M-2000® Specifications

The M-2000® Spectroscopic Ellipsometer is the perfect combination of speed and accuracy. Measurements covering the entire spectral range from deep ultraviolet to near infrared are accomplished in seconds–making the M-2000 ideal for a large range of applications: quick quality control, real-time process monitoring and in situ control, uniformity mapping, and more.

J.A. Woollam
Ellipsometry Solutions

Features

Patented Rotating Compensator Ellipsometer (RCE) Technology

RCE technology overcomes the limitations of other ellipsometers.

	RCE	RAE	RPE	Phase Modulated
Measure all Ψ/Δ accurately	Yes	No	No	* Requires 2 measurements
Measure Δ handedness	Yes	No	No	Yes
Measure Depolarization	Yes	No	No	*Requires 2 Measurements
Combine with fast CCD detection	Yes	Yes	Yes	No

CCD Detection System

The M-2000® uses a CCD detector for simultaneous measurement of hundreds of wavelengths. This allows measurement from the UV to NIR in less than a second.

Wide Spectral Range

The M-2000 is available in a variety of spectral ranges with options from the UV to the NIR. The widest spectral range is 193nm to 1690nm with simultaneous data collection at more than 690 wavelengths.

Precise Alignment

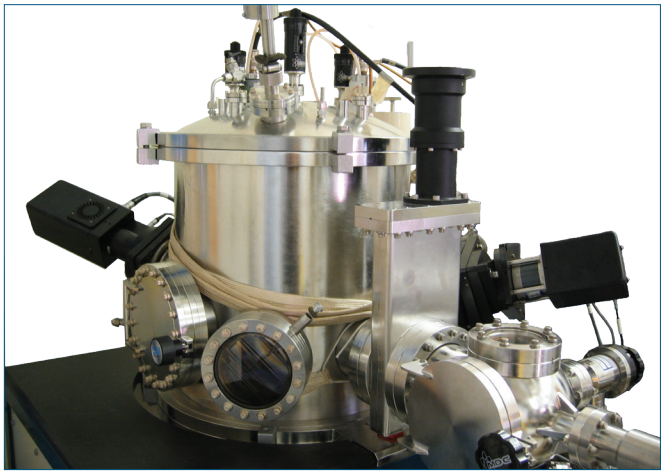
A built-in 4-quadrant alignment detector allows precise sample alignment, whether mounted on your process chamber or a variable-angle base.

Software

Ellipsometry is an effective characterization technique, but requires powerful software to get full benefit from the measurement. Our CompleteEASE® (*in situ/ex situ*) software packages provide easy calibration, data acquisition, and analysis for all of your applications.

In Situ M-2000

With fast measurement speed and high accuracy, the M-2000 is a perfect match for real-time deposition/etch monitoring and control.



M-2000 attached to a process chamber.

Ex Situ (Benchtop) M-2000

The M-2000 is offered on a variety of bases to meet your application and budget. Choose from fixed angle or automated angle with either horizontal or vertical sample mount. Additional options include focusing optics, manual or automated sample translation, heat stages, liquid cells, and more. See page 5 for available options.

M-2000 with automated angle base, featuring a horizontal sample mount.

System Specifications

Spectral Range

Model:

V	370nm to 1000nm, 390 wavelengths
VI	370nm to 1690nm, 580 wavelengths
U, X	245nm to 1000nm, 470 wavelengths
UI, XI	245nm to 1690nm, 660 wavelengths
X-210	210nm to 1000nm, 485 wavelengths
XI-210	210nm to 1690nm, 675 wavelengths
D	193nm to 1000nm, 500 wavelengths
DI	193nm to 1690nm, 690 wavelengths

"I" indicates NIR upgrade

Spectral Resolution Bandwidth

Model:

V, U, X, D	1.6nm pixel resolution ~ 5nm bandwidth
VI, UI, XI, DI	1.6nm pixel resolution (UV/Vis) 3.4nm pixel resolution (NIR) ~ 5nm bandwidth (UV/Vis) ~ 10nm bandwidth (NIR)

Data Acquisition Rate

The maximum data acquisition rate is determined by the compensator rotation speed, which is 20Hz for most M-2000® models. Typical measurements for best signal-to-noise average between 1 and 5 seconds.

Beam Diameter

2mm to 5mm, depending on model configuration.
**See Options section for focused beam sizes.*

Beam Divergence

Less than 0.3° (without focusing).

Measurable Quantities

Ellipsometry:	Ψ (0°-90°) and Δ (0°-360°)
Transmission intensity:	%Transmission
Reflection intensity:	% Reflection
Depolarization:	% Depolarization
Mueller-matrix:	Measure and fit 11 normalized elements of the Mueller-matrix. Useful for samples that are both anisotropic and depolarizing.

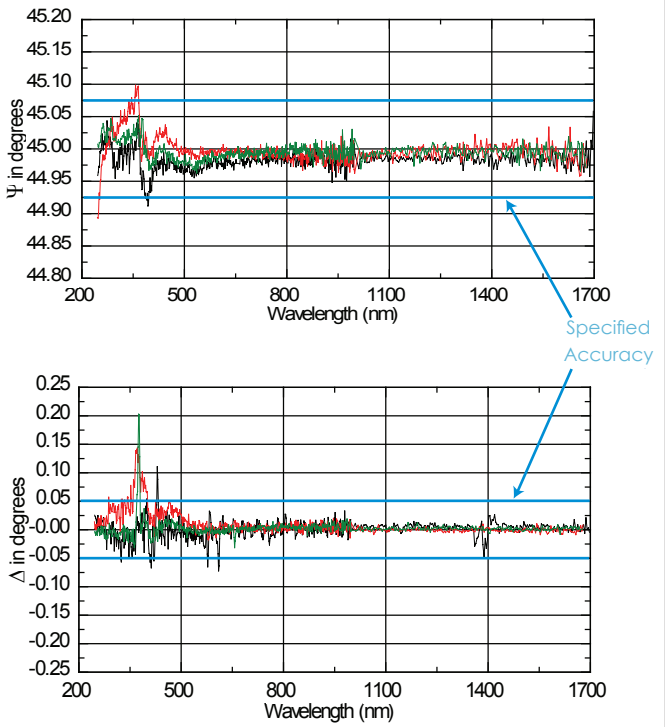
Typical Accuracy

Straight-through measurement of empty beam:
(Met by 95% of the measured wavelengths with ten second averaging time.)

$\Psi = 45° \pm 0.075°$	$\tan(\Psi) = 1 \pm 0.0013$
$\Delta = 0° \pm 0.05$	$\cos(\Delta) = 1 \pm 0.0000015$

**When looking at ellipsometric specifications, it is easy to erroneously compare Δ to cos (Δ) and Ψ to tan(Ψ). We provide both numbers for your convenience. The J.A. Woollam M-2000 is orders of magnitude better than the competition when measuring Δ near 0° and 180°. This is a benefit of our patented rotating compensator technology.*

As witnessed in the representative data shown below, the accuracy for most wavelengths is much better than specified.



** Instrument 1 is an M-2000U. Instruments 2 and 3 are M-2000UI (include NIR upgrade).*

Typical Repeatability

Thirty repeated straight-through measurements of empty beam; each with zone-averaging and ten second averaging:

$\delta\Psi = 0.015°$ *
$\delta\Delta = 0.015°$ *
*1-standard deviation

Thirty repeated measurements of SiO_2 (2nm)/Si at 65° angle and ten second averaging with fixed sample position:

δthickness = 0.003nm*
*1-standard deviation

Component Specifications

System Configuration (in order)

Light source
Fixed polarizer
Continuously rotating compensator
Sample
Fixed analyzer
Spectrometer and Detector

Light Sources

Model:

V, VI	Quartz Tungsten Halogen (QTH)
U, UI, D, DI	QTH/Deuterium
X, XI, X-210, XI-210	Xenon

Fixed Polarizer

All M-2000® systems use a calcite Glan-Taylor polarizer, except the D and DI systems, which use a MgF_2 Rochon polarizer. Both types exhibit:

Beam deviation: <1 arcmin.
Extinction ratio: $1x10^{-6}$

Continuously Rotating Compensator

Spectroscopic compensator operates over entire wavelength range.

Rotation rate: ~ 20Hz
Beam deviation: <1 arcmin.

Fixed Analyzer

Calcite Glan-Taylor or MgF_2 Rochon Polarizer (D and DI models).

Beam deviation: <1 arcmin.
Extinction ratio: $1x10^{-6}$
Mount: Stepper motor driven rotation stage that allow "zone-averaged" measurements

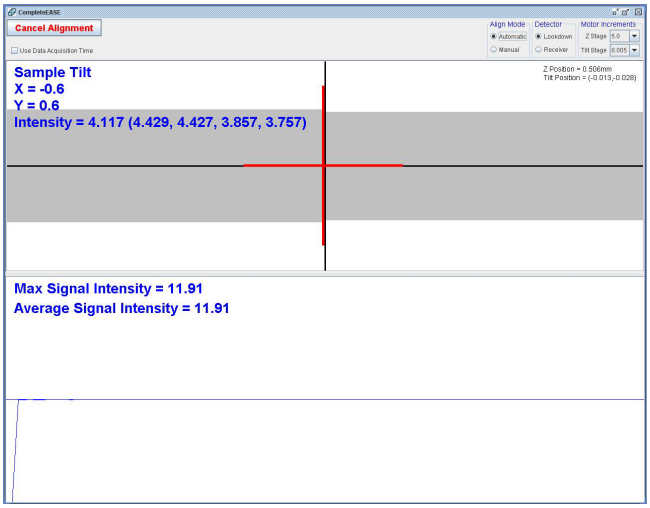
Detectors

- Back-thinned silicon CCD array (UV/VIS)
- InGaAs photo diode array (NIR)

Integrated Alignment Detector

Built-in electro-optic alignment detector is divided into four quadrants. Cross-hair generated by the detector assists accurate alignment. The figure below shows the alignment screen.

Sample alignment resolution: 0.001°



Ellipsometer Control Module

Communicates with windows host computer and controls stepper motor drivers that move the angle of incidence arms and translations stages (if applicable).

Operator Computer (Optional)

Core i7-8700 Processor
8GB RAM
500GB Hard Drive
Windows 10Pro-64 bit
8x DVD+/-RW Drive
22" monitor
MiniTower Case

**Minimum specifications, subject to change without notice.*

CompleteEASE® Software

Designed for *Ex situ* and *In situ* applications. Data acquisition, data analysis, optical simulations, routine calibrations and mapping routines.

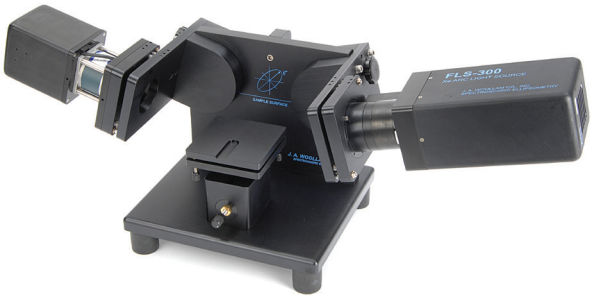
Options

Available Bases

All bases include 3 axis sample alignment.
X and Y (tip and tilt) resolution: 0.001°
Z (height) resolution: 5 µm

Test Base

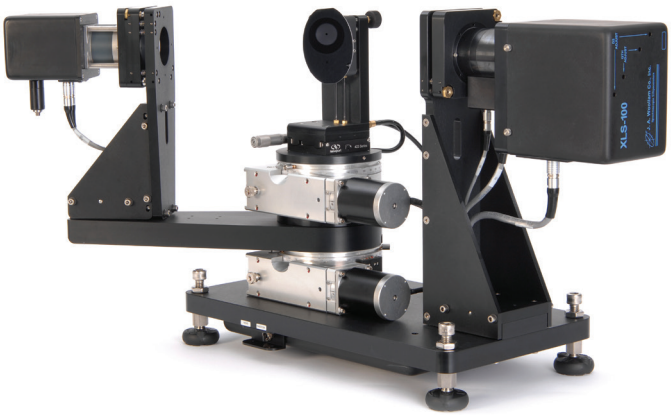
Angle of incidence: ~ 65°
Accuracy: ± 0.2°
Repeatability: 0.005°
Horizontal sample mount
Max sample size: 150mm dia.
Max sample thickness: 20mm



Vertical Automated Angle Base

Angle of incidence: 20°-90°
Accuracy: ± 0.02° or better
Repeatability: < 0.005°
Vertical sample mount via vacuum chuck
Max sample size: 200mm dia.
Max sample thickness: 20mm

** Vertical base simplifies acquisition of transmission ellipsometry and transmission intensity data.*

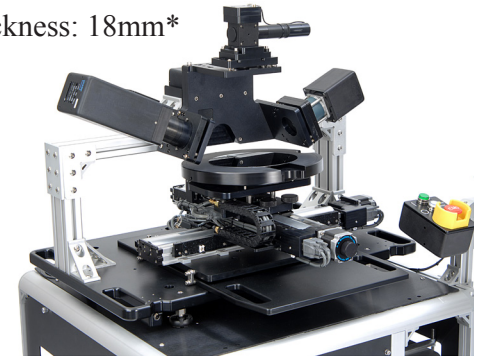


Automated Angle Base

Angle of incidence: 45°-90°
Accuracy: ± 0.02° or better
Repeatability: < 0.005°
Horizontal sample mount
Automated z-height
Max sample size: 300mm dia.*
Max sample thickness: 18mm*

Fixed Angle Base

Angle of incidence: ~ 65°
Horizontal sample mount
Automated z-height
Max sample size: 300mm dia.*
Max sample thickness: 18mm*



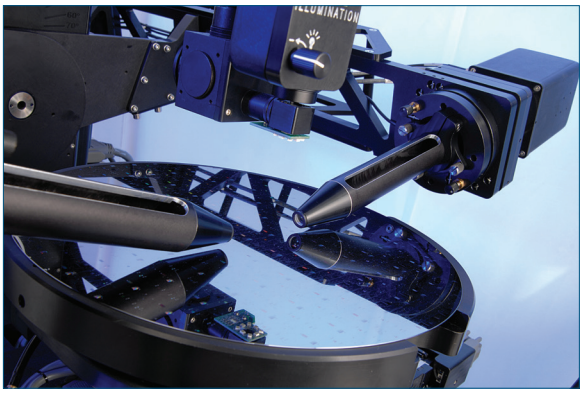
** Maximum sample size depends on system configuration. Options for larger or thicker samples may be available. Contact J.A. Woollam for details.*

Options

Focusing Optics

Model (on Fixed or Auto Angle Base)

V, VI	220µm beam dia.
U, UI, D, DI	300µm beam dia.
X, XI	120µm beam dia.



Sample Translation

Manual

50mm by 50mm XY
100mm by 100mm XY (*horizontal only*)
*Minimum step = 5µm

Computer Automated

50mm by 50mm XY *(vertical only)*
100mm by 100mm XY (*horizontal only*)
200mm by 200mm XY (*horizontal only*)
300mm by 300mm XY (*horizontal only*)
*Minimum step = 2.5µm

**Larger translation options may be available, contact us for details.*

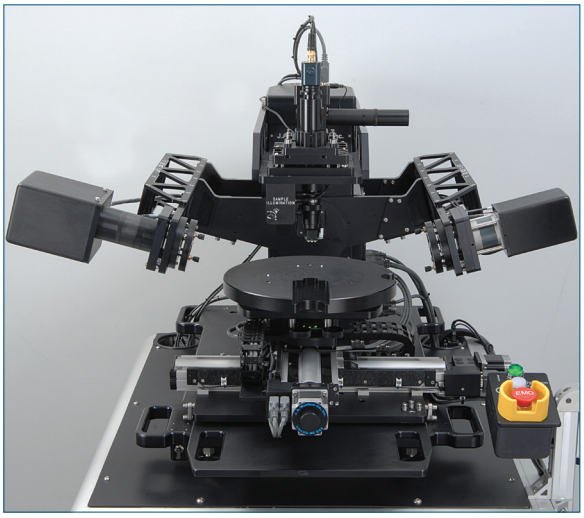
Camera

Add a camera to M-2000 systems with focused spot option to visualize the measurement area. The actual beam may not be visible on smooth surfaces, but the location can be identified based on reference location. The camera option includes a 3Mpixel CCD Camera, Lens set, and Illumination setup.

- 3x Magnification
- Field of view: 2.1 x 1.6mm
- Working distance: 77mm
- Digital zoom: up to 8x

Automated Sample Alignment

Fully automated sample alignment (tip/tilt and z-height adjustment).



Options

Integrated Table

Table designed specifically for M-2000. Rack for mounting electronic boxes, fully enclosed computer and wires. Monitor, keyboard and mouse mounted on arm.

Enclosed Table

Integrated table with rack mount for electronics, computer, EMO, storage, and complete enclosure with easily removal panels, designed to introduce samples through lift-able front panel.

Liquid Cells

Liquid cells include optical windows for measurement through liquid ambient. Allows for study of liquid/solid interfaces. For more detailed information please contact the J.A. Woollam Co. for the liquid cell spec sheet.

Liquid Cell Name	Liquid Capacity	Angle of Incidence
5mL Horizontal *(pictured)*	5mL	75°
500µL Horizontal	500µL	70°
2mL Electrochemical Horz.	2mL	70°
5mL Heated Horizontal	5mL	75°
500µL Variable Temp. Horz.	500µL	70°
37mL Electrochemical Vert.	37mL	70°

Facility Requirements

Operating Environment

A sturdy table (weight of instrument is system dependant, contact JAWCo to discuss).
Range of Weights: 50-150 lbs.
Integrated Table with rack mount cabinet (optional)
Note: Vibration isolation table is not required

Power

100-240 VAC, 50/60Hz, 5 Amps max.

Dimensions

Dimensions vary depending on options. Larger system (M-2000 DI with 300mm XY mapping and integrated table) dimensions are given in the drawings to the right.

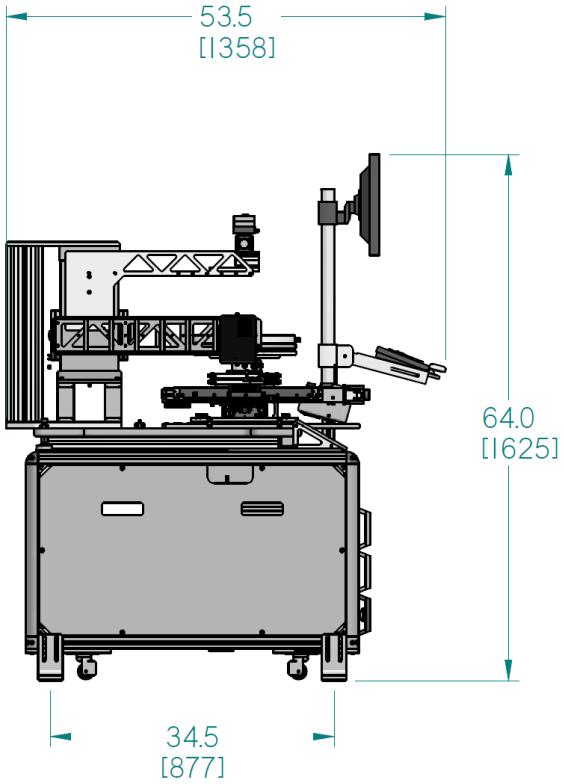
Table Layout

Recommended size:
- Width 60”
- Depth 30”
- Height 36”
- *With shelf or 19” rack mount below (optional)

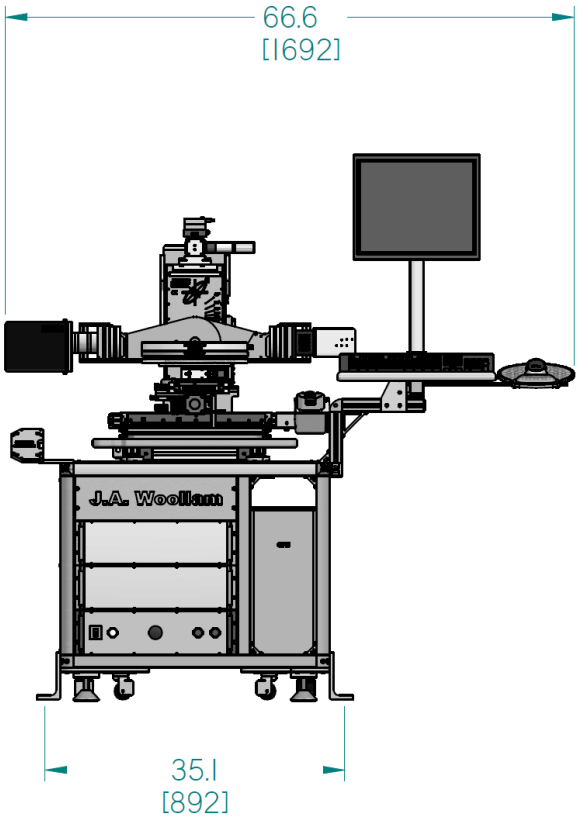
Ambient Lighting

RCE technology allows accurate measurements under normal room light conditions.

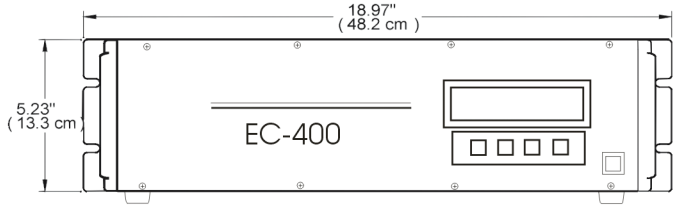
M-2000 Side View
Dimensions given in inches (mm)



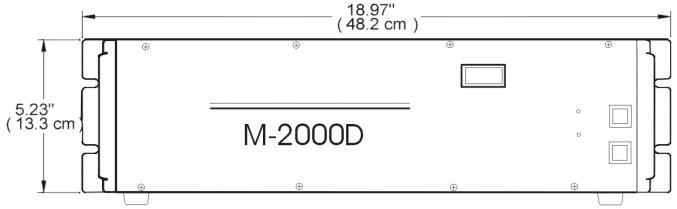
M-2000 Front View



Electronics Control Box*



M-2000 Detector Box*



*standard rack mount cases, 24" deep

M-2000® References

Prof. Zahra Fakhraai (M-2000 VI)
University of Pennsylvania
Dept. of Chemistry
Phone: (215) 746-8436
E-mail: fakhraai@sas.upenn.edu

Prof. Bryan D. Vogt (IR-VASE, M-2000)
University of Akron
Department of Polymer Engineering
Phone: (330) 972-8608
E-mail: vogt@uakron.edu

Prof. Dennis Mueller (IR-VASE, M-2000, VASE)
Colorado School of Mines; George S Ansell Dept. of Metallurgical and Materials Engineering
Phone: (214) 215-3577
E-mail: dmueller@mines.edu

Prof. Mathias Schubert (IR-VASE, M-2000, RC2, VASE, VUV-VASE, ThZ)
University of Nebraska-Lincoln
Electrical Engineering Dept.
Phone: (402) 472-5141
E-mail: schubert@engr.unl.edu

Prof. Ludvik Martinu (IR-VASE, M-2000, RC2, VASE, VUV-VASE)
Ecole Polytechnique de Montreal
Dept. of Engineering Physics
Phone: (514) 340-4099
E-mail: lmartinu@polymtl.ca

Prof. Rob Collins (IR-VASE, M-2000, RC2, VASE)
University of Toledo
Dept. of Physics and Astronomy
Phone: (419) 530-2195
E-mail: rcollins@physics.utoledo.edu

Ilya Bolshakov (alpha-SE, M-2000)
Center for Innovation & Technology Americas
Essilor of America
Phone: (972) 497-3129
E-mail: ibolshakov@essilorusa.com

Dan Dalacu, PhD. (M-2000 VI)
National Research Council of Canada
Information and Communications Technologies
Emerging Technologies Division
Phone: (613) 990-7447
E-mail: dan.dalacu@nrc-cnrc.gc.ca

Barry O'Brien (M-2000)
L3 Technologies
Phone: (480) 375-3603
E-mail: Barry.P.OBrien@L3T.com

Prof. Clifford L. Henderson (M-2000, VASE)
University of South Florida
Department of Chemical and Biomedical Engineering
Phone: (813) 974-6354
E-mail: clhenderson@usf.edu

Dean Levi, PhD. (in-situ M-2000 U, RC2)
National Renewable Energy Laboratory
Phone: (303) 384-6605
E-mail: dean.levi@nrel.gov

Prof. Grant Willson (M-2000 D, M-2000 V)
University of Texas-Austin
Dept. of Chemical Engineering
Phone: (512) 471-4342
E-mail: willson@che.utexas.edu

Brian Armstrong (M-2000 DI)
University of Michigan
Lurie Nanofabrication Facility
Phone: (734) 615-7539
E-mail: bkarmstr@umich.edu

J.A. Woollam
Ellipsometry Solutions