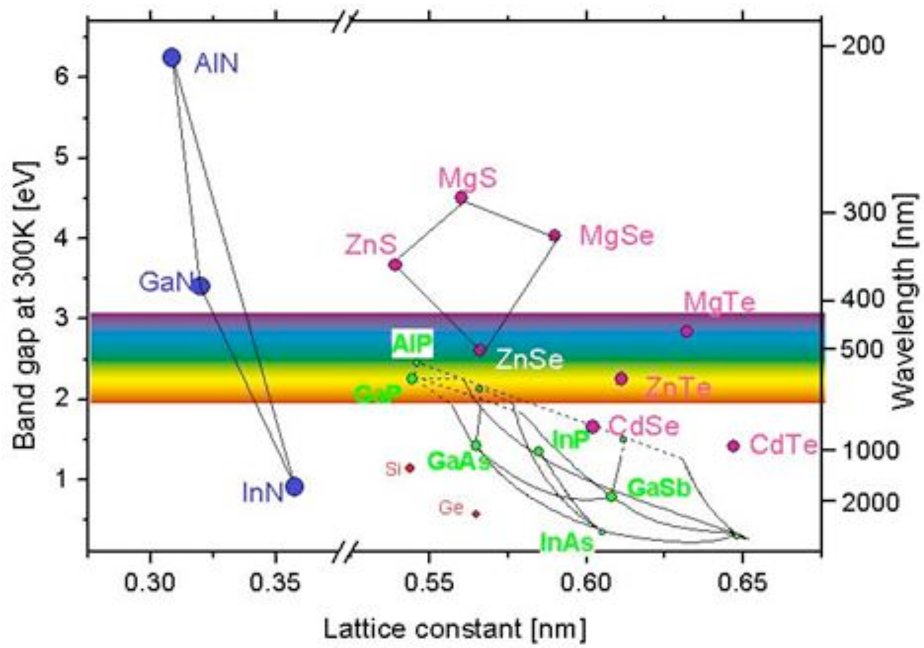
Photon detectors: GaN-based device overview



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KISS Workshop: UV Instrumentation Technology

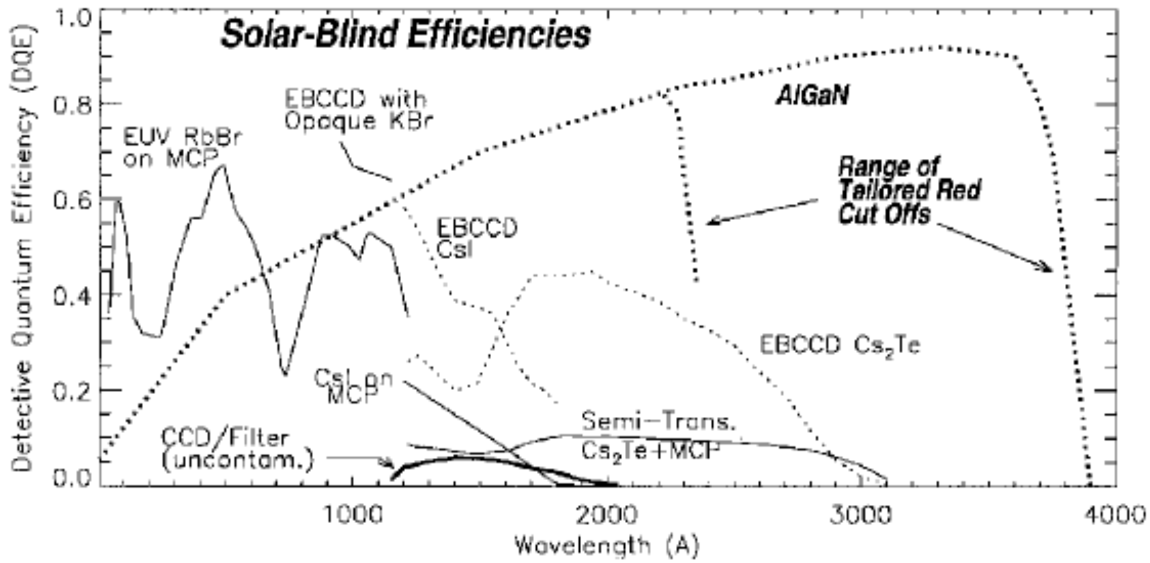
Detectors for UV Astronomy

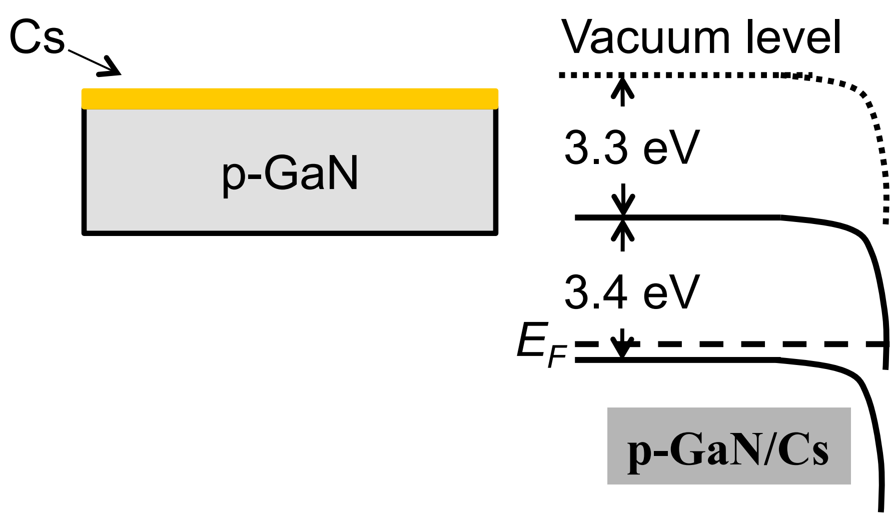
UV detectors for Astronomy applications fall into the categories of:
- Photocathodes (zero read noise)
- Solid State Detectors (may become zero read noise)
- Superconducting devices that operator at approximately 100 mK

UV detector Requirement vary depending on:
- Source strength (long integrations favor zero read-noise)
- High ratio of in-band to out-of-band requirement (UV to visible)
- High speed (>60Hz) readout
- Radiation hardness

Cs GaN based Photocathode

Cs GaN photocathodes have been demonstrated. The issue with these devices is the use of Cs

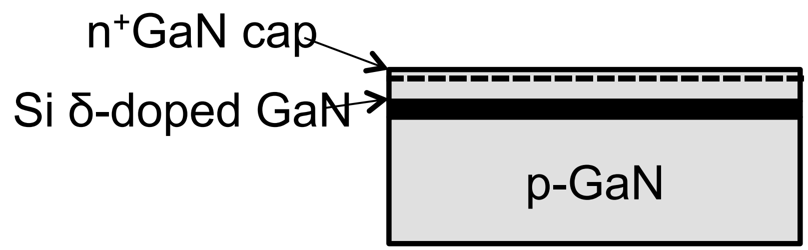


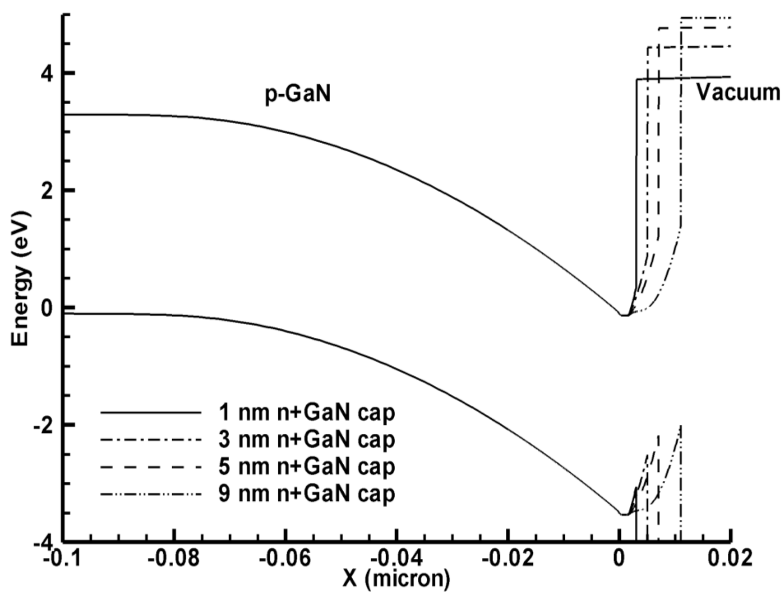


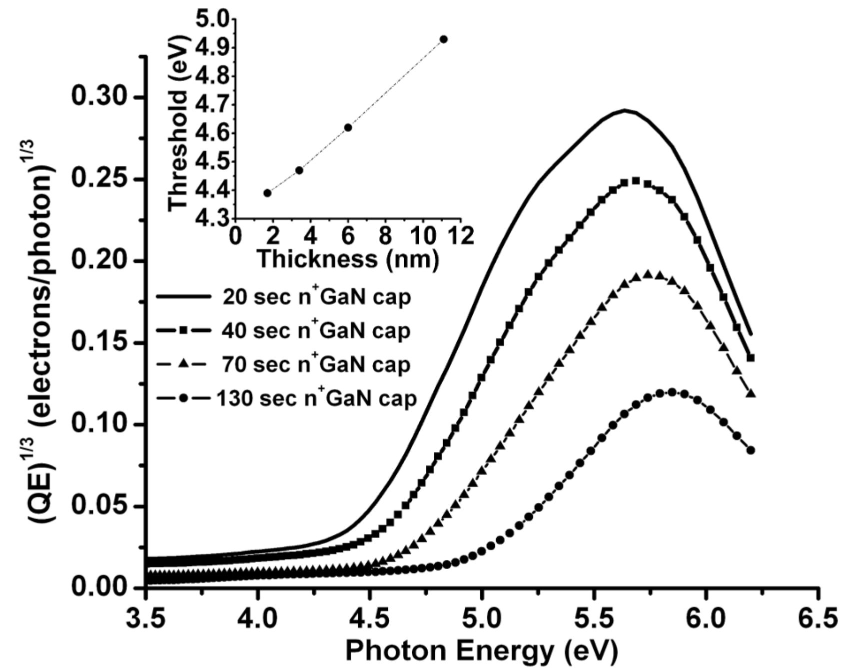
Cs GaN photocathode

- •30% QE @200 nm (Shahedipour et al. JQE, 2002)
- •70% QE (Sigmund et al. 2006)
- •2011: over 70% reported

Our objective: Cs-free GaN PC

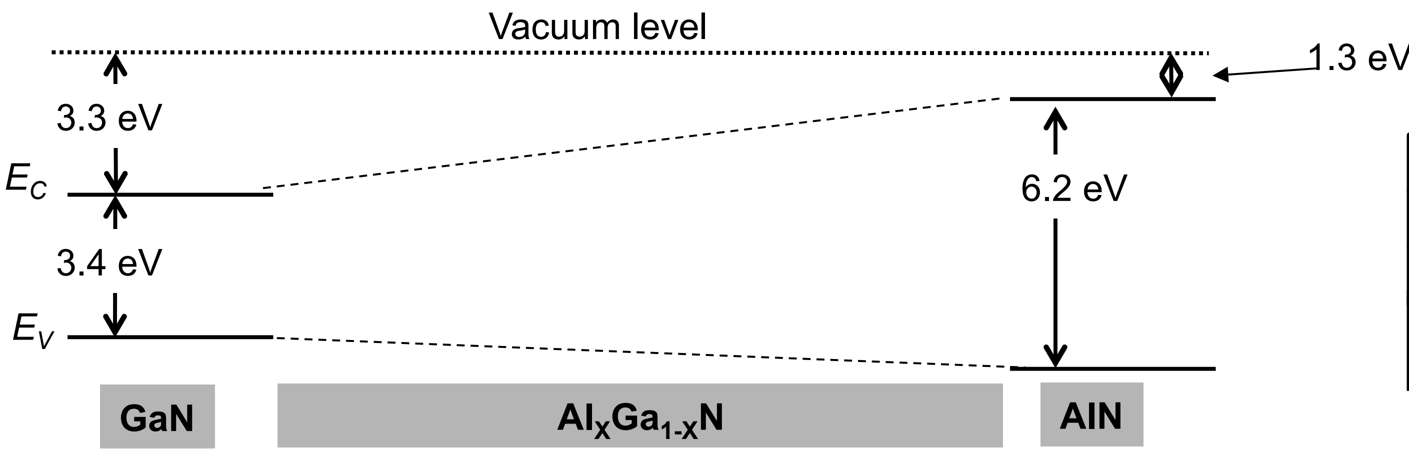


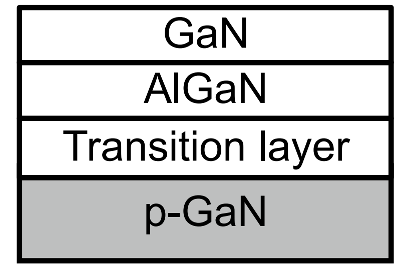


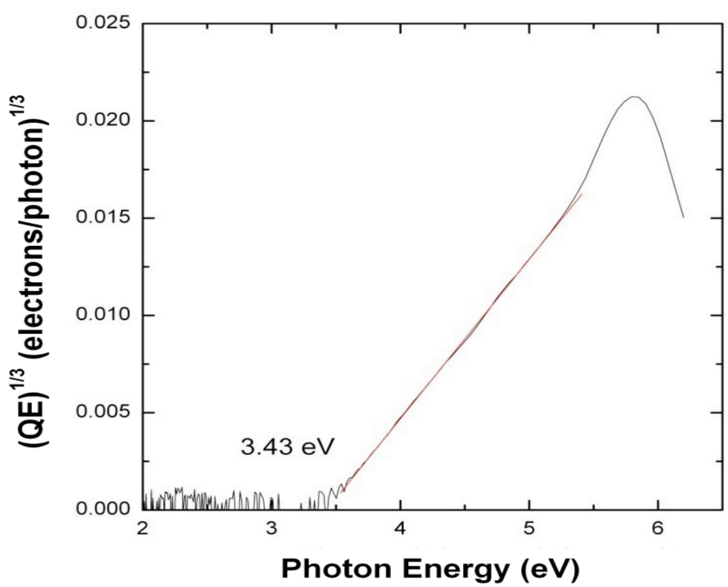


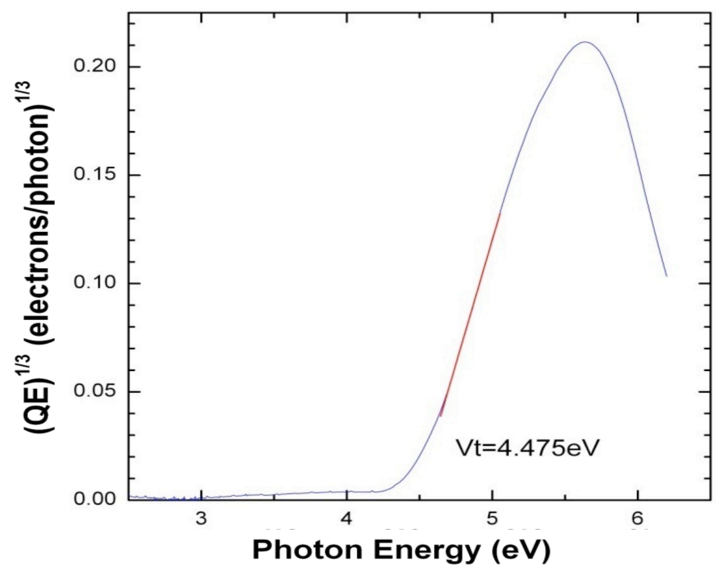
- Lowest emission threshold at 4.1 eV for a Cs-free GaN photocathode via bandgap engineering and interface/doping modification
- Presence of polarization charges may play a role in increasing the threshold energy

Cs-free GaN/AlGaN based PC: energy band engineering





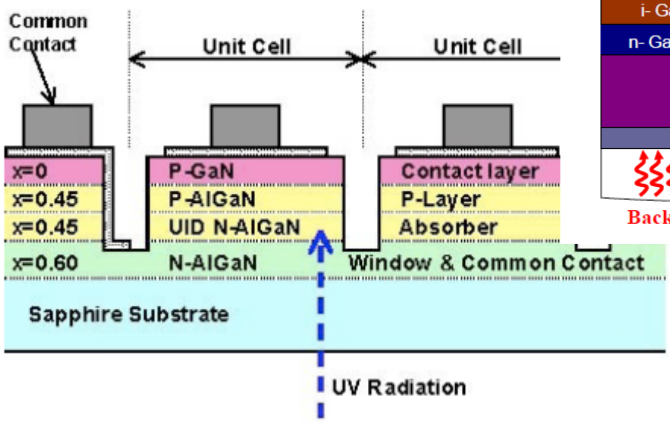


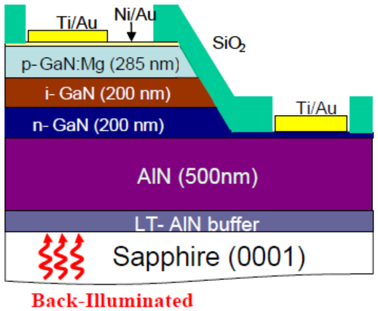


- ENEA demonstrated
- Trade-off between emission threshold and QE for these preliminary devices

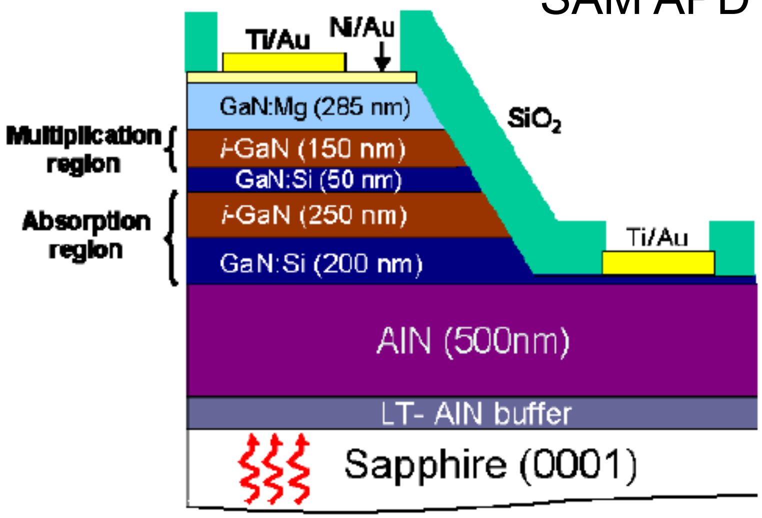
pin/APD AlGaN based SSD

p-i-n pixel and array





SAM APD



- Room temperature operation
- Radiaton hardness
- The ability to accomondate single pixel count rates at as high as 1kHz
- Negligible response at wavelength longer than 350nm
- Have 70% QE over a long wavelength region (e.g. below 350nm to the substrate cut off e.g. 150nm for sapphire))
- Bandgap engineering allows formation of solar-blind SSD
- The most suitable candidate when dominant selection criteria are mass and volume.
- Direct growth on Si possible

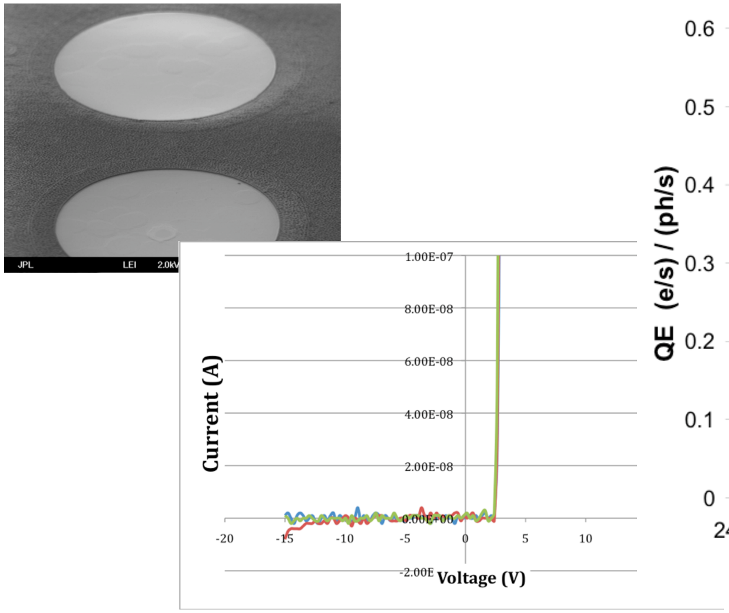
GaN pin/APD

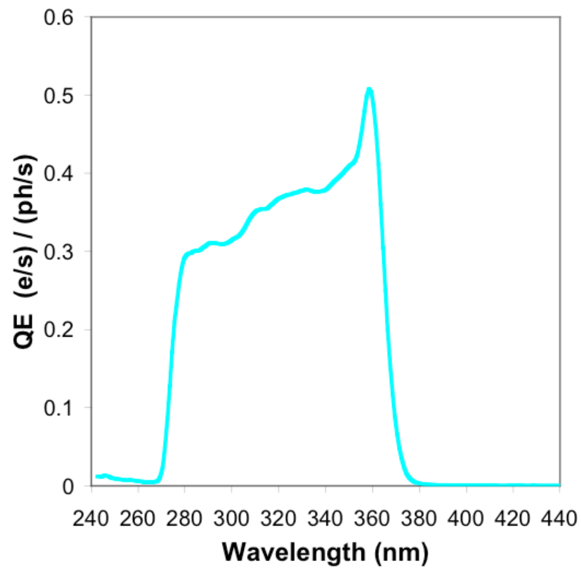
Group	Material/substrate	Type	Device area (μm^2)	D* ($cmHz^{\alpha}$ $^{5}W^{-1}$)
NWU [34]	GaN/sapphire	Back-PIN	Various 225 ~ 2025	--
NWU [35]	GaN/sapphire	Back-SAM	225	--
CAS [36]	GaN/sapphire	PIN	31416	--
Gatech [37]	GaN/GaN	PIN	7854	--
NCKU [23, 38]	GaN/sapphire	MSM	--	2.67 x 10^{10}
LU [39]	GaN/sapphire	MIS	17671	--
NCKU [23]	GaN/sapphire	MSM	11400	--
Auburn [40]	GaN/GaN	Schottky	--	--
Bilkent [24]	$Al_{0.4}GaN$/sapphire	Schottky	1257	1.4 x 10^{14}
NIT [41]	AlInN/sapphire	Schottky	17671	--
STU [42]	GaN/sapphire	Shcottky	196350	--

Group	Material/substrate	Type	Device area (μm^2)	D*[1] ($cmHz^{\alpha}$ $^{5}W^{-1}$)	I_d[2] (A/cm^2)	R_λ[3] (A/W)	UVR R[4]	M[5]	SPDE(%)[6] & DCP[7]
Gatech [26]	GaN/GaN	PIN	707	--	7n @ -5 V	--	--	1000	--
NCU [27]	GaN/sapphire	PIN	--	1.7 x 10^{13}	--	0.11 @ 365 nm, 0 V	1200	--	--
NWU [28, 29]	GaN/sapphire	Back-PIN[8]	Various 225 ~ 14063	--	--	0.082 @ 361 nm, 0 V	--	5700	20% --
Gatech [30]	GaN/GaN	PIN	4536	--	15n @ -20 V	--	--	10000	--
Gatech [31]	$Al_{0.05}GaN$/GaN	PIN	707	--	141n @ -20 V	--	--	50	--
Gatech [32]	GaN/GaN	PIN	4536	--	100n @ -45 V	--	--	30000	--
Bilkent [22]	GaN/sapphire	PIN	31416	--	64n @ -5 V	0.23 @ 356 nm, -5 V	6700	--	--
NWU [33]	GaN/sapphire	Back-SAM[9]	625	--	3.84μ @ -40 V	0.094 @ 360 nm, ~-70 V	--	51000	--

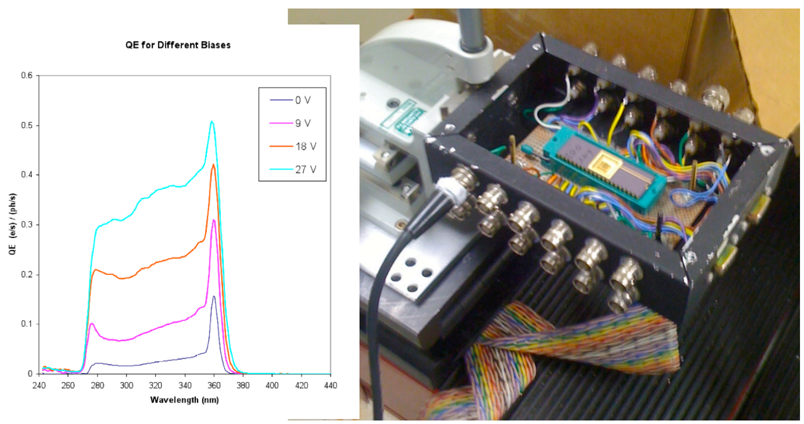
[1] Effective detectivity
[2] Reverse-biased dark current density
[3] The peak value of responsivity
[4] Ultraviolet-visible rejection ratio
[5] Linear-mode avalanche gain
[6] Single photon detection efficiency
[7] Dark count possibility
[8] Back-illuminated *p-i-n* photodiode
[9] Back-illuminated separate absorption and multiplication photodiode

Y. Zhang, Ms thesis, Aug 2009

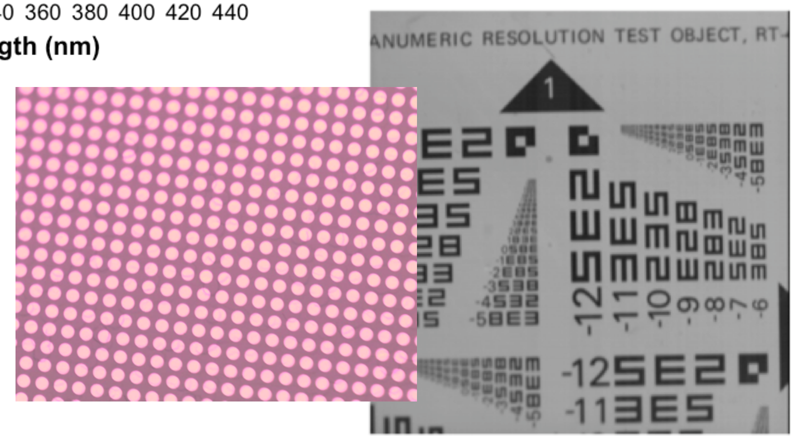




GaN p-i-n photodiodes fabricated at JPL, low reverse leakage current, 50% peak QE for a back-illuminated GaN p-i-n.

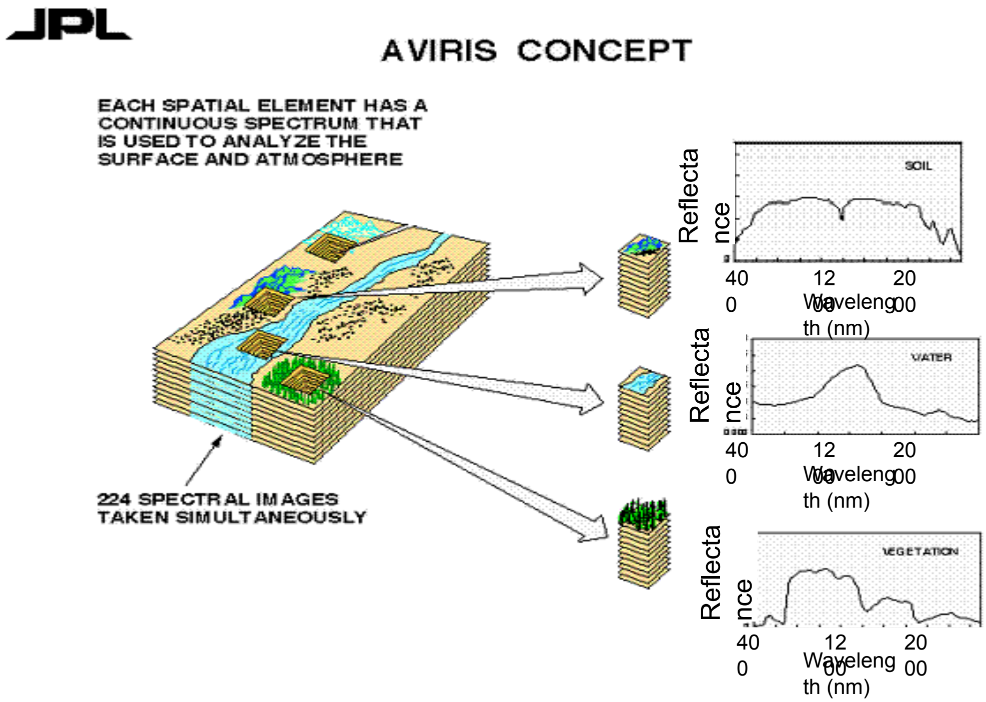


Spectral QE plot for GaN p-i-n array (left). A diode array packaged in a standard 40 pin package for characterization (right).

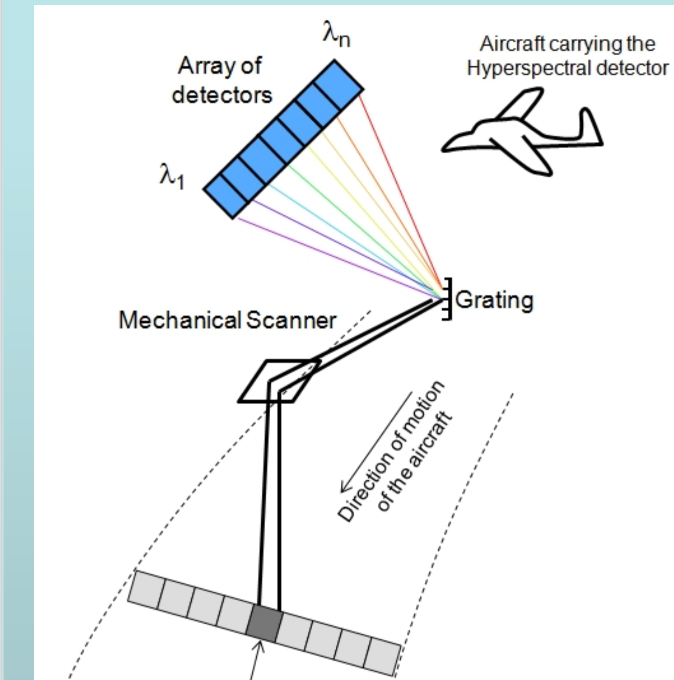


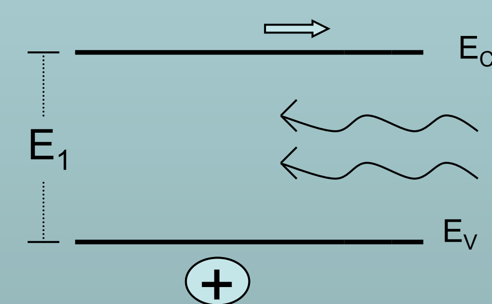
320x256 array of individual 25 μm PIN diodes, a high-resolution image obtained from a hybridized part produced at JPL.

AlGaN Based III-Nitride Layered Barrier Hypersoectral Detector

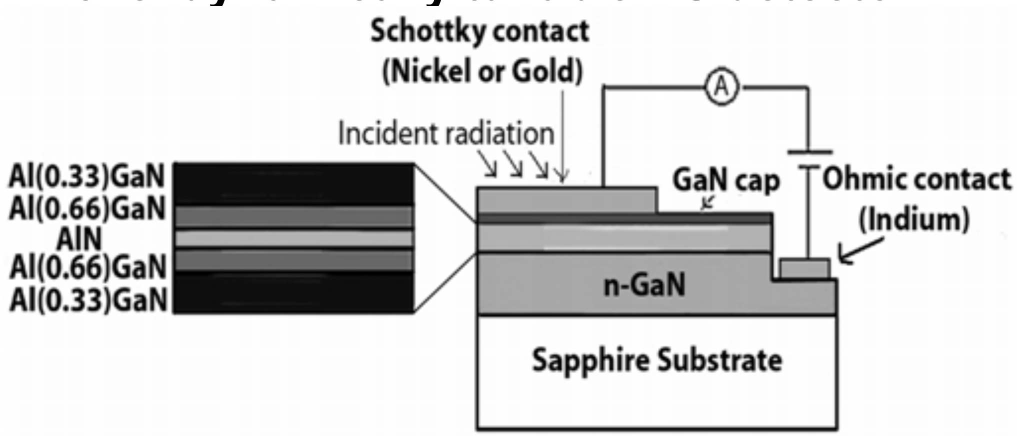


Conventional HSI



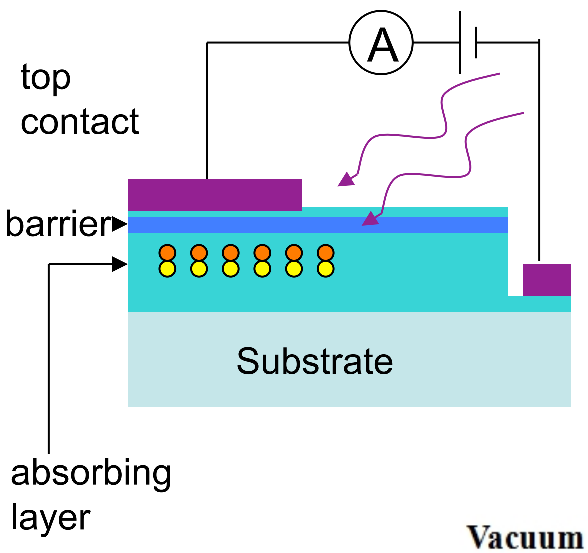


Novel dynamically tunable HS detector

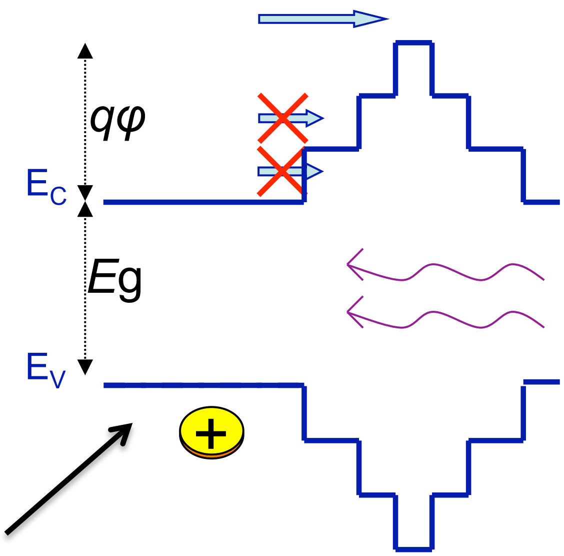


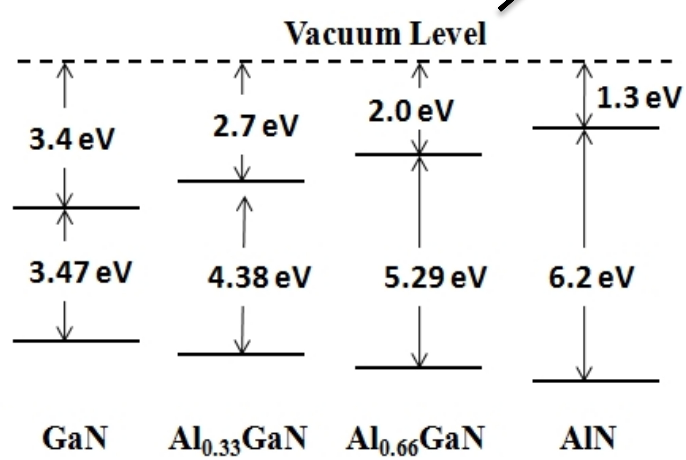
Internal photoemission measurement (IPE)

Device Schematic

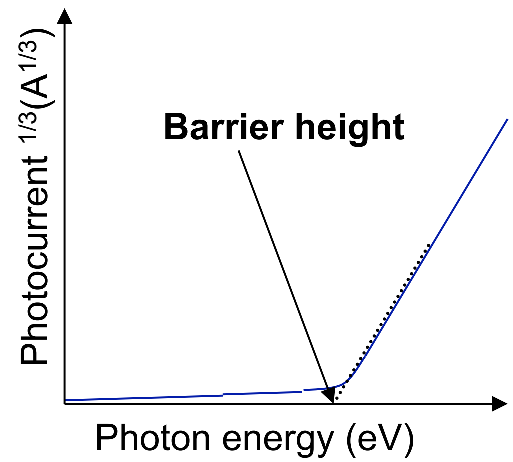


Band Diagram



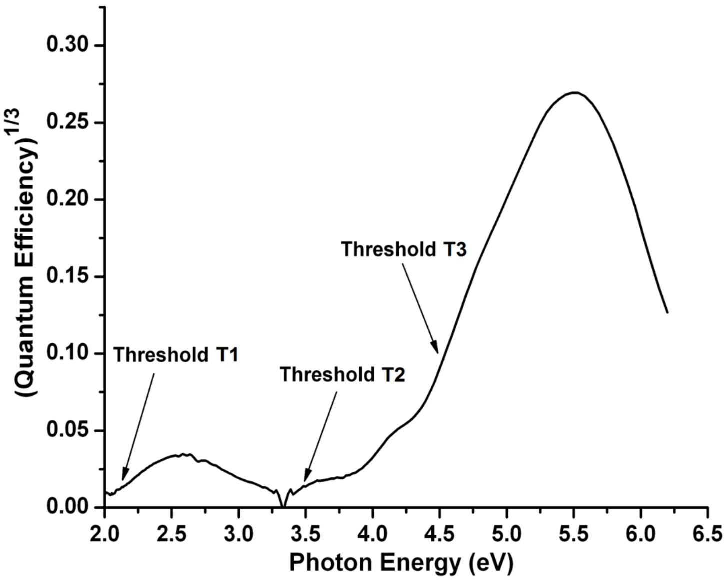


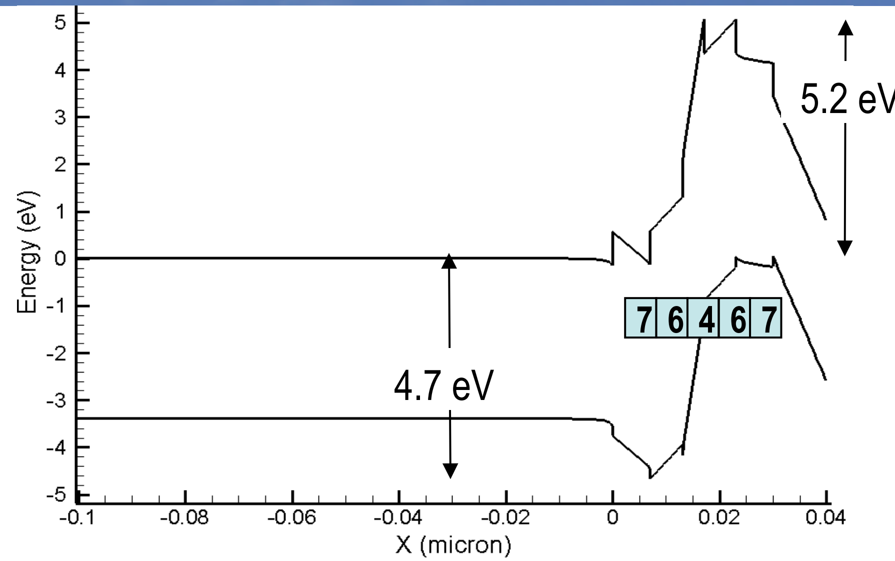
IPE spectrum

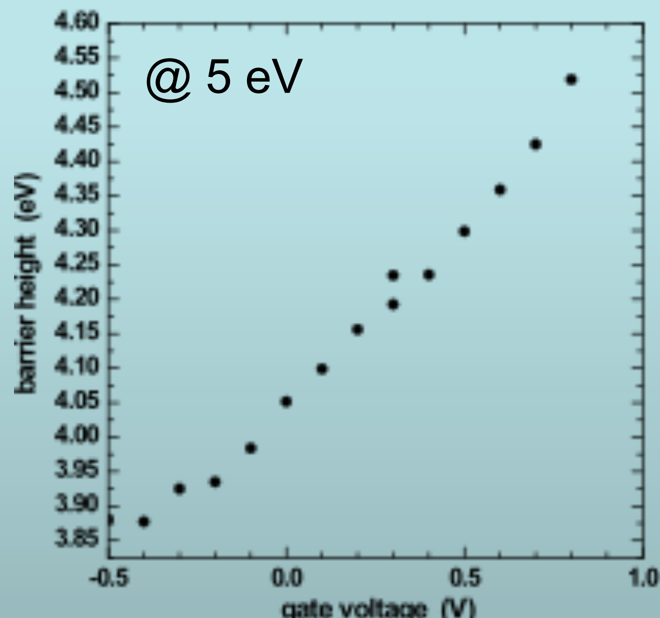


$$Y(h\upsilon) \propto (h\upsilon - E_g - q\varphi - \hbar\omega)^3$$

IPE

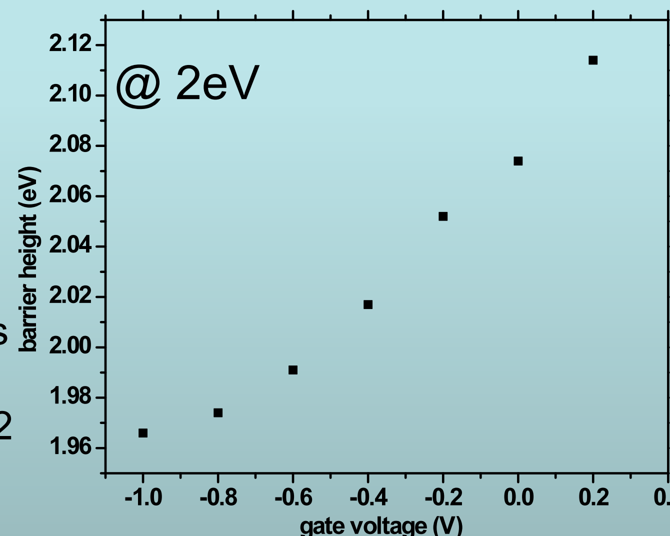




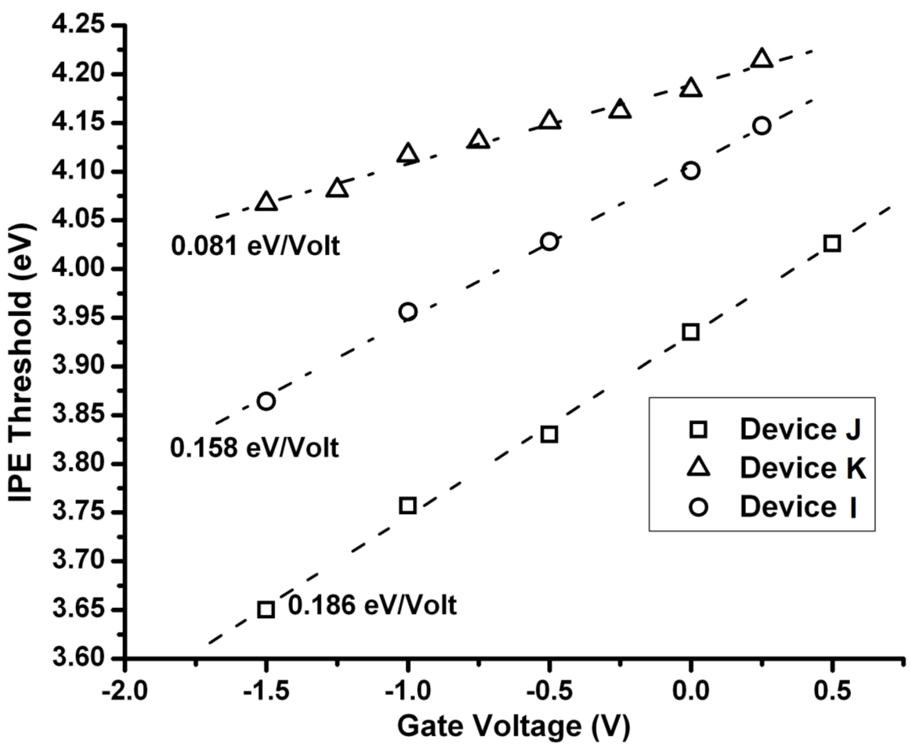


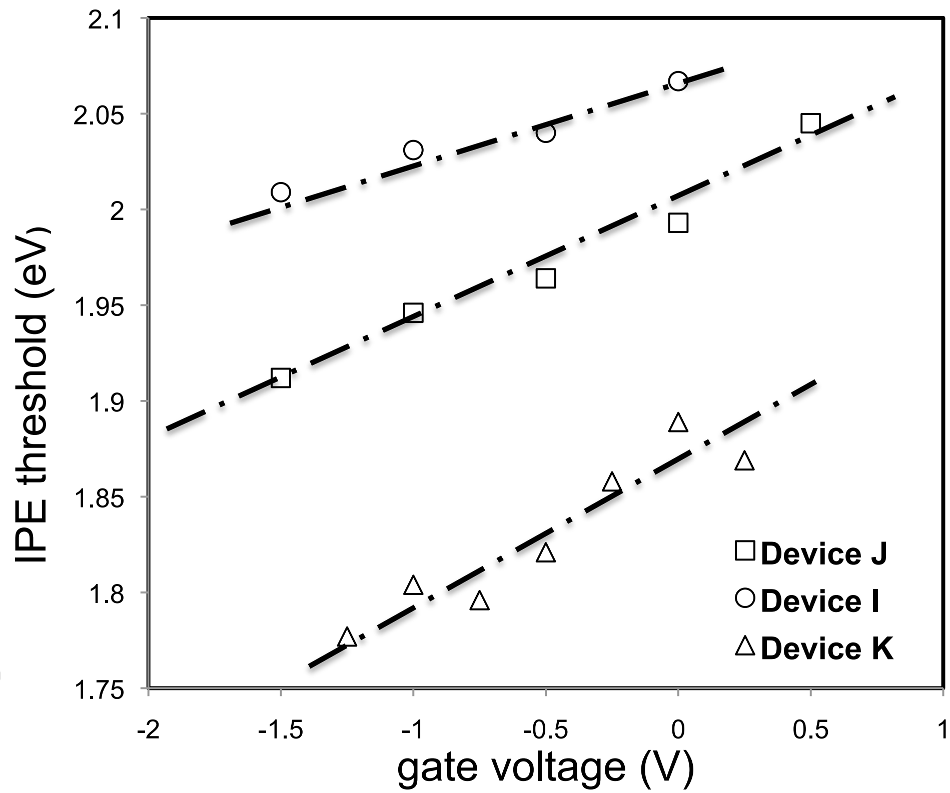
Barrier tuning from 4.52 eV to 3.88 eV, for applied bias between –0.6 V and 0.8 V

Barrier lowering from 1.97 eV to 2.12 eV for applied bias between -1.0 V to 0.2



Tunability rate

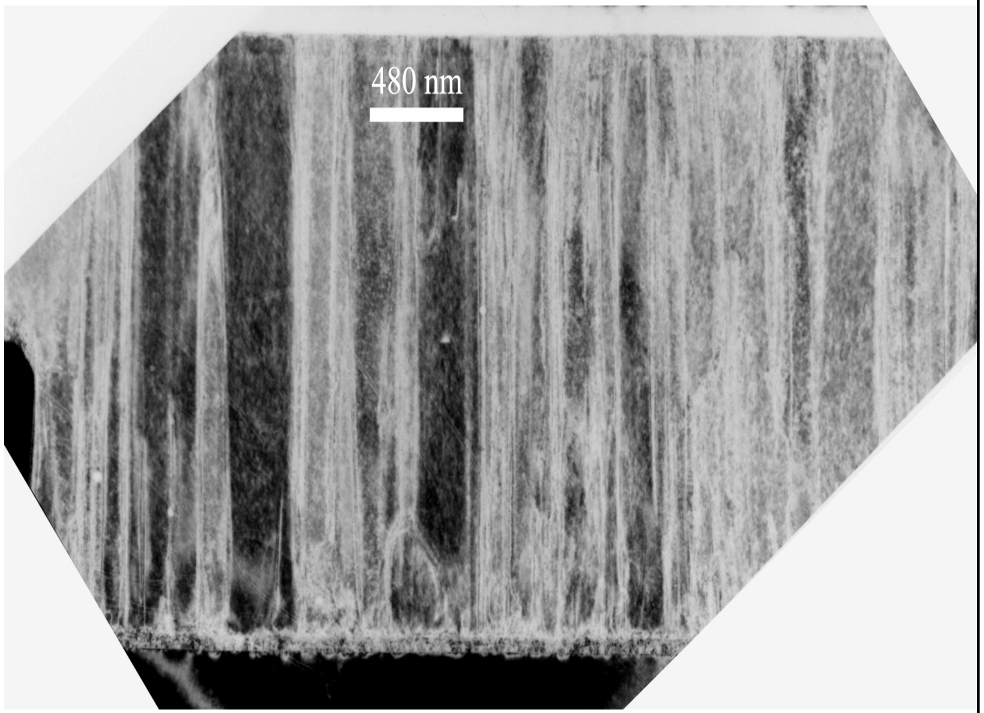




Layer	Device I	Device J	Device K
Al(0.33)GaN	5 nm	7 nm	3 nm
Al(0.66)GaN	4 nm	5 nm	3 nm
AlN	2 nm	2 nm	2 nm
Al(0.66)GaN	4 nm	3 nm	5 nm
Al(0.33)GaN	5 nm	3 nm	7 nm
n-GaN	n-GaN	n-GaN	n-GaN

N. Tripathi, L. D. Bell, F. Shahedipour-Sandvik, **J. Appl. Phys. 109, 124508 (2011).**

Challenges

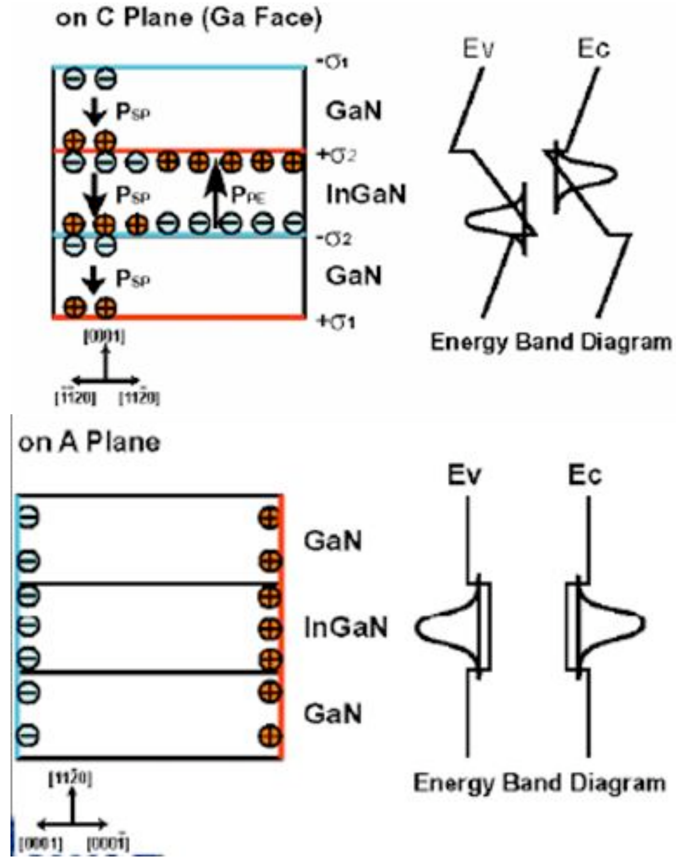


TEM micrograph for GaN on Si showing dislocations formed because of lattice and thermal mismatch

Reliability in Electronic Devices

Droop in Emitters

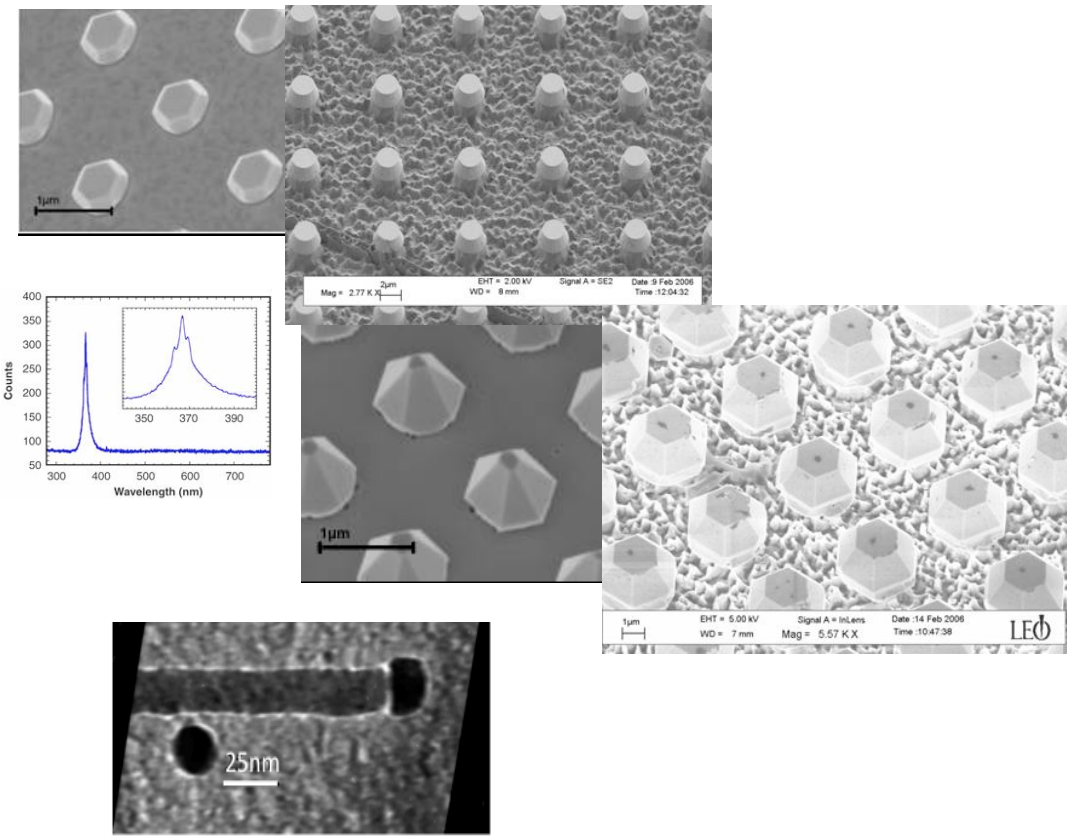
Dislocations: Act as non-radiative centre and path for leakage current degrading optical and electrical characteristic of devices



QCSE: Electric field in quantum wells spatially e^- and h^+ which causes decrease in recombination efficiency

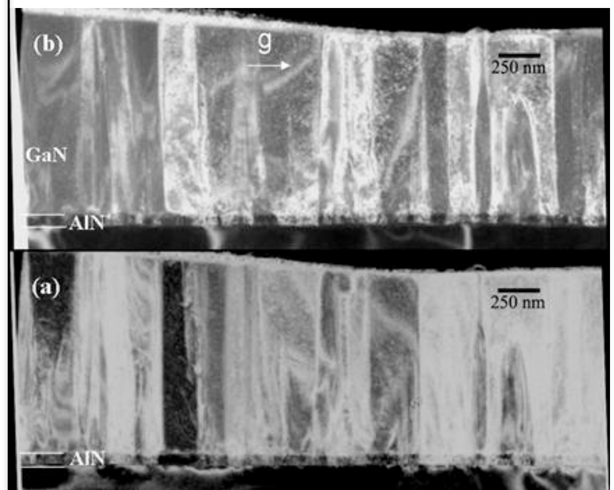
A few solutions

Nano(Al)GaN: dislocation defect reduction

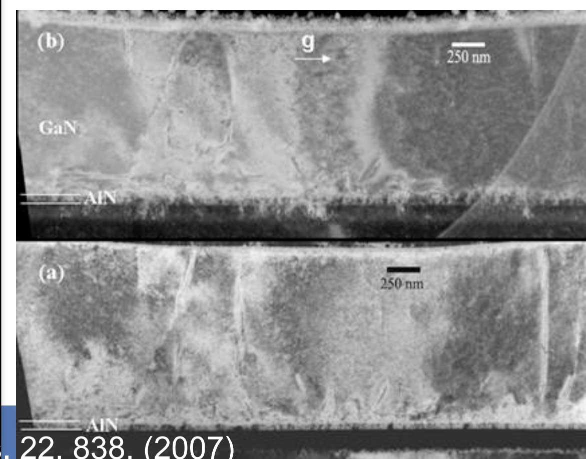


GaN/Si:

One order of magnitude in defect reduction after substrate engineering



Implanted ($2\times10^{16}/cm^2$, 60 keV)



Homo/heteroepitaxy on Bulk GaN (AlN) substrates

V. Jindal, J. R. Grandusky, F. Shahedipour-Sandvik et al., J. Mater. Res. 22, 838, (2007)
M. Jamil, J. R. Grandusky, V. Jindal, N. Tripathi, and F. Shahedipour-Sandvik, J. Appl. Phys. 102, 023701 (2007)