SAND2012-9880P

IWN2012

International Workshop on Nitride Semiconductors October 14-19, 2012, Sapporo, Japan

Abstract Book

Sponsored by
The Japan Society of Applied Physics

Co-sponsored by
The Japanese Association for Crystal Growth
The 162nd Committee on Wide Bandgap Semiconductor Photonic and Electronic Devices,
Japan Society for the Promotion of Science

Review of IWN2012

A. Allerman

- GaN Electronics
- Bulk GaN
- GaN on Si

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Sandia National Laboratories

PL-1 (plenary) 9:15 - 10:15
InGaN-based nanocolumns for photonic devices

*K. Kishino(*1,*2), V. Ramesh(*1), K. Yamano(*1), and S. Ishizawa(*1)
*(*1)Sophia University, Japan and (*2)Sophia Nanotechnology Research Center, Japan*

Nanowire LEDs

Red LED

Kishino – Nanocolumn LEDs

- Review of earlier work
- IR LED (86%InGaN)

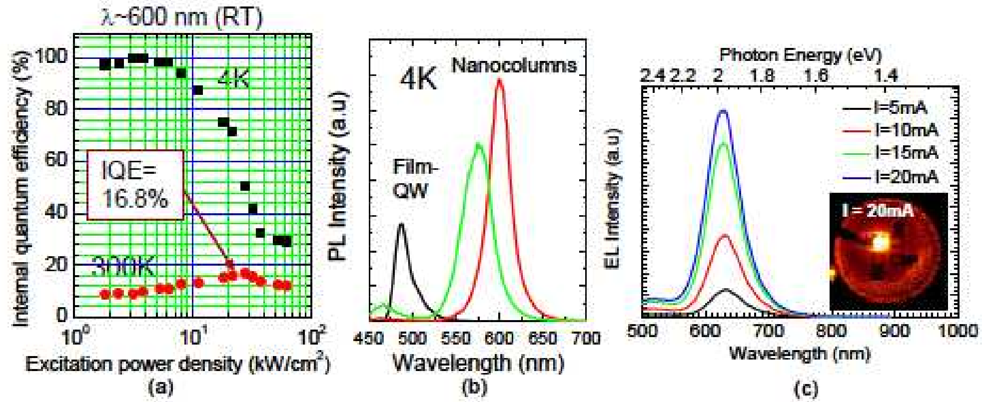


Fig. 1 (a) Estimation of internal quantum efficiency, (b) 4K PL spectra of red-emitting nanocolumns and film-QW ref. sample, and (c) spectrum of a red-emitting nanocolumn LED

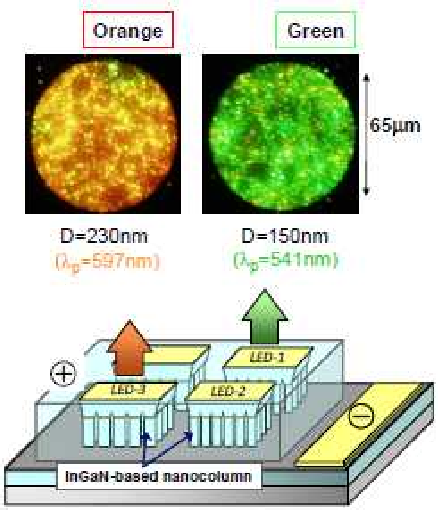


Fig. 3 Green and orange light nanocolumn LEDs monolithically integrated on the same substrate

IR LED

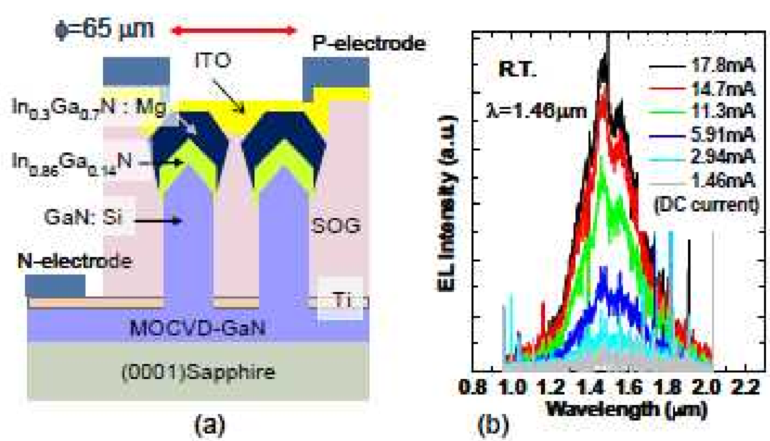


Fig. 4. (a) Nanocolumn LEDs with In-rich $In_{0.86}Ga_{0.14}N$ active layer and (b) the infrared EL spectra emitting at 1.46 μm.

S2-1 (invited) 14:00 - 14:30

Bulk-GaN based low-droop light-emitting diodes for lighting applications

*Michael R Krames

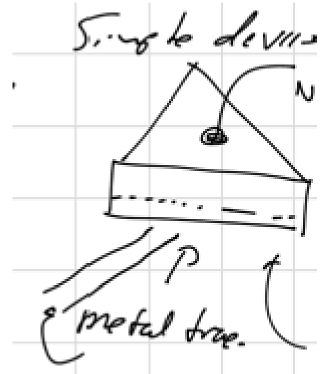
Soraa, Inc., United States of America

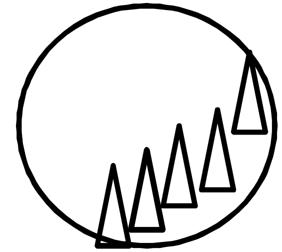
LEDs - Soraa

Droop

- **Auger is it! (optical, electrical)**
  (Not carrier leakage from wells)

- **Keep carrier density low**
  => thicker wells, m-plane





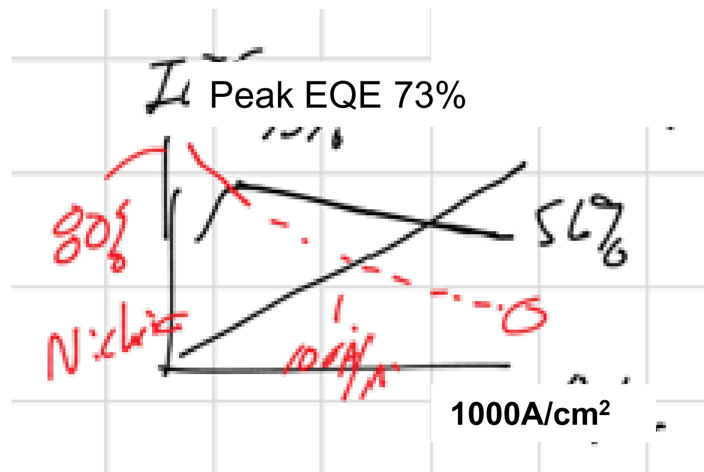
MR-16

Simple chip: p-down mount
no substrate removal (heat spreader)

No change in Po for 1000hrs, 160A/cm2

LEDs are currently HVPE GaN (face?)
(working on bulk)

GaN on GaN
- **low dislocation, reliability @ 1kA/cm2**
- **Thermal dissipation**
- **Less droop**
- **Cost driven by lm/mm²**



Very big proponent of GaN substrates

The Sixteenth International Conference on Metal Organic Vapor Phase Epitaxy
ICMOVPE-XVI
May 20~25, 2012
Paradise Hotel Busan, Busan, Korea

Droop

From ICMOVPE-16:

1. **Droop largely due to polarization of QWs…. Go to non/semi-polar planes**
2. **Focused on EBL. InAlGaN improved EL.**
3. **Bulk GaN**

MoA1-1 [Invited]	11:10~11:40	Improvement in Efficiency Droop of GaN-Based Light-Emitting Diodes by Optimization of Active Regions Hao-Chung Kuo, National Chiao Tung University, Taiwan

TuA1-5	10:00~10:20	GaN-Based Light Emitting Diodes with a p-InGaN Layer P. H. Chen, Cheng Huang Kuo, W. C. Lai, L. C. Chang, and C. S. Lee, National Chiao Tung University, Taiwan

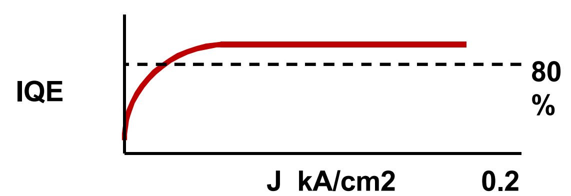
WeP-18	Enhanced Optical Power of InGaN/GaN Light-Emitting Diodes by Bandgap-Engineered Electron Blocking Layer Sang-Jun Lee[1], Chu-Young Cho[1], Sang-Hyun Hong[1], Sang-Heon Han[1], Sukho Yoon[2], and Sung-Tae Kim[2], [1]Gwangju Institute of Science and Technology, Korea, [2]Samsung LED, Korea

FrA1-1 [Invited]	09:30~10:00	In and Impurity Incorporation in InGaN Hiroshi Amano, Nagoya University, Japan

1. **M-plane LEDs**
   IQE 96%
   No droop to 600 A/cm-2
   Doesn't understand why droop is so low.

4. **C-plane LEDs**
   "Little" droop to 200Å/cm-2

5. **IQE low at low current density**
   (point defects in InGaN?)



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Rump Sessions

Rump sessions (Oct. 17 (Tue) 18:30-20:30)

What is the best substrate for nitride devices?

Organizers: Kou Matsumoto (Taiyo Nippon Sanso EMC, Japan)
Christian Wetzel (Rensselaer Polytechnic Institute, USA)
Room: Conference Hall

Recently, there have been many reports on new substrates for nitride semiconductors such as ammonothermal GaN and Si. However, advantages in the use of these new substrates instead of conventional substrates from a standpoint of final products are not clear yet. In this rump session, both crystal growers and device engineers will get together and discuss when and how these substrates will be used in mass-production.

Strategies to overcome efficiency droop in high-power LEDs

Organizers: Ulrich T. Schwarz (Fraunhofer IAF, Germany)
TBA
Room: Mid-sized Hall

Several strategies have been suggested to overcome droop in higher-power, high-efficiency LEDs. This includes wide QWs, nanocolumn LEDs, semi- and non-polar LEDs, large area GaN on Si, and low dislocation (bulk) GaN. In this rump session, the potentials and/or limits of the diverse technologies, e.g. for high temperature operation, will be discussed.

Physics and Engineering of Light Extraction

Organizers: Tu Li-Wei (National Sun Yet-Sen University, Taiwan)
Kazuyuki Tadatomo (Yamaguchi University, Japan)
Room: 107/108

In nitride-based LEDs, improvement of light extraction efficiency is still an important issue. Variety of approaches such as patterned sapphire substrate, nano-structure fabrication and surface plasmon has been studied for this purpose. In this rump session, physics and engineering of such approaches for improvement of light extraction will be discussed.

What is the appropriate "gate structure" for normally-off operation?

Organizer plan: Umesh Mishra (UCSB, USA)
Masaaki Kuzuhara (University of Fukui, Japan)
Room: Small Hall

Power conversion applications using GaN transistors have been attracted much attention. Most important issue to enter these markets is how to realize "Normally-off" operation using GaN transistors. Many technologies to obtain normally-off characteristics are proposed in the literature. In this session, the current status and future prospect of gate structure technology for normally-off transistors will be discussed. Process technology, growth technology, and reliability will be focused, comparing different gate structures.

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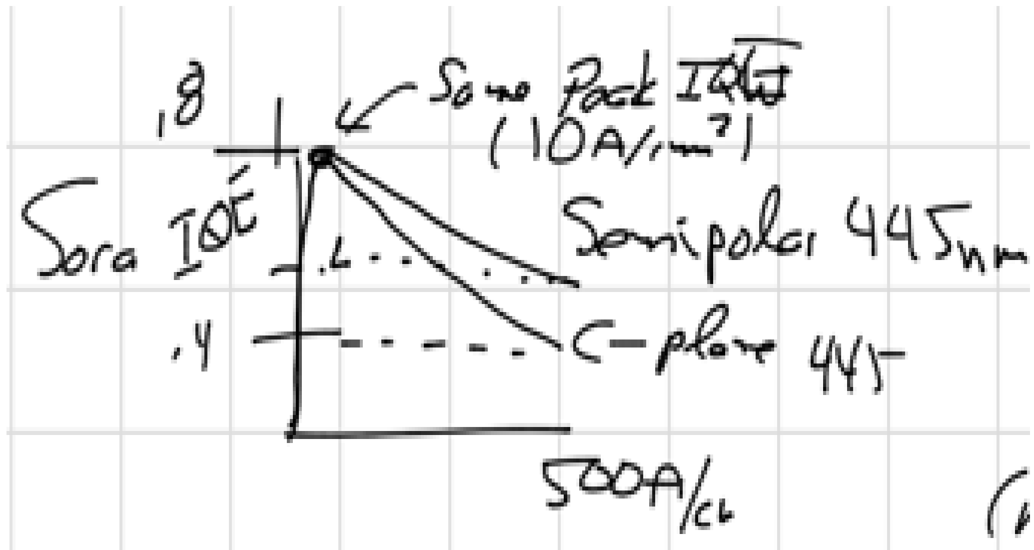
Rump Session: Strategies to overcome droop

Soraa (?)

- Polarization fields contribute to droop
  - Lower carrier density
  - m-plane should help, not clear
- Compare LEDs on c- and m-
- M-plane has lower droop
  - Faster radiative recombination
  - 2x more active material
  - m-plane other material problems



Fred Schubert

- Presented was to reduce droop based on his explanation of droop

J3-1 (invited) 11:00 - 11:30
Unraveling the Mystery of the Efficiency Droop in GaInN LEDs

*E. Fred Schubert
Rensselaer Polytechnic Institute, United States of America

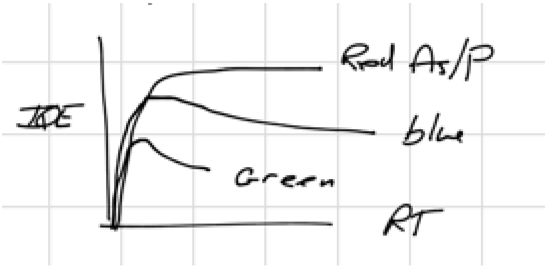
Rump Session: Strategies to overcome droop

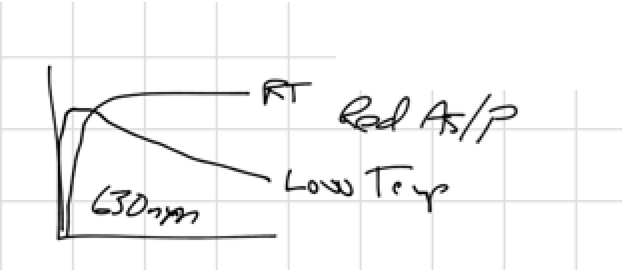
Jong-In Shim, Hanyang University

J3-4 (invited) 12:00 - 12:30
Comprehensive Understanding of Efficiency Droop by the Saturated Radiative Recombination Rate in InGaN-based Light-Emitting Diodes

*Jong-In Shim(*1), Dong-Soo Shin(*1), Hyunsung Kim(*1), and Han-Youl Ryu(*2)
*(*1)Hanyang University, Republic of Korea and (*2)Inha University, Republic of Korea*

- **For I > $I_{peak\ IQE}$**
  - ➡ **radiative recombination rate decreases (appears that non-radiative recombination rate is increasing)**





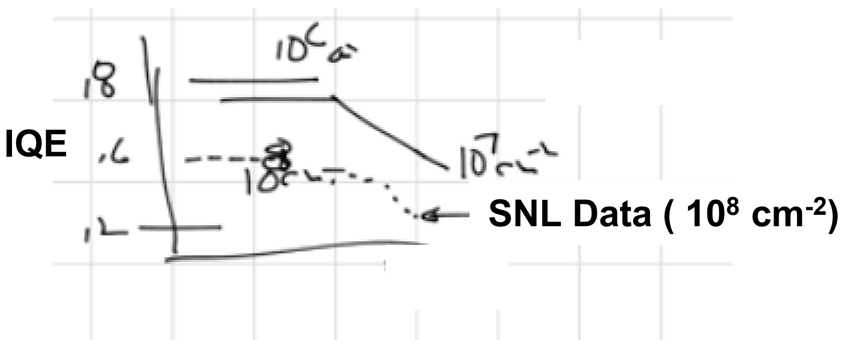
Radiative recombination rate will saturate more at a given current:

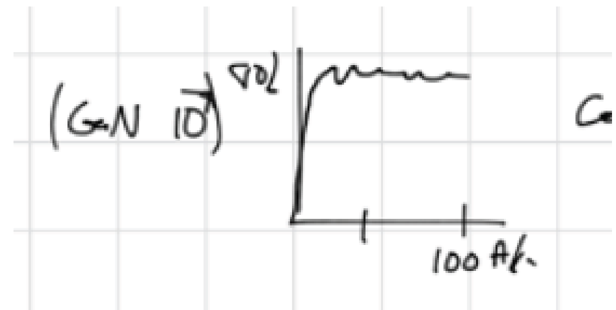
- ➡ **High carrier density**
- ➡ **Low temperature**
- ➡ **Small active volume**
- ➡ **High piezoelectric field**
- ➡ **Unbalanced e- & h concentrations**

Amano

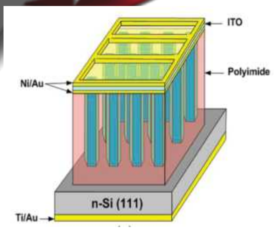
1. Wants thick InGaN well, ~ 20nm, very hard
   ➡ so thin barriers.

2. Low dislocations… bulk GaN (from ICMOVPE-16)





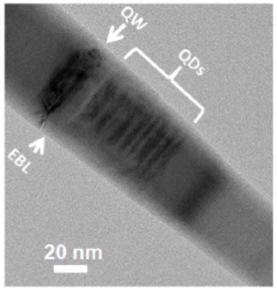
Rump Session: Strategies to overcome droop



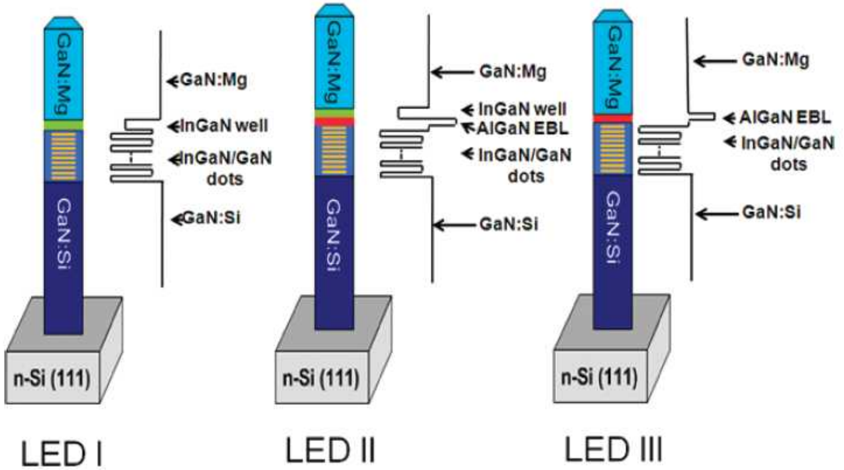
NanoLetters 12 (2012) p1317

Controlling Electron Overflow in Phosphor-Free InGaN/GaN Nanowire White Light-Emitting Diodes

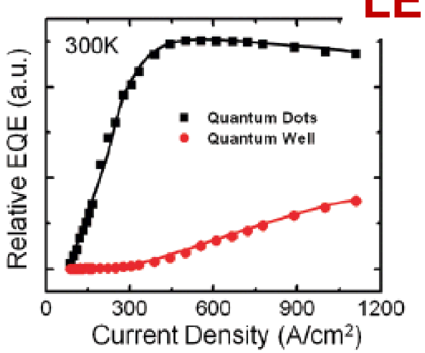
Hieu Pham Trung Nguyen,[†] Kai Cui,[†] Shaofei Zhang,[†] Mehrdad Djavid,[†] Andreas Korinek,[‡] Gianluigi A. Botton,[‡] and Zetian Mi*,[†]

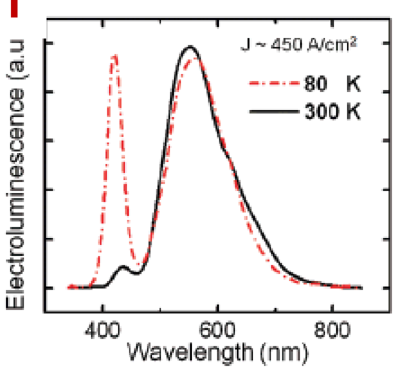


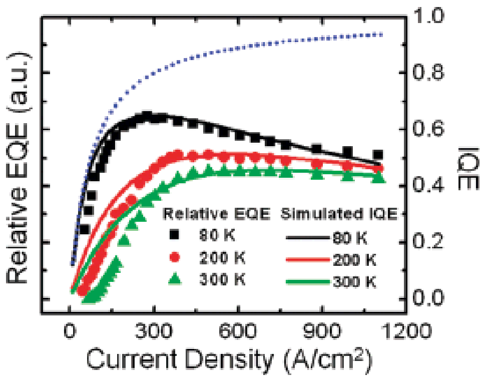
1. Electron leakage in GaN nanowire LEDs with InGaN dots embedded in GaN
2. Electron leakage is responsible for LED degradation with current
3. Adding a p-AlGaN e-block stopped leakage, no droop to 2200A/cm-2.
4. Clearly droop is not dominated by Auger



LED 1







Rump Session: Strategies to overcome droop

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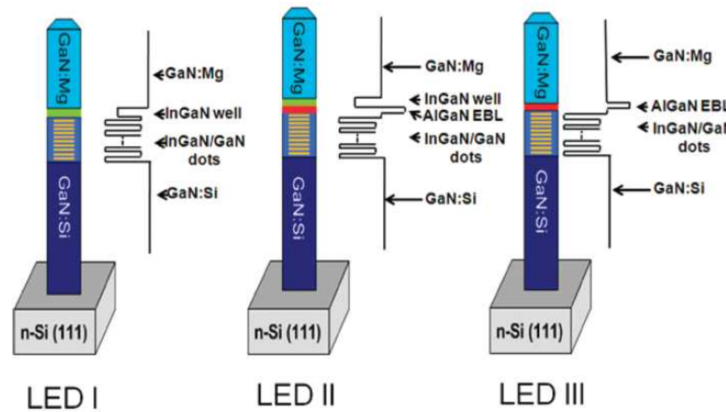
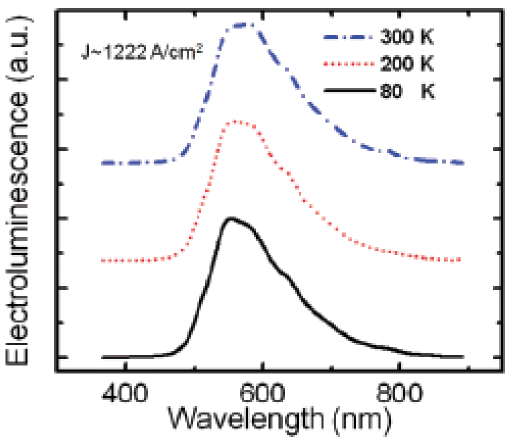
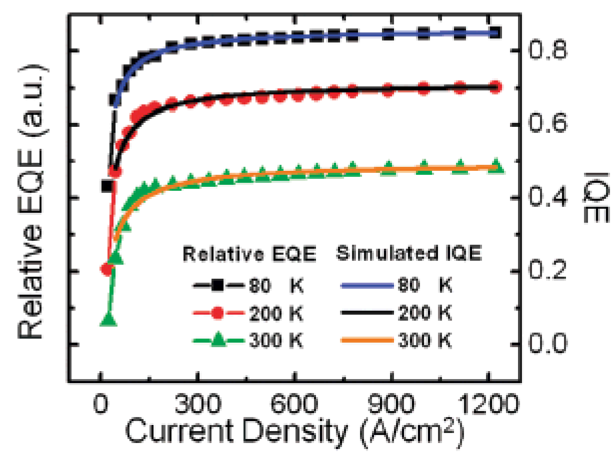


LED 2 – Add EBL between dots and QW



- ➡ No emission from QW
- ➡ No e- leaking to QW

LED 3 – EBL, no QW



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S3-2 (invited) 16:30 - 17:00
Feasibility of large area nitride devices prepared by pulsed sputtering
*Hiroshi Fujioka
Institute of Industrial Science, the University of Tokyo, Japan

GaN on "anything"

Higher surface migration
=> Lower Tg
=> No phase separation
=> No substrate interaction

Roll to roll processing:
Mica sheet
Large grain metal
Graphite sheet

Might be same process as PLD presented at EMC and ICNS several years ago. (Univ. of Tokyo)

Table 1 Summary of growth techniques for GaN

	MOCVD	rf-MBE	Pulsed Sputtering Deposition (PSD)
Maximum growth rate	10 μm/hr	1 μm/hr	10 μm/hr
Typical growth temperature	1000–1200 °C	700–800 °C	0–900 °C
Cost for apparatus	High	High	Low
Substrate scale-up	Difficult	Difficult	Easy
Toxic gas	Necessary	Unnecessary	Unnecessary
Demonstrated devices	LEDs, LDs, HEMTs, Solar Cells, *etc.*	LEDs, LDs, HEMTs, Solar Cells, *etc.*	LEDs, HEMTs, and Solar Cells

Table 2 Typical optical and electrical properties of GaN prepared by PSD

Electron mobility	600-700 cm^2/Vs (at carrier concentrations on $10^{16}/cm^3$)
Hole mobility	5–15 cm^2/Vs (at carrier concentrations on $10^{17}/cm^3$)
FWHM of room temperature PL	30–40 meV

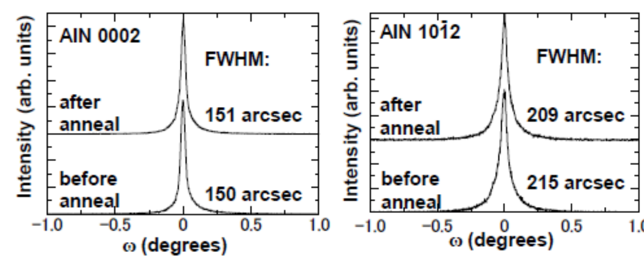
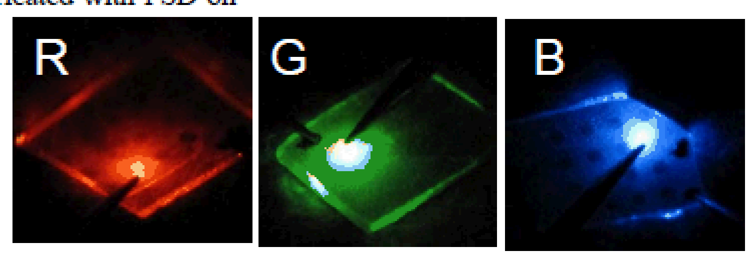


Fig. 1 XRCs for PSD-AlN grown at room temperature on 6H-SiC before and after annealing at 1200°C

Fig.2 RGB LEDs fabricated with PSD on conventional substrate



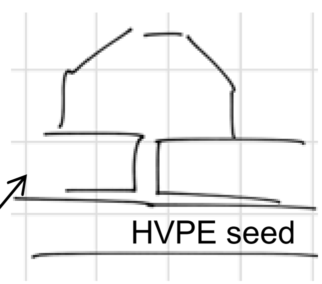
S3-3 (invited) 17:00 - 17:30
Bulk GaN crystal growth by Na flux method

*Yusuke Mori, Mamoru Imade, Mihoko Maruyama, and Masashi Yoshimura
Graduate School of Engineering, Osaka University, Japan

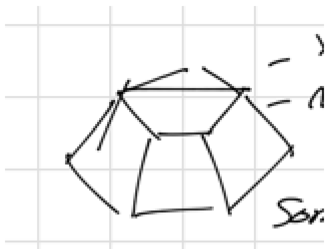
GaN Substrates

Start with HVPE seed and lower dislocations (some variation of "confined epitaxy")

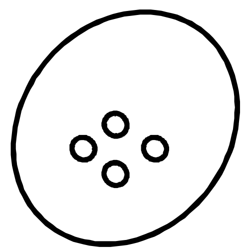
Like Amano, ELOG through opening Grow seeds together



Thick sapphire mask with hole

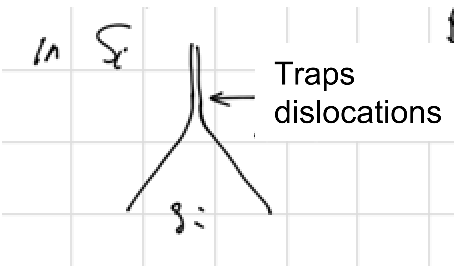


Dislocation free, XRD: 2.1"



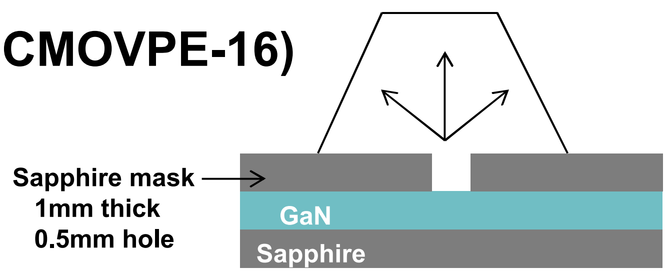
Grow multiple openings and coalesce

"Necked down" like in Si



Amano (ICMOVPE-16)

The Sixteenth International Conference on Metal Organic Vapor Phase Epitaxy
ICMOVPE-XVI
May 20~25, 2012
Paradise Hotel Busan, Busan, Korea



- Na Flux process, 800°C
- 1.6cm, 400hrs
- Single grain emerges from hole in sapphire mask
- Dislocations: 0 to 1000 cm-2
- XRD: (002) – 27"
  (102) – 26"

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GR1-1 (invited) 14:00 - 14:30

Bulk GaN crystals grown by Acidic Ammonothermal Technology

*Yutaka Mikawa, Hideo Fujisawa, Kazunori Kamada, Makoto Saito, Shinichiro Kawabata, Yuji Kagamitani, and Toshinari Fujimori
Mitsubishi Chemical Corporation, Japan

GaN Substrates

Super Critical Acidic Ammonothermal Technology (SCAT)

- 150 – 300 Mpa
- 500 – 650C
- 30-600 um/day
- (Sapphire, 20,000kg / 50 days)

Very nice 16x36x5mm GaN crystal

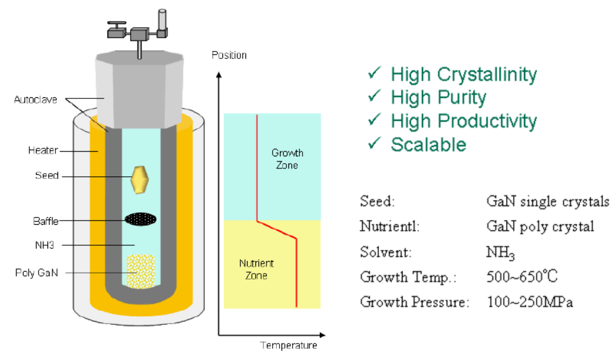


Fig. 1 Schematic diagram of SCAAT™ and its features

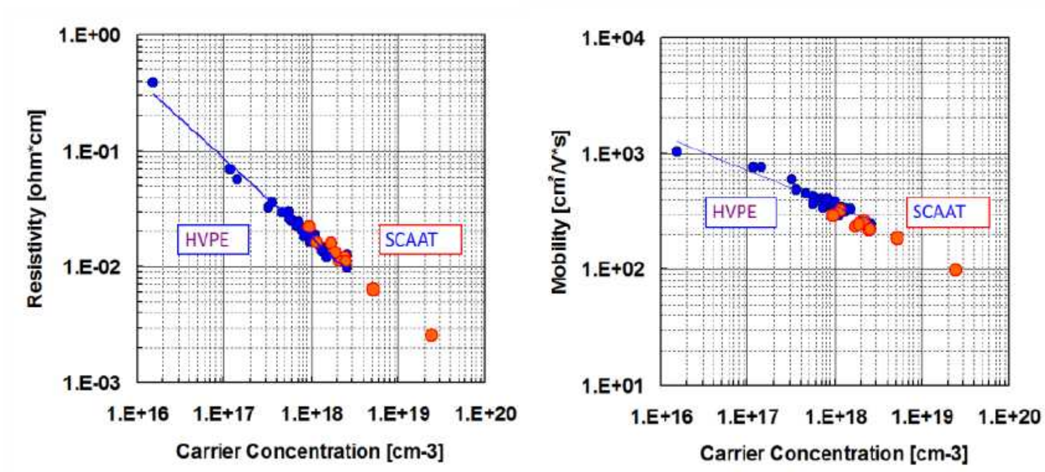


Fig. 2 Electric properties for SCAAT™ and HVPE GaN

Sandia National Laboratories

GaN Substrates - Soraa

GR1-2 14:30 - 14:45
High Quality, Low Cost Ammonothermal Bulk GaN Substrates

Dirk Ehrentraut, Rajeev T. Pakalapati, Derrick S. Kamber, Wenkan Jiang, Douglas S. Pocius, Bradley C. Downey, Melvin B. Mclaurin, and *Mark P D'evelyn
Soraa, Inc., United States of America

For LEDs … all the known reasons

Power Electronics. Now can consider vertical devices

SCoRa – Scalable Compact Rapid Ammonothermal

- **10-30um/hr => 5-100x higher than conventional ammonothermal GaN**
- **Dislocations 1e5 – 1e6 cm-2, XRD 300-200" (not state of the art)**
- **N-type background, yellowish**

GaN Substrates

GR1-3 14:45 - 15:00
Properties of High Transparency GaN substrates obtained by ammonobasic technology

*Robert Dwilinski, Roman Doradzinski, Marcin Zajac, Romuald Stankiewicz, and Robert Kucharski
AMMONO SA, Poland

GR1-4 15:00 - 15:15
Powder synthesis and ammonothermal crystal growth of GaN using Ga metal as a starting material

*Chiaki Yokoyama(*1), Quanxi Bao(*3), Hiromi Sawayama(*1), Takanori Hashimoto(*1), Fukuma Sato(*1), Kouji Hazu(*1), Yuji Kagamitani(*2), Takayuki Ishinabe(*2), Makoto Saito(*2), Rinzo Kayano(*3), Daisuke Tomida(*1), Kun Qiao(*1), Shigefusa f Chichibu(*1), and Tohru Ishiguro(*1)
*(*1)Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Japan, (*2)Mitsubishi Chemical Corp., Japan, and (*3)Muroran Research Laboratory, The Japan Steel Works, Ltd., Japan*

GR1-5 15:15 - 15:30
The coalescence growth of high-quality GaN crystals using the Na flux method

*Masayuki Imanishi, Kosuke Murakami, Hiroki Imabayashi, Hideo Takazawa, Yuma Todoroki, Daisuke Matsuo, Mihoko Maruyama, Mamoru Imade, Masashi Yoshimura, and Yusuke Mori
Department of Electrical, Electronic and Information Engineering, Osaka University, Japan

Many other presentations on GaN substrates.

PR3-3 9:45 - 10:00

A density functional theory study of the "pipe" diffusion of Si, Mg, Ga, N and vacancies in dislocation cores in GaN

*Matthew K Horton(*1), Gabor Csányi(*2), and Michelle A Moram(*1)

*(*1)Department of Materials, Imperial College London, United Kingdom and (*2)Department of Engineering, University of Cambridge, United Kingdom*

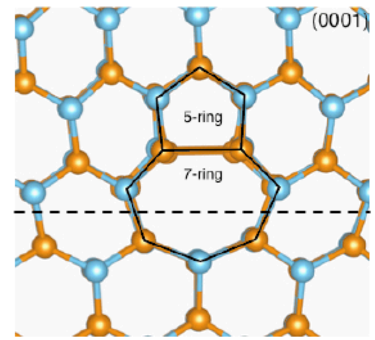
Structural Analysis

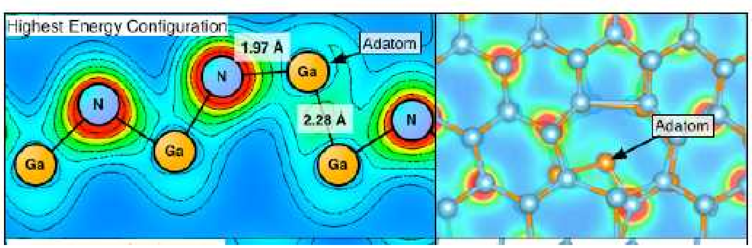
APL 97, 261907 (2010)

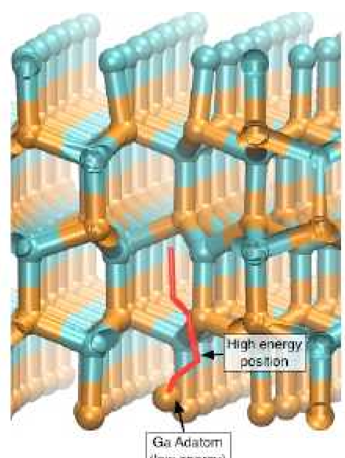
- Calculated activation energies for pipe diffusion Ga, N & vacancies along dislocations

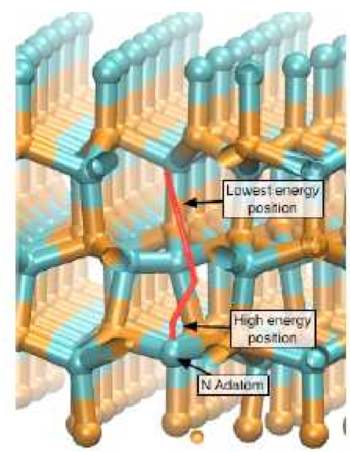
  Mechanism for dislocation climb?

- Open core dislocations (a-type) 4, 8 & 5/7 atom rings
- N diffusion in 5/7 ring, Ea > 1.5eV, complex, not rate limiting
- Ga diffusion in 5/7 ring, Ea > 3.3eV , Ga_v even higher Ea
- Si: Ea > 5.5eV, Mg: Ea > 3.5eV









GR5-5 16:15 - 16:30
InGaN growth on GaN/Sapphire by high pressure MOVPE
*Yoshio Honda, Seiya Sakakura, Tomohiro Doi, Tomoyuki Tanikawa, Masahito Yamaguchi, and Hiroshi Amano
Nagoya Univ. Elec. Eng., Japan

High pressure growth of InGaN

How to grow better InGaN:

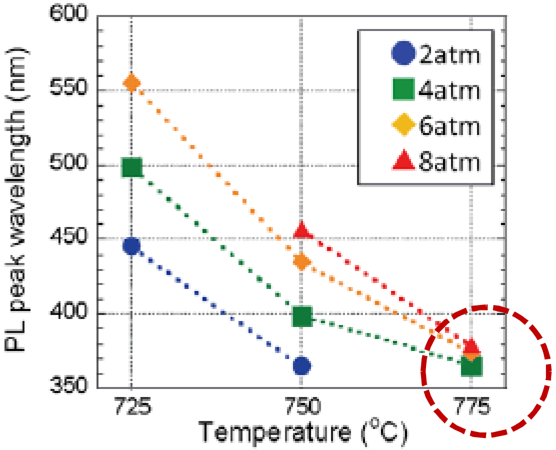
- Tg < 800C ➡ Impurity incorporation is high
- Tg > 800C ➡ In is lost from surface

High pressure is needed to keep In on surface

- Target growth to 10 atms.
- Novel 2-stage system for bubblers

Presented data on Xin vs. pressure in QWs

- QWs have poor XRD, gas change out at high pressure



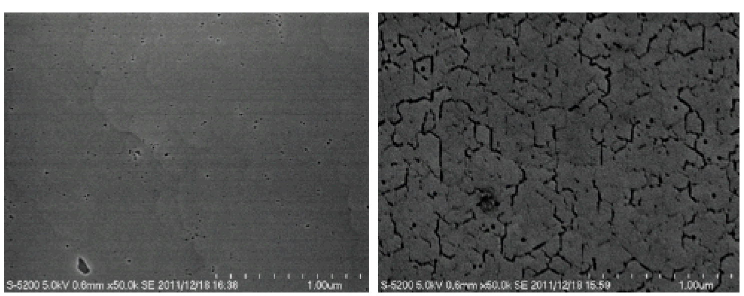
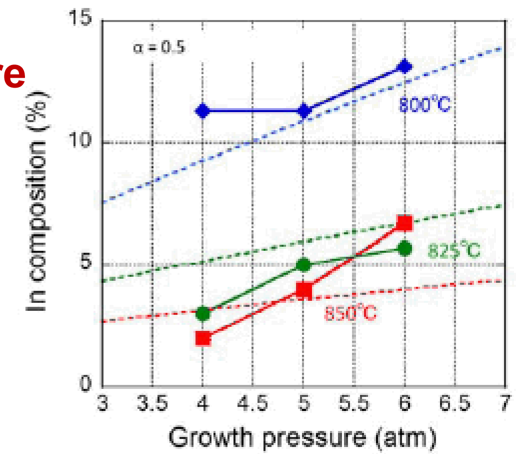


Fig. 2 SEM image of 90nm thick InGaNsurface grown at 850oC, 800oC. The morphology was much improved at 850oC growth.



Xin vs Pressure,
--- thermo-analysis

InGaN Laser Diodes - Nichia

PL-4 (plenary) 10:00 - 11:00
Current status and future prospects of GaN-based LDs

*Shinichi Nagahama
Nichia corporation, Japan

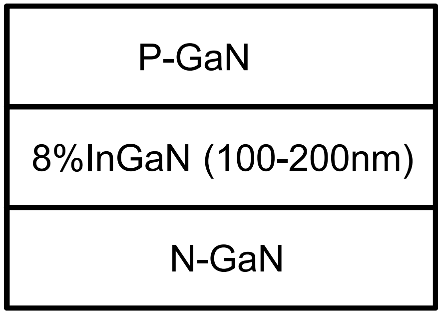
Power Blue and Green LD for micro-projectors

- **c-GaN, cleaved facets**

	525nm	520nm	450nm
Ith (mA)	430	360	230
Jth (kA/cm2)	2.38	2.0	0.64
Po (W)	0.83	0.97	3.75 (2.3A)
Vf (V)	4.81	4.74	4.29
WPE (% @ 1.5A)	11.5	13.6	38.5% (2.3A)

S2-3 (invited) 15:00 - 15:30
Realization of high efficiency nitride-based solar cells
*Motoaki Iwaya(*1), Mikiko Mori(*1), Shinichiro Kondo(*1), Shota Yamamoto(*1), Tatsuro Nakao(*1), Takahiro Fujii(*1), Tetsuya Takeuchi(*1), Satoshi Kamiyama(*1), Isamu Akasaki(*1,*3), and Hiroshi Amano(*2,*3)
*(*1)Faculty of Science and Technology, Meijo University, Japan, (*2)Graduate School of Engineering, Nagoya University, Japan, and (*3)Akasaki Research Center, Nagoya University, Japan*

Solar – Iwaya, Amano



InGaN cell on free standing GaN

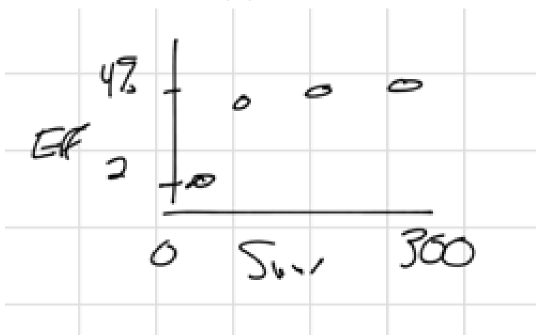
- **Argued that InGaN can be produced economically**
- **Working toward multi-junction InGaN**

1. **Improved InGaN with GaN substrate**

Too much strain
=> pits, misfit dislocations

2. **Use InGaN SL rather than single layer**

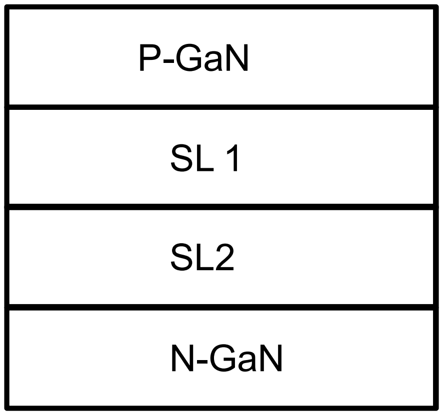
@ 300suns: Efficiency – 4%
FF- 79%
Voc – 2.2V



Use InGaN/InGaN SL

SL1: (3nm 6%, 3nm 17%)

SL 2: (3nm GaN, 3nm 17%)



Sandia National Laboratories

S1-2 (invited) 12:00 - 12:30

A Novel Insulated GaN Gate-Driver with Wireless Power Transfer Technology

*Daisuke Ueda(*1), Nobuyuki Otsuka(*1), Shuichi Nagai(*1), Noboru Negoro(*2), Takeshi Fukuda(*1), Hiroyuki Sakai(*1), Tatsuo Morita(*2), Tetsuzo Ueda(*2), and Tsuyoshi Tanaka(*2)
*(*1)Advanced Technology Research Laboratories, Panasonic, Japan and (*2)Industrial Devices Company, Panasonic, Japan*

HEMTS - Panasonic

2. Power switching required DC isloatio
   - Use RF coupling circuit
     "Drive by microwave"
   - DC isolation to 10kV
   - Monolithic DC-DC, inverters…etc.

Review previous work
- 10kV HEMTs
- Gate Injected Transistor (p-AlGaN gate)

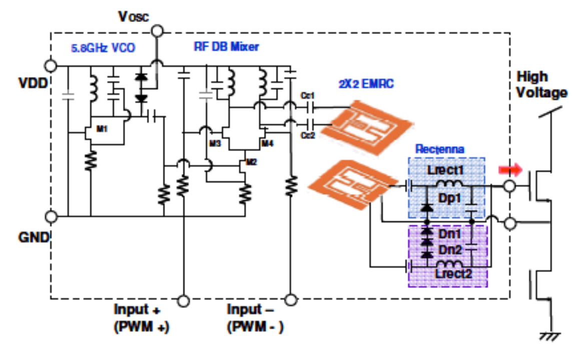
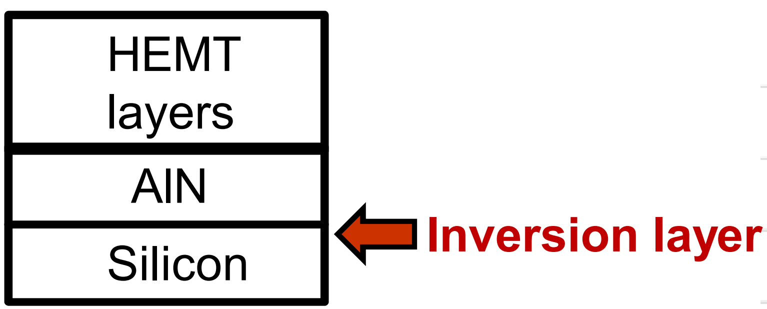
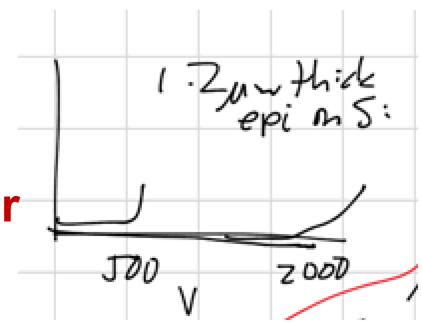


Fig.2 Drive-by-Microwave Circuit with "butterfly coupler"

New work
1. AlN on Si (not in abstract)
   - Build HEMT structures on thick AlN/Si
   - Thinner epi with 2kV breakdown





HEMTS - Toyota

ED1-1 (invited) 9:00 - 9:30
GaN Power Devices for Future Automotive Systems
Masakazu Kanechika
Toyota Central R&D Labs., Inc.

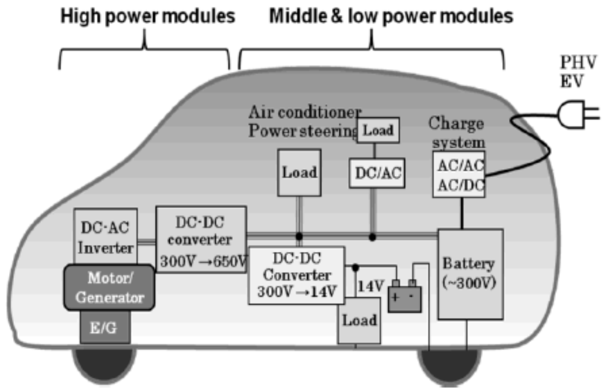


Fig. 1 Power modules in the HV/PHV

Current hybrids – 2 cooling systems (engine - 100C, Si electronics – 65C)

GaN devices will replace Si (IGBT, MOSFET)

GaN (vertical) - High power modules > 50kW
- GaN substrates

GaN on Si (lateral) – Low, mid-power modules

Challenges for GaN electronics

- **Current collapse**
- **Avalanche capacity**
- **Insulated gate lifetime**

Si devices survive avalanche event, GaN doesn't

Sandia National Laboratories

HEMTS

S3-1 (invited) 16:00 - 16:30
GaN-on-Si: soon on the fast lane

*Alois Jakob Krost
Otto-von-Guericke University Magdeburg, Germany

Similar to ICMOVPE-16 talk

ED4-1 (invited) 9:00 - 9:30
GaN-on-Si: Recent progress for high performance power devices

*Marianne Germain, Stefan Degroote, Bram Sijmus, Domenica Visalli, and Joff Derluyn
EpiGaN nv, Belgium

***In-situ* SiNx passivation critical**

ED1-4 10:00 - 10:15
Design and Simulation of Novel Enhancement Mode 5-20kV GaN Vertical Superjunction HEMTs for Smart Grid Applications

*Zhongda Li and T. Paul Chow
Rensselaer Polytechnic Institute, United States of America

Design and simulation of vertical GaN transistor

Talks by Transform

PL-3 (plenary) 9:00 - 10:00
High Efficiency GaN Power Devices: The Technology & Business Opportunities

*Yifeng Wu
Transphorm Inc., United States of America

ED1-2 9:30 - 9:45
First demonstration of high performance 1kV AlGaN/GaN HEMTs on Si and their use in the drive of both an induction motor and a permanent magnet motor

*Srabanti Chowdhury, Don Kebort, Jesus Magadia, Dietrich Graumann, Nick Fichtenbaum, Jim Honea, Yifeng Wu, Primit Parikh, and Umesh Mishra
Transphorm Inc., California, United States of America