SENresearch 4.0
Spectroscopic Ellipsometer

Spectral range configurations:
(190 nm; 240 nm) ... (1000 nm; 1700 nm; 2500 nm; 3500 nm)

Product description

- The ultimate, individual solution is configured to match your application choosing from the widest spectral range, highest spectral resolution, and field upgradable accessories.
- Measurement of the entire spectral range by one click
- Highly sensitive, highest resolution and low noise FTIR ellipsometry in the NIR spectral range
- Step Scan Analyzer (SSA) principle. There are no moving optical parts for best measurement results.
- Full Mueller matrix by innovative 2C design
- SpectraRay/4 - comprehensive software for spectroscopic ellipsometry including sophisticated multiple angle, multiple sample, and combined photometric data analysis, Mueller matrix formalism, Generalized ellipsometry, Scatterometry, programmable customer interface and advanced reporting
- Easy operation for both, experts and beginners (Recipe mode and Interactive mode)
- SENTECH material library and sample applications for efficient modeling
1. General description

The SENresearch 4.0 is the top of the line of SENTECH’s spectroscopic ellipsometers. It is the ideal tool for thin film and material characterization from deep UV (DUV) to NIR. Every individual SENresearch 4.0 spectroscopic ellipsometer is a customer-specific configuration of spectral range, options and field upgradable accessories.

SENresearch 4.0 operates on the Step Scan Analyzer (SSA) principle. The SSA decouples the intensity measurement from mechanical movement, thereby allowing to analyze even rough samples. All optical parts are at rest during data acquisition. Furthermore, the SENresearch 4.0 includes a fast measurement mode for mapping and in situ applications. The SSA is dedicated to fit perfectly SENTECH’s goal of fast and accurate measurements of refractive index, absorption and film thickness.

SENresearch 4.0 uses fast FTIR ellipsometry for the NIR up to 2500 nm or 3500 nm, respectively. It provides broadest spectral range with best S/N ratio and highest, selectable spectral resolution. The measurement speed of FTIR ellipsometry compares to linear diode array configuration, which is also selectable up to 1700 nm.

The motorized unique Pyramid Goniometer features an angle range from 20 deg to 100 deg. Optical encoders ensure highest precision and long term stability of angle settings. The spectroscopic ellipsometer arms can be moved independently for scatterometry and angle resolved transmission measurements.

The operation of the SENresearch 4.0 is extremely user friendly. The entire ellipsometric spectrum between 190 nm and 3500 nm can be measured by just one click and the results are displayed in a few seconds. The transition between DUV, UV/VIS and NIR is seamless due to a sophisticated, automated channel switching concept.
The computer controlled and electrically stabilized dual light source comprises a Deuterium lamp for the DUV and a halogen tungsten lamp for the VIS. If a FTIR is selected for the NIR spectral range, it adds a second modulated halogen tungsten lamp as light source. If the NIR range is selected via a linear diode array, the halogen tungsten lamp within the dual light source is used for NIR spectral range as well. The detection unit for the DUV-VIS spectral range is based on a DUV enhanced grating spectrograph with a DUV sensitive CCD.

The SENresearch 4.0 uses a compensator which is highly stabilized against changes of the environmental temperature to provide lowest drift and lowest measurement error even at Delta around 0 deg. The ellipsometric angle $\Delta$ can be measured in the whole range from 0 – 360 degrees with extreme accuracy and ultimate precision.

While the SENresearch 4.0 allows to measure 11 normalized elements of the Mueller matrix, it may be upgraded with the innovative 2C design to measure the full Mueller matrix (15 normalized elements) using a dual compensator setup.

The SENresearch 4.0 data acquisition can be tuned for highest measurement accuracy for each individual application. The polarizer position is computer controlled and can be set to dedicated values according to the optical response of the sample (polarizer tracking).

Precise sample alignment is vital for highly accurate ellipsometric measurements. The SENresearch 4.0 features the Auto Collimating Telescope (ACT) for aligning the tilt and an optical microscope for adjusting the focus of the sample. A camera is used for showing the status of alignment on the operation monitor.

Smooth operation of the instrument is guaranteed by SENTECH's controller concept. While the software runs on a state of the art PC under Windows 7 the complete hardware is separately controlled by its own embedded microcontroller.

SENTECH's proprietary ellipsometer software SpectraRay/4 comprises two modes of operation: recipe mode and interactive mode. In situ and mapping modules are dedicated to specific tasks. The recipe mode allows for easy execution of repetitive applications. In interactive mode, ellipsometric measurements are enhanced by an interactive, guiding graphical user interface. A mapping module allows to scan automatically areas on the sample. An in situ module allows to capture and analyze spectra in timed intervals. The operation of SpectraRay/4 is very intuitive and satisfies the demands for ease of use and multiple user operation.

SpectraRay/4 is the software to operate the SENresearch 4.0 and includes data acquisition, modeling, fitting, and extended reporting of ellipsometric, reflection, and transmission data. It supports variable angle, multi-experiment, and combined photometric measurements. SpectraRay/4 contains a huge library of materials data based on SENTECH measurements and literature data as well. The large number of dispersion models allows modeling of nearly any type of material. The scripting capability allows easy automation of routine measurements. Third party hardware like sensors, heaters, or cryostat can be controlled.
The **SENresearch 4.0** comprises the mechanical setup with a manual or automatic goniometer for multiple angle measurements, the optical components, the optical fibers, the FTIR instrument or NIR linear diode array spectrometer (depending on the selected spectral range), an electronic rack, a desktop PC with Windows 7, and the SENTECH **SpectraRay/4** software. Light sources are integrated within the ellipsometers sender arm. The UV-VIS spectrometer and the selectable NIR linear diode array spectrometer are coupled to the ellipsometer receiver arm by optical fibers.

### 2. Technical Specifications

A spectroscopic ellipsometer can be selected as a basis for further configuration.

<table>
<thead>
<tr>
<th>Ellipsometer</th>
<th>Spectral range [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>190 ... 240</td>
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<tr>
<td></td>
<td>240 ... 1000</td>
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<tr>
<td></td>
<td>1000 ... 1700</td>
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<td></td>
<td>1700 ... 2500</td>
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<td>2500 ... 3500</td>
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<tr>
<td>SER 800</td>
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<tr>
<td>SER 800 DUV</td>
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<tr>
<td>SER 850</td>
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<tr>
<td>SER 850 DUV Z</td>
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<td>SER 850 Z</td>
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<tr>
<td>SER 850 DUV Z</td>
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</tr>
</tbody>
</table>

#### 2.1 General

**Max. sample size**: 6”, optional 8”

Maximum substrate thickness 8 mm

Larger and/or thicker samples on request

**Layers**: Opaque or transparent

Software allows for an unlimited number of layers to be analyzed

The practical number of layers that can be measured depends on the sample. More than five layers is possible for almost all samples

#### 2.2 Optical, electrical and mechanical components

**Ellipsometer operation principle**: PSCA setup:

P: polarizer

S: sample

C: compensator

A: Step Scan Analyzer

Specifications and technical data are subject to change without notice.
Light sources

Deuterium – Halogen combination lamp (all devices):
- 190 nm / 240 nm – 1000 nm
- 190 nm / 240 nm – 1700 nm (linear diode array)

Halogen lamp (FTIR):
- 1000 nm – 2500 nm / 3500 nm

Polarizer/ analyzer:

- Step Scan Analyzer (SSA) principle
- Computer controlled analyzer and polarizer (polarizer tracking)
- Angular precision better than 0.02°
  - ≥240 nm: Calcite prism, >5 x10^{-6} extinction ratio
  - ≥190 nm: MgF_{2} prisms, 1 x10^{-6} extinction ratio

Compensator

- Highly stabilized compensator for UV-VIS and NIR spectral range
- The use of compensator enables the user to measure the ellipsometric angle Δ in the whole data range from 0° to 360° with extreme accuracy.

Measurement spot:

- Manually variable beam diameter from 1.5 mm to 3 mm
  - Optional: 200 µm micro spot, smaller spot size on request

Spectral discrimination:

- For the spectral region below 1000 nm the detection is based on the Step Scan Analyzer measurement mode and fast CCD array detection: The reflected light is analyzed at fixed analyzer positions with an optical multichannel analyzer, consisting of a grating and a CCD array detector.
  - Spectral resolution: 5 nm FWHM,
  - Pixel resolution: 0.45 nm
- For the NIR a Fourier Transform Infrared (FTIR) Spectrometer is selectable. Applying FTIR ellipsometry adds speed, high resolution and a high signal to noise ratio. It provides automatic wavelength calibration as well.
  - Spectral resolution: 1 cm^{-1} up to 64 cm^{-1} (0.06 ... 2 nm @800 nm; 0.5 nm ... 18 nm @ 2500 nm)
- If a linear diode array is selected for the NIR spectral range:
  - Spectral resolution: 12 nm FWHM
  - Pixel resolution: 4 nm
- Ellipsometric spectra are measured automatically in the whole spectral range of both detection systems

Detector:

- UV/VIS: highly sensitive Si CCD array detector,
- NIR: Si/InGaAs sandwich photo detector (with FTIR), linear InGaAs diode array (without FTIR)
- Optional InAs detector for extension to 3500 nm (only in combination with ellipsometers having a FTIR spectrometer)
Sample stage: Fixed sample stage with 150 mm sample platform, height- and tilt adjustable, vacuum chuck.

Optional: mapping stages
50 mm x 50 mm (manual and motorized, Resolution: 5 µm, Precision: 2 µm),
150 mm x 150 mm (motorized, Resolution: 5 µm, Precision: 2 µm),
200 mm x 200 mm (motorized, Resolution: 5 µm, Precision: 2 µm)
300 mm r, theta (motorized; Theta: Resolution: 0.04°, Prec.: 0.01°; Linear: Resolution: 0.5 µm, Precision: 1.5 µm),
other stages on request

Sample holder for T measurements
Fast exchange with standard sample stage via quick lock
90 deg measurement position of ellipsometer arms, sample is clamped to holder
Minimal sample diameter 10 mm
other configurations on request

Goniometer: Manual Goniometer, 40° - 90°, set in 5° steps
Precision: better than 0.02 °

Optional:
Computer controlled Pyramid goniometer, incident angle range from 20°-100°,
minimum step width 0.002°, precision: 0.001°

Sample alignment:
Auto collimating telescope and optical microscope for sample alignment (height and tilt)
Video camera for ACT, it also gives a picture of the measured area

Measurement time:¹ UV-VIS: 5 s
NIR: 10 s (with FTIR)

Controller: Modular unit with bench top ellipsometer optics and goniometer.
Separate rack contains ellipsometer controller with electronic boards and microcontroller unit, spectrophotometer

Computer: State of the art desktop PC, monitor, keyboard, mouse,
Windows 7 professional operation software (x86 and x64 are supported)

Output device:
Windows printer compatible
Software interface to export and import spectroscopic data
Network card

Power requirements: Rated voltage:115/230 VAC auto select (100-132 VAC or 207-264 VAC)
Rated frequency: 50-60 Hz
Rated power: 600 W

¹ Shortest time to full ψ, Δ spectra. Measurement time for Fourier coefficients s₁, s₂ are shorter.
2.3 **Options**

The following options may be added before factory shipments. See specifications above for details.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SER 800-2</td>
<td>computer controlled Pyramid goniometer</td>
</tr>
<tr>
<td>SER 800-30</td>
<td>reflectometer based on FTPadv, 450-920 nm, 80µm spot, incl. FTP Reflectometer software</td>
</tr>
<tr>
<td>SER 850-NIRE</td>
<td>extended spectral range to 3.5 µm</td>
</tr>
<tr>
<td>SE 800 LN2 Cryostat</td>
<td>HV cryostat for optical measurements, 80 K – 700 K</td>
</tr>
<tr>
<td>SE 800 He cryostat</td>
<td>HV cryostat for optical measurements, 5 K – 700 K</td>
</tr>
</tbody>
</table>

The SER 850 DUV and SER 850 DUV Z are shipped with a Pyramid goniometer SER 800-2 as standard configuration.

2.4 **Field upgradable accessories**

These accessories can be upgraded after factory shipment at the customer site.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SER 800-AFT</td>
<td>auto height &amp; tilt adjustment for SENresearch 4.0</td>
</tr>
<tr>
<td>SER 800-PST</td>
<td>transmission sample holder with quick lock</td>
</tr>
<tr>
<td>SE 800-3</td>
<td>micro spot, 200 µm diameter of the beam spot in the UV/VIS spectral range</td>
</tr>
<tr>
<td>SER 800-2C16M</td>
<td>extension to SER 850 DUV /SER 850 Z DUV for the measurement of 16 Mueller matrix elements (15 normalized elements) including second compensator, motorized turntable and analysis software</td>
</tr>
<tr>
<td>SER 15</td>
<td>mapping stage, 150 mm motorized x-y stage, manual (z,tilt) adjustment, 150 mm stage diameter</td>
</tr>
<tr>
<td>SER 16</td>
<td>mapping stage, 200 mm motorized x-y stage, manual (z,tilt) adjustment, 200 mm stage diameter</td>
</tr>
<tr>
<td>SER 17</td>
<td>mapping stage r,theta, 300 mm sample platform</td>
</tr>
<tr>
<td>SER 5AR</td>
<td>computer controlled turntable for measurement of anisotropic samples</td>
</tr>
<tr>
<td>SER 5AM</td>
<td>manual turntable</td>
</tr>
</tbody>
</table>
### 2.5 Accessories

The following list is independent from the ellipsometer and may be ordered before or after factory shipment.

<table>
<thead>
<tr>
<th>Accessory</th>
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</tr>
</thead>
<tbody>
<tr>
<td>SE 20</td>
<td>Liquid cell for in situ measurements, Teflon, one pair of windows liquid at rest</td>
</tr>
<tr>
<td>SE CFH26</td>
<td>Liquid cell 26 ml volume heated up to 70°C, incidence angles 50°, 60°, 70°, fluid flow, Cells with other parameters on request</td>
</tr>
<tr>
<td>SE HC1</td>
<td>Heating stage room temperature to 150 °C</td>
</tr>
<tr>
<td>SE HC2</td>
<td>Heating stage room temperature to 300 °C</td>
</tr>
<tr>
<td>SE HC3</td>
<td>Temperature controlled stage -190 °C to 600 °C</td>
</tr>
<tr>
<td>SE K20</td>
<td>SENTECH thin film test wafer, nominal 20 nm SiO2 on Si</td>
</tr>
<tr>
<td>SE K100</td>
<td>SENTECH thin film test wafer, nominal 100 nm SiO2 on Si</td>
</tr>
<tr>
<td>SE K400</td>
<td>SENTECH thin film test wafer, nominal 400 nm SiO2 on Si</td>
</tr>
<tr>
<td>SE 51</td>
<td>SpectraRay/4 license for work station</td>
</tr>
<tr>
<td>SE 5A</td>
<td>SpectraRay/4 license for anisotropic sample analysis</td>
</tr>
<tr>
<td>SE 5 3D</td>
<td>SpectraRay/4 3D Profiling, license for linear gratings analysis based on scatterometry</td>
</tr>
</tbody>
</table>
3. Data acquisition and analysis software: SpectraRay/4

Recipe mode: Push button operation of routine applications (recipes),
A recipe includes the hardware settings, measurement conditions, model and
measured data.
A set of standard recipes is delivered with the software. New recipes can be built
up by adapting already existing recipes or importing corresponding data from the
interactive operation part of SpectraRay/4 after a new ellipsometric application
was solved.
A measurement can be directly started after loading a new recipe.
All settings can be optimized / set by the user (password based user
management available).
The measured results (measured and fitted spectra, fit parameters) are shown in
the operation window of the module.
Recipes can be used in mapping applications as well if computer controlled xy
stage is available.

Interactive mode: The standard sequence of measuring, creation of a sample model, fitting one or
more spectra and reporting is assisted in a step by step sequence. This mode
allows to combine multiple data sets and implements a multiple sample analysis.
The interactive mode extends the recipe mode for development of optical models
and is applied to tasks that cannot be reduced to a single button click action.

Mapping module: (Option) The automated measurement of samples allows to get 2D information on
thicknesses or any other fitting parameter. All standard patterns are supported (as
mesh, user defined or SEMI patterns).

In situ mode: The measurement and analysis of spectra in timed intervals is added with this
module. It allows to capture spectra (limit is only hard disk space) at high speed
(minimum is 200 ms). Analysis is done in parallel with any model setup in
interactive mode. A recalculate feature allows to modify the model and to
recalculate all data at later time.

Anisotropy analysis: (Option) Stacks of biaxial anisotropic samples can be used. Even incoherent layers as
quartz substrates can be modeled for ellipsometric spectra and spectra of Mueller
matrix elements.

3D profiling: (Option) The module adds the measurement and analysis of grating structures with layers.
It comes with its own rigorous coupled wave analysis (RCWA) module for fast
analysis. See separate product description for details.

Features: SpectraRay/4 operating and analysis software comprises
• Interactive and recipe mode of operation
• Computer controlled sample stages
• Mapping module for computer controlled sample stages (description see also
  mapping options)
• In situ module for the measurement and analysis in timed intervals (number of
spectra only limited by hard disk space)

- Mueller matrix measurement and analysis (the SER 800-2C16M accessory allows to upgrade from 11 to 15 normalized elements)
- Analysis of biaxial anisotropic layer stacks
- 3D profiler module for scatterometry of gratings
- Built in system calibration routines
- Automatic setting up of optical and mechanical components
- Easy and guided software operation including data acquisition, modeling, fitting and reporting
- Complete experiments can be saved as recipes
- Recipe mode for routine applications
- Advanced reporting of measured and fitted spectra, measurement data, user comments, sample information in a Word-like environment

**Measurement output:**

- Ellipsometric angles $\psi; \Delta$, Fourier coefficients $s_1$, $s_2$ vs. energy, wavelength or wavenumber (related to sample position, angle of incidence) of single or multiple angle or time dependent measurements
- Mueller matrix elements
- Polarized reflectivity $R_p$, $R_s$ and transmission
- Dispersion relation
- Dielectric function
- Degree of polarization
- Graphic representations of measured and calculated ellipsometric spectra
- Data clipping to selected wavelengths and angles without changing original data
- Merge function for combining sets of different wavelength ranges
- Combine function for combining sets of different data in one file
- Reduction of data as modulo or average
- Extract angle traces from multiple angle and time dependent data

**Modelling, simulation and fit:**

* SpectraRay4 is able to fit any multilayer structure (single film, layer stack, periodical groups of stacks) for $\psi$, $\Delta$; $\tan \psi$, $\cos \Delta$, Mueller matrix and Fourier coefficients, transmission, reflection etc. This includes anisotropic substrates and layers (separate software license).

- Large material library (more than 200 data sets), user expandable and application adaptable
- Large set of dispersion relations to describe the optical properties of layers and bulk materials: data file (data table), 2D table, Cauchy, Sellmeier, Schott, Drude-Lorentz, Lorentz, Leng, Tauc-Lorentz, Harmonic oscillator, Cody-Lorentz, Brendel, Hamberg, Selenerius, Forouhi-Bloomer, Afromovitz, Tanguy, spectral combination layer for combining different dielectric models, user defined dispersion formula, dispersion formula for uniaxial and biaxial anisotropic materials, dispersion formula for periodic layer stacks
• Each layer of a model stack can be a homogeneous film, an interface, a surface roughness, a homogeneous growing layer, an index gradient (effective medium approximations: Maxwell-Garnett, Bruggemann, Lorentz-Lorenz, Clausius-Mossotti)

• Material gradients can be modeled by one of the following type of functions: linear, exponential, error function like, Gaussian (symmetrical or asymmetrical) like, parabola like.

• Fast regression algorithms for fitting calculated spectra to measured spectra

• Graphical representation of fitted spectra

Fit of composite data: The fit algorithm does not only allow fitting of ellipsometric data but also transmission and reflection spectra as well. The fit can be based on multiple measurements ($\Psi, \Delta, R, T$) and different samples with same layer material. External data of other instruments can be imported as ASCII data and analyzed / fitted

Fit parameters: Customer defined, depending on the model. There is no fundamental limit for the number of fit parameters or layers in a layer stack. Fit parameters could be e.g.: film thickness, refractive index, extinction coefficient, constituent fractions, incident angle, composition profile, temperature, and time.

Fit statistics: Fit error and correlation matrix are calculated. Device -, wavelength - and sample alignment errors can be taken into account.

File management functions: The software is based on Windows 7 and provides full file management functions.

User management: The software provides full user level management and allows user specific assignment of rights on a function level basis.

Customized user interface: SpectraRay/4 includes a software package to develop user defined measuring and operation routines based on an easy to use script language.

4. Software options

<table>
<thead>
<tr>
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<td>SE 5A</td>
<td>SpectraRay/4 license for anisotropic sample analysis</td>
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<td>SE 5 3D</td>
<td>SpectraRay/4 3D Profiling, license for linear gratings analysis based on scatterometry</td>
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</table>

The mapping software is delivered at no additional cost with the optional computer controlled sample stages (xy and R/Theta).
5. Floor plan

All units are in millimeter.