News from LayTec

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Outline

- The Missing Piece
- From Epi to Etch
- Expanding Analysis Capabilities

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The missing piece…

- LayTec‘s software suite contains
  - Measurement software
  - Calibration tools
  - Analysis functions for single layers
  - …
- But one important piece was missing for years
  - A simulation and fitting tool for the complete layer stack

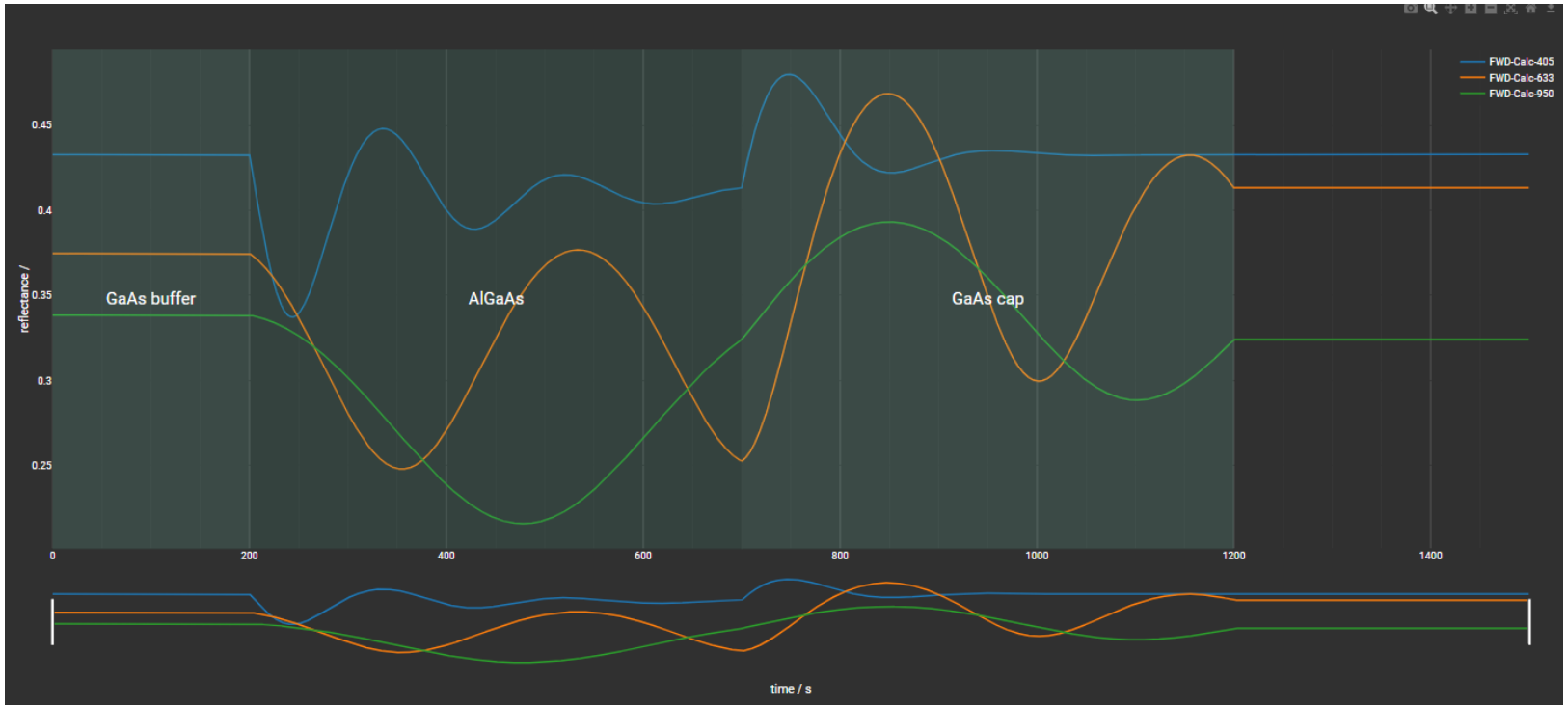
SimulyzR

What is LayTec SimulyzR?

- Simulation and fitting tool for reflectance of complete layer stacks
  - Definition of various materials and layer thicknesses
  - Definition of fittables
  - Definition of known parameters
  - Simulation and plot of full stack
  - Fit and refine stack on actual measured data from SQL-Database („EpiNet“)
  - Multi-wavelengths analysis
- Uses LayTec know-How
  - LayTec n,k material database
  - e.g. NKR and composition fit
- Highly Customizable through partial stack definition with virtual layer interface

Simple GaAs-based example

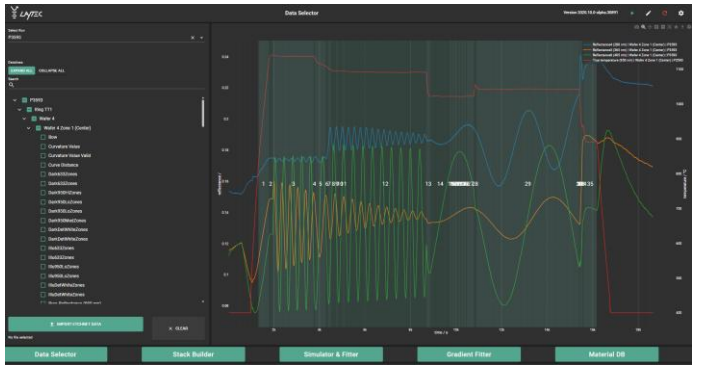
- Simple stack definition: GaAs|AlGaAs|GaAs
- Simulation of transients
- Simulation for 405/633/950nm @ 900K

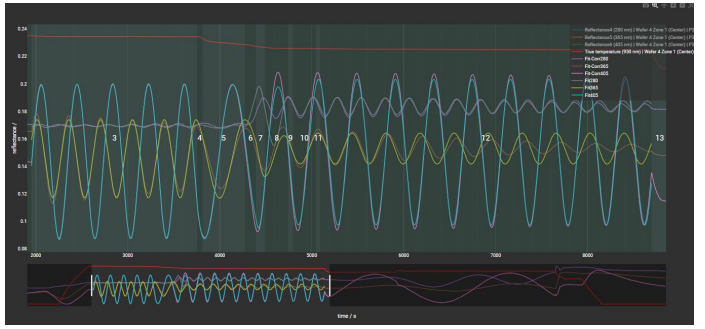


	#	Step Code	Layer	Material	Composition (X) [0...1]	Temperature [K]	Start Time Offset [s]	End Time Offset [s]	Duration [s]	Start Thickness [nm]	End Thickness [nm]	Growth Rate [nm/s]	Count
☐	3	0	GaAs cap	GaAs	0.000	900.0	0.0	500.0	500.0	0.0	125.0	0.250	
☐	2	0	AlGaAs	AlGaAs75	0.750	900.0	0.0	500.0	500.0	0.0	125.0	0.250	
☐	1	0	GaAs buffer	GaAs	0.000	900.0	0.0	200.0	200.0	0.0	50.0	0.250	

Layer Stack Definition, Simulation and Fit

- Layer material and composition
  - linked to LayTec‘s material database
- Gradient layers
  - divided into sublayers to enhance fit
- Growth temperature
- Non-growth steps (like temperature ramps)
  - ignored
- Step codes
  - must match growth recipe





Layer Stack Definition: GaN example

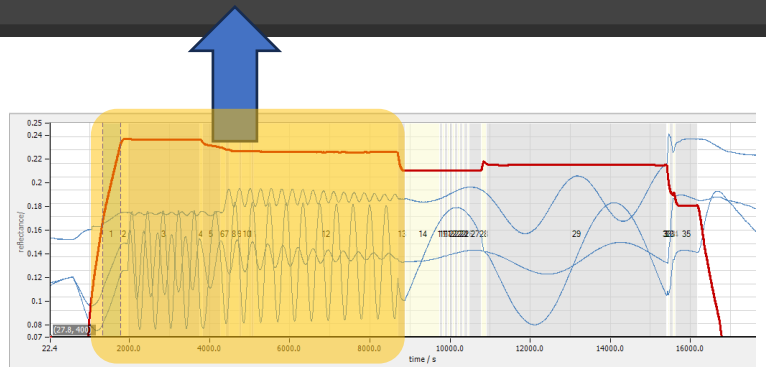
Layer Stack Editor Type: Layer Stack ID: UV-LED

GROUP UNGROUP Gradient Properties Vertical

#	Step Code	Layer	Material	Composition (X) [0...1]	Temperature [K]	Start Time Offset [s]	End Time Offset [s]	Duration [s]	Start Thickness [nm]	End Thickness [nm]	Growth Rate [nm/s]	Count
10	12	AlGaN-105	AlGaN80	0.800	1365.0	48.2	3648.5	3600.3	0.0	900.1	0.250	
9	11	AlGaN-104a	AlGaN80	0.800	1365.0	0.0	0.0	0.0	0.0	0.0	0.250	
8	10	AlGaN-104	AlGaN80	0.800	1365.0	48.0	299.7	251.8	0.0	62.9	0.250	
7	9	AlGaN-103a	AlGaN80	0.800	1365.0	0.0	0.0	0.0	0.0	0.0	0.250	
6	8	AlGaN-103	AlGaN85	0.850	1365.0	0.0	251.7	251.7	0.0	62.9	0.250	
5	7	AlGaN-102	AlGaN90	0.900	1370.0	0.0	99.9	99.9	0.0	25.0	0.250	
4	6	AlGaN-101	AlGaN95	0.950	1380.0	0.0	119.8	119.8	0.0	30.0	0.250	
3	5	AlN-LT	AlGaN100	1.000	1390.0	59.9	519.6	459.6	0.0	114.9	0.250	
2	4	AlN-Tgrad	AlGaN100	1.000	1400.0	0.0	0.0	0.0	0.0	0.0	0.250	
1	3	AlN-HT	AlGaN100	1.000	1411.0	180.3	1981.6	1801.3	0.0	450.3	0.250	
					0.0 SET 0				SET 0	SET 0	0.00	

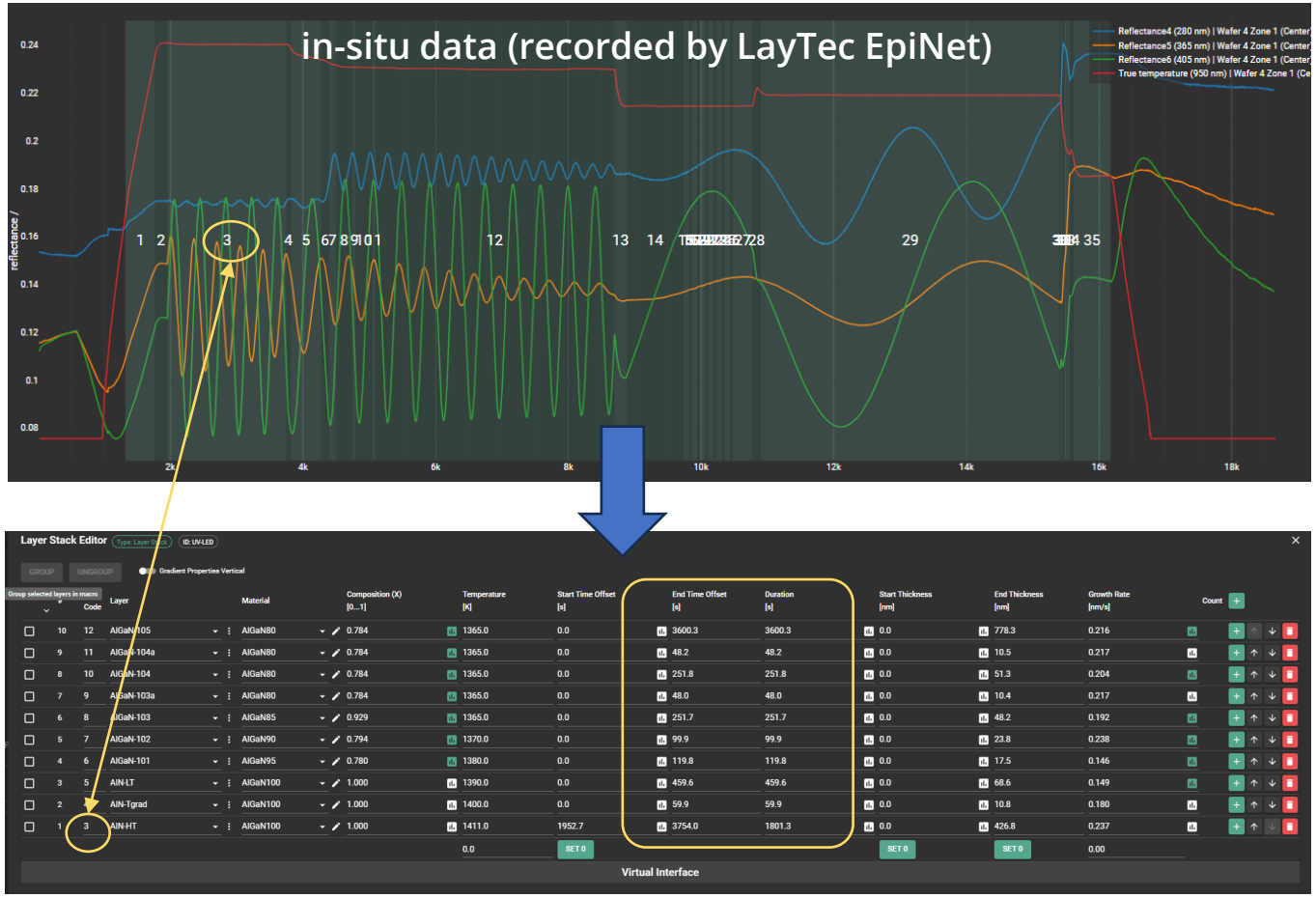
Virtual Interface

- Define full stack
- Customize parameters
- Define substrate or virtual interface (e.g. for templates)



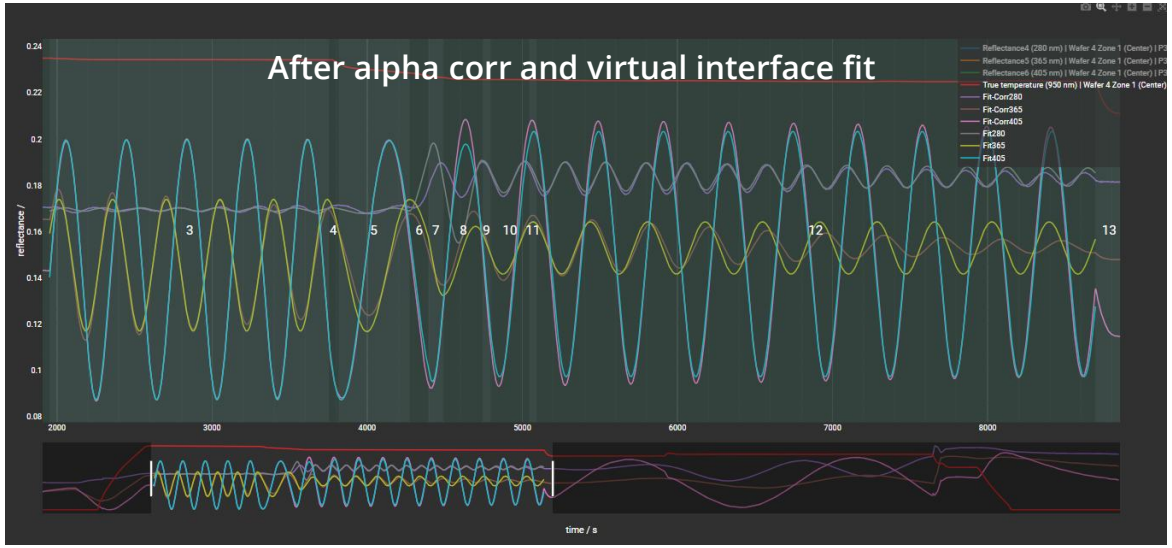
Load measured in-situ data → Enriched Layer Stack

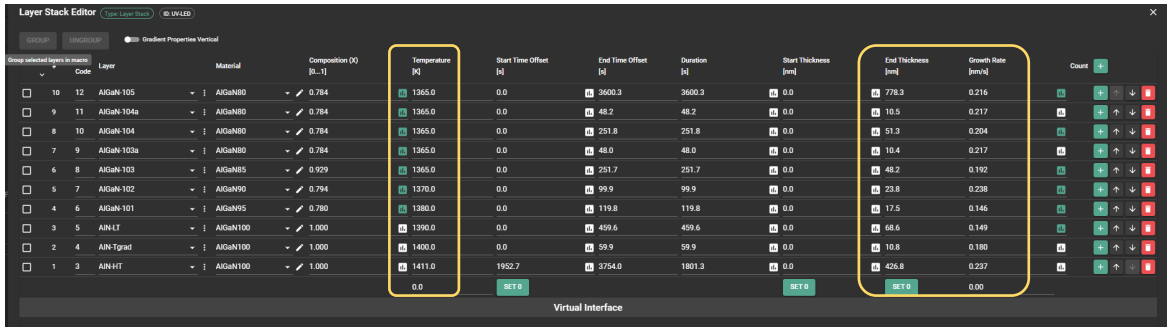
- „Step codes“ used as reference to synchronize time from in-situ data of growth and layer stack definition



Convert „nominal layer stack“ to „real layer stack“ of an individual wafer

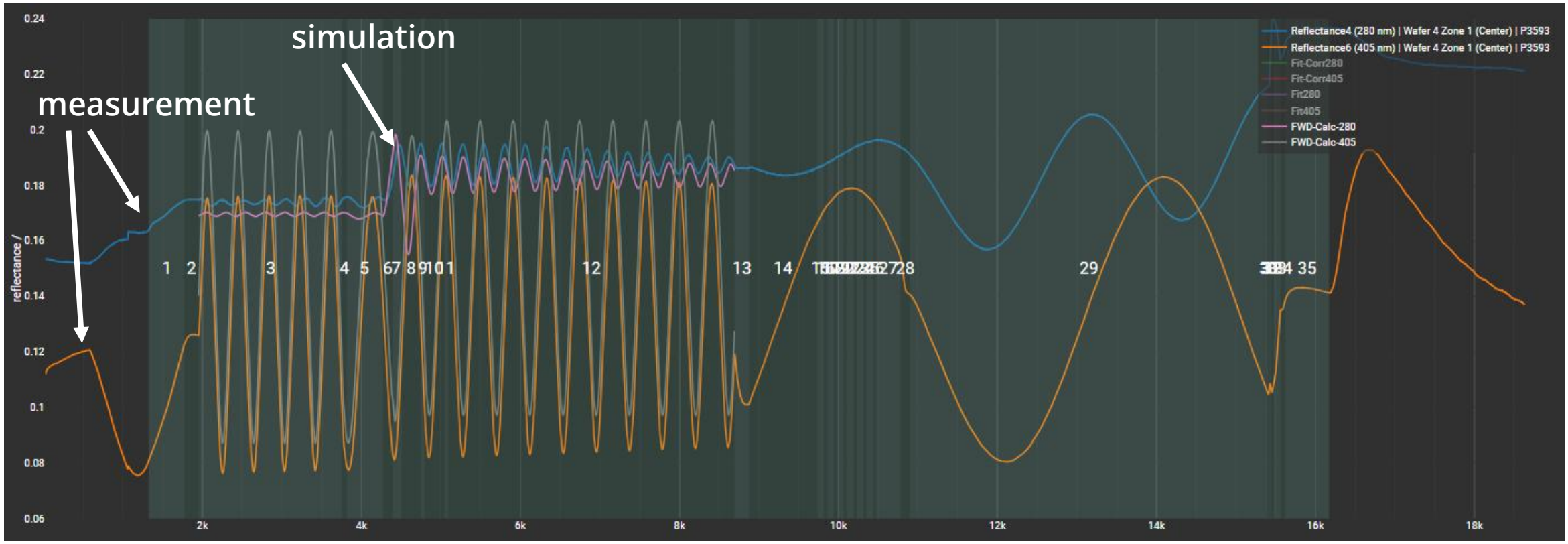
- If needed, redo reflectance calibration for all wavelengths
  - e.g. to compensate window coating
- Layer by layer fit of stack model to data
- Nominal values updated by „real“ growth values
  - layer thickness and growth rate
  - optical constants (n&k)
  - ternary material composition





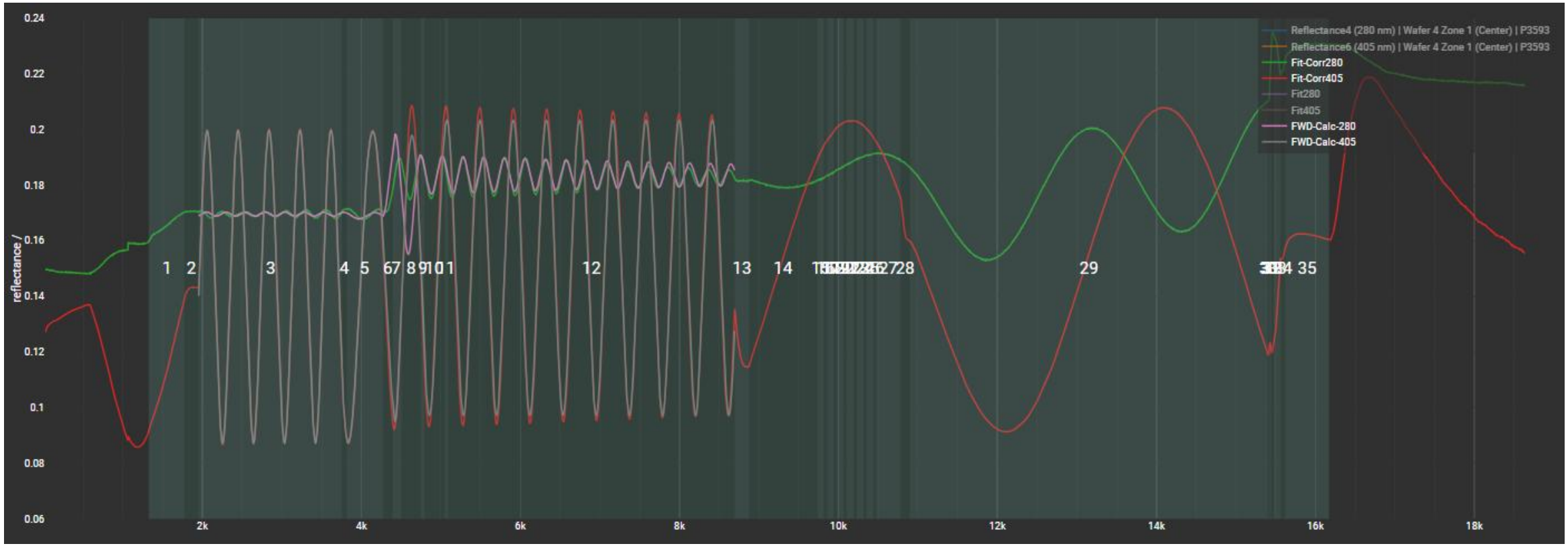
fit results for each sublayer
(composition, thickness, growth rate)

Simulation („forward calculation“) of GaN structure



- Offset between measured and simulated reflectance
- Non-ideal reflectance calibration during measurement

Correction of reflectance calibration („alpha“)



- SimulyzR can correct reflectance clibration of measured data
- Simulation and fit in excellent agreement with measured data

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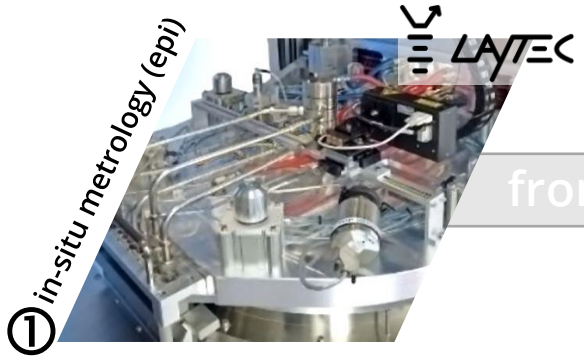
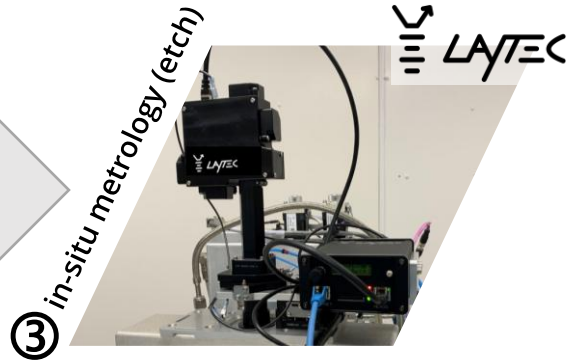
- From Epi to Etch
- Expanding Analysis Capabilities

Optical metrology along the semiconductor manufacturing chain



from epi to etch



Connected Metrology

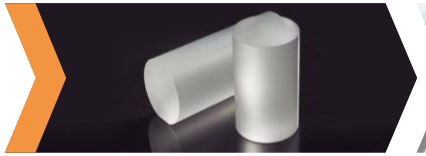
Substrate

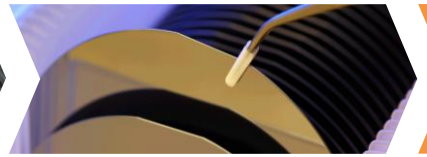
Front-end
Level 0 - Epitaxy

Epi-wafer

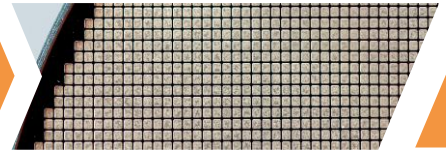
Front-end
Level 1 – Dry Etching

Dies-on-wafer

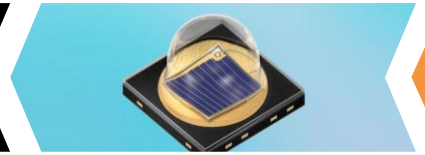




Inspection, masking/ lithography, etching, metallization, facets … etc.



Prediction and control of device performance



Die attach & interconnections, phosphors, encapsulation & optics, testing & binning

Substrate separation & bonding, die singulation, testing & binning

systems & applications

Packaged device

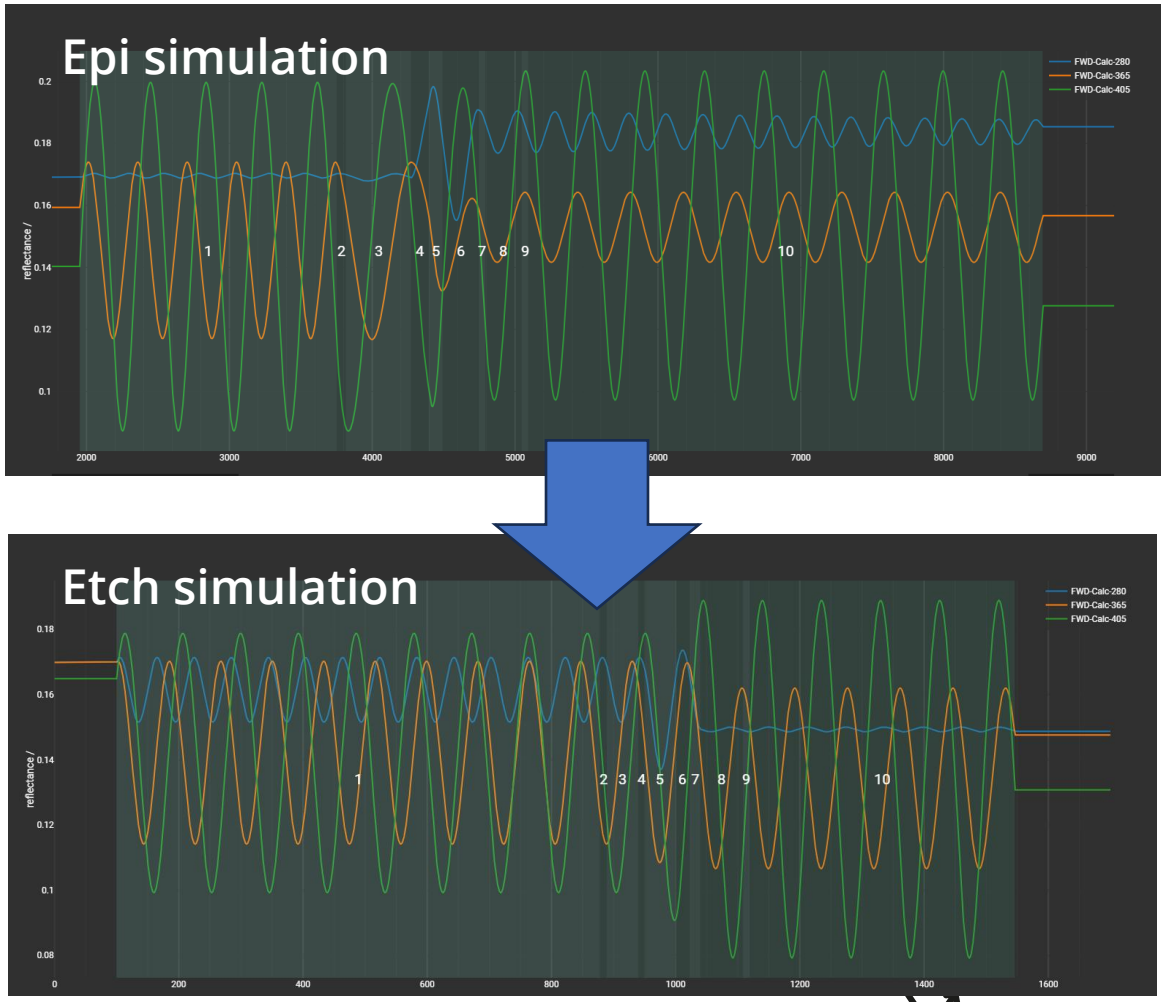
Back-end
Level 1 – Packaging

dies

Back-end
Level 0 – Packaging

SimulyzR: Transformation from Epi to Etch

- SimulyzR can convert „growth stack“ into „etch stack“
- Conversion of
  - Temperatures
    - during etching usually much lower
  - Wavelengths
    - Epi and etch monitoring may be done at different wavelengths
  - Timeline
    - Time-inverted: start of etch at top of stack
    - etch rate different from growth rates
    - etching is a continous process whereas growth could be paused between layers and usually no temperature ramps

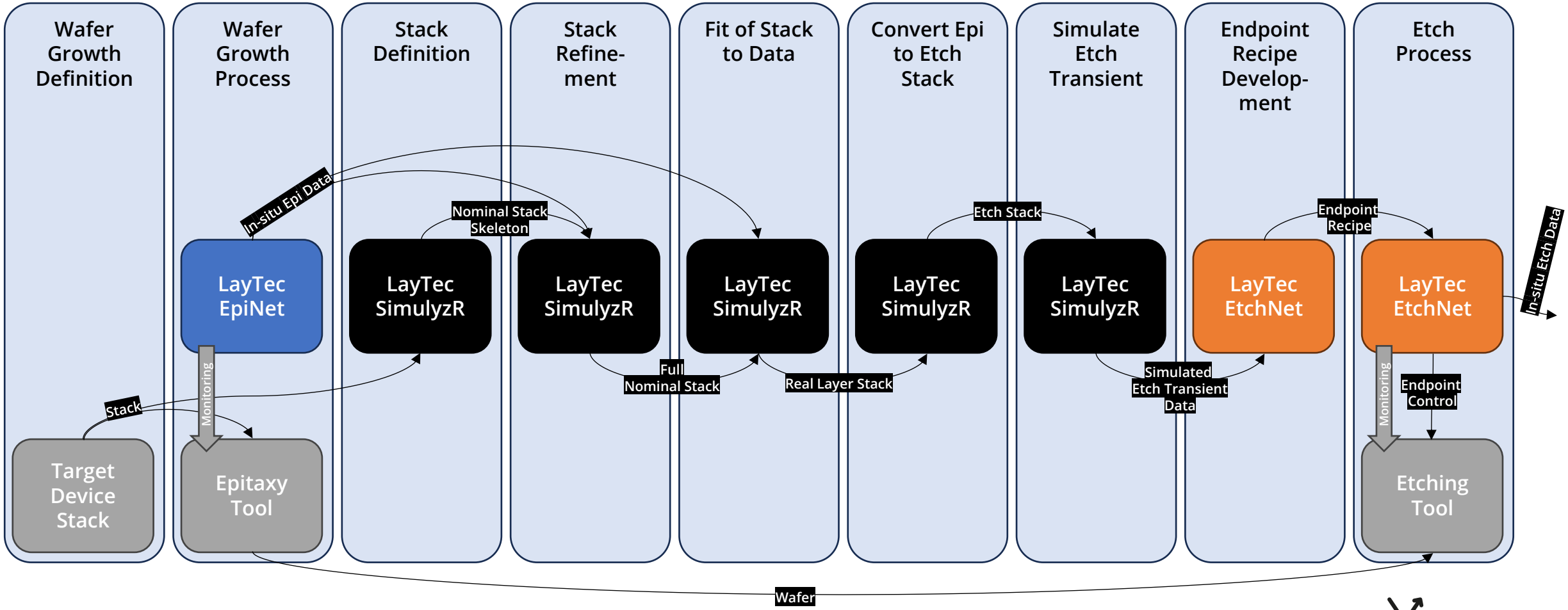


Etching Predition → Etching Endpoint Recipe

- SimulyzR canprovide a target trace for etch run
- Based on inverted stack of in-situ measurement during epi
- With real thickness of individual wafer
- Data exchance from LayTec SimulyzR to LayTec EtchNet
- Endpoint recipe development in EtchNet based on simulated etch transients
- Enabling automated etch control by endpoint detection

endpoint defined by recipe

Full process flow in LayTec software with SimulyzR as central part



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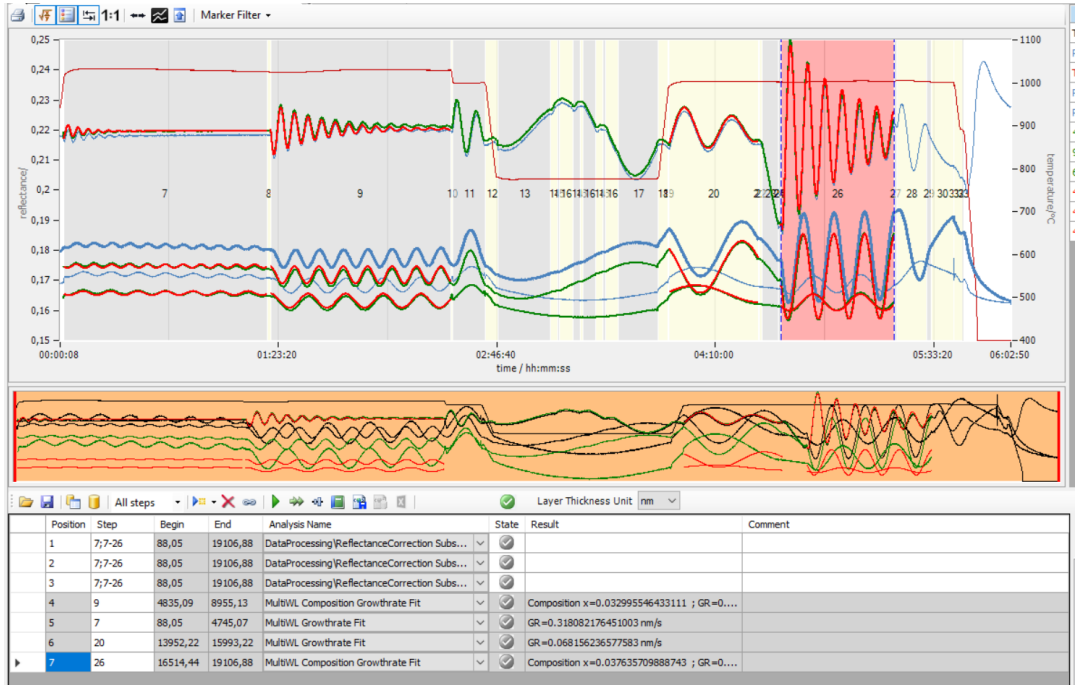
Expanding analysis capabilities – *LayTec Analytics*

- EpiNet already has a long list of analysis functions
- However, sometimes it is not flexible enough
  - e.g. exporting colorplots or performing analysis of compositional grading
- Some things are missing
  - e.g. analysis of line scans



- We have developed a new infrastructure for data analysis that increases flexibility and capabilities substantially

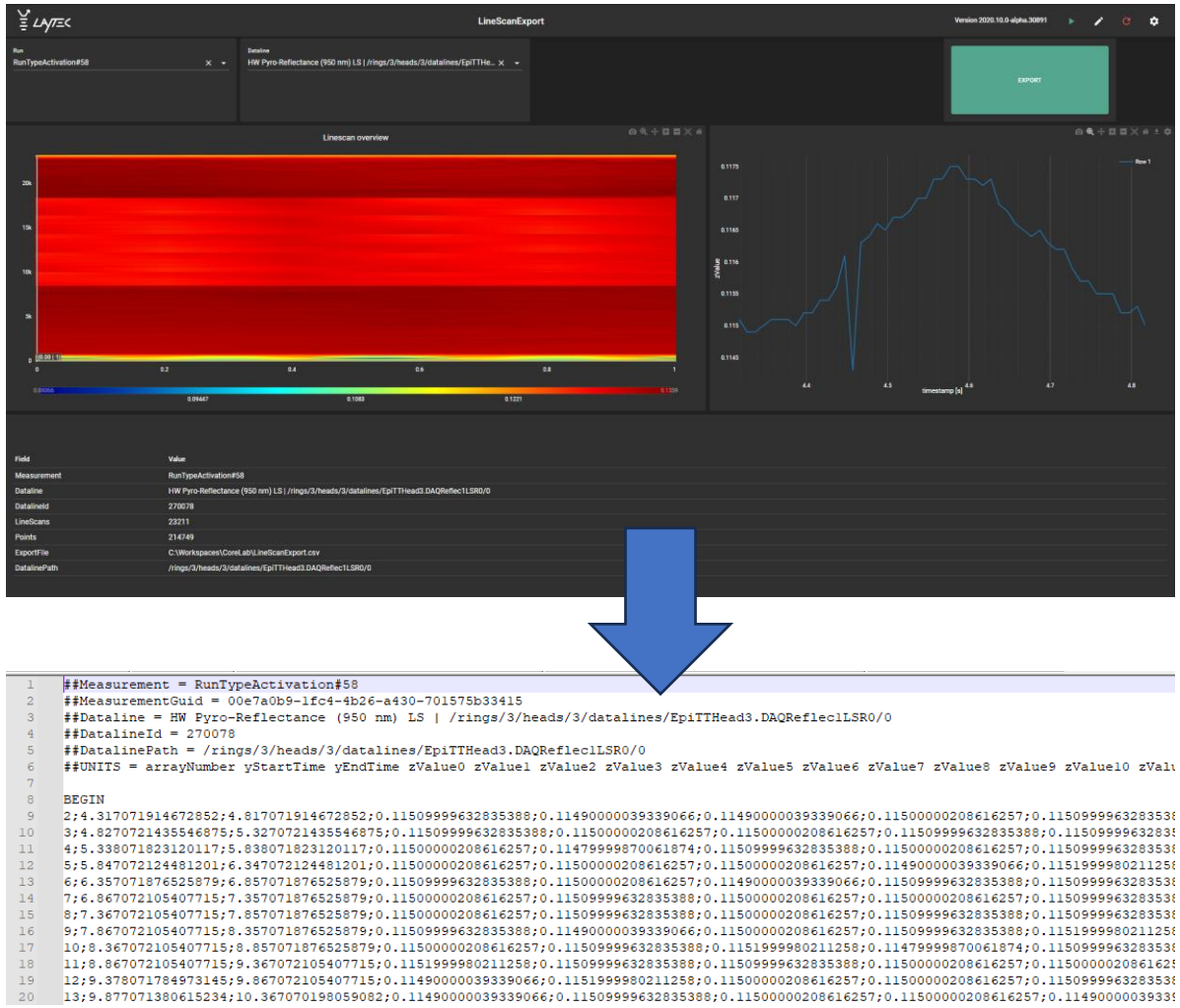
The technology behind *LayTec Analytics:* LAL (*LayTec Analysis Language*)

- Script based language
- Set up parameters to define user interface, manipulation, analysis and output of the data
  - Enable customer to implement own analyses
  - Pre-defined set of scripts for commonly used functions
  - Run real-time analysis
- Usage of any EpiNet Analysis possible
  - e.g. real time growth rate data line
  - e.g. Analyze any data of your line scans
- Very flexible and versatile

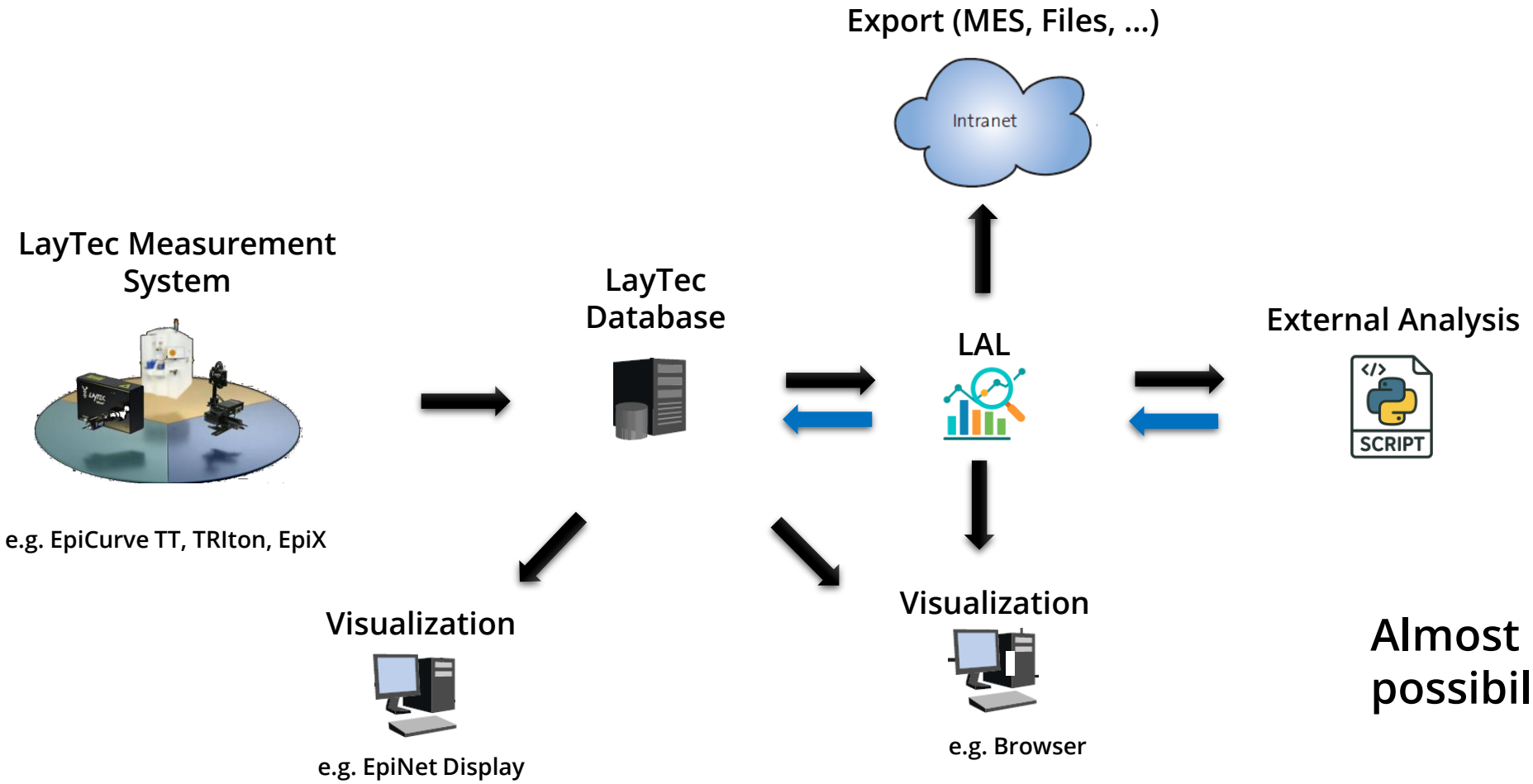
```
// Iterate over all transients to export the interesting part
for(i=0; i < pointsPerRound; i++)
{
    var indexAsDouble   = ToDouble(i);
    var normIndex       = indexAsDouble / pointsPerRound;
    var indexAsAngle    = normIndex * 360.0;

    // Update process progress
    ProcessState        = indexAsDouble / pointsPerRound * 100.0;

    save_ROI = false;
    for(var j=0; j < sizeOfAngles; j++)
    {
        var a = angles[j];
        if((indexAsAngle >= (a - window)) AND (indexAsAngle <= (a + window)))
        {
            save_ROI = true;
            break;
        }
    }
```

Great capabilities with LAL

- No need to learn the script language
- „Skill“ for LLM (e.g. ChatGPT) available to create your own scripts
- Usable for everyone without having to dig deep into the language
  - e.g. exporter plus interactive 3D to 2D Plot – done with *Codex (ChatGPT)* without developer support in ~2 hours
- Skill can be developed further



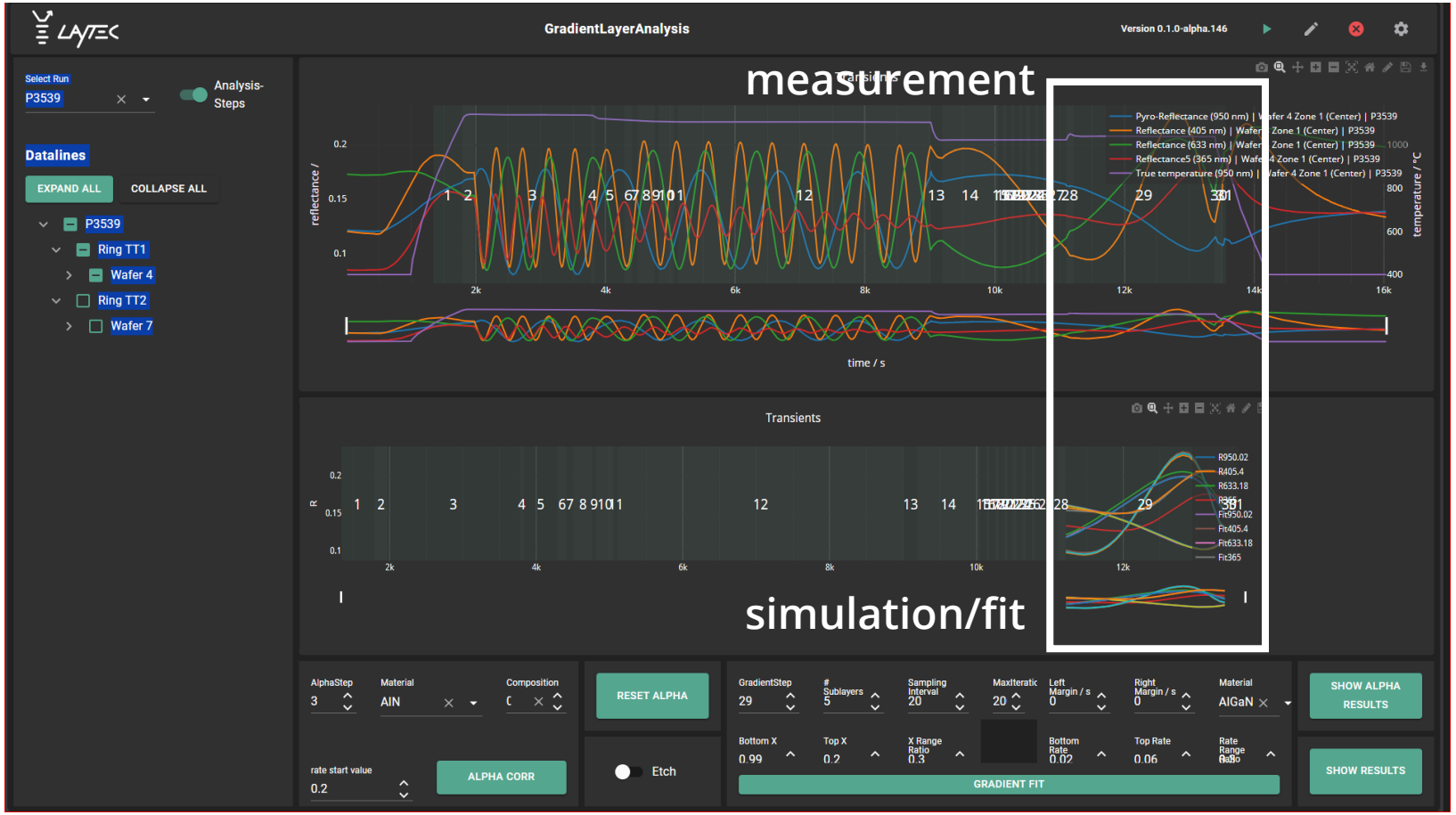
LayTec Analytics - Data Flow Topology



Almost endless possibilities!

Example: Composition Analysis of graded AlGaN Layer

- AlGaN grading from AlN to ~75% AlGaN
- Question:
  What is the Al-dependence over thickness?
- Can be analyzed in SimulyzR using LAL



Example: Composition Analysis of graded AlGaN Layer - Results

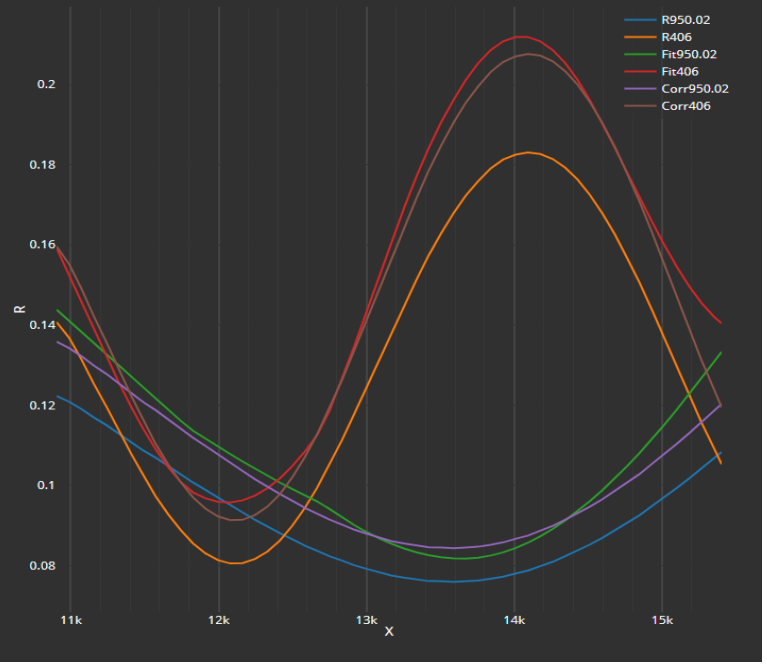
Fit results

Composition Fit Results

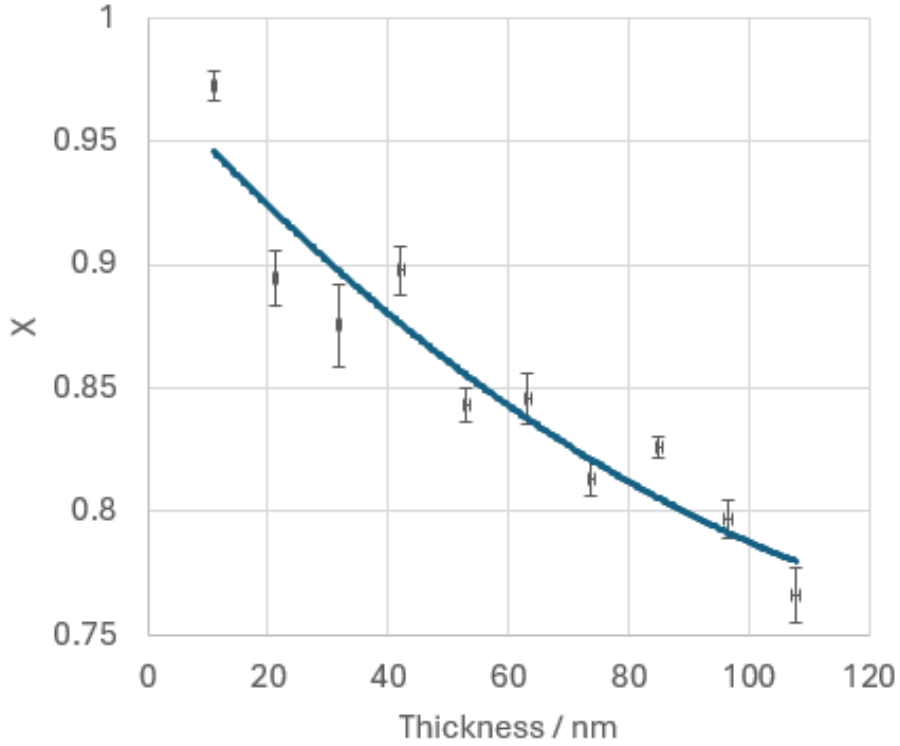
Id	Fix	Value
DBMaterial-1/X/1	☐	0.824778904572596
DBMaterial-2/X/1	☐	0.55610419095862
DBMaterial-3/X/1	☐	0.773485920195856
DBMaterial-4/X/1	☐	0.516739584569192
DBMaterial-5/X/1	☐	0.259924580203799

Rate Fit Results

Id	Fix	Value
LayerRateDuration-1/Rate/1	☐	0.0220483502891833
LayerRateDuration-2/Rate/1	☐	0.0155430534458859
LayerRateDuration-3/Rate/1	☐	0.0259985345739253
LayerRateDuration-4/Rate/1	☐	0.0259991583759268
LayerRateDuration-5/Rate/1	☐	0.0231767026596483



Composition profile over thickness



Knowledge is key

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