MAKING A ***MATERIAL*** DIFFERENCE

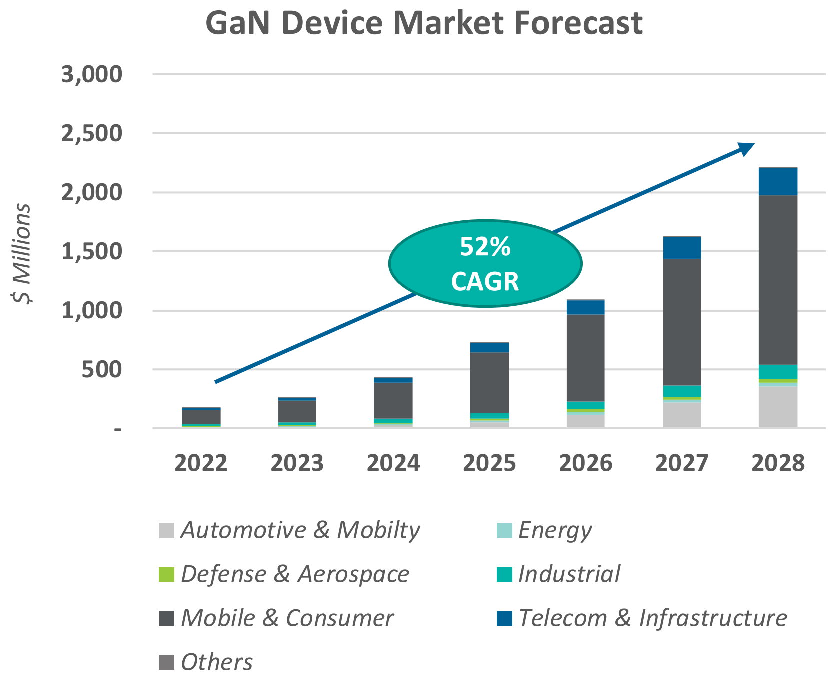
Accelerating Adoption of WBG Power Semiconductors through Single Wafer Epitaxy of GaN and SiC

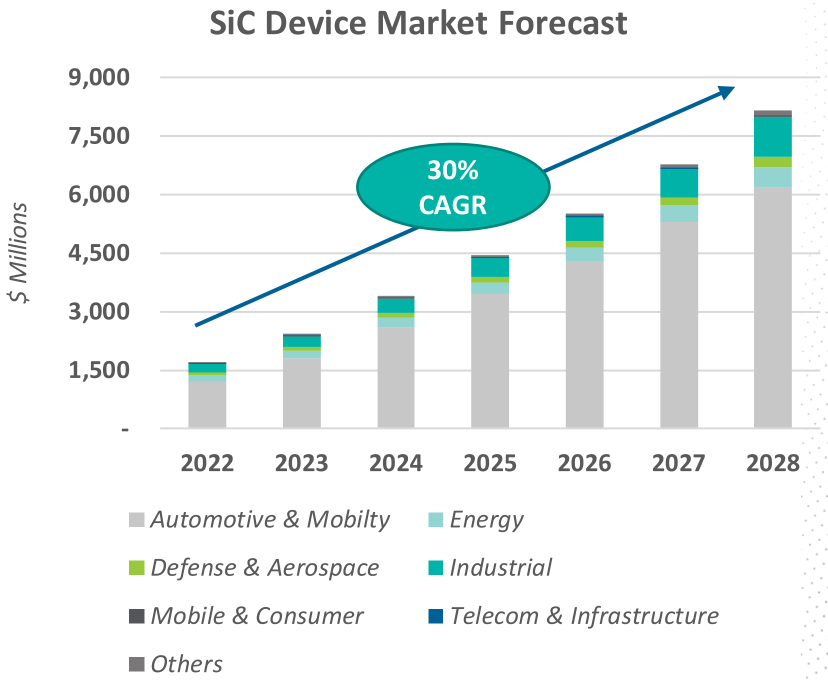
April 2023

Agenda

- Market for Wide-Bandgap (WBG) Semiconductors
- Veeco single-wafer solutions for GaN on Silicon
- Veeco single-wafer solutions for Silicon Carbide

Wide-Bandgap Semiconductors: A Fast Growing Market





Source: Yole Power SiC/GaN Compound Semiconductor Market Monitor-Q1 2023

Key Growth Enablers for Wide-Bandgap Semiconductors

GaN on Silicon

- Near Term (2023-2025)
    - *Consumer fast chargers: up to 650V*
    - *Data Center power supplies: 48V architecture*
- Long Term (2025-2030)
    - *Automotive applications: 650V+*
    - *Penetration into new markets: industrial, residential solar, etc.*
- Technical
    - *Extension to 900V and 1200V devices*
    - *Improvement of epitaxial challenges derived from lattice mismatch: wafer bow, uniformity*
    - *Overall yield improvements*
    - *Productivity and economies of scale – transition from 150mm to 200mm to 300mm*

Silicon Carbide

- Near Term (2023-2025)
    - *EV traction inverter adoption: 800V architecture*
    - *EV fast-charging*
- Long Term (2025-2030)
    - *Cost reductions: 8” wafer production*
    - *Penetration into new markets: renewables, industrial motor drive, rail, etc.*
- Technical
    - *Defectivity improvements*
    - *Wafer-to-wafer uniformities improvement*
    - *Productivity and economies of scale – transition from 150mm to 200mm*

MOCVD Solutions For Advanced Material Applications

Batch Solutions

EPIK® 868 System

GaN LED/ MiniLED

- Proven performance and reliability
- Lowest CoO
- Compact cluster design

Lumina® System

MicroLED (R), EEL, VCSEL

- Best-in-class performance and reliability
- 150mm / 200mm AsP
- 75mm / 100mm InP

Single Wafer Solutions

Propel® 200 HVM Propel® 300 HVM

GaN Power, RF, MicroLED (B/G)

- Available in up to C6 (200mm) and up to C3 (300mm) configurations
- 200mm Silicon, Sapphire
- 300mm Silicon
- Cassette to Cassette automation

SiC CVD

Power SiC

- C1 and C2 configurations
- Cassette to cassette automation

Single Wafer MOCVD Equipment for GaN Epitaxy

Propel® 200 HVM and Propel® 300

Key Benefits

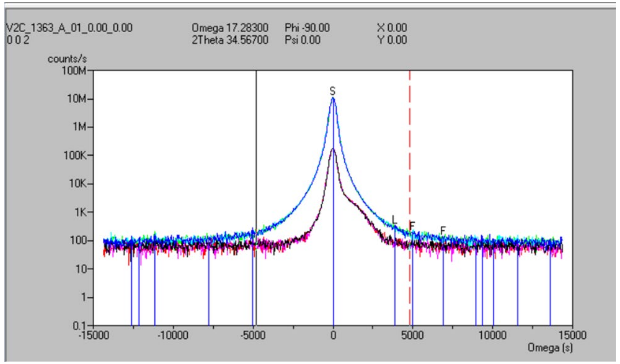
- Excellent WiW* uniformity with low EE**
- High availability – in-situ clean not needed
- High productivity (>100 runs PM interval) with smooth post-PM process recovery
- Lowest yielded-area CoO for GaN on Si
- Process is scalable from 8” to 12” with a similar recipe

Veeco’s Propel® is the leading single wafer architecture platform in the industry

* *Within Wafer*
** *Edge Exclusion*

Propel® 200mm HVM GaN-on-Si Epitaxy Performance

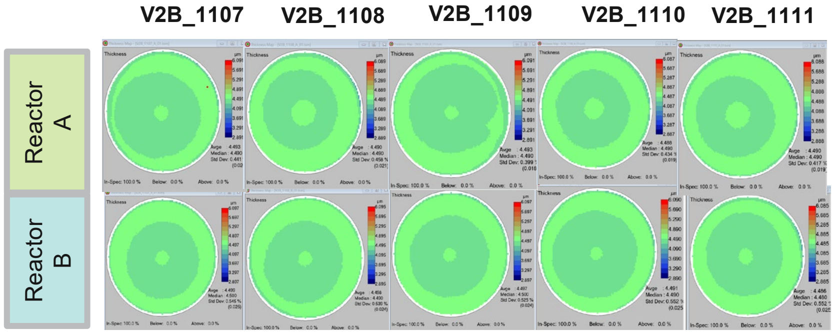
High Quality Undoped GaN-on-Si



Locations (mm) →	(0,0)	(0, 45)	(0, 90)
(002)ω (arcsec)	329	324	359
(102)ω (arcsec)	385	382	379

Excellent R-t-R Thickness Uniformity

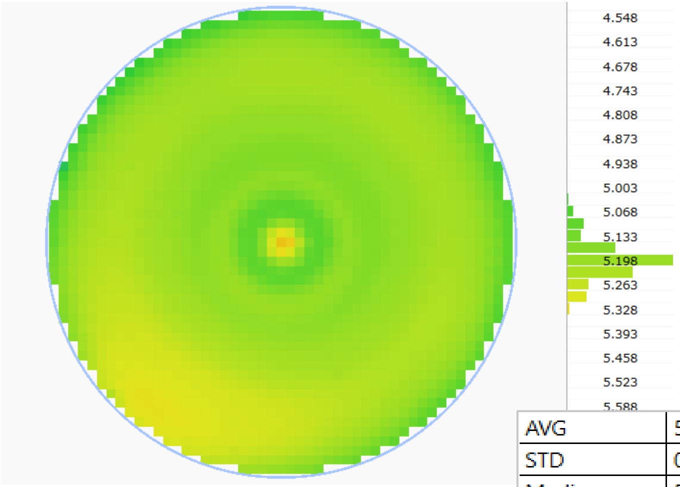
without process tuning



	V2B_1107		V2B_1108		V2B_1109		V2B_1110		V2B_1111	
Reactor	A	B	A	B	A	B	A	B	A	B
Thickness (μm)	4.49	4.50	4.49	4.50	4.49	4.50	4.49	4.49	4.49	4.49
Std %	0.44%	0.55%	0.46%	0.54%	0.40%	0.53%	0.43%	0.55%	0.42%	0.55%

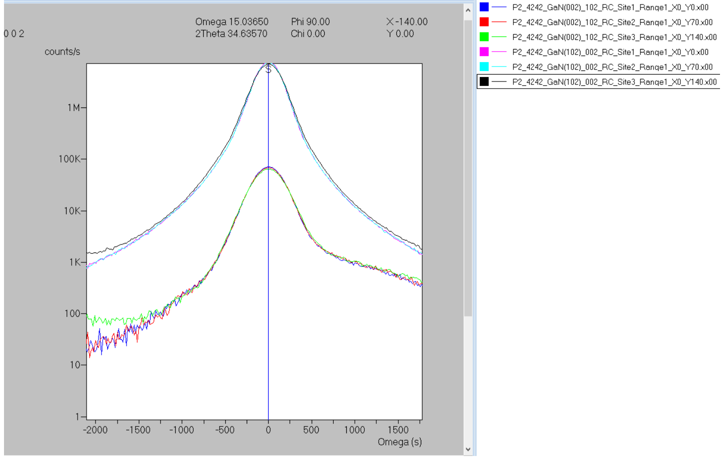
Propel® HVM provides excellent film quality and r-t-r uniformity to enable the highest quality, lowest cost GaN devices

Propel® 300mm GaN-on-Si Epitaxy Performance



AVG	5.1988
STD	0.0527884
Median	5.20293
Max	5.37068
Min	4.95159
Top 10%	5.26905
Bottom 10%	5.12669
Count	1877

Thickness: 5.2µm
StdDev./Avg. ~1.0% @ 0 mm EE



Position	GaN (002)	GaN (102)
0 mm	298”	373”
70 mm	308”	380”
140 mm	325”	392”

Single wafer epitaxy enables the transition of GaN on Si to 300mm wafers

Epiluvac is now Veeco SiC CVD

1993

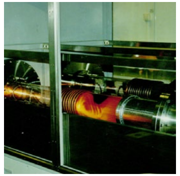
Epigress founded
Started cooperation with Linköping university, Sweden, regarding SiC epi and bulk growth

1994

First **SiC CVD system**
Delivered to IMC, Kista, Sweden

1996

First **Hot-Wall System**
Delivered to ABB, Linköping, Sweden



2014

Epiluvac founded

2015

Focus
8”process

2020

3rd Generation SiC CVD
Focus on lowest cost per wafer

2022

First **Epiluvac SiC System** shipped

2023

First PO from Industrial Partner

2023

Epiluvac acquired by Veeco

Epiluvac’s rich history is closely linked to the history of SiC development

Veeco SiC CVD Benefits for Silicon Carbide Production

① Temperature tuning

② Gas Flow tuning

More tuning parameters lead to processes with better yields

③ Quick and Repeatable Preventive Maintenance (PM)

④ Separate Pre-Heat and Cool-Down Chambers

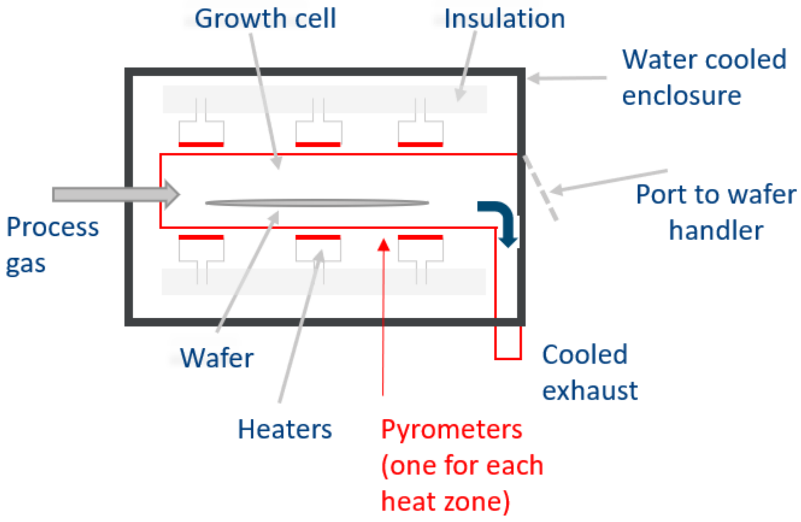
⑤ Seamless Switching between 6” and 8” Wafers

Design simplicity and configurability lead to highest productivity

Better yields and highest productivity drive highest wafer throughput and lowest costs of ownership

① Temperature Tuning

- Uniform chamber temperature
  - Multiple resistive graphite heaters and pyrometers
  - Automatic chamber temperature adjustment
- Tunable temperature profile
  - Independent heating zones adjust the temperature across chamber
  - Chamber cooling-off effects can be offset
- Stable temperature profile, even as insulation ages or gas flow varies

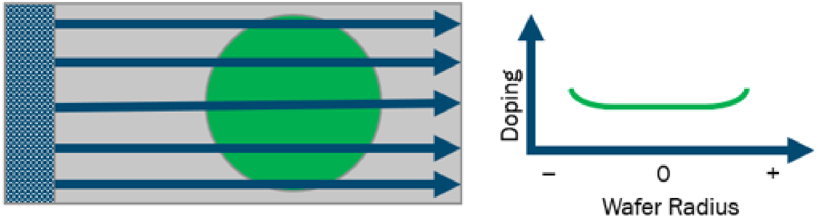


Multiple-zone resistive heating enables unique temperature profiles to improve uniformity and reduce parasitic deposition

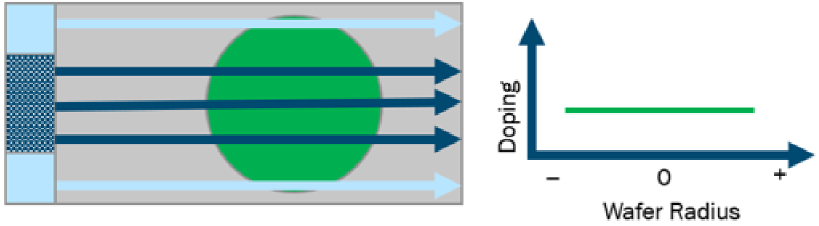
② Gas Flow Tuning

- 3-Zone gas injector can intentionally set different gas concentrations from center to edge
    - Growth rate can be adjusted from center to edge
    - Doping can be adjusted from center to edge
- Gas flow and composition can be independently varied and controlled at edge vs. center
- Growth rate and doping are not linked together

Conventional Gas Injector



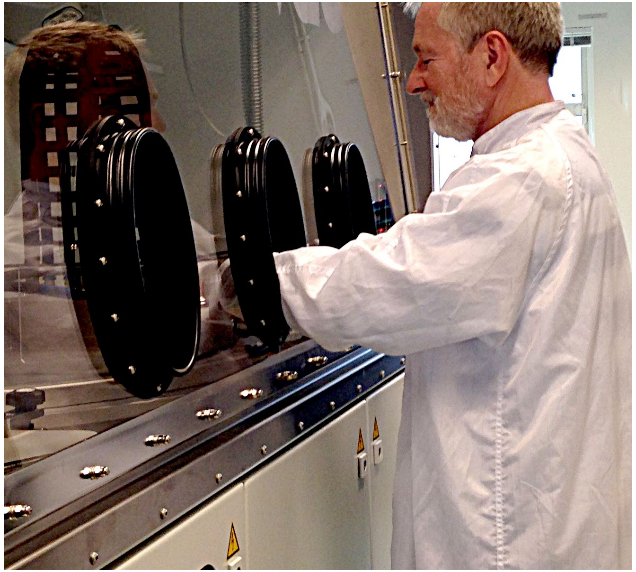
3-Zone Gas Injector



Independent adjustment of center-to-edge gas concentrations decouples adjustments of doping and thickness uniformities

3 Regular Maintenance inside Glove Box

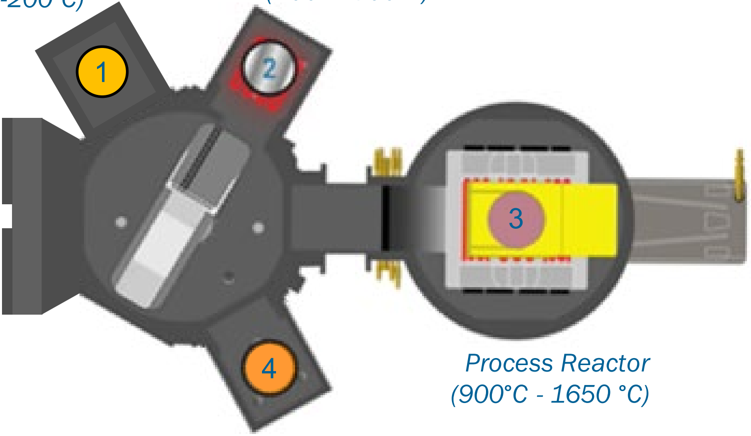
- Regular maintenance completed in total green-to-green time of < 5 hours
- Inside of growth reactor is easily accessible for routine cleaning through the glove box
- Graphite ceiling is quickly removed and replaced via load-lock in glove box
- Entire operation is quickly performed in inert environment without disassembly or any other major disruptions



Chamber maintenance done inside purged glove box, reducing maintenance time by ensuring chamber stays clean and dry

④ Separate Pre-Heat and Cool-Down Chambers

- Carrier and wafer are pre-heated to 900 °C to prevent thermal shock
- Growth chamber stays warm (900 °C) when reloading and between runs
  - reduces cycle time
  - extends graphite lifetime
  - reduces thermal cycling-induced particle generation



De-gassing chamber and carrier storage (0°C-200°C)

Pre-Heat Chamber (200°C 900°C)

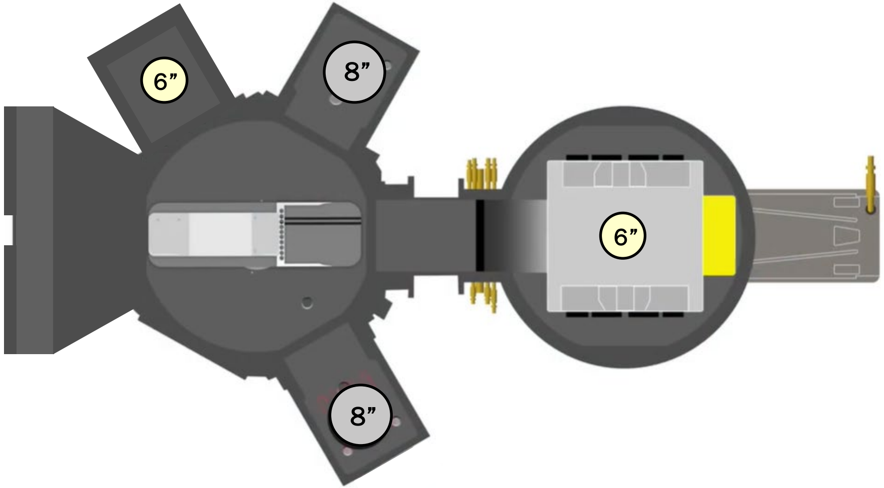
Process Reactor (900°C - 1650 °C)

Cool-Down Chamber

Wafer pre-heating reduces cycle time, prevents wafer damage, lowers consumable costs, and reduces defectivity

5 Seamless Switching between 6” and 8” Wafers

- No hardware or software changes when changing wafer size
- Wafers will circulate on carriers available in different sizes



Tool throughput and uptime are maintained even when changing from one wafer size to another

Conclusion

- GaN and SiC are fast-growing wide-bandgap technologies enabling the electrification of the automotive industry and a more energy-efficient tech future
- Technical challenges in the fabrication of wide-bandgap devices need to be addressed in order to meet the performance and cost targets required by the industry
- Veeco's single wafer epitaxy equipment provides advanced solutions at multiple wafer sizes for both GaN-on-Si and SiC, with the best cost of ownership in the industry

Veeco

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