LARGE AREA FUNCTIONAL *THIN FILM PROPERTIES MAPPING* USING *IN-LINE HYPERSPECTRAL IMAGING* DURING ROLL-TO-ROLL MAGNETRON SPUTTER DEPOSITION

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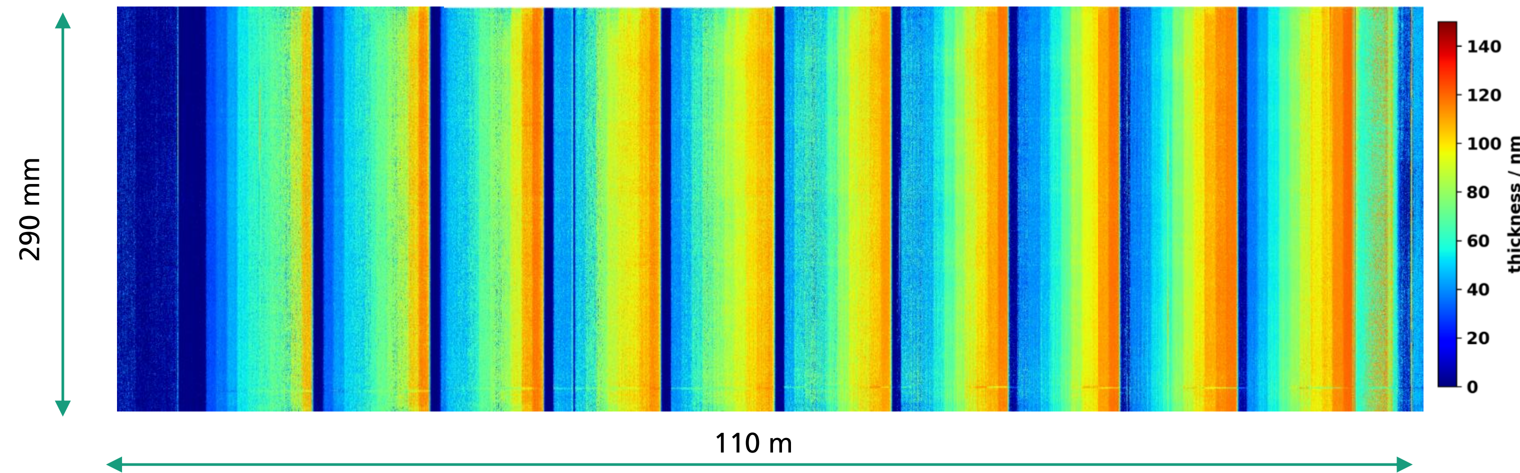

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The challenge

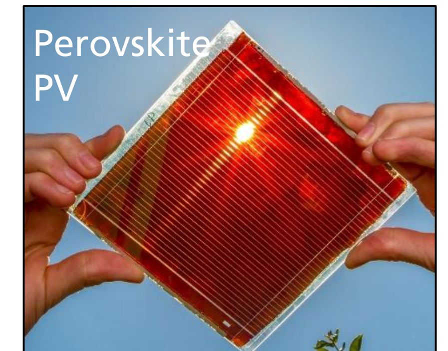
- **We need** precise *(< ± 1%)* control of
  - Thin film thickness
  - chemical composition
  - Solid-state phase / crystallinity
  - Surface roughness / morphology

in thin film processing on large area in multilayer stacks

- **We miss** *fast, efficient and accurate* methods to measure
  - thickness of ultrathin transparent layers (≤ 100 nm)
  - individual layer properties in multilayers
  - „in-situ“ access to solid state phase
  - access to nano-roughness / density
  - inline access to functional properties

source: EControl-Glas, GmbH, Plauen

Question:
How can we map/image the (in)homogeneity of relevant thin film properties on large areas (up to 100m²) at high speed?



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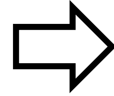
NanoQI concept

high-speed at-line / in-line
XRR / XRD



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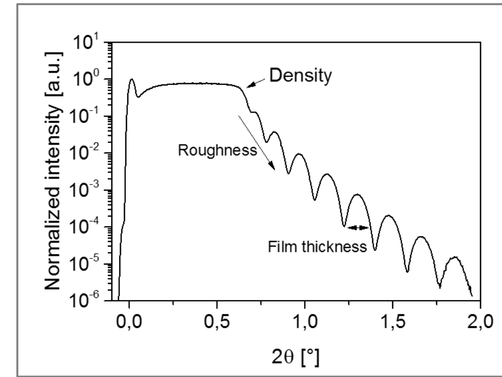
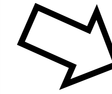
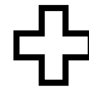
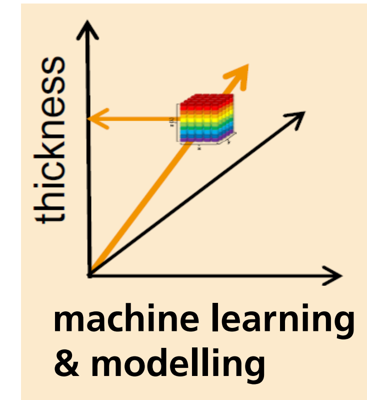






- fast large area surface inspection
- nano material quality control
- real-time process feedback



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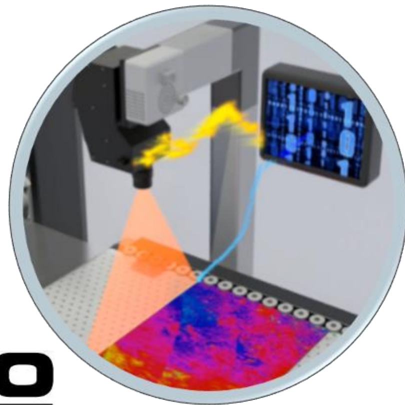

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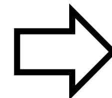
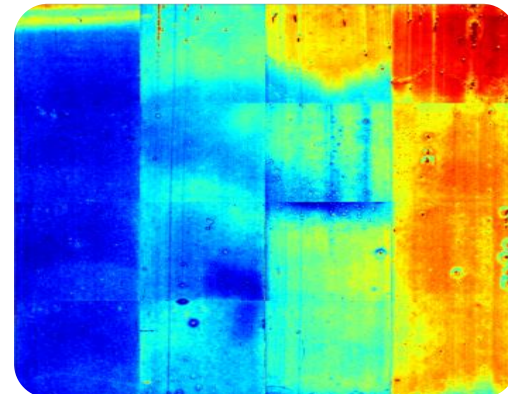
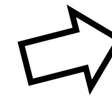
real-time in-line
hyperspectral imaging







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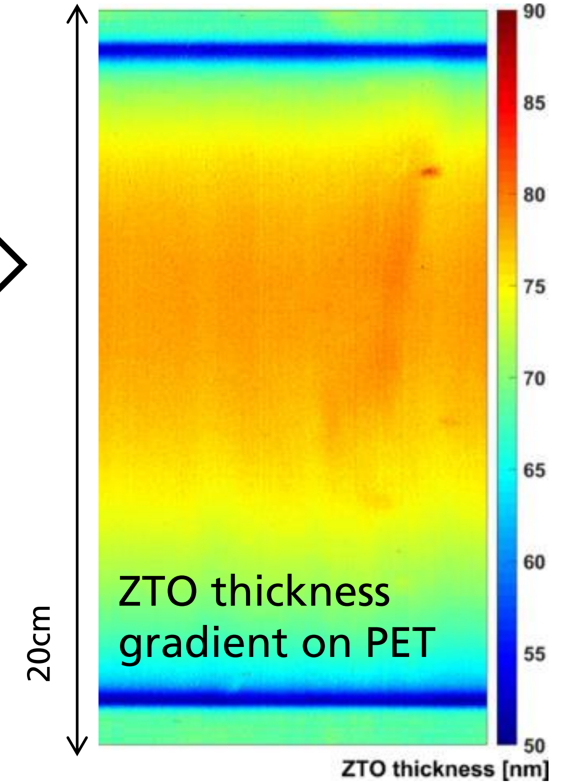

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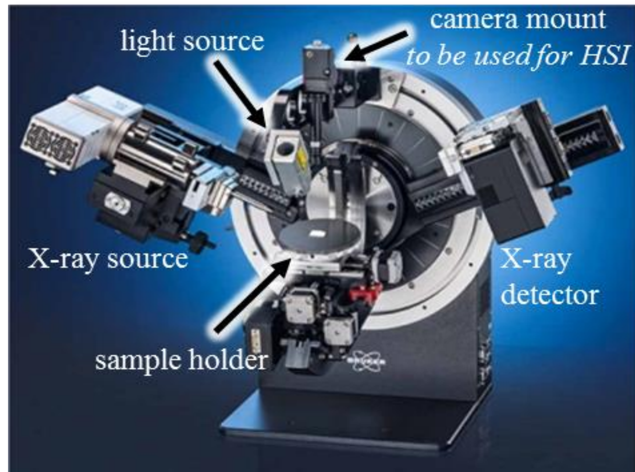
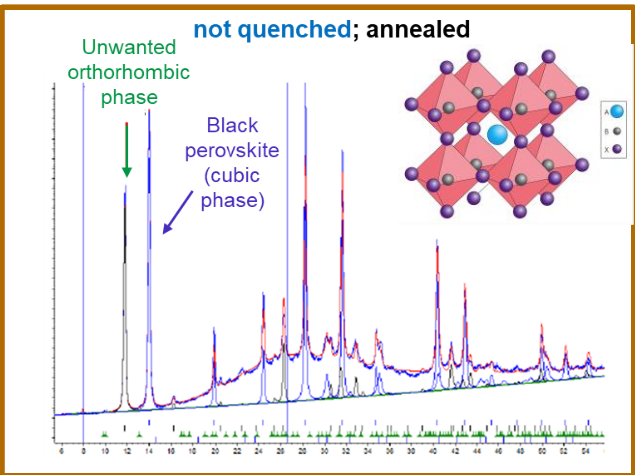
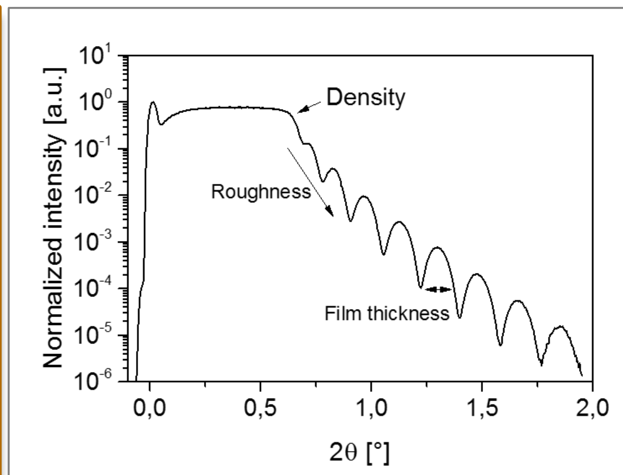
NanoQI methods

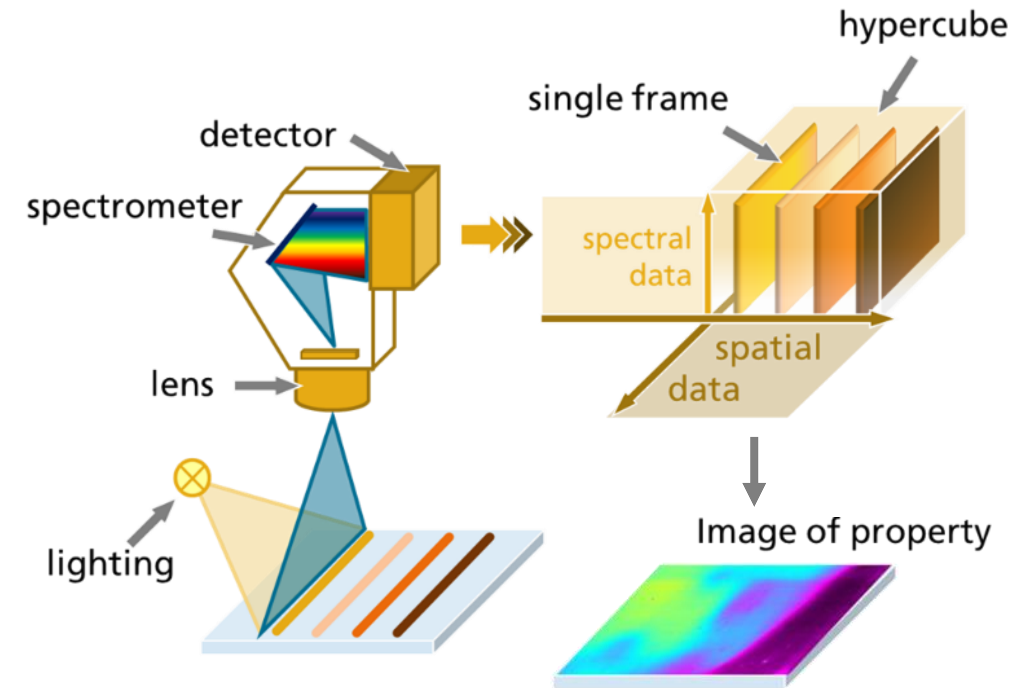


- **X-ray diffraction analysis**
  - Phase analysis
  - Chemical composition
- **X-ray reflectometry**
  - Thickness / Multilayers
  - Roughness
  - (electron) density





- High-speed & high accuracy semi-automated sample evaluation for quality control & HSI model training (calibration)



- **Hyperspectral Imaging**
  - 2D Spatially resolved optical transmission/ reflection spectrometry
  - Detect defects, gradients, property drifts
  - Large area imaging of functional properties
  - Inline integration to thin film processing

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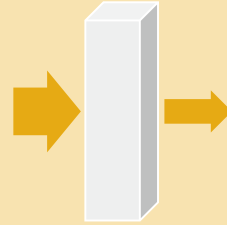
Data evaluation options for HSI data

Hard modeling

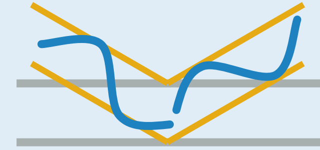
Physical description of received data set

→ Could be slow

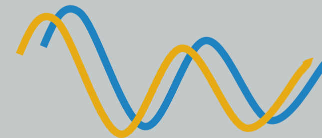
→ No external ground truth needed



Lambert-Beer's law
$E = \varepsilon * c * d$



Bragg's law
$n * \lambda = 2 * d * \sin\,\theta$



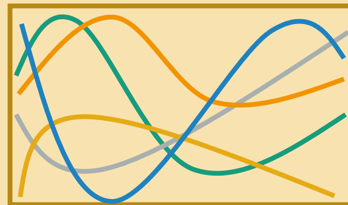
Dielectric function
$\varepsilon(\omega) = \varepsilon_{\infty} - [\varepsilon_0 \rho(\omega^2 \tau + i\omega)]^{-1}$

Soft modeling

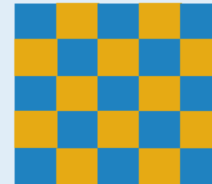
Pattern recognition by means of un-/supervised data evaluation algorithms

→ Could be fast

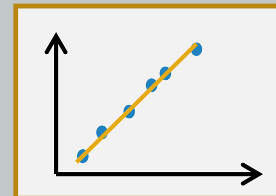
→ Prediction model must be trained



Spectral pattern recognition, chemometrics
(i. e. PCA, LDA, SIMCA)



graphical pattern recognition
(i. e. wavelet analysis)



multivariate correlation algorithms (i. e. PLS)

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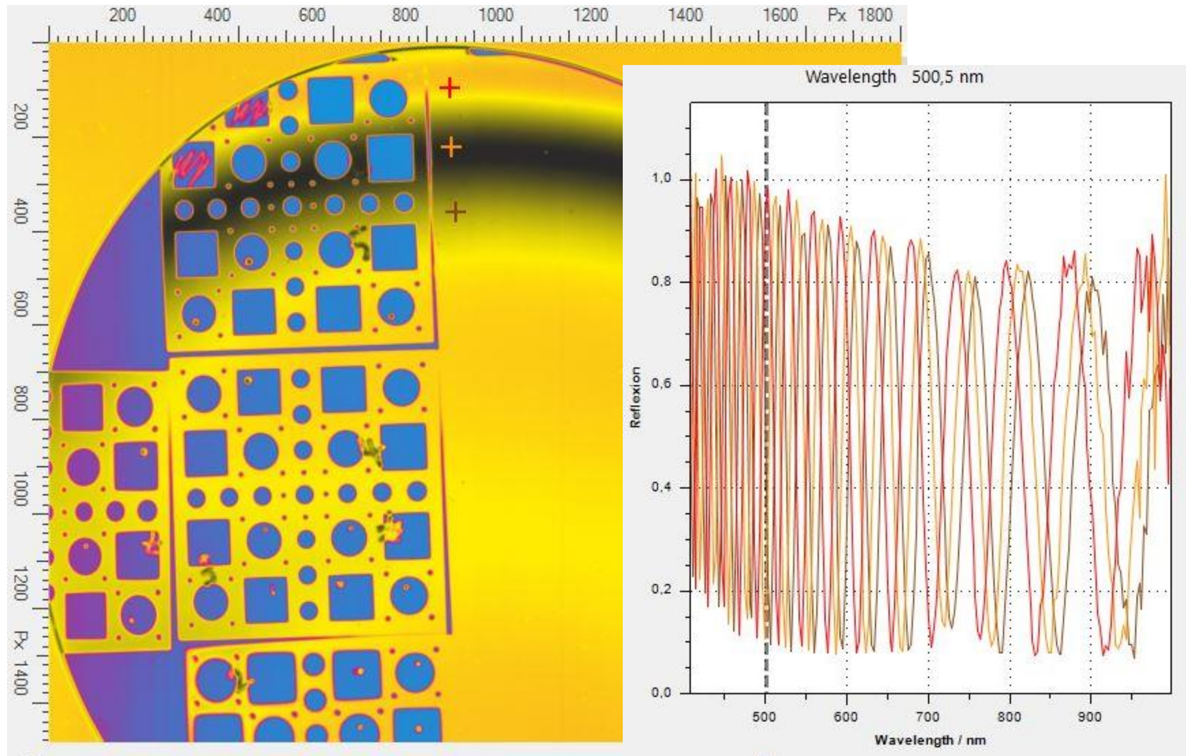
HSI example: Thickness gradient modelling of AlN on Si wafer



HSI reflection „image"
@ 600nm

z-axis = intensity (raw data)

optical reflection spectra
at selected pixels:
interference pattern
-> thickness information

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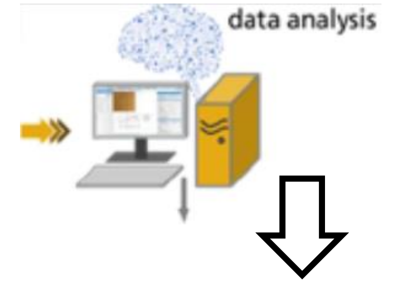
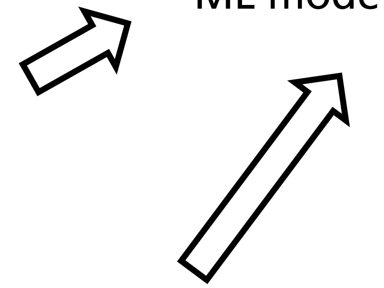
HSI example: Thickness gradient modelling of AlN on Si wafer

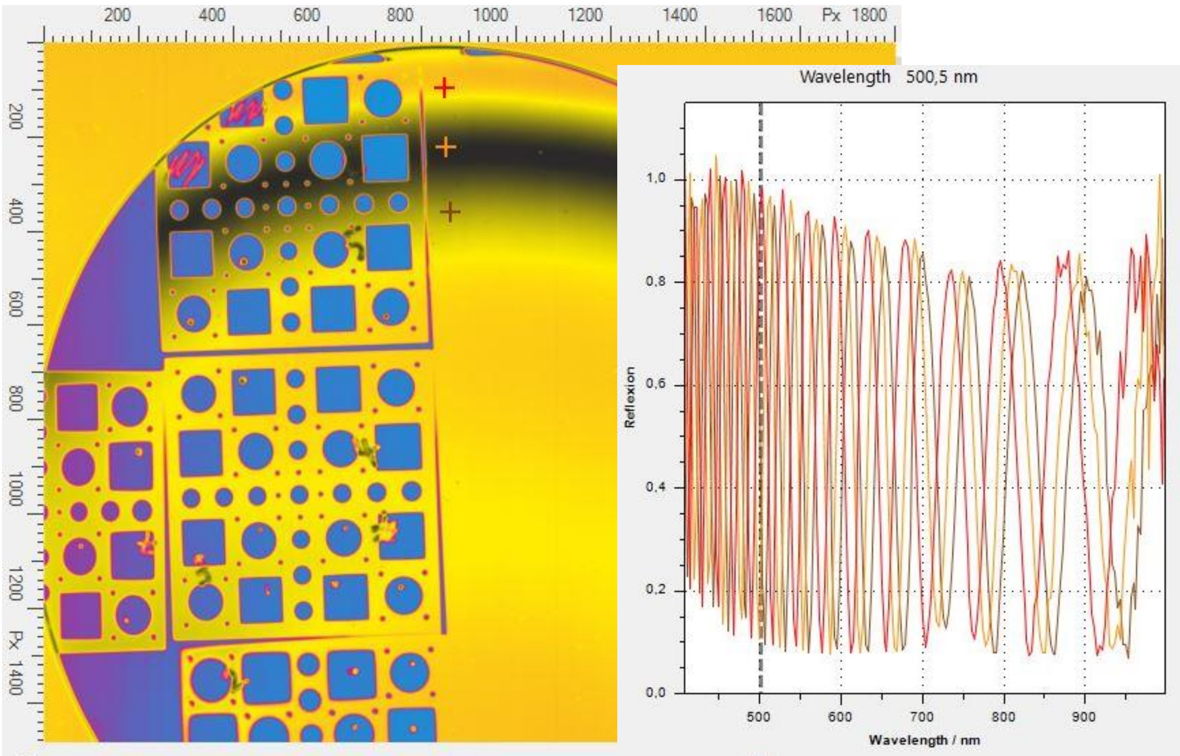


Vector normalization

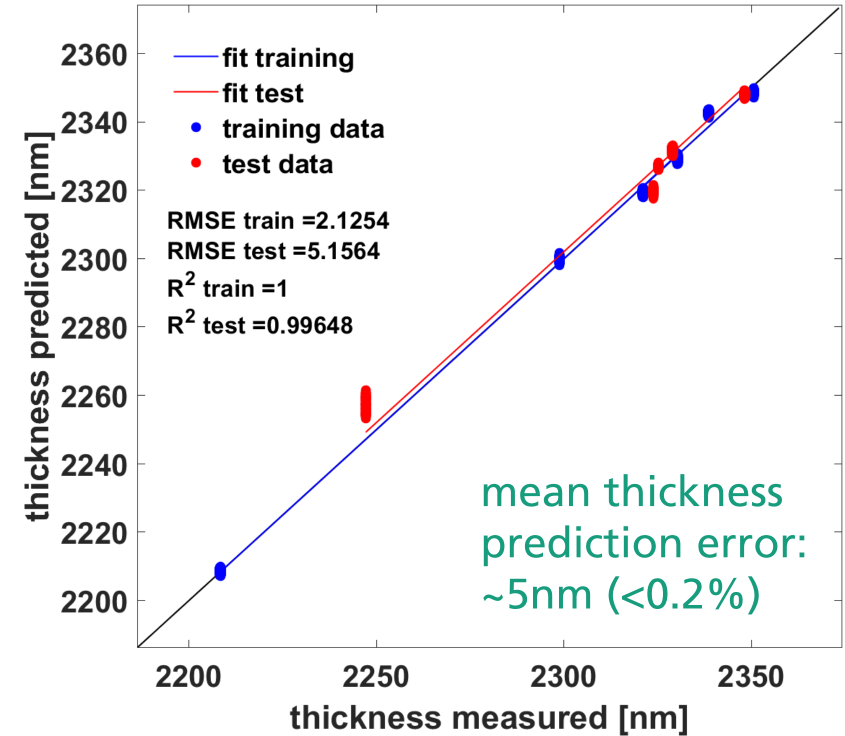
Principle Component Analysis

ML model training & verification





+ 10 thickness values from locations across wafer by external method (spectroscopic ellipsometry)



mean thickness prediction error: ~5nm (<0.2%)

HSI reflection „image“ @ 600nm

z-axis = intensity (raw data)

optical reflection spectra at selected pixels: interference pattern -> thickness information

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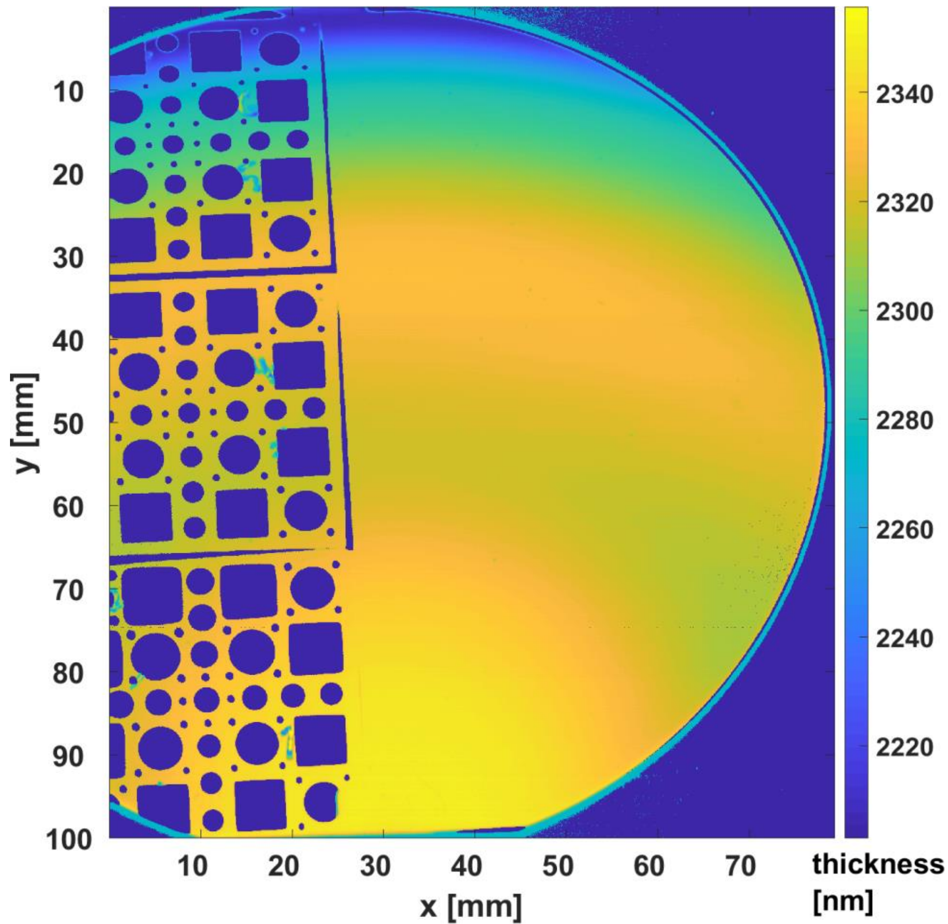
HSI example: Thickness gradient modelling of AlN on Si wafer



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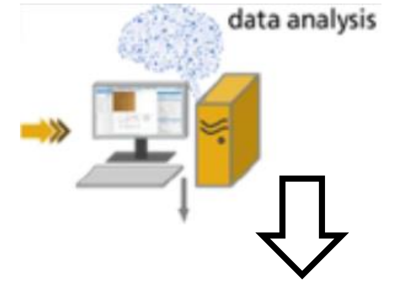
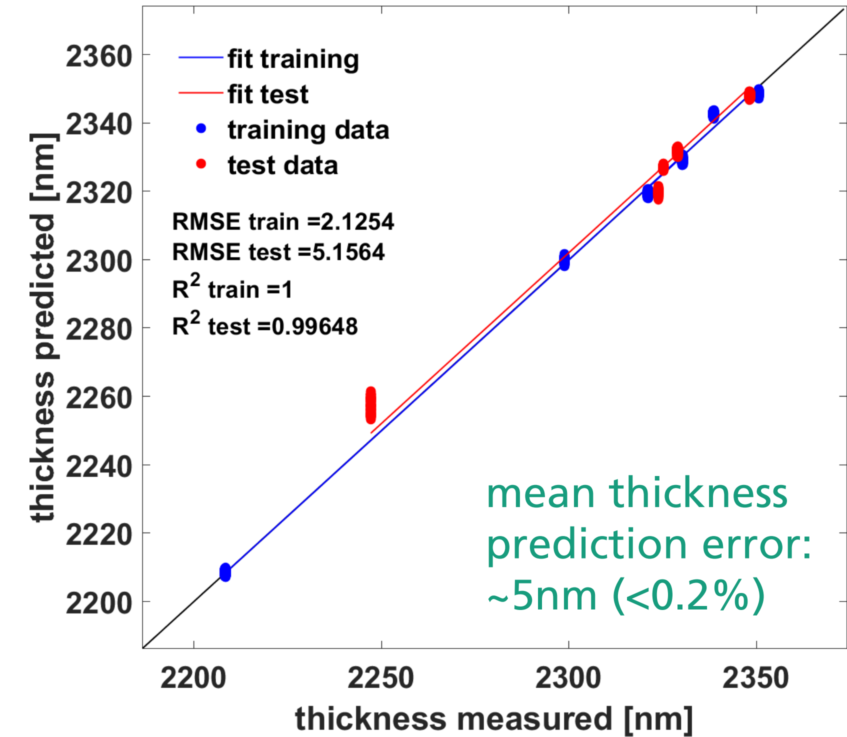


data transformation



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Result

- thickness map of complete wafer with sub-mm spatial resolution
- HSI model can now be used for any unknown AlN/Si sample (without external data)

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In-line HSI @ coFlex® 600 pilot web coater: performance parameters

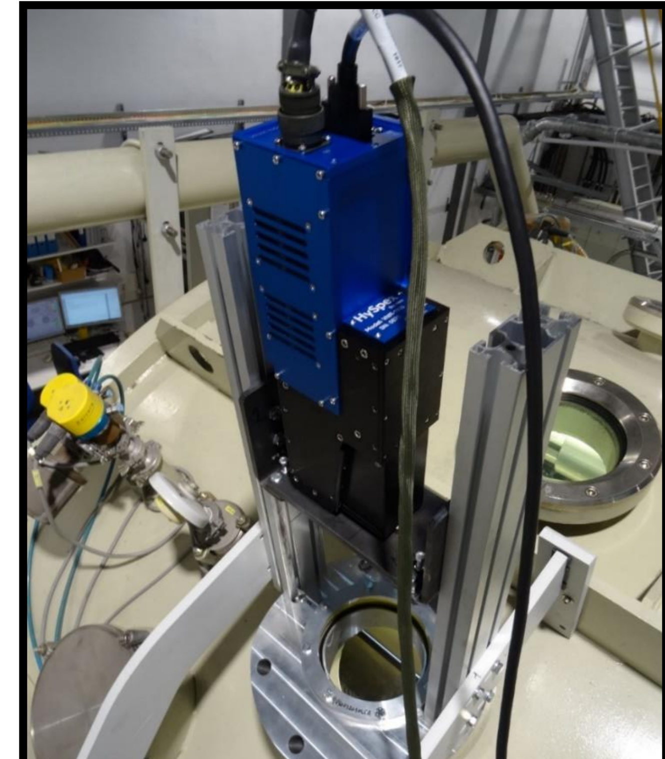
Configuration

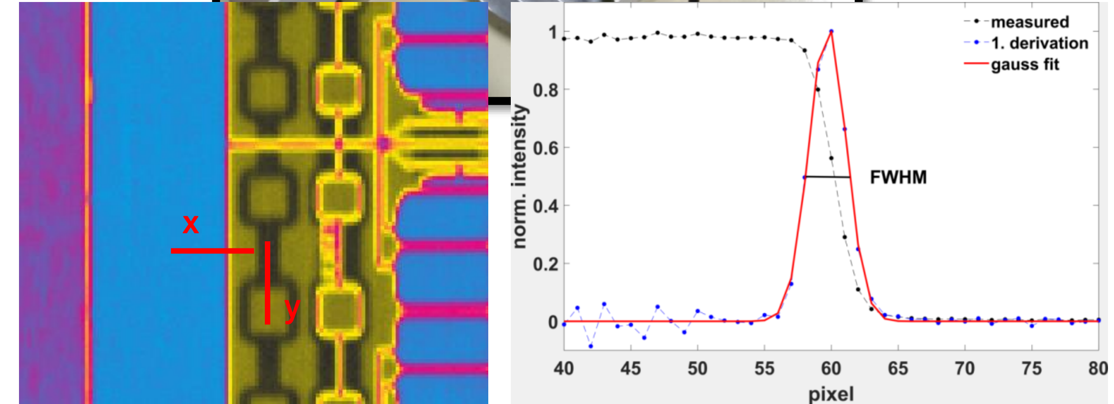
• HSI camera working distance:	100 cm	~66 cm
• HSI camera FoV angle	16°	40°
• Web speed*	<1.5 m/min	~2.5 m/min

Experimental parameters:

Field of View (FoV):	292 mm	450 mm
Pixel size:	0.162 mm/px	~0.3 mm/px
Spatial Resolution (using FWHM of 1st derivative)	~0.25 mm (x) ~0.70 mm (y)	~0.4 mm ~1.1 mm

*) much higher web speed possible via
- accepting some image spatial distortion (in coating direction)
- intelligent „online“ HSI data reduction
- increasing HSI data bandwidth





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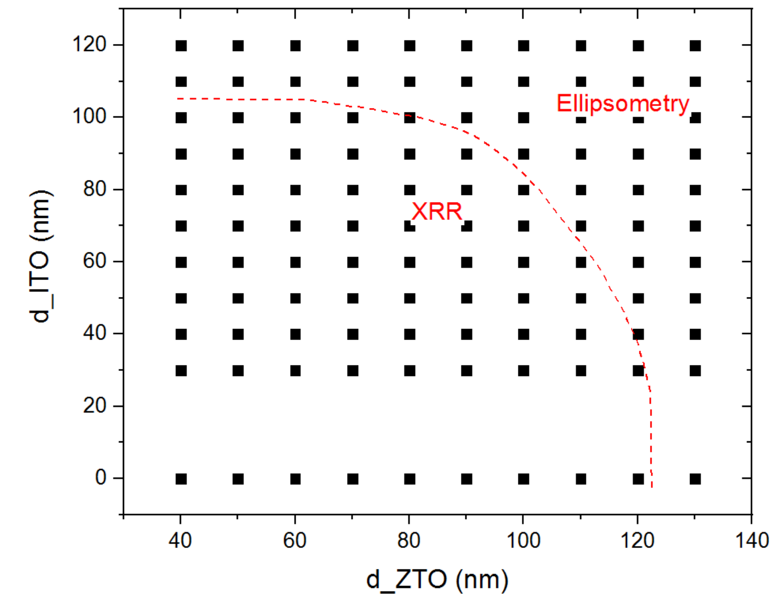
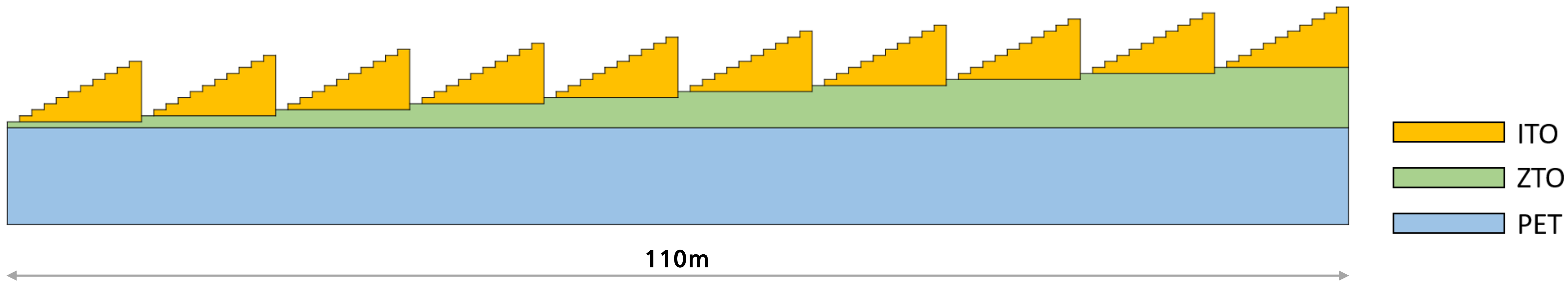
In-line HSI @ coFlex® 600 pilot web coater: performance parameters

- Transparent oxide double layer
- Complex test object for HSI on coFlex® 600
- Layer thickness determination for modeling still pending





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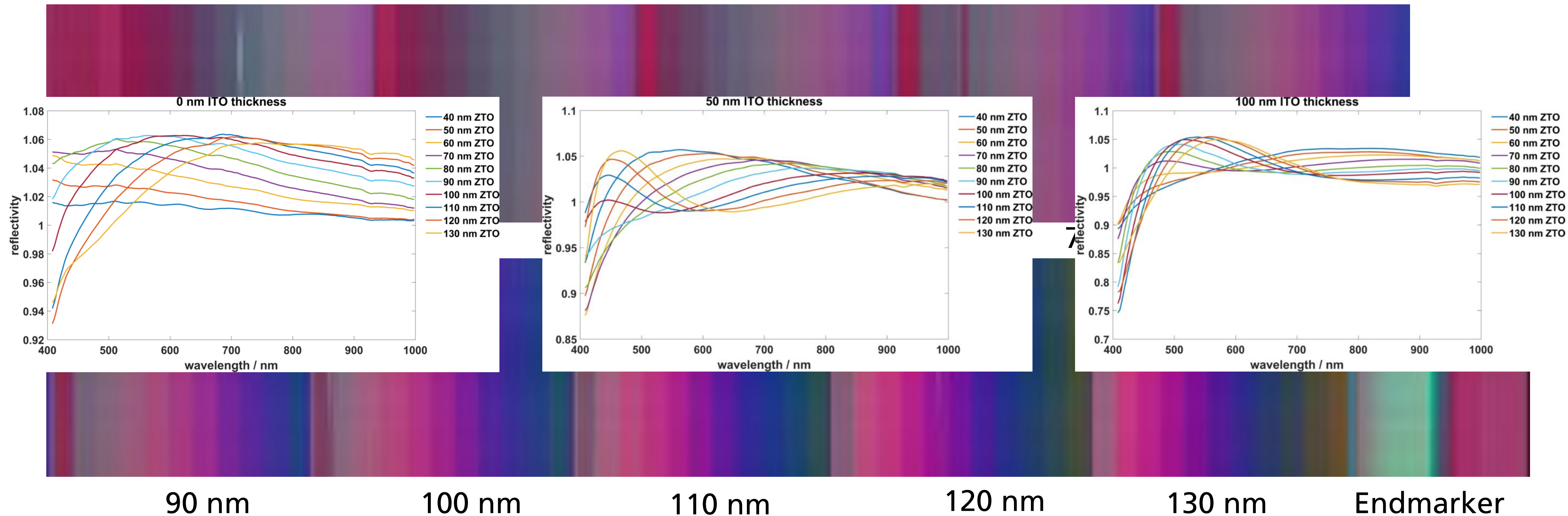
In-line HSI @ coFlex® 600 pilot web coater: performance parameters

- PCA of the referenced (and normalized) spectra makes spectral differences visible!
- Target: RGB image of the first 3 PCs: different color = different spectral properties



- Different areas of the 10 nm steps are clearly visible → Input for HSI Model

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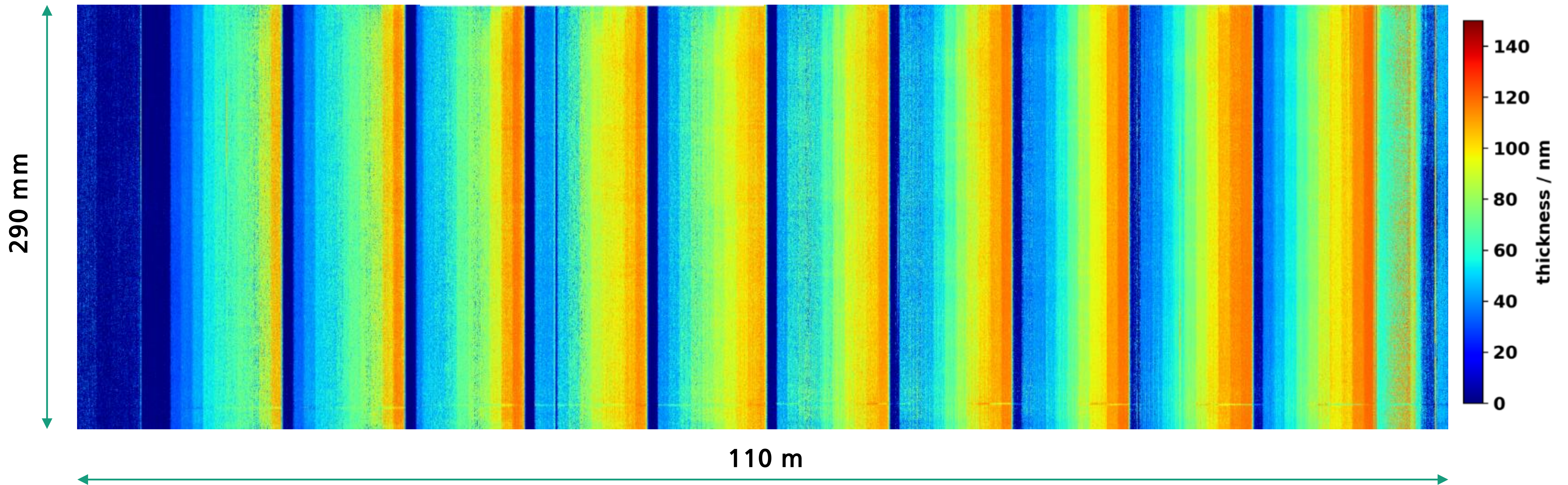
In-line HSI @ coFlex® 600 pilot web coater: performance parameters

Nanoscale, flexible & functional inline method for Materials research and development on large industrial surfaces is just around the corner!



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Thank you for listening

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Multimodal X-ray and Hyperspectral
Thin-Film Nanomaterial Evaluation and Quality Imaging

AMIRES

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