VASE®

Variable Angle Spectroscopic Ellipsometer

J.A. Woollam Co., Inc.

Ellipsometry Solutions

Accurate

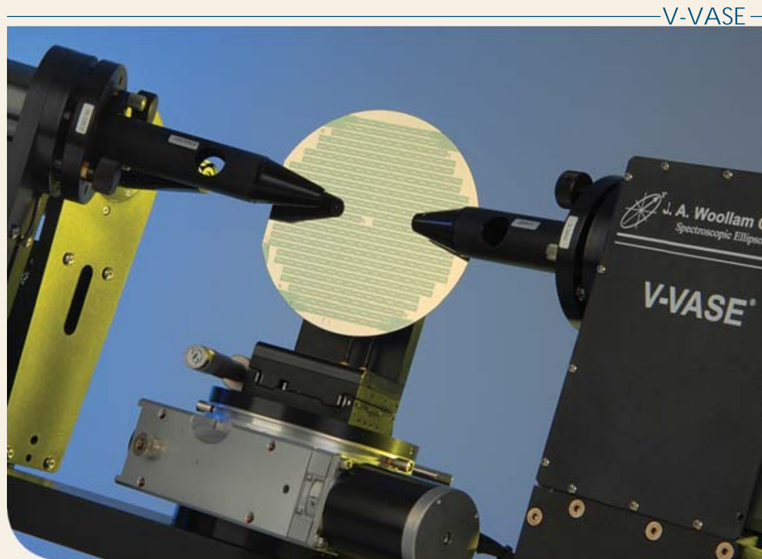
$\vec{E}$

Capabilities

The VASE® is an accurate and versatile ellipsometer for research on all types of materials: semiconductors, dielectrics, polymers, metals, multi-layers, and more. It combines high accuracy and precision with a wide spectral range - 193 to 3200nm. Variable wavelength and angle of incidence allow flexible measurement capabilities, including:

- Reflection and Transmission Ellipsometry
- Generalized Ellipsometry (Anisotropy, Retardance, Birefringence)
- Reflectance (R) and Transmittance (T) intensity
- Cross-polarized R/T
- Depolarization
- Scatterometry
- Mueller-matrix

V-VASE



Why a VASE?

Focused Beam

Maximum Data Accuracy

The VASE features a rotating analyzer ellipsometer (RAE) combined with our patented AutoRetarder® for unparalleled data accuracy.

High Precision Wavelength Selection

The HS-190™ scanning monochromator is designed specifically for spectroscopic ellipsometry. It optimizes speed, wavelength accuracy and light throughput, while automatically controling selection of wavelengths and spectral resolution.

Flexible Measurements

The V-VASE features a vertical sample mount to accommodate a large variety of measurement geometries including reflection, transmission, and scattering.

Advanced Technology

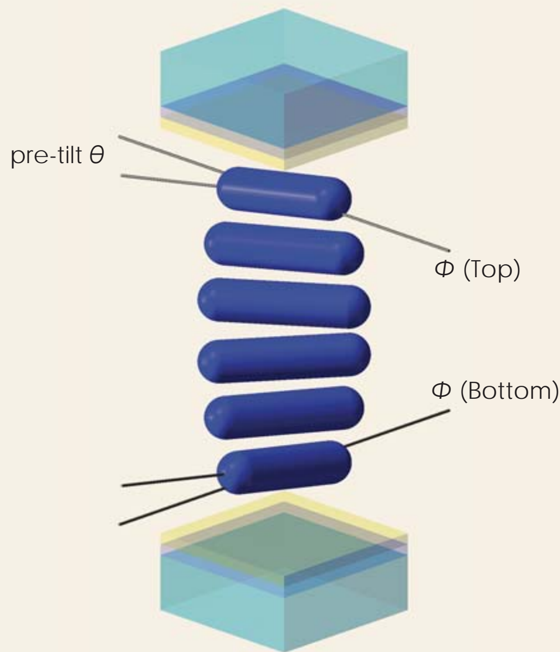
AutoRetarder® Technology

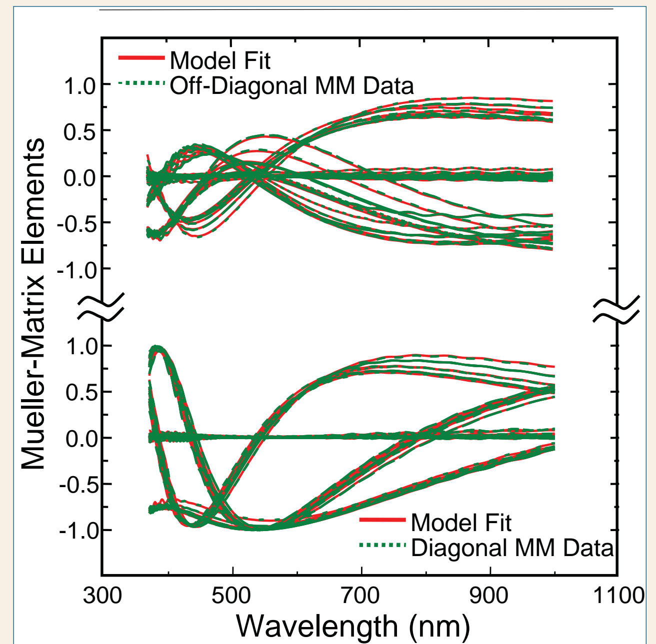
Rotating Analyzer Ellipsometers (RAE) maximize data accuracy near the “Brewster” condition - where Ψ/Δ data are content-rich. However, this region can be limiting for samples with reduced signal. The patented AutoRetarder is a computer controlled waveplate which modifies the light beam polarization before it reaches the sample. This produces optimum measurement conditions for any sample - under any conditions.

AutoRetarder accurately measures:

- Ψ and Δ over the full range!
- Generalized (anisotropic) Ellipsometry
- Depolarization data
- Mueller-matrix data

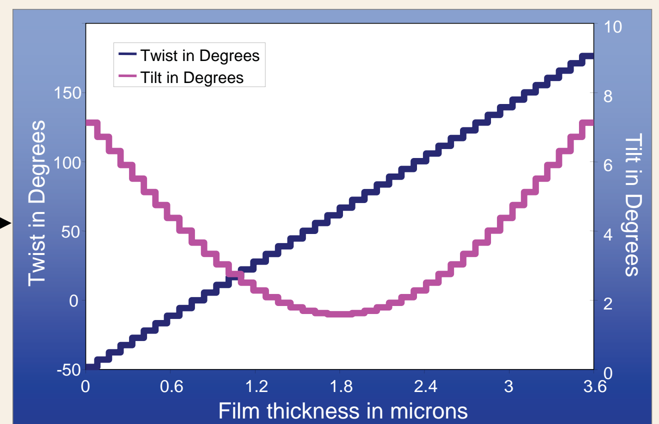
Anisotropy





Mueller-matrix measurement of a super twisted nematic liquid crystal.

Layer	Thickness
Glass Substrate	
ITO	20nm
Polyimide	135nm
STN Liquid Crystal	**3.6 µm**
Polyimide	135nm
ITO	20nm
Glass Substrate	



Generalized Ellipsometry is used to successfully measure anisotropy, twist and pre-tilt of a super twisted nematic liquid crystal film.

Applications

Optical Coatings

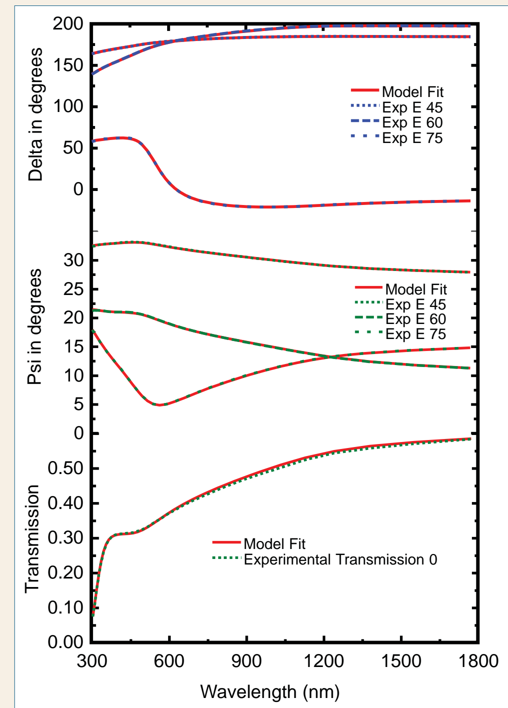
The AutoRetarder® measures Δ accurately even when close to 0° or 180° which helps characterize thin films on transparent substrates, such as glass or plastics. Applications include decorative coatings, anti-reflection and high-reflection layers and stacks, low-emissivity films, electrochromic and photochromic layers and more.

Laser optics

Accurate wavelength selection using monochromator allows measurements at the operating wavelength for optics, e.g. 1550nm, 1310nm, 980nm, 632.8nm, 589nm …

Thin Films

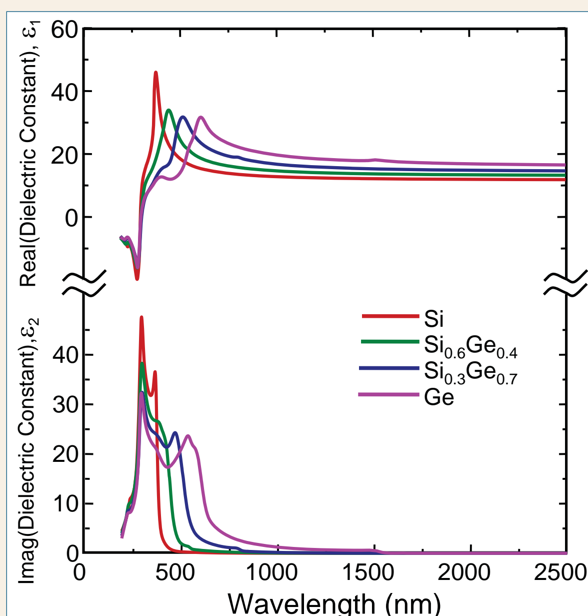
VASE is sensitive to layer thickness down to sub-nanometer. For absorbing layers, the VASE allows measurement of SE and Transmission Intensity (T). When analyzed simultaneously, SE + T often allow determination of n, k, and t. For example, this thin metal layer is only 14 nm thick.



SE + T for thin metal layer.

Semiconductors

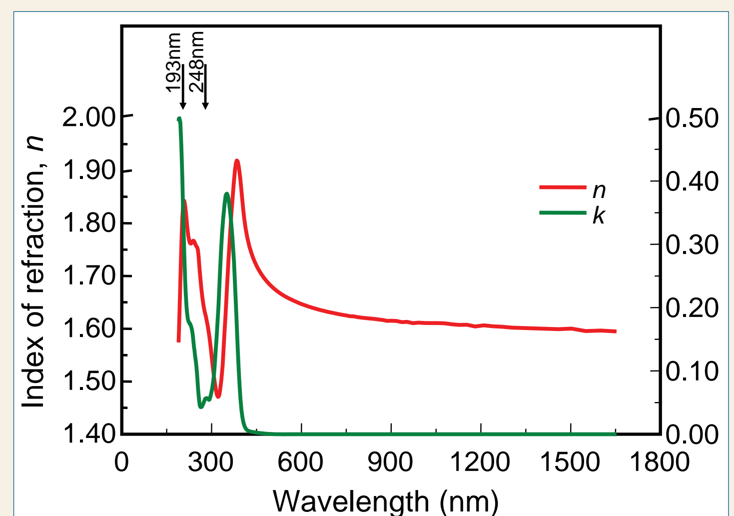
Bandgap, electronic transitions and critical points can be measured for semiconductor materials such as GaN, InP, SiGe, CdTe, etc. Good wavelength resolution and ability to measure depolarization insure accurate optical constants.



SiGe optical constants with varying composition.

Photosensitive Materials

The monochromator is positioned before the sample, so only low intensity monochromatic light strikes the sample. This prevents exposure of photosensitive samples.



Optical constants of a photolithography film.

Applications

Metamaterials

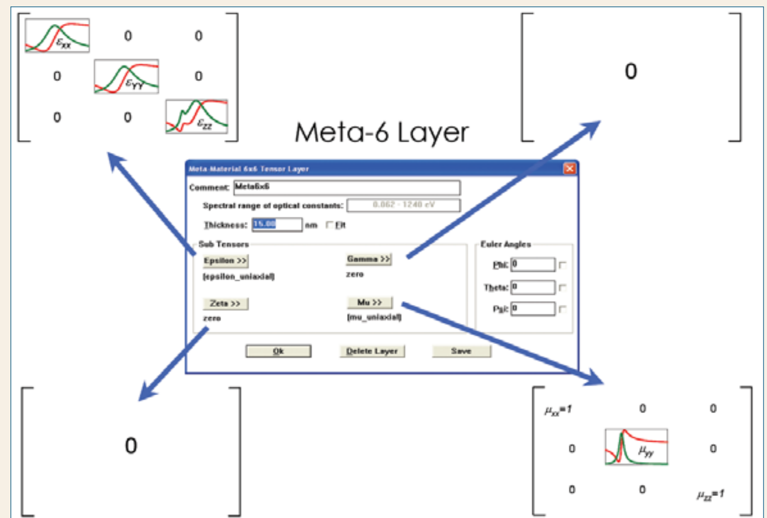
Metamaterials consist of artificially-created arrays of small structures, usually smaller than the measurement wavelength. These structures have properties tailored to interact with incoming ElectroMagnetic waves in ways generally not observed in natural materials. Up to four relative constitutive functions (ε, μ, γ and ζ) can be required to completely model metamaterials structures. Furthermore, they can be anisotropic, requiring 3X3 tensors for each function, as shown below:

$$\begin{bmatrix} D_x \\ D_y \\ D_z \end{bmatrix} = \varepsilon_0 \begin{bmatrix} \varepsilon_{xx} & \varepsilon_{xy} & \varepsilon_{xz} \\ \varepsilon_{yx} & \varepsilon_{yy} & \varepsilon_{yz} \\ \varepsilon_{zx} & \varepsilon_{zy} & \varepsilon_{zz} \end{bmatrix} \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} + \frac{1}{c} \begin{bmatrix} \gamma_{xx} & \gamma_{xy} & \gamma_{xz} \\ \gamma_{yx} & \gamma_{yy} & \gamma_{yz} \\ \gamma_{zx} & \gamma_{zy} & \gamma_{zz} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix}$$

$$\begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} = \frac{1}{c} \begin{bmatrix} \zeta_{xx} & \zeta_{xy} & \zeta_{xz} \\ \zeta_{yx} & \zeta_{yy} & \zeta_{yz} \\ \zeta_{zx} & \zeta_{zy} & \zeta_{zz} \end{bmatrix} \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} + \mu_0 \begin{bmatrix} \mu_{xx} & \mu_{xy} & \mu_{xz} \\ \mu_{yx} & \mu_{yy} & \mu_{yz} \\ \mu_{zx} & \mu_{zy} & \mu_{zz} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix}$$

These equations are embodied in the *Meta-6* layer, as shown below with different Genosc layers describing the various anisotropic dielectric tensors.

Metamaterials are usually anisotropic and are often depolarizing; meaning that they usually require either generalized ellipsometry (g-SE) measurements or even Mueller-matrix ellipsometry (MM-SE).



The VASE® can measure a wide variety of advanced measurement types, to help characterize the various elements of a Metamaterial.

MM-SE, g-SE, and Intensity (like and cross-polarizations).

- Reflection angles between 15° and 90°.
- Transmitted angles between -30° and +90°

* MM-SE measurements include the first 3 rows of the 4x4 Mueller-matrix.

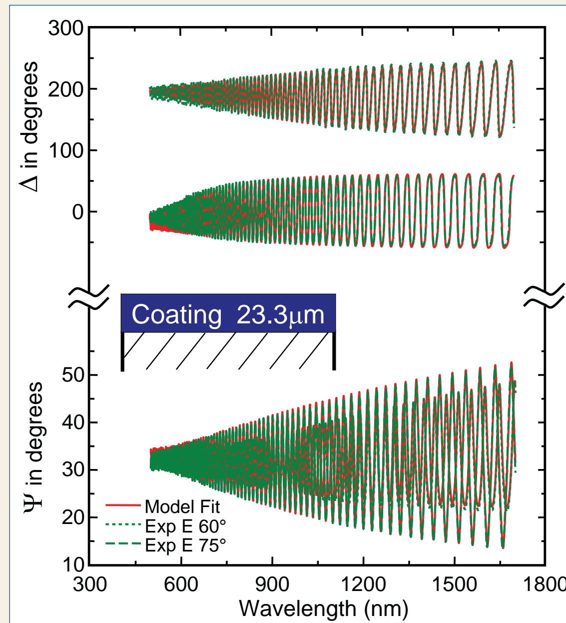
Benefits of Extended Near Infrared Wavelengths

The VASE is now offered with extended near infrared wavelengths to 1700nm, 2500nm and 3200nm.

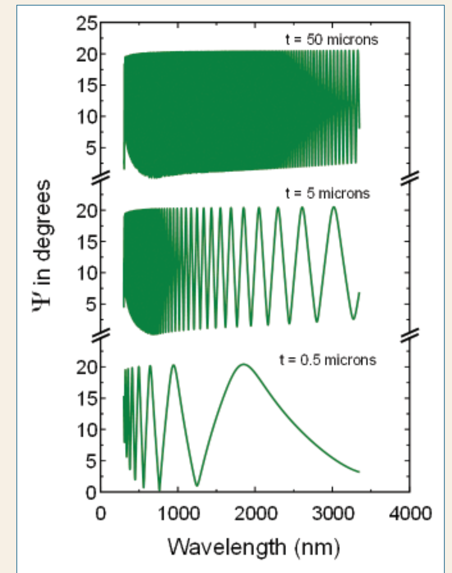
Thick Films

For thicker films (>5 µm), good spectral resolution is needed to resolve the interference oscillation features of Ψ/Δ data. Operator defined monochromator step size and narrow bandwidth help resolve fine spectral features.

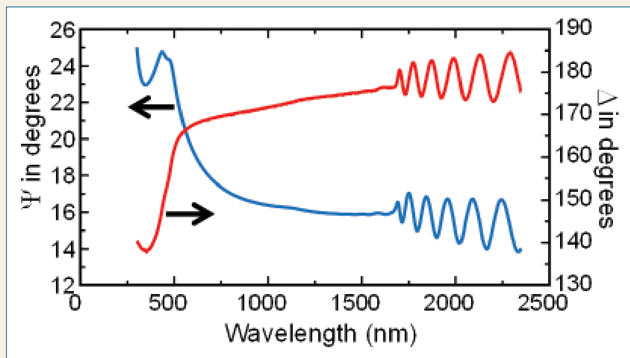
In addition, the interference oscillations associated with film thickness naturally spread-out as wavelength increases. Thus, near infrared measurements help extend the useful thickness range to films that are tens-of-microns.



Fine wavelength resolution required for this thick epoxy layer.



Only the extended near infrared can separate oscillations from very thick films.

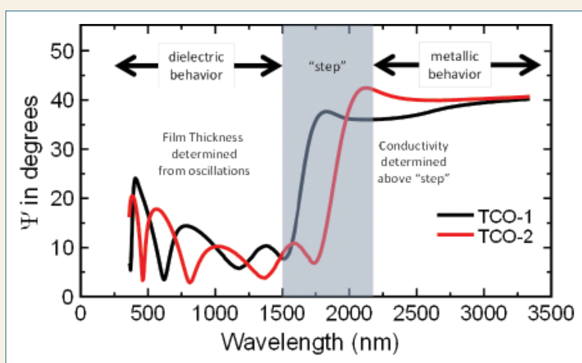


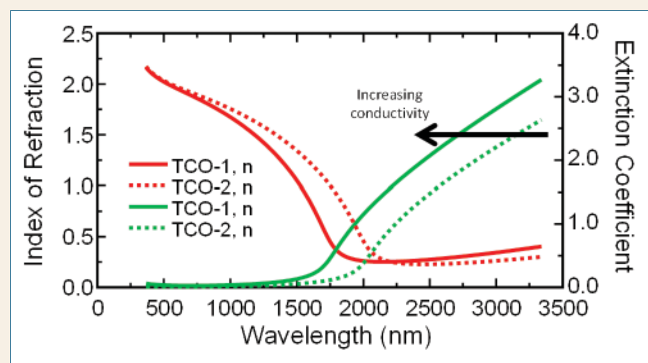
Low Bandgap Materials

The extended near infrared is also valuable when characterizing low-bandgap semiconductors, that remain absorbing across the ultraviolet and visible spectrum. The longer wavelengths probe the transparent region of these materials, allowing thickness determination for films such as InGaAs.

Transparent Conductive Oxides (TCOs)

Layers such as indium tin oxide (ITO), aluminum doped zinc oxide (AZO), and fluorinated tin oxide (SnO_2:F) are conductive transparent layers used in many modern products – touch-screen phones, solar panels, widescreen televisions, etc. While transparent across the visible, they are conductive. Their conductivity leads to near infrared absorption. Figure below shows measurement of two different TCO layers. They both exhibit similar behavior: i) data at short wavelengths oscillates due to the transparent film thickness, and ii) data at long wavelengths is flat and film behaves like a metal. The "step" between these behaviors occurs in the near infrared and can give insight into the properties of the TCO layer. As the "step" moves to short wavelengths, the film conductivity also increases, as determined by Drude-oscillator modeling.



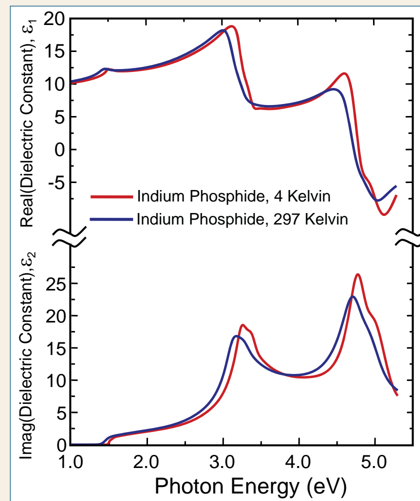


Accessories

Temperature Control

Add cryostat or heat stage for variable temperature studies. Measure samples at both low and elevated temperatures.

Cryostat (4.2K to 500°C)



InP optical constants at 4 Kelvin and room temp.

Instec Heat Stage
(-70°C to 600°C)

HTC-100 Heat Stage
(Room Temp. to 300°C)

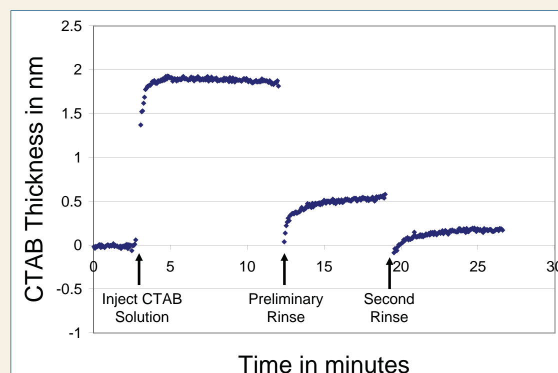
Liquid Studies

Add cell with optical windows for measurement through liquid ambient. Allows characterization of liquid/solid interface.

37mL Electrochemical Cell

270µL Vertical Liquid Cell

5mL Vertical Liquid Cell



Organic layer thickness deposited from a solution in a liquid cell.

Flip Down Sample Mount

Allows convenient horizontal sample mounting. Sample vacuum mounted, then stage is returned to vertical orientation for measurements. Helpful for small samples.

Flip Down Sample Mount

Sample Rotator

High precision sample rotation (360° Theta-only) useful when studing anisotropy. Transmission measurement possible from 0° ± 19°.

Sample Rotator

Alternate Focusing (200µm minimum diameter)

Focusing & Camera

Add focusing and optics to decrease beam diameter. Standard focusing option allows 100µm minimum diameter. Alternate focusing option allows 200µm diameter, and can be used during transmission measurements. Focusing optics are detachable for normal use. Camera option also available to view spot location on sample.

Standard Focusing (100µm minimum diameter)

Mapping

Provides computer controlled or manual XY mapping of samples of various sizes.

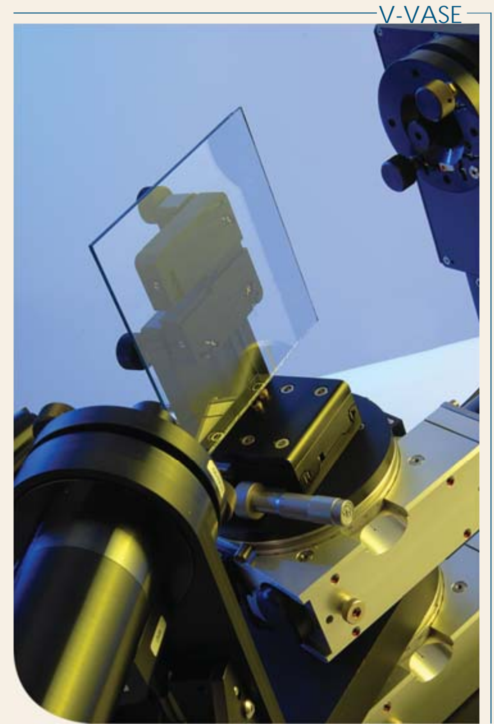
Automated 50 x 50 mm XY

Automated 150 x 150 mm XY*

Manual 45 x 45 mm XY

*Automated sample alignment (tip-tilt-Z) available with this Automated 150 x 150 mm mapping.

Specifications



Spectral Range

250-1100nm (single chamber standard)
240-1100nm (double chamber standard)
DUV extension to 193nm
NIR extension to 1700nm
XNIR extension to 2500nm
XXIR extension to 3200nm

Angle of Incidence

Fully Automated
Range: 15°-90° (standard system)
Accuracy: 0.01°

System Configuration

Rotating Analyzer Ellipsometry (RAE) with patented AutoRetarder®. Automated wavelength selection via monochromator.

Data Acquisition Rate

Typical: 0.1 to 3 seconds per wavelength, depending on reflectivity of sample.
High Accuracy: measurements using full AutoRetarder capability with zone averaged polarizer require 20 seconds per wavelength.

Versatile

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