Heterogeneous Integration of GaN and Silicon for Power Conversion

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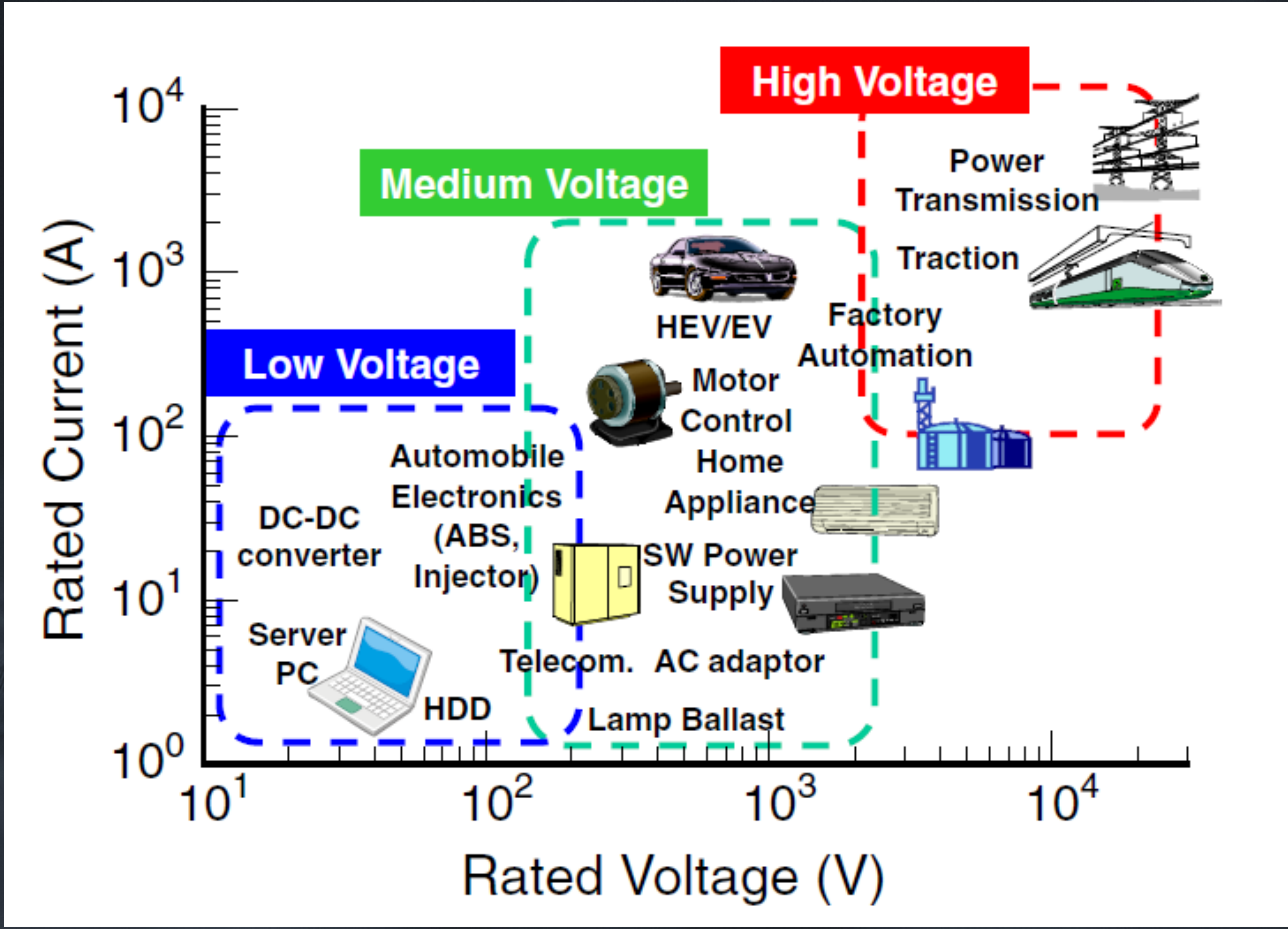
GLOBALFOUNDRIES®

Agenda

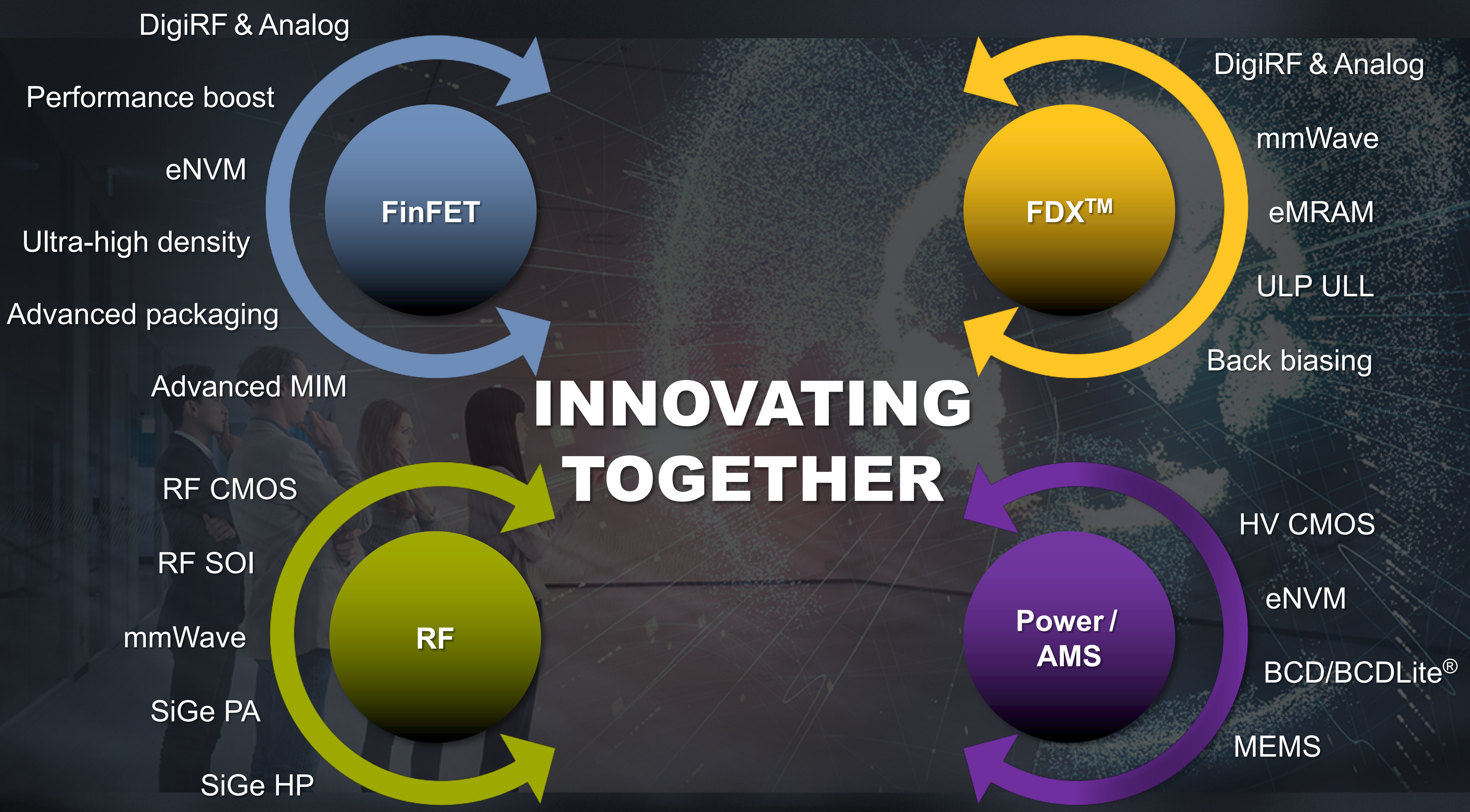
Enabling Power Semiconductors – A Foundry perspective

- Power Semiconductor industries grow exponentially
  - Driven by power conversion in a wide range of electronics and equipments
  - Fundamental requirement of energy efficient and cost effective solutions
  - Foundries provide mainly Si-based power devices in current state
  - Marching towards wide bandgap materials to achieve higher voltage power efficient performance.
  - Much sought after: higher level integration of power devices and high voltage analog switches with high voltage output control circuits on a single chip or package.
- PowerSoC appears to have great potential
  - Innovative ways to achieve reduced area and increased system-level efficiency & performance
  - Co-optimization of design, IC process, inductors, capacitors, packaging
  - Requires multi-disciplinary collaboration (foundry / fabless / OSAT model)



T Kimoto -Japanese Journal of Applied Physics 54, 040103 (2015)

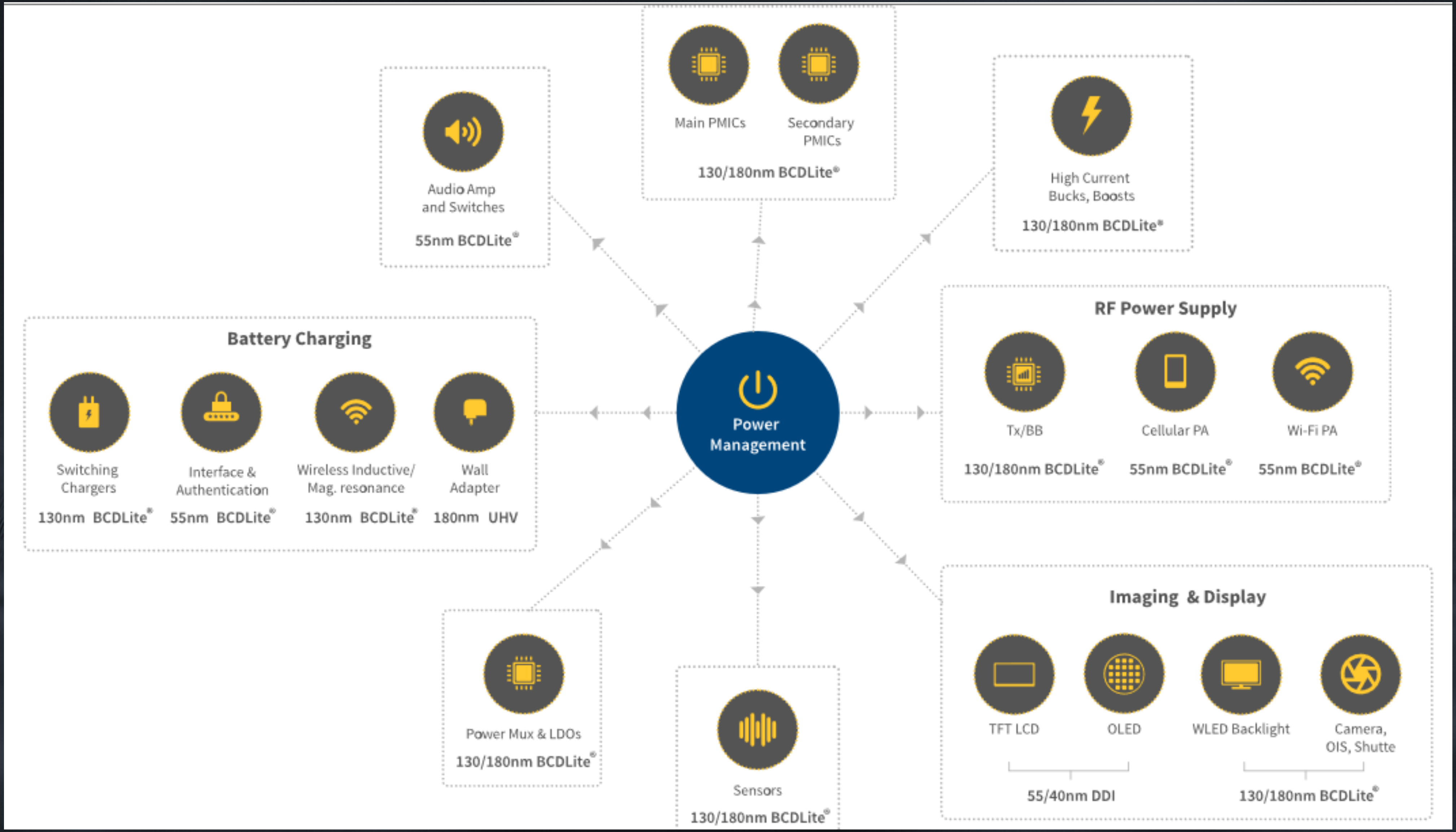
A New Breed of Differentiated Foundry



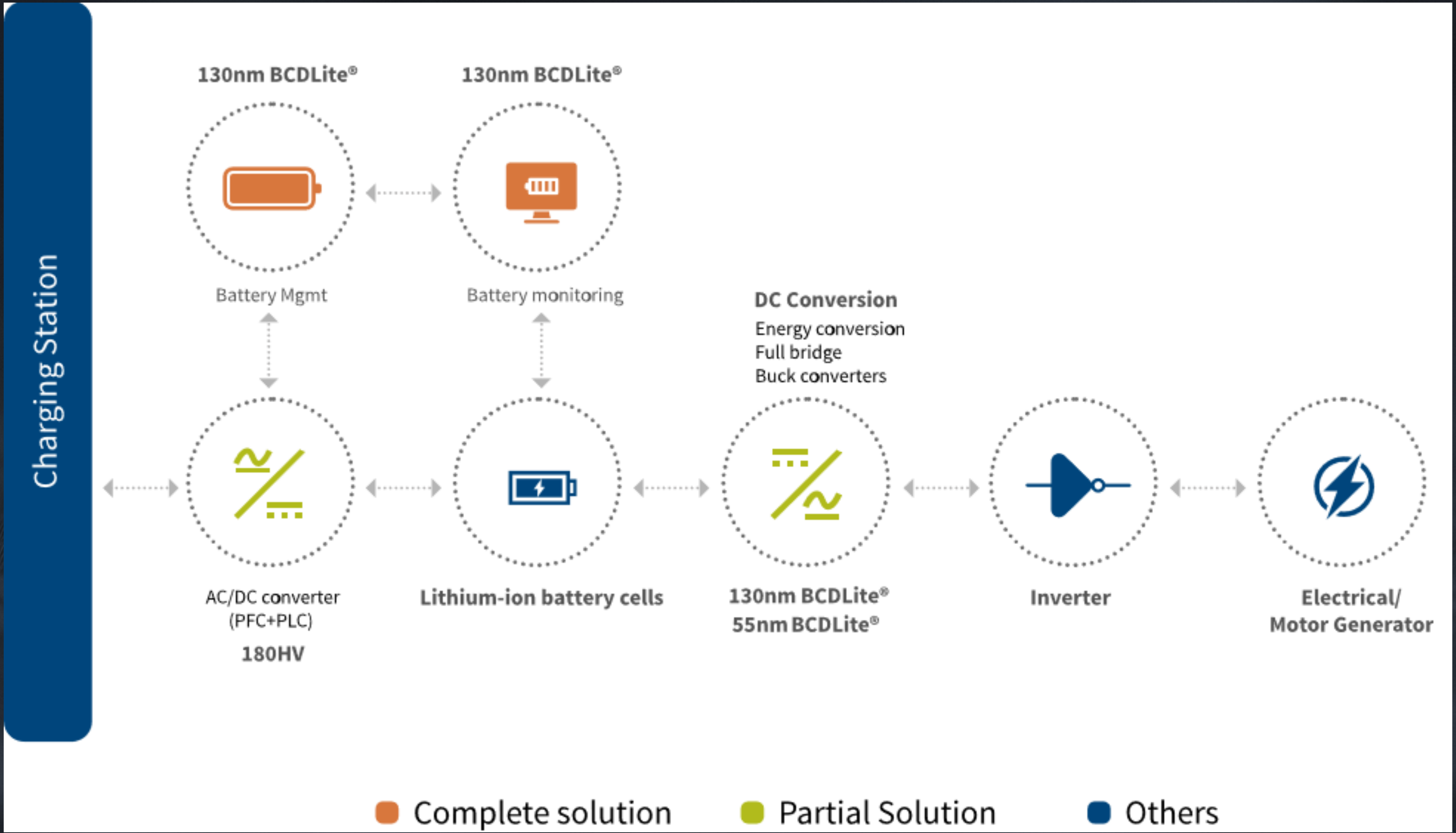
From Mobility, IoT to Automotive, GF has you covered

- Broad portfolio of CMOS Mainstream Technologies for the ideal fit and applications

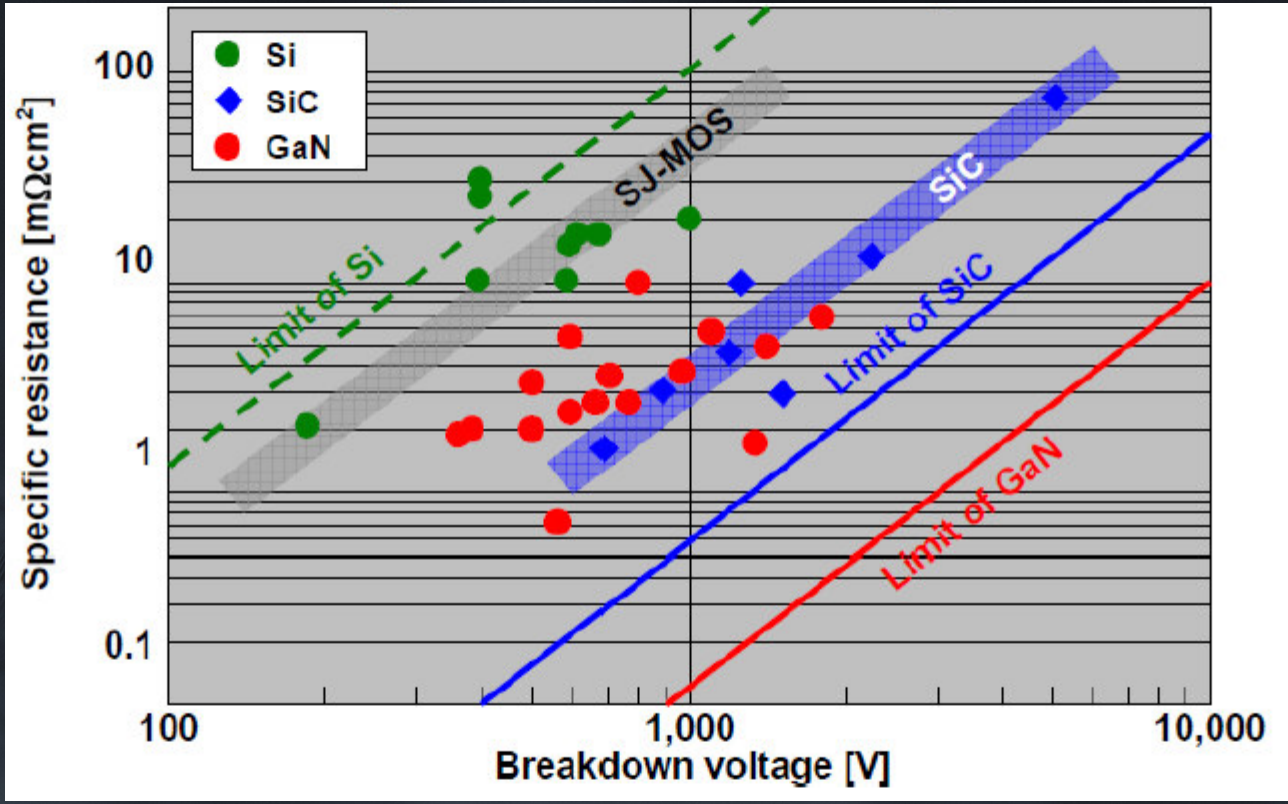
Mobile Power: Different Subsystems

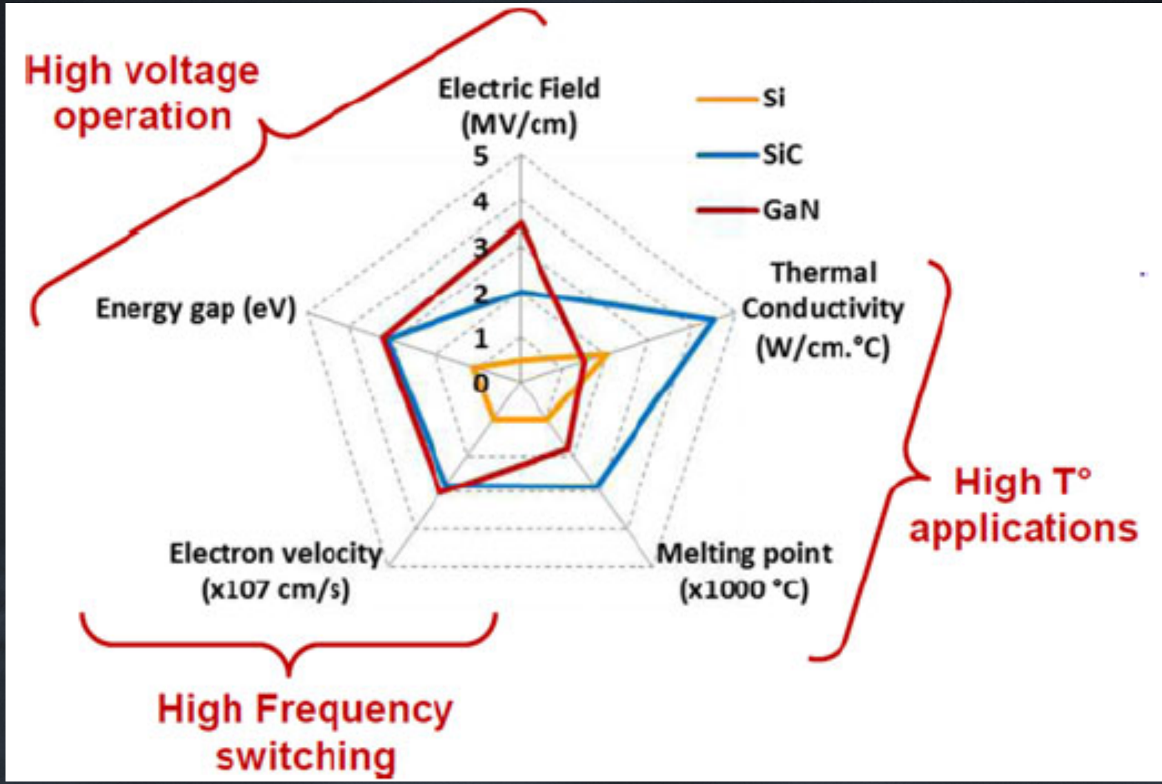


Automotive Power: EV Battery System Solutions



GaN *vs* other semiconductor materials





- Si power devices are approaching the theoretical limit of material property
- GaN has much advantage: Low Specific R_{ON} and high breakdown voltage

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GaN2BCD™ Introduction

- GF has developed a unique integrated GaN+BCD solution (GaN2BCD™).
- GaN2BCD is a heterogeneous integration of GaN HEMT device with BCD control circuit.
- GaN HEMT vs. Si LDMOS
  - Much lower Rsp, lower conduction loss for given area
  - Much higher current capability in given area
  - Lower capacitance, lower switching loss, higher switching speeds
- GaN2BCD vs. package or PCB integration
  - Minimized parasitic inductance and resistance
  - Closely coupled gate driver circuit for minimum ringing, overshoot, etc.
  - Smaller footprint
  - Ability to pre-test complete system at the wafer level
  - Ability to perform wafer-level trimming to adjust BCD circuit to match coupled GaN HEMT
  - Direct sensing of GaN HEMT current, temperature, voltage by BCD circuits
  - Improved temperature cycle reliability (matched CTE of GaN-on-Si and Si BCD)

GaN2BCD™ Potential Applications

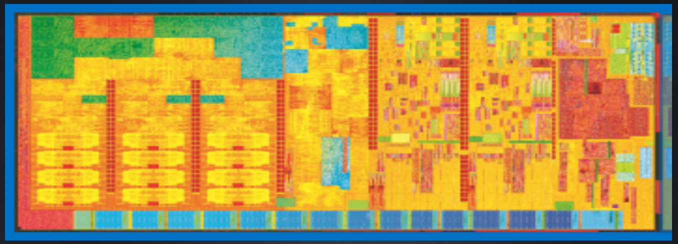
- Existing markets to benefit from GaN2BCD™ enablement
  - RF power amplifiers for mobile phones, tablets, netbooks
  - Displays (integrated drivers and optical devices)
  - RF communications for V2V networks
  - High-speed D/A converters and signal processing
  - High-performance class-D audio amplifiers
- New markets created by GaN2BCD™
  - Ultra-compact power conversion for IoT and wearables
  - Fully integrated AC/DC power supplies (using IVR and GaN2BCD™)
  - Integrated high-power photonics communication chips

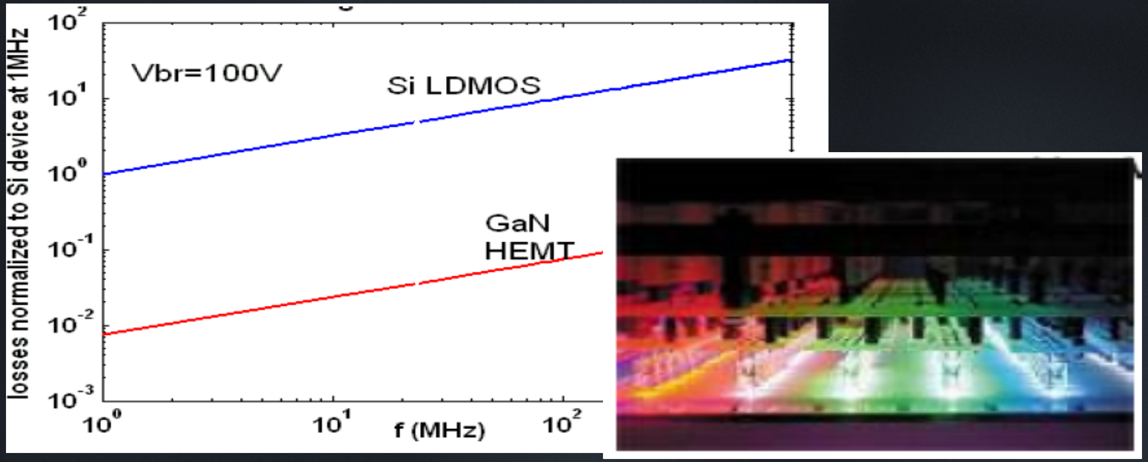
Agenda

GaN2BCD Approach

- Leverage established GF's BCDlite™ processes
  - Broad offering of silicon devices, circuit blocks, and design support
  - Capitalize on our core competence as a pure-play foundry
  - High-quality, high-volume foundry service
- Collaborate with III-V device vendors for GaN devices
  - Leading provider of GaN transistors
  - Well-respected experience and expertise
- Provide turnkey solution for GaN2BCD wafers with integrated BCD + GaN devices
- Longer-term: provide an integrated design environment

GaN2BCD™





Silicon will remain the dominant material for semiconductors

Cheap, plentiful, huge infrastructure for design and manufacturing

III-V materials have fundamental advantages over silicon

Reduced size, increased speed, excellent optical properties

- GaN2BCD™ will provide the “best of both worlds”
- Silicon CMOS circuits monolithically integrated with III-V devices
- Density and performance not achievable by silicon or III-V alone

Agenda

GaN2BCD^{TM} Demonstrations

S/N	Application	Development status	Collaboration
1	Integrated 3.3V-70V boost converter with GaN HEMT	• Gen-1 & 2 demos successful • Gen-3 under fabrication	[1]
2	Integrated CMOS driver and GaN LED for smartphone camera flash	• Gen-1 & 2 demos successful • Gen-3 ready for testing • Gen-4 final product version under fabrication	[2]
3	Class-D audio amp	• Gen-1 demo successful • Gen-2 under fabrication	[1]
4	Integrated 48V-1V Buck converter with GaN HEMT	• Gen-1 designed and under fabrication	[3]
5	LED Bulb	• Gen-1 fabricated and tested successfully	[4]
6	Micro LED display	• Gen-1 fabricated and tested successfully	[4]
7	Wireless charger with integrated GaN HEMTs	• Gen-1 under fabrication	[1]
8	Envelope Tracking Supply	• Gen-1 under fabrication	[1]

[1] Fanyi Meng, Boon Chirn Chye, et. al., VIRTUS IC design team, Nanyang Technological University, Singapore
[2] Zou Qiong, Yeo Kiat Seng, et. al., IC design team, SUTD, Singapore
[3] Heng Goh, Liter, et. al., VIRTUS IC design team, Nanyang Technological University, Singapore
[4] Mei Yu, IPP with SUTD, IC design team, SUTD, Singapore

GaN2BCD™ Demonstrations

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[illegible]	[illegible]	• Gen-[illegible] and tested successfully
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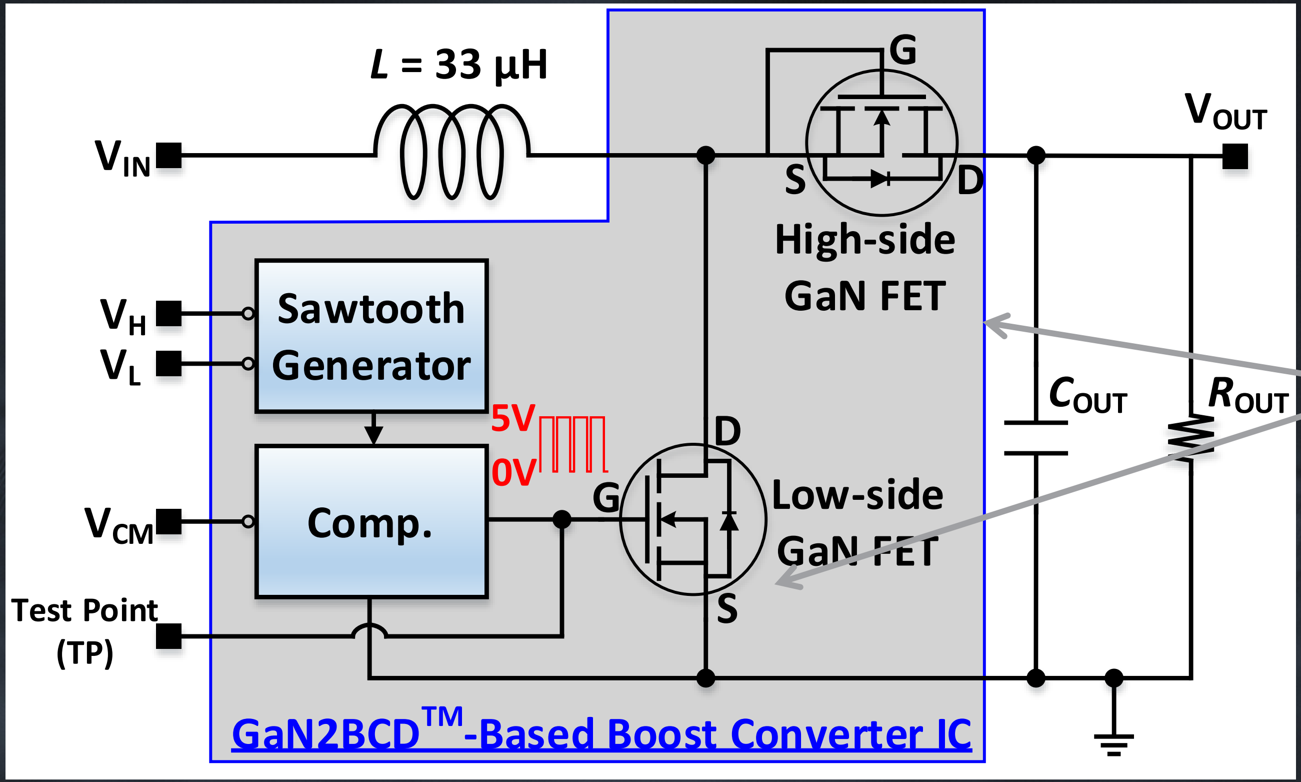
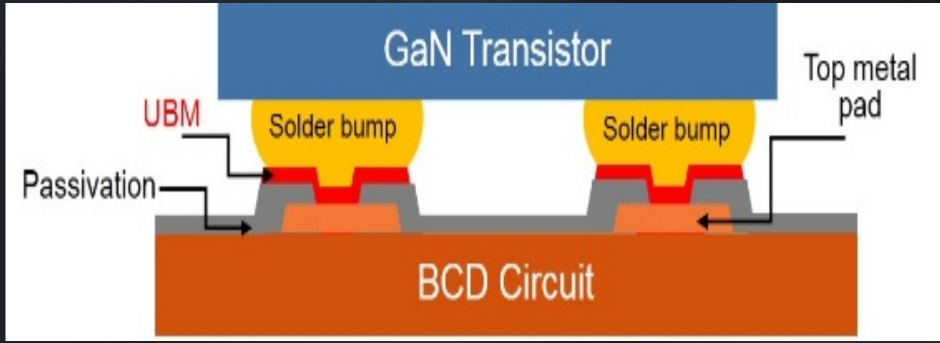
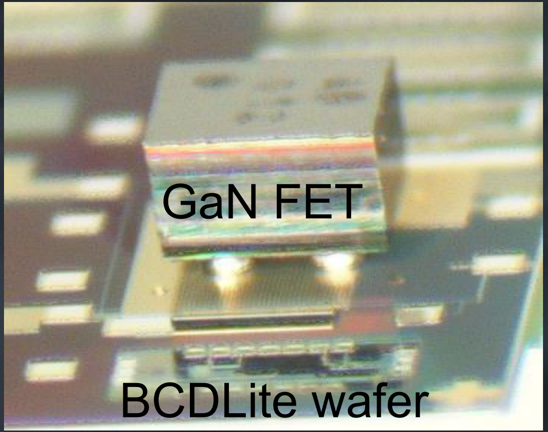
GaN2BCD Boost Converter



Schematic of the 3.3V to 70V boost converter prototype



80V DMOS (R_{ON} 1~2 Ω)
Replaced with GaN FET
Low R_{ON} 65 mΩ



GaN FET bonded on 180BCDLite wafer

GaN2BCD™ Boost Converter *vs* others

- The efficiency of the on-chip integrated boost converter outperforms the others

Ref	Tech.	Boost Diode	V_{IN}/V_{OUT} (V/V)	$P_{OUT,MAX}$ (W)	η_{MAX} (%)	Area (cm×cm)
[1]	GaN + CMOS + IPD	Int. #	12/18	4.16	47.3	0.94× 0.98
[2]	80 V BCD	OTS *	3.3/80	0.35	53	0.1× 0.1
[3]	80 V BCD	OTS *	3.3/70	0.3	52	not mentioned
GaN2BCD™	GaN + BCD	Int. #	3.3/70	1.68	70.3	0.32× 0.18

intergated *Off-the-Shelf

[1] M. J. Liu and S. S. H. Hsu, *IEEE Trans. Power Electron.*, vol. PP, pp. 1-1, 2018.
[2] Y. Y. Yang, S. W. Wang, C. Y. Hsieh, T. C. Huang, Y. H. Lee, and K. H. Chen, *IEEE Trans. Ind. Electron.*, vol. 60, pp. 2627-2637, 2013.
[3] *76V, 300mW boost converter and current monitor for APD bias applications (3 ed.);* online: https://datasheets.maximintegrated.com/en/ds/MAX15059.pdf
[4] F. Meng et. al., *IEEE Trans. Power Electron.*, accepted, 2018

GaN2BCD™ Demonstrations

S/N	Application	Development status
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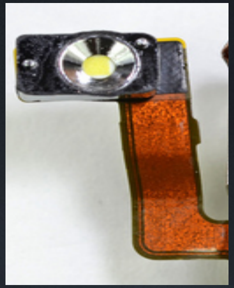
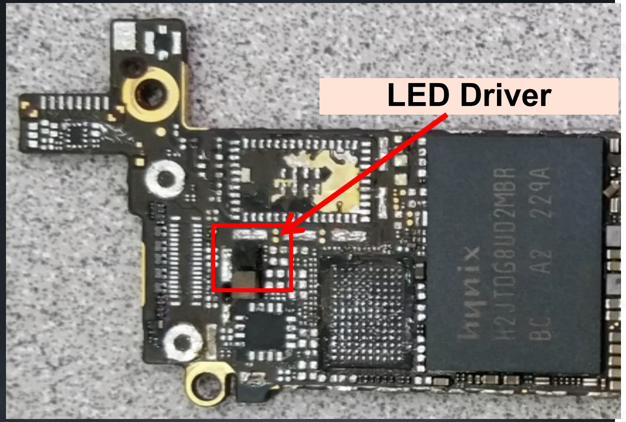
4	Integrated 48V-1V Buck converter with GaN HEMT	• Gen-1 designed and under fabrication
[illegible]	[illegible]	• Gen-1 [illegible] and tested successfully
6	Micro LED display	• Gen-1 fabricated and tested successfully
7	Wireless charger with integrated GaN HEMTs	• Gen-1 under [illegible]
8	Envelope Tracking Supply	• Gen-1 under fabrication

LED integrated IC driver for phone flash - Heterogeneous *vs.* board-level integration

On-board integration

- Conventionally LED chips & control IC's are molded into separate package and assembled on board.
- A cable connects control IC and LED
- Two separate packages for LED and control IC → higher packaging cost

On-chip integration

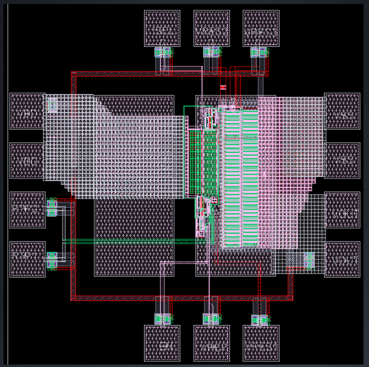
- In the heterogeneous on-chip integration, the LED is bonded directly on top of the control IC
- Eliminates the use of ribbon cable to connect LED and control IC.

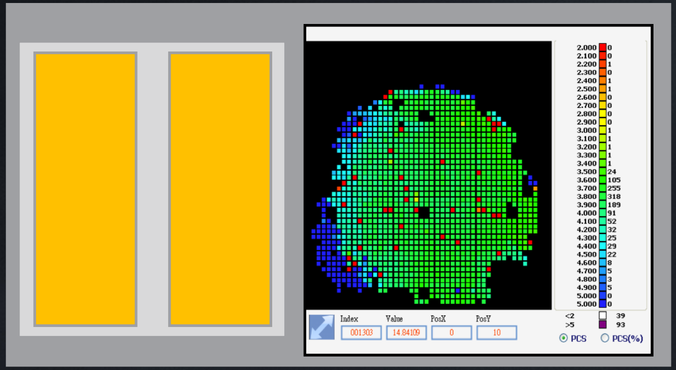
<u>Advantages:</u>

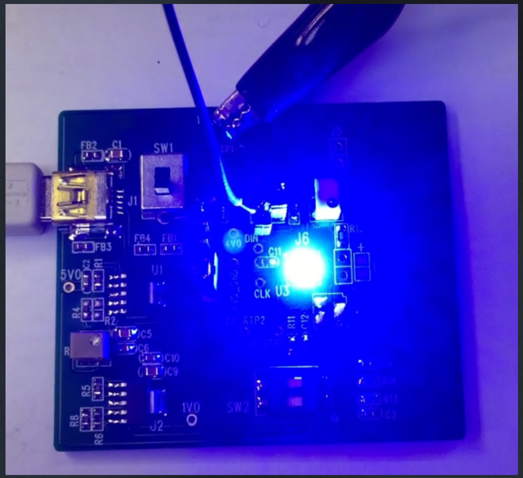
- Reduced foot print, Reduced parasitic resistance and packaging costs
- Improved efficiency and performance
- Advanced sensing and control functions

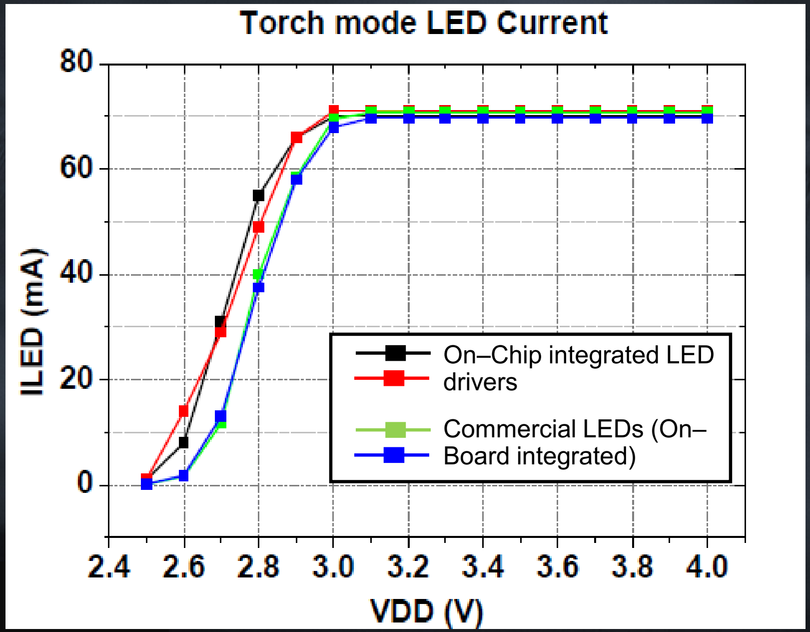
LED integrated IC driver for phone flash

- Direct integration of GaN LED on the CMOS control IC









- First-pass successful demonstration of LED above control circuit
- Results compared to commercial LED driver ICs with separately-packaged LEDs

	GaN2BCD™ approach					Commercial LED driver assembled on-board		
	Torch	Flash	Torch	Flash		MAX 1577 Y	LTC 3218	LTC 3216
Efficiency, max (%)	**87.8**	**85.7**	**87.5**	**85.5**	Efficiency, max (%)	92	85	89

GaN2BCD™ Ongoing Demonstrations

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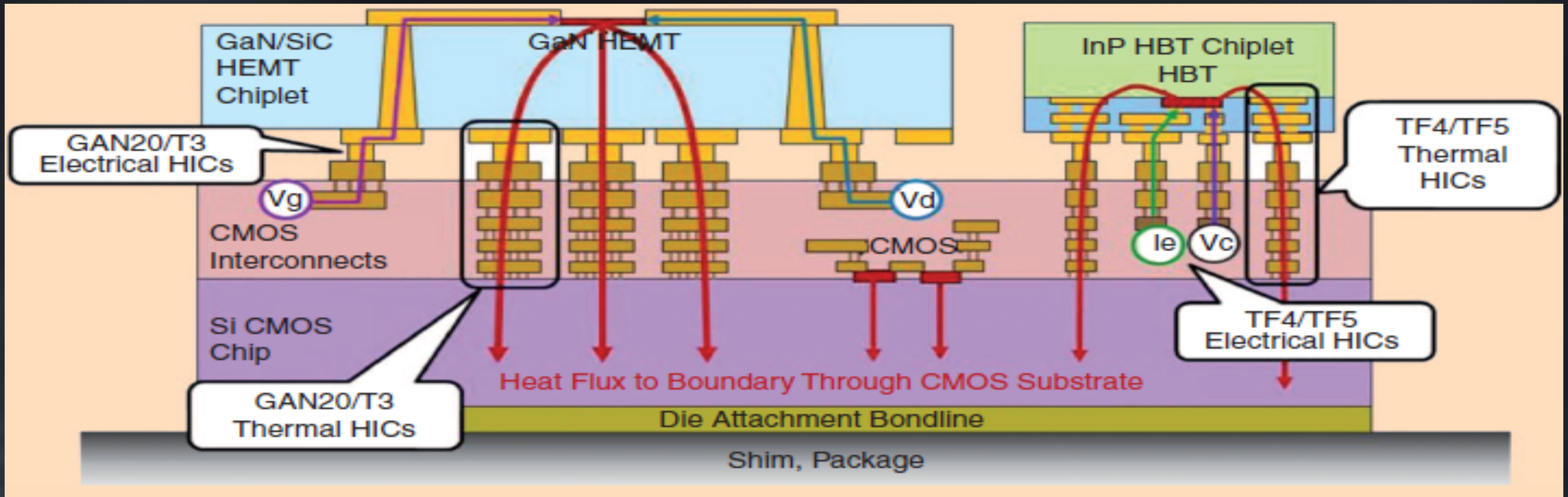
8	Envelope Tracking Supply	• Gen-1 under fabrication

Other Work on CMOS & III-V integration

- Diverse, Accessible Heterogeneous Integration (DAHI) - DARPA sponsored technology



[IEEE microwave magazine, 2017 Pp. 60]

- EU Consortium to develop CMOS and III-V integration
  - GaNonCMOS: 4 year project, launched in 2017
  - Integrating GaN power switches with CMOS drivers
  - Chip or wafer level bonding
  - https://www.compoundsemiconductor.net/article/101160-ganoncmos-project-to-drive-power-integration-densities.html

Agenda

Summary

- GaN2BCD^{TM} R&D platform set-up in GLOBALFOUNDRIES
- Demonstrated novel III-V and Silicon integration schemes for a wide variety of power and lighting applications
- GF is transitioning this R&D effort into commercialization

Acknowledgements:

- Prof. Boon Chirn Chye & team, VIRTUS IC design team, Nanyang Technological University (NTU), Singapore
- Prof. Yeo Kiat Seng & team, IC design team, Singapore University of Tech Design (SUTD), Singapore
- Prof. Siek Liter & team, VIRTUS IC design team, Nanyang Technological University (NTU), Singapore

Thank you

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