M-2000®

J.A. Woollam Co., Inc.

Ellipsometry Solutions

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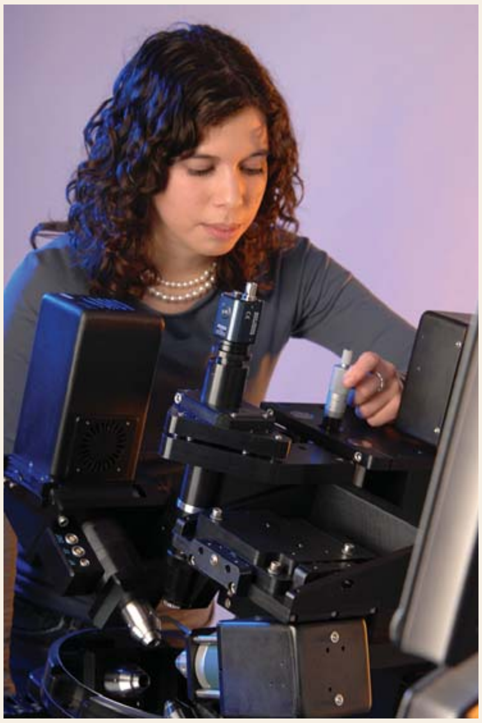
Speed

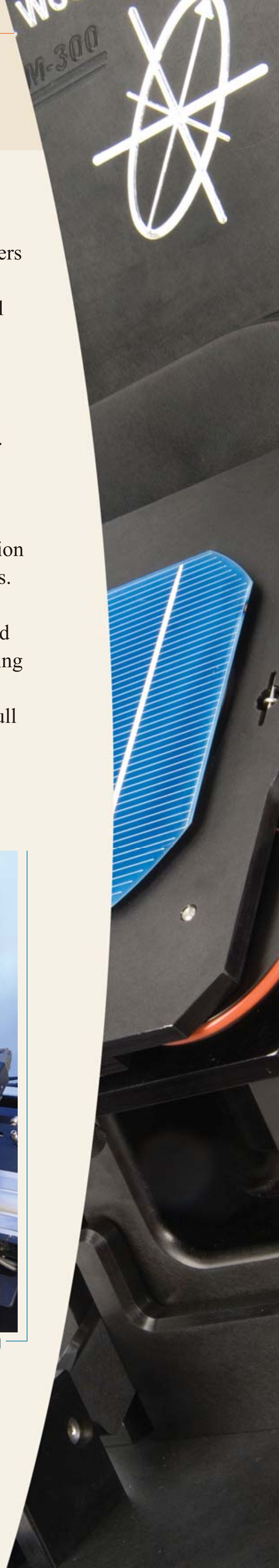
Discover the Difference

Focused M-2000



The M-2000® line of spectroscopic ellipsometers is engineered to meet the diverse demands of thin film characterization. An advanced optical design, wide spectral range, and fast data acquisition combine in an extremely powerful and versatile tool.

The M-2000 delivers both speed and accuracy. Our patented RCE technology combines Rotating Compensator Ellipsometry with high-speed CCD detection to collect the entire spectrum (hundreds of wavelengths) in a fraction of a second with a wide array of configurations. The M-2000 is the first ellipsometer to truly excel at everything from in-situ monitoring and process control to large-area uniformity mapping and general purpose thin film characterization. No other ellipsometer technology acquires a full spectrum faster.



Why an M-2000?

Advanced Ellipsometer Technology

The M-2000 utilizes our patented RCE (rotating compensator ellipsometer) technology to achieve high accuracy and precision.

Fast Spectral Detection

The RCE design is compatible with advanced, proven CCD detection to measure ALL wavelengths simultaneously.

Wide Spectral Range

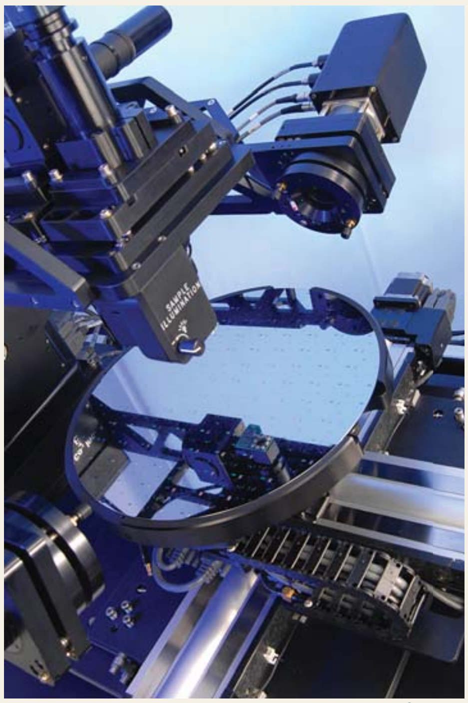
Collect over 700 wavelengths from the ultraviolet to the near infrared – all simultaneously.

Flexible System Integration

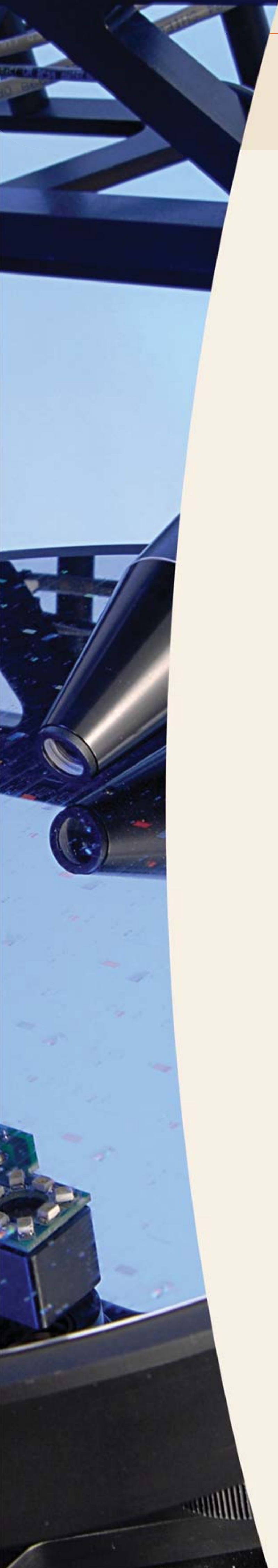
With modular optical design, the M-2000 is suited for direct attachment to your process chamber or configured on any of our table-top bases.

Accuracy

Advanced design ensures accurate ellipsometry measurements for any sample.



300 mm Mapping



Thin Film Characterization

The M-2000 is most commonly used to measure thin film thickness and optical constants. It is sensitive to less than a monolayer of material (sub-nm) on a surface and yet can determine thickness for transparent films up to tens of microns. The M-2000 can also measure the optical constants (both n and k) from any type of material, whether dielectric, organic, semiconductor, or metal. In addition to optical constants, there are additional material properties that can be indirectly determined based on how they affect changes to a material's optical constants.

Film Thickness

When the measurement light beam from an M-2000 interacts with a thin film, it produces spectral data features due to each returning component of the light beam. Any light that travels into the film and reflects from the underlying interface will recombine with the surface reflection. The result is constructive and destructive interference, depending on (i) the relative phase of each light component, as shown in Figure 1, and (ii) the light wavelength. The light traveling through a thin film is delayed by both the thickness and the index of refraction (*n* defines the phase velocity). Thus, the resulting data are directly affected by the film properties.

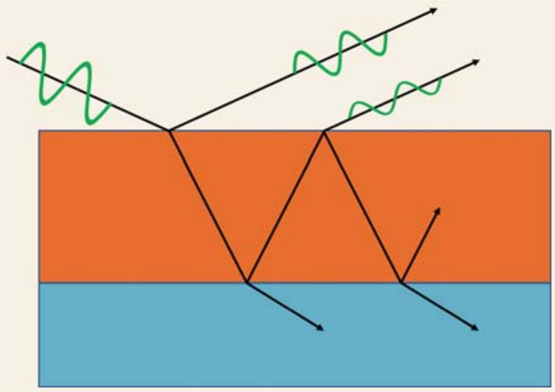


Figure 1. Reflections from multiple interfaces.

Figure 2 shows two measurements of a dielectric layers on silicon. The number of oscillations increases as the film thickness increases.

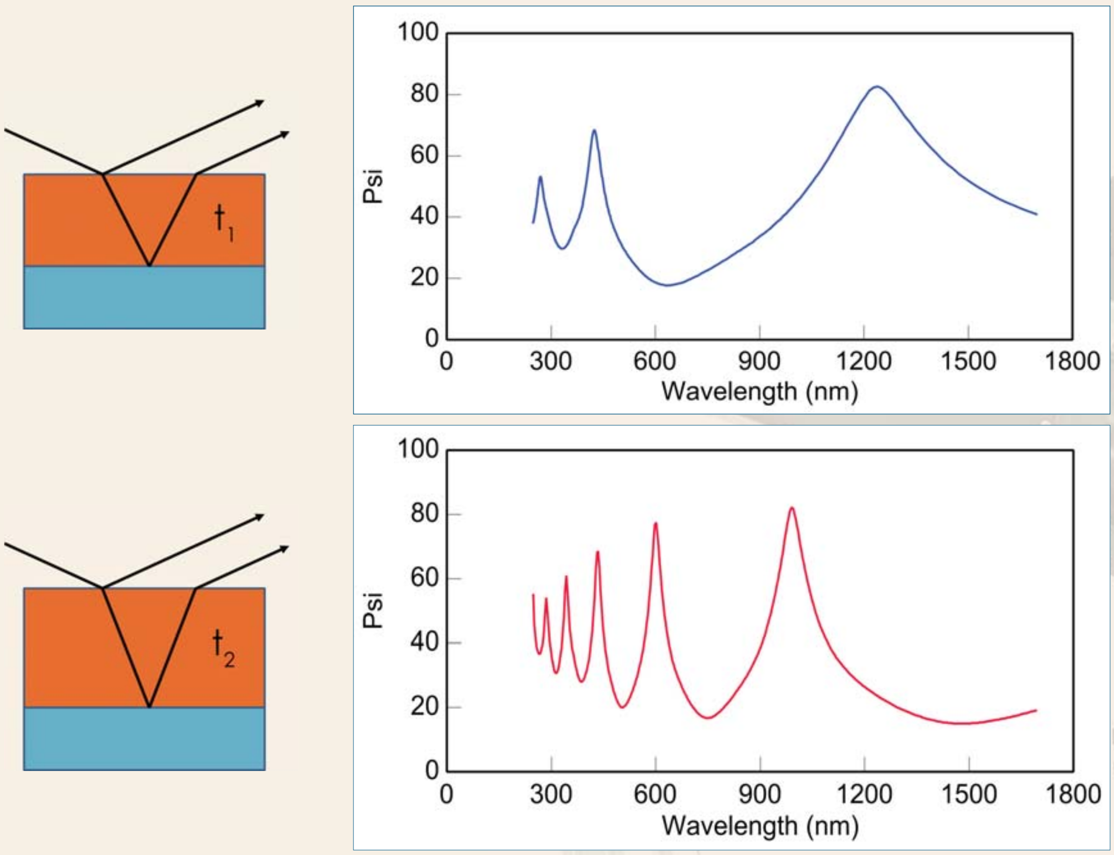


Figure 2. Experimental data for two thin films. The number of oscillations increases for film #2, as $t_2 > t_1$.

Refractive Index (*n*)

The amplitude of data oscillations is related to the film optical constants. If the film index is closely matched to the substrate index, less light will reflect back to the surface. This is demonstrated for SiO_2 film on glass (Figure 3), where index of glass and SiO_2 are very similar. When the film and substrate have very different indices, the oscillations can be much larger, as is the case for Ta_2O_5 on glass (Figure 3).

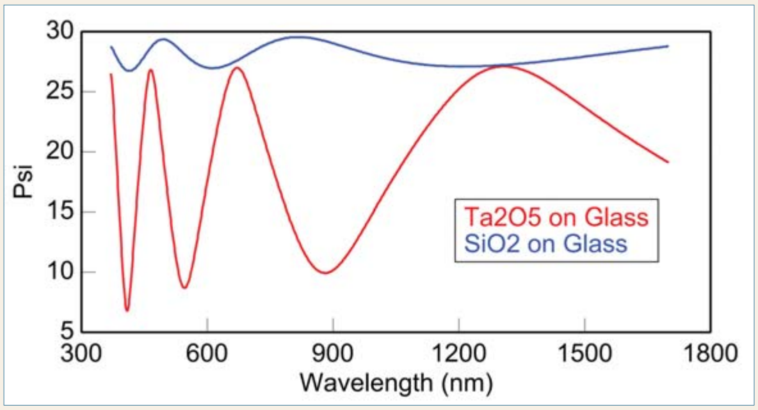


Figure 3. Data from transparent films on glass with different refractive indices.

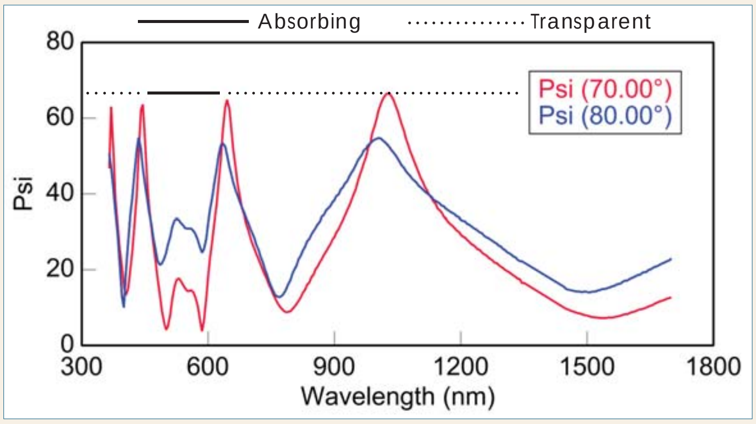
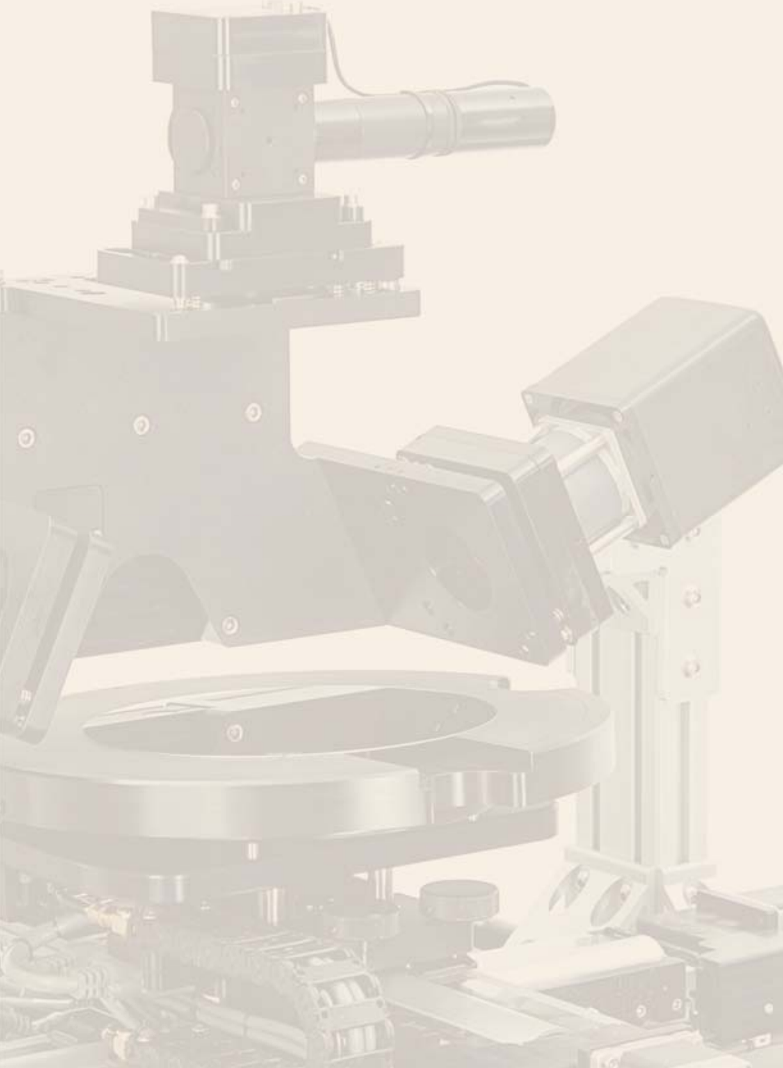


Figure 4. Measurement from an organic dye showing regions where the film is transparent (··········) and where the film is absorbing (———).

Extinction Coefficient (*k*)

The measured data are also affected when the film becomes absorbing. The amount of light traveling in the film may be partially or completely absorbed before returning to the surface. This affects the shape of the measured data, as shown in Figure 4. In the transparent region for this organic dye layer, the light produces the typical oscillating data shape. In the visible, where the dye absorbs light, the data oscillations are suppressed. Here, only the surface reflection is measured.



Material Properties

Other common material properties can be measured with the M-2000 based on the changes induced in the layer optical constants. These properties include: composition, crystallinity, conductivity, anisotropy, surface and interfacial roughness. Figure 5 shows the variation in optical constants as the crystallinity changes within a Germanium thin film.

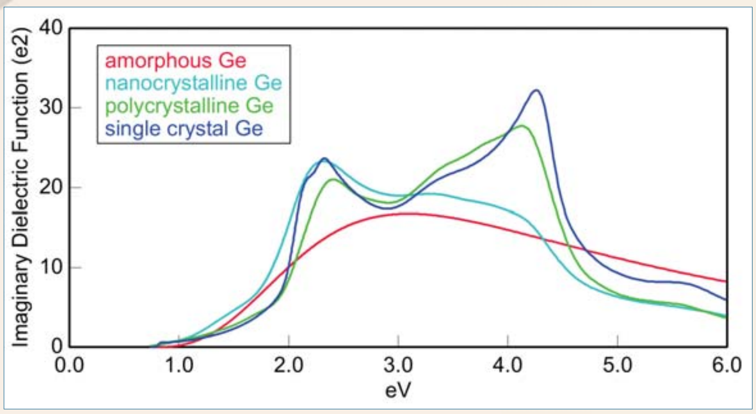


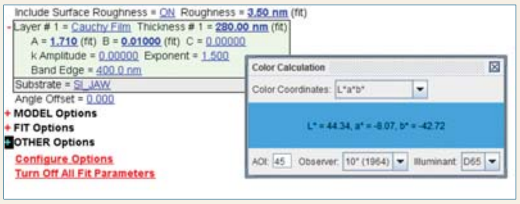
Figure 5. A series of germanium films with different crystallinity. The absorption peaks are well-defined when the material has long-range crystal structure. Toward amorphous states, the absorption features broaden.

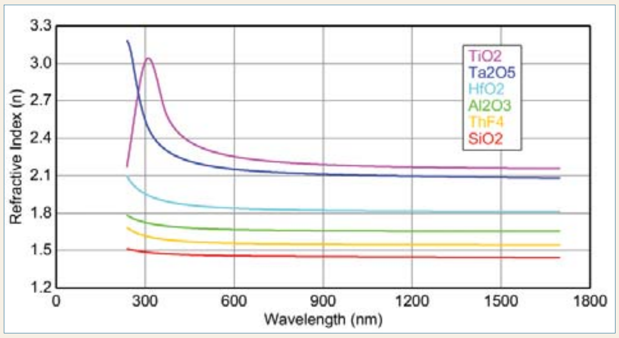
Applications

The M-2000® is a versatile spectroscopic ellipsometer, suited to many different sample types. Coatings can be dielectrics, organics, semiconductors, and even thin metals.

Optical Coatings

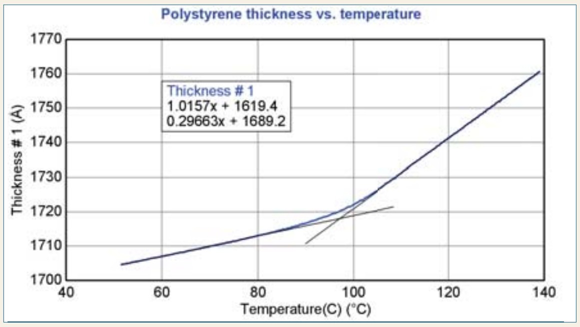
Characterize both thickness and refractive index for single- and multi-layer coatings; anti-reflection, high-reflection, or decorative coatings. Calculate the color coordinates for your coating stack under different lighting conditions.





Chemistry/Biology

The M-2000 can be used for a variety of chemical and biological applications, either as a stand-alone tool or in combination with one of our many accessories. Study materials under liquid ambient, at high or low temperatures, or in conjunction with QCM-D measurements.

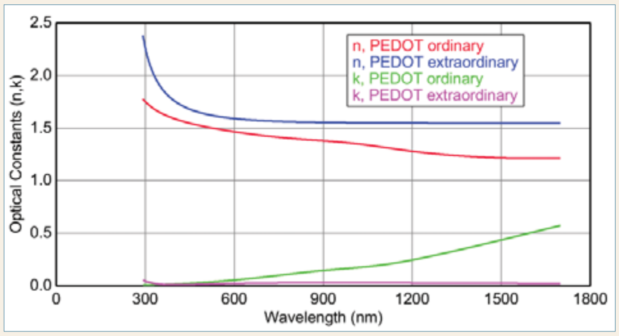


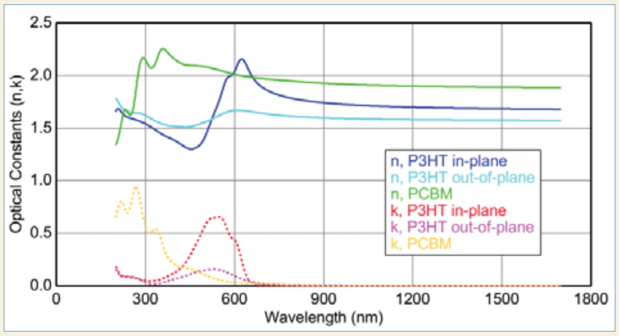
Glass transition of polystyrene.

QCM-D Cell on M-2000 Ellipsometer.

Conductive Organics

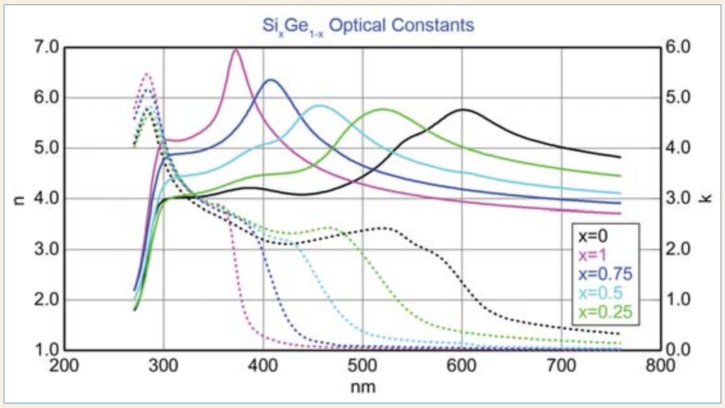
Great progress has occurred in the area of organic layers and stacks used for display (OLED) or photovoltaic applications. There are many different materials being studied, from small molecules such as Alq3 to conjugated polymers such as P3HT. Often multiple materials are blended together – which requires the wide spectral range of the M-2000 – to probe different wavelengths where the organics are optically different. Long-chain molecules may also have significant anisotropy, where orientational stacking of the polymer chains produces different optical constants in different directions.





Semiconductors

Traditional ellipsometry applications are still going strong. Characterize any semiconductor material: resists, photomasks, SiON, ONO stacks, low-k dielectrics, high-k gates, SOI, SiGe, II-VI and III-V ternary and quaternary compounds.

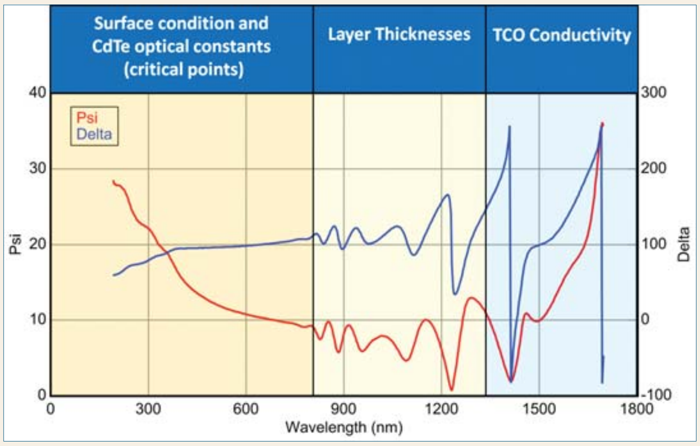


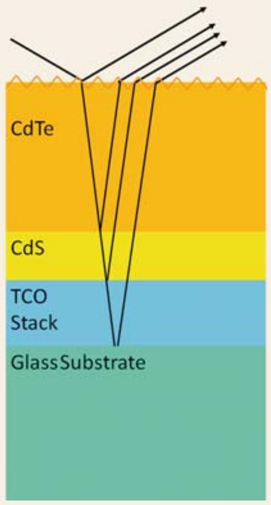
SiGe optical constants vs. composition.

M-2000 DI Ellipsometer with Automated Angle.

Photovoltaics

Film thickness and optical properties are critical to performance of solar devices. Ellipsometry is used for development and monitoring of all PV materials: a-Si, μc-Si, poly-Si, AR Coatings (SiNx, AlNx…), TCO Films (ITO, ZnOx, doped SnO2, AZO), CdS, CdTe, CIGS, organic PV materials, and dye sensitized films.

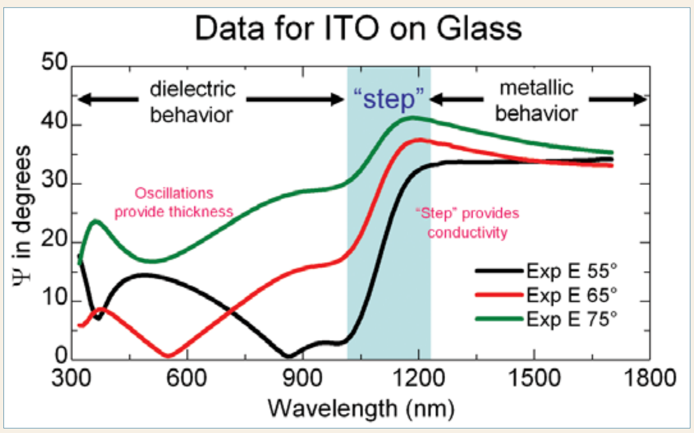




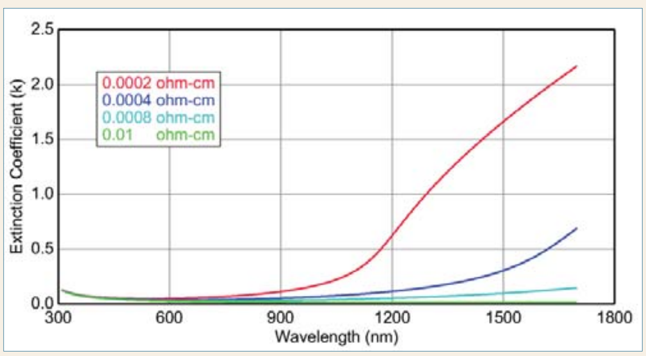
Solar cell multilayer structure showing regions of absorption, transparency and conductivity.

Display

Measurements of a-Si, poly-Si, microcrystalline-Si, OLED layers, color filters, ITO, MgO, polyimide, and liquid crystals are beneficial during diaplay R&D and production.



Transparent conductive oxides appear metallic at long wavelengths and dielectric in the visible. The M-2000 can gather info about the film from both of these regions.



ITO conductivity is related to NIR absorption.

Flexible Spectral Range

M-2000V

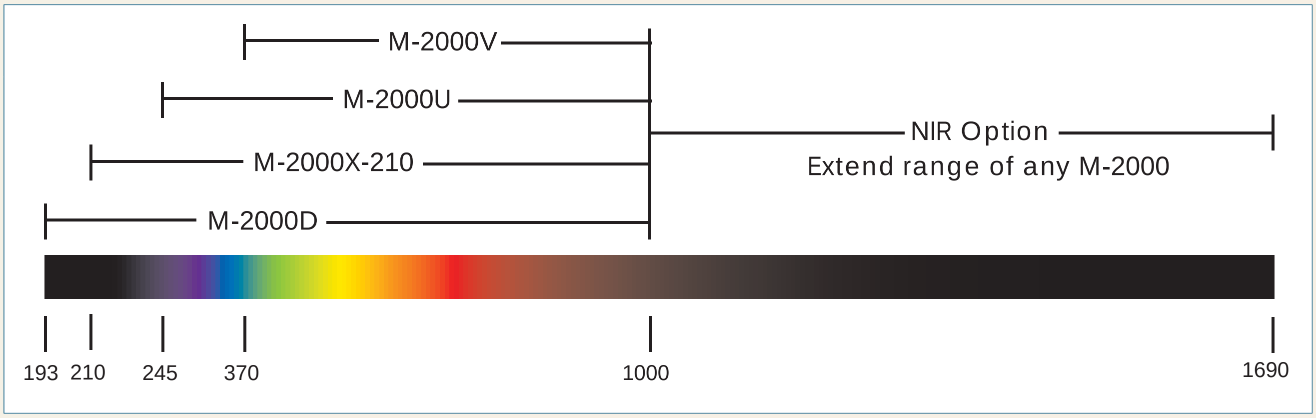
370-1000nm, 390 wavelengths

Spectral coverage is ideal for dielectrics, organics, and amorphous semiconductors. Speed, accuracy, and compact optics combine in an affordable package.

M-2000U

245-1000nm, 470 wavelengths

Ideal for many thin films: dielectrics, organics, semiconductors, metals, and more. Measure optical constants and thickness for coatings from sub-nanometer to tens of microns.



M-2000X-210

210-1000nm, 490 wavelengths

Enhanced UV coverage down to 210nm from a special design that provides a smaller focused spot and higher intensity for in-situ applications.

M-2000D

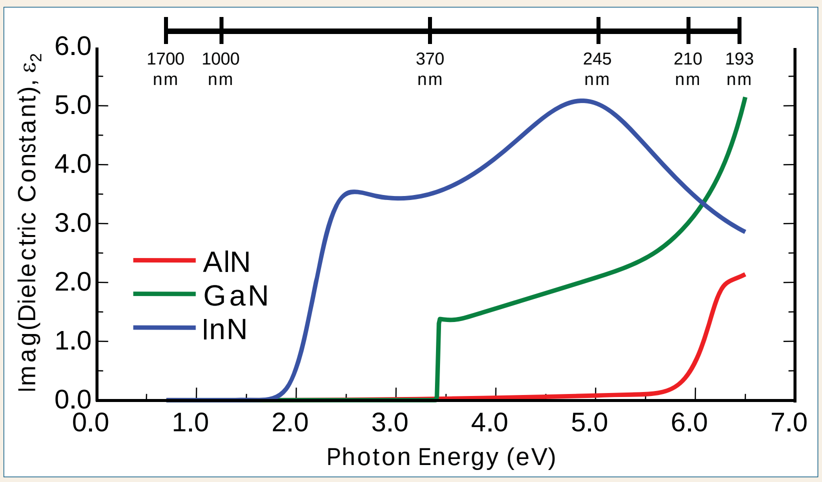
193-1000nm, 500 wavelengths

Perfect for semiconductor industry requirements. Measure at each lithography line – 193nm, 248nm, and 365nm. Short wavelengths can increase sensitivity to ultra-thin films, while simultaneous collection at longer wavelengths ensures accurate thickness of transparent films.

NIR Extension

1000-1690nm, 200 wavelengths

Extend any M-2000 into the near infrared. Long wavelengths enable characterization of transparent conductive oxides like ITO, telecommunications films, and semiconductors like Si_xGe_{1-x} that are absorbing at shorter wavelengths. The NIR is also preferred for thick films and complicated multi-layers.



Extended UV and IR spectrum opens up higher and lower energy ranges for semiconductor characterization.

Flexible Configurations

Fixed Angle

For many applications, the simplicity and affordability of a fixed angle systems offers great value.

Manual Angle

A flexible system covering the same applications (and options) as more automated systems.

Automated Angle

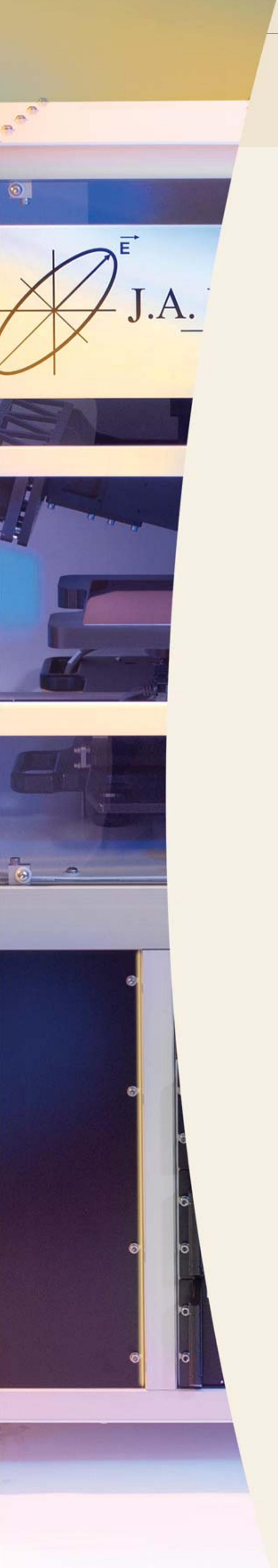
Combine flexibility with convenient automation. Available in horizontal or vertical configuration.

Vertical system offers wide angle range and flexibility. Independent control of sample and detector angle for diverse reflection or transmission measurements.

Horizontal system offers wide range of options like large area mapping, liquid cells, and heat stages.

Focused

The smallest M-2000 spot size available (25 by 60 microns) for demanding feature sizes.



Accessories

Mapping

Map thin film uniformity and other properties. Computer controlled or manual mapping options available. Available in sizes from small samples requiring focused measurements up to large flat panel display glass.

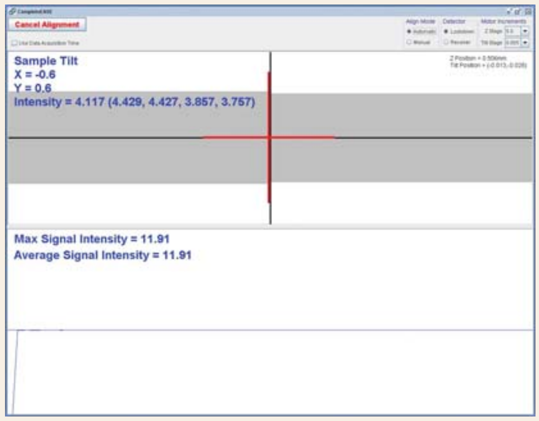
Automated 300 x 300 mm XY mapping.

Focusing & Camera

Add focusing optics to reduce beam diameter. Standard focusing optics are detachable for normal use. Camera option also available to view spot location on sample.

Automated Alignment

Computer automated tip-tilt and sample height options provide quick, effortless sample alignment.



Transmission

Transmission accessories are available for horizontal M-2000 systems to hold samples vertically in the path of the light beam. Normal incidence or variable angle options available.

Sample Rotation

Computer controlled and manual options available to rotate sample 360°. Useful when studying anisotropy.

Automated Rotation for vertical M-2000 systems

Liquid Studies

Add cell with optical windows for measurement through liquid ambient. Monitor the liquid/solid interface in real-time. Temperature-controlled options available.

37mL Electrochemical Cell

5mL Horizontal Liquid Cell

5mL Heated Liquid Cell
(Room Temp. to 50°C)

Temperature Control

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

Cryostat (4.2K to 500°C)

Instec Heat Stage (-70°C to 600°C)

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

Porous Sample Chuck

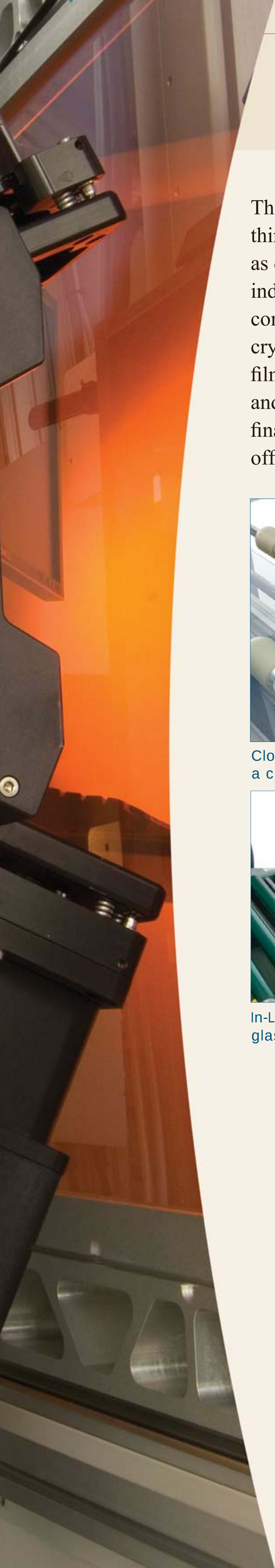
Allows flat mounting of thin plastic substrates.

QCM-D Mounting Stage

Combine SE and QCM-D measurements to detect sub-monolayer changes in thickness and mass.

Table

Integrated table with rack mount for electronics, computer and EMOs. Options for enclosure are also available.

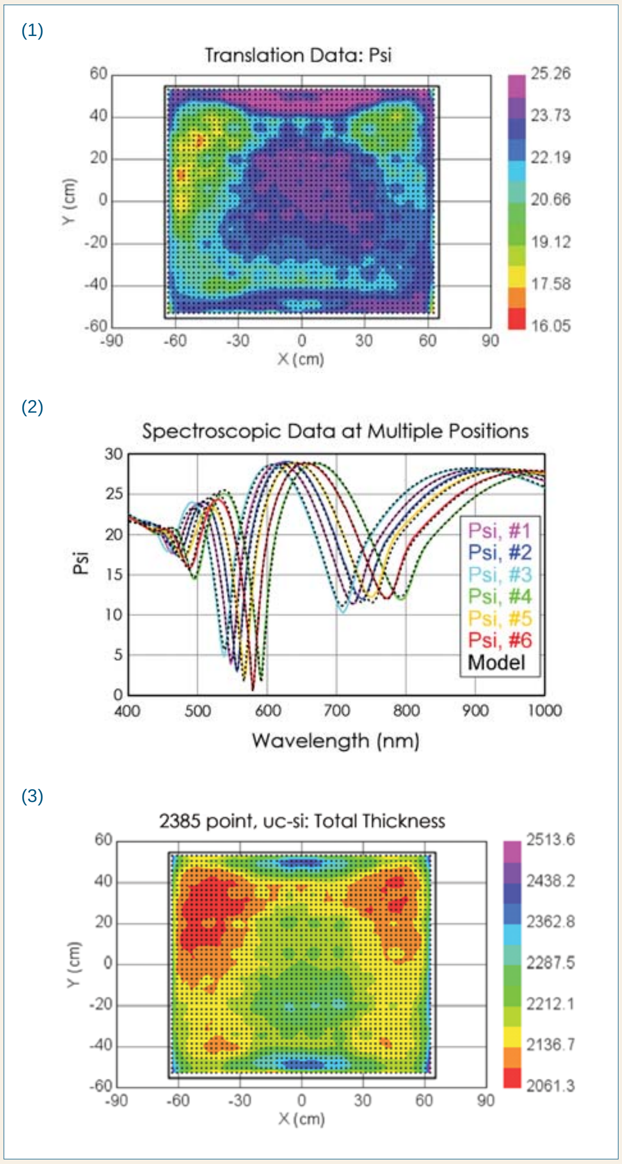


Large Panel Mapping

The M-2000 is commonly used to map thin film uniformity for large panels used as displays and for photovoltaics. In these industries, measurements of transparent conductive oxides, amorphous and nano-crystalline silicon layers, semiconductor films such as CdTe and CIGS, and oxide and nitride anti-reflection coatings ensure final device quality. We offer in-line and off-line solutions.

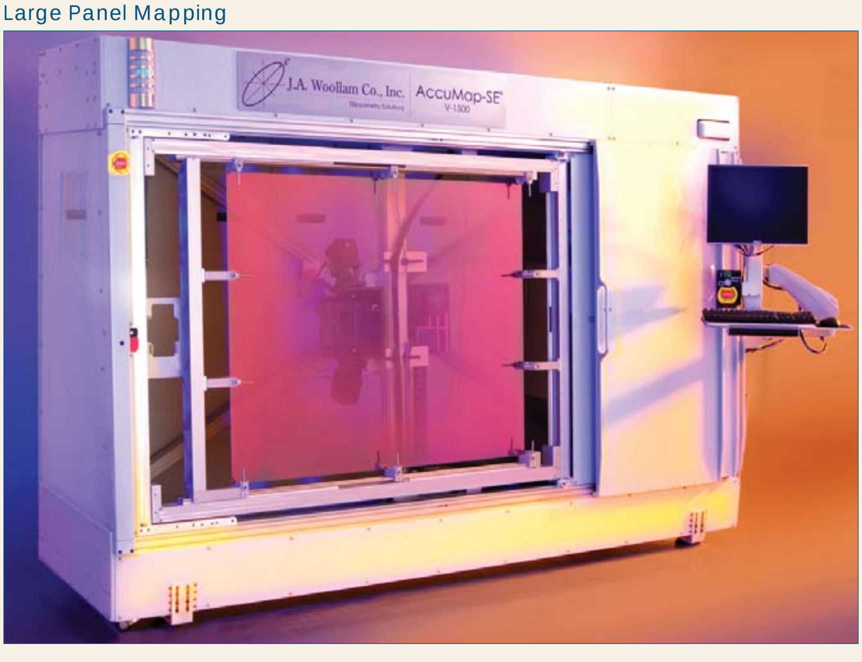
Close-up of an In-Line ellipsometer integrated within a conveyor system.

In-Line ellipsometer measuring a film through a glass panel.



A microcrystalline silicon film was mapped at hundreds of points across a 1.1 x 1.3 meter panel. User defined routines acquire data over full panel (Figure 1). Full spectra are analyzed at each position versus wavelength (Figure 2). Thickness and index maps over full panel are obtained (Figure 3).

AccuMap-SE® for Large Panel Mapping

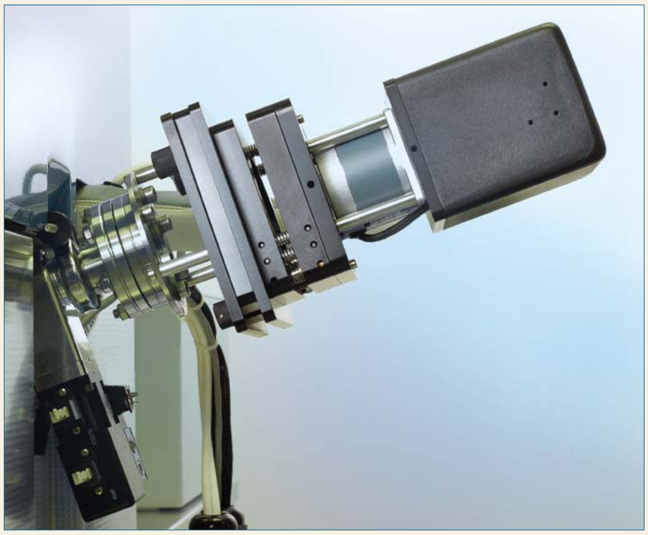


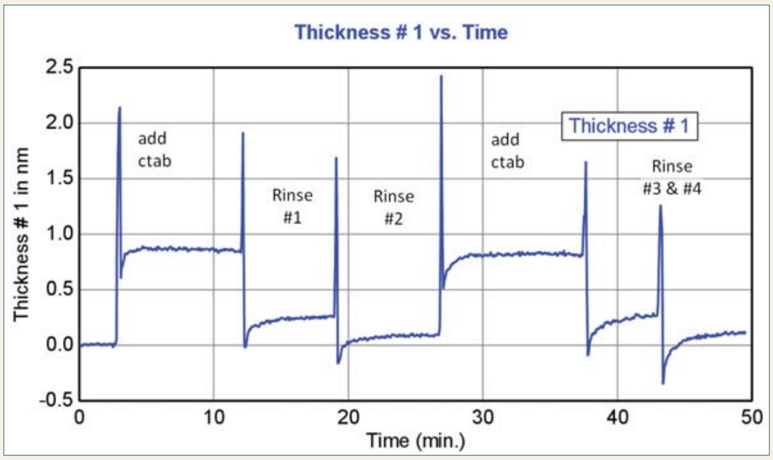
In Situ

The M-2000 is ideal for in-situ monitoring and process control. It is used successfully with many different processes to provide real-time results:

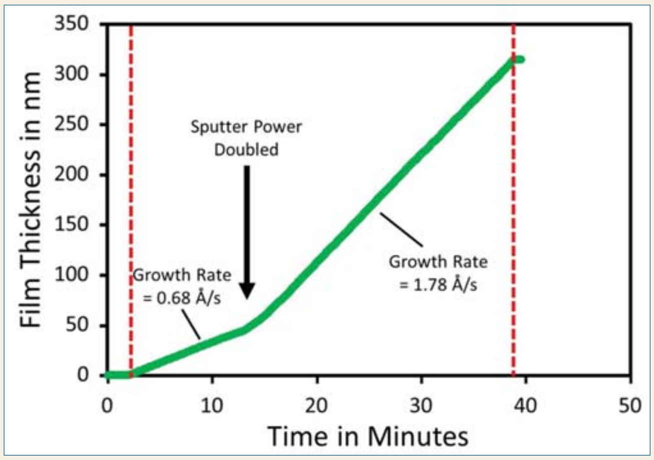
- MBE
- Plasma etch
- Liquid Cell
- ALD
- Cryostat
- PECVD
- Sputter
- ECR
- Heat Stages
- E-beam evaporators
- MOCVD
- PLD

Ellipsometry is commonly used in real-time to determine growth or etch rates, measure optical constants with varying process conditions, track index versus temperature to determine transitions in material properties, and monitor adsorption within liquids with sub-monolayer sensitivity.

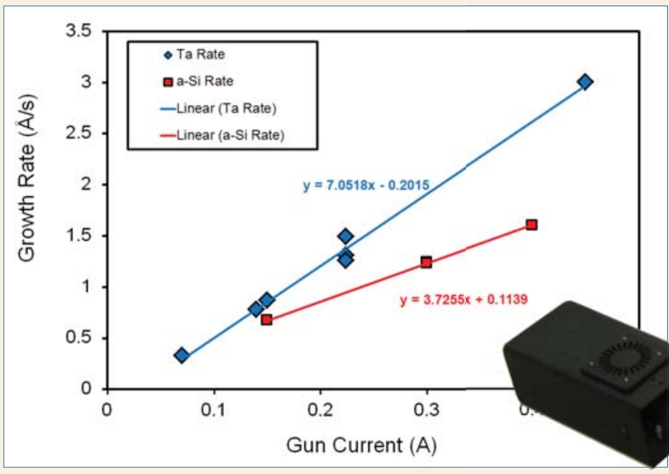

M-2000 ellipsometer on an atomic layer deposition chamber.



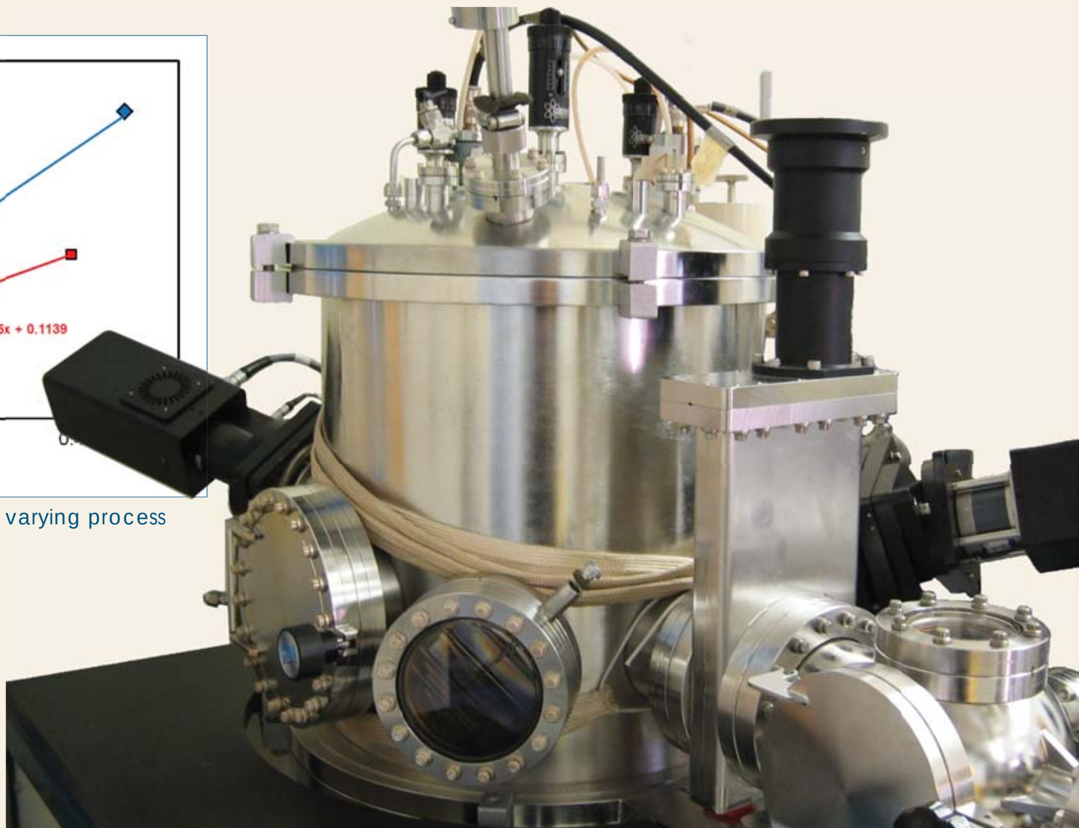
Monitor adsorption within liquids with sub-monolayer sensitivity.



M-2000 on sputter chamber: determine growth or etch rate.



Determine film properties (thickness,n,k) with varying process conditions.



Advanced Measurements

In addition to highly accurate ellipsometry measurements, the M-2000® offers advanced measurements of complex samples.

Intensity Reflectance and Transmittance

Measure Reflectance (%R) and Transmittance (%T) at multiple angles and wavelengths.

Anisotropy

The M-2000 offers Generalized Ellipsometry for complete measurement description for anisotropic samples. Data include both standard ellipsometry measurement plus additional terms to describe cross-polarization from the sample. Anisotropic materials include plastic substrates, liquid crystals layers, and non-cubic crystals.

Mueller-Matrix

For complicated samples with both anisotropy and depolarization, the most complete measurement involves the Mueller-matrix. The M-2000 measures 11 Mueller-matrix elements – perfect for highly complex samples.

Depolarization

Depolarization measurements quantify effects due to thickness non-uniformity, patterned layers, and incoherent backside reflections.

Specifications

Wavelength Range:

M2000V	370-1000nm, 390 wavelengths
M2000VI	370-1690nm, 590 wavelengths
M2000U	245-1000nm, 470 wavelengths
M2000UI	245-1690nm, 670 wavelengths
M2000X-210	210-1000nm, 490 wavelengths
M2000XI-210	210-1690nm, 690 wavelengths
M2000D	193-1000nm, 500 wavelengths
M2000DI	193-1690nm, 700 wavelengths

Angle Range:

Fixed Angle	60° or 65°
Manual Angle	45° - 90°
Horz. Auto Angle	45° - 90°
Vert. Auto Angle	20° - 90°
Focusing	65°

System Overview:

Patented rotating compensator ellipsometry, simultaneous CCD detection of all wavelengths, flexible system integration

Data Acquisition Rate:

Data collected 20 times per second. For optimal signal-to-noise, typical measurement times for full spectrum is between 0.5 and 5 seconds.

Precision

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