SAND2017-2018C

Current and Emerging Applications of UWBG semiconductors

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Outline

- UWBG for UV-C opto-electronics
- UWBG for power electronics
- UWBG for rad-hard electronics
- UWBG radar

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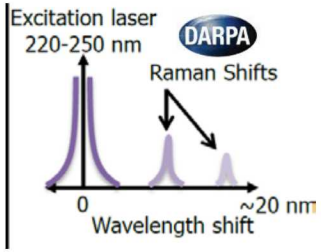
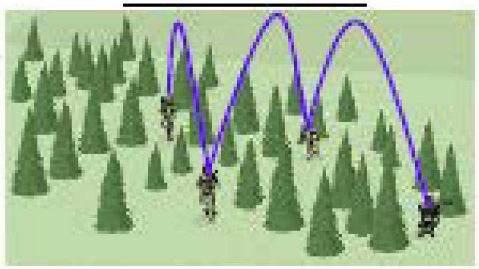
UV-C detector technology gaps

Raman Spectroscopy
(biological agents)

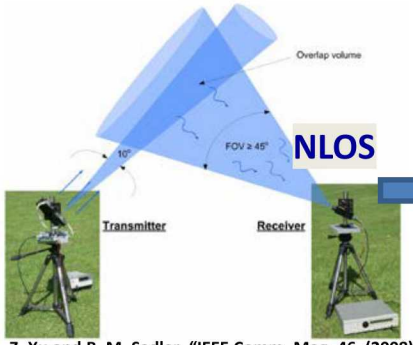


Non-line of sight communication
(covert radio)

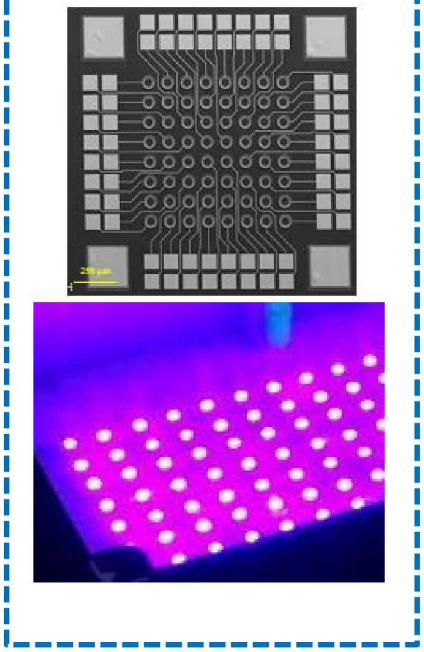


Solar-blind detection
(missile launch, sniper fire)

Benchtop → **Man-portable** → **Microelectronic**



Z. Xu and B. M. Sadler, "IEEE Comm. Mag. 46, (2008).



➢ Miniaturization and efficiency are technology drivers

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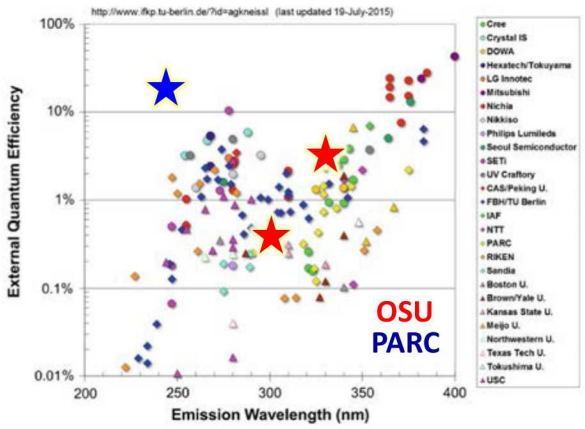
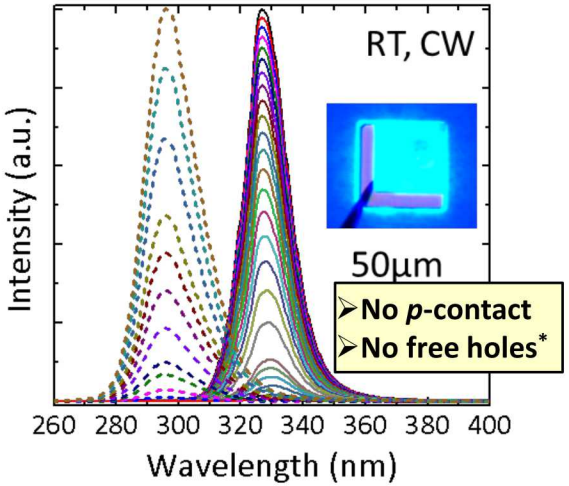
AlGaN for UV-C direct emitters

AlGaN UV LED EQE vs. λ



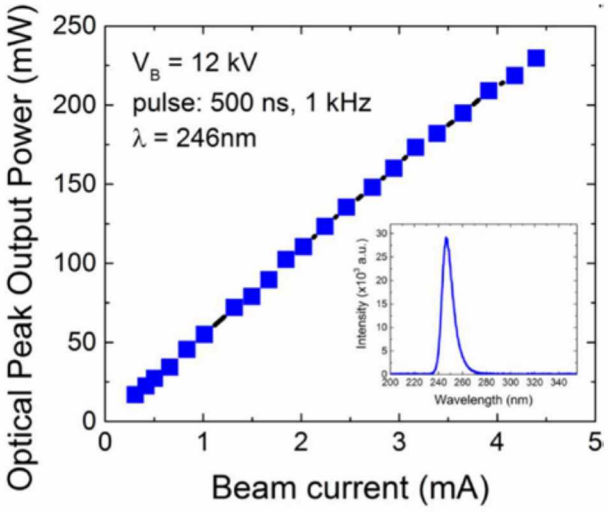
Kneissl III-Nitride UV Emitters, Springer

UV Tunnel Junction LED



1. Zhang et al. APL 109, 191105 (2016).
2. Zhang et al. APL 109 121102 (2016).

e-beam pumped LEDs



2. Tabataba-Vakili APL 109 181105 2016

- Hole injection is main limitation due to *universal* challenge of asymmetric doping in UWBGs
- Need radical approaches to achieve bipolar functionality in III-N's
- Tunnel junctions,[1,2] e-beam,[3] BN/AlGaN heteroepitaxy,[4] 2-D/3-D heterovalent integration[5]

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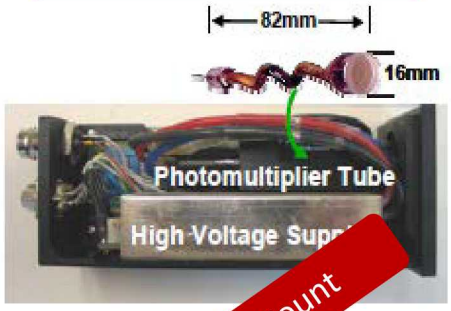
4. Majety APL 100 061121 2012 5. Krishnamoorthy APL 109 183505 2016

UWBGs for high photo-gain solar-blind detectors

Technology Challenges

Photomultiplier Tubes

High Voltage = Large



High Dark Count

Si Ava… Photodiodes (APDs)

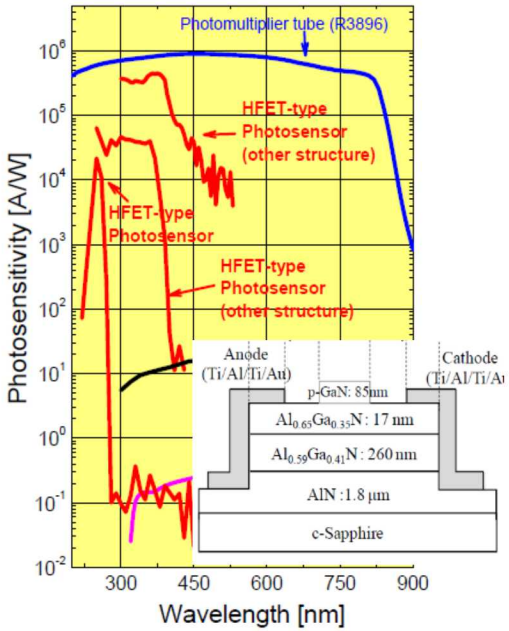
Parameter	Hamamatsu S10362-11 Series Device Suffix -025C	-050C	-100C	Units
Physical area	1x1	1x1		
Number pixels	40x40	20x20		
Pixel size	25	50	100	μm
Fill factor	30.8	61.5	78.5	%
SPDE at 400nm	25	50	65	%
SPDE at 270nm	8	12	20	%

Cryogenic

Proc SPIE 7320 1 2009

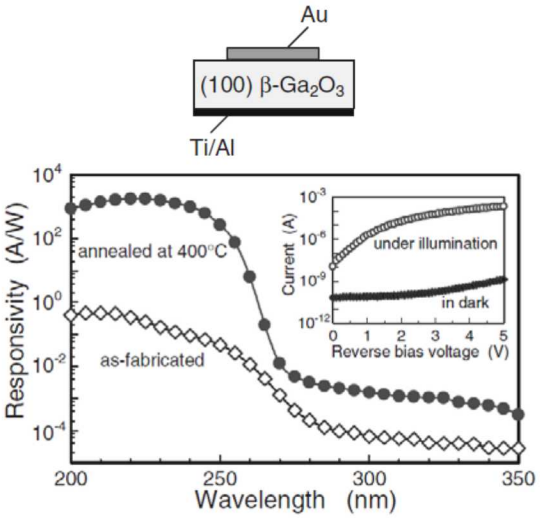
Expensive optical filters

UWBG AlGaN Photo-HEMT



Iwaya PSS C 6 S972 (2009).
Yoshikawa JJAP 55 05FJ04 (2016).

β-Ga_2O_3 Schottky diode



Suzuki et al. APL 94, 222102 (2009).

- UWBG solar-blind detectors with high gain can be low voltage (small), non-avalanche (low dark count), filter-free (inexpensive), non-cryogenic (robust)
- Path to ubiquitous, persistent, unobtrusive/clandestine, multi-vector threat detection

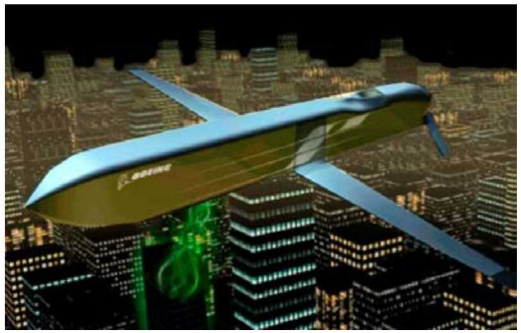
Andre

UWBG semiconductors for Power Electronics

DOE

USN

USAF

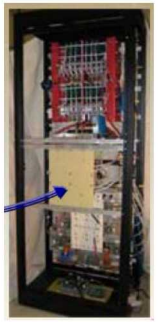


USA

Silicon

- 2.7 MVA
- 6 tons
- 10 m^3

SiC



- 2.7 MVA
- 2 tons
- 6.5 m^3

UWBG

- 2.7 MVA
- <1 ton
- <1 m^3

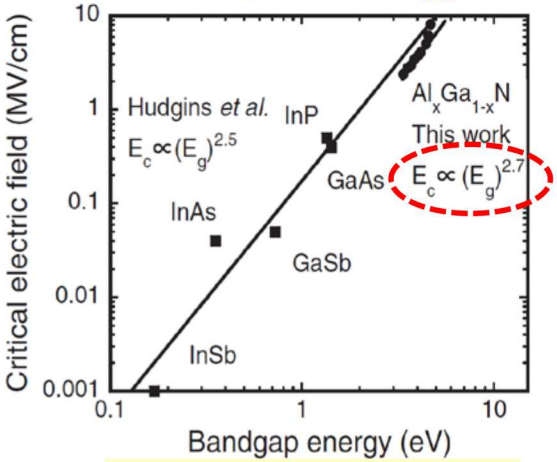
- Electrification of sensors, weapons, CM, and propulsion demand >100 kV, >1000 kA, or >100 MW
- Requires higher voltage, power density, and thermal margin than SiC or GaN provides

UWBG power devices are coming

$$R_{on,sp} = \frac{4V_{br}^2}{\epsilon \mu E_{crit}^3}$$

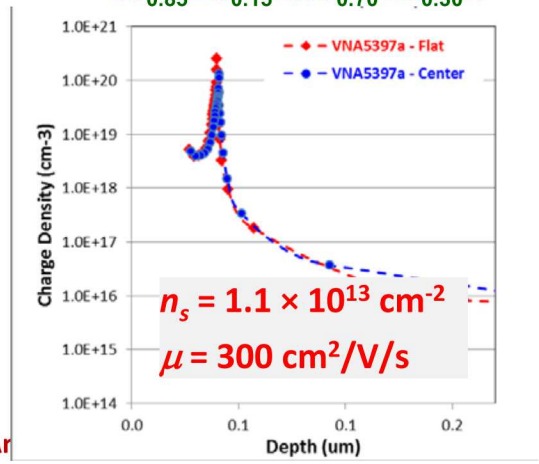
$E_{crit} \sim E_g^{2.5} \rightarrow$ Power density $\sim E_g^{7.5}$

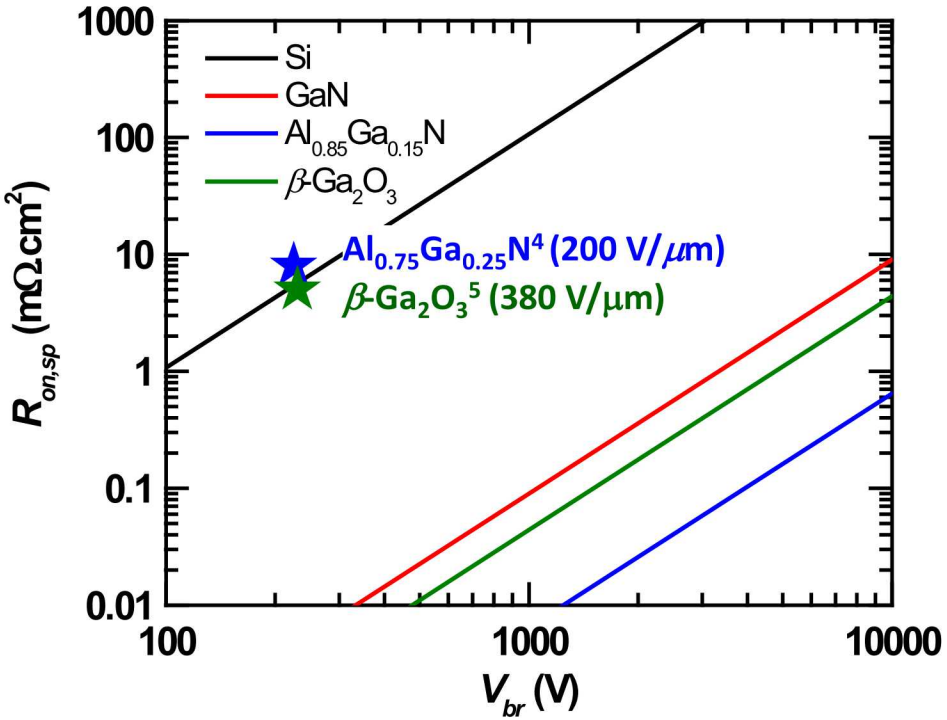
AlGaN *pin* diode E_{crit}



Nishikawa, *et al.*, JJAP 46, 2316 (2007).

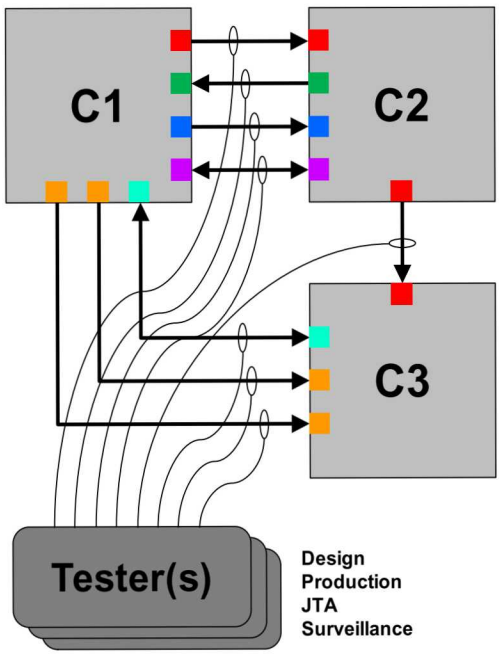
$Al_{0.85}Ga_{0.15}N/Al_{0.70}Ga_{0.30}N$

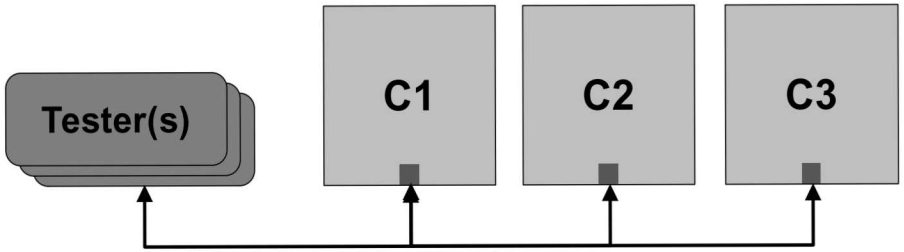




1. Nanjo et al. APL 92 263502 (2008).
2. Nanjo et al. IEEE Trans. Electron Dev. 60 1046 (2013).
3. Tokuda et al. APEX 3 121003 (2010).
4. Bajaj et al. IWN 2016
5. Green et al. IEEE EDL 7 902 (2016) .

UWBG PE would shrink and simplify DOE systems





- Assurance
- Agility
- Affordability

- DOE systems have complex interconnectivity among many disparate systems
- Extremely expensive to maintain and update
- Electrification of sub-systems would enable modular, bus-based architecture
- UWBG power electronics provide maximum benefit due to involuble volume constraints

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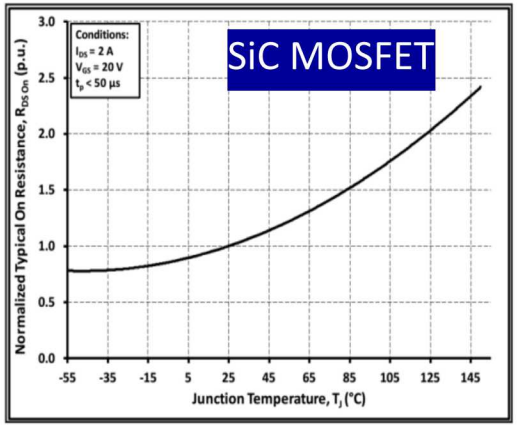
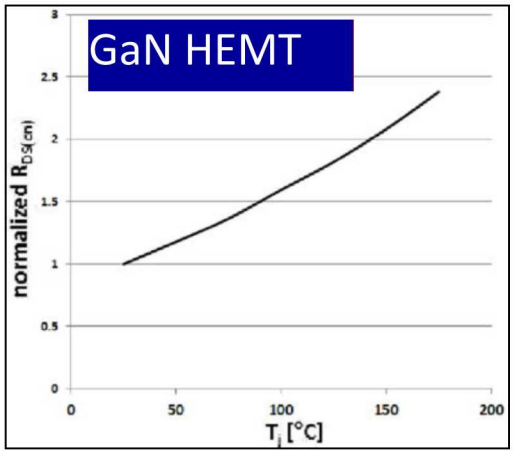
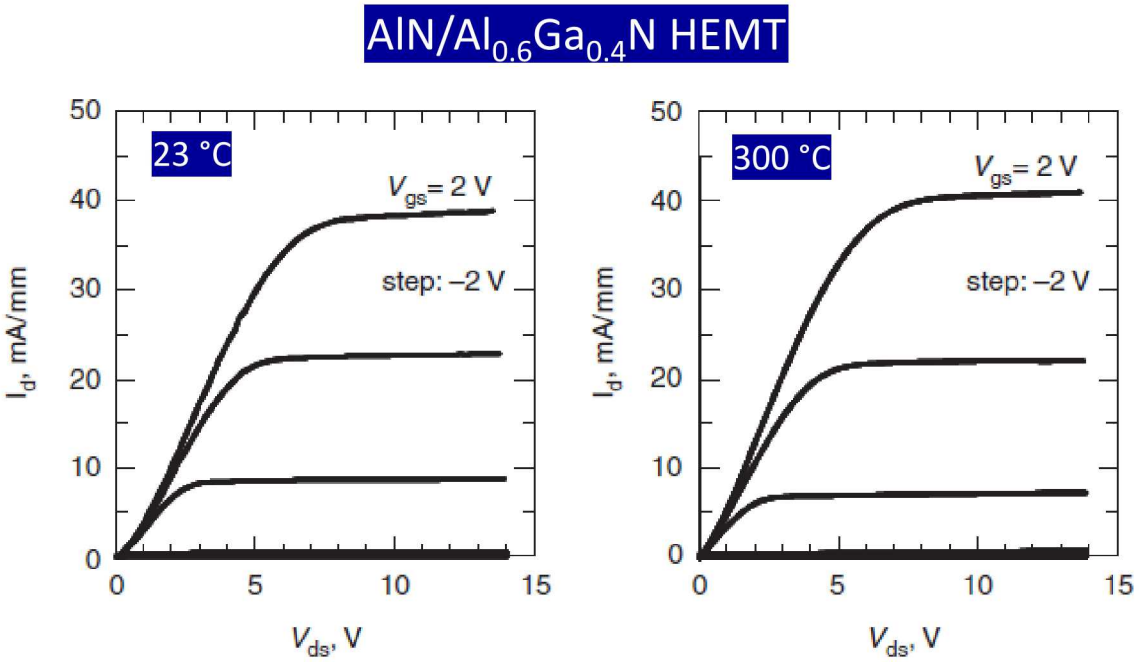
UWBG PE thermal margin reduces system size







Yafune et al. Electon. Lett. 50, 211 (2014).

- >2x increase in WBG $R_{on,sp}$ at 150 °C requires severe de-rating for high T operation
- UWBG PE temperature-independent I_{DS} to 300 °C
- Enhanced thermal margin reduces or eliminates need for liquid cooling

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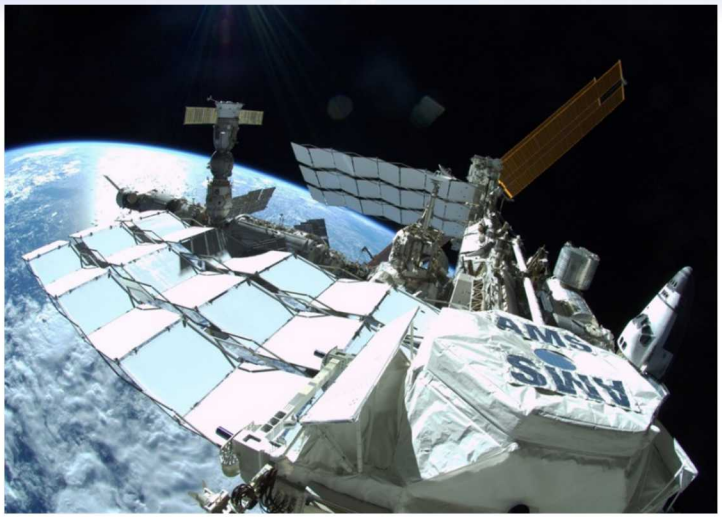
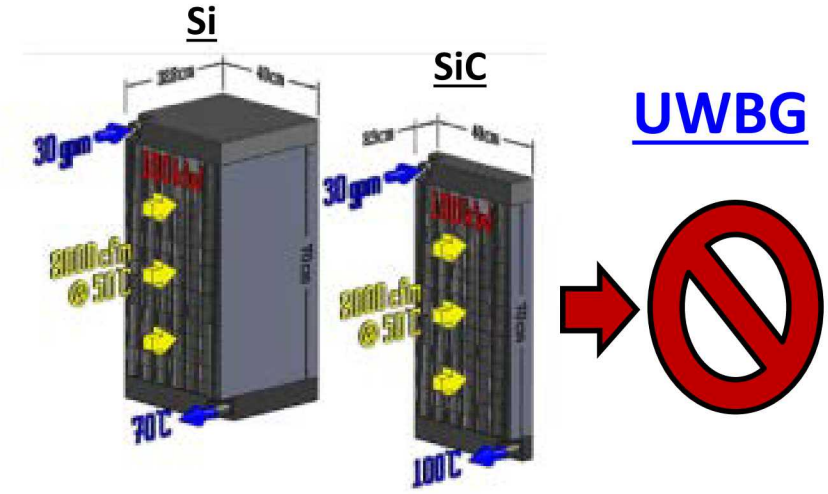
UWBG PE thermal margin increases survivability





www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA548232

- Thermal shock resistance for hypersonic and re-entry vehicles
- Reduce radiator size and weight for ground, high altitude, and space vehicles
- Ability to operate without active cooling enhances system survivability

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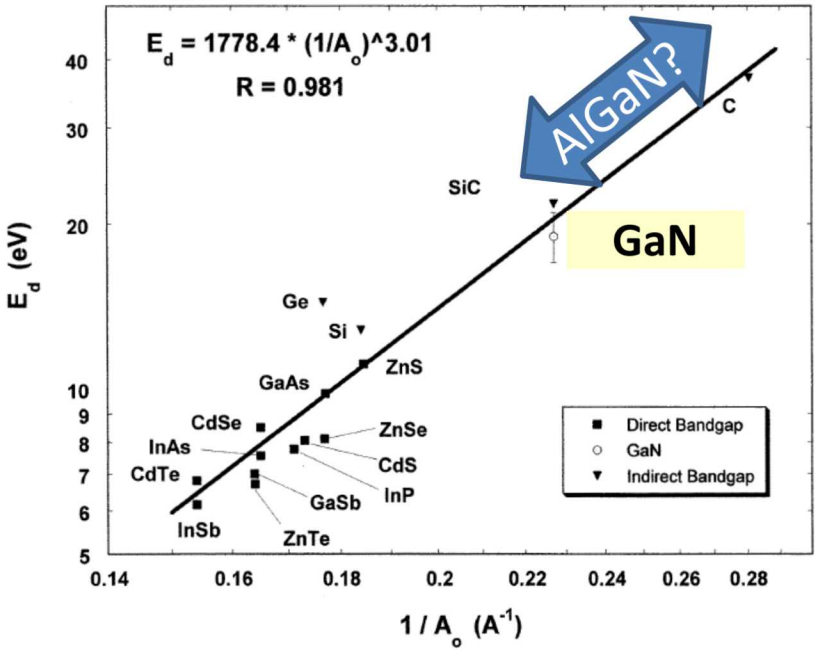
UWBG for rad-hard electronics

Property	Si	GaAs	4H-SiC	GaN	AlN
Bandgap (eV)	1.1	1.4	3.3	3.4	6.2
Ionization energy (eV/e-h pair)	3.6	4.8	8.7	10.3	~18

Atomic displacement energy



Ionascut-Nedelcescu, IEEE TNS 49 2733 (2002).

- AlGaN *anticipated* to have extremely high radiation tolerance
- Systematic studies *vs*. band gap energy underway at Sandia

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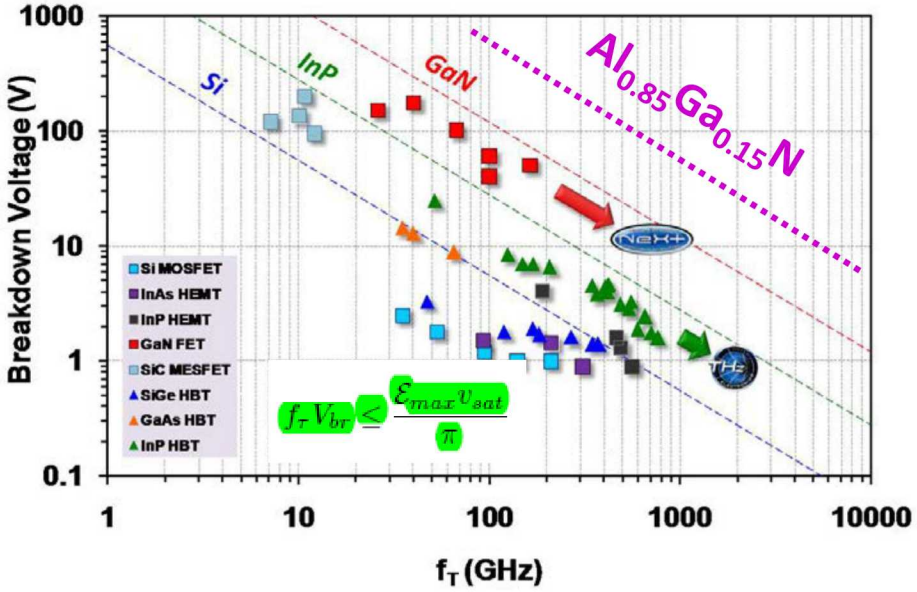
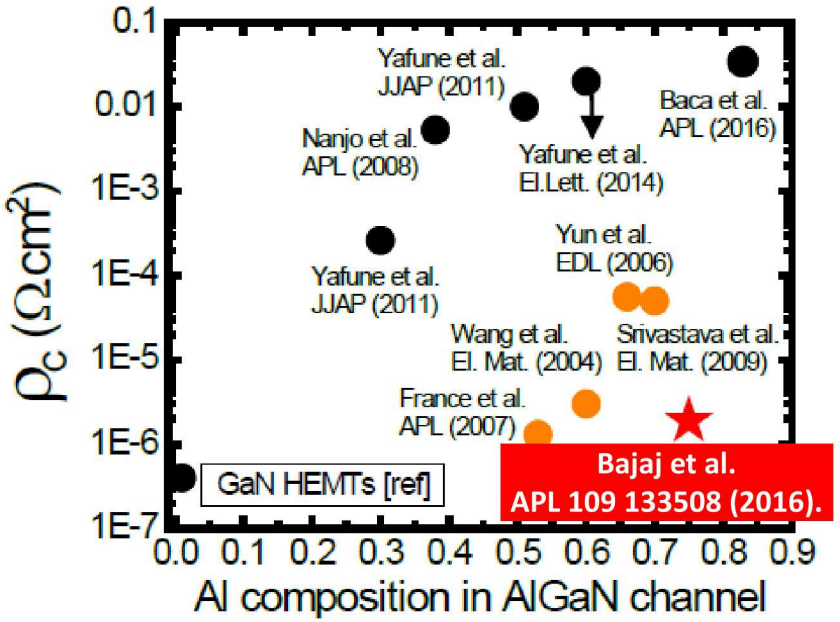
UWBG and future radar

JFOM



UWBG AlGaN ohmics



- AlGaN fundamental electronic properties E_{crit} = 14 MV/cm, v_{sat} = 2 × 10^{7*} cm/s are promising
- Breakthrough in ohmics has opened the door to high current density UWBG FETs

*Albrecht et al. APL 83 1446 (1998).

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