Applications, Technology Optimization and Manufacturing of 8-inch GaN-on-Si technology

Dr. Denis Marcon

Innoscience

APEC'22 Industry Session IS07

Integration in WBG Semiconductors: Increased Power Density and Advanced Functionalities at Application Level

March 23, 2022

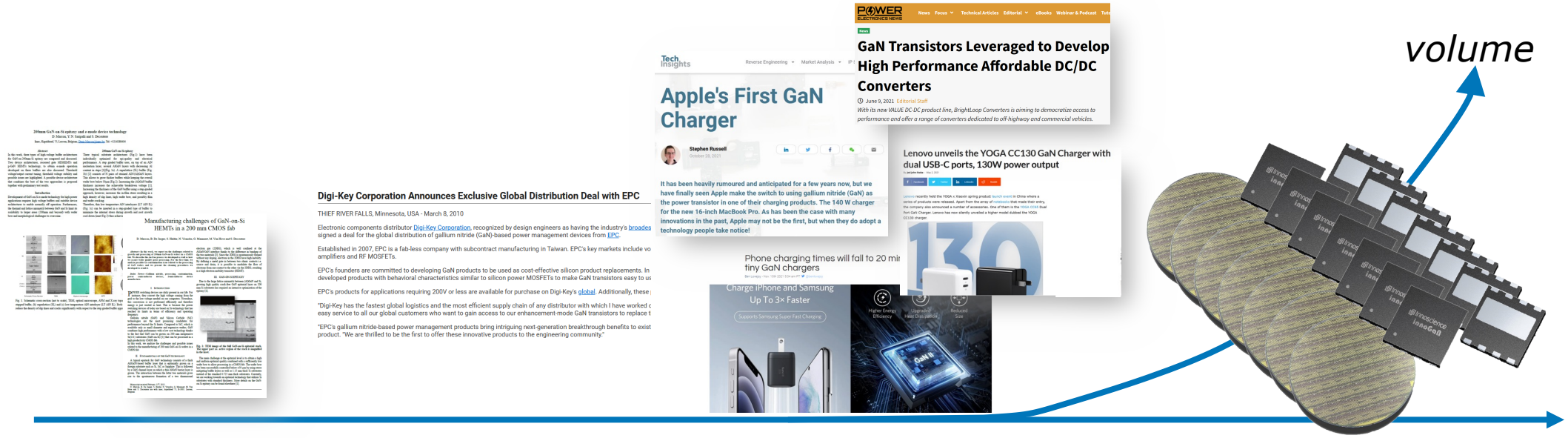
What I will show you today

- GaN is (being) accepted as technology for next generation power applications. We are entering a phase where there is a big demand of:
  - Capacity
  - Security of Supply
  - Price reduction
- Innoscience is addressing these needs by using:
  - Large high-throughput Si manufacturing facilities (for GaN)
  - 8-inch wafer size (= 1.8x 6-inch wafer)
  - Technology optimized for mass manufacturing

- Reliability is key for GaN and Innoscience is performing standard and advanced reliability characterization
  - Switching Acceleration Lifetime Test

- Applications for GaN: PD chargers, data-centers and LIDAR

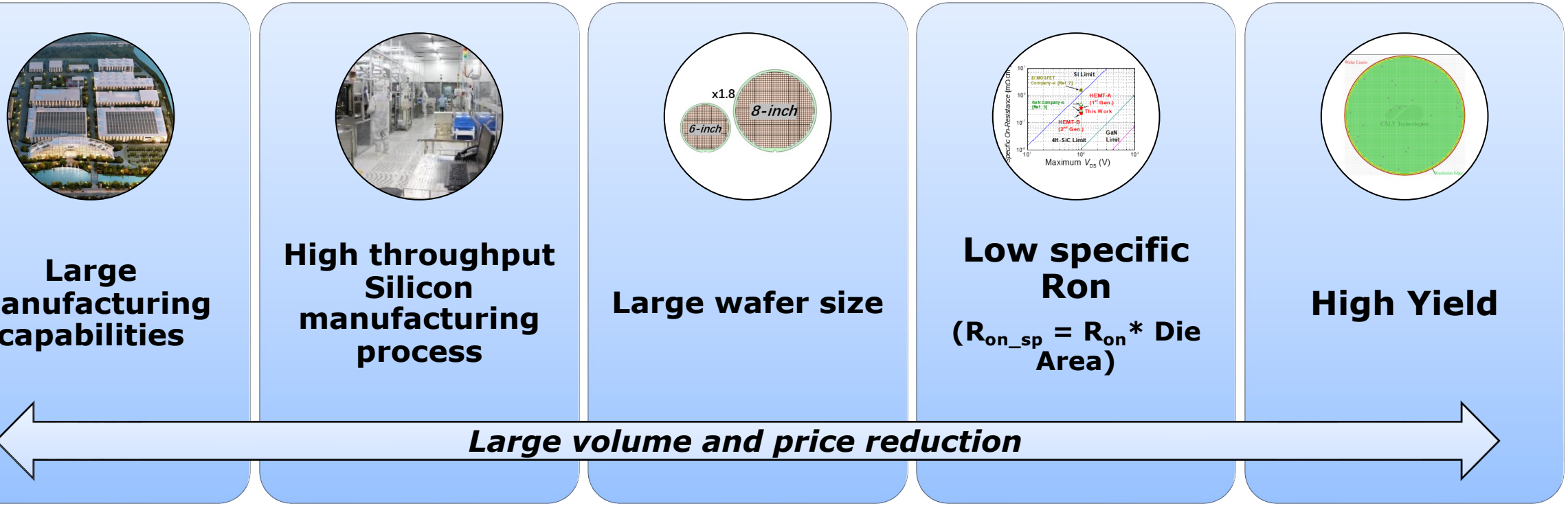
GaN evolution over the years



	…2010	2010-2015	2015-2021	2022…
Phase	**Phase 1 R&D**	**Phase 2 Industrialization for epi and device production**	**Phase 3 System dev't and commercialization of products based on GaN**	**Phase 4 (Today) Price reduction, security of supply and mass manufacturing**
Needs	• Prove the GaN technology	• Make devices available in the market	• Prove improved (system) performance with GaN technology • Sell products with GaN technology inside	• Dramatic price reduction • Mass manufacturing to provide security of supply, handling big volume and its normal fluctuations

How to mass manufacture GaN and reduce its price?

1. By using manufacturing facilities optimized for high volume as the one used in Silicon technology
2. By increasing the overall number of dies per wafers
3. By increasing the number of good dies per wafer (yield)



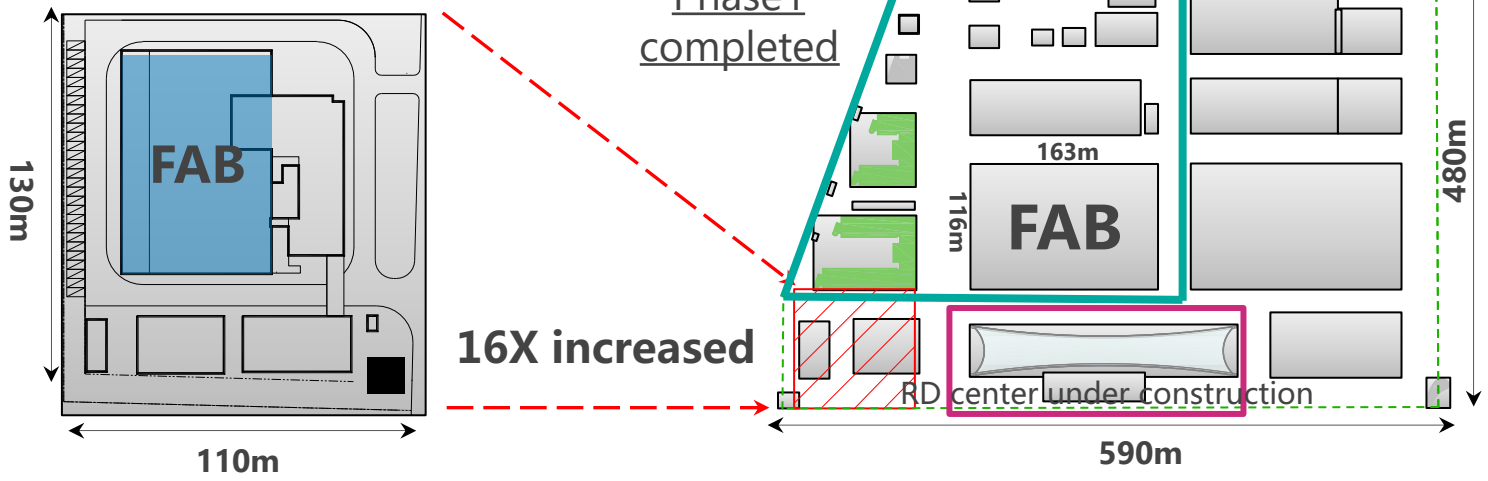
Largest 8-inch fabs dedicated to GaN-on-Si technology

wpm = wafer per month

Zhuhai Wafer Fab

(1.4-Hectare)

Capacity : **4K wpm**



Suzhou Wafer Fab

(24.5-Hectare)

Today : **6K wpm**

Total future Capacity (at Fab completion) : **65K wpm**

Zhuhai wafer fab
R&D and manufacturing

Suzhou wafer fab
Manufacturing

Suzhou wafer fab
Today

Process capabilities: 8-inch Silicon manufacturing line

Taking advance of high through-put Silicon wafer manufacturing technology to process GaN wafers

MOCVD
20+ Aixtron G5+C

Lithgraphy (i-line)

Implant

Thin Film & Diffusion

Dry Etch

Test & Monitor

Reliability and FA

AIXTRON

21. NOVEMBER 2018 | PRESS RELEASES

InnoScience powers GaN device development with multiple AIXTRON MOCVD systems

AIX G5+ C high-volume manufacturing platform paves way to high-performing 650V GaN-on-Si devices

Herzogenrath/Germany, November 21, 2018 – AIXTRON SE (FSE: AIXA), a worldwide leading provider of deposition equipment to the semiconductor industry, will deliver multiple AIX G5+ C MOCVD systems to InnoScience Technology Co., Ltd. (China) for the development of GaN (gallium nitride) power devices which are more and more favored over Si (silicon) power devices in various applications due to their superior performance at high frequency. All AIXTRON cluster tools will feature a 5x200 mm configuration and will be shipped until Q2/2019.

GaN power devices have very low conduction loss, switching loss and off state loss compared to the traditional Si-based power chips due to a higher breakdown strength, faster switching speed, higher thermal conductivity and lower on-resistance. GaN power devices are being used already today for applications such as efficient power supplies for PC and servers or LiDAR (Light Detection And Ranging) and wireless power transfer requiring high-speed switching higher than 1 MHz. In addition, they also

https://www.aixtron.com/en/investors/InnoScience%20powers%20GaN%20device%20development%20with%20multiple%20AIXTRON%20MOCVD%20systems_n1083

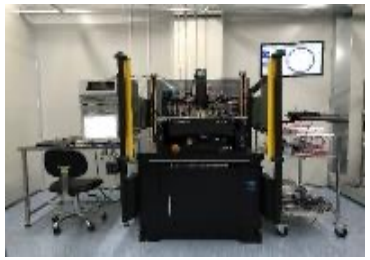
Innoscience and ASML signed collaboration agreement

作者：爱集微 1.7w

来源：Innoscience #Innoscience# 01-21 18:35

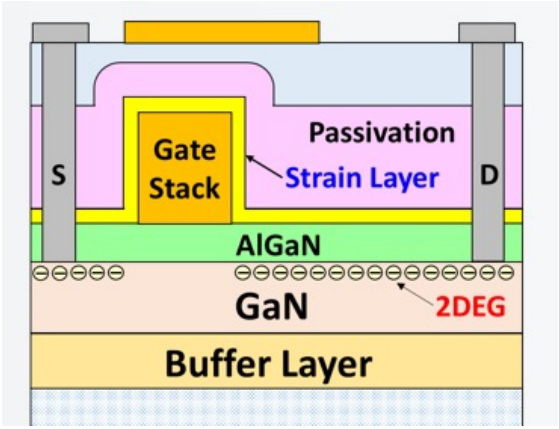
January 21, 2021 – InnoScience and ASML reached a volume purchase agreement for upgraded versions of high throughput i-line and KrF TWINSCAN scanners for advanced GaN on Silicon power semiconductors

https://laoyaoba.com/n/771010

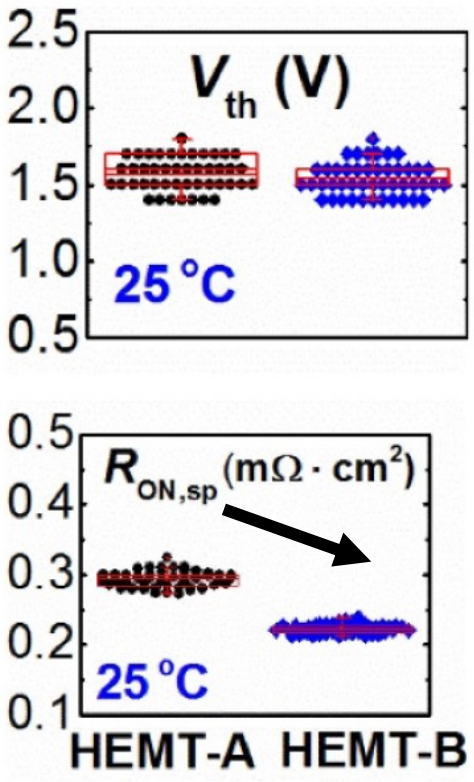


How did we lower the specific Ron?

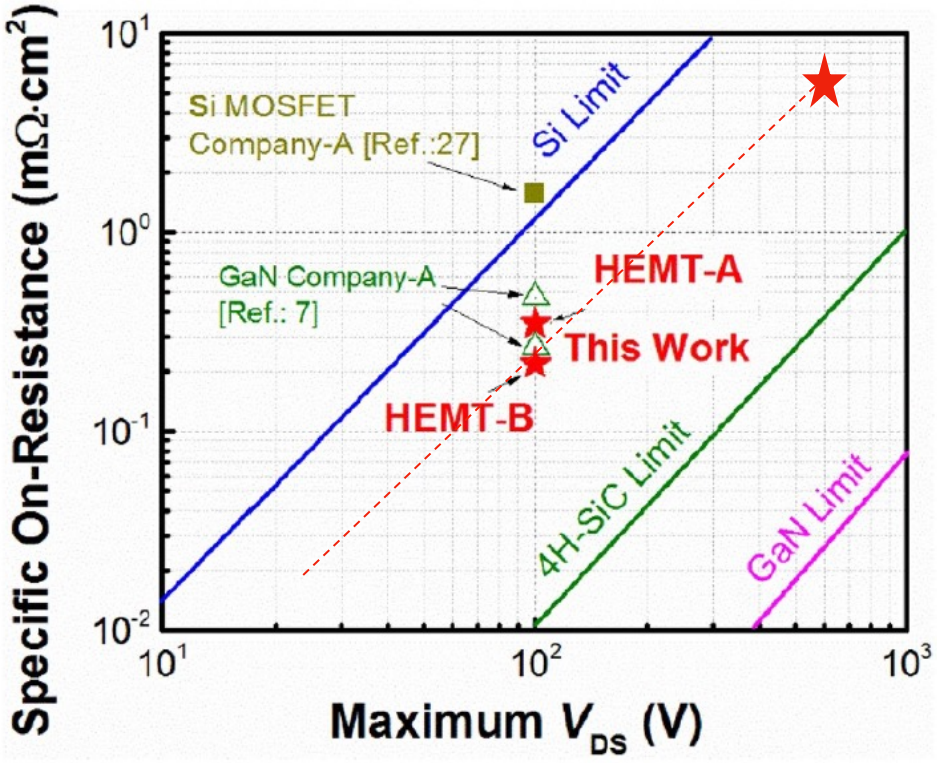
By introducing a stress enhancement layer, we significantly decreased the on-resistance in the access region without affecting other parameters like threshold voltage, leakage etc…



- Gate Formation
- Strain Enhancement Layer Deposition
- Passivation Deposition
- Ohmic Contact Formation
- Inter-layer Dielectric Deposition
- Interconnect Contact Formation
- Metal-1 Formation
- Inter-metal Dielectric Deposition
- Via and Substrate Contact Formation
- Metal-2 Formation
- Passivation Formation



HEMT-B features stress enhancement layer



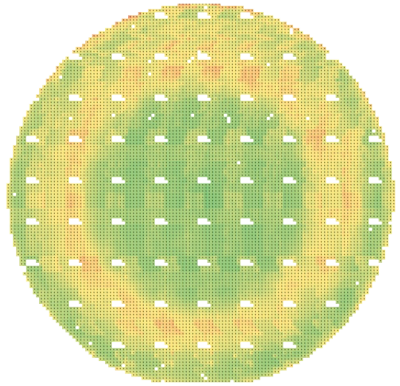
Roy K.-Y. Wong, *et. al.* "High Performance GaN-on-Si Power Devices with Ultralow Specific On-resistance Using Novel Strain Method Fabricated on 200 mm CMOS-Compatible Process Platform" , ISPSD 2019.

Roy K.-Y. Wong, *et. al.* "Comprehensive GaN-on-Si power device platform: epitaxy, device, reliability and Application" , Semicond. Sci. Technol. 36 (2021) 064001, https://doi.org/10.1088/1361-6641/abe551

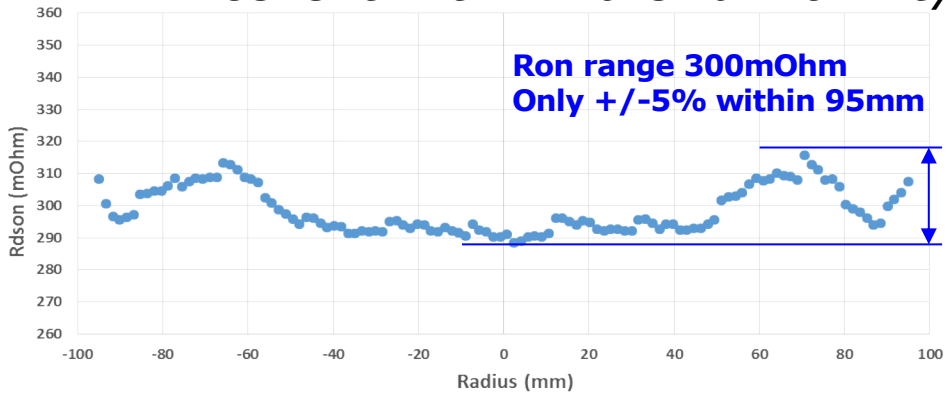
High yield

Both Epitaxy as well as Device processing have been optimized to obtain high reproducibility and yield

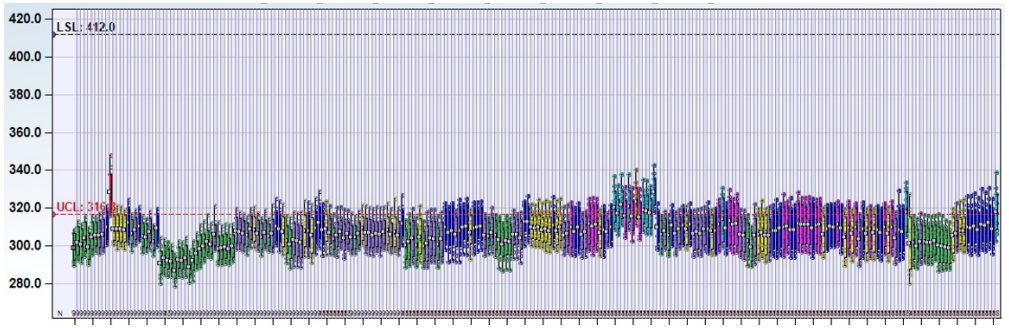
$R_{DS(on)}$



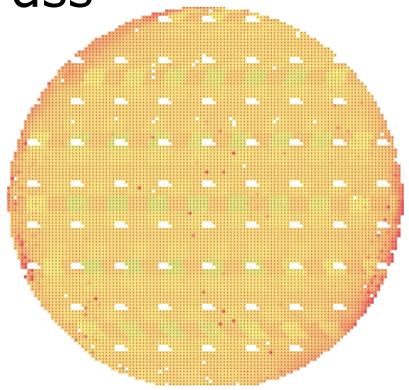
Excellent within wafer uniformity

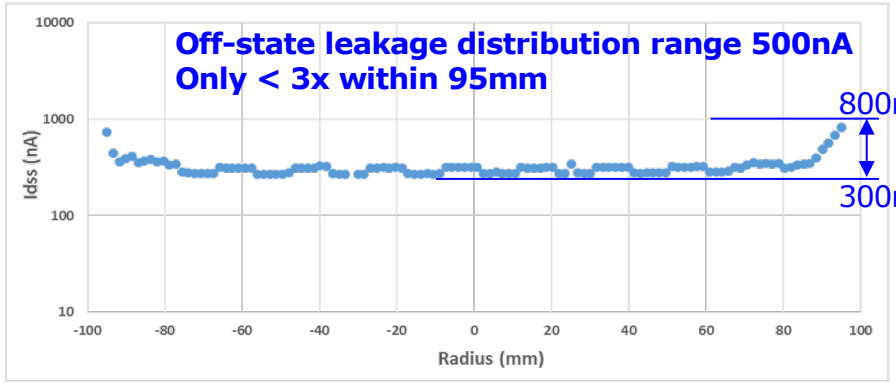


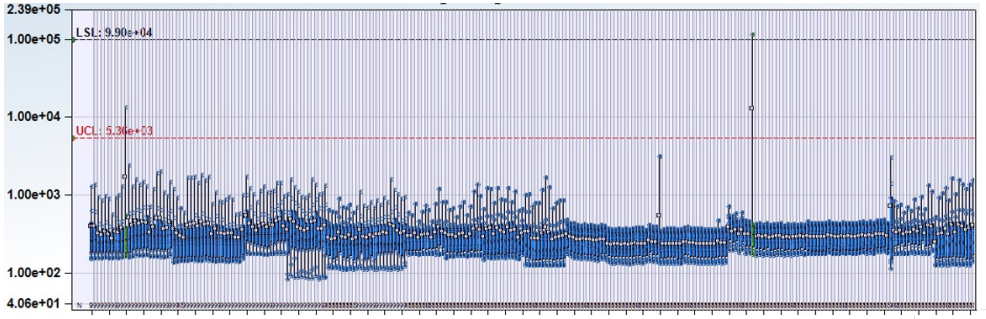
Excellent wafer-to-wafer reproducibility



I_{dss}







Question:

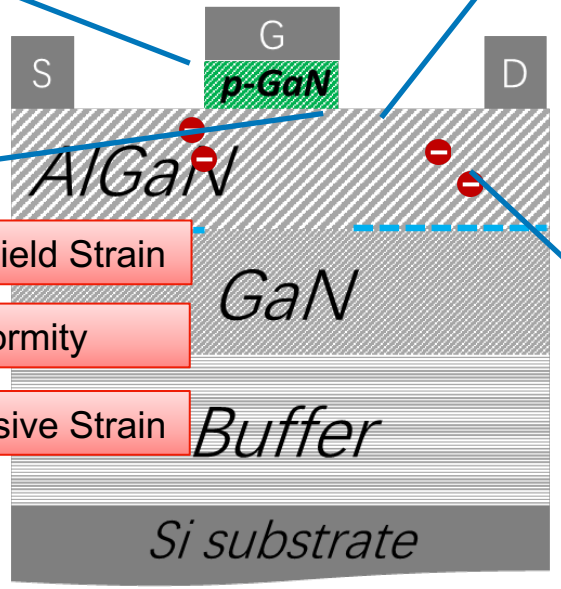
What about the reliability?

Reliability of GaN-on-Si HEMTs

Occur TDDB btw G-S/S-G
HTGB

Occur failure G-D/G-S
ESD tests

Occur TDDB btw D-S
HTRB



Electric Field Strain

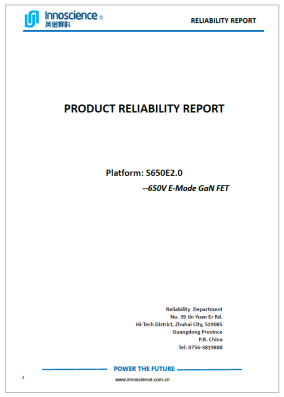
Uniformity

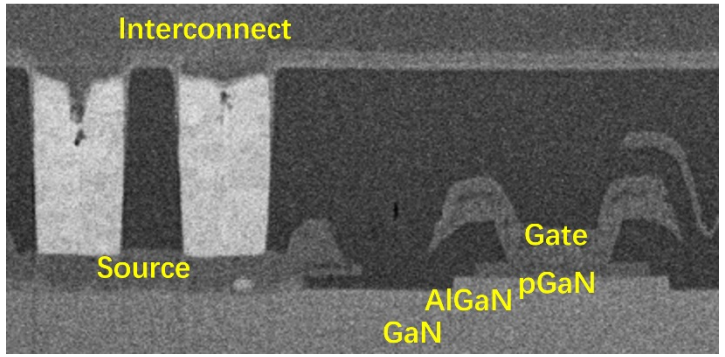
Compressive Strain

Package tests

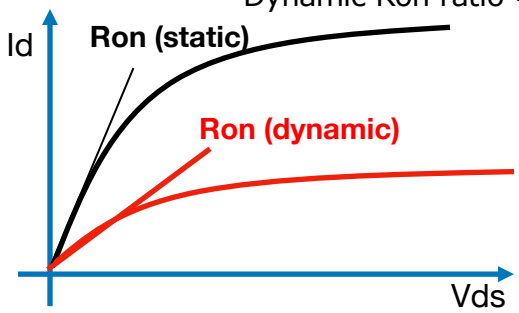
Temperature Cycle
TC

Temp Humidity & bias
THB





Dynamic Ron ratio = (dynamic Ron / static Ron)



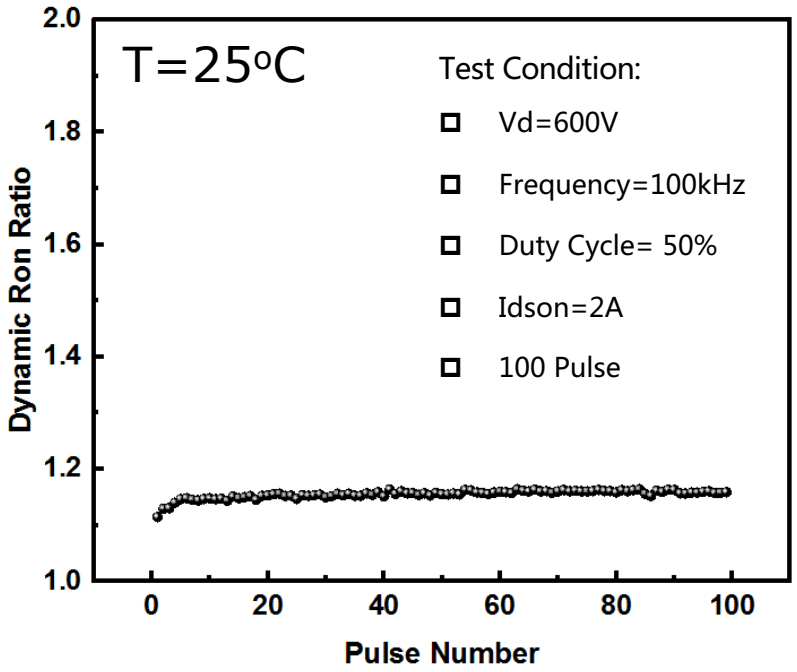
Trapping effects G-D
Dynamic R_{ds_on}

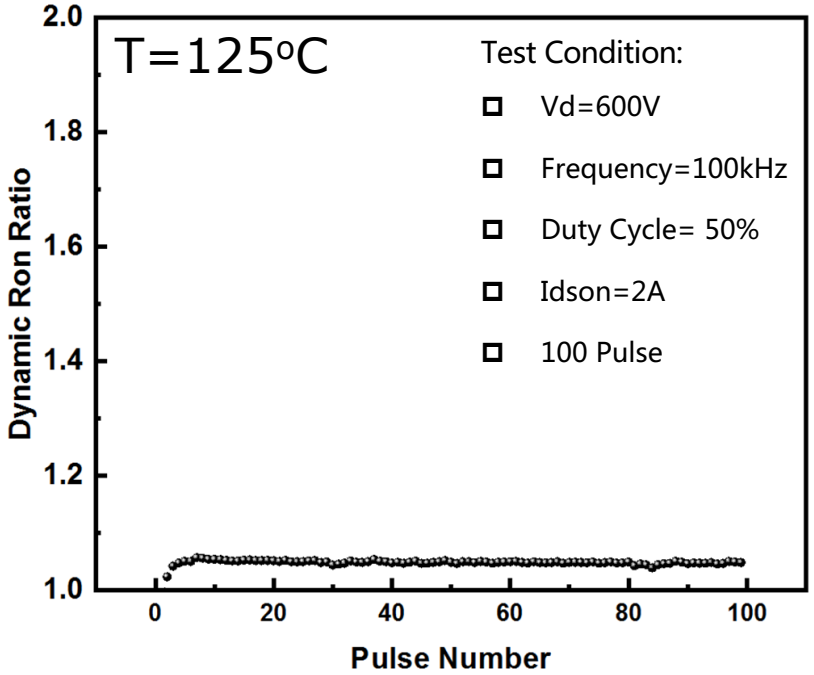
Dynamic High temperature Operation Lifetime
DHTOL

Switching Acceleration Lifetime Test
SALT

Main issue:
High Current & High Drain Voltage in switching

At Innoscience we have optimized both the epitaxy as well as the device technology (processing and design) to systematically obtain low R_{ds_on}

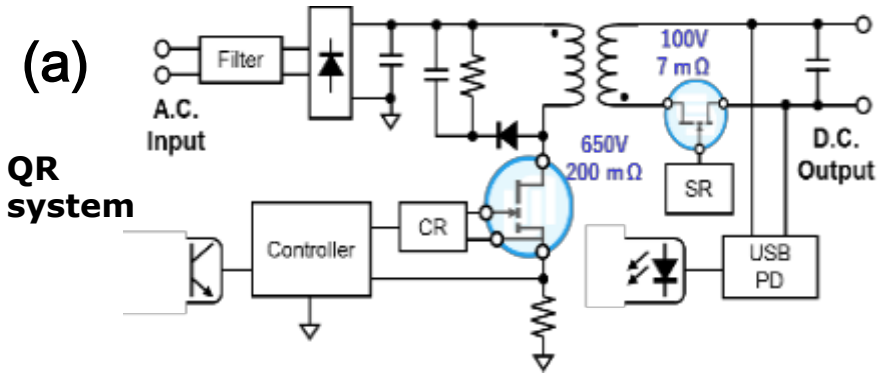


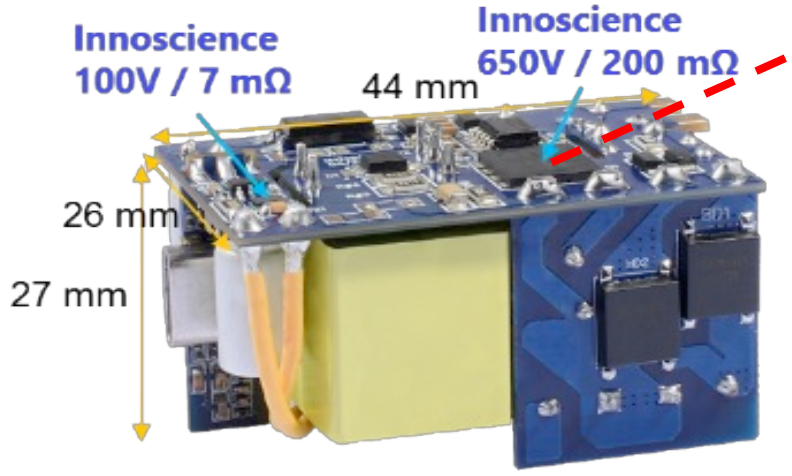


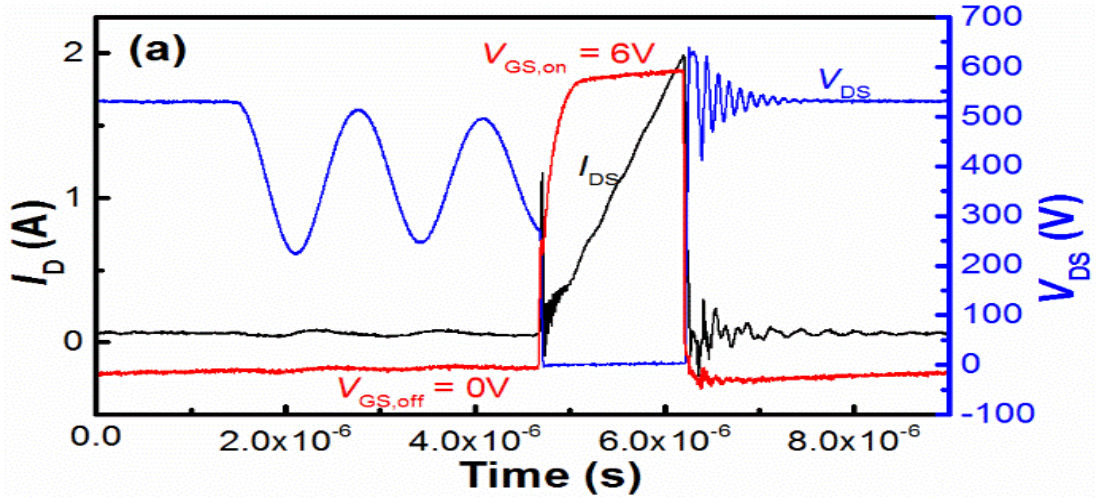
Low dynamic R_{DSON} over the full temperature and voltage range

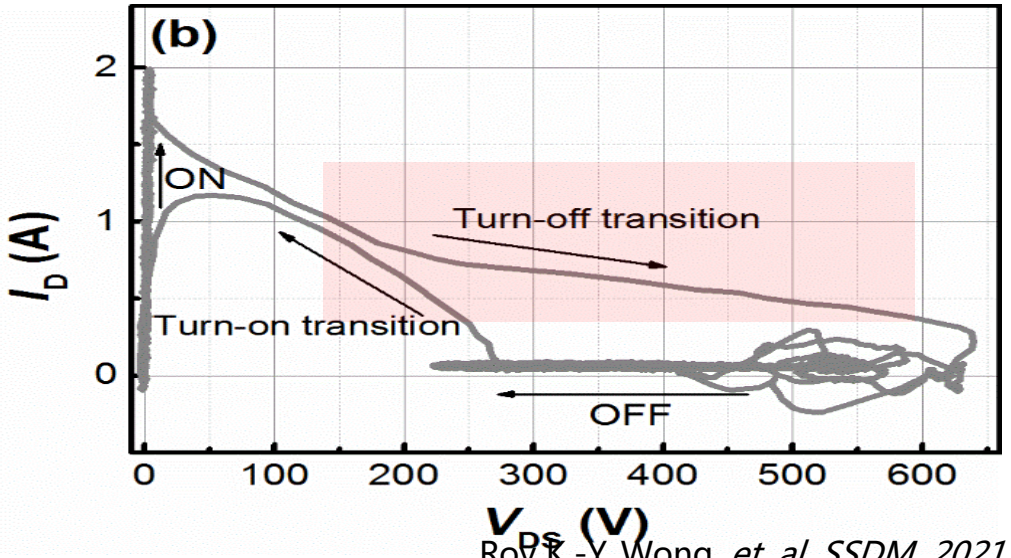
Dynamic Ron ratio = (dynamic Ron / static Ron)

During hard switching, the device transition through regions of high current/voltage!







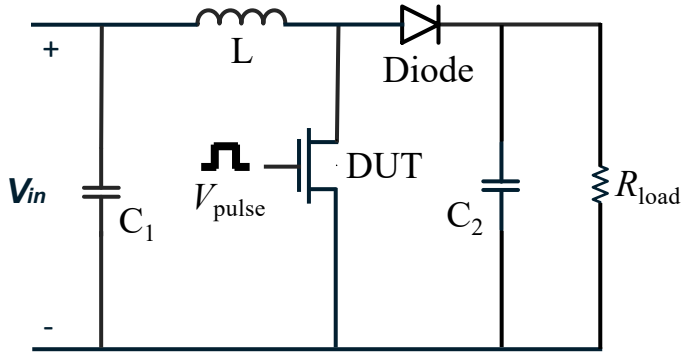


Vin= 264 V, Vout=20 V, Ipeak=2 A, f =102 kHz, and on-duty=19.8 %

Roy K.-Y. Wong, *et. al. SSDM, 2021.*

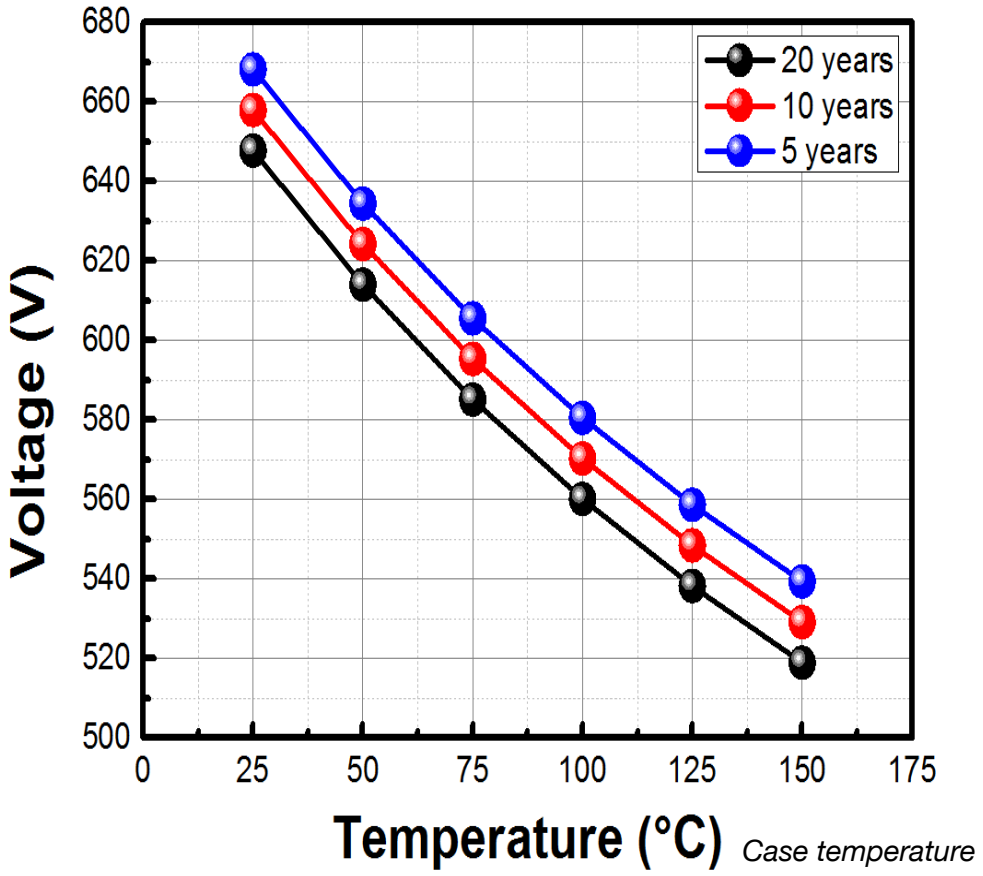
Switching Acceleration Lifetime Test – SALT - (QR Topology)

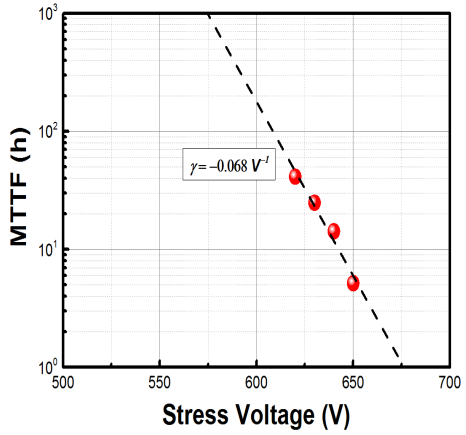
Boost Converter

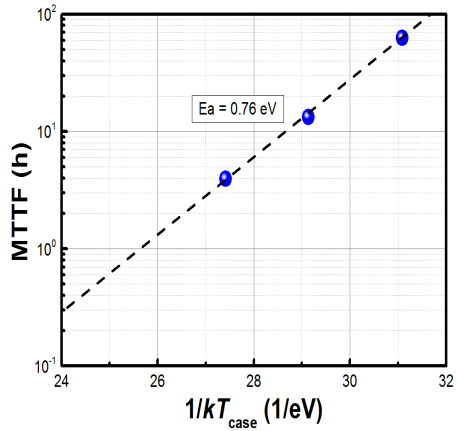


I_{peak} = 1.5 A,
T_{case} = 150 °C (junction temperature is higher)
f = 100 kHz
D = 55 %

- **Fail criterion:** *Dynamic* R_{on} up to ×1.5 times
- **Lifetime model:** *Lifetime (E-model)*= $A \times e^{-\gamma V}$





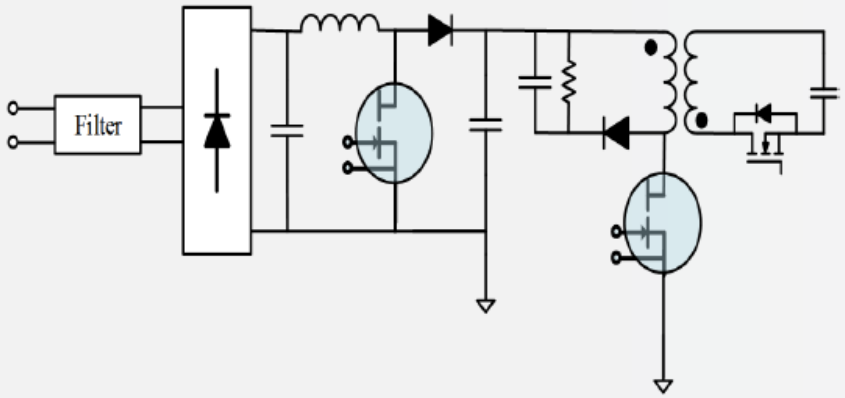


Lifetime (E-model)=20 years at 520 V/150°C

Roy K.-Y. Wong, *et. al. SSDM, 2021.*

System (PFC-QR) Reliability- Dynamic High Temperature operating life test (DHTOL)

PFC-QR system:



Criteria : Efficiency shift lower 0.2%.

Qual. lot	1st Qual. lot		2nd Qual. lot		3rd Qual. lot	
Vin	90V	264V	90V	264V	90V	264V
Efficiency shift after stress1000h	-0.16%	-0.18%	0.07%	0.08%	0.04%	0.02%
	-0.05%	-0.05%	-0.13%	-0.17%	0.04%	0.02%
	0.00%	0.00%	0.09%	0.09%	0.13%	0.08%
	-0.09%	-0.07%	0.03%	-0.04%	0.16%	0.14%
	-0.16%	-0.17%	0.17%	0.01%	-0.09%	-0.13%
	-0.19%	-0.18%	-0.07%	-0.08%	0.19%	0.18%
	-0.18%	-0.16%	0.13%	0.12%	0.03%	0.02%
	-0.14%	-0.18%	0.06%	0.05%	0.12%	0.14%
	-0.13%	-0.16%	-0.03%	-0.11%	-0.03%	-0.05%
	-0.11%	-0.12%	0.16%	0.14%	0.09%	0.06%

Case temperature ~ 90°C

Very stable efficiency after 1000hrs of DHTOL test

Question:

Which applications?

Increase Power Density

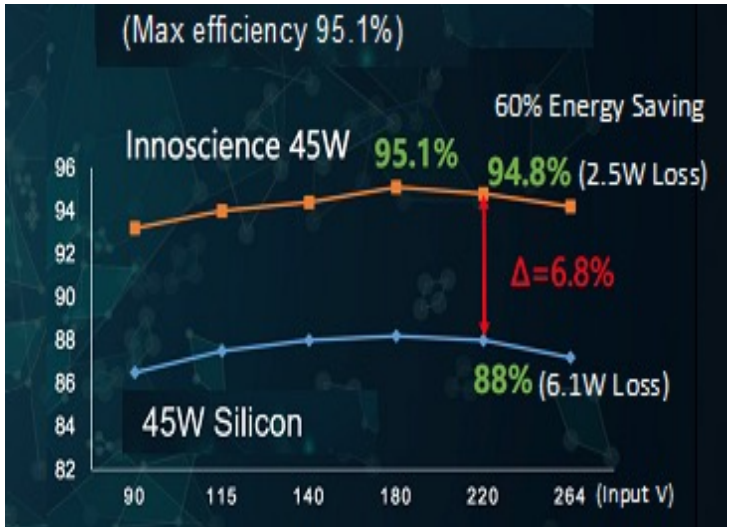
Reduce Size & Increase Power

45W traditional charger

65*65*28.5mm

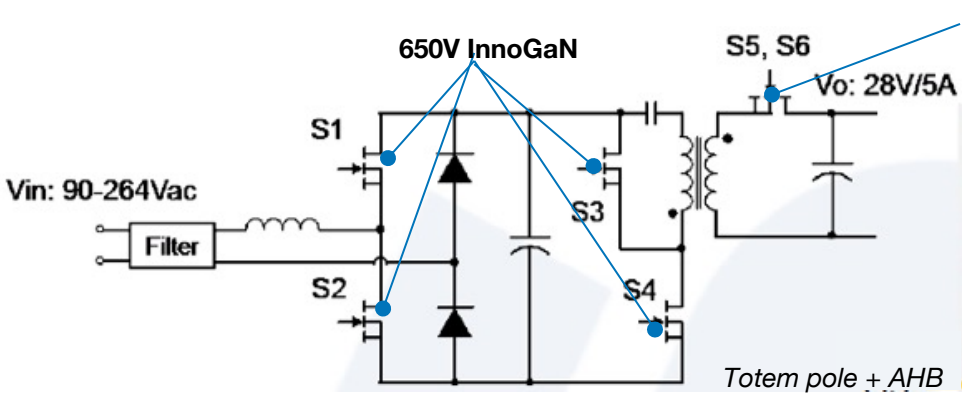
Innoscience 45W

52*43 *24mm

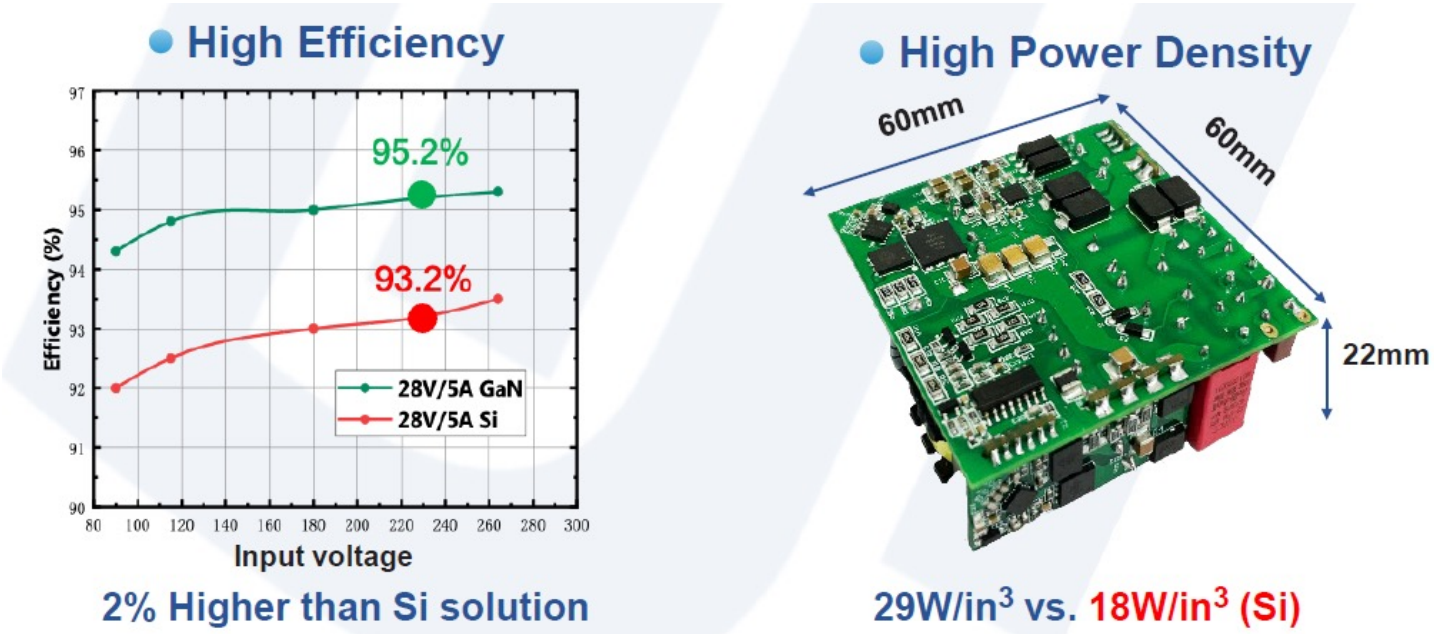


Innoscience Technology inside

HV and LV InnoGaN enables 140W 300kHz AC/DC Adapter with (much) higher power density



- **HV (650V) InnoGaN (S1-S4)**
- **LV (150V) InnoGaN (S5-S6)**

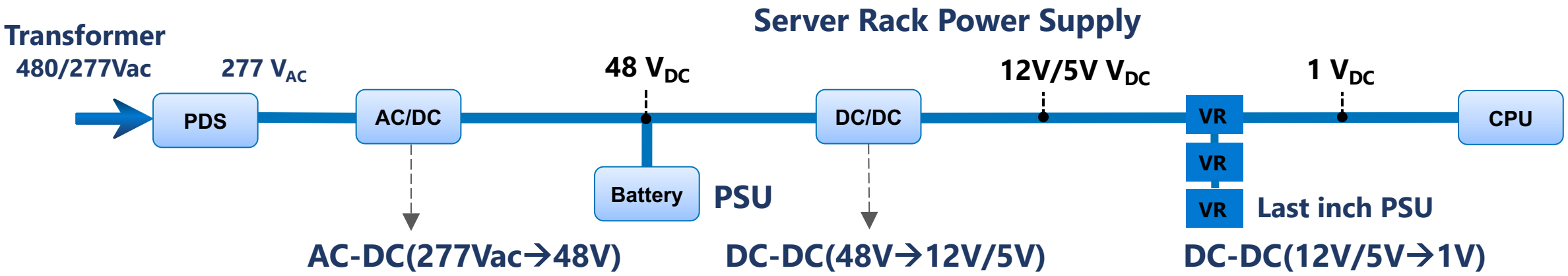


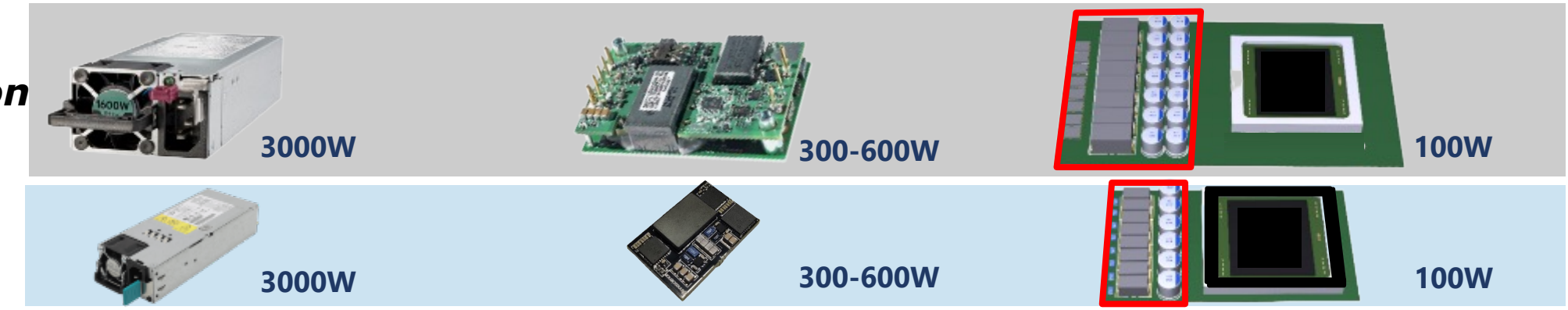
- **140W** power supply demo
- Efficiencies of over 95%(230VAC;5V/28A).
- 60x60x22mm(2.4x2.4x0.9in)
- Class-leading power density of 1.76W/cm^3 (29W/in^3)

Reducing the power dissipation by 30%
Increase power density by 60%

Inside a data centre power supply rack

※ PDS: Power Delivery System, PSU: Power Supply Units, VR: Voltage Regulator





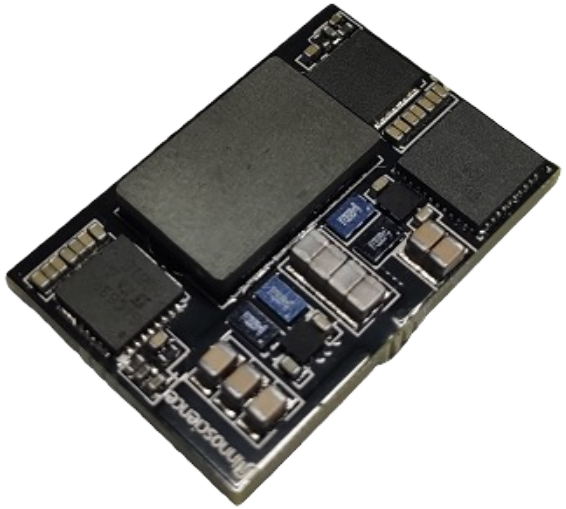
GaN vs Si

AC-DC(277Vac→48V)	DC-DC(48V→12V/5V)	DC-DC(12V/5V→1V)
Efficiency : **2.5%** higher	Efficiency : **2%** higher	Efficiency : **1%** higher
Power saving **63%** (79.3W)	Power saving **58%** (10.5W)	Power saving **15%** (1.1W)
Power Density: **2X** higher	Power Density: **2X** higher	Power Density: **2X** higher
Frequency: **5X** higher	Frequency: **5X** higher	Frequency: **4X** higher
Size : **2X** smaller	Size : **2X** smaller	Size : **2X** smaller

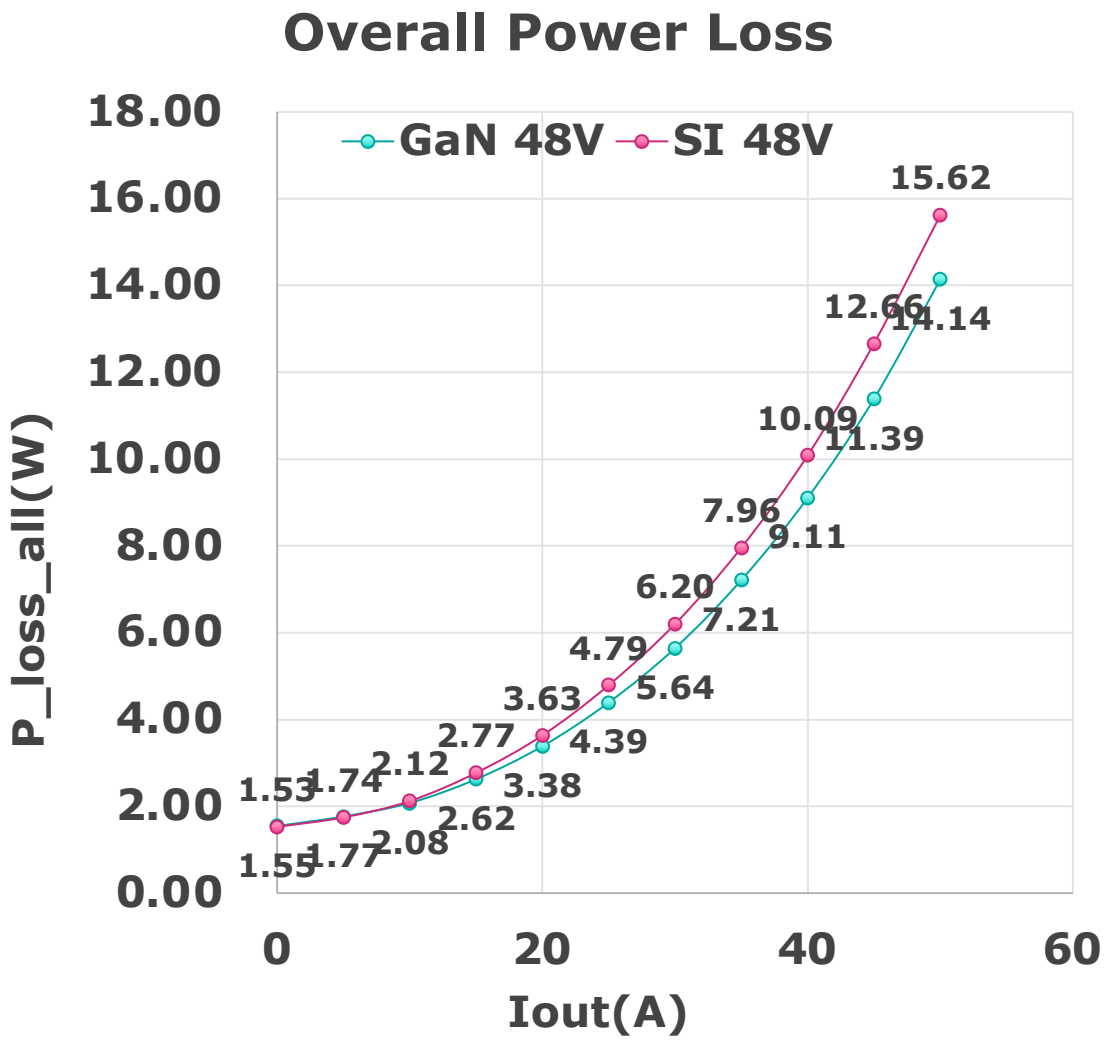
Increase Efficiency → Less energy loss → Cheaper to run (lower energy bill)

Increase Power density → converter closer to the unit (shorter Cupper lines) → cheaper and more efficient

300W DC-DC converter (48V-5V)



Parameter item	Specifications
Input voltage	36-60V
Output voltage	3.6-6V
Output Power	300W
Operating frequency	915kHz
Demo size	27mm*18mm*6mm
Power density	1700W/in^3
Efficiency	97%(peak) 95.5%（full load）



10% reduction in Power Loss

10% reduction in your energy bill

Future perspective

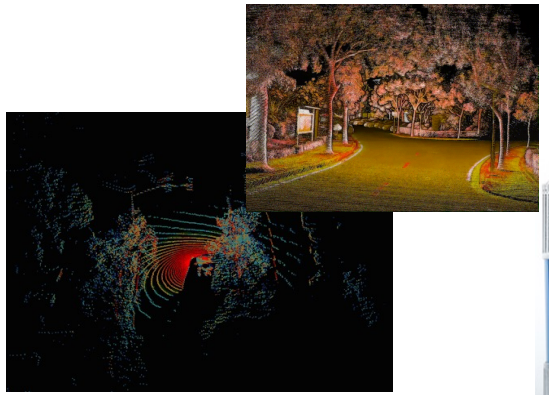
100 TWh saved in 2030

(20 nuclear reactors)

Innoscience's fabs are already certified for automotive parts productions (and design)
Innoscience is already working with an automotive customer to qualify specific devices for automotive

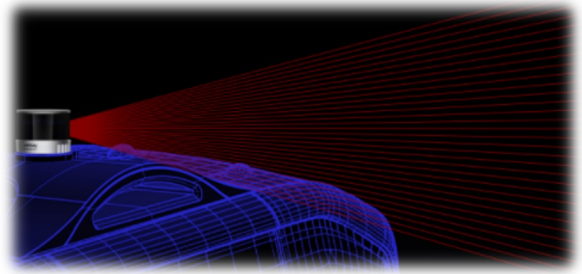
...Innoscience will have automotive qualified devices in 2022/2023

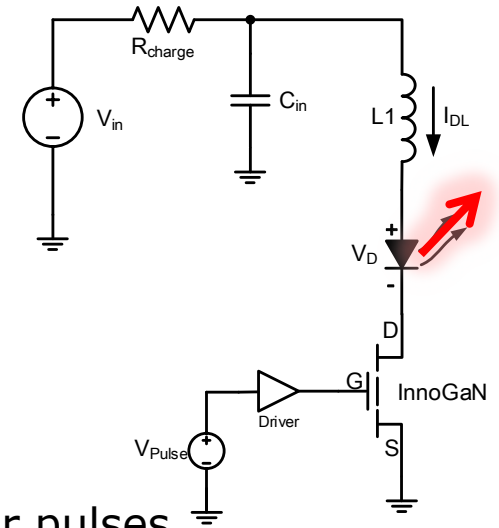
GaN applications: LIDAR (Light Detection and Ranging)



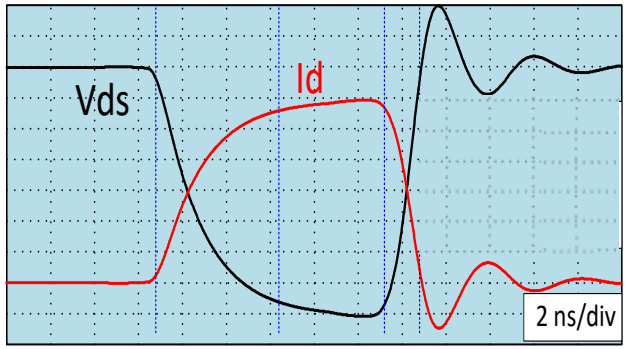
www.hesaitech.com/en

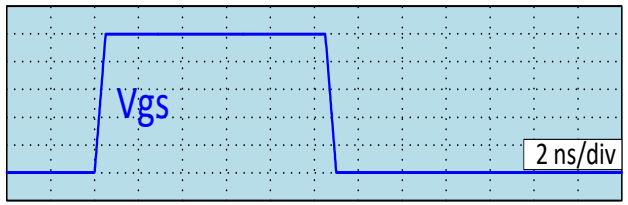
InnoGaN being qualified for Hesai

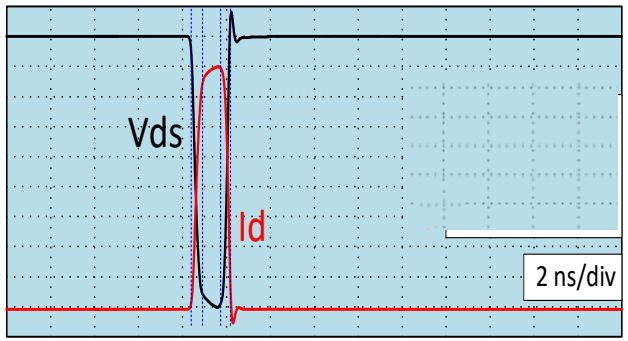


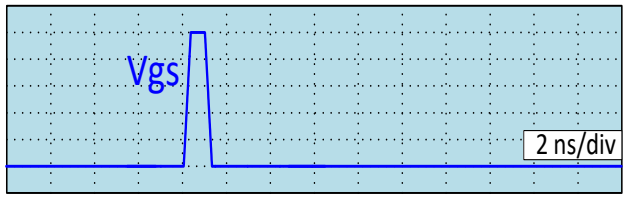


LIDAR sensors are based on laser pulses.
The shorter/faster the pulses, the higher the resolution.





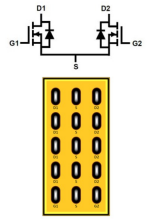




100V Silicon MOSFET
(BSZ146N10LS5)

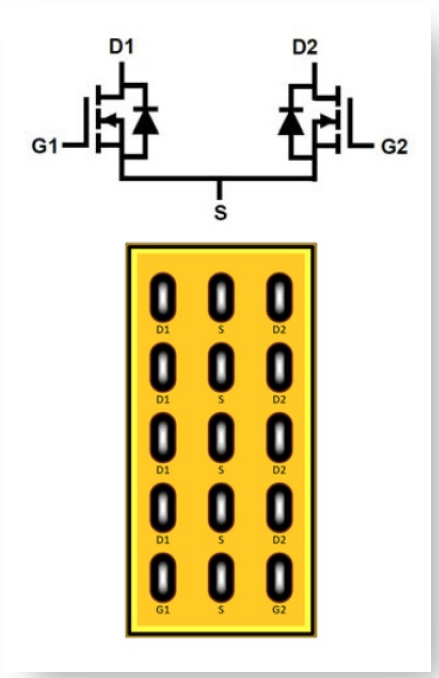
Turn on Speed: 13X faster
Pulse width: 5X Narrower

100V InnoGaN
(INN100W14)

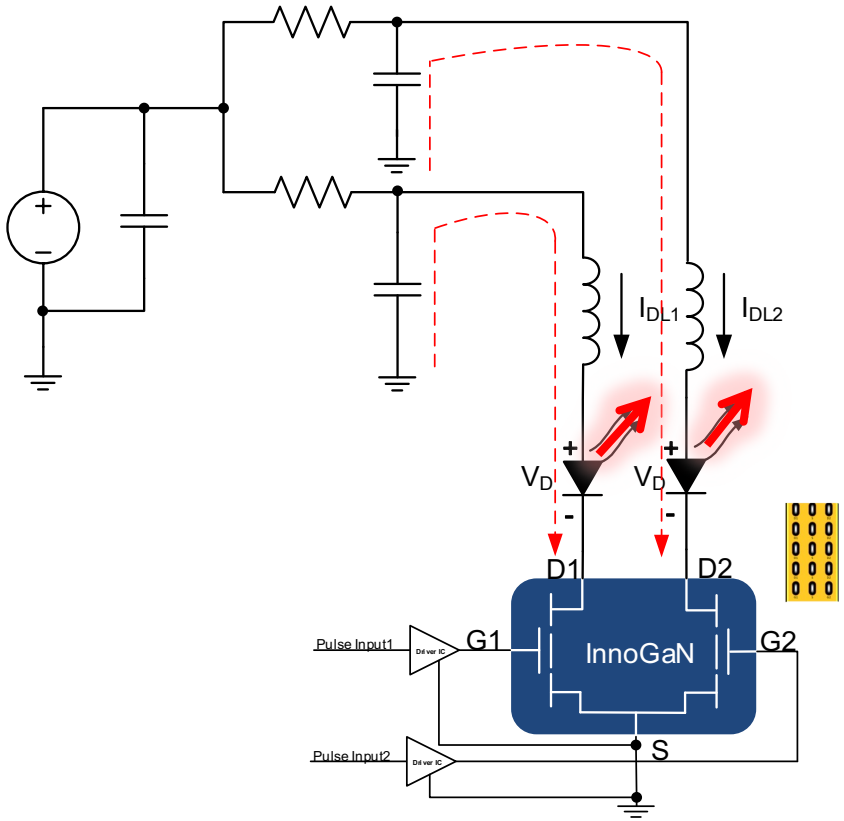


BSZ146N10LS5 ref https://www.infineon.com/dgdl/Infineon-BSZ146N10LS5-DataSheet-v02_03-EN.pdf?fileId=5546d4625696ed760156e6c1a0a327fc

Why a dual/2 channels device for Lidar applications?



100V InnoGaN
(INN100W14)



Dual InnoGaN device

- Two InnoGaN on the same chip
- Common source
- One input voltage
- Drive 2 lasers independently

Benefits:

- **Cheaper and simpler than using 2 separated devices and associated circuits**
- Smaller size

Conclusion

- GaN is (being) accepted as technology for next generation power applications.
  We are entering a phase where there is a big demand of:
  - Capacity
  - Security of Supply
  - Price reduction
- Innoscience is addressing these needs by using:
  - Large high-throughput Si manufacturing facilities (for GaN)
  - 8-inch wafer size (= 1.8x 6-inch wafer)
  - Technology optimized for mass manufacturing

- Reliability is key for GaN and Innoscience is performing standard and advanced reliability characterization
  - Switching Acceleration Lifetime Test

- Applications for GaN: PD chargers, data-centers and LIDAR

Thank you for your interest.

Denis Marcon
Email: denismarcon@innoscience.com
Phone: +32 471 138822

APEC'22 Industry Session IS07

Integration in WBG Semiconductors: Increased Power Density and Advanced Functionalities at Application Level
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Innoscience