Characterization of thin films and critical dimensions in SiC and GaN process flows

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CS INTERNATIONAL
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Presentation Outline

- Introduction to Onto Innovation
- Markets and Technologies Served
- Power Market Landscape
- SiC and GaN Device Fabrication Challenges
  - Epi Layer Control and Characterization
  - OCD and Thin Film Metrology
  - Metallization Metrology
- Onto Innovation Product Portfolio
- Discussion

Onto Innovation Snapshot

High tech capital equipment company specializing in optical process solutions for semiconductor and related markets

1,580 EMPLOYEES

9,000 ACTIVE METROLOGY & INSPECTION TOOLS INSTALLED

75 Fabs FAB-WIDE YIELD/DEFECT SOFTWARE INSTALLED

>400 PATENTS ISSUED FOR METROLOGY, INSPECTION, LITHOGRAPHY & SOFTWARE

> $1Bn REVENUE FY 2022

Portfolio of Synergistic Technologies Across Multiple Markets

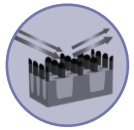
Foundation for new products and solutions to customers future challenges

SILICON WAFER MANUFACTURING
Raw material for chips

Physical Defect Control
Cracks | Pits | Foreign material

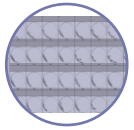
Material Analysis
Silicon purity | Unwanted elements

DEVICE FABRICATION
Advanced Nodes



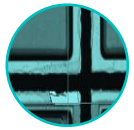
3D Metrology
Nanometer measurements | Feature shape/slope/angles | Film thickness

Macro Defect Inspection
Foreign material | Scratches | Residue

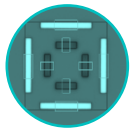


Yield Analysis Software

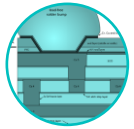
DEVICE FABRICATION
Specialty Segments



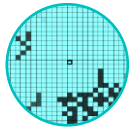
Macro Defect Inspection



CD Overlay

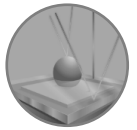


Metal Film Metrology

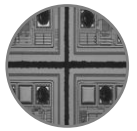


Yield Analysis Software

ADVANCED PACKAGING
Separating wafers to individual chips, connecting multiple chips into a single package

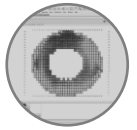


3D Metrology
Bump connections | Thru-silicon via's



Macro Defect Inspection
Placement locations

Lithography
Printing connecting circuits



Yield Analysis Software

Experience the Power of **Connected Thinking**

onto innovation

Power Device Market Landscape

Data Center P/S
(Si / SiC)

Electric Vehicle
(Si / SiC / GaN)

Distributed Power &
Power Management
(Si BCD)

Portable Technologies
(GaN / Si BCD)

Fast Charge
(GaN)

Industrial Robotics
(Si / Si BCD)

Solar Inverter
(Si / SiC / GaN)

Power Device Market Enabled by New Device Technology Trends

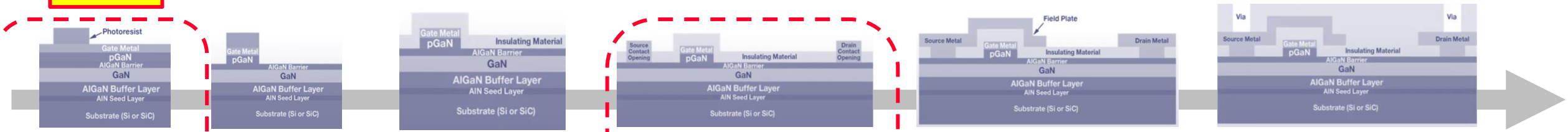
- **Wafer Size Migration** (Si, SiC, GaN)
- **Compound Semi (SiC, GaN)** enabling new power application technologies
- **Epi Layer Composition & Quality**
- **Dopant Profile Control**
- **High Aspect Ratio Trenches** (Si/SiC SJM, BCD Isolation)
- Front/Back **Metallization Schemes**
- ….and much more…

SiC Mosfet and GaN HEMT Process Control Requirements

SiC

Epi and Implantation	Hard Mask Deposition	Lithography	HM Etch	Trench Etch	Poly Deposition	Oxide CVD	Metal Deposition
Epi Thickness, Depth, Concentration	Thickness	PR CD/profile	Hard Mask Open CD/profile	Trench CD bottom shape	Poly Thickness/Recess	Ox thickness	Metal layer thickness
Element S	Atlas S	Atlas S	Atlas S	Atlas S	Atlas S	Atlas S	Echo

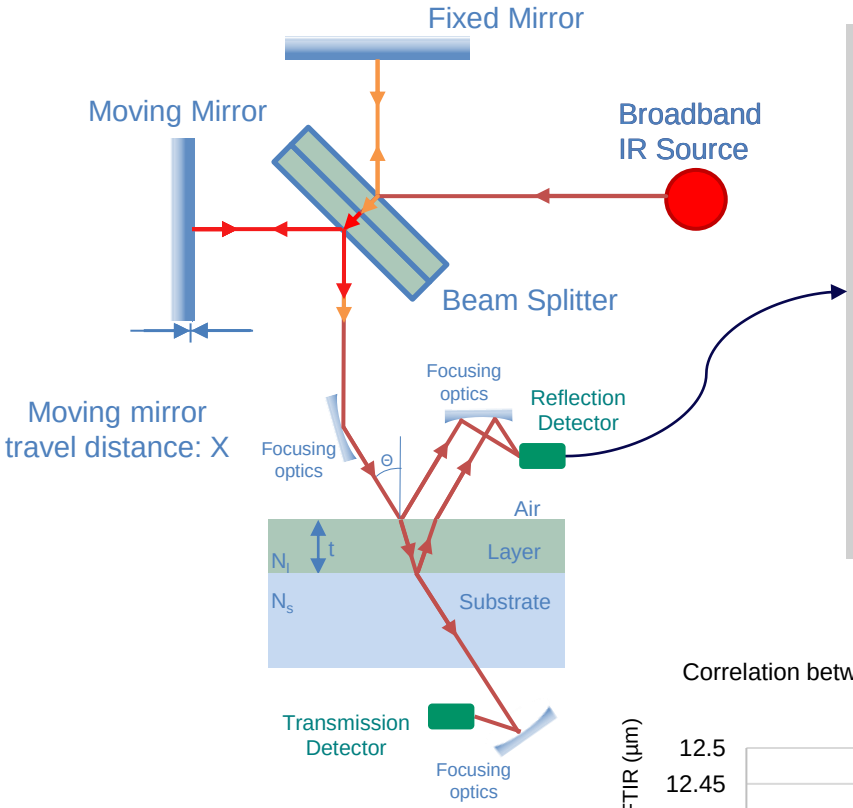
GaN

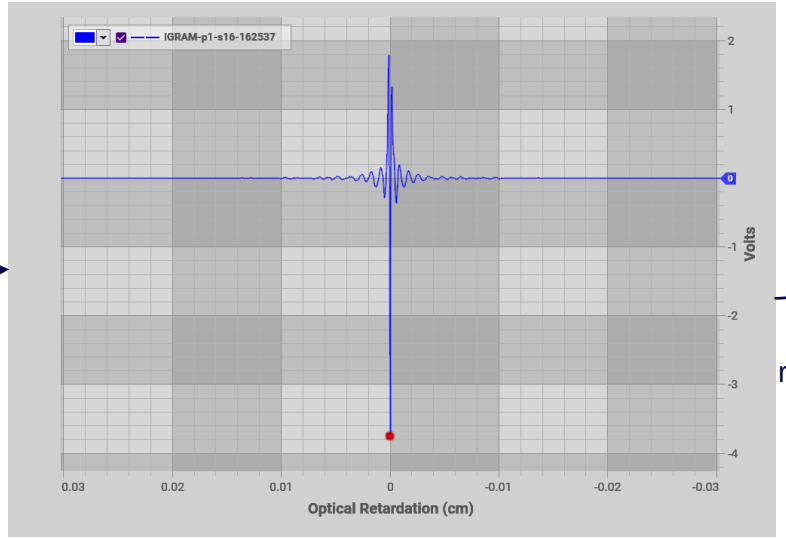


Epi Films	Gate	Dielectric films	S/D recess etch & metal stack	Metal 1 deposition	Dielectric Deposition, via etch
Epi films thickness, doping concentration;	Gate CD profile	Films thickness, non uniformity;	CD/profile; metal stack characterization	Metal layer thickness	CD/profile
Element S	Atlas S	Atlas S	Echo	Echo	Atlas S

SiC and GaN Epitaxial Layer Characterization using FTIR

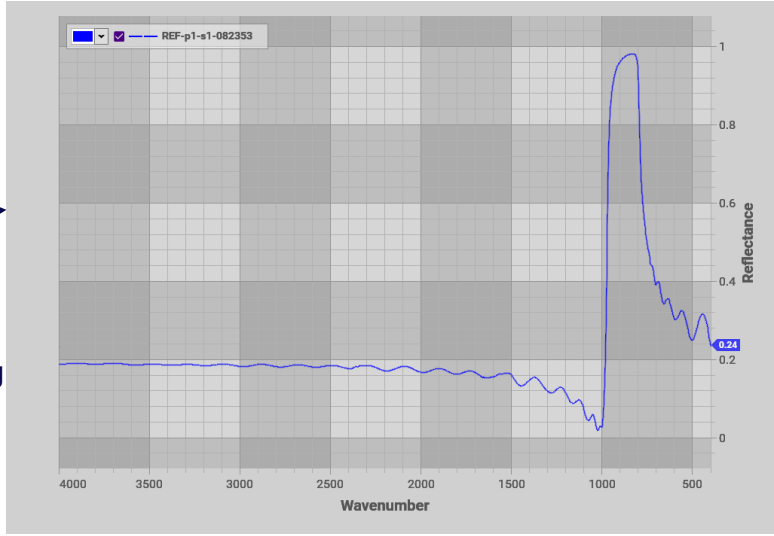
Wide Adoption in Specialty Markets (SiC, GaN, GaAs, etc.)



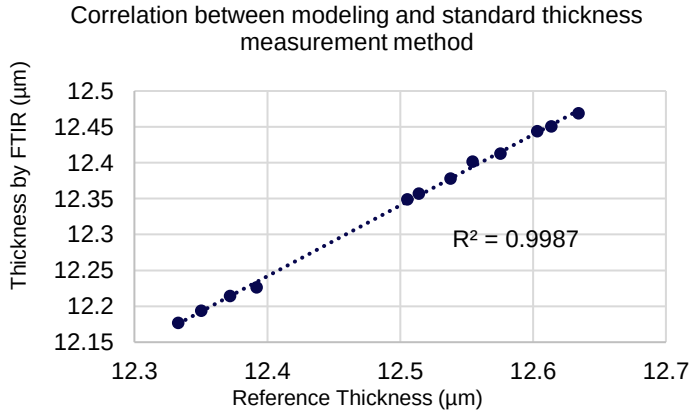


Detector signal: Interferogram

FFT and referencing



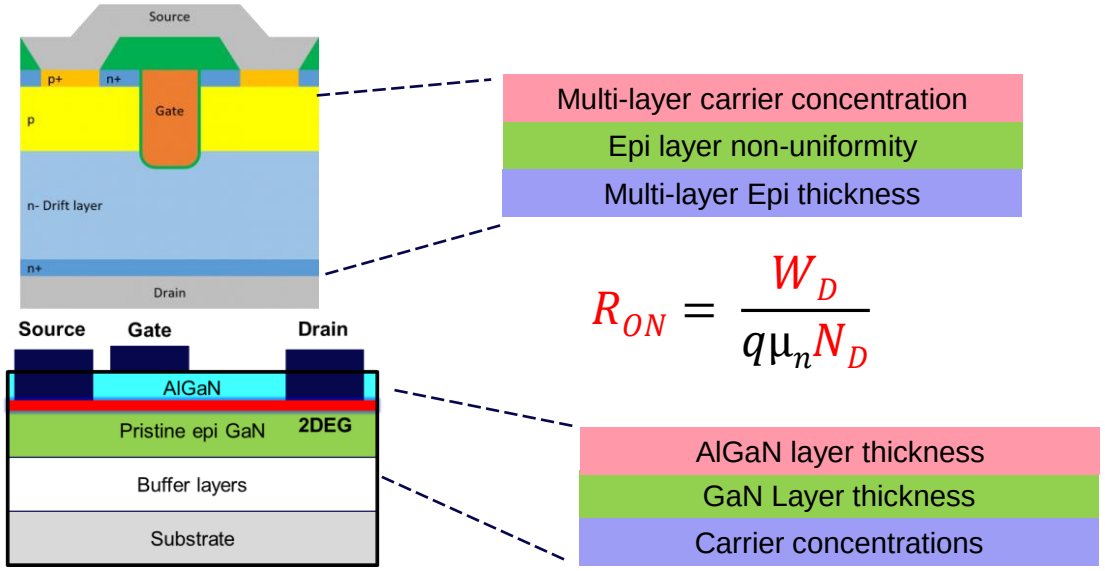
Reflectance Spectrum



- Fast, non-contact, non-destructive and accurate measurements of epi layer film thickness, non-uniformity and carrier concentration
- Collect the interferogram using a Michaelson interferometer, then FFT to get reflectance spectrum $R = I_R/I_0$
- Match theoretical and measured reflectance spectra
- Excellent correlation to reference thickness measurements

Epitaxial Layer Metrology

SiC and GaN Power Device Epi Process Challenges



Multi-layer carrier concentration

Epi layer non-uniformity

Multi-layer Epi thickness

$$R_{ON} = \frac{W_D}{q\mu_n N_D}$$

AlGaN layer thickness

GaN Layer thickness

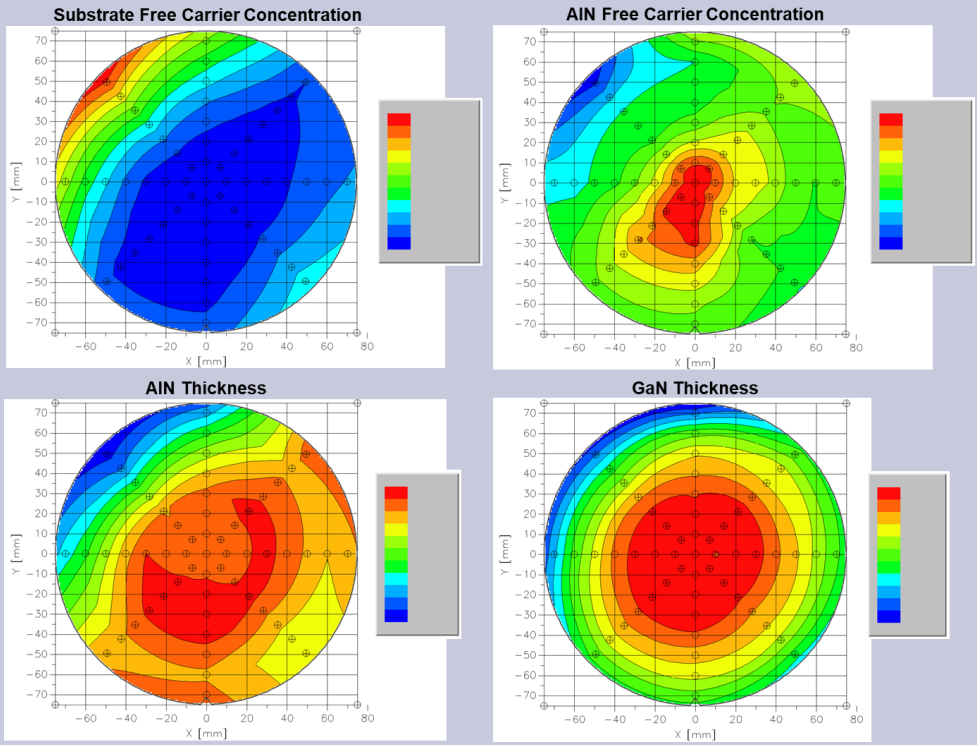
Carrier concentrations

❑ Epitaxial Layer Metrology Requirements

- **Epi layer thickness** needs to increase for higher V_{bd}
- R_{on} depends on **drift layer thickness as well as dopant concentration**
- **Multi-layer thickness** control for epi layers
- **Carrier concentration** in epi layers for GaN

FTIR technology provides unique solution to multi-layer epitaxial layer metrology

GaN: Epi Layer Thickness; Dopant Concentration

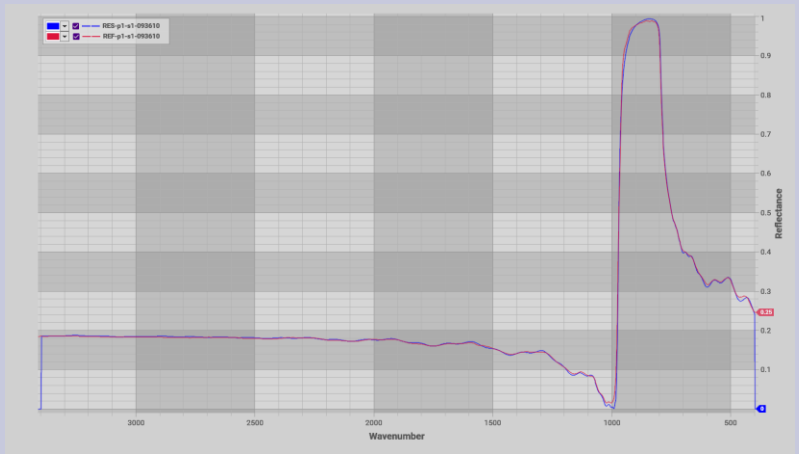


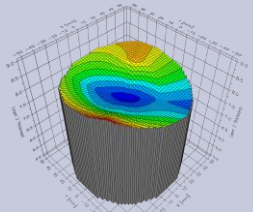
GaN:
Epi layer thickness and AlN/SiC carrier concentration

Epitaxial Layer Metrology

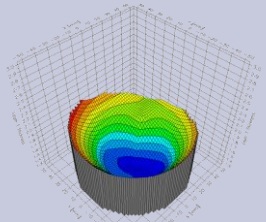
SiC: Epi Layer Thickness; Dopant Concentration

L4	EPI Layer 2	Constant Model
L3	Buffer 2	Free C. C.
L2	EPI Layer 1	Constant Model
L1	Buffer 1	Free C. C.
	Substrate	Free C. C.

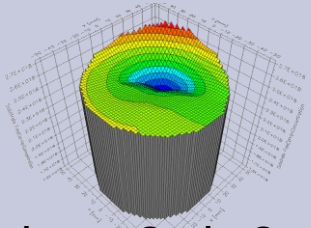




Layer 2 Thickness

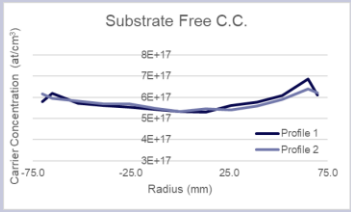


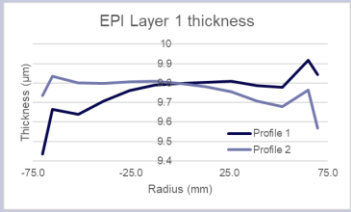
Layer 1 Thickness

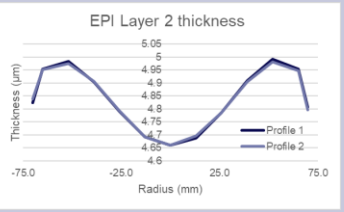


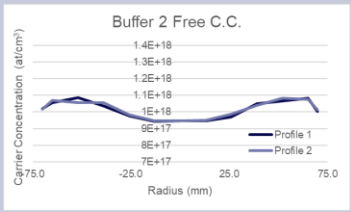
Substrate Carrier Conc.

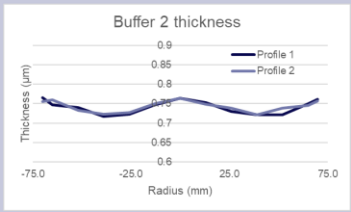
Parameter		Wafer Average	Wafer Stdev
Substrate	Free C.C. (at.cm^{-3})	5.8e17	3.75e16
EPI layer 1	Thickness (µm)	9.751	0.098
Buffer 2	Thickness (µm)	0.741	0.015
	Free C.C. (at.cm^{-3})	1.02e18	4.96e16
EPI layer 2	Thickness (µm)	4.849	0.108







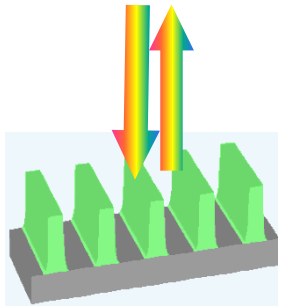


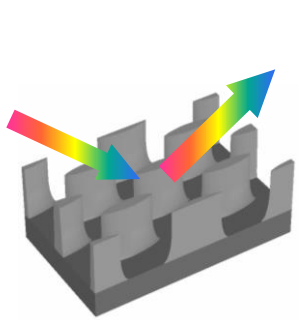


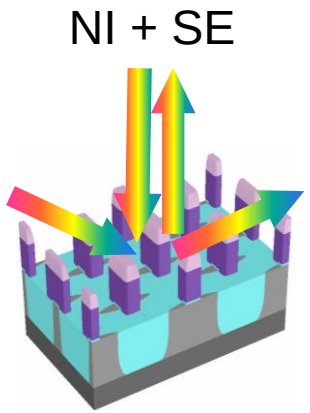
FTIR modeling can perform accurate measurements on complex SiC structure with repetitions of buffer & drift layers

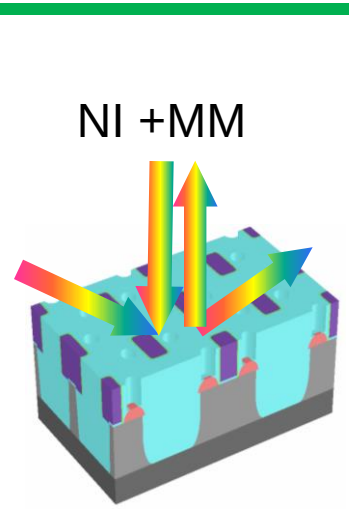
Thin Films and OCD on the Same Platform

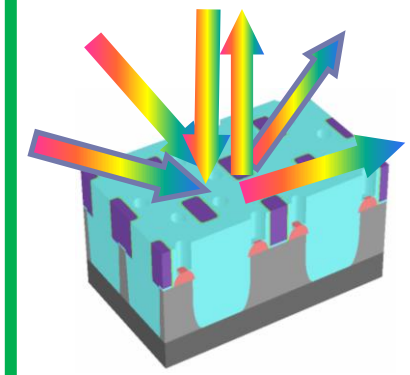
Advance Node Metrology now being used for Specialty Market



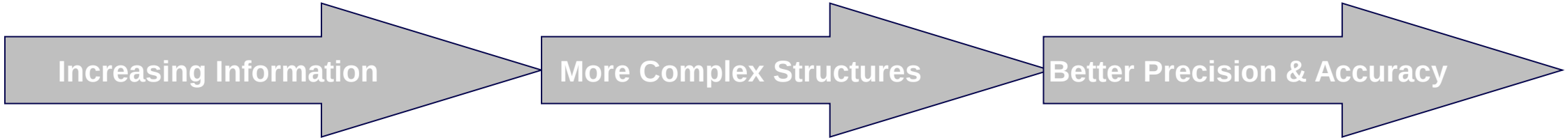






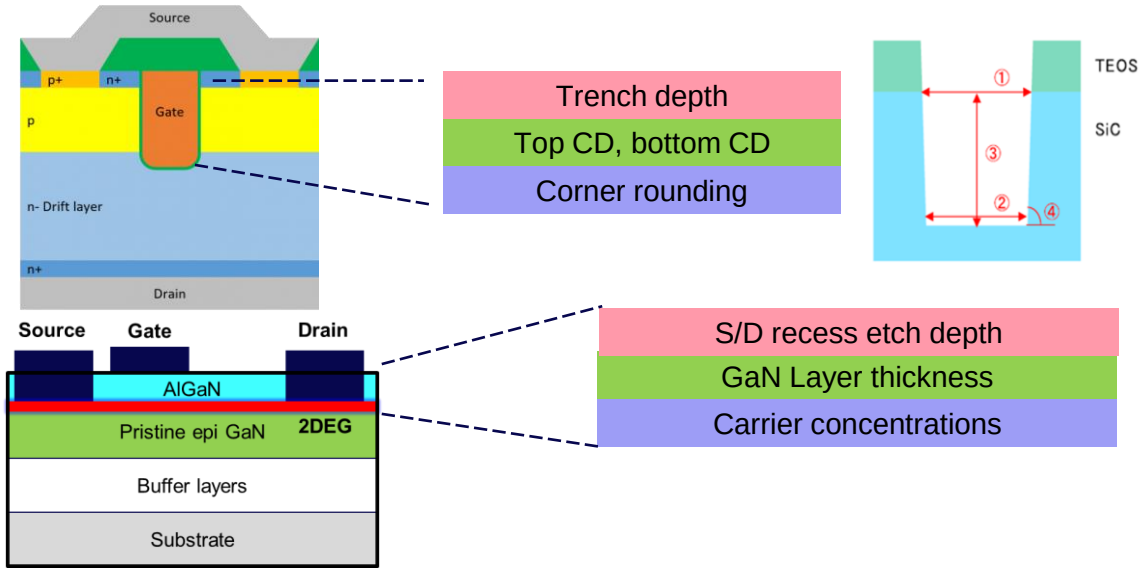


	NI OCD	SE (RCE)	NI+SE	NI+Mueller	NI+SE0+SE90 NI+MM1+MM2
Data	TE/TM	N, S, C	TE/TM/N, S, C	TE/TM/ MM	TE/TM, SE or MM for multi-azimuths



Optical Critical Dimensions, and Thin Films Metrology

SiC and GaN Power Device Critical Dimensions

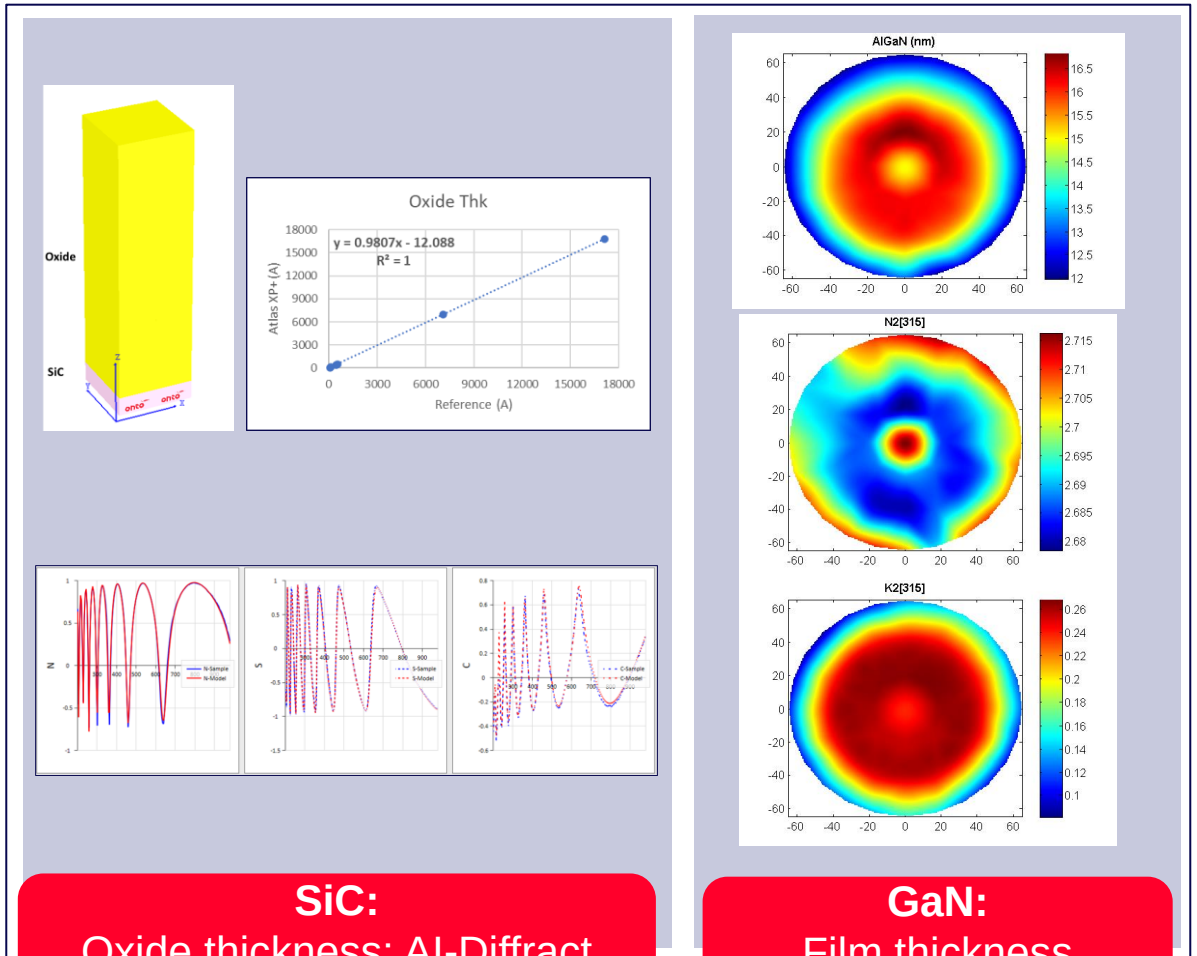


❑ OCD Requirements

- **Must control depth, top CD and bottom CD** to accurately extend inversion layer for free carrier flow for all devices across the wafer
- **Corner rounding** is needed to hold off high electric field density
- **S/D contact recess etch depth** critical to stop at the 2DEG
- **Film thickness** and uniformity controls breakdown voltage

Optical CD measurements enable uniform trench profiles and etch CDs across the wafer

Thin film characterization

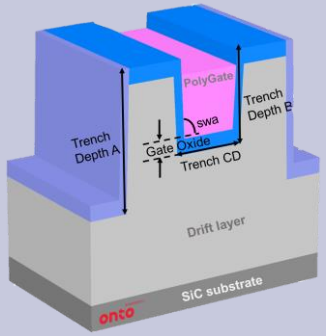


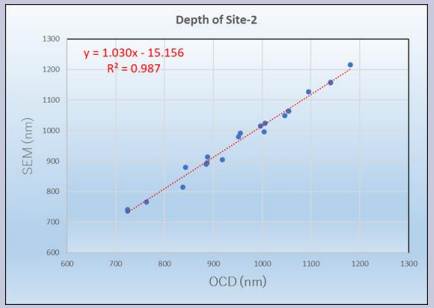
SiC:
Oxide thickness; AI-Diffract Model Fit; Correlation to SEM

GaN:
Film thickness n/k measurements

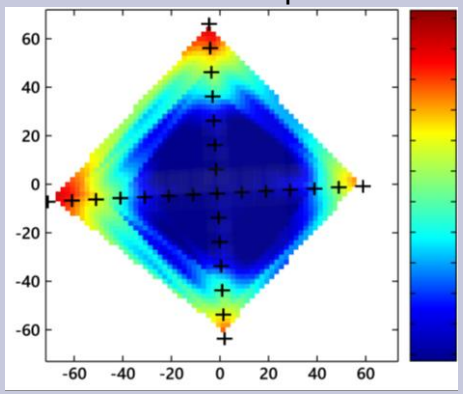
Optical Critical Dimensions, and Thin Films Metrology

Dual-trench depth profiles

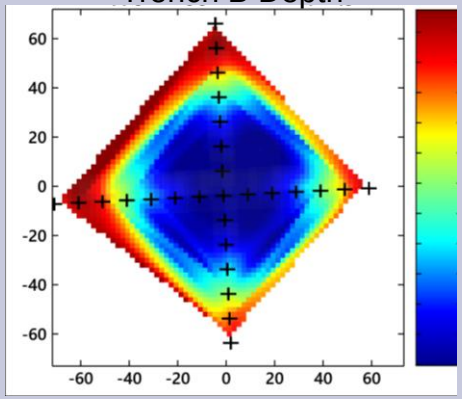




Trench A Depth

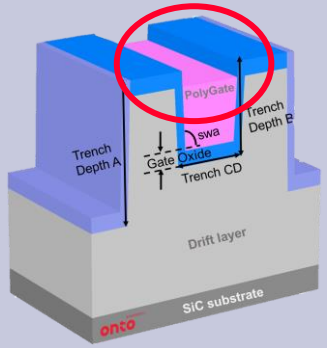


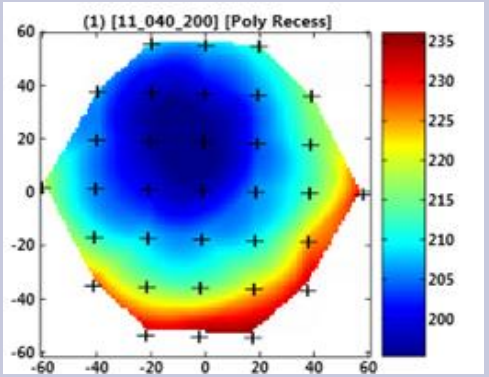
Trench B Depth

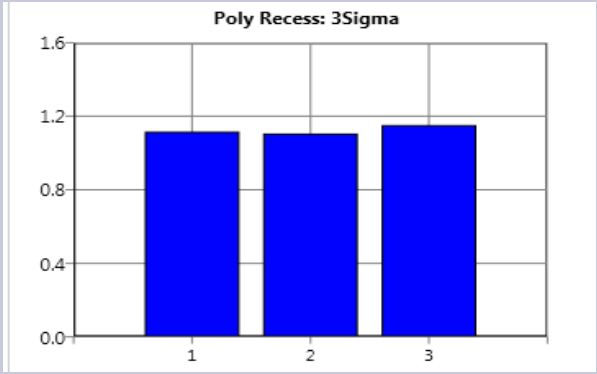


Double trench depths mapped
Correlated to SEM data

SiC: Poly recess etch and trench depth mapping



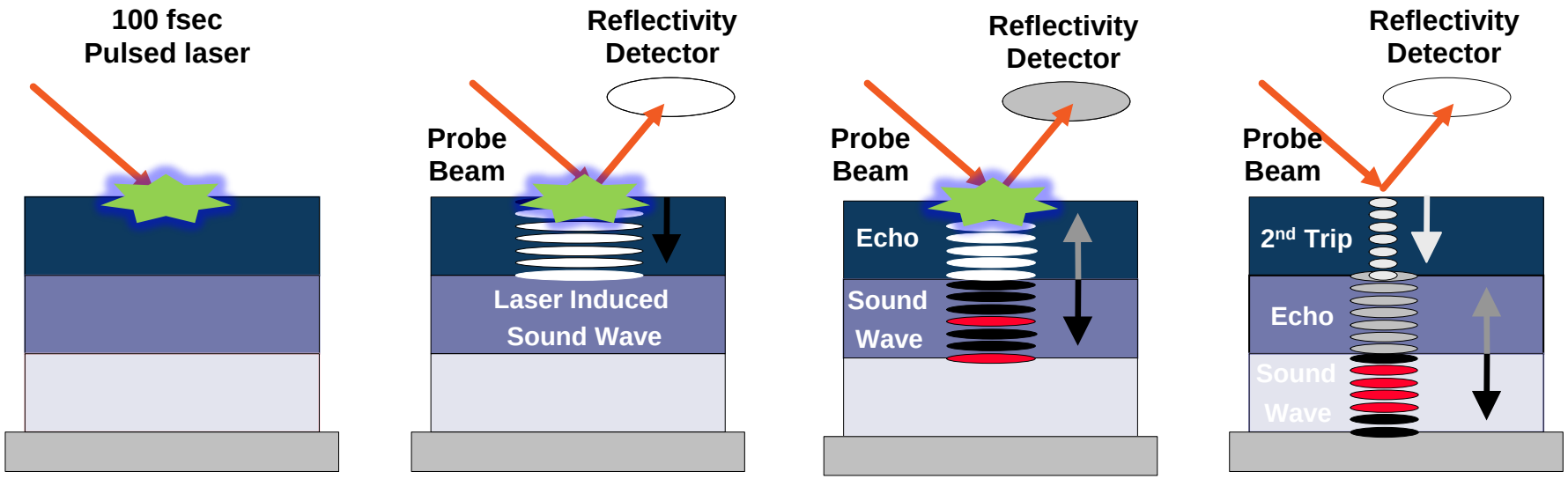




Poly recess etch mapped – accurate recess important for next step (dielectric dep), which controls V_{SG}

PULSE Technology for Metallization Metrology

Unique Picosecond Laser Ultrasonics



Ultrafast laser generates a sound wave at the surface of the filmstack

The sound wave moves down through the film until it reaches an interface

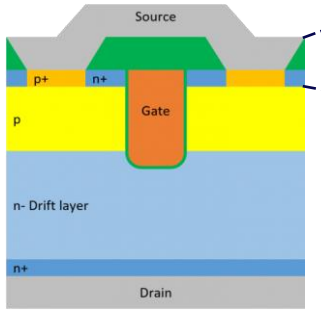
An “echo” is generated at the interface and travels back to the surface where it is detected by a change in reflectivity

The sound wave and its reflections continue to travel, resulting in further reflectivity changes at the detector

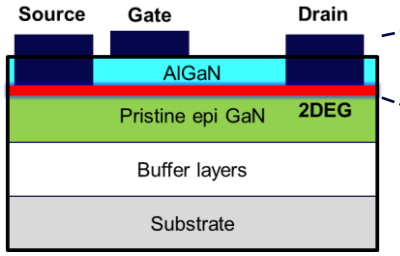
Time to the Echo = Thickness
Size/shape/decay of echo = Material Properties (roughness, adhesion, density)

Opaque Films Challenges, and HVM Solution

SiC and GaN Power Device Metal Process Challenges



Protection:Au, Ag, Al
Conduction layer: Al, Ni, Cu
Ohmic Contact: Ti, TiW, Ni



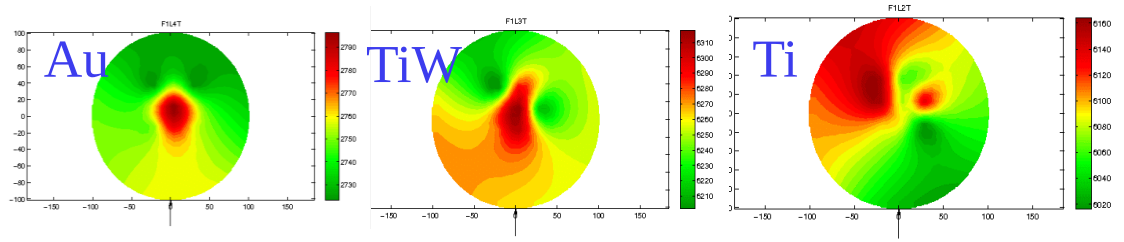
Corrosion prevention Au
Conduction layer: Al
Diffusion barrier: Ni
Adhesion: Ti

❑ Metallization Challenges & Requirements

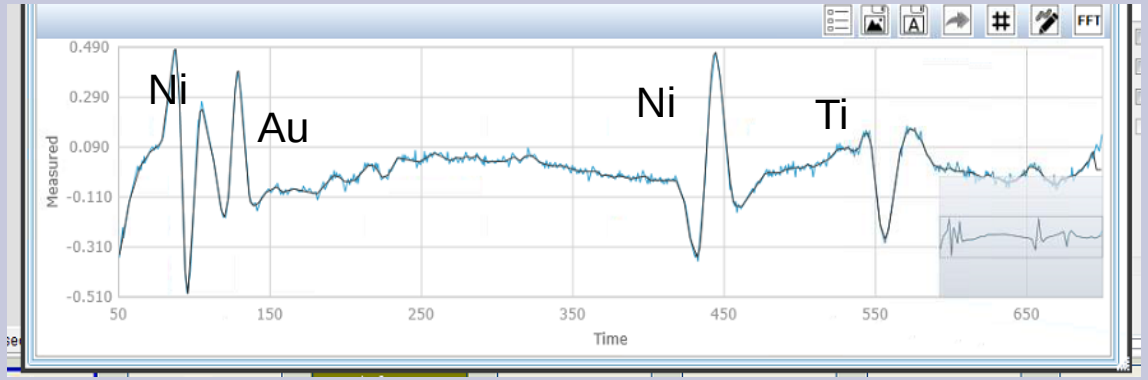
- **Contact resistance** control between metal and SiC
- **Multi-layer thickness** control for each layer
- **Uniformity control** for 10-20nm thin films like diffusion barriers
- **Uniformity control** for > 150mm wafers

Need HVM-ready non-destructive high throughput method to monitor multi-layer metal films

Multi-layer measurements



Ni/Au/Ni/Ti

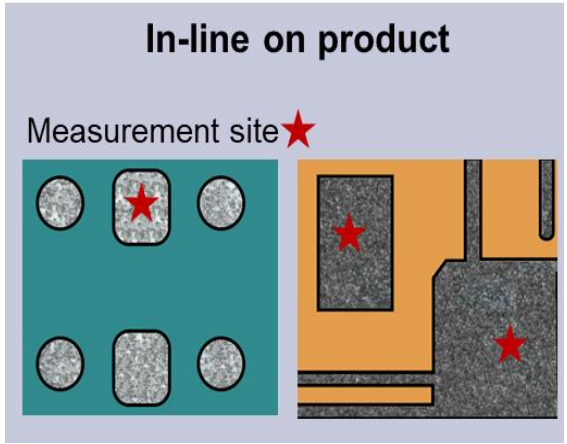


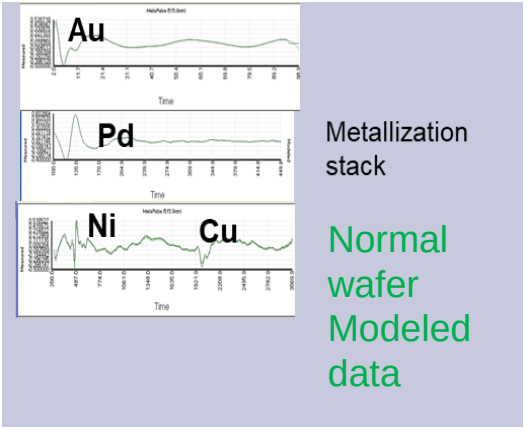
Within-wafer uniformity mapping

Measurement of repeating layers of same metal

Opaque Films Challenges, and HVM Solution

Multilayer metallization stack; in-line HVM solution



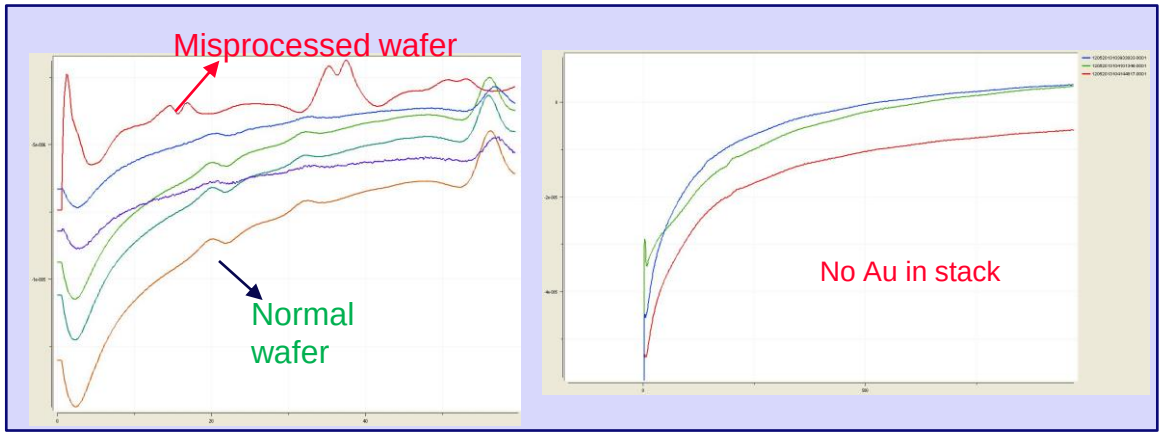


❑ Metallization Challenges & Requirements

- **Simultaneous** measurement
- Gage-capable **repeatability** on on wafer; pattern loading effects
- Detection of **missing layers** or misprocess

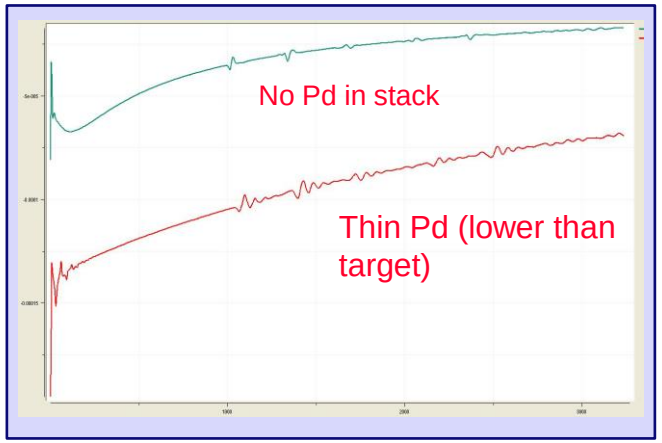
Metallization: Simultaneous measurement of multi layers

Misprocess Detection **Au/Pd/Ni/Cu**



❑ Echo signatures

- **Missing layers** or misprocessed layers in 4-layer stack flagged automatically using GOF criteria
- Data validated w/X-SEM



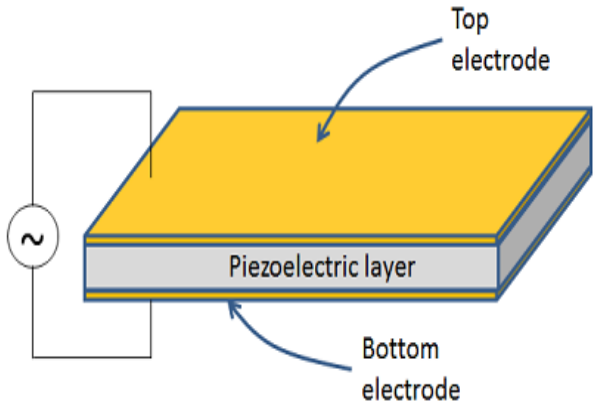
HVM solution for detecting misprocessing

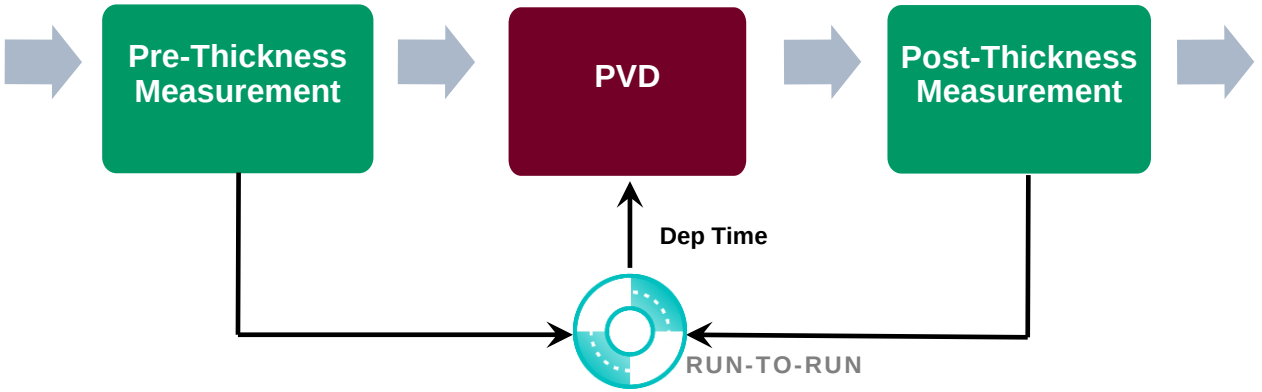
Example of Total Solutions: W-i-W Frequency Mismatch

Unique HW + Enterprise SW + Customer HVP = Solution

- **Issue:**
  - High WiW non-uniformity of film deposition across the wafer can lead to different frequencies in MEMS devices center-to-edge of the wafer
- **Onto Solution:**
  - **ECHO™** can measure metal films in-line
  - **Discovery R2R** monitors the film, data are fed forward/backward into the PVD chamber for precise WiW and WtW thickness control of PVD piezoelectric films
- **Result:**
  - 50% - 100% improvement in Cpk is seen in film thickness uniformity and stress

Schematic of BAW Resonator





Experience the Power of **Connected Thinking**

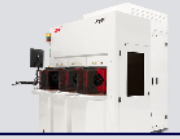
Conclusions

M&I Technology Adopted for Advance Nodes now used in Specialty Markets

Technology	Solutions for SiC/GaN
FTIR: ▪ Fast, non-contact, non-destructive and accurate measurements of films thickness and carrier concentration	▪ Accurately monitor epi layer thickness and dopant concentration, thereby reduce variability of V_{bd} and R_{on} in devices W-i-W and W-t-W
OCD/Thin-Film Metrology: ▪ Optical characterization for trench and recess etch critical dimensions ▪ Spectroscopic ellipsometry for thin film thickness mapping	▪ Control of trench top/bottom CD accurately extends inversion layer in drift region ▪ Measurement/control of corner rounding reduces localized hot-spots resulting from high electric field density ▪ OCD metrology enables excellent control of S/D recess etch in GaN – critical for making ohmic contact
Opaque Films Metrology ▪ Unique acoustic technology to monitor metal films ▪ Multiple layers can be monitored simultaneously, and missing layers can be flagged	▪ Accurate control of thin films will ensure good adhesion and diffusion-barriers in metal stack ▪ Thin film control will become much more critical as SiC wafers transition from 150mm to 200mm

Onto Innovation's Major Products

Atlas® V, Atlas® S
Standalone thin film and OCD metrology



Aspect®
OCD metrology for 3D NAND and high aspect ratio structures

IMPULSE® V
Integrated thin film and OCD metrology

Echo™
Acoustic film metrology

Iris™
Thin film and common OCD metrology

IVS™
Overlay and CD metrology

Element™ S
FTIR metrology

AWX™ FSI
Unpatterned frontside inspection

EB40® / NovusEdge®
Automated all-surface defect inspection for patterned and unpatterned wafers

Dragonfly® G3
2D/3D inspection and metrology

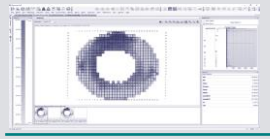
Firefly®
Sub-micron panel inspection

NSX® and F30®
2D inspection, CD, RDL/TSV, 2D bump, 2D/3D metrology, all-surface ready

JetStep®
Litho for Advanced Packaging and FPD

Analysis Software
Inline yield and defect management

Control Software
Fabwide R2R and FDC



Classification Software
ADC, SPR, and review solutions

Ai Diffract™ Software
AI-guided OCD modeling and analysis software

≤ 200mm

300mm

METROLOGY INSPECTION LITHOGRAPHY SOFTWARE

Thank You

谢谢 | 謝謝	ありがとう	Obrigado
Danke	감사합니다	Merci

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