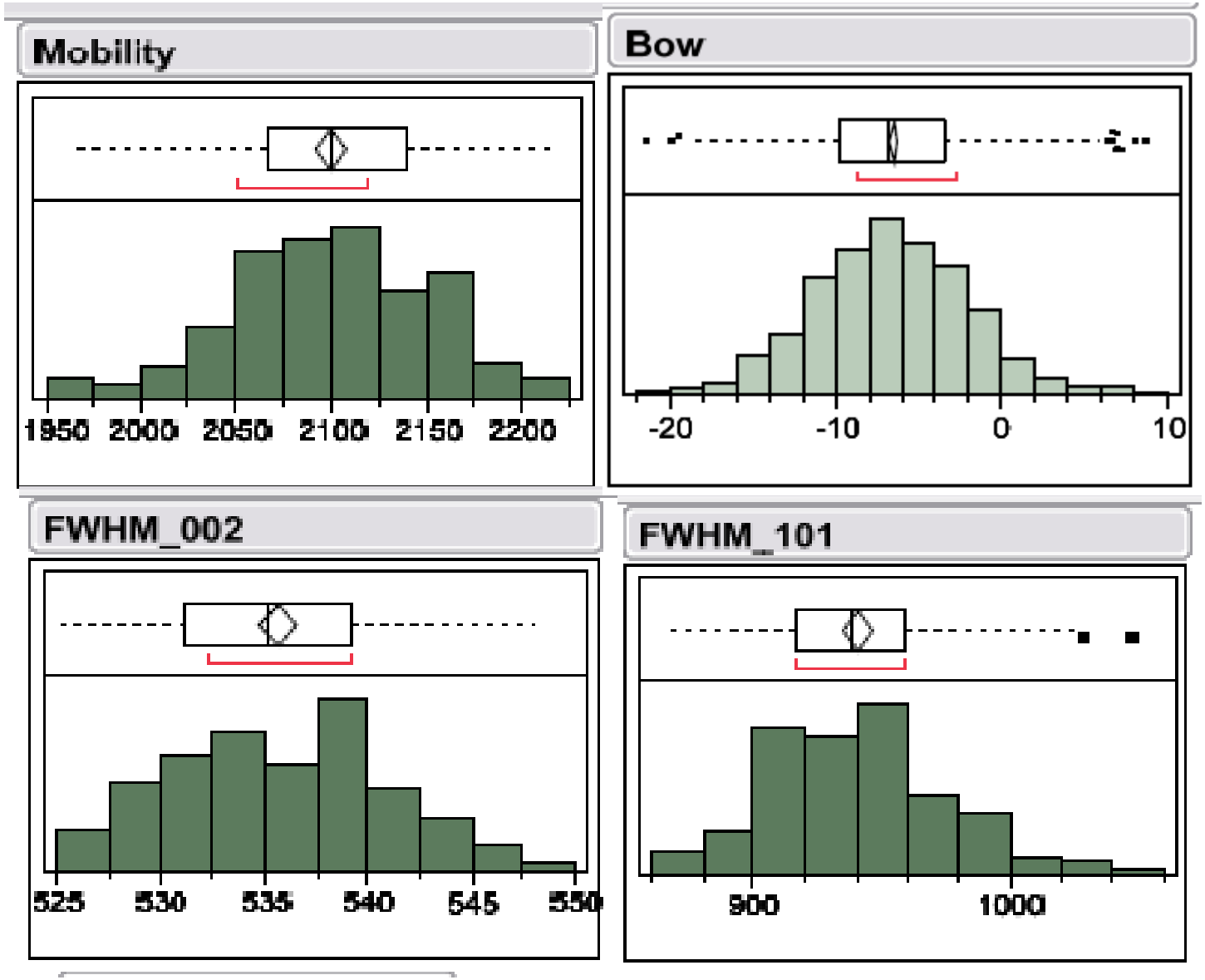
**P/C (GaN) > 2-3 x P/C (Si)**

- Epi + substrate cost < \$3/ $cm^2$ (i.e. silicon)
- I leak < 0.1 µA / mm , Ion / Ioff > $10^6$
- 2 DEG mobility > 1800 $cm^2/Vs$
- Truly Crack Free epi (< 1 mm from edge) with low active defect density
- Yields >80% for 10$mm^2$
- Stable electrical performance (eg: $R_{DS}$(on), R*Qg, Isat, Vp, Ileak )
- Large diameter ( > 150 mm) substrates with < 50 µm bow after epi growth
- High Volume ( > 10 k wafers/ wk) Si Wafer Fab Compatible
- Supply needed: >$10^6$ 150 mm wafer equivalents (to support 10% total power semiconductor market at current utilization rates)

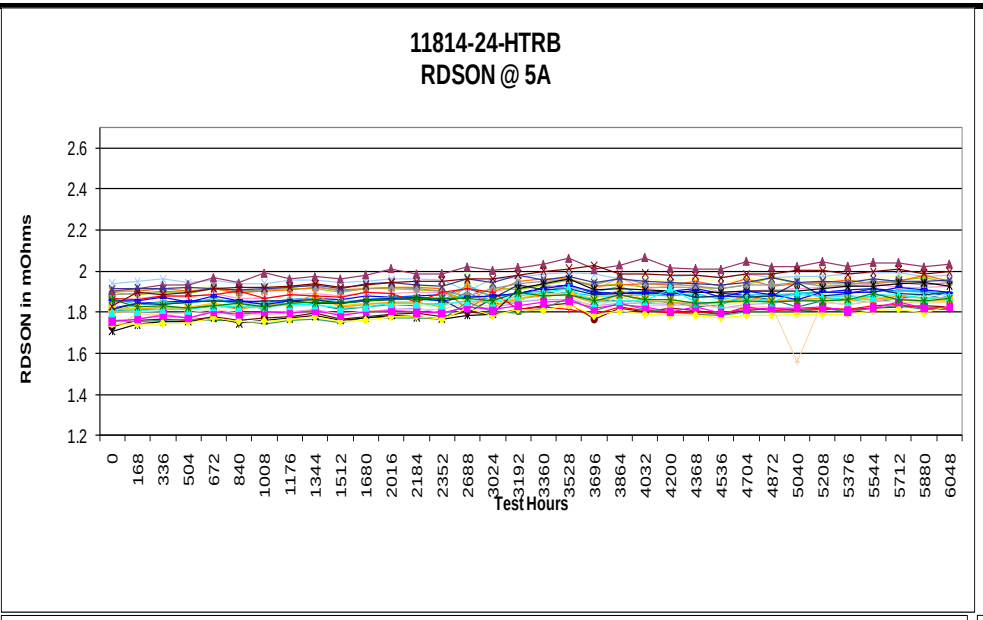
# 6” GaNpowIR Device Fabrication - > 2 um epitaxy – NO cracks

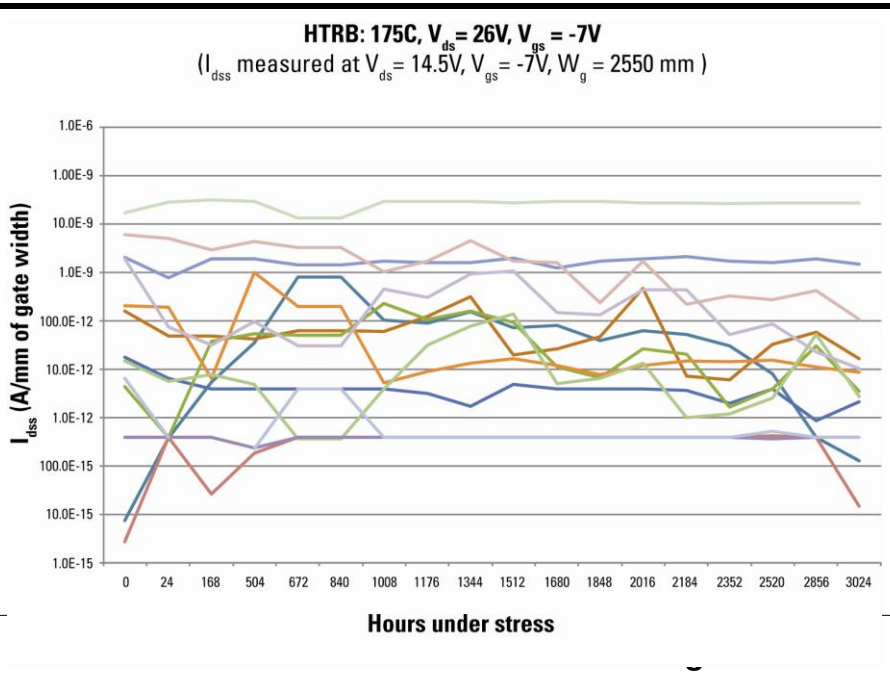


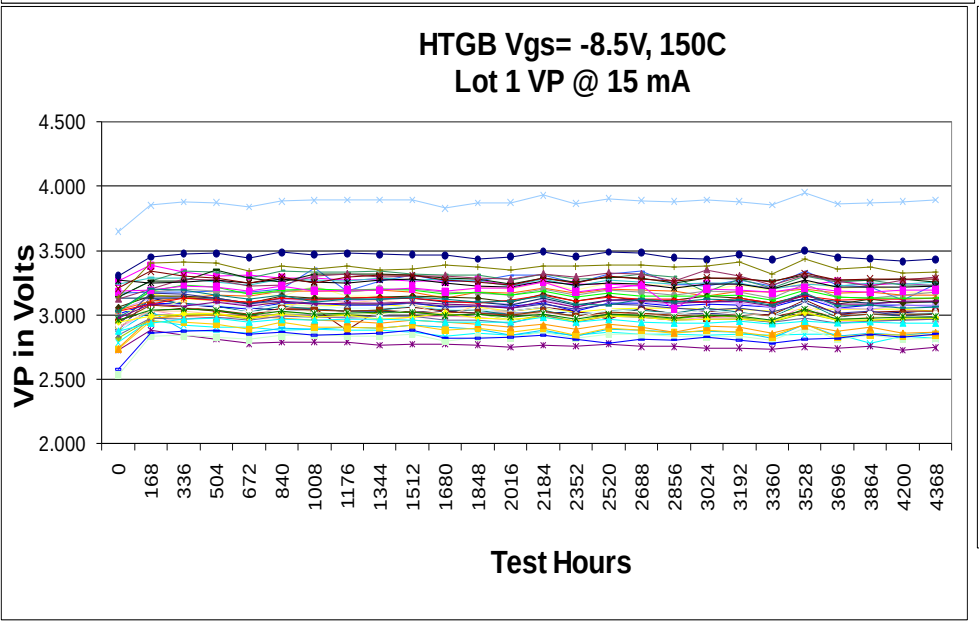
# IR GaN Heteroepitaxy 2 µm epi on 150 mm Si wafers

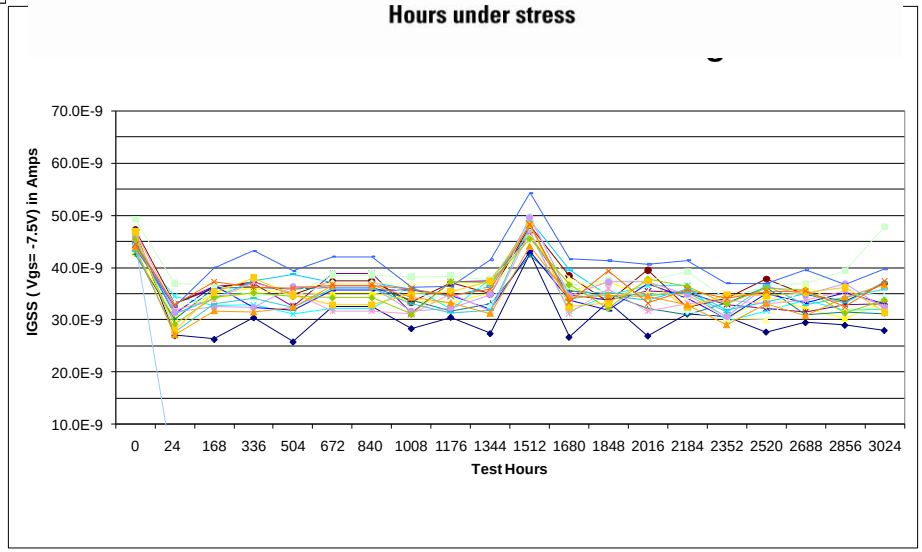


# > 7,000,000 Device Hours Reliability



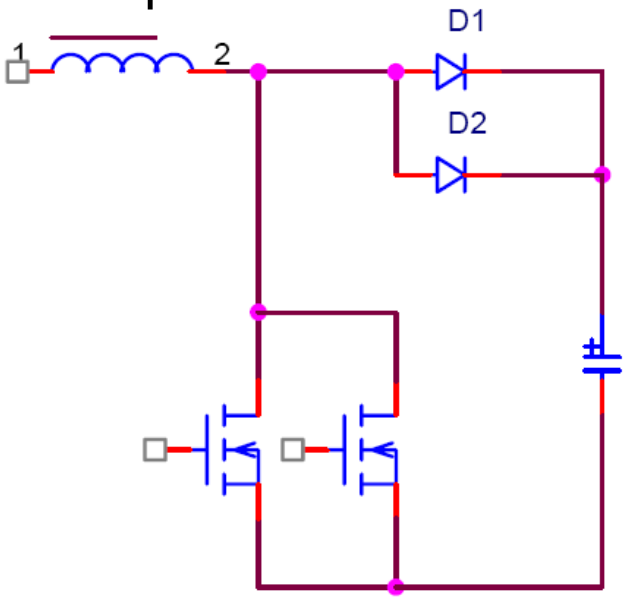



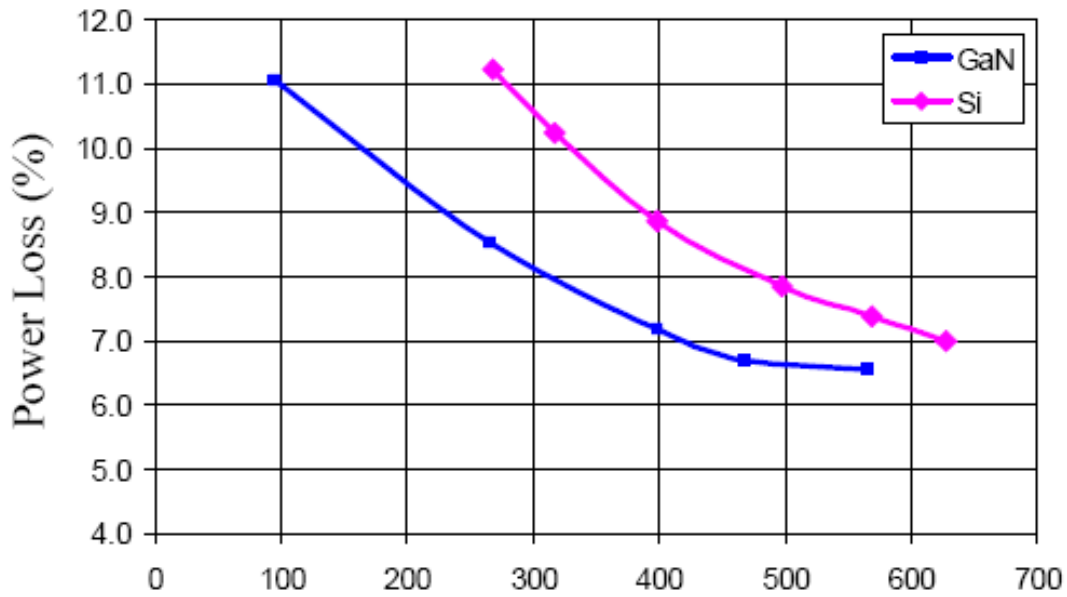



# Applications PFC Rectifier

- GaN Schottky diodes offer the same performance benefits as SiC diodes when used in Boost circuit topology (i.e PFC) but with much lower cost to be expected



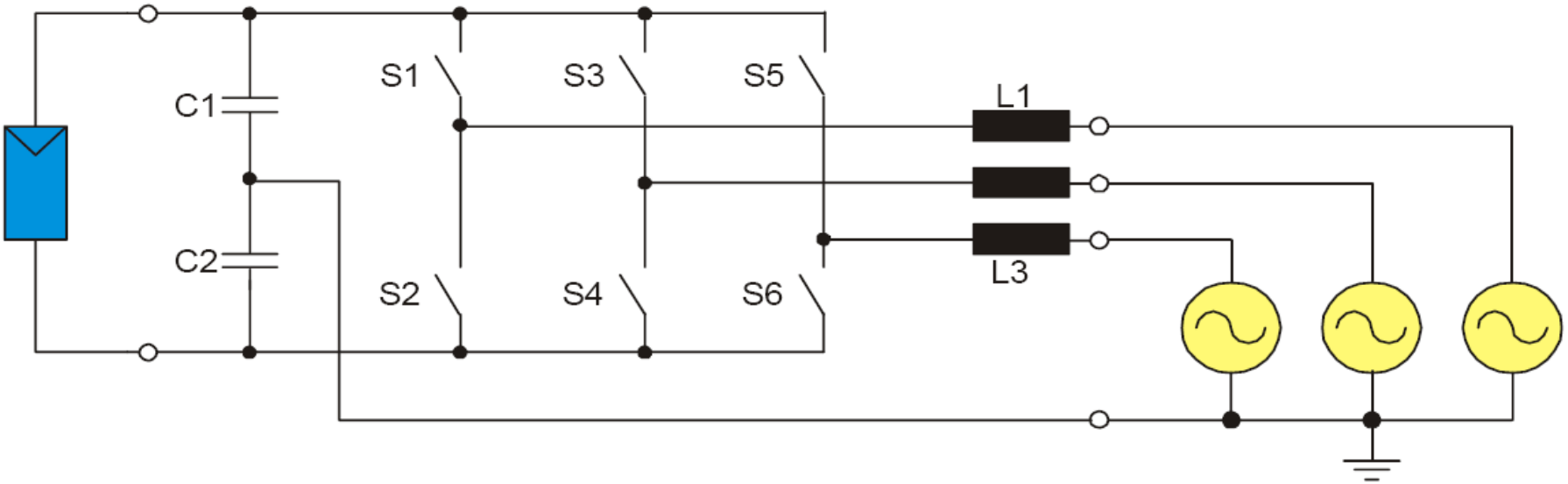




- Performance of GaN diodes as demonstrated by Velox in 2009 using GaN on Sapphire.

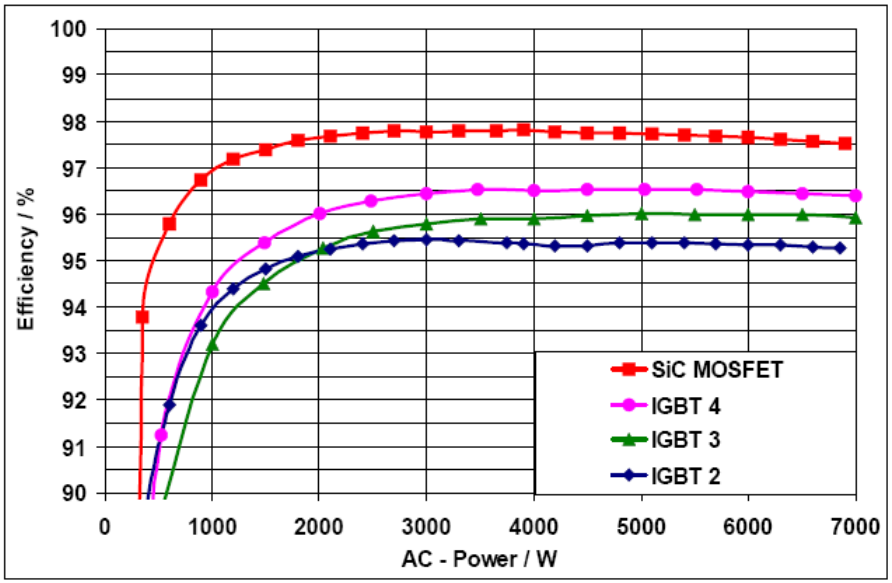
Novel 600 V GaN Schottky Diode
Delivering SiC Performance Without the SiC Price


Authors: Isaac Cohen[a], Ting Gang Zhu[b], Linlin Liu[c], Michael Murphy[b], Milan Pophristic[b], Marek Pabisz[b], Mark Gottfried[b], Bryan S. Shelton[b], Boris Peres[b], Alex Ceruzzi[c], Rick A. Stall[c]
[a]Lambda, 45 Fairchild Avenue, Plainview, NY 11803
[b]VELOX Semiconductor Corporation, 394 Elizabeth Avenue, Somerset, NJ 08873
[c]EMCORE Corporation, 145 Belmont Drive, Somerset, NJ 08873

# Advanced Semiconductors in Solar Applications



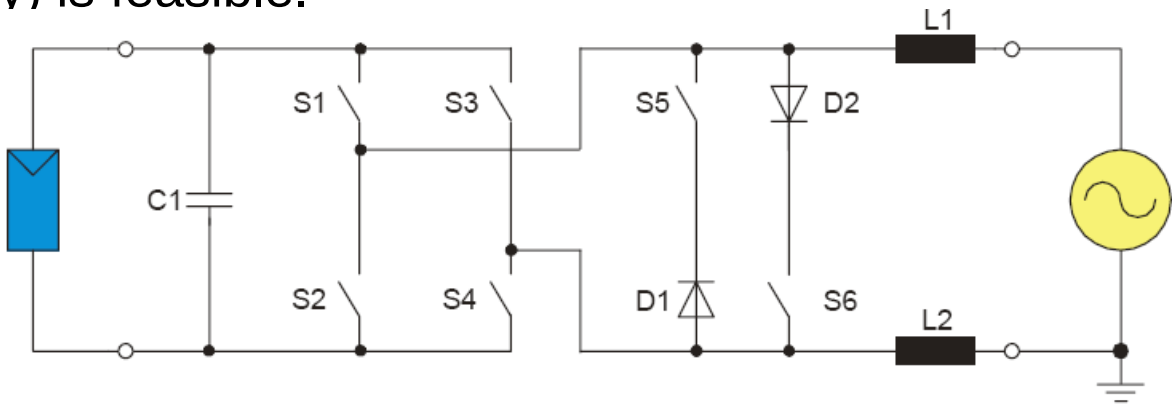

- In 2008 Fraunhofer Institute demonstrated higher efficiency in PV Inverters using SiC JFet replacing traditional IGBTs and power Mosfets.

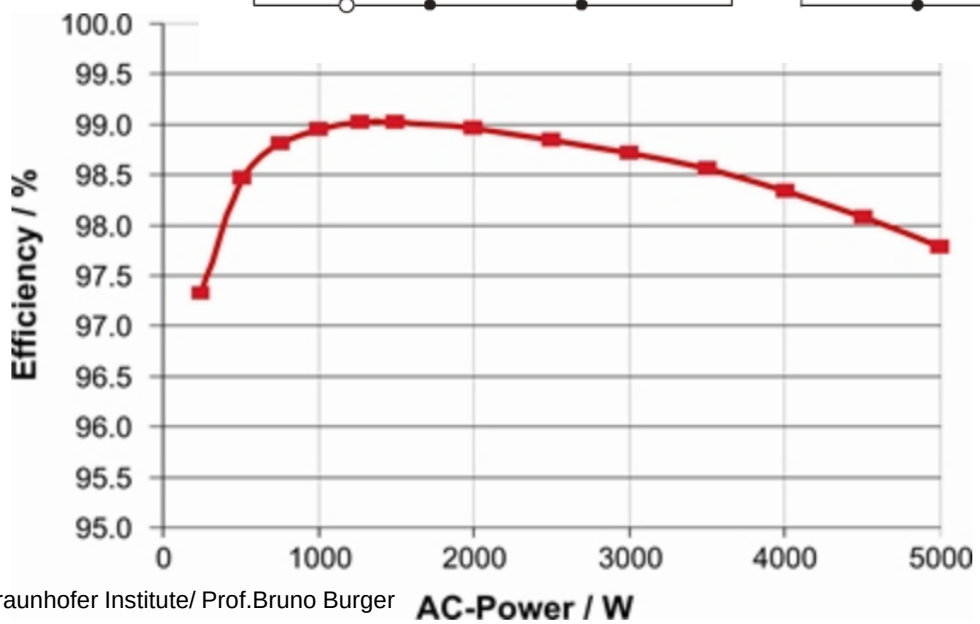



**"98.5% Inverter Efficiency with SiC-MOSFETs", Bruno Burger, Benriah Goeldi, Dirk Kranzer, Heribert Schmidt. 23rd EU PVSEC, 1st to 4th September 2008, Valencia, Spain**

# Advanced Semiconductors in Solar Applications

In 2009 Fraunhofer Institute demonstrated that, with SiC components, 99% efficiency in Single Phase PV Inverter efficiency (HERIC Topology) is feasible.



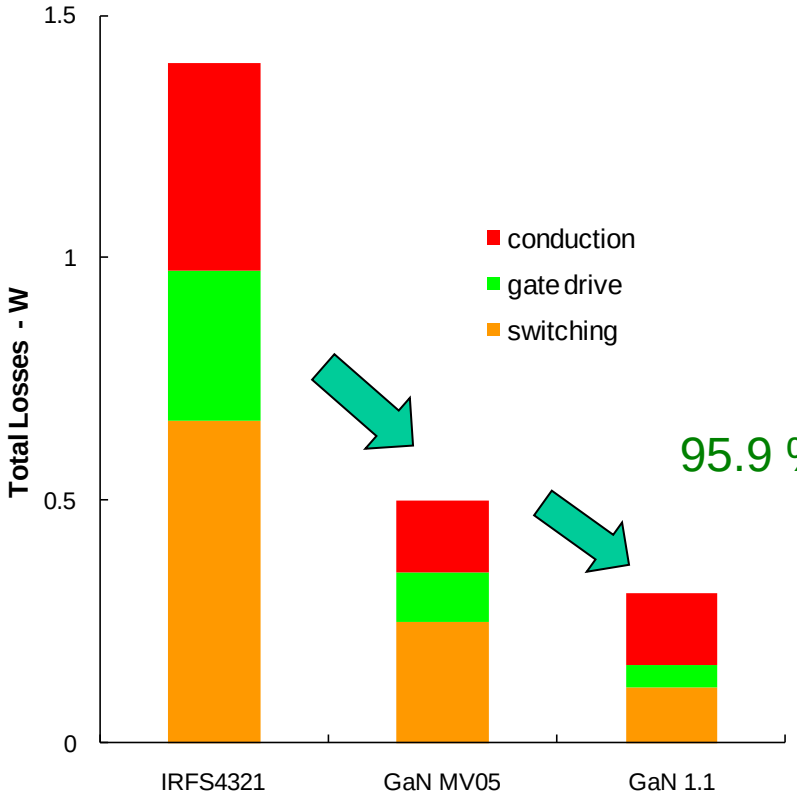




Ref: Fraunhofer Institute/ Prof.Bruno Burger

- Efficiency is no longer the problem
- Cost is the Problem
- GaN technology has the potential to deliver highest performance/cost benefit.

# Power Losses Comparison - Flyback Topology

| | Rdson | Qoss | Qgd | Qg | Qrr | BV |
|---|---|---|---|---|---|---|
| IRFS4321 | 12mΩ | 36nC | 16nC | 71nC | 150nC | 150V |
| GaN MV05 | 5mΩ | 55nC | 8nC | 22nC | 5nC | 150V |
| GaN Gen1.1 | 5mΩ | 35nC | 5nC | 15nC | 3nC | 150V |



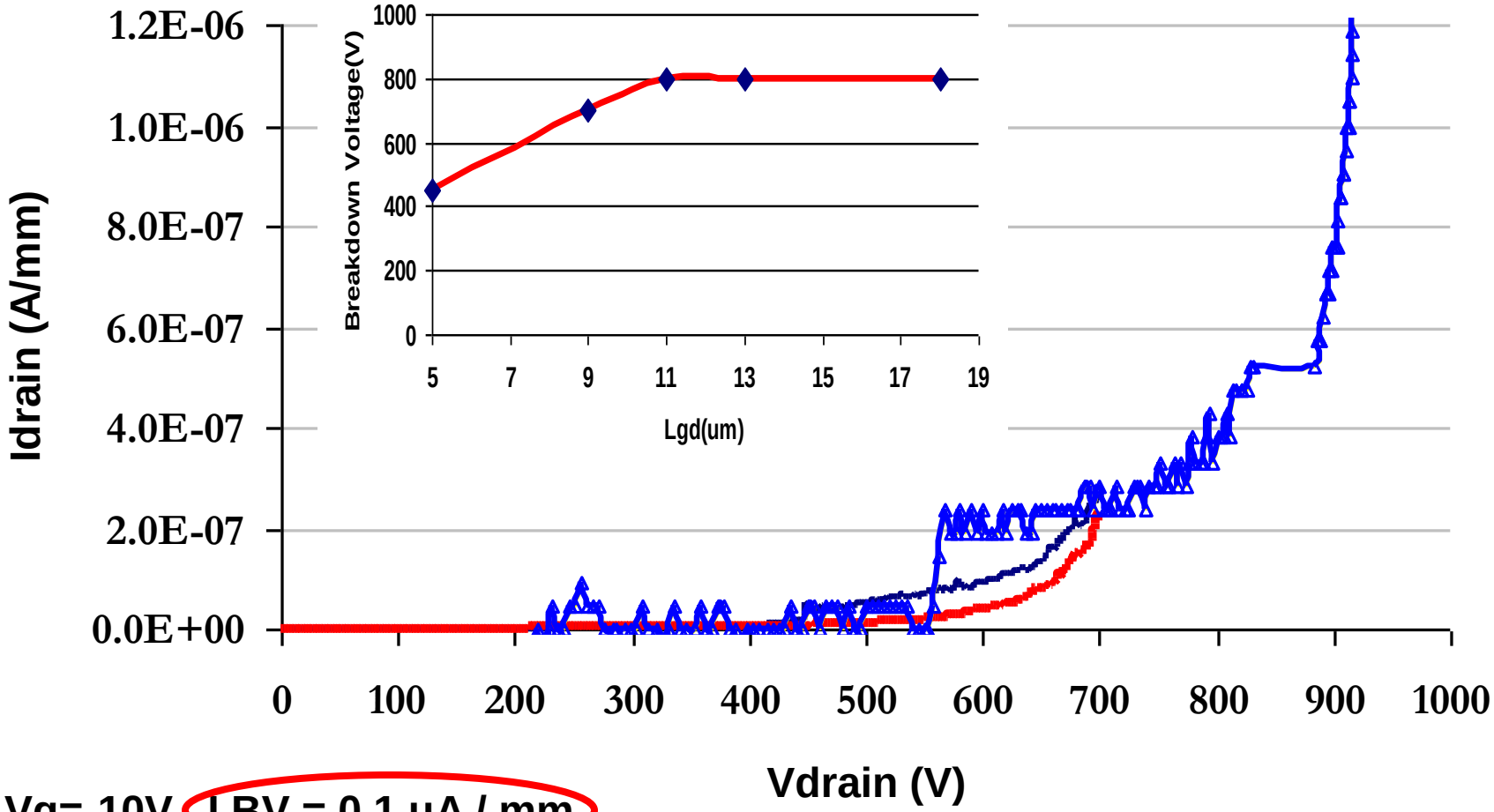

95.9 % Tested

96.4% Projection
(Model Simulation)

# HV HEMT Reverse Blocking Characteristics

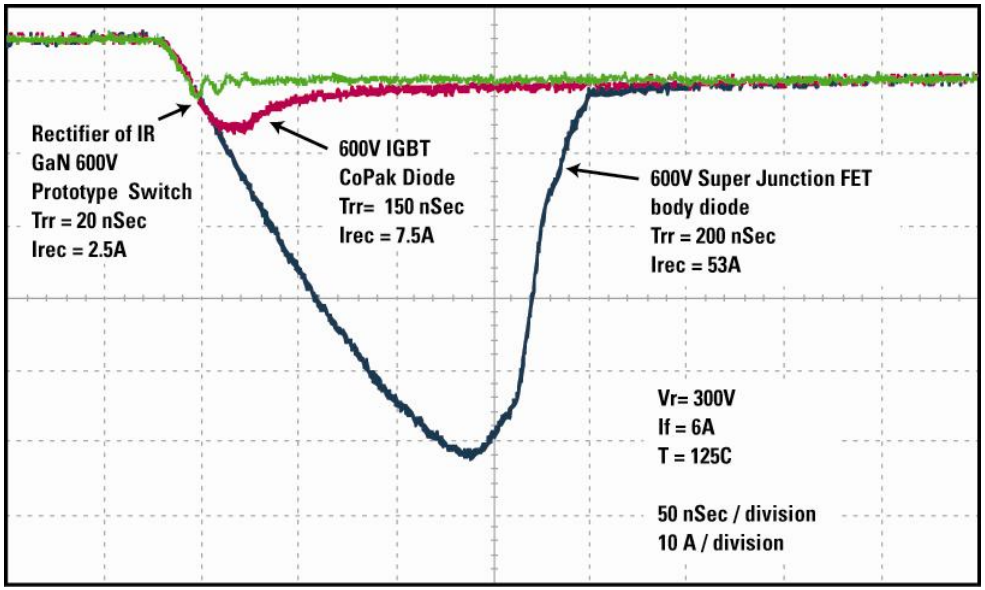
## ( Wg=100 mm, Lg=2um)

**Ion/Ioff(600 V) > $10^6$**



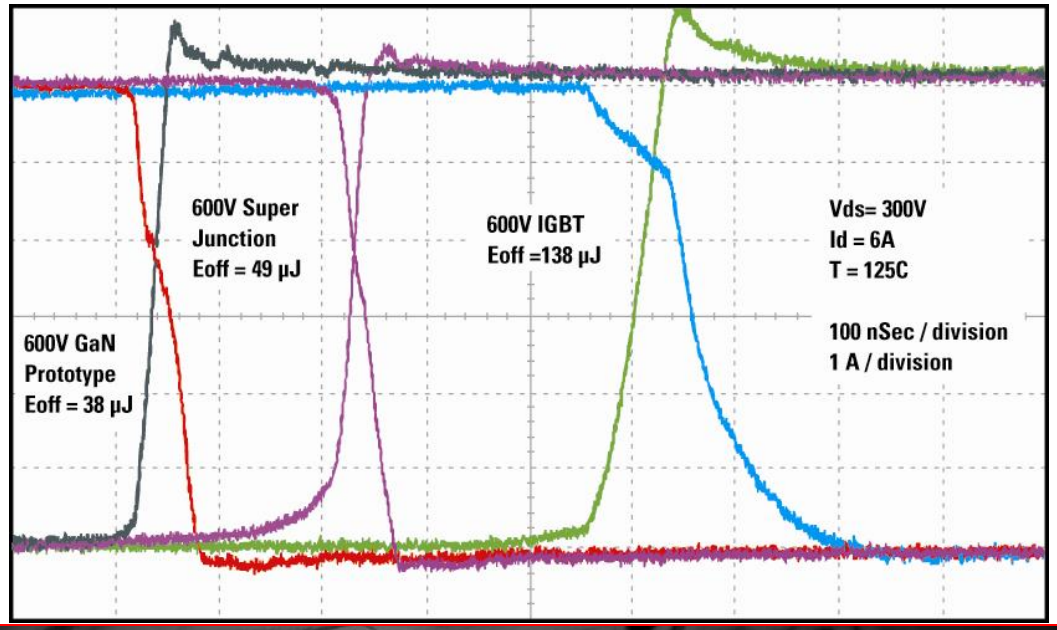

**Vg=-10V , I BV = 0.1 uA / mm**

# 600 V Device Switching Performance Comparison

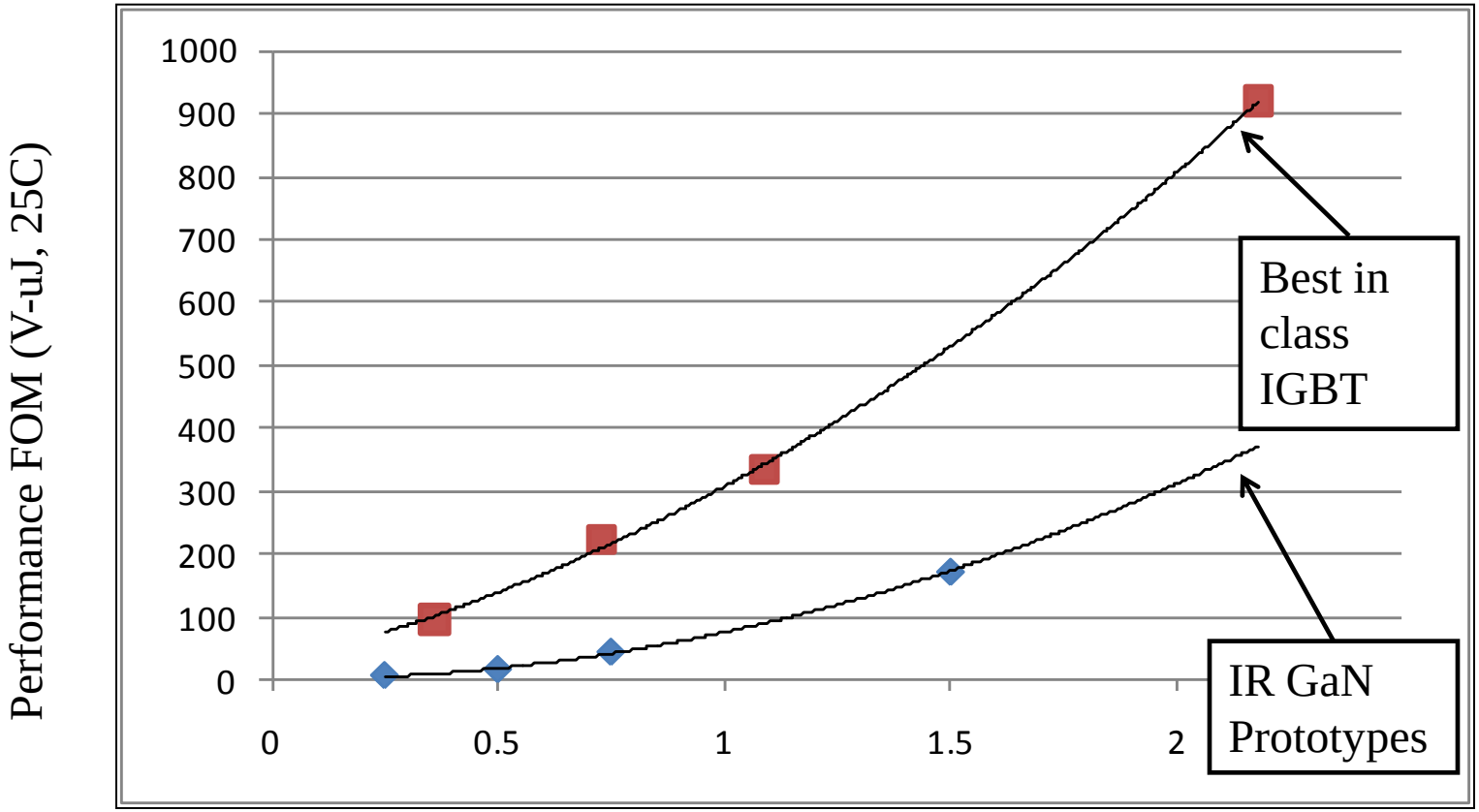



Rectifiers:
GaN based device has 20x Lower Qrr compared to IGBT Copak and more than 200x less than Super Junction body diode

Switches :
GaN Eoff (Off switching loss) is 72% less than for IGBT



# Performance vs. Current Density (6A device):




Current Density (A/mm^2)

Performance FOM: Vds(on) * (Eon + Eoff)

# Barriers to benefits of GaN in Solar Power

- Must achieve Performance required :
  - Cover broad range of voltage (depends on conversion topology)
    - 20-1200V expected (30 -200 now, 650V CY2011)
    - Even Higher voltage GaN devices possible
  - Integrate!

- Must define and meet reliability requirements:
  - 20 year useful life? At what allowable failure rate?
  - On the surface this is more demanding than automotive applications
  - Typical (Silicon) components used today not manufactured /designed to meet these requirements

# Opportunities for ARPA-e:

- **Invest in reliability engineering of GaN based power devices for use in PV solar power**
  - Meet environmental requirements
  - Meet lifetime requirements
  - Meet FIT expectations
- **Invest in developing high density/frequency power conversion :**
  - Realize smaller form factor (eg: for use in micro and nano inverter applications)
  - Higher frequency allows use of more reliable passives
- **Invest in system level integration to maximize cost effectiveness**
  - Lateral GaN HEMT technology is inherently integratable
  - Potential to monolithically integrate multiple power devices and drivers

**Thank You**

**for**

**Your Kind Attention**