Accelerating Semiconductor Technologies for the Green Revolution

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ICAPS

APPLIED MATERIALS®
make possible

Forward-Looking Statements

This presentation contains forward-looking statements, including those regarding anticipated growth and trends in our businesses and markets, industry outlooks and demand drivers, technology transitions, our business and financial performance and market share positions, our investment and growth strategies, our development of new products and technologies, and other statements that are not historical facts. These statements and their underlying assumptions are subject to risks and uncertainties and are not guarantees of future performance.

Factors that could cause actual results to differ materially from those expressed or implied by such statements include, without limitation: the level of demand for our products, our ability to meet customer demand, and our suppliers' ability to meet our demand requirements; global economic, political and industry conditions, including rising inflation and interest rates; the implementation and interpretation of new export regulations and license requirements, and their impact on our ability to export products and provide services to customers and on our results of operations; global trade issues and changes in trade and export license policies; our ability to obtain licenses or authorizations on a timely basis, if at all; consumer demand for electronic products; the demand for semiconductors; customers' technology and capacity requirements; the introduction of new and innovative technologies, and the timing of technology transitions; our ability to develop, deliver and support new products and technologies; the concentrated nature of our customer base; our ability to expand our current markets, increase market share and develop new markets; market acceptance of existing and newly developed products; our ability to obtain and protect intellectual property rights in key technologies; our ability to achieve the objectives of operational and strategic initiatives, align our resources and cost structure with business conditions, and attract, motivate and retain key employees; the effects of geopolitical turmoil or conflicts, and of regional or global health epidemics; acquisitions, investments and divestitures; changes in income tax laws; the variability of operating expenses and results among products and segments, and our ability to accurately forecast future results, market conditions, customer requirements and business needs; our ability to ensure compliance with applicable law, rules and regulations; and other risks and uncertainties described in our SEC filings, including our recent Forms 10-Q and 8-K. All forward-looking statements are based on management's current estimates, projections and assumptions, and we assume no obligation to update them.

AGENDA

- Intro to Applied Materials
- Clean Energy Revolution
- SiC
- GaN
- Conclusions

AGENDA

- Intro to Applied Materials
- Clean Energy Revolution → SiC, GaN
- SiC
- GaN
- Conclusions

World's #1

semiconductor and display equipment company

We provide sophisticated **manufacturing systems** and **comprehensive services** to the semiconductor and **display** industries


IoT
Comms
Auto
Power
Sensors

ICAPS I Key Device Technologies

Broadest Semiconductor Equipment Portfolio for ICAPS Nodes

BROADEST

DEEPEST

PVD	CVD	DRY CLEANS	DEGAS	ETCH	EPI	PLATING	ALD	WET CLEANS	POLISHING	ANNEALS	NITRIDATION/ OXIDATION	IMPLANT	METROLOGY/ INSPECTION
DC PVD	Thermal CVD	CCP Plasma	Standard	CCP Etch	RP Epi	Dual Damascene	ALD funnel	Mask Blank Cleans	Triple Platens	ATM Thermal	RP Thermal	High Current	Optical Wafer Inspection
Ionized PVD	Thermal CVD w Plasma	ICP Plasma	Dual Mode	ICP Etch	ATM Epi	Packaging Plating	Radical Enhanced ALD	Brush Box	Dual Platen	Backside Thermal	Decoupled Plasma	High Energy	eBeam Inspection
RF PVD	HD Plasma CVD	Radical Enhanced Plasma		Radical Enhanced	Next Gen RP Epi		Spatial ALD	CMP Pre-Clean		Laser Anneal		Medium Current	eBeam Metrology
Pulsed DC	Radical Enhanced CVD	Chemical Clean		Mask Etch			Minibatch ALD	IPA Marangoni SRD		Laser Anneal		Plasma Doping	eBeam Review
MC PVD										UV Cure			Optical Mask Inspection

300mm

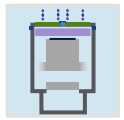
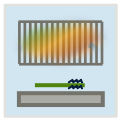
≤200mm & 300mm

150/200/300mm Equipment for Silicon and Compound Semi

>20 New ICAPS Products Since 2019

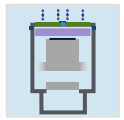
2019: Applied Compound Semi Portfolio

✓ HVM
↗ Pilot/Demo

Material	Wafer Size	 CMP	 Etch	 PVD	 CVD	 ALD	 Plating	 Implant	 Anneal	 M&I
SiC	4→6”		✓	✓	✓					
GaN	4”→6”		✓	✓	✓					
GaAs	4”→6”						✓	✓		
InP	3”→4”									

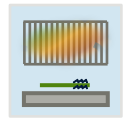
Today: Applied Compound Semi Portfolio

✓ HVM
↗ R&D/Ramping








Material	Wafer Size	CMP	Etch	PVD	CVD	ALD	Plating	Implant	Anneal	M&I
SiC	6→8”	✓	✓	✓	✓	↗	✓	✓	↗	✓
GaN	6”→8”	✓	✓	✓	✓	✓	✓	✓	✓	✓
GaAs	4”→6”→8”	✓	*Opportunity to Engage*		✓	✓	✓	✓		✓
InP	4”→6”					✓				

Grew Compound Semi Portfolio 3x

Clean Energy Revolution Driving New Power Semi Opportunities

Electric Vehicles

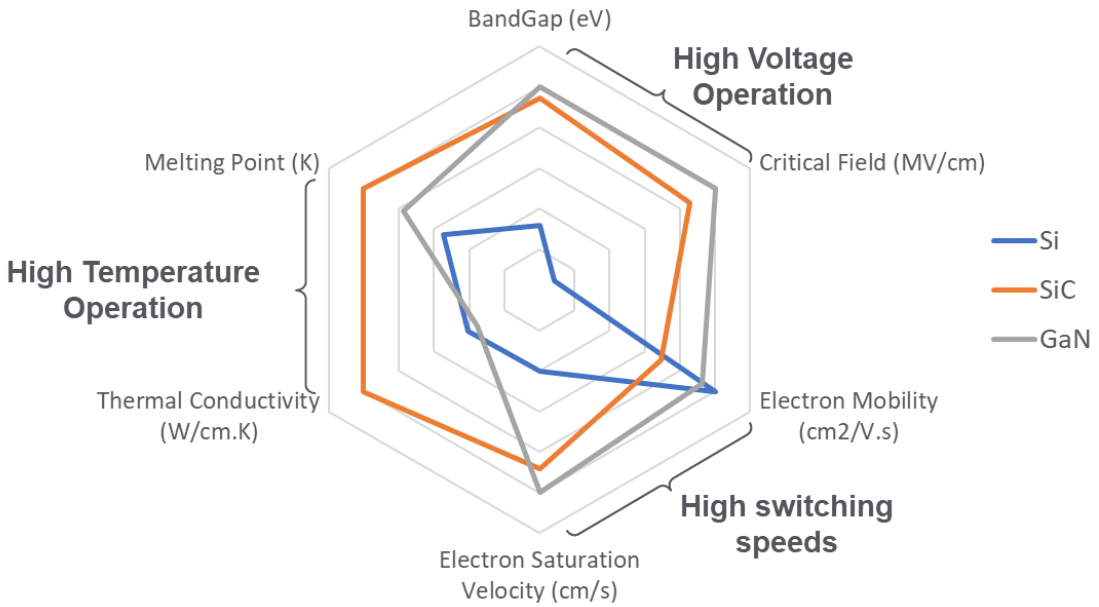
Wind and Solar

Smart Grid

Emerging Material Systems in Power Electronics | SiC and GaN

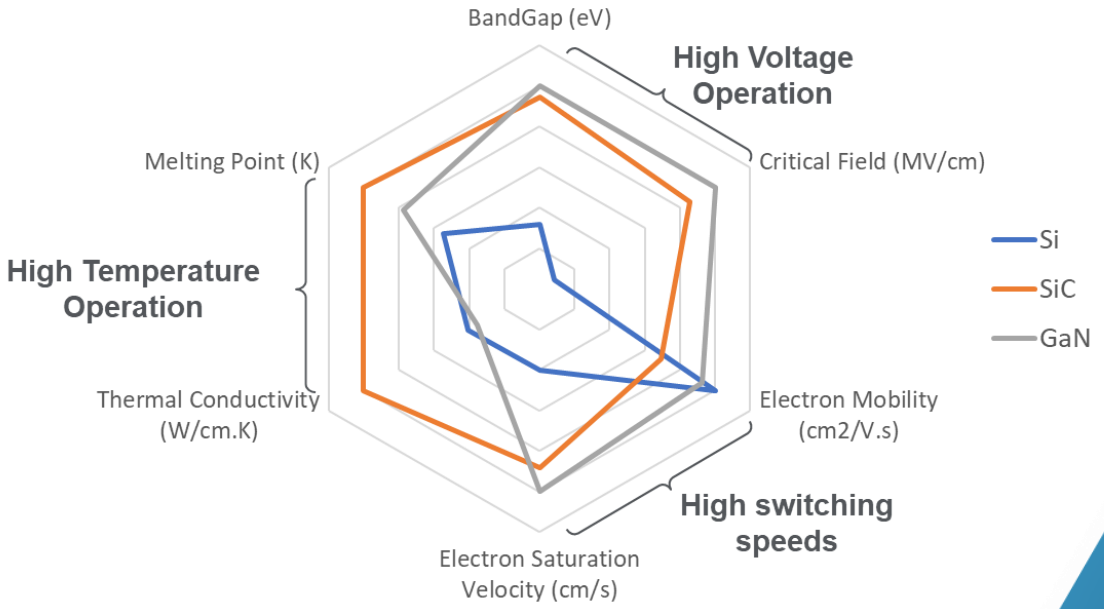
Emerging Material Systems in Power Electronics | SiC and GaN

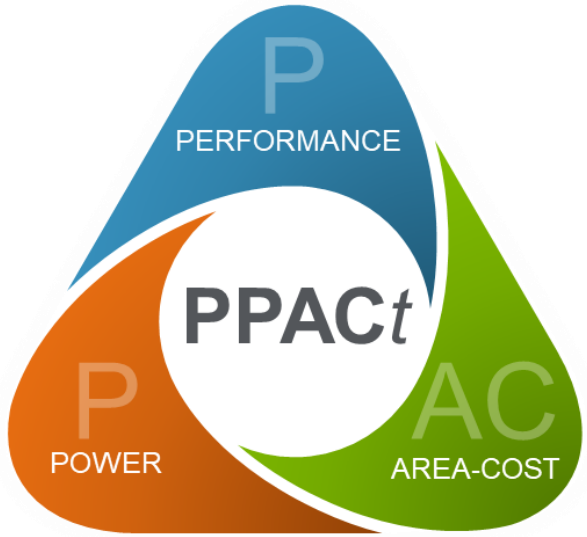
Value propositions for SiC and GaN



Emerging Material Systems in Power Electronics | SiC and GaN

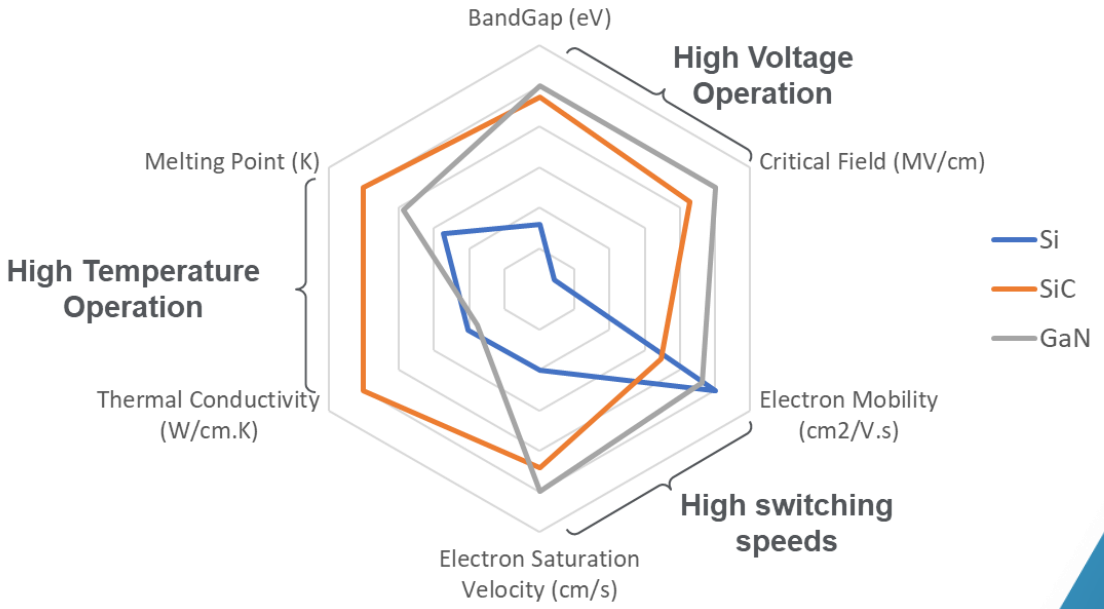
Value propositions for SiC and GaN





Emerging Material Systems in Power Electronics | SiC and GaN

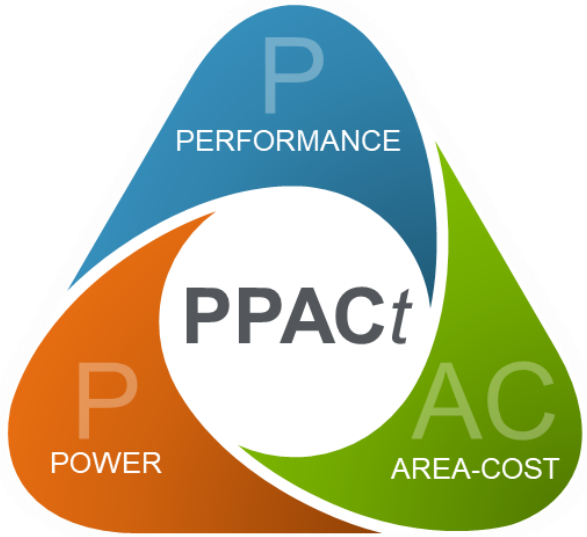
Value propositions for SiC and GaN



SiC die can get 4x smaller

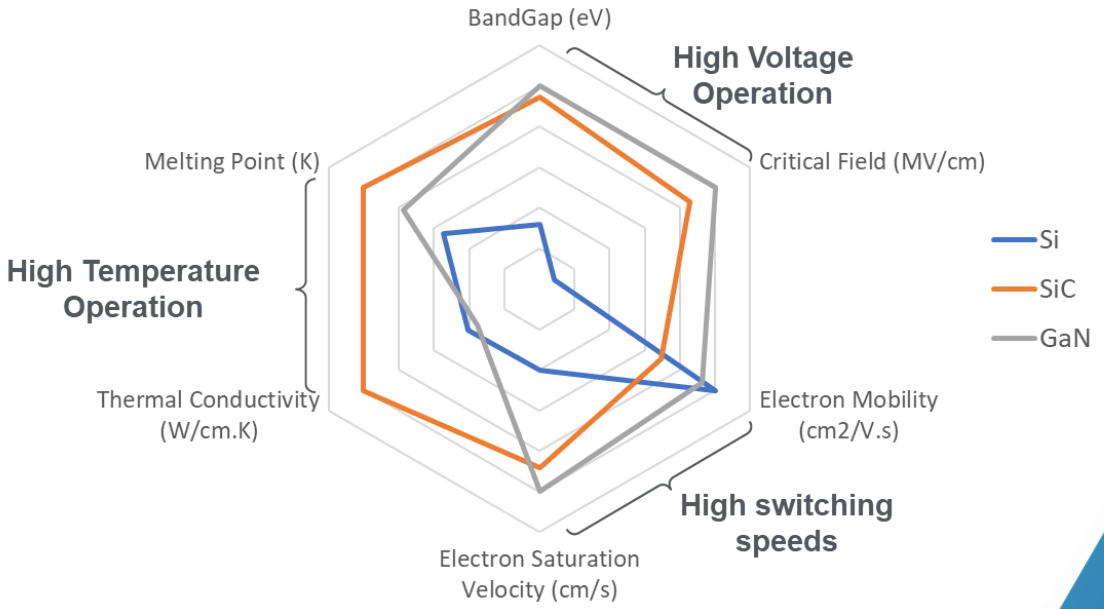
GaN die can get 10X smaller

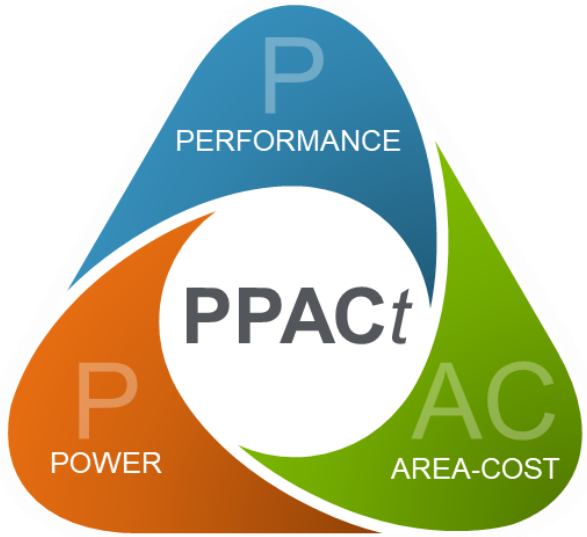
Compared to Si



Emerging Material Systems in Power Electronics | SiC and GaN

Value propositions for SiC and GaN





SiC die can get 4x smaller

GaN die can get 10X smaller

Compared to Si

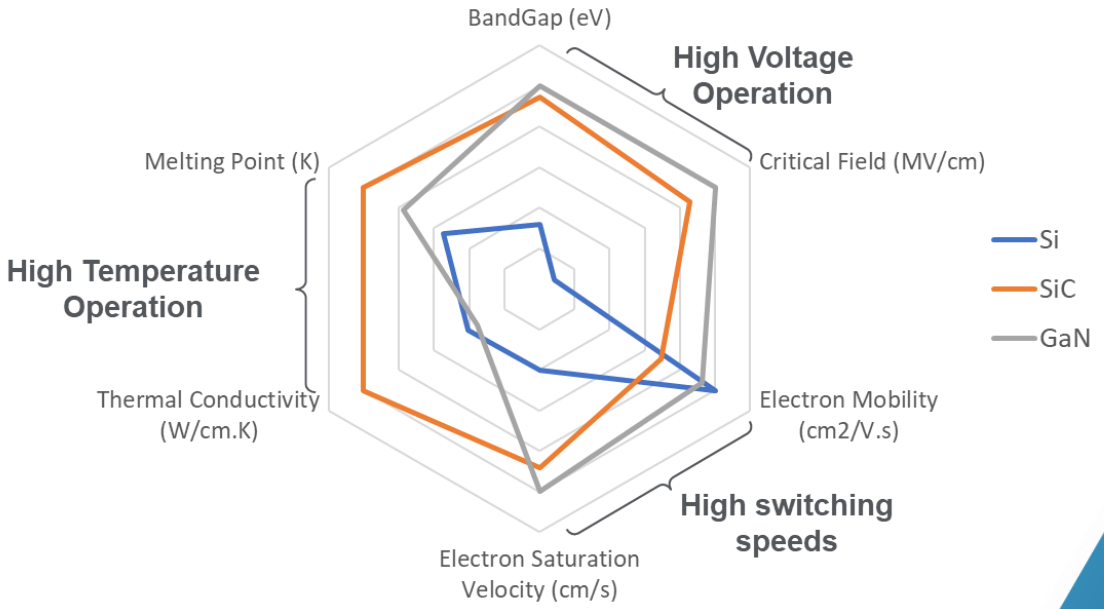
10X smaller EV charger with SiC

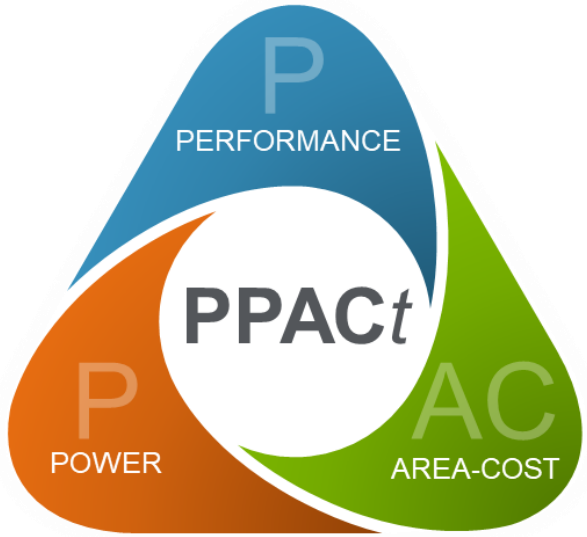
3X smaller PSU using GaN

Compared to Si

Emerging Material Systems in Power Electronics | SiC and GaN

Value propositions for SiC and GaN





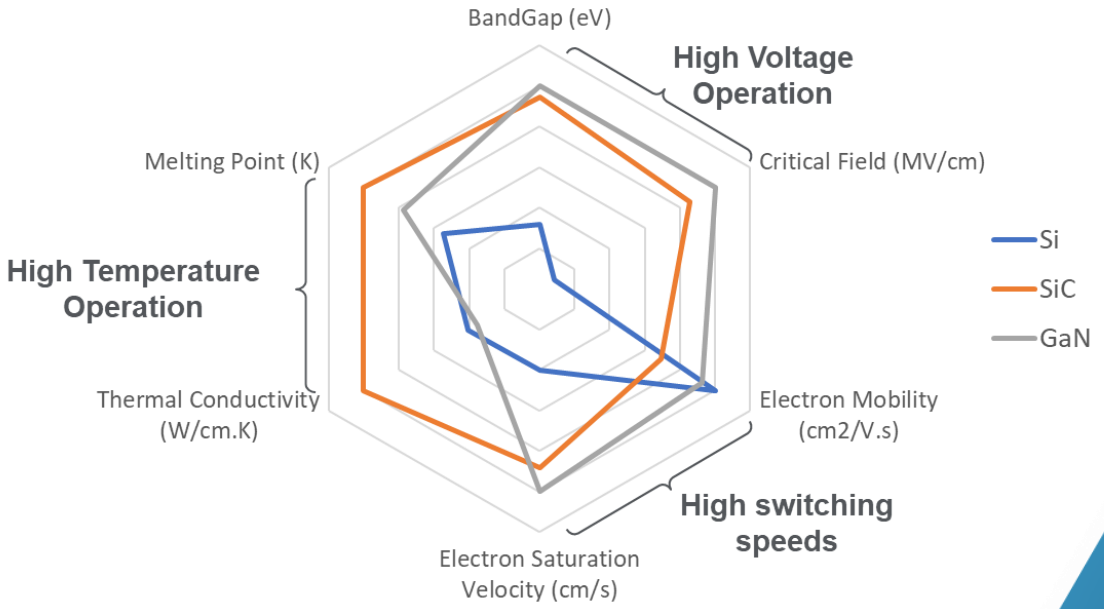
SiC die can get 4x smaller
GaN die can get 10X smaller
Compared to Si

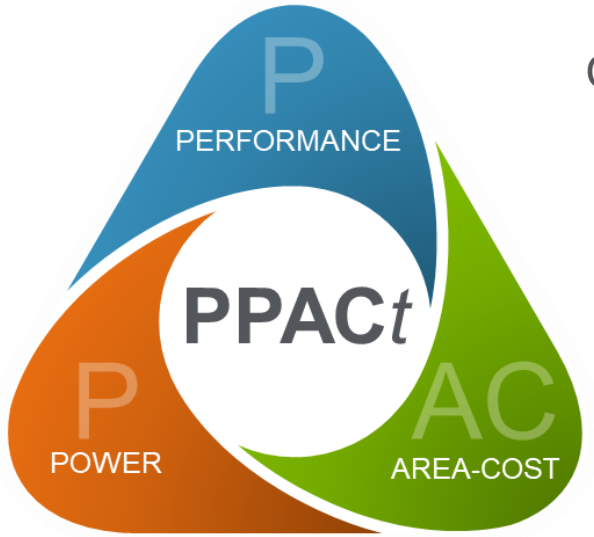
10X smaller EV charger with SiC
3X smaller PSU using GaN
Compared to Si

SiC die is 3X more expensive
GaN die is 5X more expensive
Compared to Si

Emerging Material Systems in Power Electronics | SiC and GaN

Value propositions for SiC and GaN





SiC die can get 4x smaller

GaN die can get 10X smaller

Compared to Si

10X smaller EV charger with SiC

3X smaller PSU using GaN

Compared to Si

SiC die is 3X more expensive

GaN die is 5X more expensive

Compared to Si

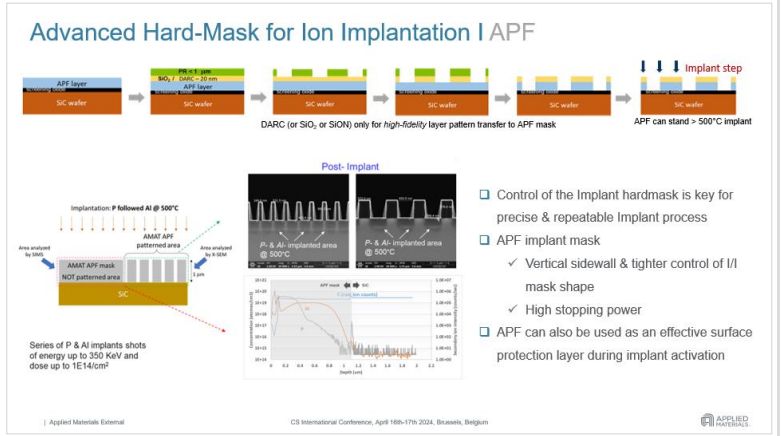
Time to market is key…

SiC scaling to 200mm slower than expected

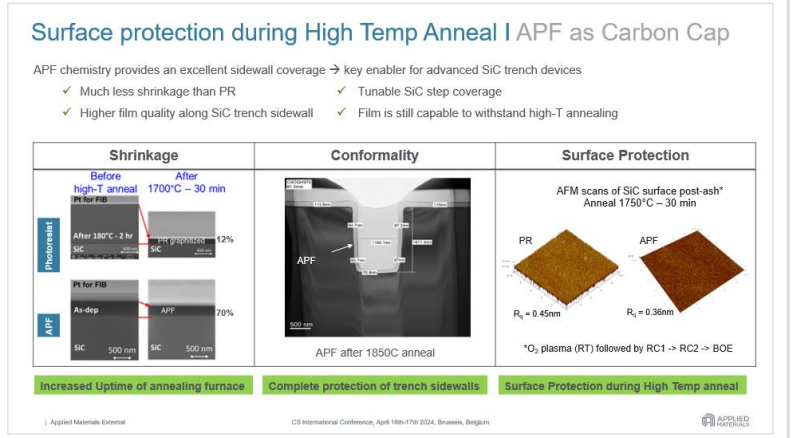
GaN scaling to 200mm/300mm is challenging

Addressing SiC Device Challenges

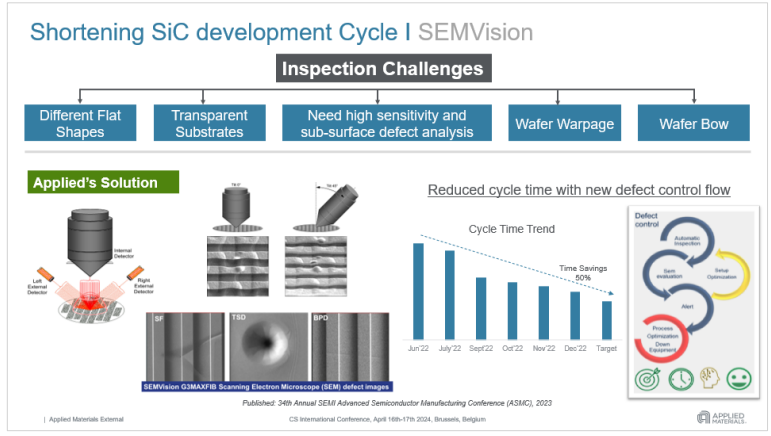
Precise dopant control



Surface Integrity



Faster development cycle



Applied Producer® APF™

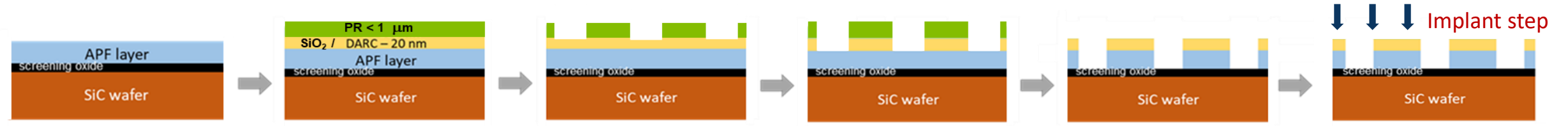
Applied Centura® Etch

Applied VIISTA® Implant

Reveal™

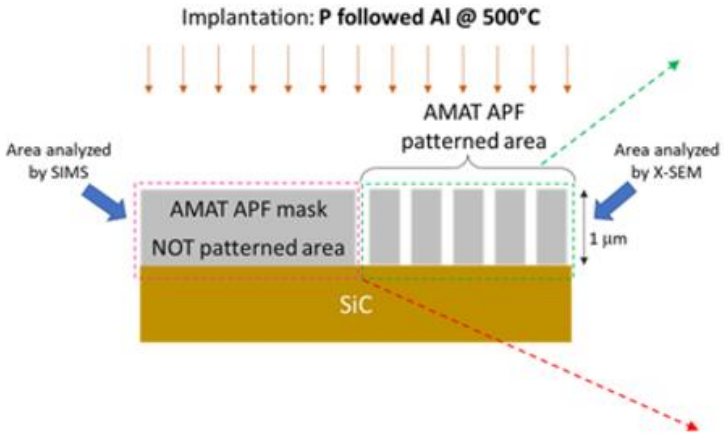
VeritySEM™ 6C

Advanced Hard-Mask for Ion Implantation I APF

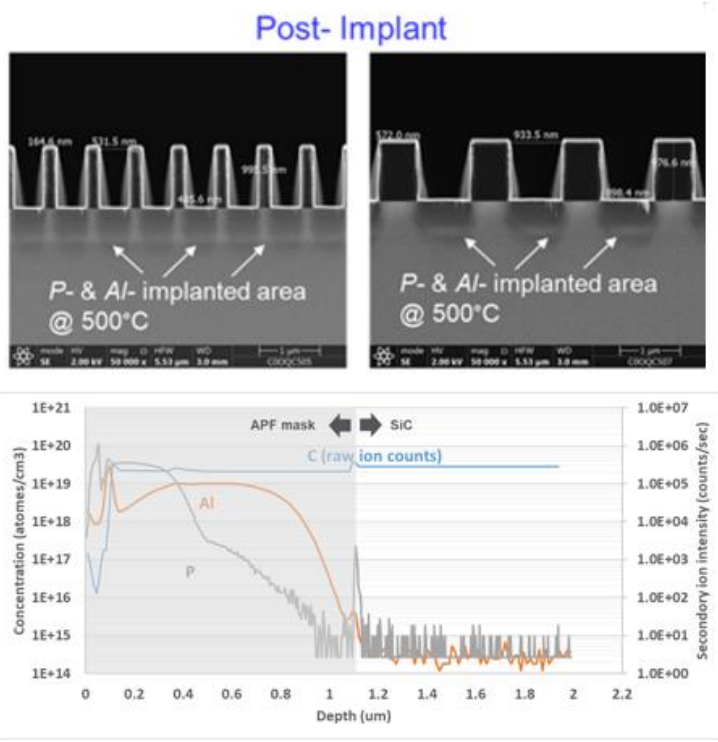


DARC (or SiO_2 or SiON) only for *high-fidelity* layer pattern transfer to APF mask

APF can stand > 500°C implant



Series of P & Al implants shots of energy up to 350 KeV and dose up to 1E14/cm²



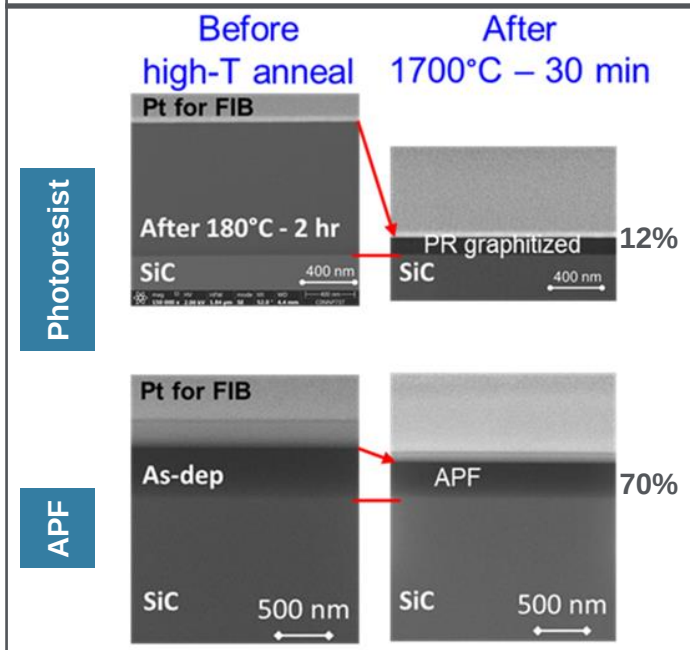
- Control of the Implant hardmask is key for precise & repeatable Implant process
- APF implant mask
  - ✓ Vertical sidewall & tighter control of I/I mask shape
  - ✓ High stopping power
- APF can also be used as an effective surface protection layer during implant activation

Surface protection during High Temp Anneal I APF as Carbon Cap

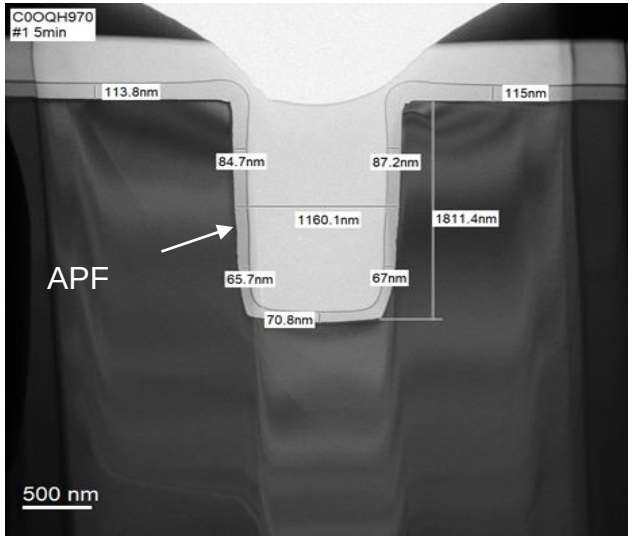
APF chemistry provides an excellent sidewall coverage → key enabler for advanced SiC trench devices

- ✓ Much less shrinkage than PR
- ✓ Higher film quality along SiC trench sidewall
- ✓ Tunable SiC step coverage
- ✓ Film is still capable to withstand high-T annealing

Shrinkage



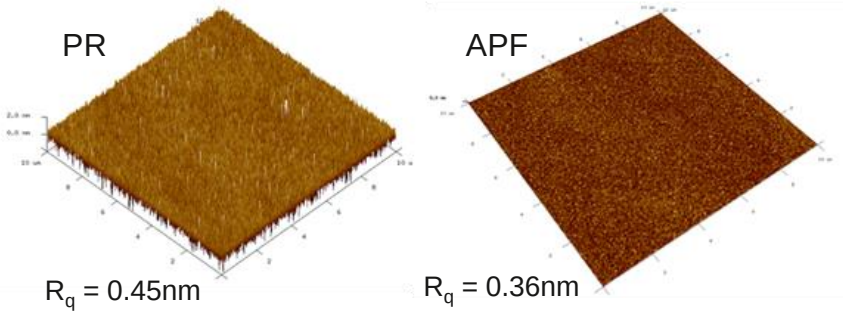
Conformality



APF after 1850C anneal

Surface Protection

AFM scans of SiC surface post-ash*
Anneal 1750°C – 30 min



*O_2 plasma (RT) followed by RC1 -> RC2 -> BOE

Increased Uptime of annealing furnace

Complete protection of trench sidewalls

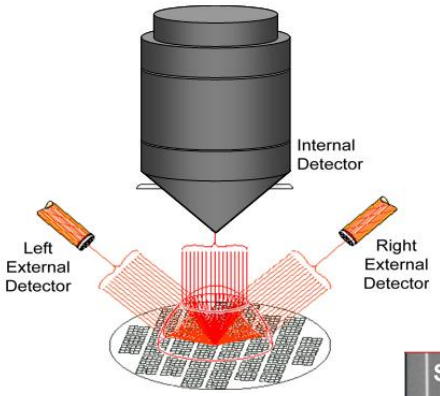
Surface Protection during High Temp anneal

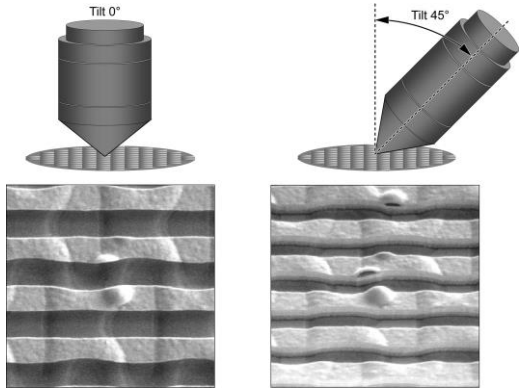
Shortening SiC development Cycle I SEMVision

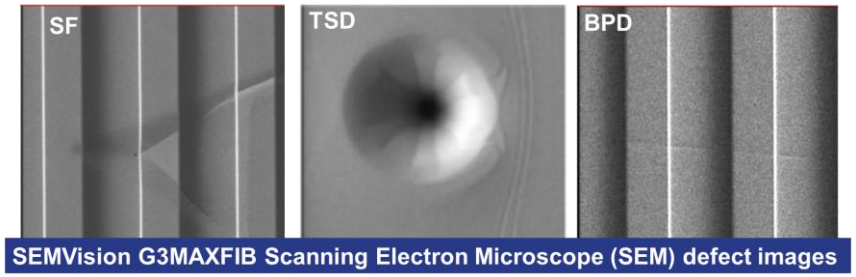
Inspection Challenges

- Different Flat Shapes
- Transparent Substrates
- Need high sensitivity and sub-surface defect analysis
- Wafer Warpage
- Wafer Bow

Applied's Solution

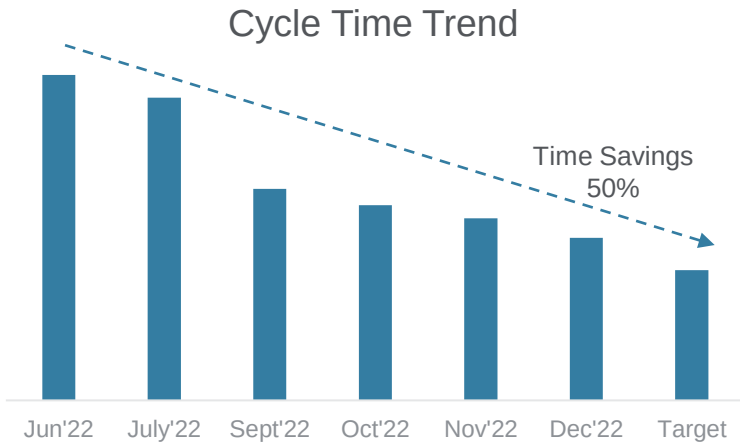


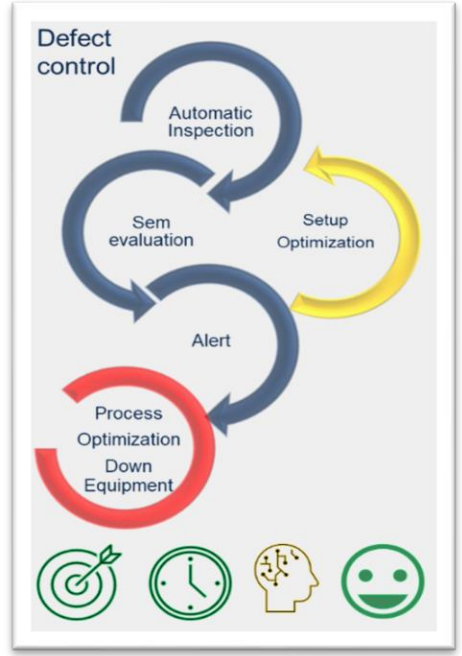




SEMVision G3MAXFIB Scanning Electron Microscope (SEM) defect images

Reduced cycle time with new defect control flow

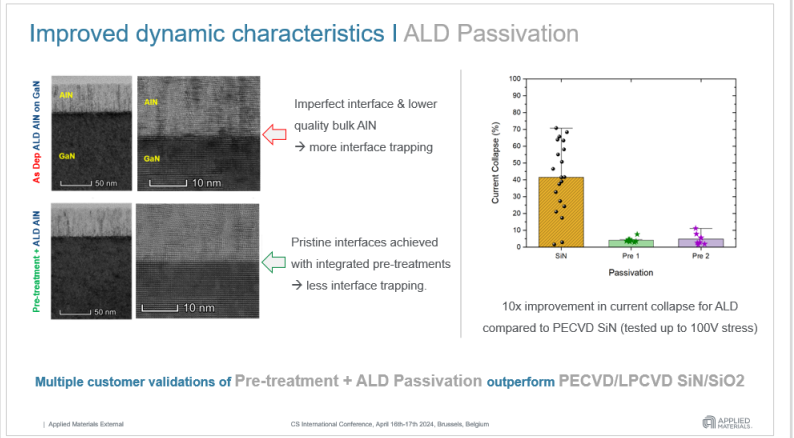




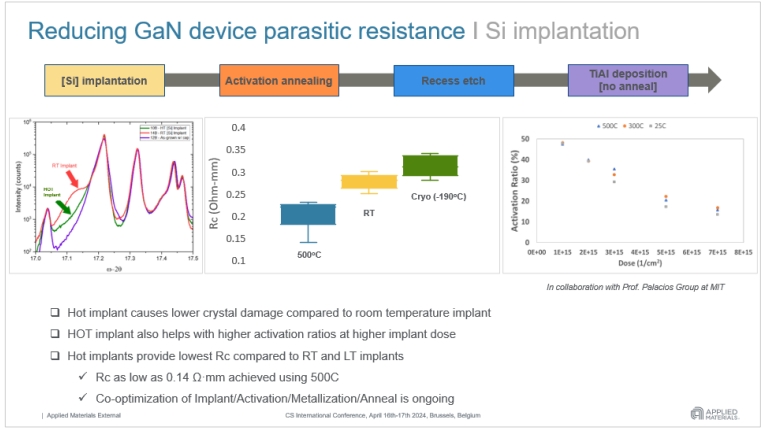
Published: 34th Annual SEMI Advanced Semiconductor Manufacturing Conference (ASMC), 2023

Addressing GaN Device Challenges

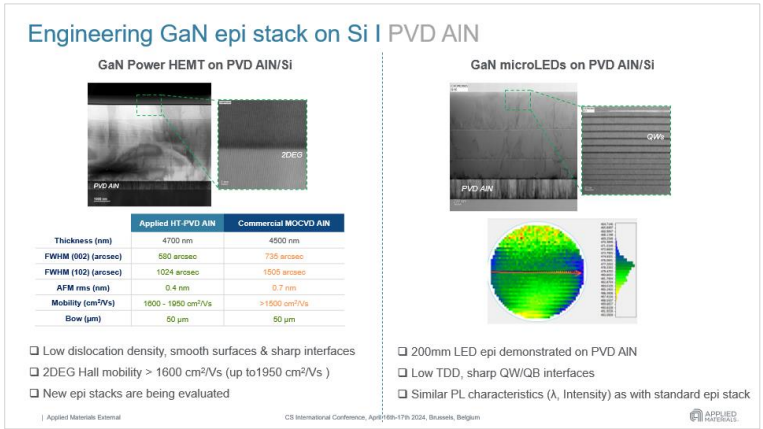
Device dynamic response



Lower Parasitics



Simplifying epi structures



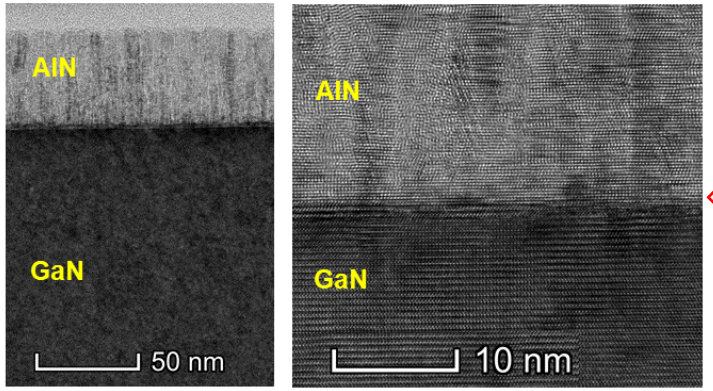
Morpher™ ALD

Applied VIISta® Implant

Applied Endura® PVD

Improved dynamic characteristics I ALD Passivation

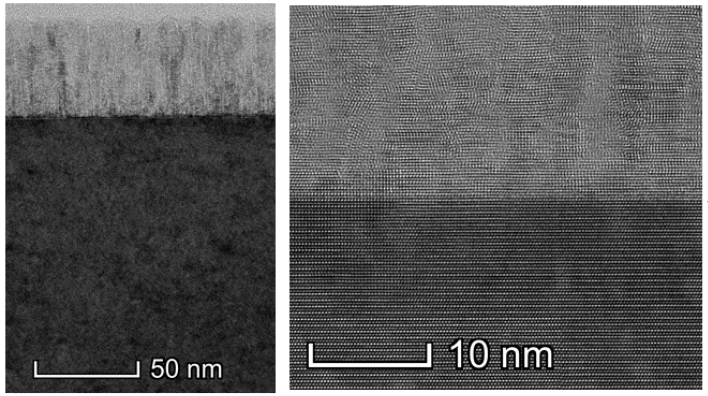
As Dep ALD AlN on GaN



Imperfect interface & lower quality bulk AlN

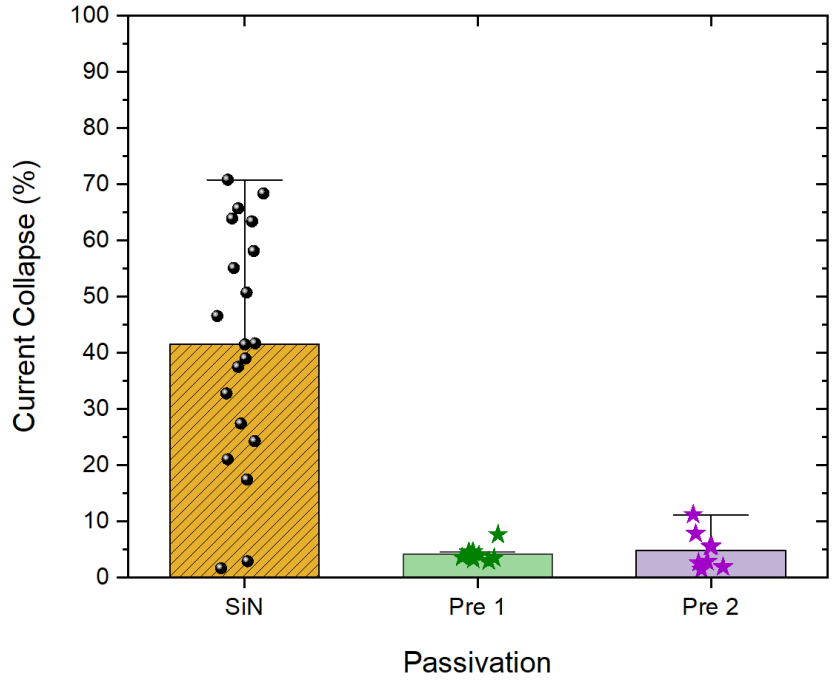
→ more interface trapping

Pre-treatment + ALD AlN



Pristine interfaces achieved with integrated pre-treatments

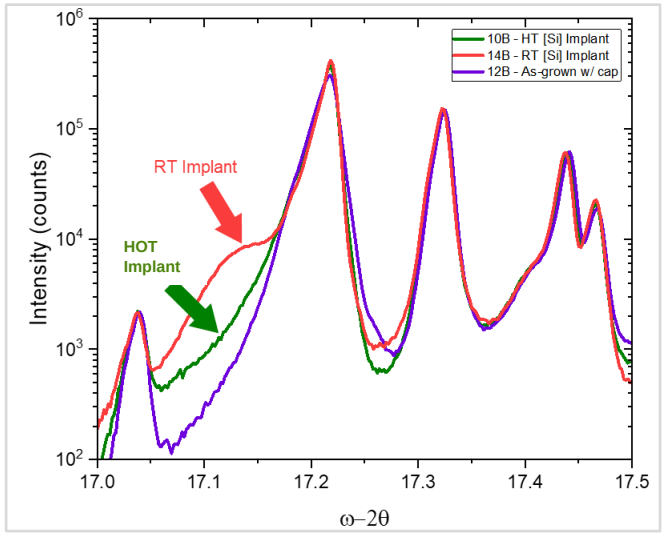
→ less interface trapping.

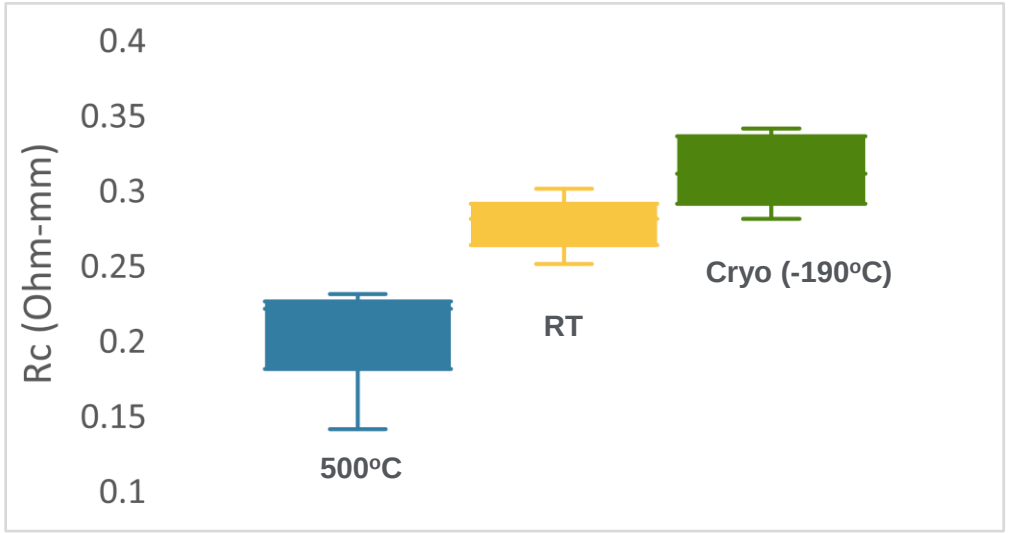


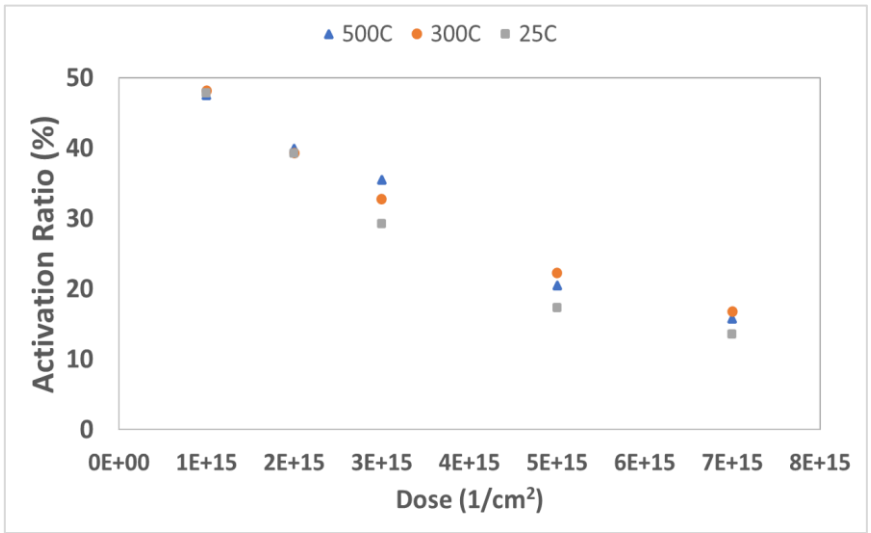
10x improvement in current collapse for ALD compared to PECVD SiN (tested up to 100V stress)

Multiple customer validations of Pre-treatment + ALD Passivation outperform PECVD/LPCVD SiN/SiO2

Reducing GaN device parasitic resistance I Si implantation





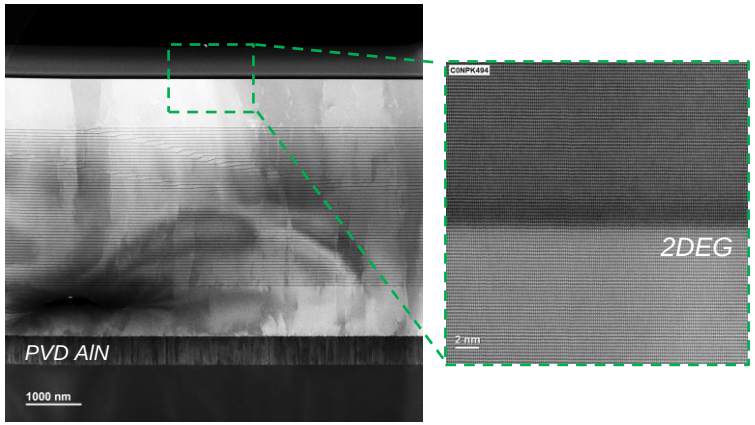


In collaboration with Prof. Palacios Group at MIT

- ❑ Hot implant causes lower crystal damage compared to room temperature implant
- ❑ HOT implant also helps with higher activation ratios at higher implant dose
- ❑ Hot implants provide lowest Rc compared to RT and LT implants
  - ✓ Rc as low as 0.14 Ω·mm achieved using 500C
  - ✓ Co-optimization of Implant/Activation/Metallization/Anneal is ongoing

Engineering GaN epi stack on Si I PVD AlN

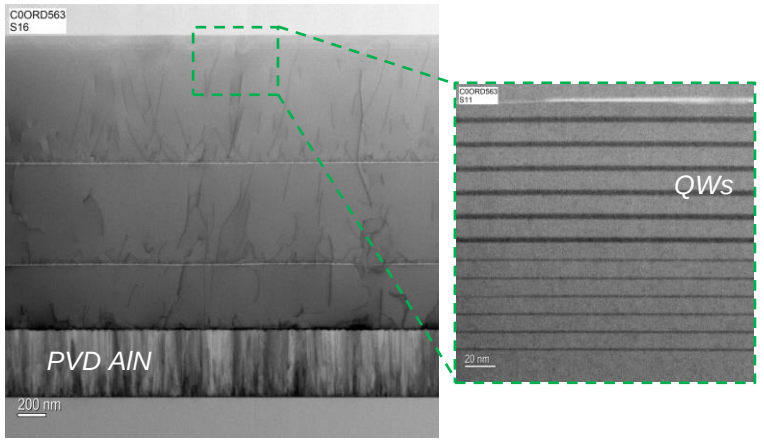
GaN Power HEMT on PVD AlN/Si

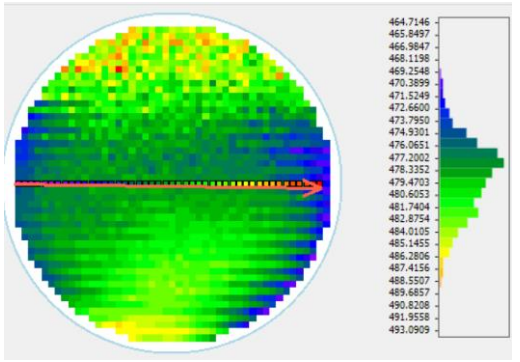


	Applied HT-PVD AlN	Commercial MOCVD AlN
Thickness (nm)	4700 nm	4500 nm
FWHM (002) (arcsec)	580 arcsec	735 arcsec
FWHM (102) (arcsec)	1024 arcsec	1505 arcsec
AFM rms (nm)	0.4 nm	0.7 nm
Mobility (cm^2/Vs)	1600 - 1950 cm^2/Vs	>1500 cm^2/Vs
Bow (µm)	50 µm	50 µm

- ❑ Low dislocation density, smooth surfaces & sharp interfaces
- ❑ 2DEG Hall mobility > 1600 cm^2/Vs (up to1950 cm^2/Vs)
- ❑ New epi stacks are being evaluated

GaN microLEDs on PVD AlN/Si





- ❑ 200mm LED epi demonstrated on PVD AlN
- ❑ Low TDD, sharp QW/QB interfaces
- ❑ Similar PL characteristics (λ, Intensity) as with standard epi stack

Applied's HVM Solutions for SiC and GaN


Centura® Etch


Centura® RTP


ComPLUS Inspection


Endura® PVD


Mirra® CMP


Morpher™ ALD


Producer® CVD


Raider® Edge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Broadest Product Portfolio for Highest Level of Process Co-Optimization

GaN and SiC Processing on 150/200mm Wafers

- Fully automated single-wafer SiC CMP for best defectivity performance
- High-temperature ion implantation for challenging material doping
- DRIE for high aspect ratio and smooth sidewalls without micro-trenching
- CVD oxides for lower interface trapping and higher carrier mobility
- ALD dielectrics for conformal and damage-free passivation
- PVD for ultra-pure frontside and backside metallization
- State-of-the-art wafer inspection and defect review
- Extensive service and support network

Thank You

Contributors…

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…and his team


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