Park Systems GmbH - Accurion
Stresemannstr. 30 37079 Goettingen, Germany
+49-551-999600 (Germany)
parksystems.com inquiry@parksystems.com

Current Trends in Microscopic Characterization: Spectroscopic Imaging Ellipsometry (SIE)

Imaging Ellipsometry

Imaging ellipsometry, **combines** the power of **ellipsometry** with **optical microscopy**. It achieves the highest lateral resolution in the field of ellipsometry and offers a very sensitive imaging technology for thin films. Typical samples range from tiny samples like flakes of 2D materials to inhomogeneous surfaces like some CWD samples of 2D materials or terraces at Epitaxial Graphene surfaces.

The ep4 is the latest microscopic imaging spectroscopic ellipsometer with unique measurement capabilities. It can provide real-time ellipsometric enhanced contrast images, and maps of the ellipsometric angles Psi and Delta. These data can be transferred into Thickness and the complex refractive indices by computerized optical modeling.

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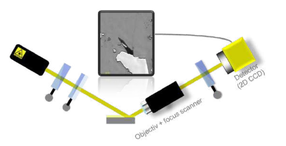
For an introduction to our technology please visite our technology page



Setup of an imaging ellipsometer including objective and 2D CCD

For additional information, please visit our EP4 page

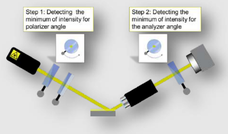
Imaging spectroscopic elliipsometer nanofilm_ep4

For additional information, please watch our EP4-Model video at

Regions of Interest

- Imaging ellipsometry offers the option to study portions of the sample by selecting corresponding pixels in the image of the 2D detector.

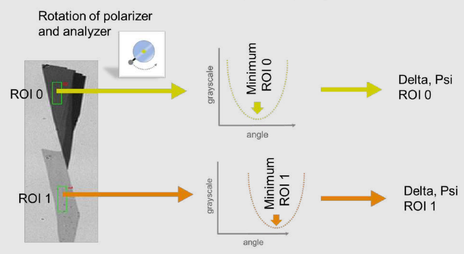
The intensity changes are recorded only for the pixels, that represent the Region of Interest (ROI). With this method, a much higher lateral resolution is available and similar areas can be measured in parallel.



angles $P, C, A \longrightarrow \Delta, \Psi$

ideal instrument, $C = 45°$:
$\Delta = -2P \mp 90°$ $\quad \Psi = \pm A$

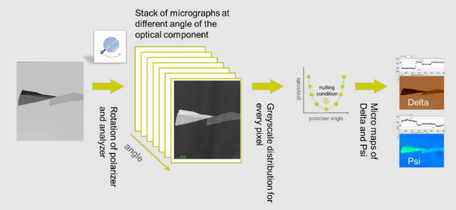
Procedure to detect the ellipsometric angles Delta and Psi:
Step 1: detect the minimum for polarizer angle (P)
Step 2: detect the minimum of the analyzer angle (A)
Step 3: Computing Delta and Psi

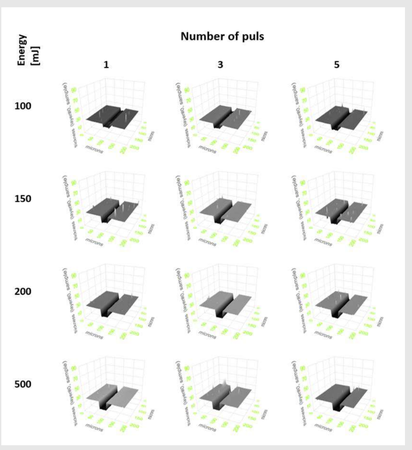


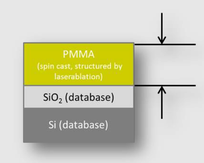
Graphene mono and multilayer (Air|Graphene|$SiO_{2(native)}$|Si)

Microscopic Mapping

- Microscopic mapping offers the highest lateral resolution in the field of ellipsometry. (down to 1 µm)
- each pixel works as a single detector.





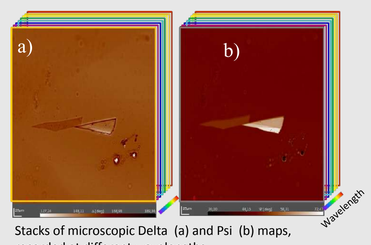


Sample: PMMA | SiO_2 (native) | Si

PMMA was spin-cast on Si/SiO_2. The surface was structured by laser ablation by varying the number and power of the laserpuls. The thickness maps were calculated out of Delta maps, recorded at an AOI of 50 ° at a wavelength of 500 nm using a 20x objective.

Extracting Wavelength Spectra

- The extraction of spectra from a stack of microscopic maps is a tool to measure the complete spectra of the smallest regions of interest.



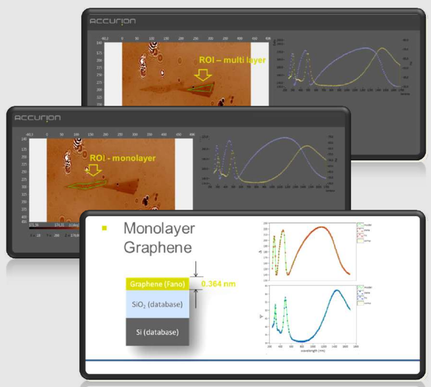
Stacks of microscopic Delta (a) and Psi (b) maps, recorded at different wavelengths

Record Delta and Psi maps at different wavelengths

Select a region of interest in one representative map

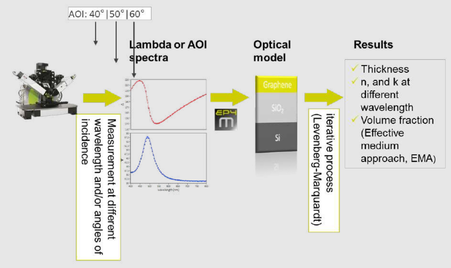
Software calculats the delta and Psi values for the ROI

Send spectra to the modell and calculate the parmeter of interest



Optical Modeling

- Calculation of optical- and metrological parameters for ultrathin films
- Effective medium approach (EMA) also offers information about chemical composition

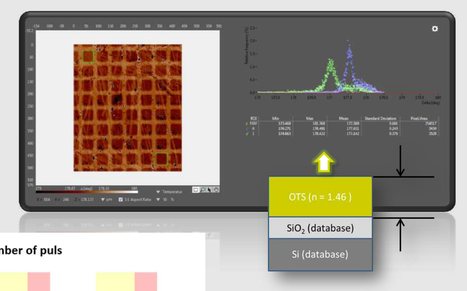


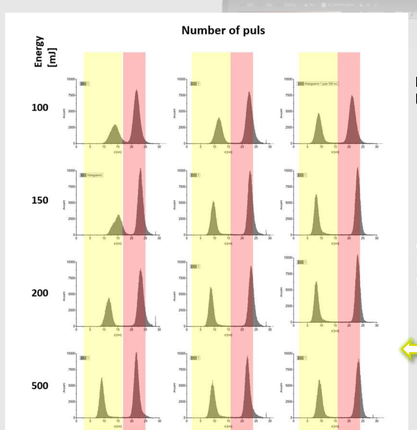
The Drude equation connects the ellipsometric angles Delta and Psi with the Total reflection coefficient of the Fresnel equation and on this track with physical parameters like the complex refractive index and the layer thickness. By using different wavelengths the dispersion function of the layers and/or of the substrate is available. The number of fit parameters is related to the number of measured parameters. To increase the number of parameters, angle of incidence, and wavelength spectra can be measured.

For additional information, please watch our EP4-Model video at

Histograms, data distribution

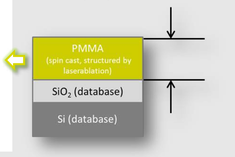
- A histogram is a graphical representation of the distribution of numerical data. Can be used as well for Delta and Psi as for the result.





Histograms of ROIs – screenshot of the EP4-datastudio.

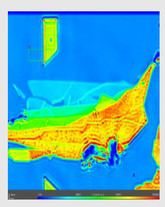
Comparison of areas after laser treatment (yellow) with the untreated substrate (red).



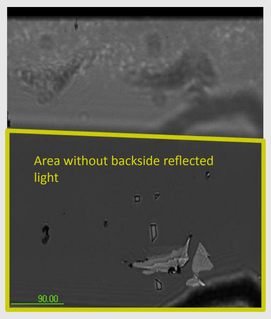
Knife Edge Illumination

- No contribution by backside reflected light
- Non destructive, no treatment of the backside .

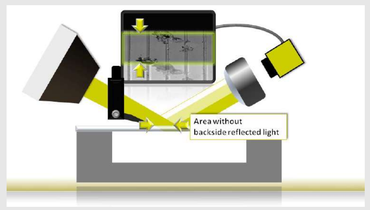
Beam cutter in park position (a) and working position (b).



MoS_2-flake: Ellipsometric enhanced contrast micrograph



Ellipsometric enhanced contrast micrograph of a MoS_2 flake on sapphire.



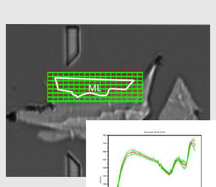
Working principal of a beam cutter.

Sample provided by: Ursula Wurstbauer et al. TU München

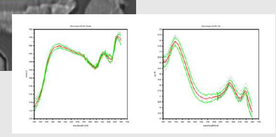
For additional information, please watch our beamcutter video at

Optical Properties

- Ellipsometry is more sensitive to out of plan component of optical constants than reflectometry.



For more details: Funke et al. (2016)

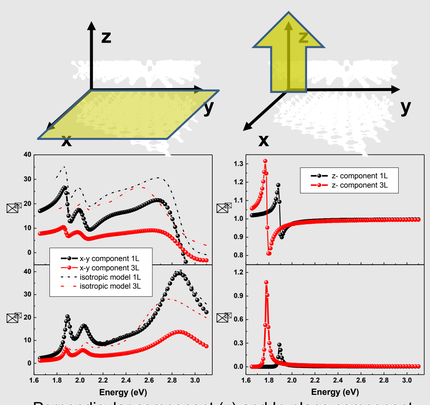


Array of ROIs (this case: 126)

Average ROIs 93-101 (Monolayer)

Optical model based on Lorentz- and Tauc-Lorentz oscillators

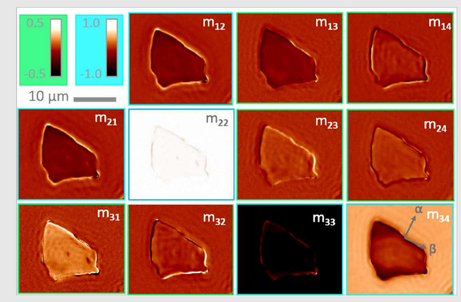
Pseudo dielectrical function of **MoS_2 Monolayer**



Perpendicular component (z) and In-plane component (x,y) of the complex dielectric function.

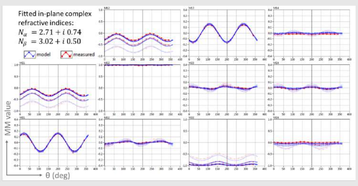
Microscopic Müller Matrix

- Müller Matrix Ellipsometry is the method of choice for anisotropic samples.
- First microscopic Müller Matrix Ellipsometry



- Example: micro-structured flakes of black phosphorus (anisotropic) on silicon substrate.
- Application type: anisotropic thin-film layer.
- Overall focused Mueller-matrix images with microscopic lateral resolution.
- Identification of isotropic and anisotropic regions.
- Determination of anisotropic refractive indices and orientation of optical axis.

Micromaps of normalized MM (m_{11}=1) at θ=0° and λ=550 nm. Mind different scale bars for block diagonal (blue frames) and block off-diagonal (green frames) matrix elements. Arrows in m34-graph indicate the orientation of in-plane optical axes obtained from ellipsometric modelling of θ-scan.



θ-spectrum of the normalized 3x4 MM of black phosphorus at different angles of incidence obtained from ROI-evaluation of MM-micromaps. Indices of fitted complex refractive indices N_α and N_β refer to principal in-plane axes of index ellipsoid (c. figure left, inset in m_{34}-micrograph). Mind different y-scales for block diagonal and block off-diagonal MM-elements.

Sample provided by: Aday J. Molina-Mendoza (University of Madrid, Spain) & Andres Castellanos-Gomez (IMDEA Nanoscience, Madrid, Spain)

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