Homo-epitaxial Growth of GaN and Device Applications

Hai Lu (陆海)

School of Electronic Science and Engineering, Nanjing University
Nanjing, China (e-mail: hailu@nju.edu.cn)

Collaboration with Prof. Rong Zhang, Prof. Youdou Zheng at Nanjing University, and Prof. Xian-an Cao at West Virginia University

The Hong Kong Institution of Engineers
Electronics Division
香港工程師學會電子分部

Department of Electronic Engineering,
The Chinese University of Hong Kong
香港中文大學電子工程系

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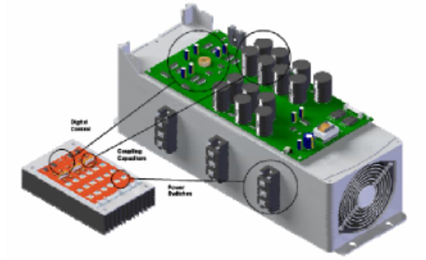
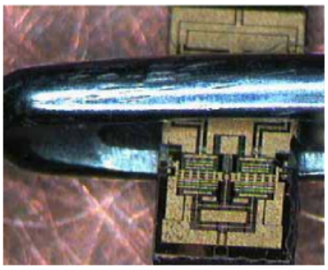
Outline

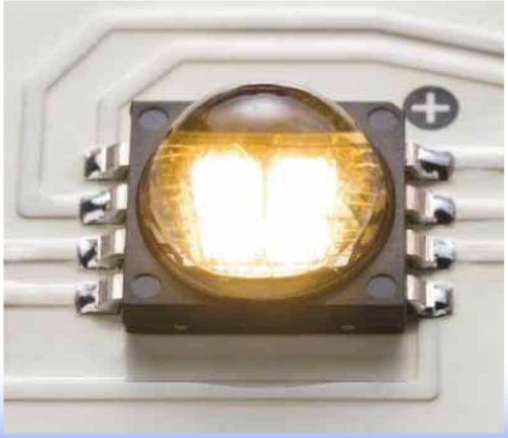




- Why bulk GaN and homoepitaxy ?
- Material characterization techniques: CL mapping
- Homoepitaxy
- Devices: LED, photo-detector, Schottky rectifier

GaN LEDs for solid-state lighting

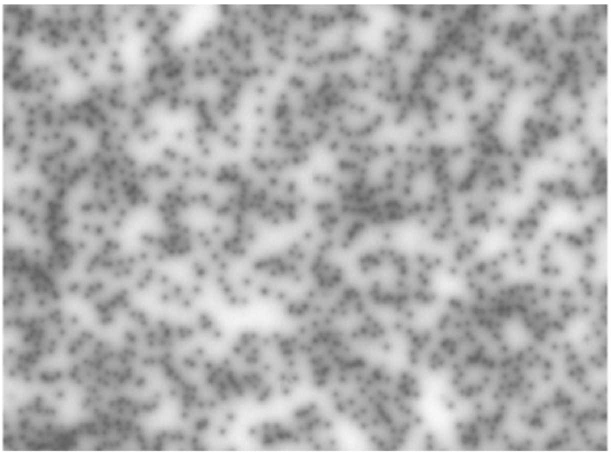
SSL saves energy, $$$, and benefits environment



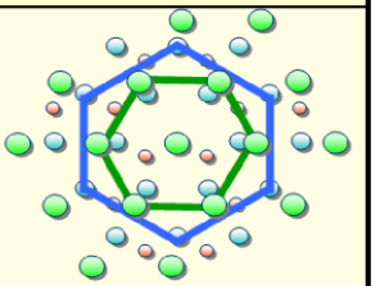
In early 2010, Cree reported a white power LED with record efficiency of 208 lm/W _ 50 mA.

Electrical Efficiency	95%
Internal Quantum Efficiency	90%
Extraction Efficiency	90%
White Conversion Efficiency	75%
Target (K×η total)	200 lm/W

A BEST MOCVD GaN on sapphire

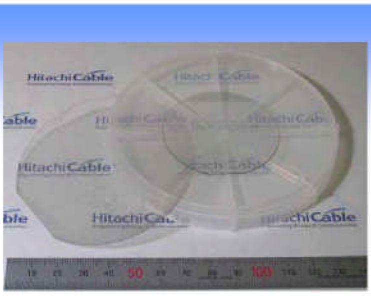


Large lattice mismatch

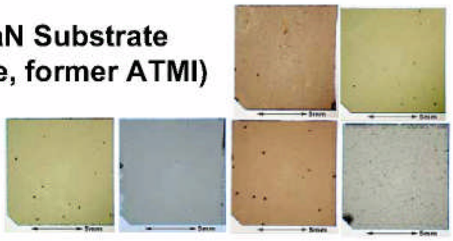
	$[11\text{-}20]_{III\text{-}N}//[10\text{-}10]_{Sap}$ 30 ° Rotation
Atomic arrangement	
GaN a=3.189 Å	+16.1%

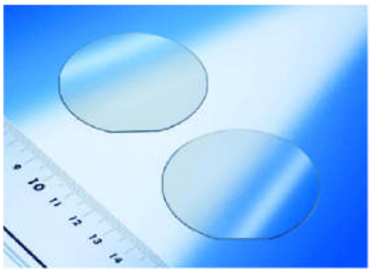
It is well accepted that defects in GaN, especially TDs, are:

- non-radiative recombination centers
- leakage paths
- carrier traps
- and scattering centers ……



GaN Substrate
(Cree, former ATMI)





Sumitomo
Electric's
bulk GaN

HVPE GaN template
(Nanjing Univ.)

Bulk GaN is gradually commercially available, but what we really need is high-quality epi-layer.

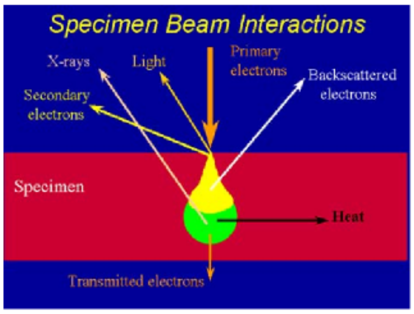
⇩

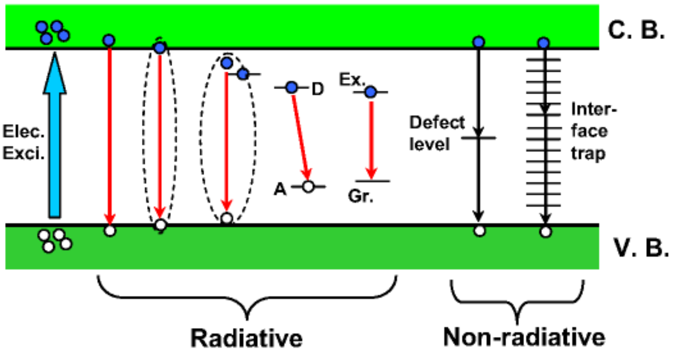
Homoepitaxy

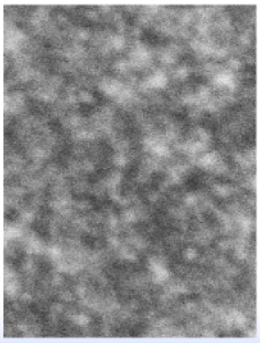
Before epi, to establish a reliable method to count TDs in bulk GaN is a must !

TEM	Limited by small view area
AFM	Hard to judge where TD really is !
Selective etching	Highly dependent on the etchant and etching conditions used; destructive • Hot H_3PO_4 acid、KOH solution 、PEC ….. : seldom accurate • Molten KOH/NaOH: good but requires fine control and involves dangerous chemicals
CL mapping	Reliable、 fast、non-destructive

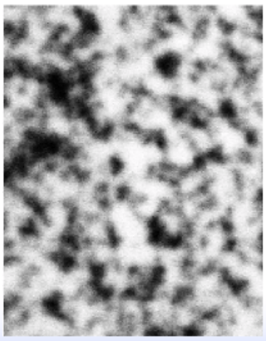
CL mapping for defect characterization



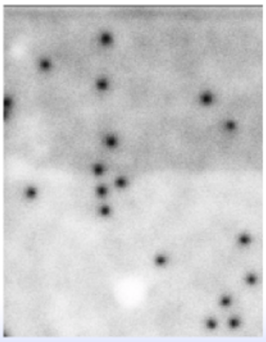




GaN on silicon

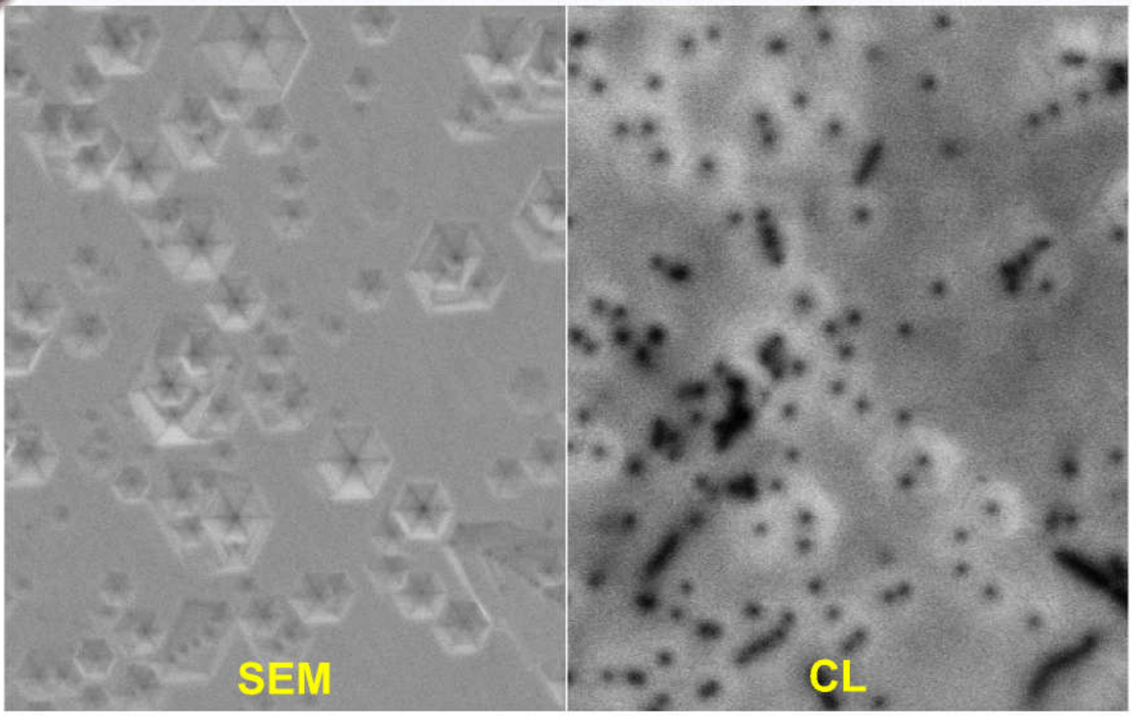


GaN on sapphire



Thick HVPE GaN

Melton-KOH-etched bulk HVPE GaN



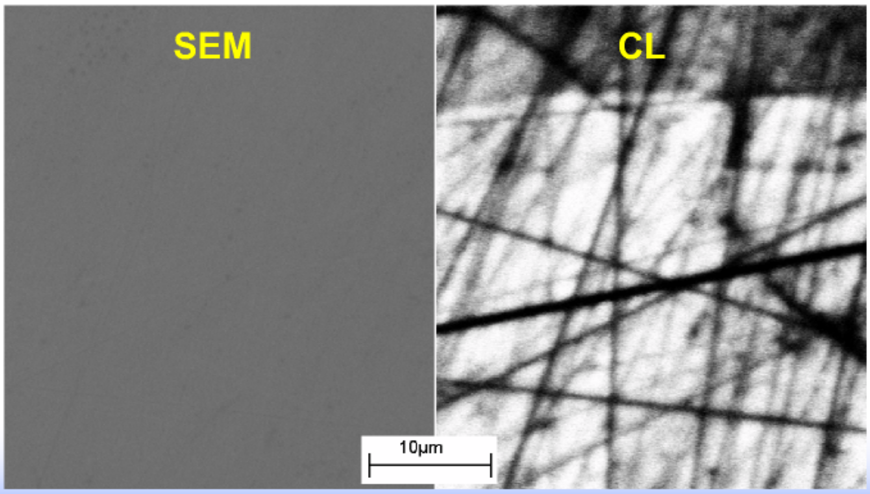
Here, clear correlation is established.

The problems faced by homo-epi

- Different thermal conductivity
- Small wafer size normally

Need more experience

- The bulk GaN technology is not that mature. The GaN substrate might not be truly epi-ready.



An extreme case:

Severe sub-surface damage revealed by CL, rms roughness ～ 0.5 nm

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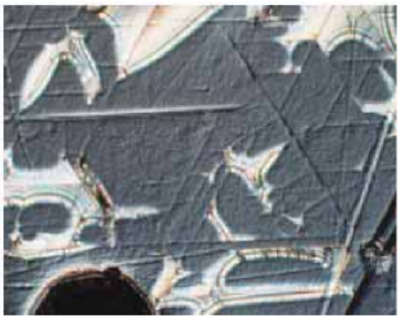
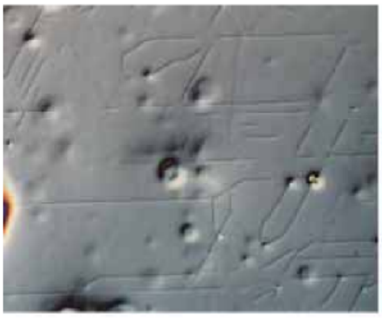
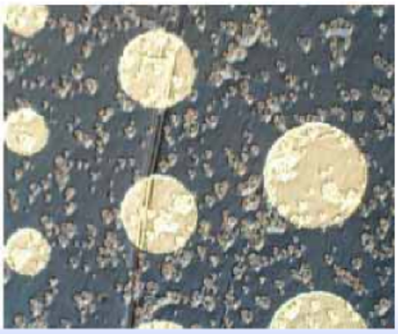
Examples of poor homo-epi growth



Delamination



Remained pits and scratches



Very leaky devices

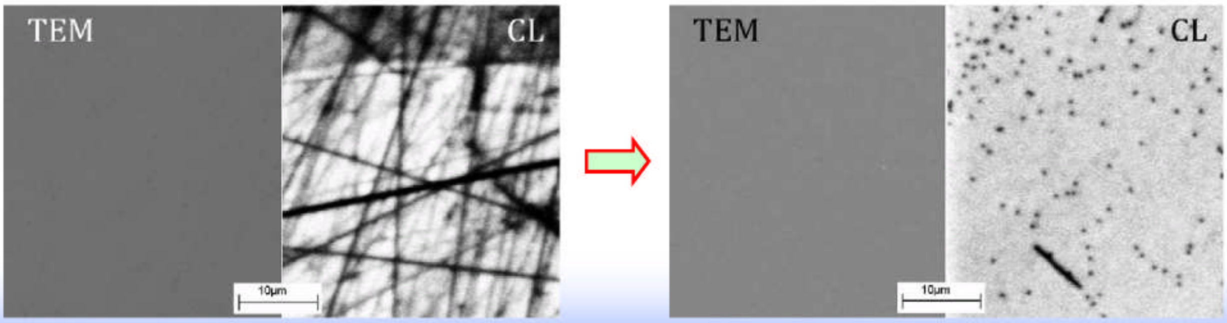
Although nice epi-layers can be obtained occasionally, our old process lacks good repeatability.

In-situ micro-etching technique

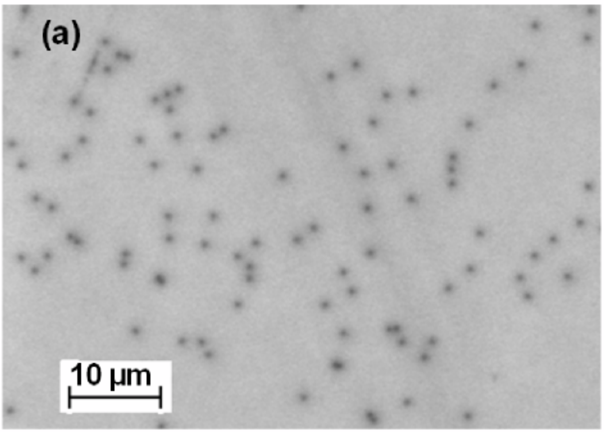
Materials: bulk GaN substrates from several vendors and HVPE GaN template prepared by Nanjing Univ.

Process: annealing the samples in a mixture of NH_3 and H_2 at the high temperature for a certain time period.

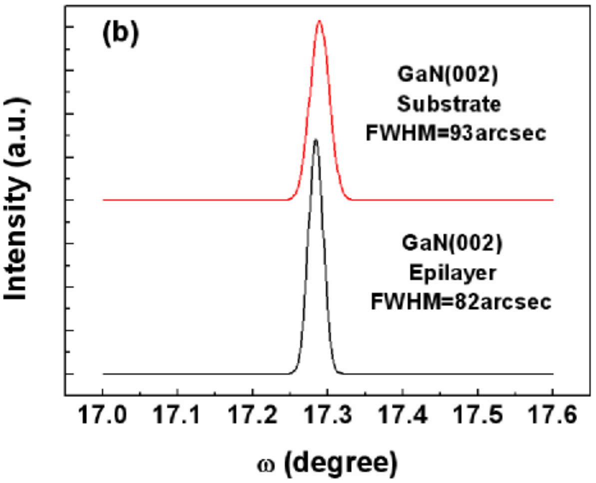
What happens: we believe that the residual surface damages can be reduced by this controlled decomposition process.



High crystalline-quality GaN homo-epilayer



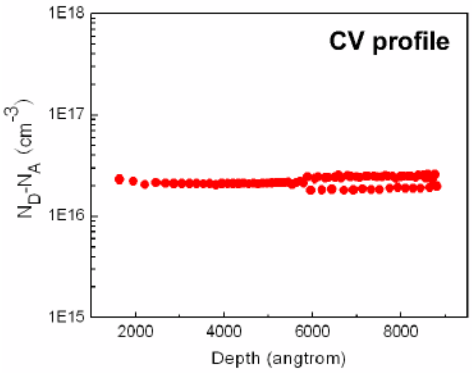
DD ～ 4×10^6 cm^{-2}
GaN substrate dependent



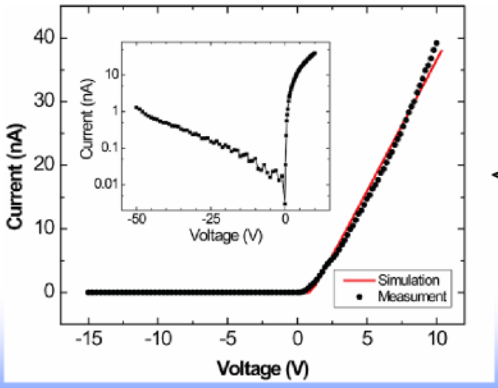
Crystalline-quality is further improved through homo-epi

Wide-range-control of n-type doping

- **High-doping**: up to ～ high 10^{19} cm^{-3}
- **Low-doping**: down to ～ low 10^{16} cm^{-3}



- **Semi-insulating**:

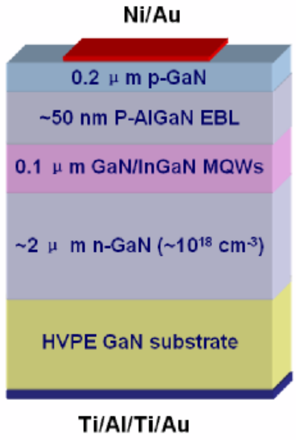


By using a Schottky-diode-like structure, the RT resistivity is estimated as high as 10^{10} Ω cm.

Several promising device applications

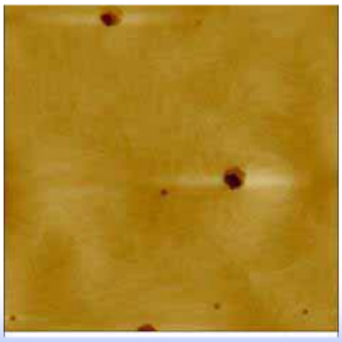
Blue LEDs on bulk GaN

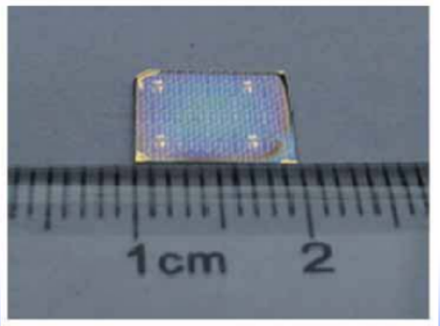
LED on GaN
R_q ~ 0.2 nm


Ni/Au
0.2 μ m p-GaN
~50 nm P-AlGaN EBL
0.1 μ m GaN/InGaN MQWs
~2 μ m n-GaN (~10^{18} cm^{-3})
HVPE GaN substrate
Ti/Al/Ti/Au

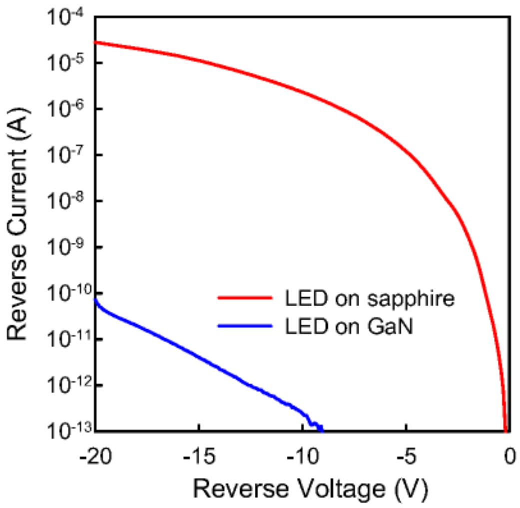
standard
300x300 μ m^2

LED on Sapphire
R_q ~ 0.6 nm

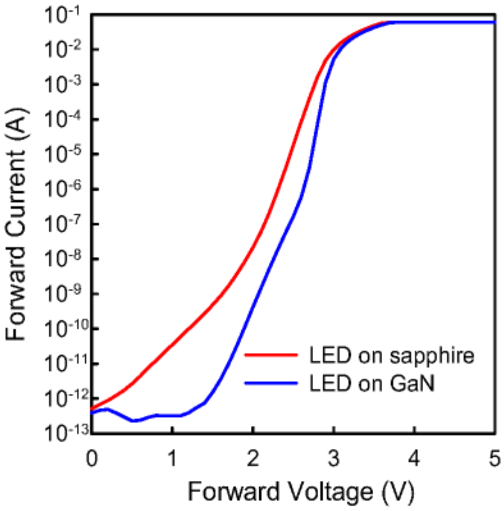




Homo-LEDs with reduced leakage current

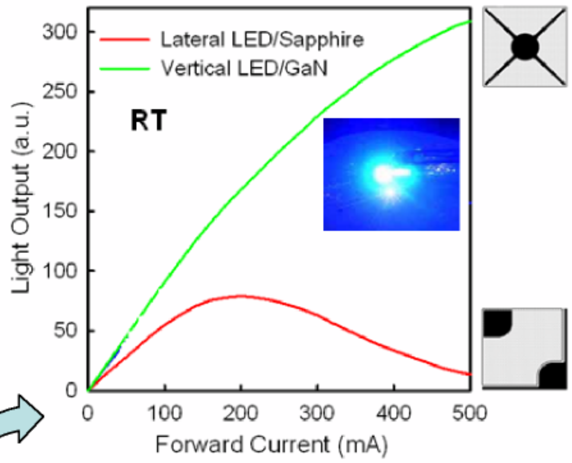


Reverse leakage

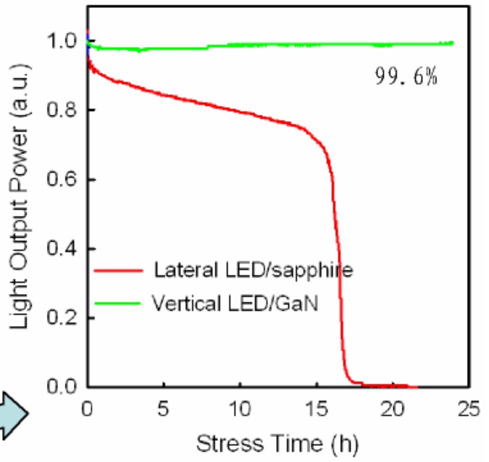


Low forward-voltage leakage

Comparisons of light output and reliability



600 A/cm² DC stressing



Low injection current: high QE

High injection current: improved heat dissipation

Reduced diffusion of point defects through TDs or just a thermal-degradation effect

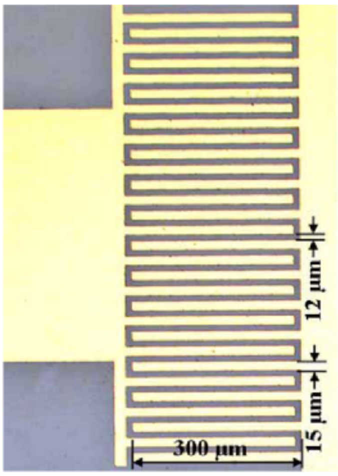
The above comparisons were done by on-wafer testing.

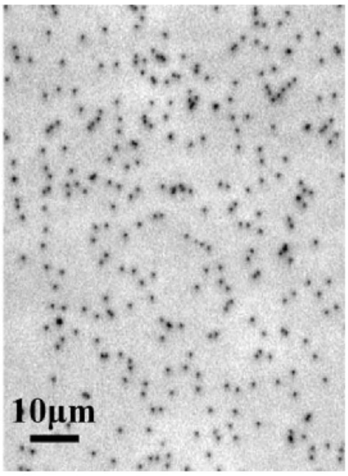
MSM-PDs on GaN homo-epilayer

- **MSM PDs have many intrinsic advantages over other types of PDs.**

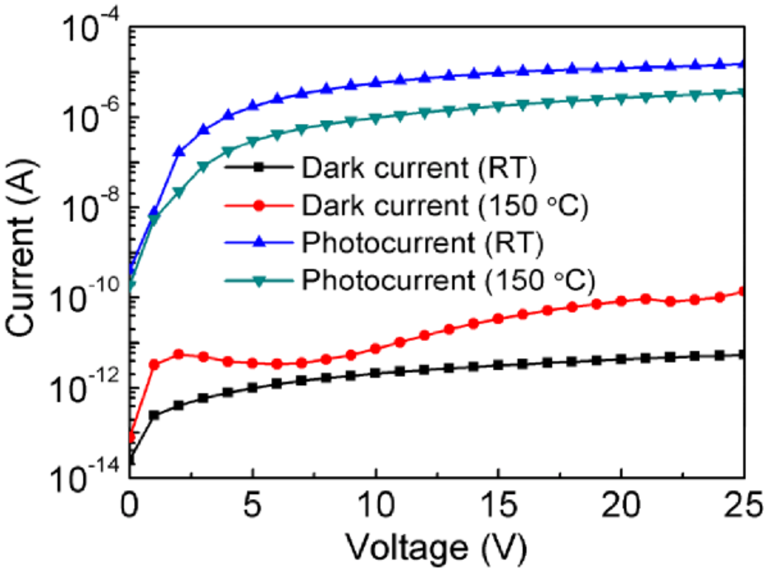
- **Dark current determines weak-signal-detection capability. But past MSM-PDs fabricated on sapphire usually suffer from high dark current.**

MSM-PDs on Bulk GaN



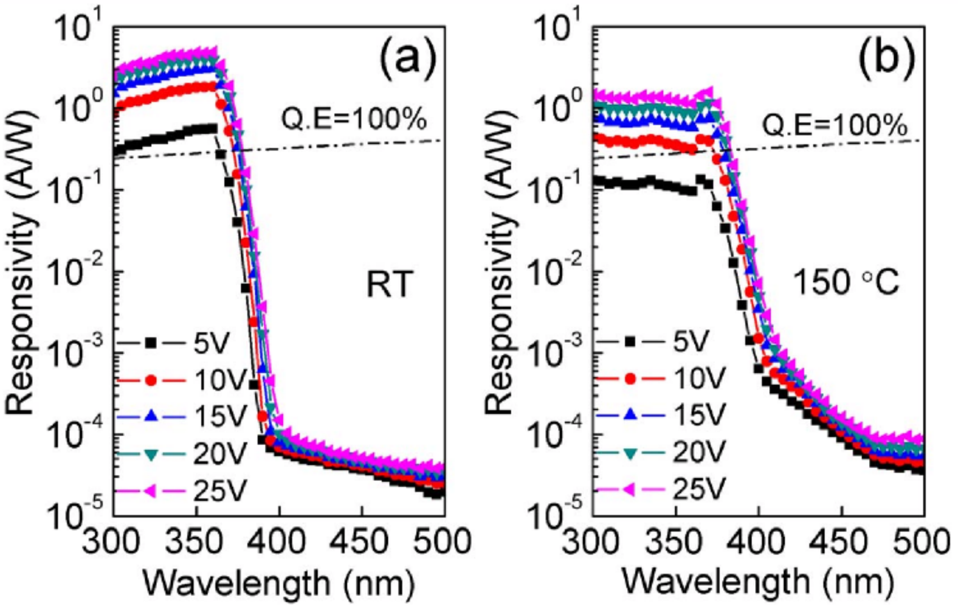


Ultra-low dark current is achieved !



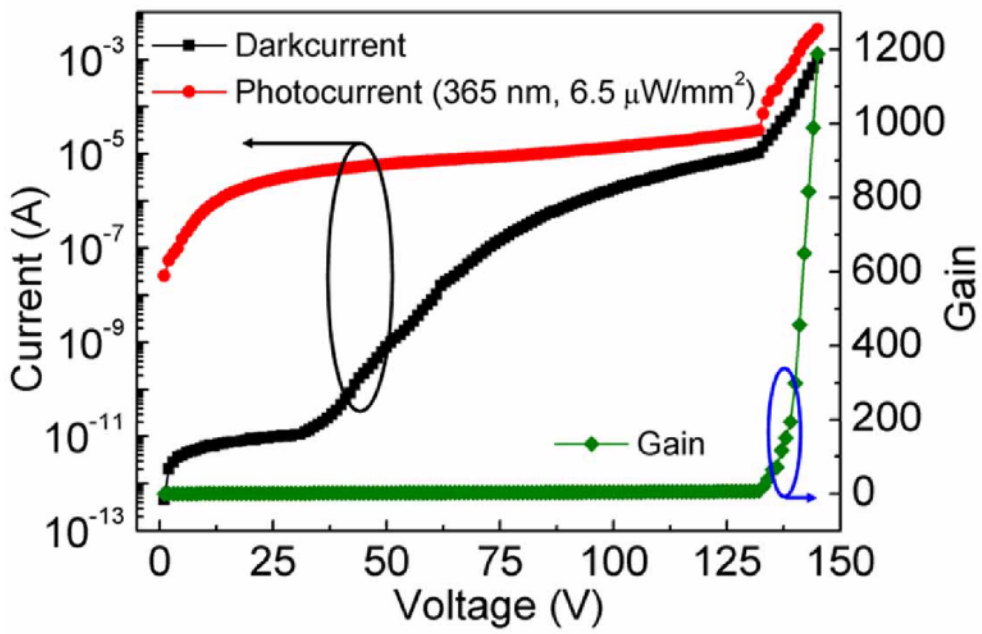
Dark current of the PD is significantly reduced, even at elevated temperatures.

High UV-to-visible rejection ratio



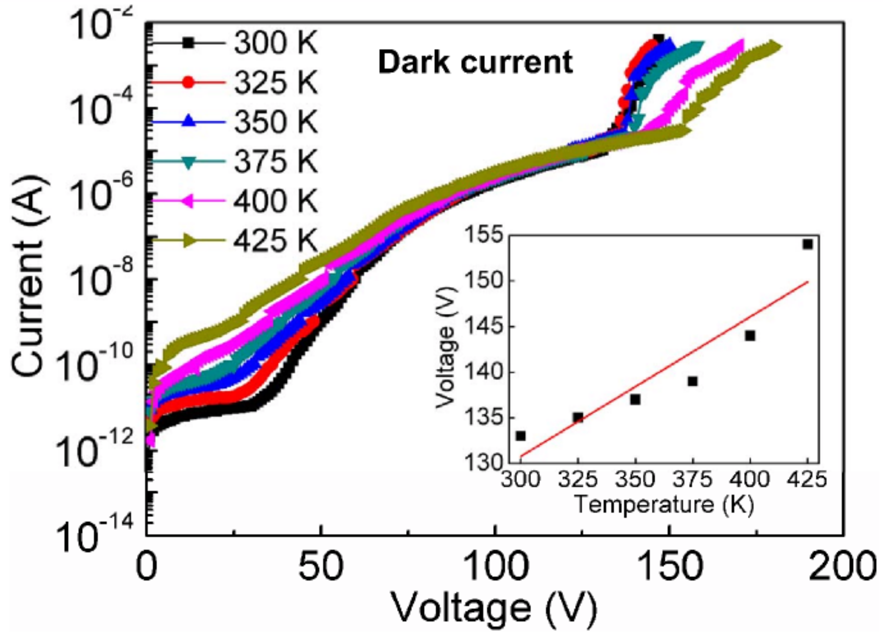
The PD still exhibits an internal gain mechanism, which is attributed to photo-generated holes trapped at the semiconductor/metal interface as well as field-induced image-force lowering effect.

MSM-APDs on GaN homo-epilayer



If we further increase bias until the critical electrical field of GaN is reached along the edge of contact electrodes, the MSM PD just introduced could change into an APD !

Temperature dependent breakdown characteristics



The BVs of the MSM-APD show a positive temperature coefficient of 0.15 V/K, confirming that the gain is dominated by avalanche breakdown mechanism.

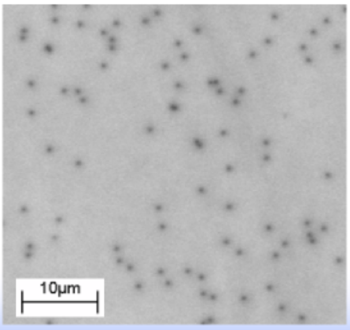
Schottky rectifiers on bulk GaN

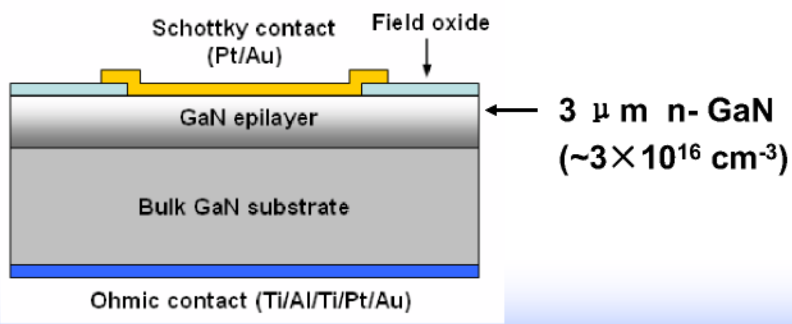
Power device

- High voltage
- High current
- Enhanced temperature

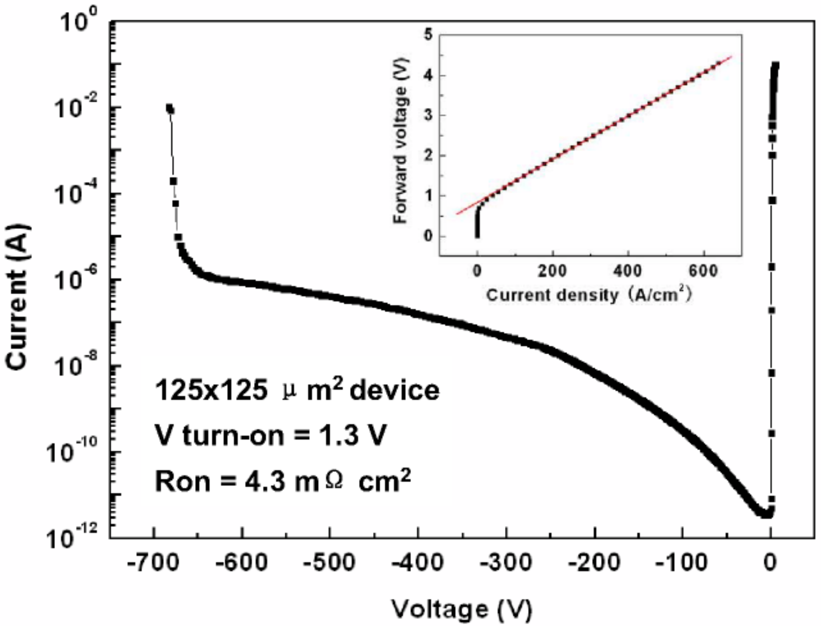
→ **Requires high crystalline quality**

GaN-based Schottky rectifiers are being preferentially developed as a unipolar device, which offers a high switching speed as well as a much smaller switching loss.





Current-voltage characteristics



670V BV, close to but still lower than the theoretical limit of 750-800V.


Thank you