End-point Detection for Plasma Etching – *Knowing When to Stop*

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NNCI Etch Symposium 2022 @ UPenn

Penn
University of Pennsylvania

April 21-22, 2022

About The Presenter: Joshua Perlstein

- Currently a lead applications engineer for SPTS North America (deposition products), I went to school at the University of Central Florida where I got degrees in mechanical engineering (BS) and materials science (MS); I worked with optical thin films and device fabrication heavily in graduate school.
- I have worked previously as a process development engineer, manufacturing equipment engineer, and field service engineer.
- I like airplanes, houseplants, the great outdoors, travel, and watching wafers move around a fab.

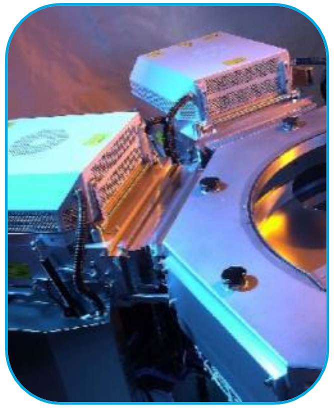
About SPTS Technologies

A leading manufacturer of etch and deposition process solutions and equipment for the semiconductor manufacturing industry

- SPTS Technologies is part of the Electronics, Packaging and Components (EPC) Group of KLA Corp.
- Global presence – operate across 19 countries
  - Headquartered in the UK
  - Manufacturing sites in UK and US
- Support our customers with local Sales and Service teams

Etch

PVD



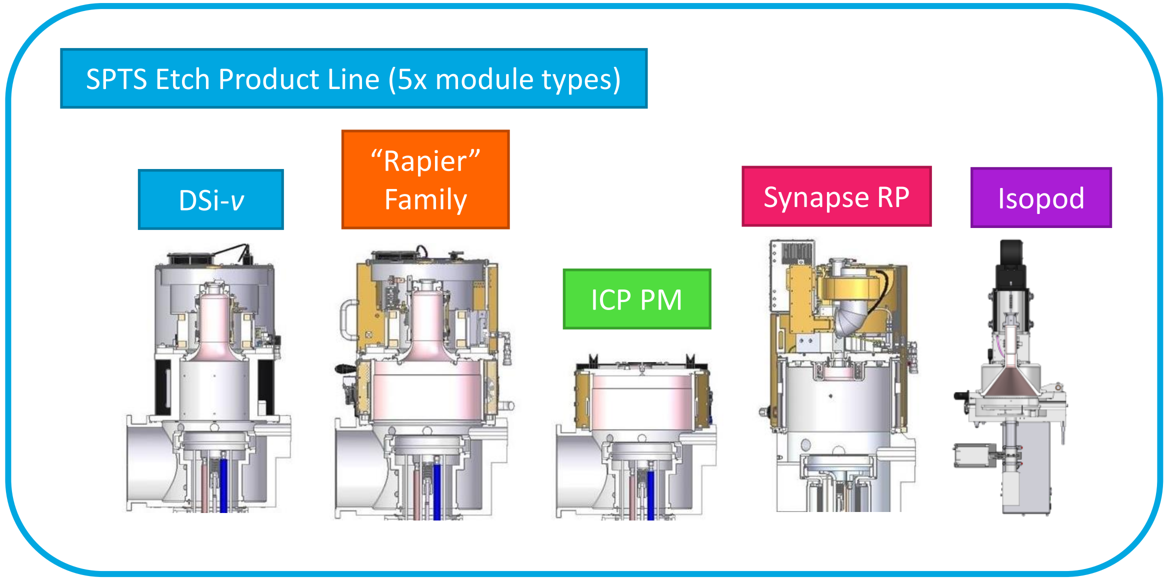
PECVD

Release Etch & MVD

Contents

2022 NNCI Etch Symposium

National Nanotechnology Coordinated Infrastructure



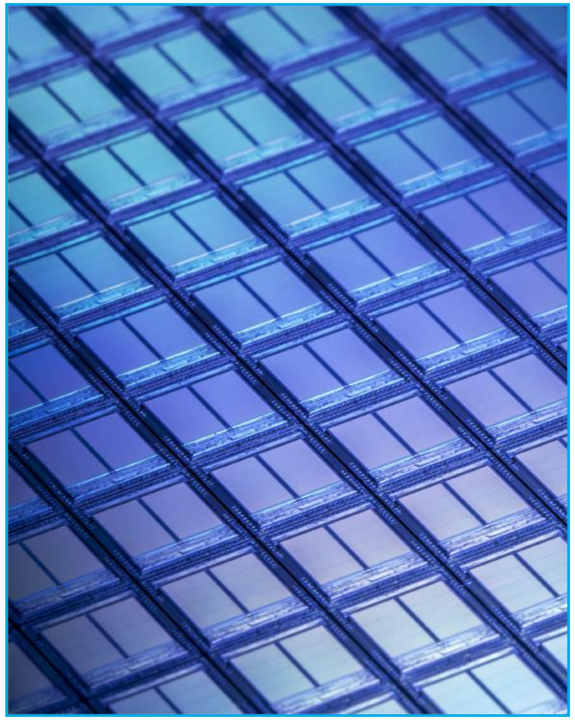
- What is End-point Detection (EPD)?
- Why do we need EPD?
- What methods exist for EPD?
- 'Troublesome' etches?

- Examples of EPD for Critical Etch Applications ….
  - **Parametric**
  - **Optical Emission Spectroscopy** (OES)
    - Including Claritas™
  - **Reflectance & Interferometry**
    - White Light
    - Visible LASER
    - Near infrared LASER
  - **Image Capture** - ReVia®, Ascent™
- Summary table of EPD methods
- Conclusions

KLA

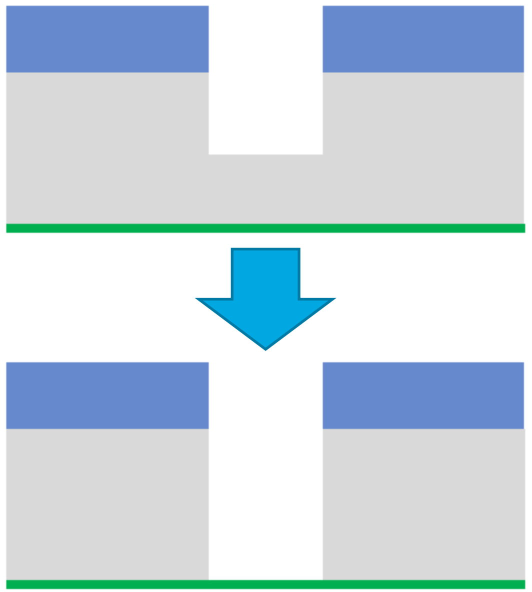
What is End-point Detection?

- Plasma Etching
  - Critical step in fabrication of all semiconductor devices and most other microfabricated devices.
- Important to know when the process is complete
- Techniques employed to detect the process completion point, or a point in the process prior to completion, are referred to as *'End-point Detection (EPD)'*



Why Do We Need EPD?

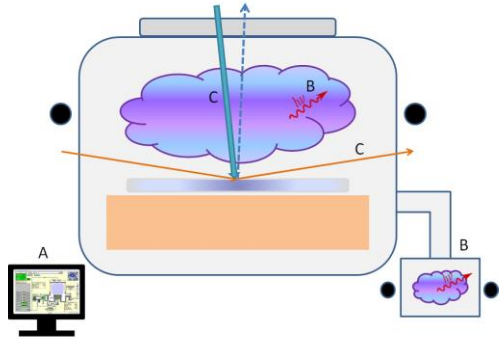
- Time based etching has limitations
  - Variations in film thicknesses
  - Variations in film composition or density
  - Variations in etch rate – from chamber condition
- End-point Detection offers benefits
  - Etch time can ‘float’ – reducing test wafers
  - Track certain layers or depths
  - Modify process eg when we reach a stop layer
  - Improve process repeatability
  - Prevents under-etching → eliminating scrap or re-work
  - Prevents over-etching → better CD control, better sidewall quality
    better under-layer loss, better notching
    better throughput, better device performance
    better Yield



EPD selling price can be
8-12% of the Process Module
But ROI can be very short
99% of all Etch PMs shipped
have an EPD of some sort

End-point Detection Methods

SPTS Plasma Etch End-Point Control Options

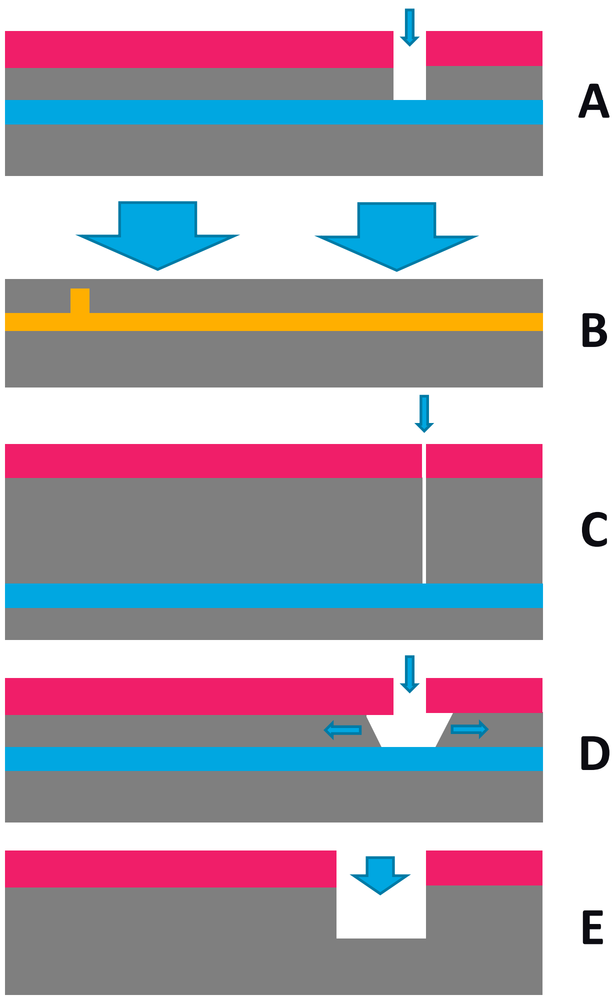


- EPD requires an aspect of the process that changes with time
  - Either as the etch depth increases
  - Or as different layers in the wafer are reached
- Three categories of EPD
  - Etch system monitoring – 'Parametric' (A)
  - Plasma or gas monitoring (B)
  - *In-situ* wafer monitoring (C)

	Method	Monitors	Based on
A	Parametric	**System**	APC angle or He flow
B	Optical emission spectroscopy (OES)	**Plasma**	Glow from plasma
	Claritas		Re-ignited glow from plasma
C	WL Reflectance	**Wafer**	Reflection
	WL Interferometry		Broad area interferometry
	LASER interferometry		Small spot interferometry
	NIR		Broad area interferometry
	ReVia, Ascent		Wafer vision

‘Troublesome’ Etches

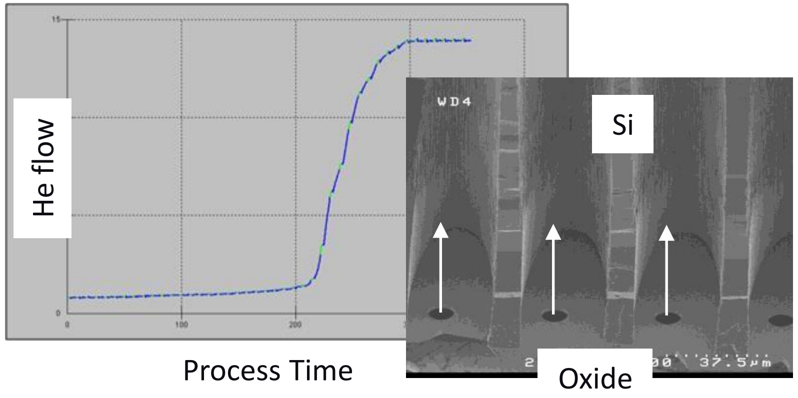
- **A.** Very low open areas
  - <1%, eg. Back Side Vias (Si, GaAs, SiC)
- **B.** Very high open areas
  - >99%, eg. Via Reveal
- **C.** High aspect ratios
  - eg. SOI at 50:1 AR
- **D.** Etching doesn’t stop
  - eg. tapered TSVs
- **E.** Blind etches – with no under-layer
  - eg. Bulk thinning or Power Trenches
- Wafers/chemistry prevent standard methods
  - eg. Ni or Cu masked SiC Via etching (SiF* optical emission is supressed by presence of metal mask)



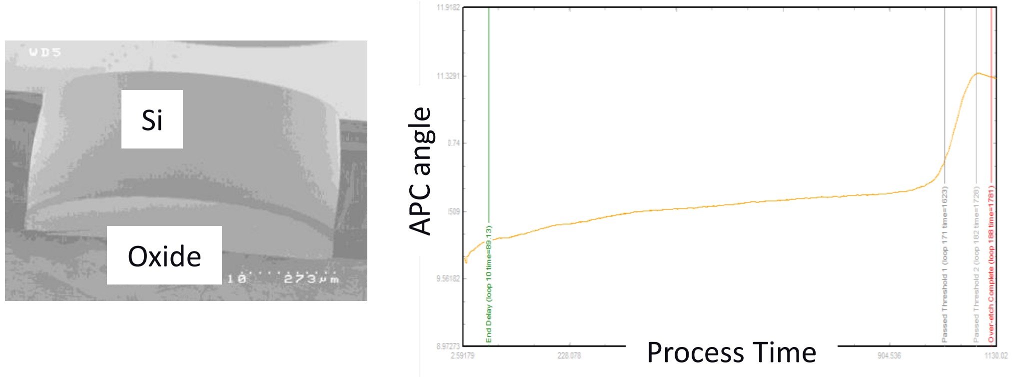
Parametric EPD

- Based on Etch system datalogs – FOC!
- APC valve position or He back side pressure flow rate

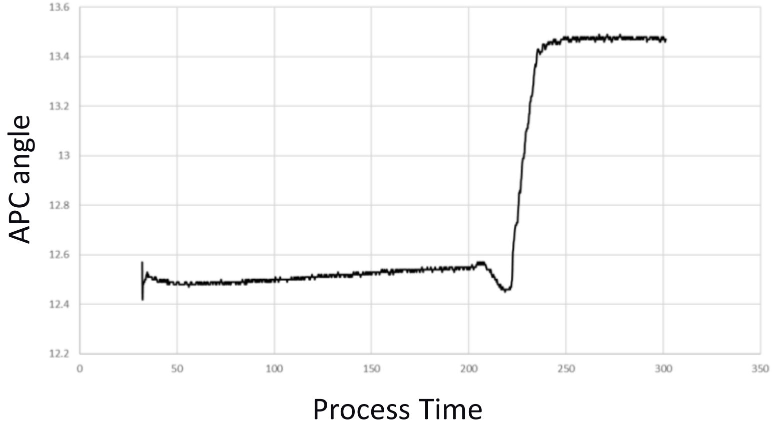
Si trenches for inkjet nozzles



Si Cavities for Microphones



Blanket Si etch-off for FO-WLP



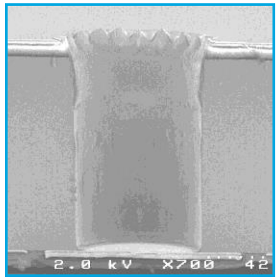
Plasma or Gas Monitoring

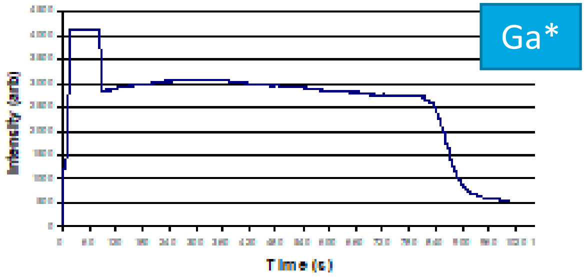
Technique	Cost	Benefits (+)	Disadvantages (-)
LASER Induced Fluorescence (LIF)	$$$$	• Provides some detail of plasma chemistry	• Limited to species that fluoresce • Difficult to interpret data • Affected by plasma glow
Mass Spectroscopy (e.g. RGA)	$$$	• Analyses all species	• Intrusive to plasma • Needs high vacuum (differential pumping) • Species are ionised/cracked before detection • Difficult to interpret data • Low filament lifetime in chemical plasmas
Optical Emission Spectroscopy (OES)	$$	• Widely applicable • Easy to use & interpret	• Limited to species that are emitting light
Langmuir Probe	$	• Easy to use	• Intrusive to plasma • Limited to ion & electron information • No chemistry information • Difficult to interpret

- OES is preferred method for Plasma Monitoring

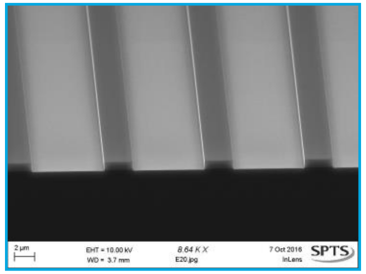
Optical Emission Spectroscopy (OES)

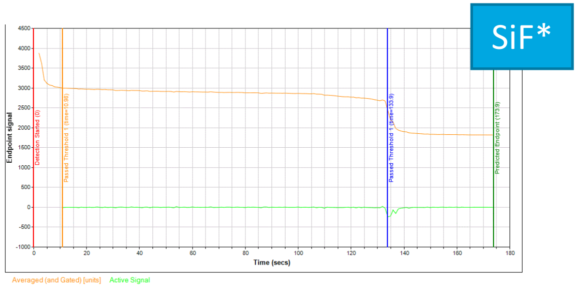
GaAs back side Via
RF device



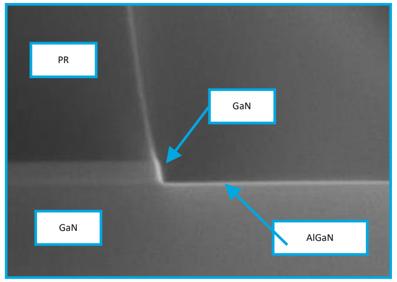


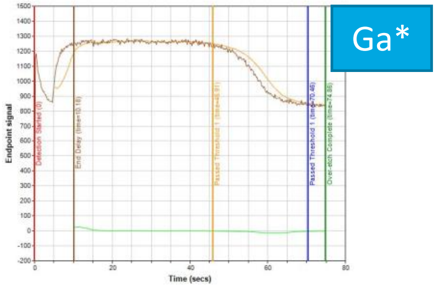
Oxide mask open
MEMS device



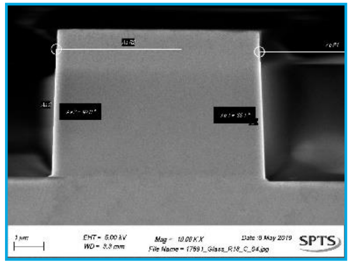


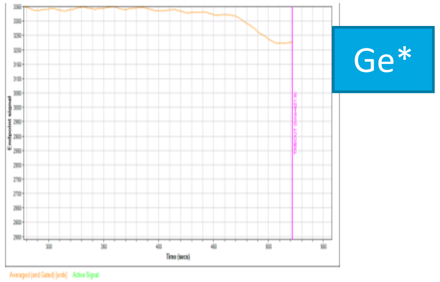
GaN to AlGaN etch
Power device





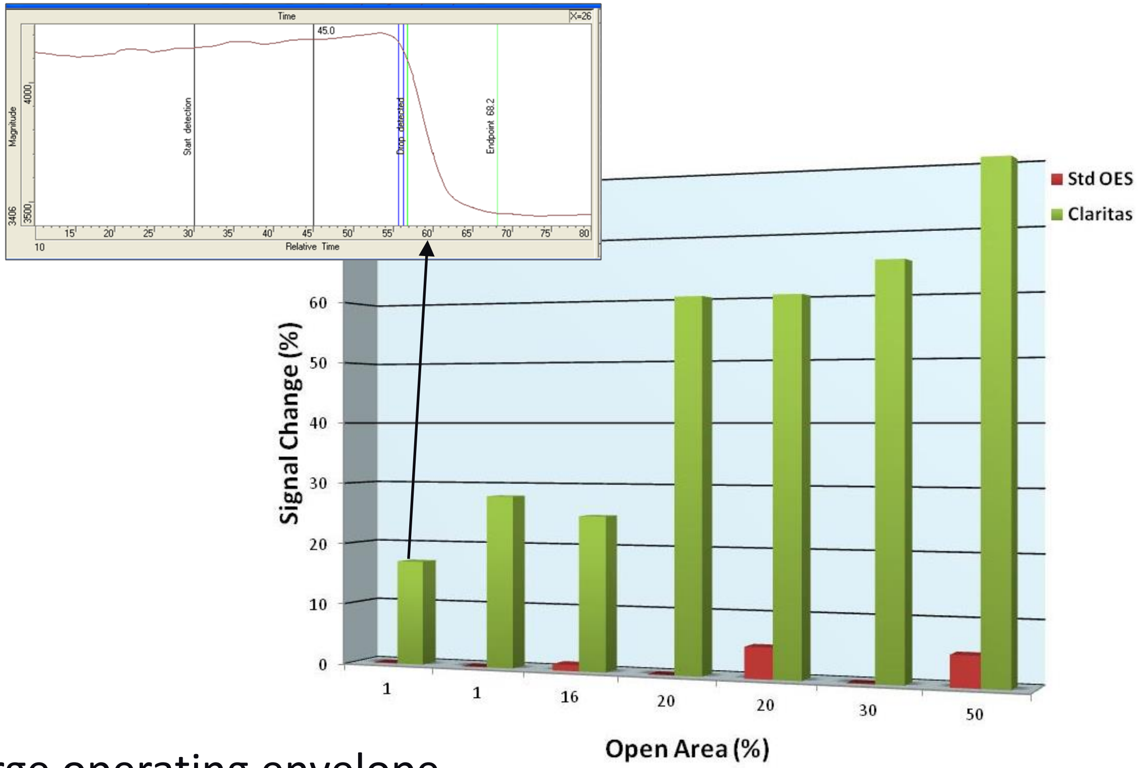
Ge-doped core etch
Photonics device





- Also used for inter-wafer cleans of the process module

Claritas™ (Patented)



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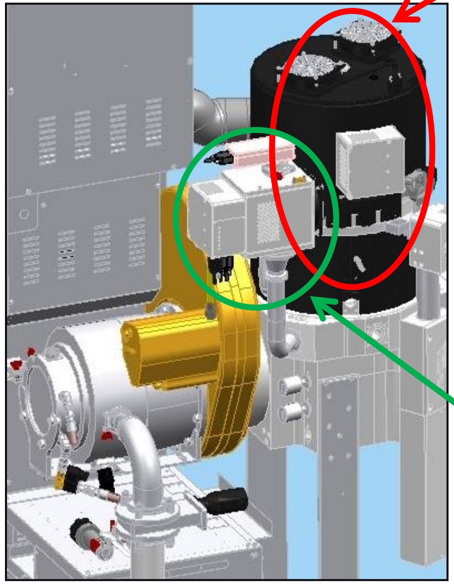


Etch Chamber

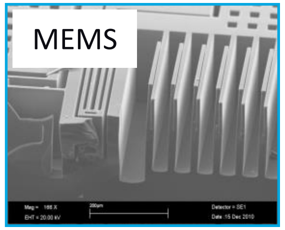
Rapid fluorination of SiF to SiF_4 Unable to 'see' SiF*

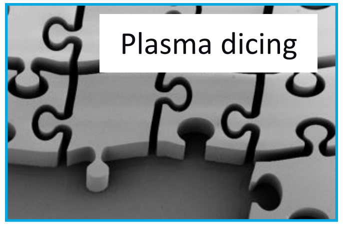
Claritas Unit

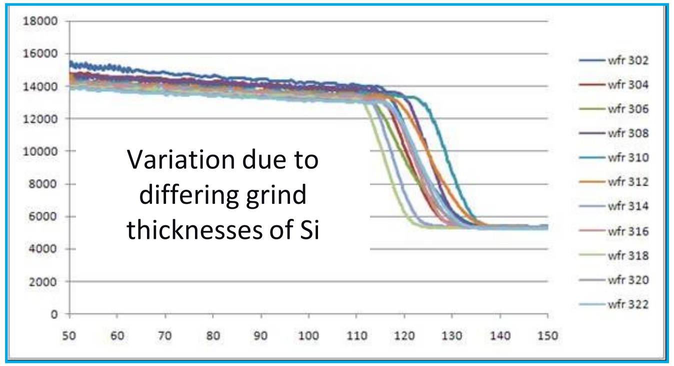
High concentration of SiF_4 cracked to re-form SiF*

Easily detected

- Large operating envelope
- For all DRIE etches to a stop layer
- Detection limit <0.05% OA



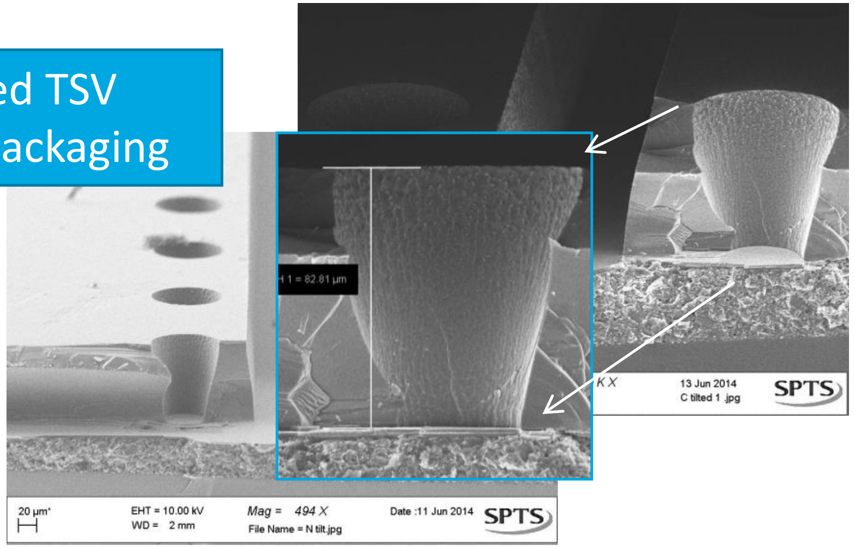


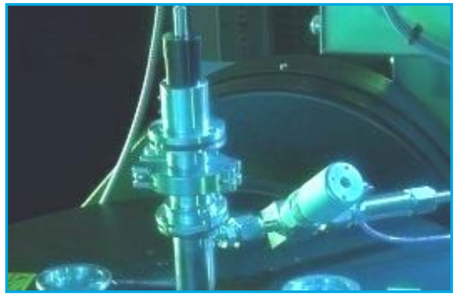


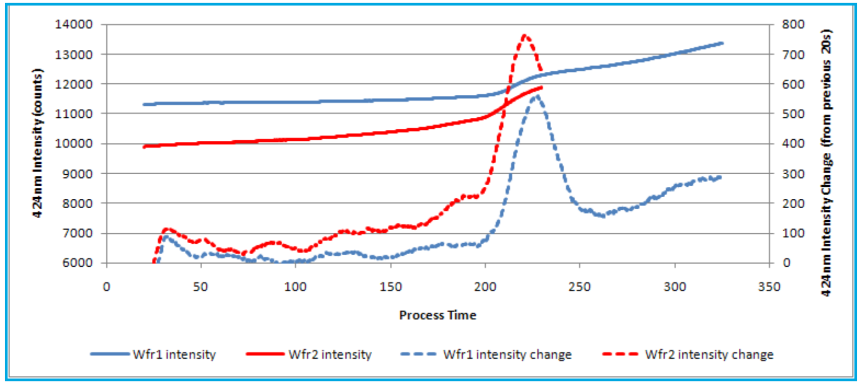
White Light Reflectance

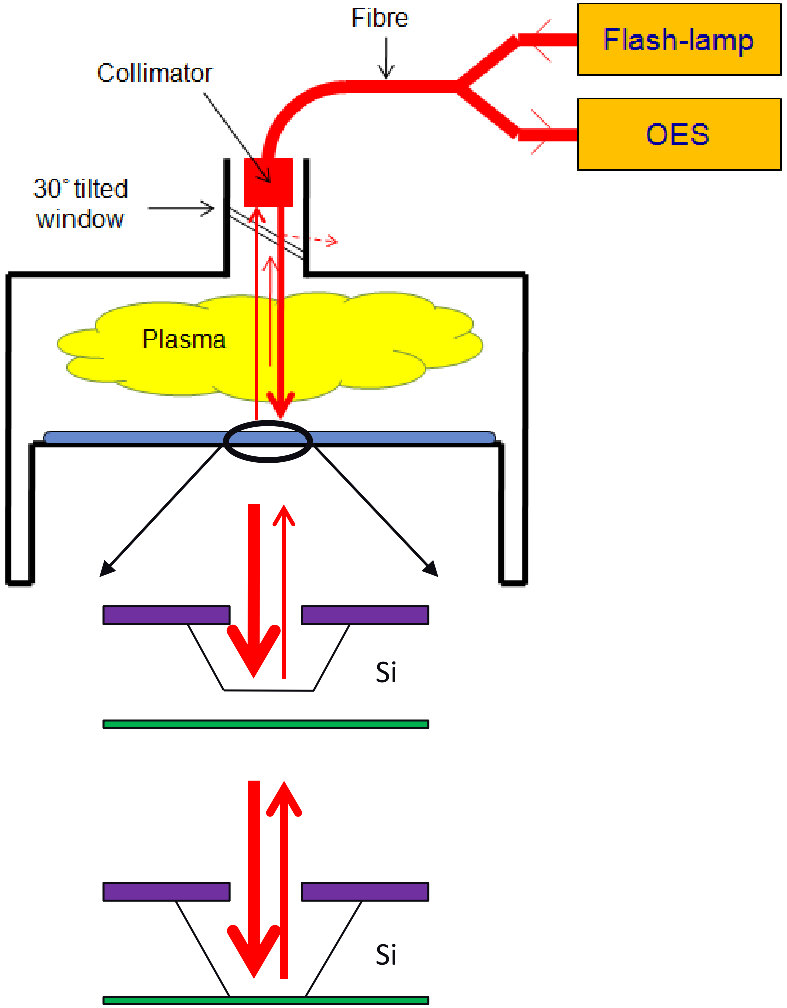
- In some cases there is no OES transition

Tapered TSV
for Adv Packaging



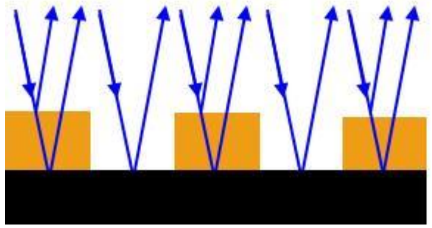






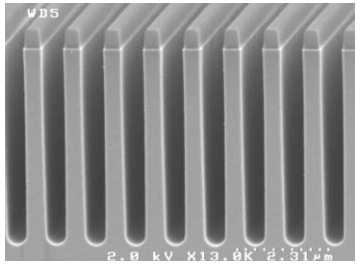
White Light Interferometry

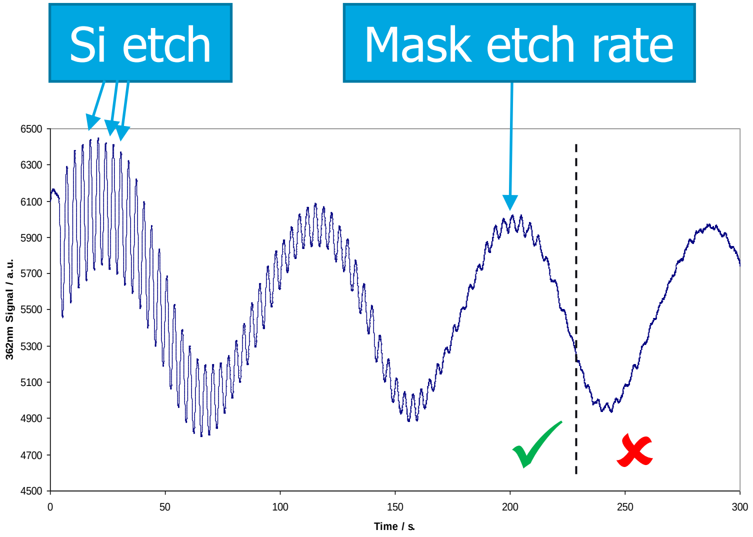
- Used for blind etches – no under-layer

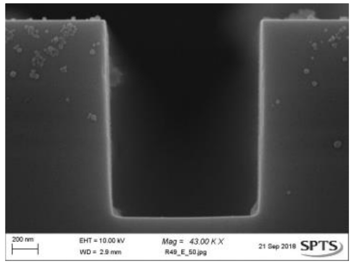


  - ~2cm spot size means no requirement for dedicated feature on wafer
  - Real time trench depth read-out on every wafer

Si trench etch for Power device

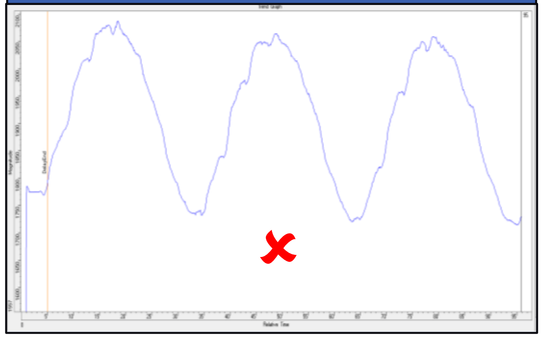




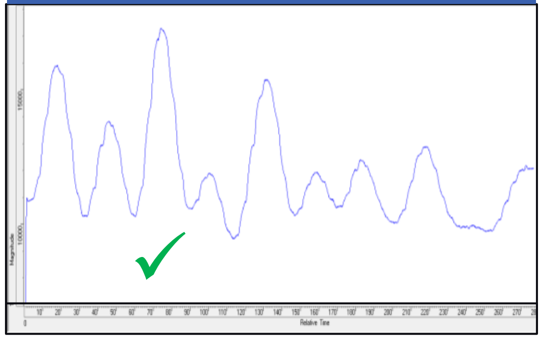


SiC trench etch for Power device

8.5% OA

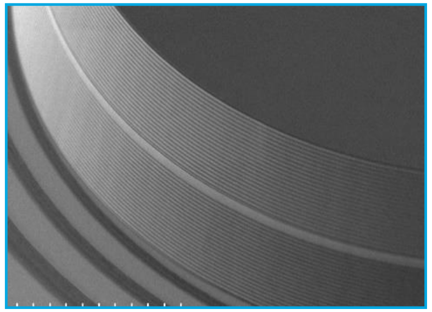


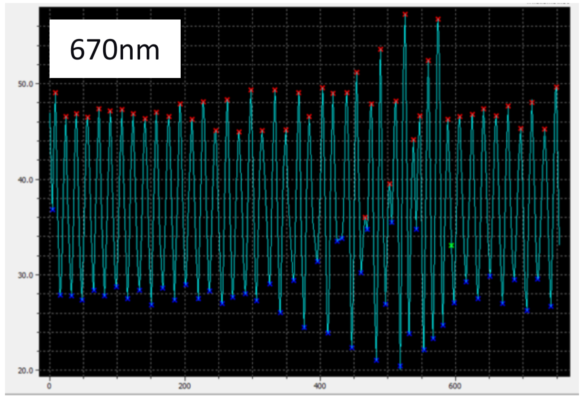
47% OA

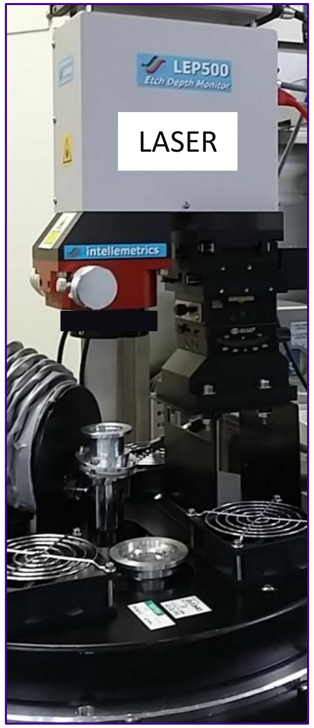


Visible LASER Interferometry

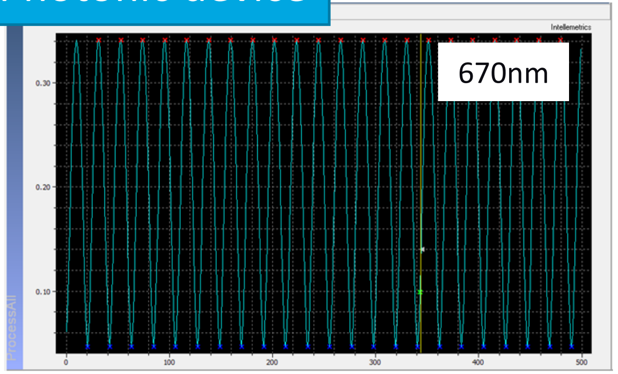
Mesa etch
for VCSEL device





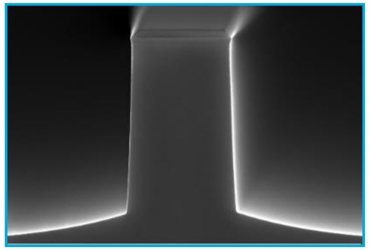


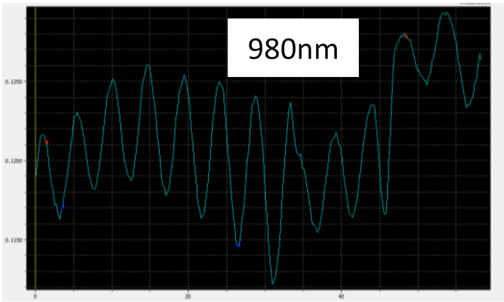
BCB blanket etch
for Photonic device

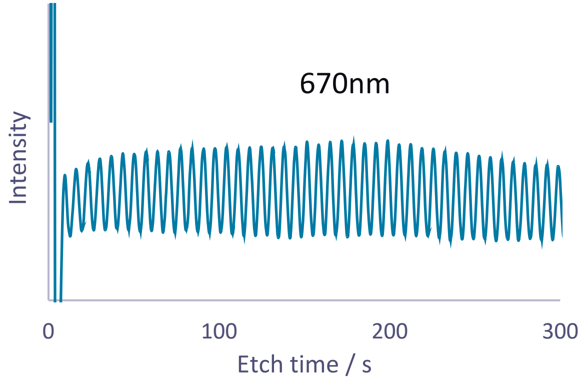


LASER spot ~20µm diameter
Target 'window' typically required at wafer centre
Wafer placement accuracy means window is 300-350µm wide
Optional **Pattern Recognition** software reduces window to 100-250µm

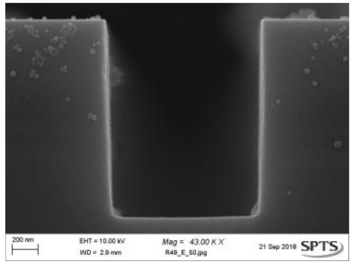
InP etch
for Photonics device





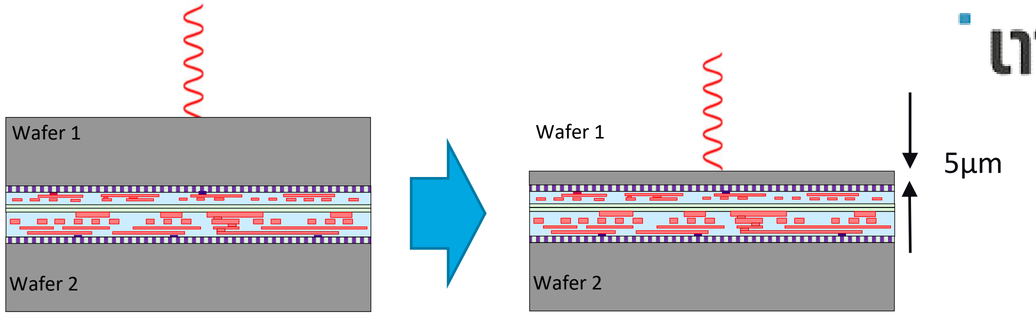


SiC trench etch
for Power device



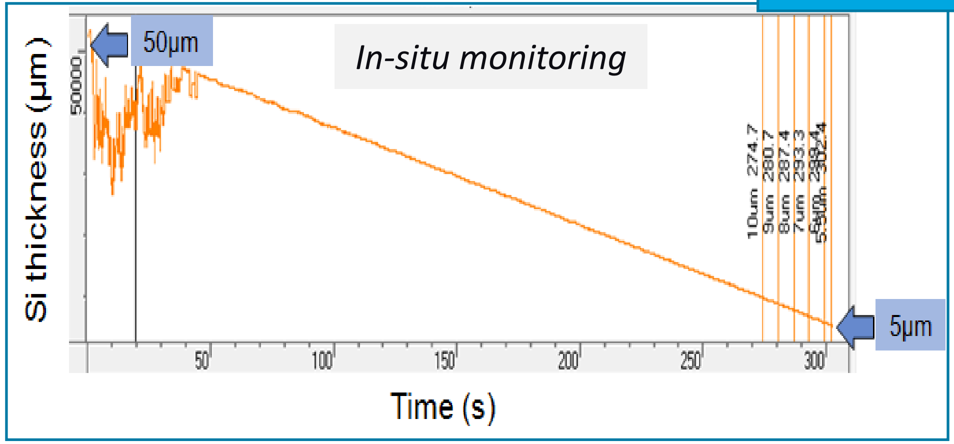
NIR LASER Interferometry

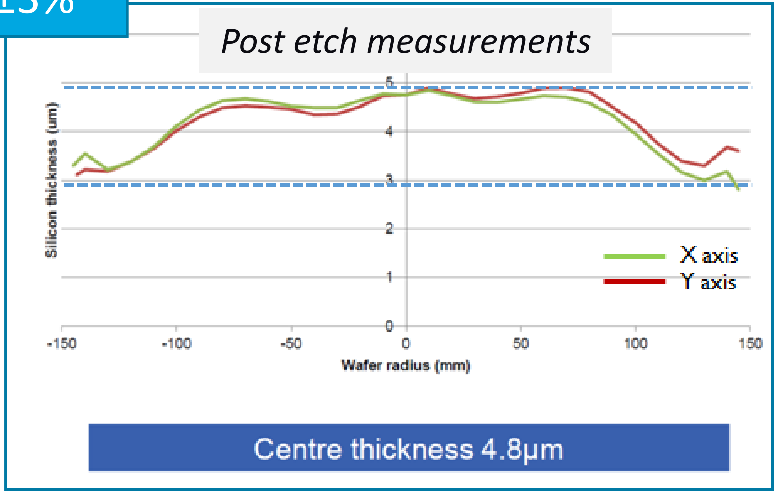
Extreme Si thinning
for Advanced Packaging



- Interferometry between front & back side faces of the Si
  - Semi-transparent in NIR (900-1700nm)
- Method correlates interference output with an optical model to compute thickness

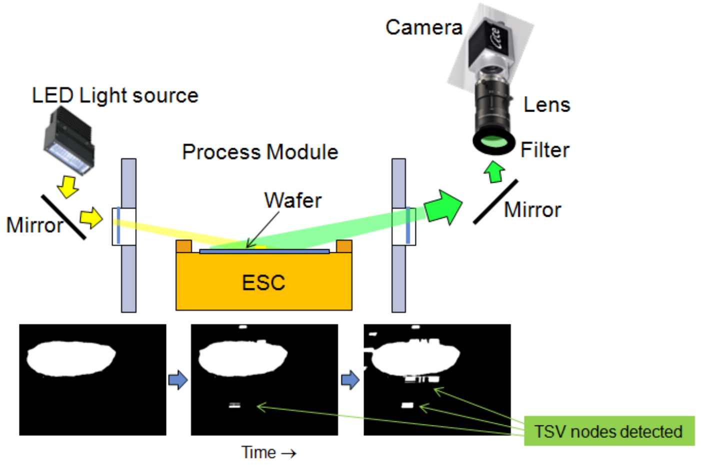
Etch rate >9µm/min
Uniformity <±3%

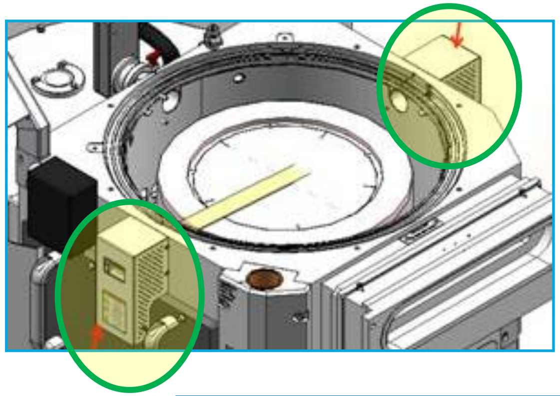


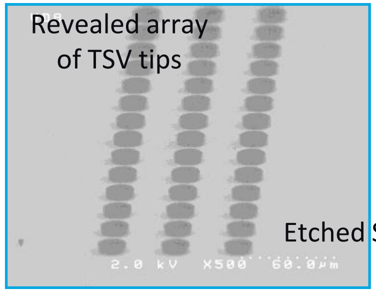


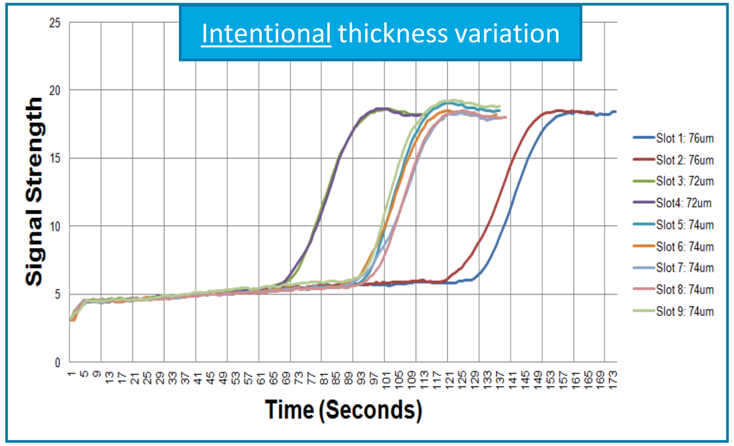
ReVia® (Patented)

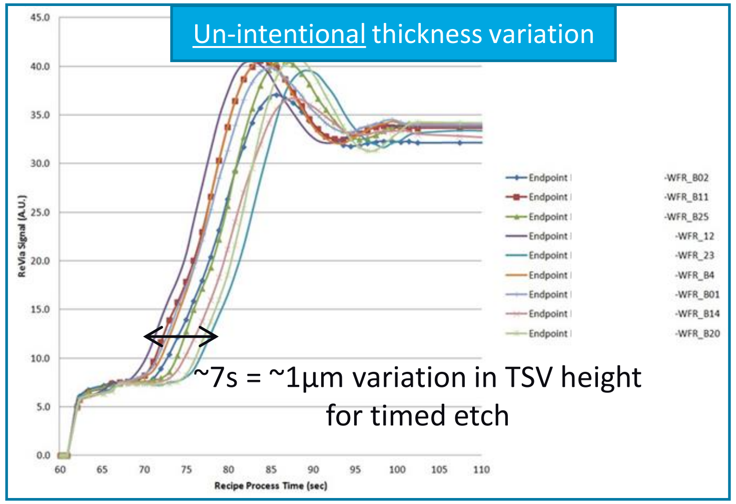
- Accounting for incoming thickness variations = increased yield

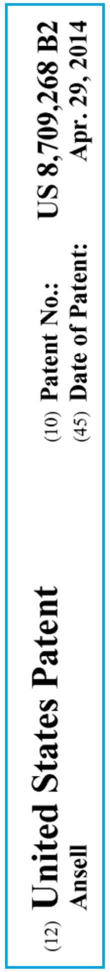








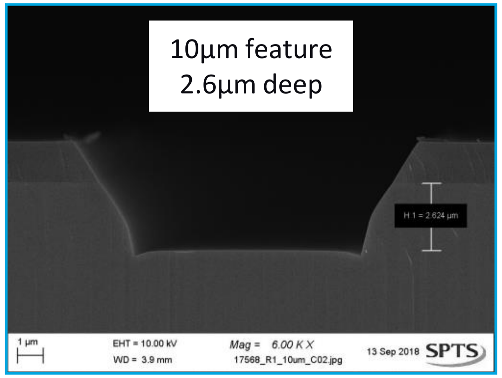




Unique & robust end-pointing for any TSV layout or RST variance

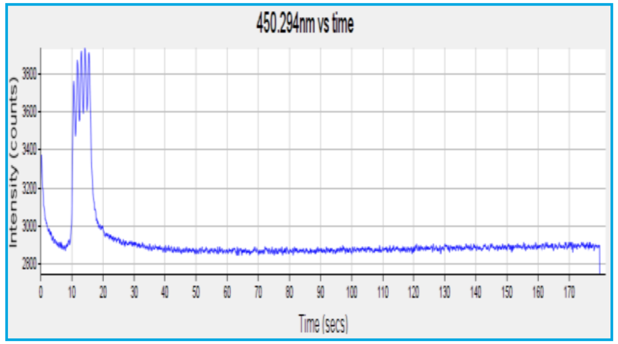
Example of EPD Method Selection

- 350nm AlGaInN/2.3µm GaN
- Blind etch with no stop layer



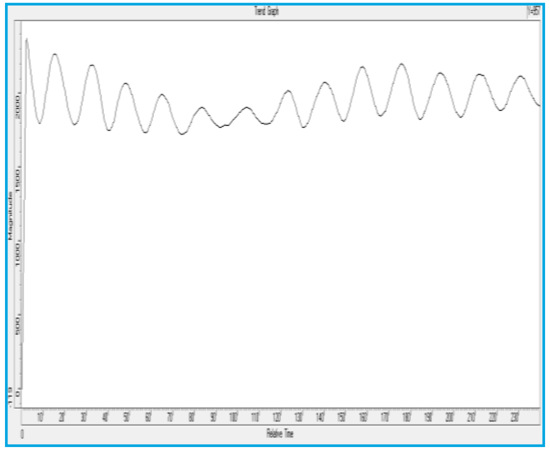
Multiple end-point systems can be applied to the same chamber (if required)

OES



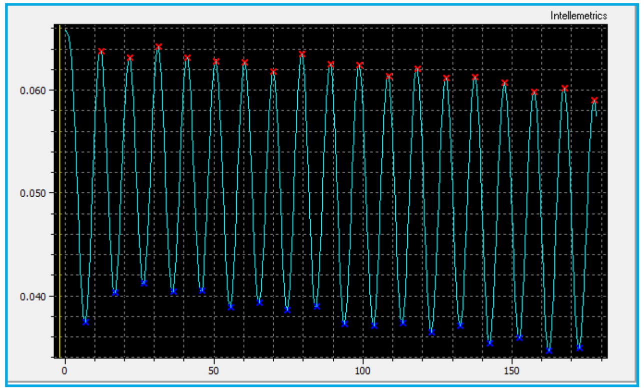
In* used to detect layer transitions

WL interferometry



Weaker signal due to larger area
Dual traces due to mask & GaN

LASER interferometry



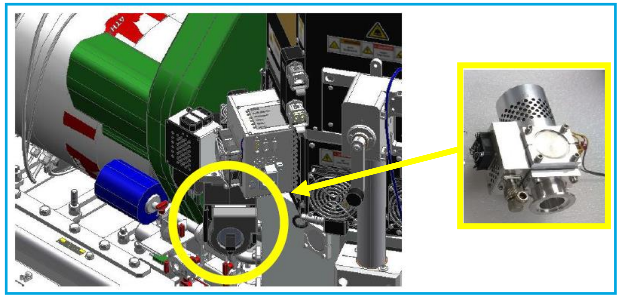
Strong signal, small area, beam in a target feature
No signal from mask

End-point Detection Methods

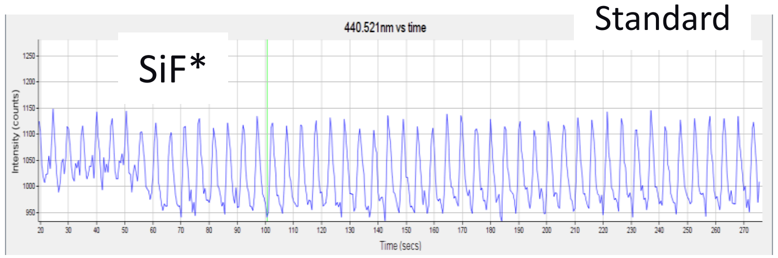
Method	Monitors	Based on	Used for
Parametric*	**System**	APC angle He flow	Large open areas Through wafer etches
Optical emission spectroscopy (OES)	**Plasma**	Glow from plasma	General purpose when stop layer present (Poly, Oxide, Al, GaAs …)
Claritas*		Re-ignited glow from plasma	Bosch Si etching
WL Reflectance*	**Wafer**	Reflection	Tapered TSVs
WL Interferometry		Broad area interferometry	Non-Bosch Si trenches SiC trenches
LASER interferometry		Small spot interferometry	VCSEL stacks SiC trenches
NIR*		Interferometry	Wafer thinning
ReVia*, Ascent*		Wafer vision	Via Reveal, SiC via etch

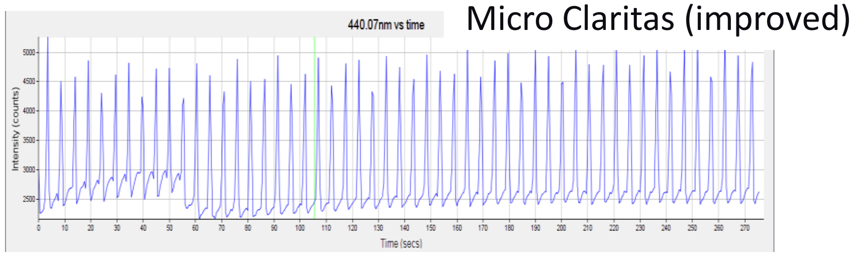
**Unique to SPTS*

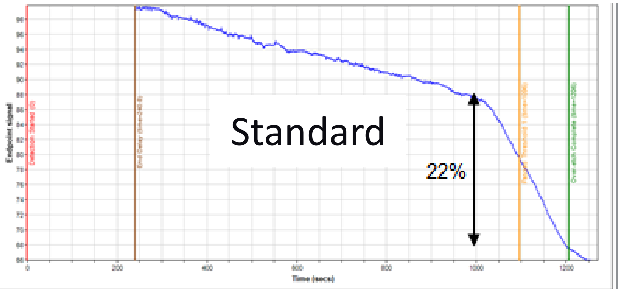
NEW Developments

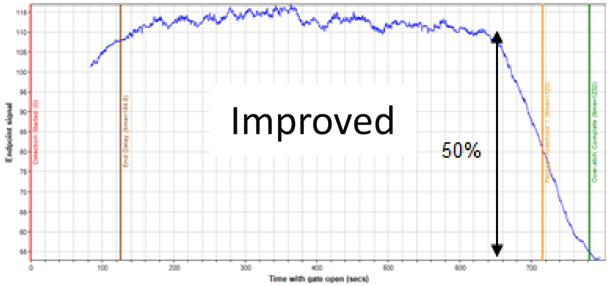


- Claritas™ improvements for Deep Si etching (*new* Micro Claritas™)



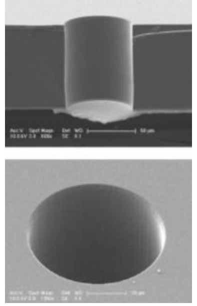




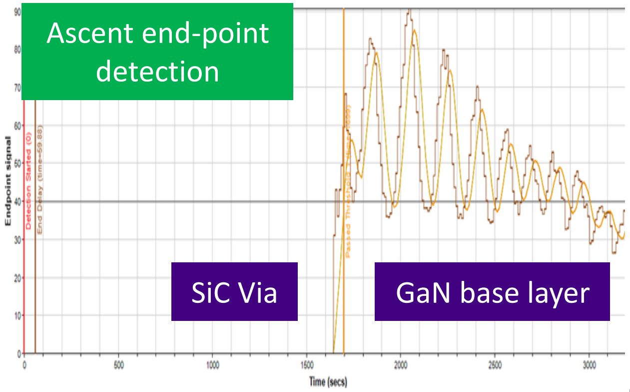


Improvements in…
- Finer step resolution
- Larger end-point change
- **Field production validated!**

- SiC via etching (*new* Ascent™)



Difficult for EPD because …
- Low via density
- Metal in plasma (from masking) reduces OES signals
- **Success with new approach!**



Patent applied for

KLA

Conclusions

- EPD is an essential tool for controlling Plasma Etching processes
  - Better devices & higher yields
- Datalogs, the plasma/gas or the wafer itself can be monitored *in-situ*
- Troublesome etches include very low OA%, high AR or blind features
- Solutions exist for a broad range of etches/device types
- SPTS has the broadest range of available methods
  - All fully integrated to the system software, multiple EPDs on the same chamber
  - Including unique methods such as ReVia® & Claritas™
  - Plus a new method for SiC vias! Ascent™
  - Contact us for more specifics for your applications and needs

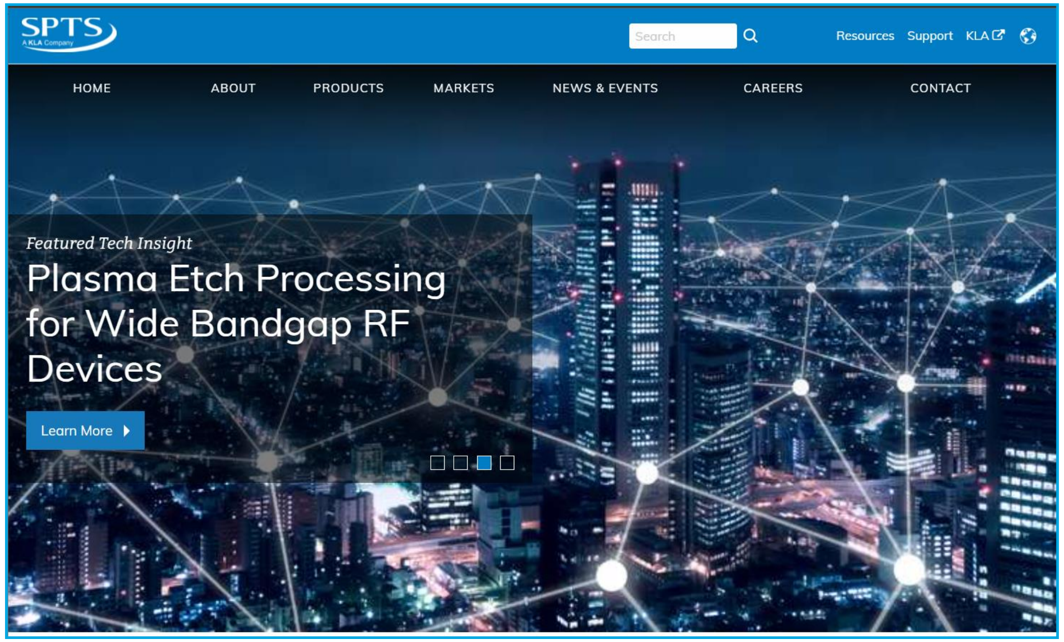
Web Resources @spts.com – **Questions?**

- Tech Insights
  - https://www.spts.com/resources/tech-insights
- Application Briefs
  - https://www.spts.com/resources/literature-library
- Published Technical/Conference Papers
  - https://www.spts.com/resources/presentations

Thank you!

More Questions?

- Contact you local SPTS Sales team
- Email enquiries@spts.com
- Keep up-to-date with SPTS! at https://www.spts.com/



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