Plasma-Etch End-Pointing in InP-Based Laser Device Structures

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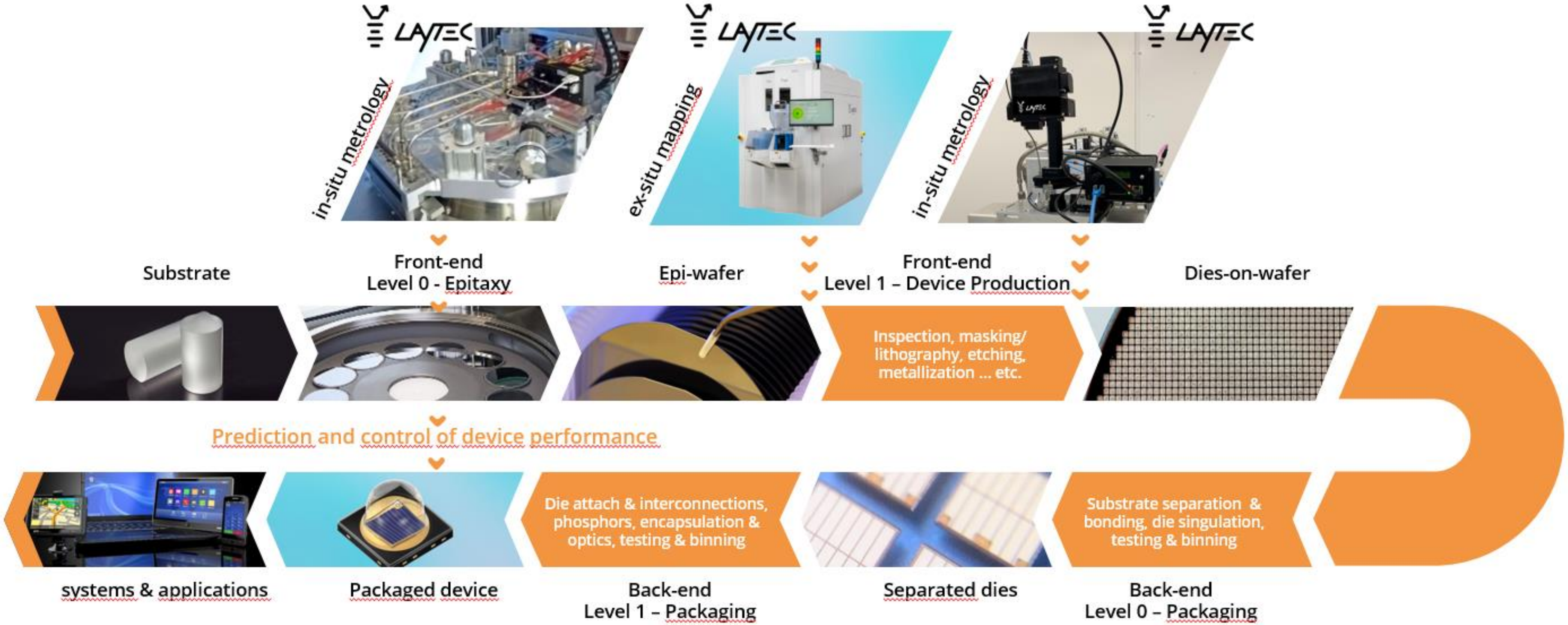
The importance of in-situ metrology

Optical metrology along the semiconductor manufacturing chain



- The same wafer is measured 3+ times
  - The amount of information increases
    - and is combined for improved analysis in downstream processes

OUTLINE

- Introduction
- Challenges in :
  - InP laser Plasma Etching
  - End-pointing with ICP-RIE (inductively coupled plasma - reactive ion etching)
- Connected metrology
- End-pointing examples
- Conclusion

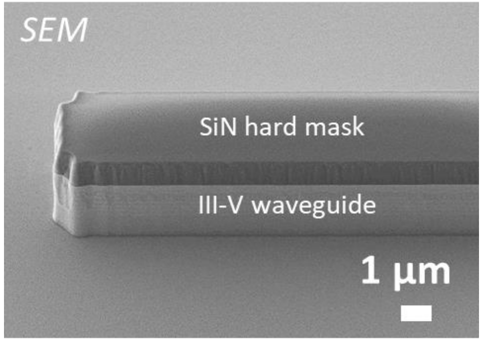
Plasma-Etch End-Pointing in InP-Based Laser Device Structures

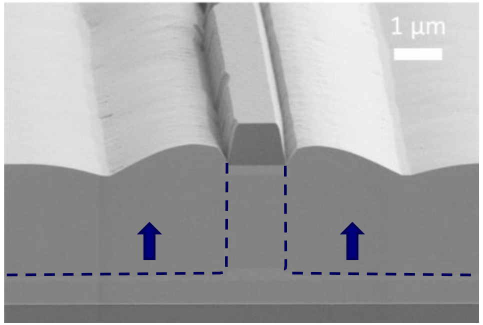
▶ Challenges in InP laser Fabrication :

- Precise etching control of the complex hetero-structure
  - Total etch depth
  - Distance from an interface
  - Remaining thickness

  => End-pointing
- Requirements of smooth surfaces and facets
- Etch depth accurately controlled from a few nm to a few µm

Example of SEM cross section of Ridge Waveguide





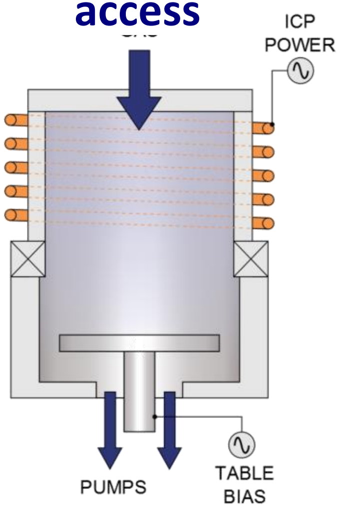
Challenges in Plasma Etching

- Time based etching has limitations
- End Point Detection (EPD) offers advantages

EPD Method	Monitors
Optical Emission Spectroscopy (OES)	Plasma
Interferometry	Wafer

Etch rate :
Slow to fast
~ 1-10 nm/sec

Metrology access

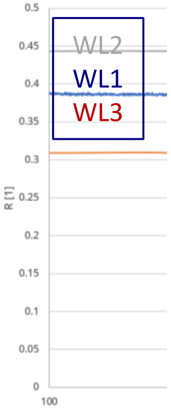


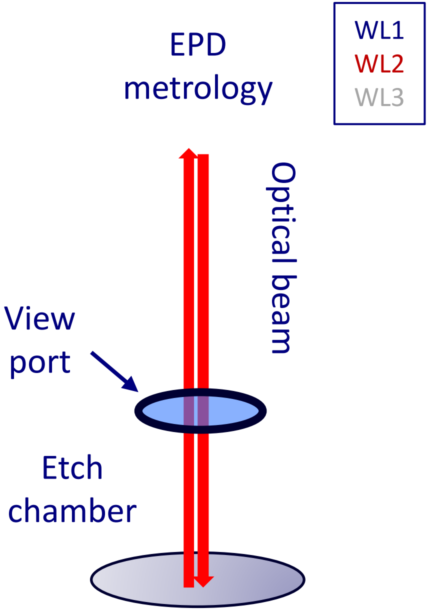
- Is interferometry based EPD suitable and precise enough for InP laser etch thickness control using ICP ?

Plasma-Etch using Interferometry EPD in Compound Semiconductor

- Real time measurement of an optical beam being reflected at a surface being etched away
- Principle of Operation: Reflectance from surface and every other interface of wafer stack

Test structure





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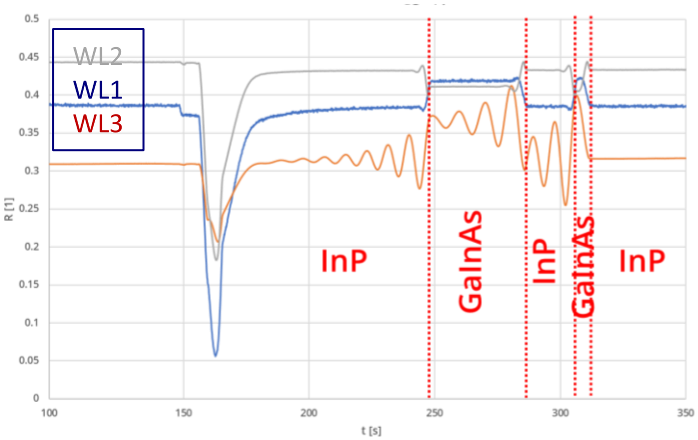

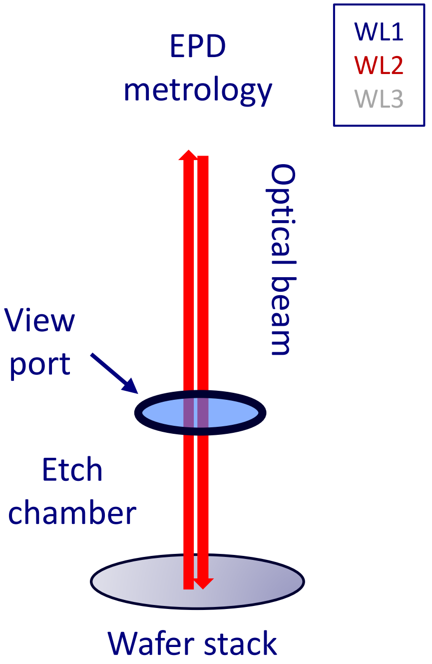

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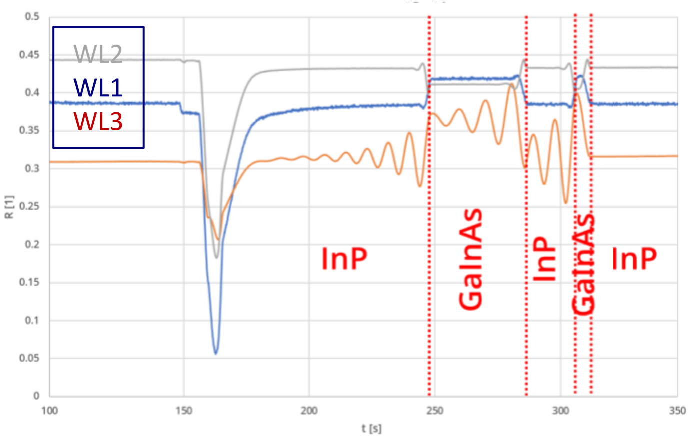
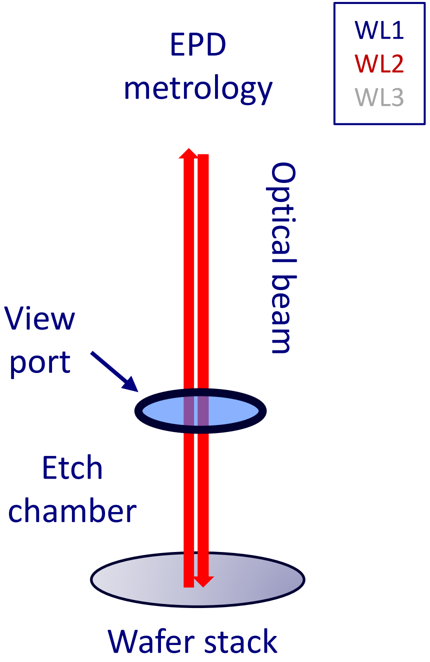
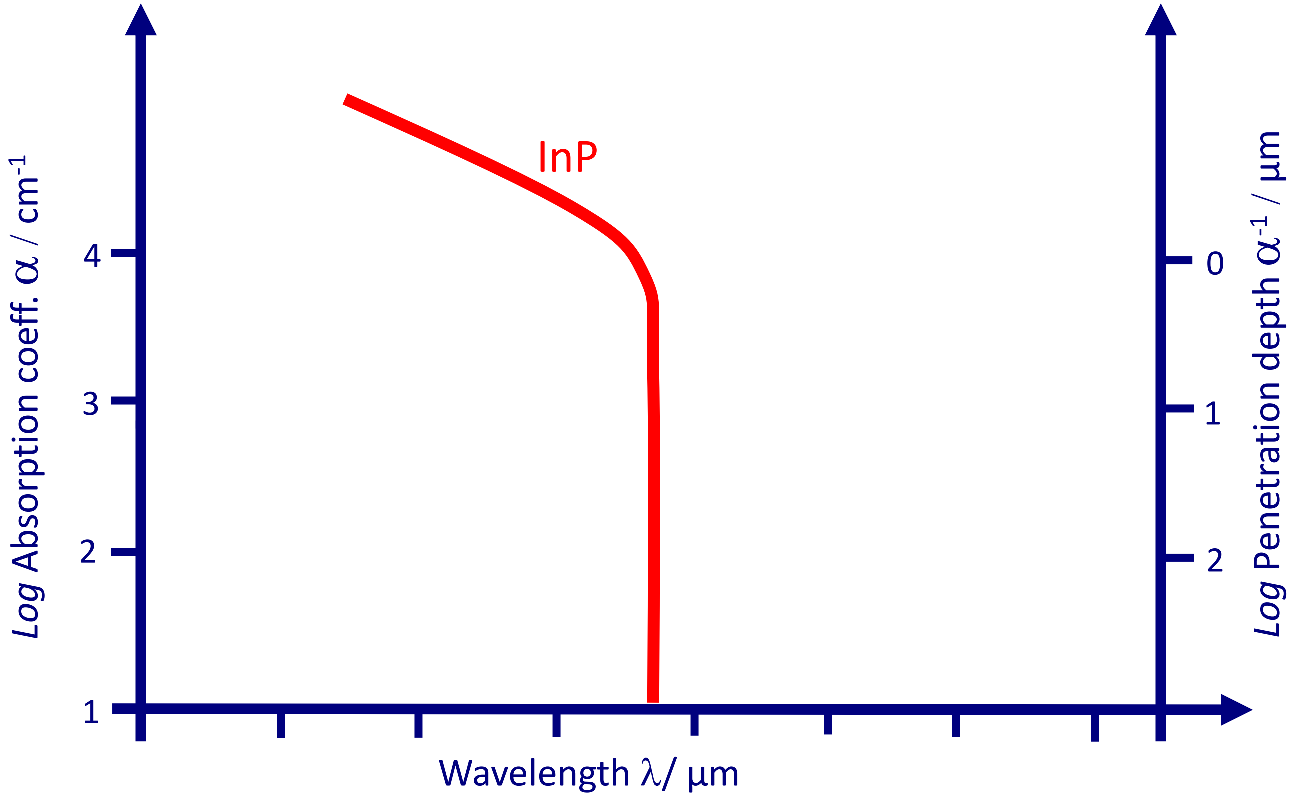


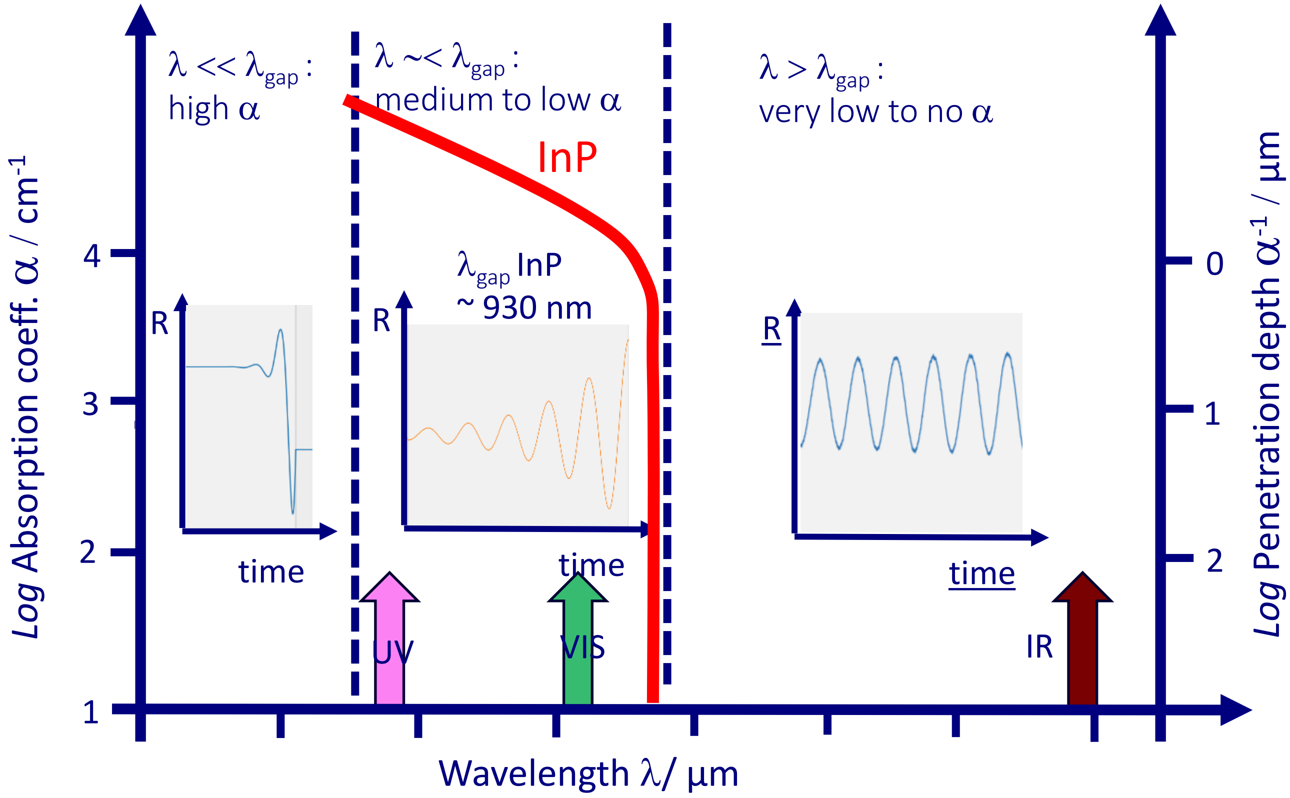


Importance of wavelength: InP & thin film reflectance



III-V lab
20 years in 2024

Importance of wavelength: InP & thin film reflectance



R: Reflectance between thin films

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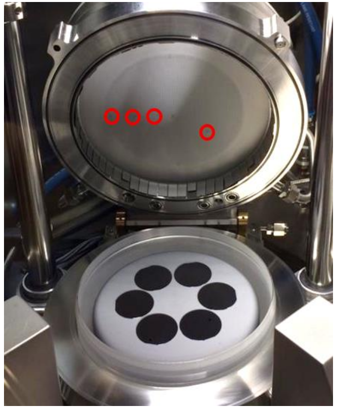
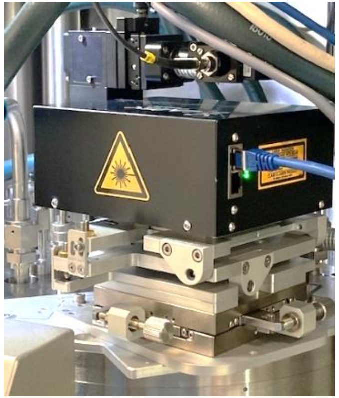
Comparison between MOCVD & Plasma Etching



Aixtron CCS reactor
6x2'', 3x3''
and 1x4'' capacity

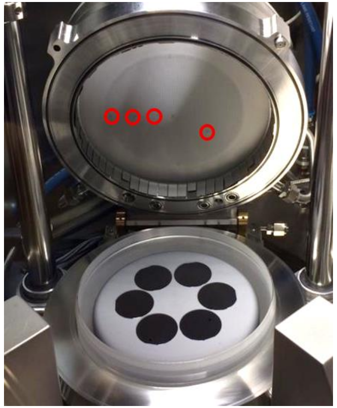


In-situ characterizations :
EpiCurveTT:
Reflectance
405, 670, 950 nm
Curvature
Pyrometry

Comparison between MOCVD & Plasma Etching

High-accuracy in-situ metrology during MOVPE.

Parameter	MOVPE
Wafer temperature	±1K by emissivity corrected pyrometry
nk(T) optical data of layers	±0.001 by XRD referencing
absolute reflectance scale	±0.002 by auto-calibration to bare substrate at start of process
internal interfaces	time correlated with the gas switching sequences



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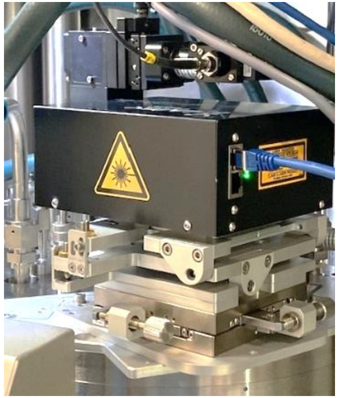

In-situ characterizations:
Reflectance
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Curvature
Pyrometry

LAYTEC
MEMBER OF THE NYNOMIC GROUP

III-V lab 20 years in 2024

Challenges in plasma etching

How to achieve high-accuracy in-situ thickness control
also in subsequent plasma etching of the same structure ?

Parameter	MOVPE	Plasma etching
Wafer temperature	±1K by emissivity corrected pyrometry	unknown, ~±30K
nk(T) optical data of layers	±0.001 by XRD referencing	unknown, somewhere between RT nk data and MOVPE nk data
absolute reflectance scale	±0.002 by auto-calibration to bare substrate at start of process	±0.02 (coarse calibration), bare substrate usually is not seen during etching
internal interfaces	time correlated with the gas switching sequences	assignment during etching is very difficult (usually just change of slope in FPOs)

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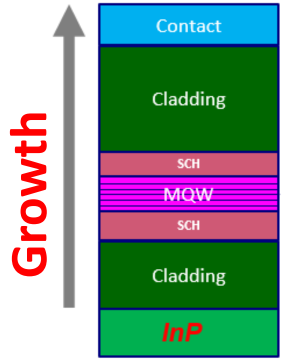
Connecting the metrologies

MOVPE

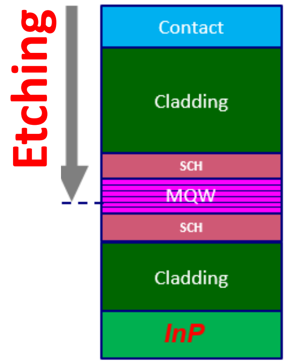


real-time thickness measurement accuracy

enabling

Plasma etching

high-accuracy **end-pointing** during plasma-etching of laser devices



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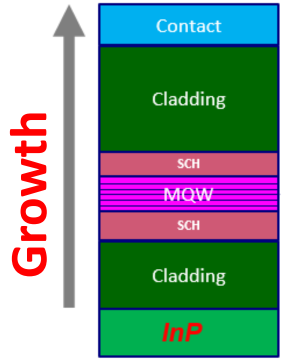
MOVPE

Plasma etching



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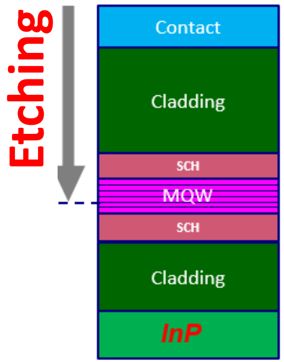
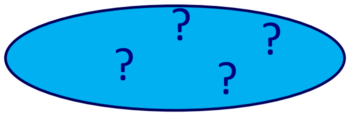
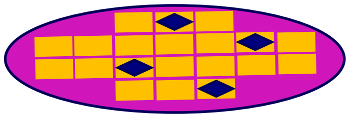




thickness uniformity

assigning →

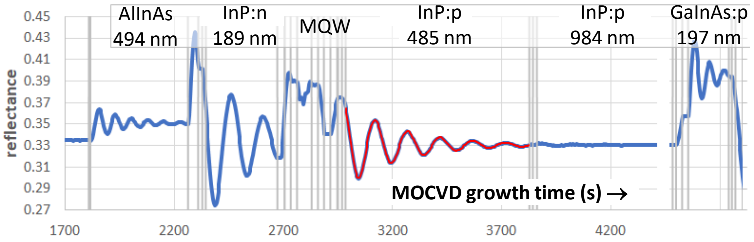
correct thicknesses in the test-pads over the masks



Plasma-Etch end-pointing in InP-based laser device structures

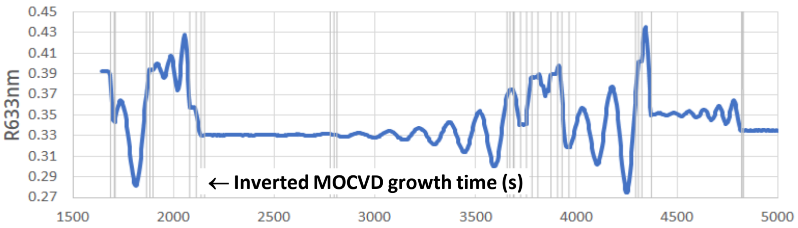
MOVPE: real-time reflectance measurement

- ❑ layer thickness measurements with accuracy in ±1nm range
- ❑ Valve actions marks begin/end of layers
- ❑ At epitaxy temperatures



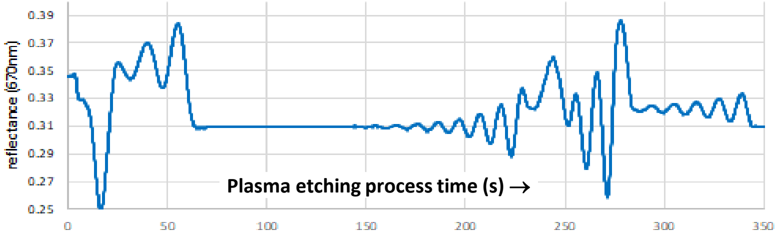
"Time inverted" reflectance signal

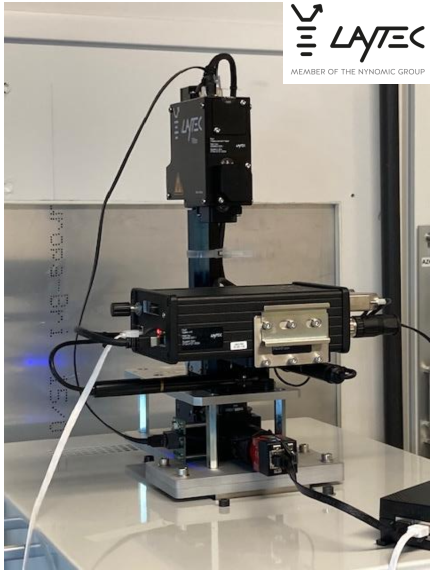
- ❑ "Preview" to etch measurements



Plasma etching: real-time reflectance measurements at 670 nm

very similar to the MOVPE signal at 633 nm





LayTec TRIton in-situ multi-wavelength metrology on top of the ICP etching tool

Plasma-Etch end-pointing in InP-based laser device structures

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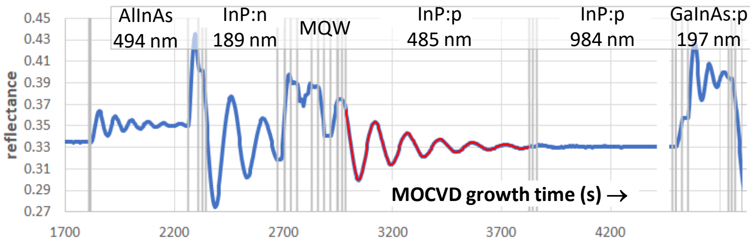

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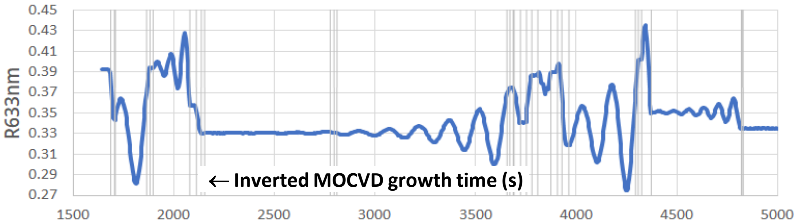
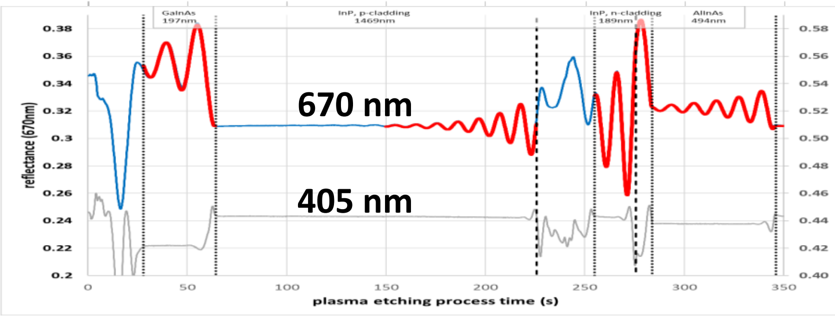
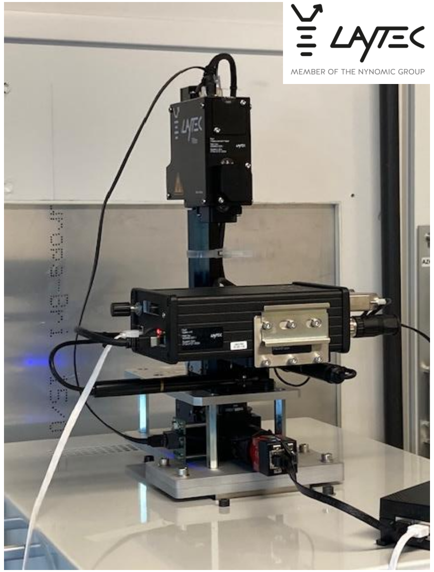


Plasma etching: real-time reflectance measurements

Assignment of interface-times with Short wavelength reflectance (405nm)

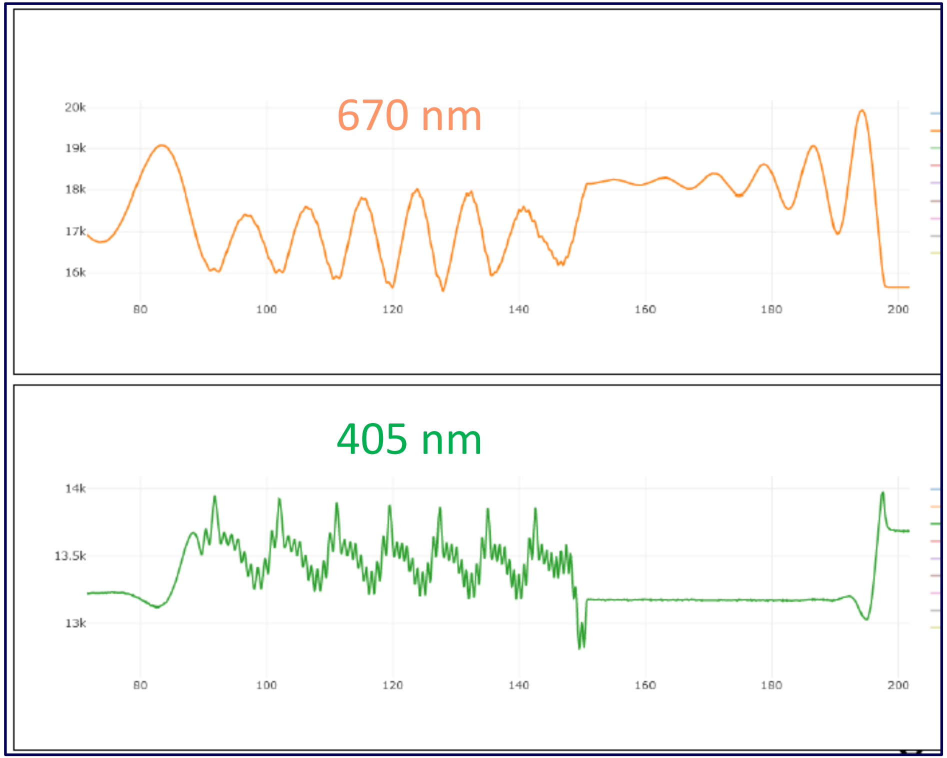




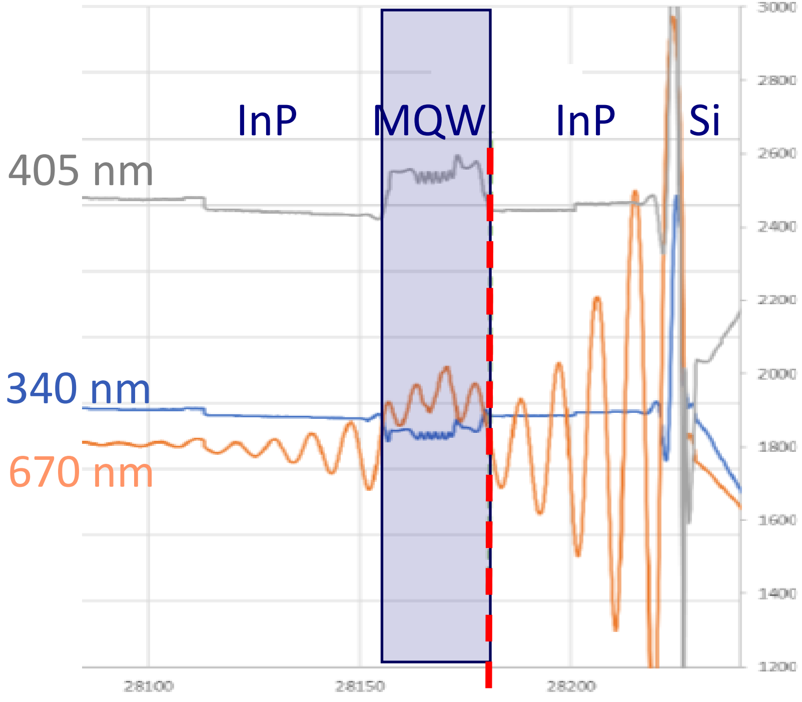
LayTec TRIton in-situ multi-wavelength metrology on top of the ICP etching tool

Example : etch run "Quantum Cascade Detector"

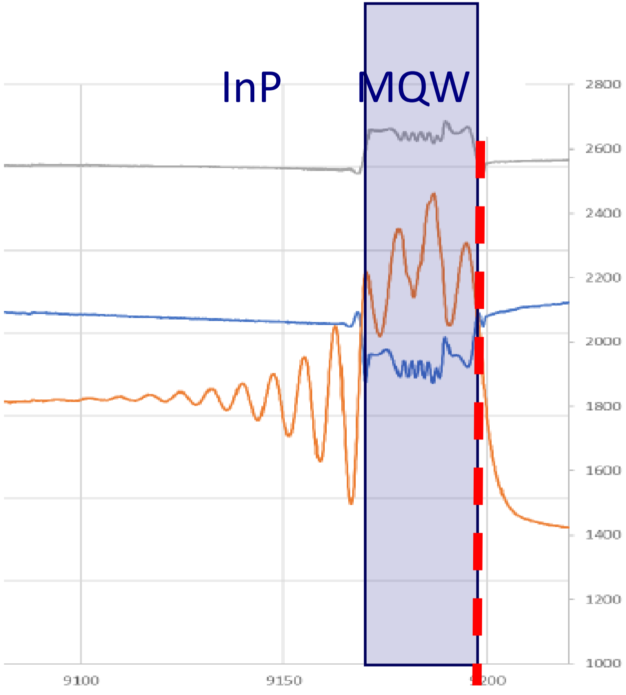
- 670 nm shows total thickness
- 405 nm shows much more details and all layers



EPD in a laser structure on InPoSi wafer



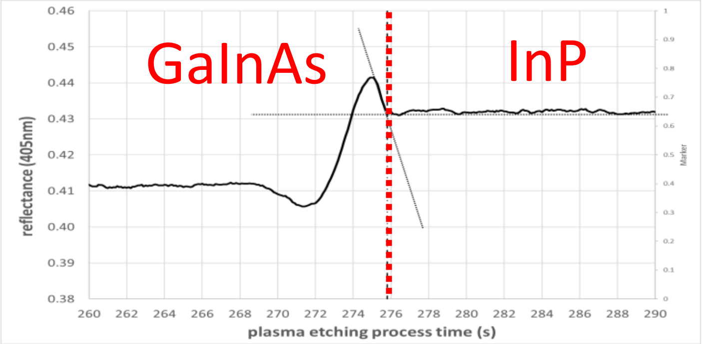
Etch through



EPD : STOP

Assignment of interface-times

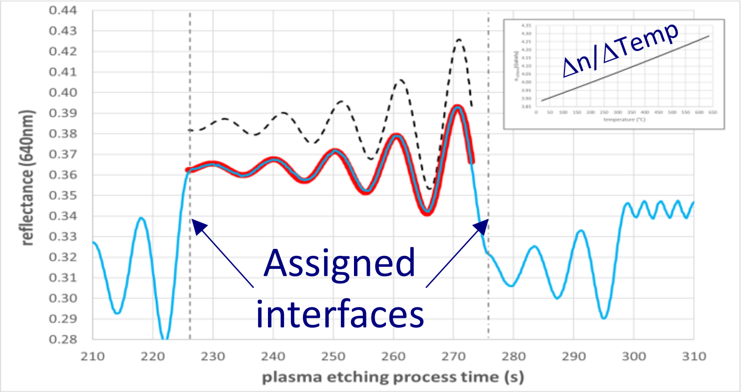
Parameter	Plasma etching
Wafer temperature	unknown, ~±30K
nk(T) optical data of layers	unknown, somewhere between RT nk data and MOVPE nk data
absolute reflectance scale	±0.02 (coarse calibration), bare substrate usually is not seen during etching
internal interfaces	assignment to measured data of times where etch-front passes through interfaces is very difficult (usually just change of slope in FPOs)



- At 405 nm reflectance, penetration depth of light is very small
- Highly damped FPO : more accurate assignment of interface : +/1 nm

Wafer temperature and reflectance scaling correction

Parameter	Plasma etching
Wafer temperature	unknown, ~±30K
nk(T) optical data of layers	**LayTec nk database** established at **plasma temperature**
absolute reflectance scale	±0.02 (coarse calibration), bare substrate usually is not seen during etching
internal interfaces	**positions of interfaces** : etch rate from MOCVD thickness and etch time



Algorithm:

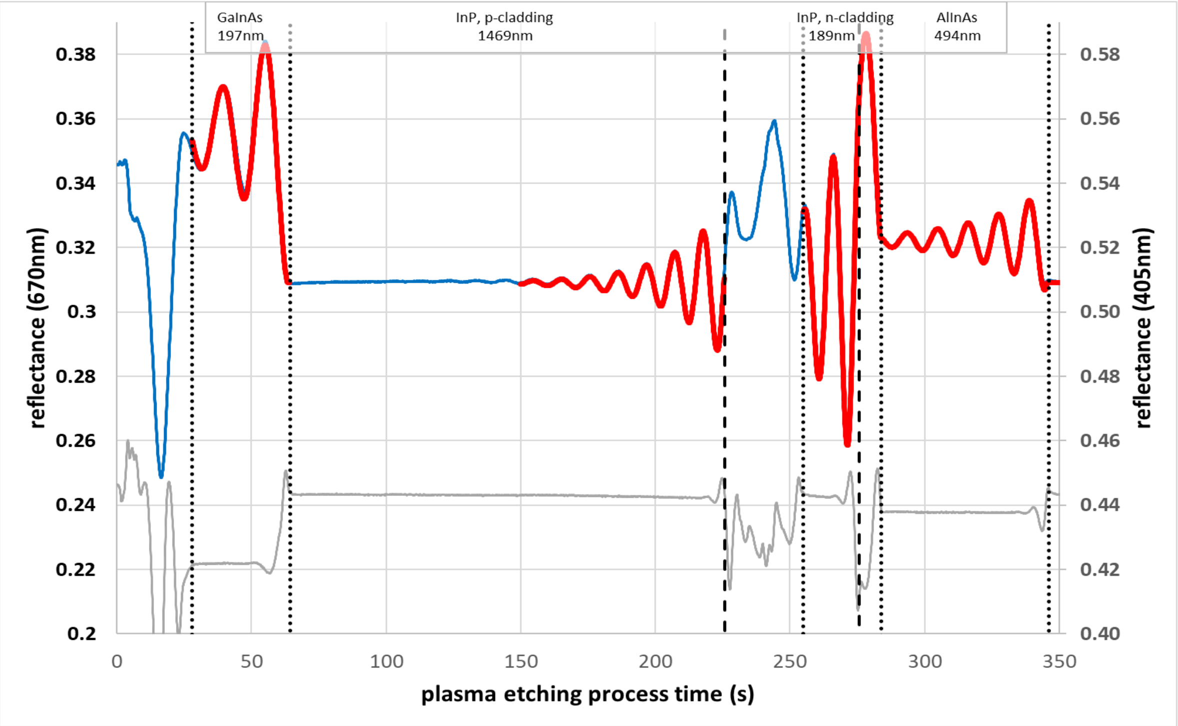
Virtual Interface fit to extract the 2 free fitting parameters still remaining:

- Wafer Temperature
- Reflectance correction factor

End-pointing in a laser structure

- Laser structure shown before
- Steps:
  - Fit on InGaAs contact layer → Temp wafer during etching + reflectance scaling factor
  - N(Temp wafer) from database
- **@ 670 nm :** Etch rate calculated from forwarded MOCVD thicknesses
- **@ 405 nm :** interface positions
- ➔ a wide range of EPD can be assigned to plasma monitoring tool

Etch rates: 5.527 9.247 9.237 8.261 nm/s



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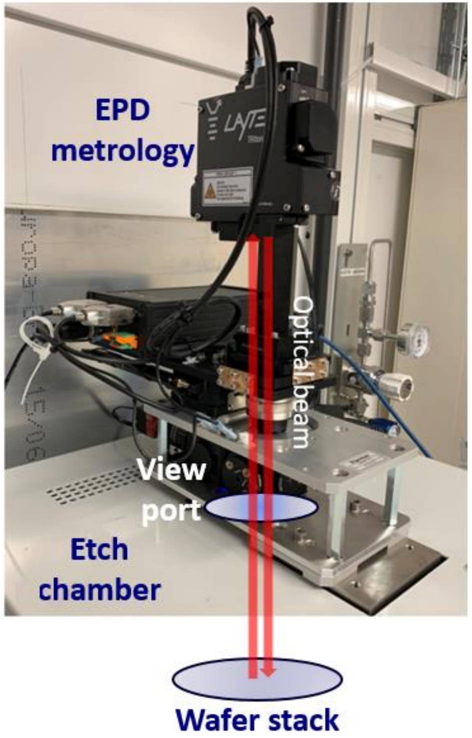

- near UV, Visible and IR wavelengths
- Camera for pattern recognition
- Communication for end-pointing
- Recipe loop waits on end-pointing signal
- Successfully demonstrated end-pointing

Conclusion

- **Highly precise +/- 1nm in-situ reflectance plasma etching of InP lasers is demonstrated**
- **Innovation stems from a combination of methods:**
  - Precise measurement of layer thicknesses during MOVPE growth
  - Forward MOVPE data into plasma etch metrology tool, enhancing precision of etch rate
  - Extraction of wafer temperature
  - Real time etch rate measurements, using 670 nm
  - Real time position of interfaces, using 405 nm
- **Combination of in-situ deposition control, post-epi mapping and in-situ etch control offers potential for even tighter process control and maximum yield**

Thank you !