alpha-SE®
Spectroscopic Ellipsometer

Hardware Manual

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Thank you for purchasing a J.A. Woollam Co. Spectroscopic Ellipsometer. We hope the information contained in this manual will help you develop a better understanding and appreciation for the alpha-SE hardware.

The contents of this manual are subject to change without notice and do not constitute a commitment on the part of J.A. Woollam Co. Every effort has been made to ensure the accuracy of this document. However, due to ongoing product improvements and revisions, J.A. Woollam Co. cannot guarantee the accuracy of the printed material after the date of publication nor can it accept responsibility for errors or omissions. J.A. Woollam Co. will update and revise this document as needed.

Contents

1. Safety Instructions

1.1. Message Boxes

Three message boxes are used in this manual. They are explained below:

Warning: This box is used to warn the user of a potential hazard to the user or persons in the area of the ellipsometer.

Caution: This box is used to alert the user that an incorrect operation or procedure could cause damage to the equipment.

Note: This box contains tips, hints, and useful information relating to the procedure in which it is located.

1.2. General Safety Instructions

Warning: For safe operation of this equipment, do not use it in any way other than what is described in this user's manual or as recommended by the manufacturer.

- Keep hands/fingers/body parts away from the instrument while making motor position changes.
- Ensure all system controls and power cables are tied/tucked away/hidden/kept away/arranged such that persons walking around the instrument area will not snag or trip on any of the cables.
- Replace bad fuses only with proper type and rated fuse.
- Never look into a tip of an optical fiber.
- Never look directly at an operating lamp, severe eye injury may result. Wear UV protective lenses, such as a welder's helmet, when working around operating lamps.

- Permanent eye damage can result from looking directly into the beam. It is best to view the beam using a piece of paper or business card.
- Before servicing this equipment, ensure that the power source is disconnected.
- Before servicing the lamp housing, be sure to disconnect all cables. Make certain the lamp is at room temperature (turn lamp off for at least 20 minutes).
- Compact arc lamps contain highly pressurized gas, and present an explosion hazard even when cold. Wear face protection, such as a full-face shield, gloves and a long sleeve shirt whenever handling lamps.

1.3. Environmental Operating Range

- Temperature: 10°C to 35°C
- Humidity: 20% to 80% (non-condensing)

2. Quick Guide

Thank you for purchasing a J.A. Woollam Co. alpha-SE Spectroscopic Ellipsometer (SE) system. This manual will help with system installation, alignment, calibration, and basic data collection procedures. You should also receive the CompleteEASE Software Manual, which covers data analysis. Feel free to contact J.A. Woollam Co. or your local representative (see Section 9.4) with any questions.

2.1. Manual Overview

The manual is organized into the following chapters:

Chapter 2: Quick Guide. Overview and quick, step-by-step guide to get you started with your new alpha-SE system.

Chapter 3: System Installation. Unpacking and setting up the alpha-SE instrument, installing the CompleteEASE software, and verifying proper operation.

Chapter 4: Initial System Checks and Calibration. Describes basic system operation, including system tests to perform upon first installation.

Chapter 5: Data Collection. Details basic measurements with your alpha-SE, including ellipsometry, transmission intensity, and Mueller-matrix SE.

Chapter 6: Hardware Tab. Overview of functions accessed within the Hardware Tab for an alpha-SE.

Chapter 7: **Accessories.** Details regarding optional accessories for the alpha-SE including focusing, camera, liquid cell, transmission mount, manual translation, and QCM adaptor.

Chapter 8: Service and Troubleshooting. Describes the lamp change procedure, upgrading CompleteEASE, and troubleshooting issues.

Chapter 9: Appendices. The appendices include additional information for your reference, including short-cut guide, overview of spectroscopic ellipsometry, and contact details for J.A. Woollam Co. and our world-wide network of representatives.

Chapter 10: Index.

2.2. Quick Setup

This section quickly guides you through the installation of your alpha-SE. More detailed instructions are given throughout the manual, and are referenced in this section. There are four major steps:

- Unpacking and assembling the instrument.
- Installing and running the CompleteEASE software.
- Checking the beam and calibrating the system.
- Collecting and analyzing data.

1. Unpack and assemble the instrument

To start, unpack all items from the box and assemble the system, as detailed in Section 3.3.

Assembly:

Attach the sample chuck to the alpha-SE, as shown in Figure 3-4.

To avoid damage to the z-motor during shipping, it has been restrained. It is important that this shipping restraint is released prior to operation. To do this, open the lamp-access door and slide the shipping restraint "bolt", as shown in the Figure 3-5 and Figure 3-6.

Note: Software must be installed on computer <u>before</u> connecting the USB cable.

2. Install, activate, and run CompleteEASE software

If you purchased a computer from J.A. Woollam Co. with your alpha-SE, it comes preloaded with the CompleteEASE software and is configured to operate your instrument. If not, you will need to install and activate the CompleteEASE software on your computer, per instructions in Section 3.4.

Connecting alpha-SE:

Connect the vacuum, power, and USB cables and turn on the alpha-SE power. If this is a new computer, the alpha-SE USB drivers will be installed. It is now time to start the CompleteEASE software (Section 3.7) by double-clicking the icon on the Windows desktop. The software will initiate communication with the alpha-SE instrument and test motors.

3. Check the beam and calibrate the system

Prior to initial use, it is good to check the beam alignment and calibrate the system. This involves:

- Straight-Through beam check (Section 4.2)
- Intensity Check (Section 4.3)
- S-T Baseline (Section 4.6)
- Off-Sample Baseline (Section 4.7)
- Angle Correction (Section 4.8)

Checking Beam and Signal

To start, move the angle of incidence to the Straight-Through position. The angles are adjusted by releasing the AOI indexer knobs, shown in Figure 4-3. In the Straight-Through position, check that the light beam is centered on the detector unit aperture, as described in Section 4.2. While at the Straight-Through position, check the signal intensity, per Section 4.3.

The alpha-SE maintains its calibration through sensors on each of the optical elements. Thus, it should be able to collect data directly out-of-the-box. However, to improve accuracy, especially upon first installation, it is preferred to perform baseline measurements that correct for any subtle changes in the system.

Note: System should be ON for > 30 minutes prior to baseline measurements.

Baseline Measurements

Baseline measurements are performed in both the Straight-Through and Off-Sample configurations. They correct slight changes in the optical configuration, such as recent intensity information, correct angle of incidence, and optical component positioning. For standard measurements on a day-to-day basis, these baseline measurements are not required. However, it is preferred to perform a baseline after first setting up the alpha-SE or just prior to Intensity or Mueller-matrix measurements.

After the system has been ON for more than 30 minutes, perform the Straight-Through baseline, per Section 4.6. Next, move the angle of incidence to 70° and mount the 25nm (250Å) reference wafer on the stage. Perform the "Off-Sample" baseline, per Section 4.7.

Angle Calibration

Finally, the angle of incidence at other positions can be calibrated by performing the procedure described in Section 4.8. This uses the same reference wafer as with the "Off-Sample" baseline.

The system is now ready for measurements.

4. Collect data

The alpha-SE is easy to operate. From the Measurement Tab, you can set the measurement mode, sample alignment, angles of incidence, and model. For most measurements, choose Standard mode, Standard Sample Alignment, the Off-Sample angles, and "none" for the model, as shown in Figure 2-1. This will collect data, which can be saved for later analysis.

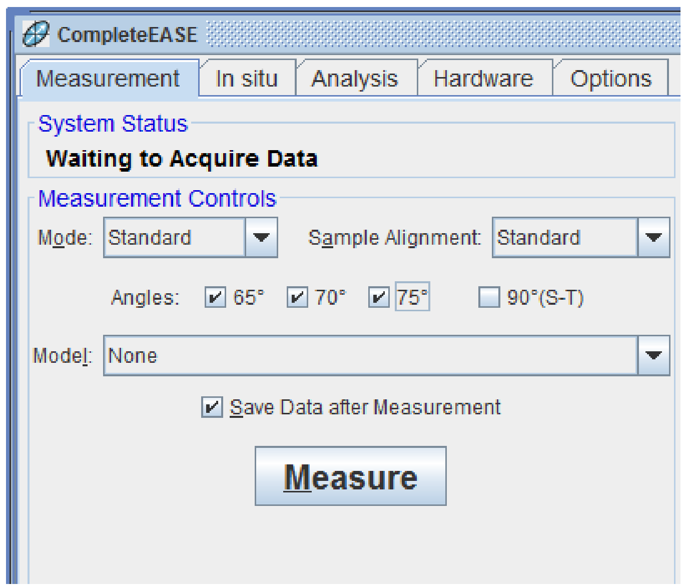

Figure 2-1. Standard Measurement settings from the ***Measurement*** *tab.*

Ellipsometry measurements contain two values (Psi and Delta) at each wavelength and angle, which describe the change in polarization that occurs upon reflection from the surface. For more details on Psi and Delta and how they are affected by the sample, refer to Section 9.1.

The reference wafers provide a good starting point to ensure that the alpha-SE instrument is operating correctly and the procedures for data acquisition are understood. This procedure is detailed in Section 4.5.

3. System Installation

Please follow the system installation instructions carefully and in the specified order.

Note: **The software must be installed and activated on the computer before connecting the USB cable.**

3.1. alpha-SE Specifications

Measurement Capabilities

- Rotating compensator ellipsometer (RCE) design enables accurate measurement of ellipsometric Psi and Delta parameters over their entire range: Psi = 0° – 90°, Delta = 0° – 360°.
- Depolarization and Intensity data are simultaneously acquired and reported with each ellipsometric measurement.
- Mueller-matrix measurements. Compensator is located after sample, providing complete access to the first 3 columns of the Mueller-matrix (12 of the 16 elements).
- Wavelength range: **380 – 900 nm**, measured at >180 wavelengths, equally spaced in photon energy at approximately 0.01 eV.
- Angles of incidence: 65°, 70°, and 75° (Off-Sample) and 90° (Straight-Through).

Data Analysis Capabilities

- Standard multiple layer optical model, with easy-to-use surface roughness and graded-index layer options.
- Dispersion layers: Cauchy, General Oscillator, Effective Medium Approximation (EMA), and B-Spline.
- Layer “Parameterization” feature to convert dispersion layer types.
- Support for backside layers and depolarization modeling for films on glass.

- Thickness “Pre-fit” and Global Fit options provide robust fit convergence, minimizing the need for accurate starting estimates.
- Automated comparison of alternative models.
- Uniqueness Simulation to test final model quality.
- Fit Logging to track and compare your results.

3.2. Facilities Requirements

Facilities requirements for the alpha-SE system are listed in Table 3-1 and the system dimensions are given in Figure 3-1. As shown in Figure 3-2, the preferred clear work area is 20 by 18 inches (500 by 460 mm), excluding the operator computer.

Table 3-1. Facilities requirements for the alpha-SE system.

SPECIFICATION	ALPHA-SE REQUIREMENT
Power	alpha-SE 100-240 VAC \ 1 Amp \ 47-63 Hz. \ IEC320 receptacle vacuum pump 100-120 VAC \ 1Amp \ 47-63 Hz. or 200-240 VAC \ 0.5 Amp \ 47-63 Hz.
Weight	39 pounds (18 kilograms) **ensure work surface will support alpha-SE**
Computer	• Windows 98 or higher, USB port version 1.1 or higher. USB 2.0 recommended (to perform at specified acquisition speeds) • Within 10 ft. (3 m.) of the alpha-SE ellipsometer

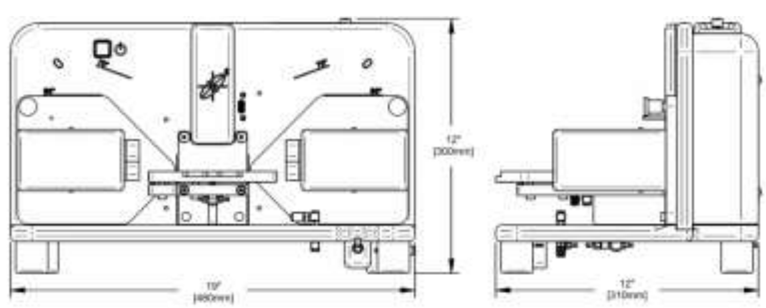

Figure 3-1. alpha-SE dimensions.

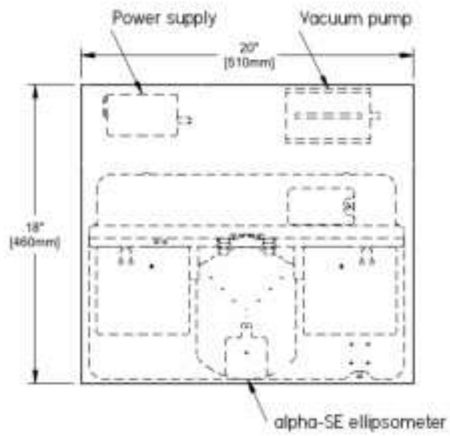

Figure 3-2. alpha-SE workspace for installation, excluding computer.

3.3. Unpacking the Hardware

Opening the Shipping Container

Move the alpha-SE shipping container to the area where the tool will be installed. Open the container and remove the top and side pieces of packing foam. Carefully remove all smaller components from the shipping container, verifying that you received all components, as shown in Figure 3-3. Finally, remove the alpha-SE ellipsometer and position it on your clear 20" by 18" (510 by 460 mm) workspace. The alpha-SE should **only** be lifted by its handles as shown in Figure 3-3.

Caution: The alpha-SE ellipsometer without sample chuck weighs approximately 37 lbs. (16 kg.). Please find an assistant to lift the alpha-SE unit out of the shipping carton and on to clear work surface. Do not lift by any component other than the handles.

Lift the alpha-SE by the handles as shown.

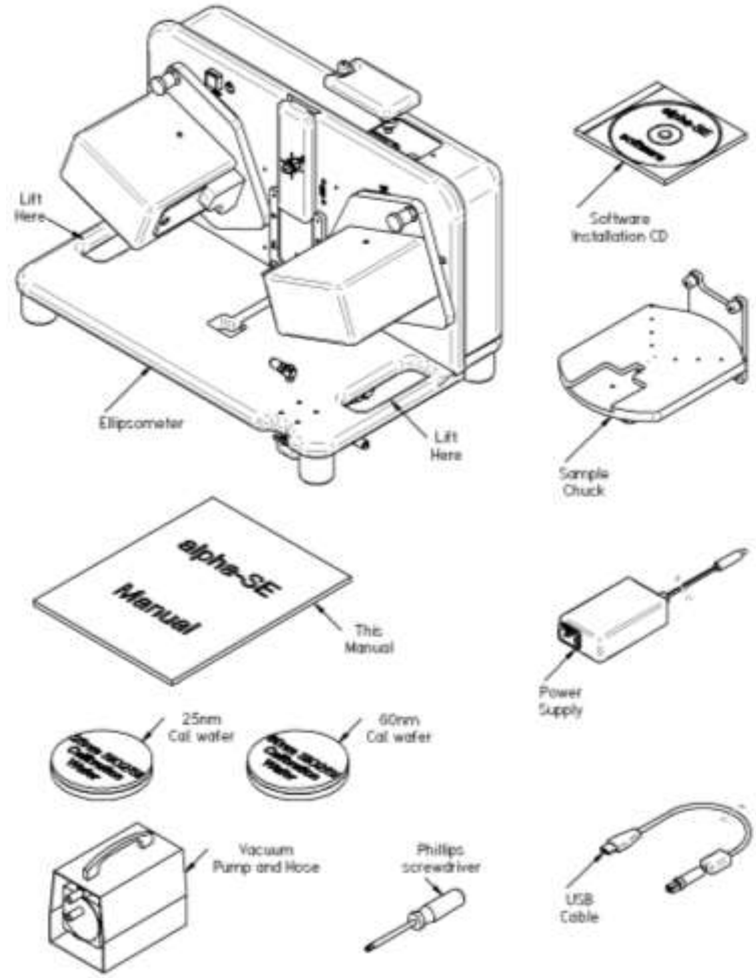

Figure 3-3. alpha-SE shipping container contents.

Attaching the Sample Chuck

You will need a #2 Phillips screwdriver for this step. Following the details shown in Figure 3-4, install the sample chuck: 1) Align the pins on the bottom of the sample chuck with the receptacles on the alpha-SE base. 2) Tighten the upper two captive thumb screws. 3) Use the Phillips screwdriver to tighten the lower two captive screws. Don't over tighten the screws! It will make it difficult to remove them in the future; just ensure that the screws are snug. 4) Connect the vacuum line from the sample chuck to the vacuum fitting on the alpha-SE base.

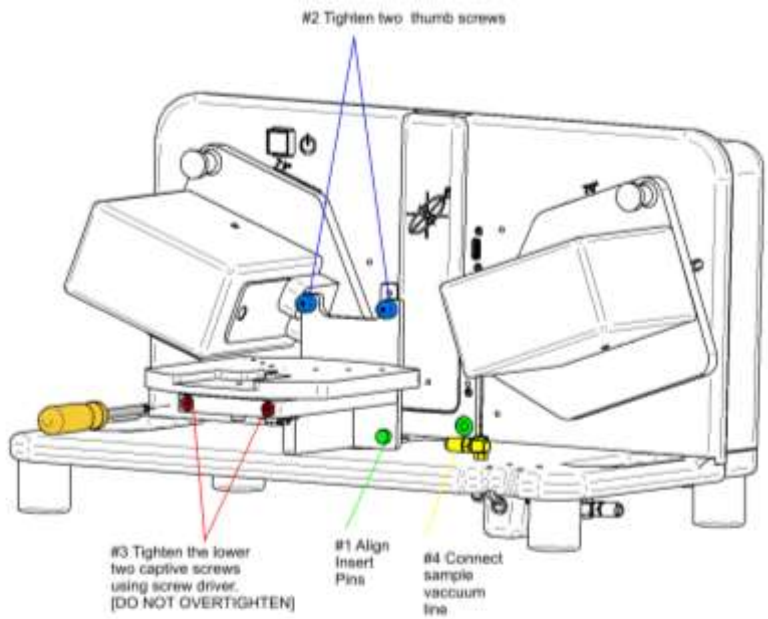

Figure 3-4. Sample chuck installation.

Releasing the Z-stage Shipping Lock

To access the Z-stage shipping lock, first loosen the captive screw on the lamp/shipping lock access door, and then open the access door by rotating 180°, as shown in Figure 3-5.

To release the Z-stage shipping lock, stand in front of the ellipsometer and use your left hand to balance the weight of the Z-stage (you will feel it lift up slightly). It will be difficult to release the shipping lock if you apply too much or not enough upward force. Next, use your right hand to move the shipping lock to the operating position (to the right, see Figure 3-6). If the lock is hard to move, you can use a tool to gain more leverage. The shipping lock will move about 1/3” [8mm] to the right.

When finished, rotate the lamp/shipping lock access door to the closed position and hand-tighten the captive screw.

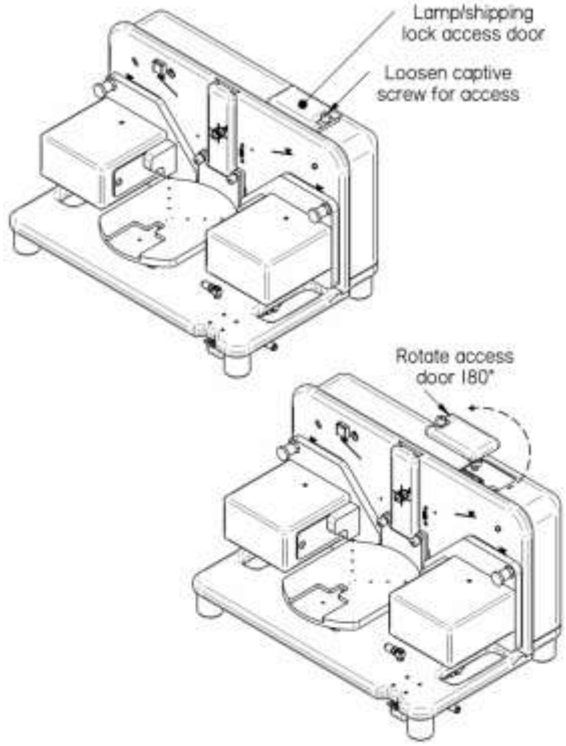

Figure 3-5. Open access door to lamp/shipping lock.

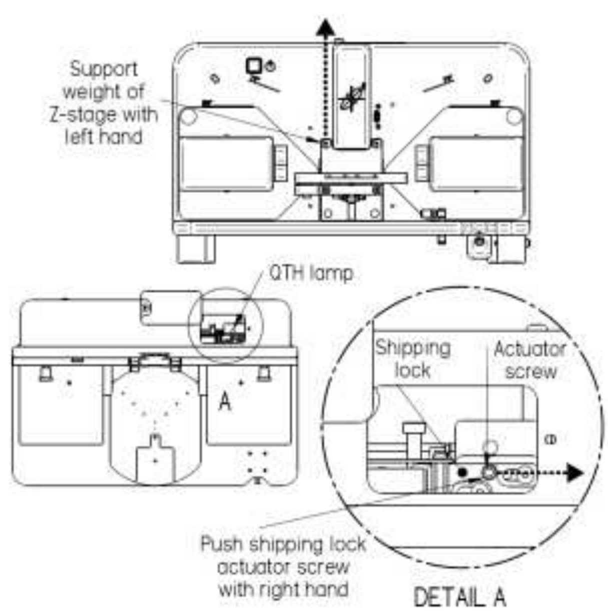

Figure 3-6. Instructions for releasing the shipping lock.

3.4. Installing the Software

Please follow the system installation instructions carefully and in the specified order.

Note: The software must be installed and activated on the computer before connecting the USB cable.

If the computer was purchased from J.A. Woollam Co. at time of alpha-SE purchase, the software should already be installed and activated. Skip to Section 3.5.

Before Installation

Verify that the computer used to operate the ellipsometer system meets all the requirements listed in Table 3-2.

Table 3-2. Computer requirements for the CompleteEASE software.

COMPUTER SPECIFICATIONS	REQUIREMENTS
Operating System	Microsoft Windows 98, ME, 2000, XP, Vista, Win 7, Win 10
Memory (RAM)	256 MB
Hard Disk Space	120 MB
USB Ports	1 required, version 1.1 or higher
Processor	Intel Pentium III, AMD Athlon, or higher 1 GHz clock speed or faster **Many operations in CompleteEASE benefit from multi-core processing power.
Display	Color display at least 800x600 pixel resolution

Running the SETUP Program

The configuration files are unique for each ellipsometer system. If you have problems with installation, consult the Troubleshooting Guide in Section 8.3

Run the "**CompleteEASE_Setup_6.xx.EXE**" application from the provided installation CD or USB. This program is located on the CD or USB along with a folder named "CNF" that contains the configuration files to match one specific ellipsometer system. Setup will install the CompleteEASE program files, the Java Virtual Machine (VM) files which are required to run CompleteEASE, and other related files (material optical constants files, optical model files, example files, etc.).

NOTE: For alpha-SE systems, the CD or USB provided with the tool will automatically install the calibration and configuration files for your specific instrument from the "CNF" directory. If your system was shipped with a computer, this was done at the factory. If your files become corrupt, you will need to copy all files from this folder into the corresponding C:\CompleteEASE\CNF\ folder after installation. These files will return the instrument to the factory setting and replace any calibrations that have been recently performed. Please contact J.A. Woollam Co. for further advice if this is required in the field.

Follow the onscreen prompts provided by the CompleteEASE_Setup program. The default directory for installation is **C:\CompleteEASE**. To minimize compatibility problems, it is recommended to install the software in this directory. This is shown in Figure 3-8. The installation CD includes configuration files for one specific ellipsometer system. If you are installing the CompleteEASE software to run this ellipsometer system, choose "Full Installation" as shown in Figure 3-9. This will install the drivers required for hardware operation. Most installation CDs provided with alpha-SE systems will automatically install the CNF (configuration) files as well. If not, it is still possible to copy the CNF files after installation.

Note: The three necessary CNF (configuration) files for alpha-SE are *alphacal.cnf*, *hardware.cnf*, and *motorinfo.cnf*.

The CompleteEASE software can be installed on multiple computers for data analysis purposes (most purchases include 5-seat license; each seat must be activated separately). If you are installing software on a computer that will not operate an ellipsometer system, choose "Data Analysis Only", as shown in Figure 3-9.

Note: The CompleteEASE software is only compatible with the encoded Experimental Data files measured using CompleteEASE. Thus, you can install CompleteEASE at multiple computers, but only for use with data collected by CompleteEASE.

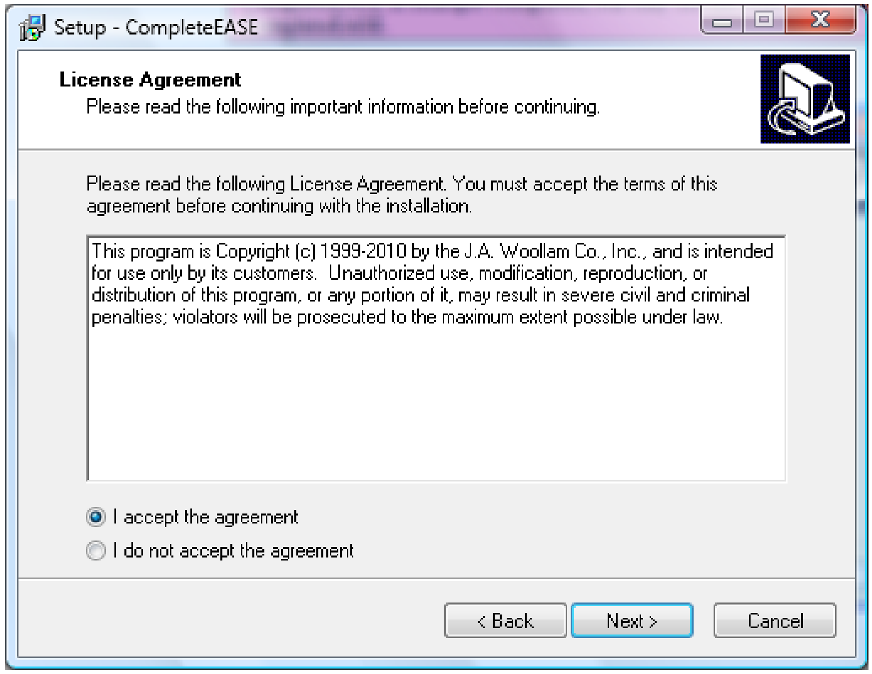

Figure 3-7. License Agreement for CompleteEASE.

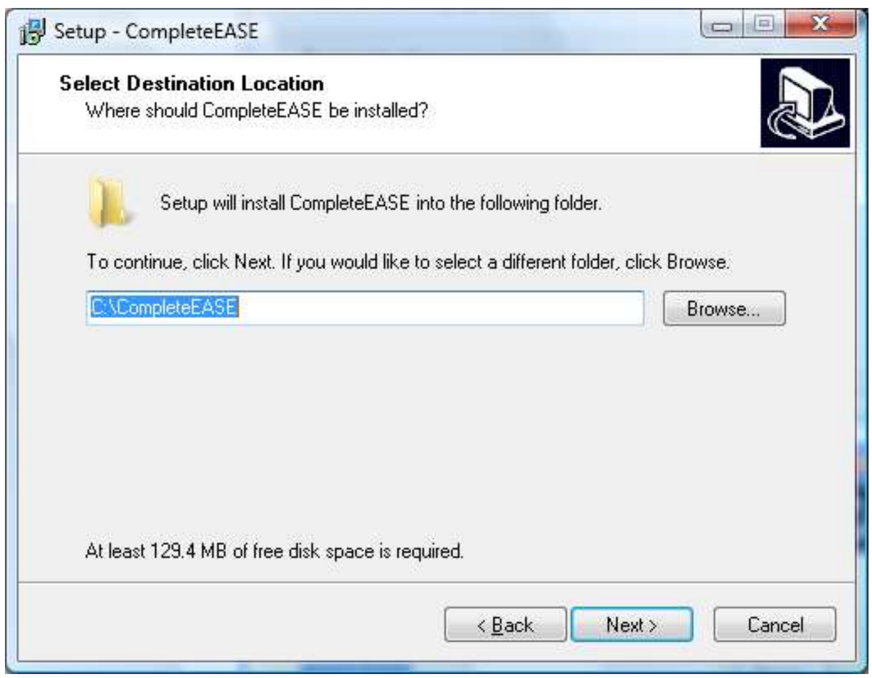

Figure 3-8. Default (recommended) folder location for CompleteEASE installation.

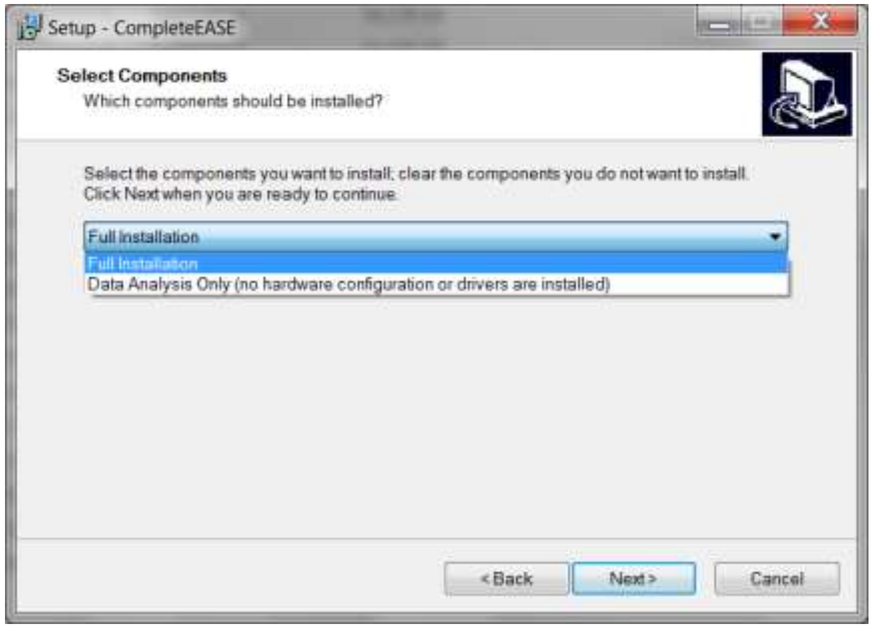

Figure 3-9. CompleteEASE Setup choices. The software can be installed for use with an ellipsometer system or for data analysis only.

The next message you will receive asks which tasks you would like the installation software to perform. The choice ranges from creating icons to associating CompleteEASE file types. These possibilities are shown in Figure 3-10. If you choose, a short-cut icon (Figure 3-12) will be placed on the Windows Desktop to start the CompleteEASE program. However, do **NOT** start CompleteEASE until following the system connection instructions. The software installation process should take less than two minutes on most computers.

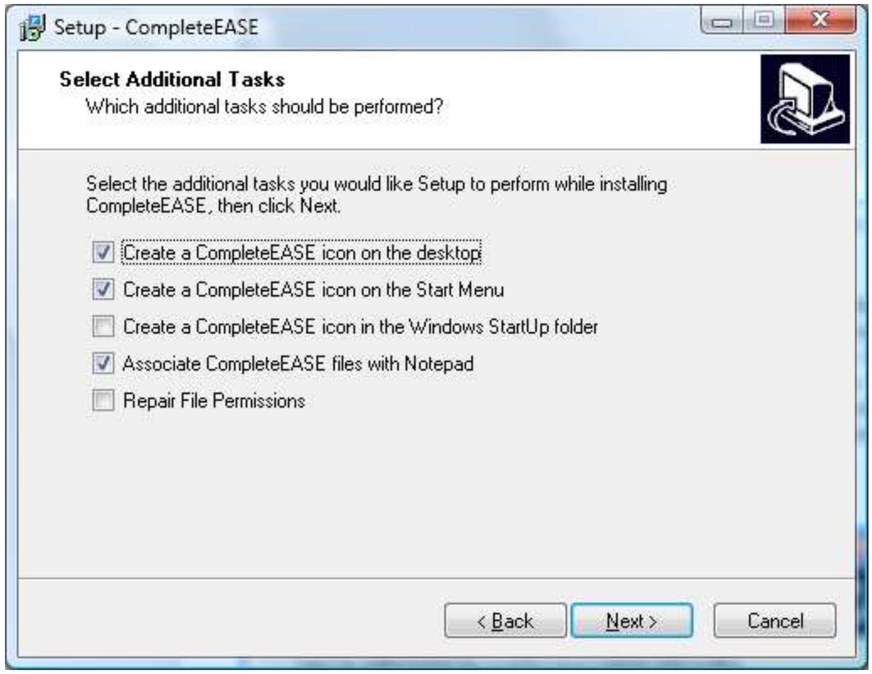

Figure 3-10. Additional Tasks desired during installation of CompleteEASE.

Note: **Repair File Permissions is only needed if recent computer activity (such as upgrading the operating system) has changed the CompleteEASE files to "read-only". This setting will change all the files associated with CompleteEASE back to full-access.**

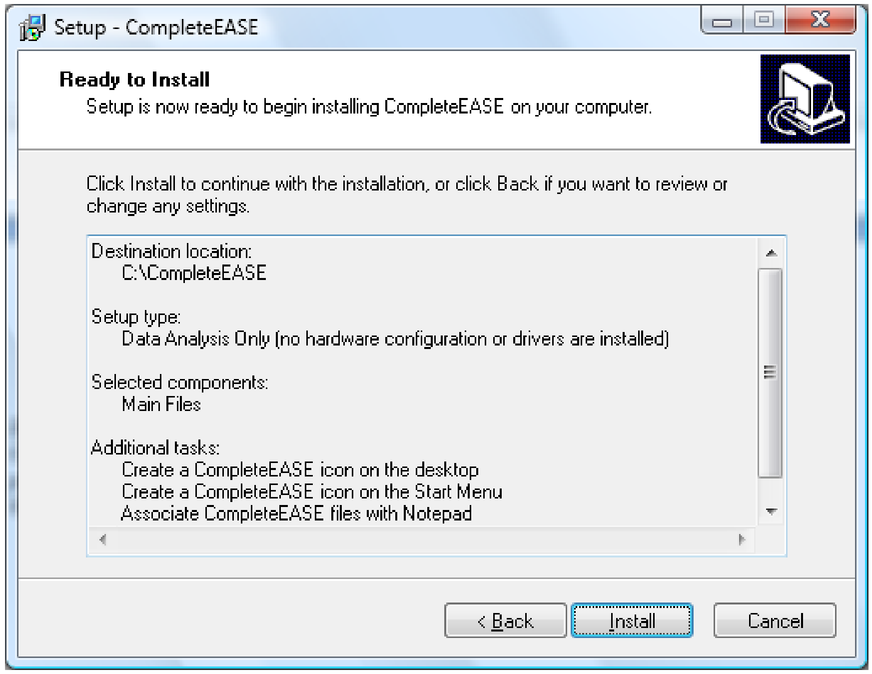

Figure 3-11. Details just before installation.

DO NOT start the CompleteEASE program at this time.

Figure 3-12. CompleteEASE icon.

Operating Hardware

If you will be operating hardware with CompleteEASE, it requires the configuration files for your instrument. These are provided with the installation CD that accompanies each instrument. Most alpha-SE installation CDs will automatically add these drivers and configuration files.

If upgrading to a newer version of CompleteEASE, the configuration files should already be installed from the factory and do not require any additional efforts. If you are installing CompleteEASE on a new computer to operate the hardware, or repairing a corrupted version, you can copy the contents of the "CNF" folder from the CD provided with the instrument to the associated folder on your hard drive: C:/CompleteEASE/CNF/.

Note: Do not copy configuration files if your system is already operating with CompleteEASE, as this will overwrite your latest calibration and return it to factory settings. This may require recalibration of your instrument.

3.5. Activating the Software

If your computer was purchased from J.A. Woollam Co., the software on this computer will already be activated. If you are supplying your own PC, or installing on additional computers for off-line analysis (most purchases include a 5-seat license), each seat must be activated.

For instructions, see supplemental document "CompleteEASE 6 Activation Guide".

3.6. Connecting the alpha-SE

After installing and activating the software, or if your computer was purchased from J.A. Woollam Co. with software pre-installed and activated, you are ready to connect the hardware.

Connect the vacuum hose, power, and USB connections to the back of the alpha-SE as shown in Figure 3-13. Also, connect the vacuum hose to the vacuum pump, the power cable to outlet, and the other end of the USB cord to the computer. The vacuum pump will need to be turned on before mounting samples.

Turn on the power to the alpha-SE unit by pressing the green power switch. If the switch does not "light up", check the power connections.

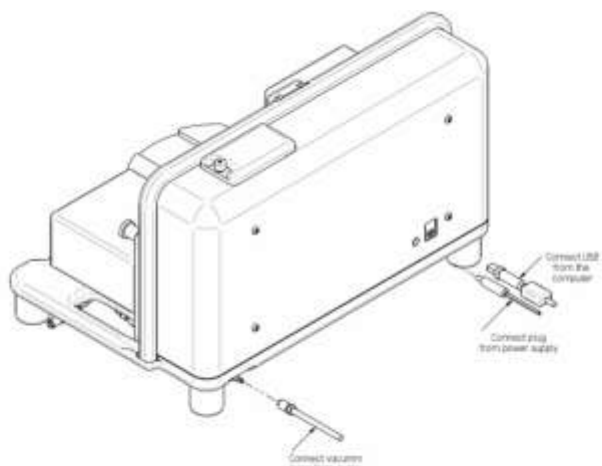

Figure 3-13. Connect vacuum, power and USB connections.

When the alpha-SE unit is connected to the computer with the USB cable, Windows will automatically detect that new hardware has been attached to the computer and install device drivers. Follow on screen prompts if needed. A "new hardware" message (Figure 3-14) will be briefly displayed near the taskbar.

Figure 3-14. Message displayed in Windows 7 when alpha-SE is initially connected to computer.

Verifying the alpha-SE Driver Installation

To verify the proper installation of the alpha-SE drivers, open the Windows “Device Manager”. For Windows 7, right-click on the “Computer” icon on the desktop or in the Start menu and choose “Properties” from the popup menu. Next, choose “Device Manager” from the panel on the left side of the dialog (Figure 3-15).

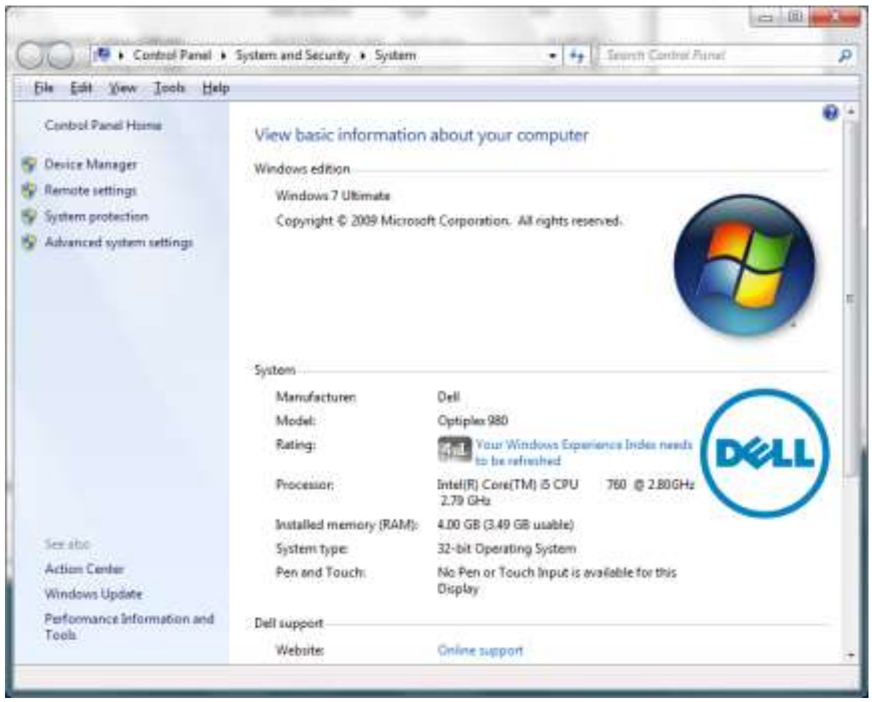

Figure 3-15. Choose “Device Manager”.

Verify that “alpha-SE Ellipsometer” is now listed under “J.A. Woollam Co. Devices” (Figure 3-16). If this is the case then the driver has been successfully installed. If “alpha-SE Ellipsometer” is listed under “Other devices”, or cannot be found at all, contact J.A. Woollam Co. for instructions.

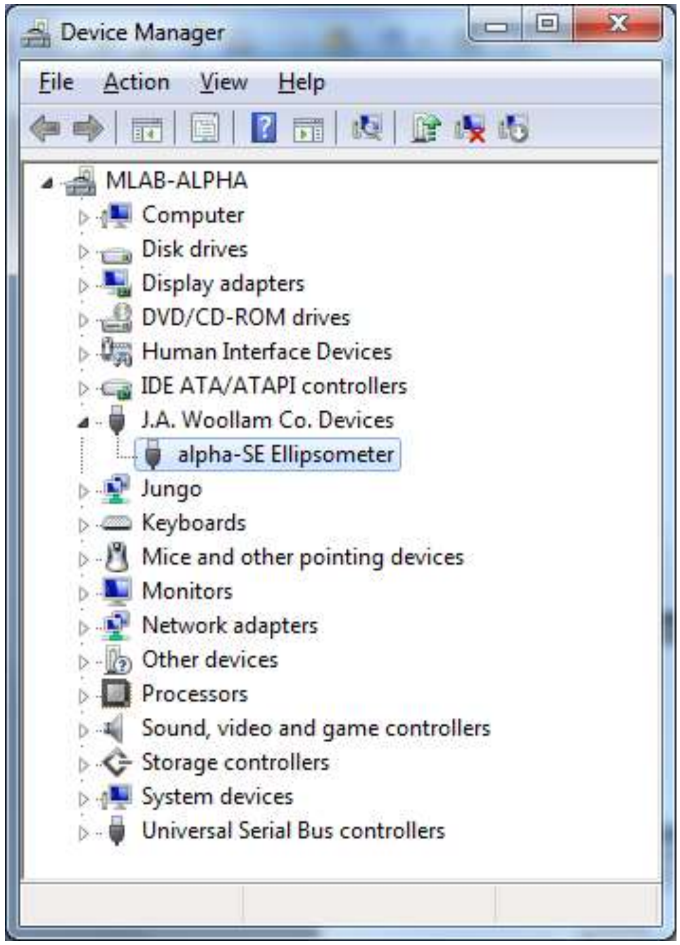

Figure 3-16. Verify listing shows "alpha-SE Ellipsometer".

3.7. Running the CompleteEASE Software

Turn the alpha-SE power switch on, and start the CompleteEASE program by double-clicking the "CompleteEASE" icon on the Windows Desktop. The software will automatically begin initializing the alpha-SE hardware and the status of initialization process will be displayed in the System Status section of the screen. If hardware initialization is successful, the System Status message will change to "Waiting to Acquire Data" as shown in Figure 3-17.

If an error occurs during hardware initialization, a message box may appear describing the problem. If the problem is not easily fixed (such as "Please turn the alpha-SE power ON" error message), contact your J.A. Woollam Co. representative before continuing.

Note: **Additional information about a hardware error can be found by clicking the 'Hardware' button from the Show Logs panel in the *Hardware* tab.**

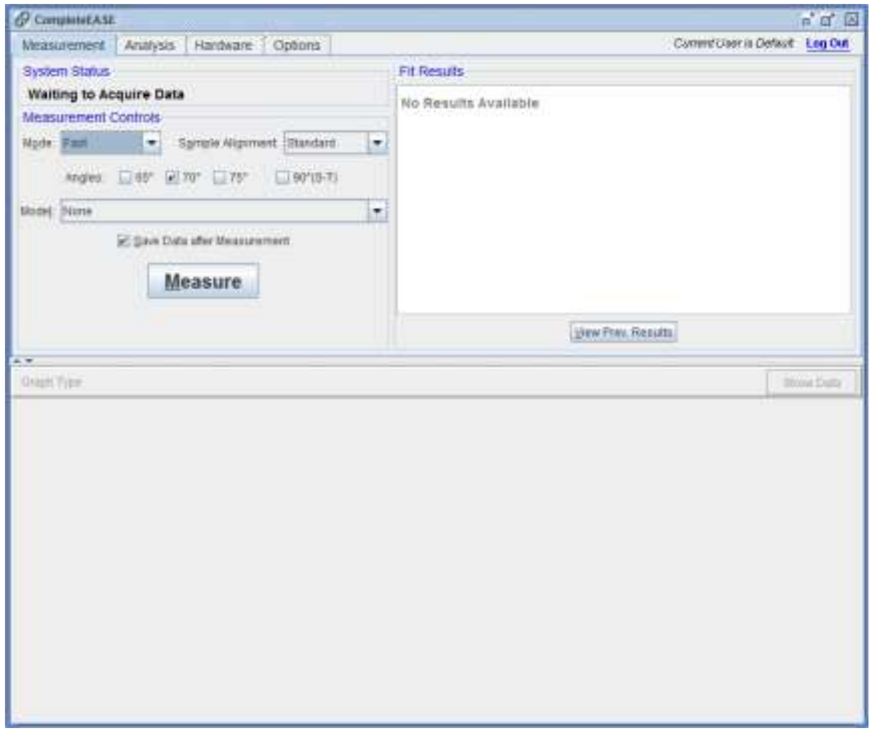

Figure 3-17. CompleteEASE after successful hardware initialization.

3.8. Learning Data Analysis

After software installation, a "*CompleteEASE Manual"* PDF will be available. It is located in the CompleteEASE directory. This manual has many excellent examples for practice, and describes the various features of the CompleteEASE program. You can also access this manual by pressing F1 key. For a hard-copy of the latest CompleteEASE manual (nearly 400 pages), as shown in Figure 3-18, please contact J.A. Woollam Co.

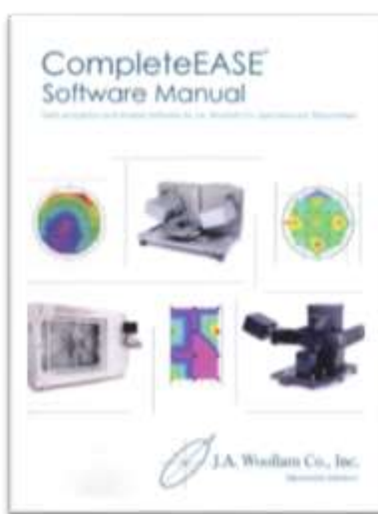

Figure 3-18. Cover of CompleteEASE data analysis manual (for ver. 4.63)

4. Initial System Checks and Calibration

This chapter discusses the initial system operation and procedures needed to ensure data accuracy. After installing an alpha-SE system, the Straight-Through beam-alignment should be verified per Section 4.2. Next, the signal intensity is verified, as described in Section 4.3. Then, the accuracy is verified with a Straight-Through measurement (Section 4.4). Off-Sample measurements can be performed with the 25nm SiO_2-Si reference wafer supplied with each alpha-SE system, as described in Section 4.5. Three calibration procedures are described. Straight-Through (S-T) and Off-Sample Baseline measurements can improve measurement accuracy, but are primarily needed before Intensity or Mueller-matrix measurements. These are described in Sections 4.6 and 4.7, respectively. The Angle Correction in Section 4.8 can calculate the actual angle of incidence for each of the three Off-Sample measurement positions and store this in a configuration file to provide correct angle during future measurements. The chapter concludes with power-down procedures.

4.1. Initial System Operation

alpha-SE System Components

The various components of the alpha-SE system are named as shown in Figure 4-1. These names will be used throughout this chapter.

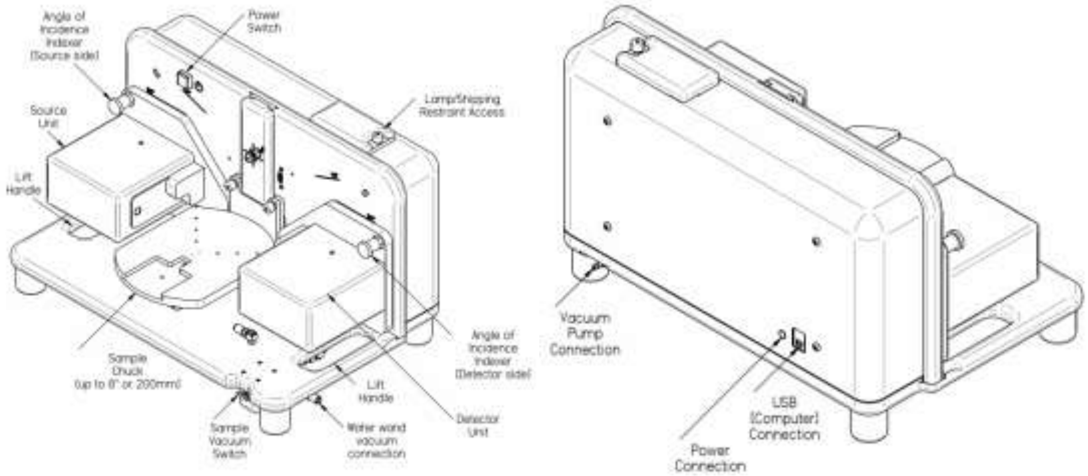

Figure 4-1. alpha-SE system components.

Figure 4-2. Support knobs for lifting the Source and Detector when changing the Angle of Incidence.

Changing the Angle of Incidence (AOI)

The alpha-SE can perform measurements at 65°, 70°, and 75° ("Off-Sample" configuration), and at 90° ("Straight-Through" configuration). To change angle, pull out and hold Source side AOI Indexer (see Figure 4-3). Lift the Source side using the support knob (see Figure 4-2) until the top edge of the Source side is lined up with the engraved angle marker (see Figure 4-4). Release the AOI Indexer. Repeat on Detector side. The angle position is detected by the software magnetically, and must match on both sides.

Caution: Avoid directly lifting the Source and Detector Unit. Lift Source and Detector sides by the support knobs shown in Figure 4-2. The top edge of Source and Detector sides should line up with the engraved 65°, 70°, 75°, or 90° reference lines before releasing AOI Indexer. When AOI Indexer is released, you may hear or feel it move into the

AOI slot. You should not be able to move the Source or Detector side up or down after the AOI Indexer is released.

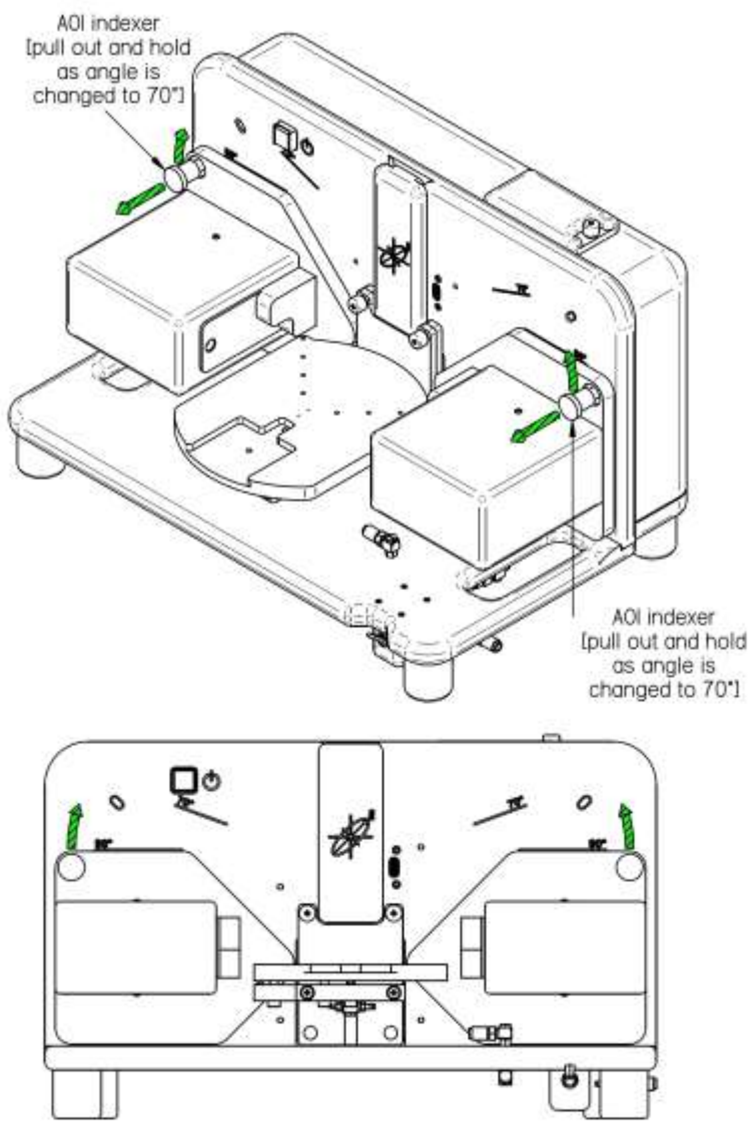

Figure 4-3. Changing the Angle of Incidence (AOI) of the alpha-SE system.

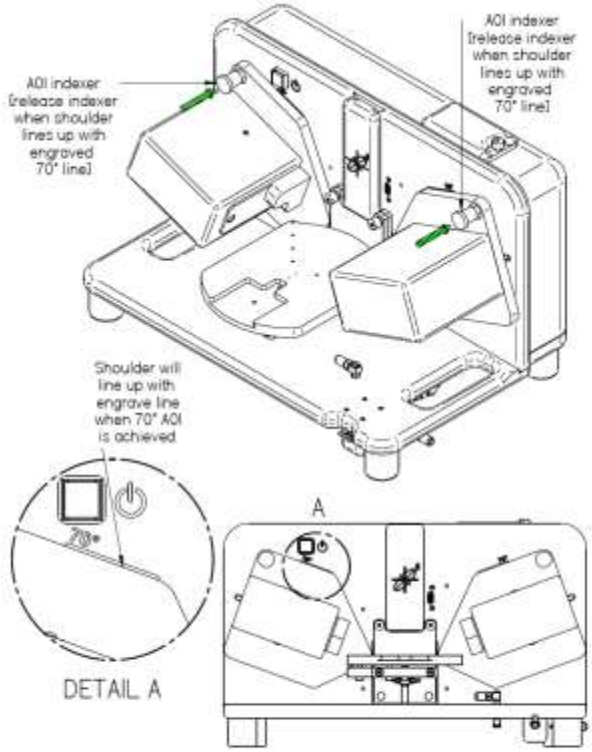

Figure 4-4. alpha-SE system set to 70° ("Off-Sample") configuration.

4.2. Checking Beam Alignment at 90°

Verify that the beam is centered on the detector unit aperture when the alpha-SE system is in the "Straight-Through" or 90° configuration, as shown in Figure 4-5. If the system is not set to 90°, pull out the "AOI Indexer" knobs on the source and detector units and adjust the system to the 90° position (Figure 4-3). If the beam is not centered on the receiver aperture, contact J.A. Woollam Co.

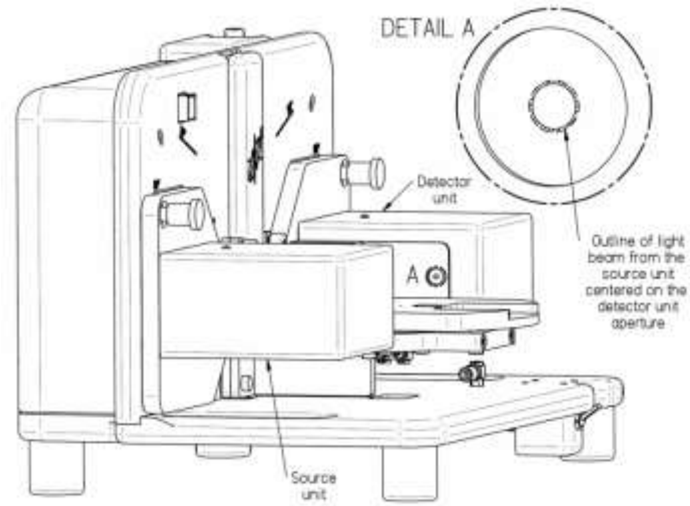

Figure 4-5. Verifying that the beam is centered on the detector aperture with the alpha-SE system in the "Straight-Through" configuration.

4.3. Checking Signal Intensity

With the alpha-SE base in the Straight-Through (90°) position (as in Figure 4-5), click ***Hardware>***'Max. Sig. Display'. The CompleteEASE screen should appear similar to that shown in Figure 4-6. Acceptable values for the average signal intensity (the "Ave=" value) range from 500 – 2000; maximum signal intensity values can range from 1200 – 3200.

Low Intensity

If the observed "Ave" and "Max" values are lower than these acceptance ranges, verify that the lamp is properly seated. To access the lamp, first loosen the captive screw on the lamp/shipping lock access door, and then open the access door by rotating 180°, as shown in Figure 3-5. The lamp is located behind the actuator screw (see Figure 3-6) and has two white wires protruding from the back of the lamp. Simply push down on the lamp to ensure that the lamp is fully seated in the lamp housing. Close access door and re-tighten captive screw when finished.

If the intensities are still low, try installing a new lamp (see Section 8.1). If this fails to bring the intensities within the acceptable range, please contact your J.A. Woollam Co. representative.

High Intensity

If the observed "Max" value exceeds the acceptance range, open the lamp access door and slowly pull the lamp out or rotate until the "Max" value is within the acceptable range.

Warning: Lamp may be hot.

After Checking the Signal Intensity, press the 'Cancel Signal Display' button in the top-center of the screen (or press ESC key).

Figure 4-6. Typical "Max. Sig. Display" screen with alpha-SE at 90°.

4.4. Checking Straight-Through SE Data Accuracy

Ellipsometer accuracy is verified on a known sample. However, due to the high sensitivity of SE measurements to surface conditions and film changes, the most stable reference is air. For air measurement, the alpha-SE should achieve the following accuracy specifications over 95% of the measured spectral range:

- Ψ: 45° ± 0.1°
- Δ: 0 ± 0.2°

To test the alpha-SE Straight-Through data accuracy, move the angle of incidence to 90° (Straight-Through) position. Next, go to the CompleteEASE ***Measurement*** tab and choose the settings shown in Figure 4-7. Click 'Measure'.

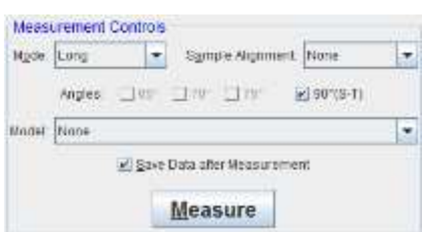

Figure 4-7. Settings to test Straight-Through Accuracy of ellipsometer, measuring air.

The "Long" measurement will take about 30 seconds, and the measured spectroscopic ellipsometric (SE) data will be graphed in the bottom half of the CompleteEASE screen (Figure 4-8). Typically the accuracy range is achieved over most of the spectrum, except at the longest and shortest wavelengths where noise may cause the data to slightly exceed the accuracy target.

If the Straight-Through accuracy is not within specification, perform a Straight-Through (S-T) Baseline measurement, as described in Section 4.6. If measurements remain significantly outside the accuracy specifications, even after performing an S-T Baseline, please contact J.A. Woollam Co. for support.

Figure 4-8. Typical Straight-Through (90°) SE data. Data over most of the spectral range should provide Psi = 45° ± 0.1° and Delta = 0° ± 0.2°.

4.5. Measuring the Reference Wafer

The alpha-SE comes with a reference (calibration) wafer, which is nominally 25nm of thermal oxide on silicon. The exact thickness may deviate from this value and can vary within a small range over measurement location and time, but this sample serves as a good surface with known optical constants for both the underlying silicon substrate and the thermal SiO_2 film. Measurements of this sample can be modeled with only adjustment of the SiO_2 thickness and the angle of incidence (in case it doesn't precisely match the nominal angle). Thus, the reference wafer serves as our second test of system performance, after Straight-Through air measurements. Because the thickness can vary with measurement location and time, we use the Mean Squared Error (MSE) as a test of whether the alpha-SE data is correct. We can also check the angle offset to make sure the angle of incidence is correctly calibrated. The Reference Wafer measurement should achieve the following:

- MSE: < 3.0
- Angle Offset: within ± 0.04°

To test the reference wafer, choose the **Measurement Controls:** settings shown in Figure 4-9: “Standard” mode, “Standard” alignment, the three Off-Sample angles, and “Si with Thermal Oxide” model (found in the Basic Folder).

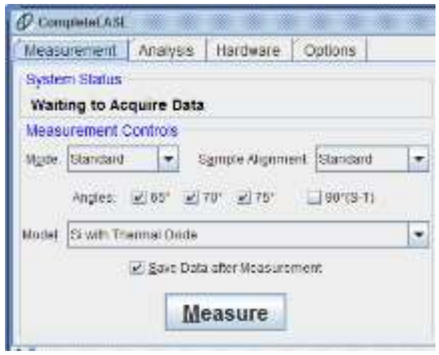

Figure 4-9. To measure the Reference Wafer, select “Standard” Mode, “Standard” Sample Alignment, all three Off-Sample Angles (65°, 70°, and 75°). The Model for the Reference sample is “Si with Thermal Oxide” found in the Basic Folder.

Mount the 25nm (250Å) reference wafer and turn the vacuum switch on, as shown in Figure 4-10, then click ‘Measure’ to begin the measurement. If the alpha-SE angle is not set to the correct angle of incidence (as determined by magnetic sensors), you will be prompted to move to the correct angle, as shown in Figure 4-11. At each angle of incidence, the alpha-SE system first adjusts the sample height (“Z-height”) to center the beam on the detector unit aperture, and then acquires spectroscopic ellipsometry (SE) data.

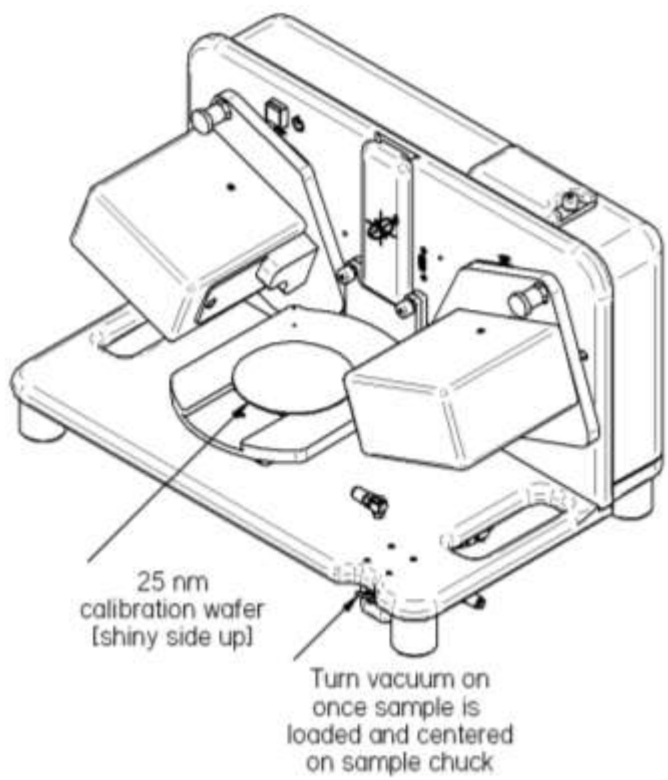

Figure 4-10. Calibration wafer mounted on the alpha-SE system at 70°.

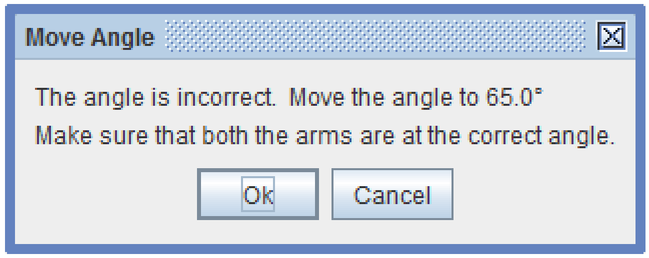

Figure 4-11. Magnetic sensors detect whether source and receiver arms are positioned at the correct angle of incidence. If incorrect, you may receive this prompt to move the angles before proceeding.

After acquiring data, the selected model will be used to analyze the data, and the results will be presented as shown in Figure 4-12. The entire process (alignment, measurement, and analysis) should take about one minute to complete.

The SE Data graph on the bottom half of the CompleteEASE screen displays the experimentally measured ellipsometric parameters “Psi” and “Delta” vs. wavelength as solid colored curves (red for the “Psi” data, and green for the “Delta” data). The black dashed curves are generated by the model analysis of the data. If the model “fits” the data, the black dashed model curves lie essentially on top of the experimental colored curves, as shown in Figure 4-12.

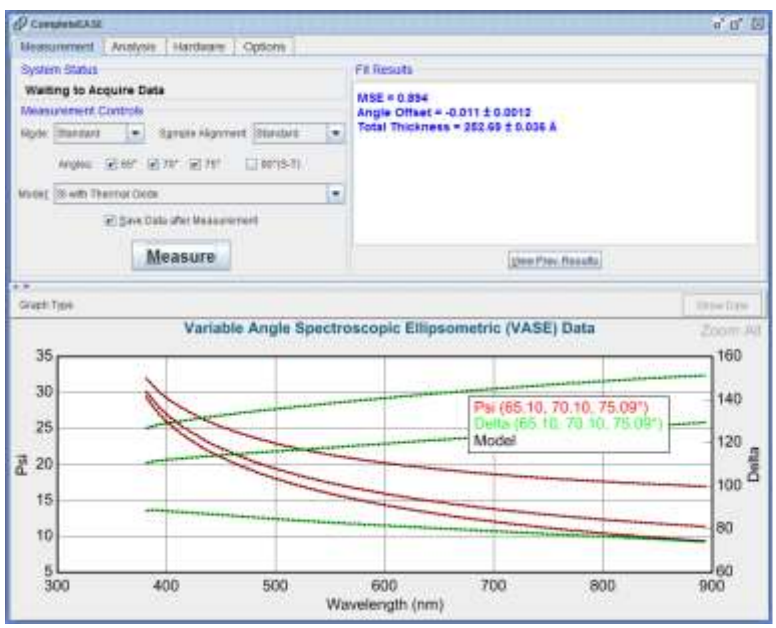

Figure 4-12. CompleteEASE screen after measuring 25nm reference wafer.

The “MSE” (Mean Squared Error) value, shown in the upper right corner of the CompleteEASE screen, quantifies how well the model data “fits” or “matches” the experimental data. The lower the MSE value, the better the data fit. If the MSE for alpha-SE measurements of the 25nm calibration wafer is less than 3, then the alpha-SE system is acquiring accurate Off-Sample SE data.

The Angle Offset is applied during the fit in case the actual angle does not precisely match the current nominal angle designation (see Angle Calibration for more details). If the Angle Offset is within 0.04°, then the Angles are well calibrated. If the Angle Offset exceeds 0.05°, you may need to perform an Angle Calibration, per section 4.8. If the Angle Offset and MSE are outside limits, then follow instructions in the next paragraph.

If the MSE is above this limit, try remounting the sample, turn the vacuum switch on, and ensure that it sits firmly on the sample chuck. Make sure both the top-surface and the back-surface of the sample are clean and perform another measurement. As an additional check on the alpha-SE system alignment, verify that the beam is centered on the detector unit aperture after the measurement. If the MSE is still outside the acceptance limits, perform an Off-Sample Baseline measurement at 70° and then an Angle Calibration, per sections 4.7 and 4.8, respectively. After finishing these two calibrations, re-measure the reference sample again. If it still exceeds either limit, please consult J.A. Woollam Co. for assistance.

4.6. S-T Baseline

Note: S-T Baseline should be performed prior to Intensity or MM measurements in Straight-Through configuration.

The Straight-Through (S-T) baseline is used to “fine-tune” the current optical component positions and determine the baseline intensity. The intensity information is not as important for accurate ellipsometry measurements as SE is a ratio of polarization directions. However, this is an important step before collecting Straight-Through Intensity or Mueller-matrix measurements.

The primary calibration of the alpha-SE, involving determination of the polarization properties of the optical elements, is done at the factory. The S-T Baseline is used in the field for slight adjustments of optical component positions and more significantly, capturing the current light intensity. Because the alpha-SE uses a step-scan method for rotating the compensator and it is important to have a baseline of the relative intensities at each optical position.

It is recommended to perform an S-T baseline i) before Straight-Through Intensity measurements, ii) before collecting Straight-Through Mueller-matrix measurements, and iii) after setting up or moving the alpha-SE. The new baseline will store current Intensity data, which should be stable for up to an hour, depending on fluctuations or “warm-up” of the lamp. Thus, if you are collecting multiple Intensity or Mueller-matrix measurements in a row, it may only require a single S-T Baseline prior to the first measurement.

Note: For best accuracy and baseline stability, it is important that the alpha-SE is ON and Hardware initialized 30 minutes before performing an S-T Baseline.

To acquire an "S-T Baseline", place the Source and Receiver arms in the Straight-Through (90°) position and go to the ***Hardware*** tab. From the **Calibration:** panel, choose the 'S-T Baseline' button (Figure 4-13).

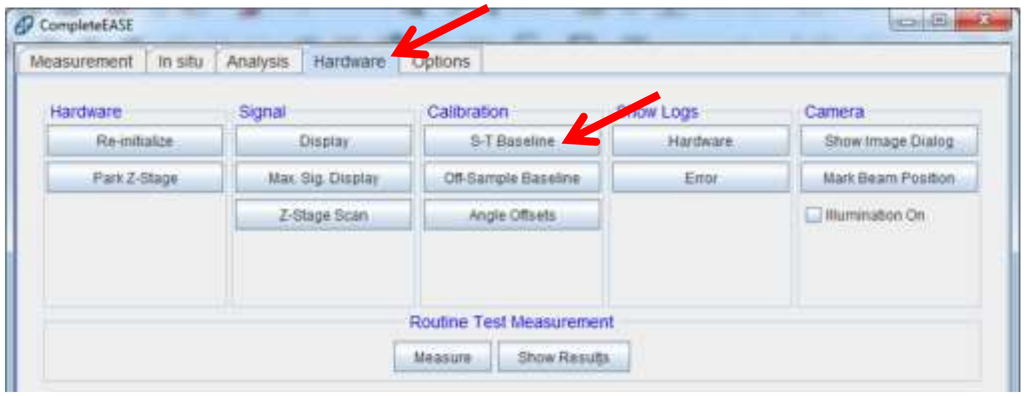

Figure 4-13. S-T Baseline button.

If the alpha-SE senses that the arms are not located in the correct position, you will see the message shown in Figure 4-14.

Figure 4-14. Set the base to Straight-Through position before proceeding with S-T Baseline.

The S-T Baseline will take a few minutes and when complete, will report the success of this test, along with MSE, as shown in Figure 4-15. If not successful, ensure the arms are Straight-Through and the beam is aligned on the Receiver aperture, with adequate Intensity and try again. If still not successful, contact J.A. Woollam Co.

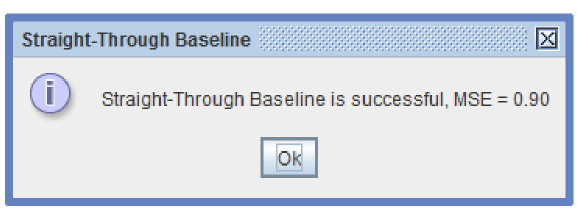

Figure 4-15. Upon completion of a successful S-T Baseline, you will receive a message with the reported MSE value.

4.7. Off-Sample Baseline

Note: Off-Sample Baseline should be performed prior to Intensity or MM measurements performed Off-Sample at the current angle of incidence. The Off-Sample Baseline can also be used to accurately determine the current angle correction.

The Off-Sample baseline is used to “fine-tune” the optical component positions, determine the baseline intensity and correct angle of incidence for the current position. The intensity information is not as important for accurate ellipsometry measurements as SE is a ratio of polarization directions. The SE measurements do benefit from the “fine-tuning” of the optical component positions, as this is relative to the current plane of incidence – defined by the reference wafer mounted on stage. In addition, SE measurements benefit from accurate angle of incidence. Section 4.8 will discuss calibration of all three angles, while this step only corrects for the current angle of incidence.

Off-Sample Baseline measurements are critical for Intensity measurements or Mueller-matrix measurements, as both rely significantly on intensity information. Because the alpha-SE uses a step-scan method for rotating the compensator and it is important to have a baseline of the relative intensities at each optical position. A recent Off-Sample Baseline should be performed at the proposed angle prior to Intensity and Mueller-matrix measurements. For best results, a new Off-Sample Baseline is repeated if the angle is moved to a new position.

Thus, it is recommended to perform an Off-Sample Baseline i) before Mueller-matrix or Intensity measurements at this same angle, ii) if the angle of incidence has been moved and current angle is uncertain, or iii) after first setting up or moving the alpha-SE. The new baseline will store current Intensity data, which should be stable for up to an hour, depending on fluctuations or “warm-up” of the lamp. Thus, if you are collecting multiple Intensity or Mueller-matrix measurements in a row, it may only require a single Off-Sample Baseline prior to the first measurement.

Note: For best accuracy and baseline stability, it is important that the alpha-SE is ON and Hardware initialized 30 minutes before performing an Off-Sample Baseline.

To acquire an Off-Sample Baseline, move the Source and Receiver arms to angle of interest in the Off-Sample configuration and go to the ***Hardware*** tab. From the **Calibration:** panel, choose the 'Off-Sample Baseline' button (Figure 4-16) and follow the prompts.

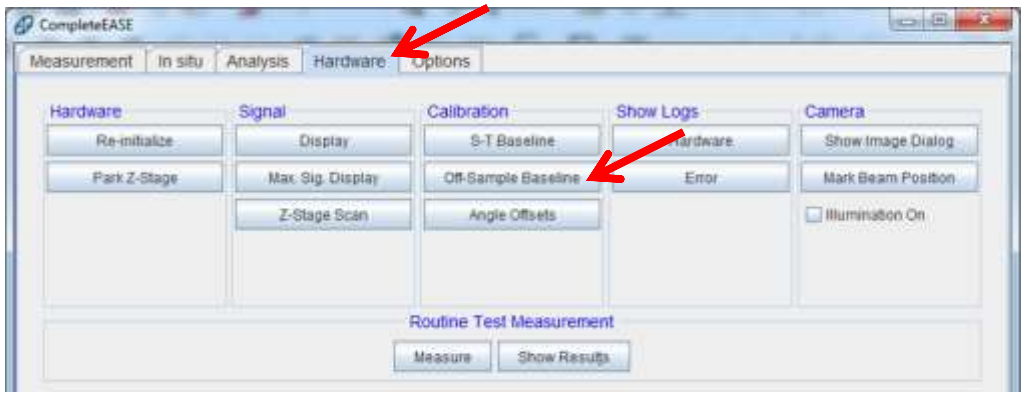

Figure 4-16. Off-Sample Baseline button.

The software will prompt user to mount the 25nm Oxide on Si reference (calibration) sample and move to starting angle. Make sure the wafer is clean, with no dust, fingerprints, or other contamination.

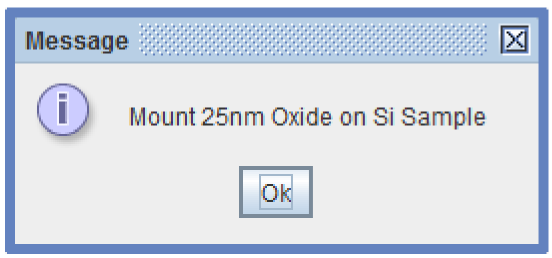

Figure 4-17. Mount 25nm Oxide on Si reference wafer.

The system automatically aligns the Z stage and proceeds with measurement. A model fit is performed to the baseline data and the screen returns the Off-Sample Baseline result as shown inFigure 4-18. From this fit, the true angle of incidence is determined and stored in the calibration file, along with the current Intensity information. The new angle is used for subsequent measurements.

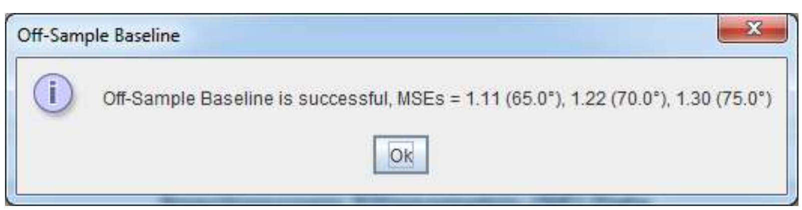

Figure 4-18. After Off-Sample Baseline measurement.

The system intensity vs. wavelength profile is also determined in this procedure, which improves the accuracy of Off-Sample intensity data.

Note: When SE data are collected, Intensity data are also collected. They can be plotted in the graph, but are not

necessarily as accurate as SE data. Thus, Intensity data are not included in the model analysis by default.

4.8. Calibrating the Angle of Incidence

Note: Angle Offset calibration should be performed if the angle offset measured from standard reference wafer (25nm SiO2 – Si) exceeds ±0.04° (see Section 4.5). This will recalculate the current angle offsets for all three Off-Sample angles.

Spectroscopic Ellipsometry is very sensitive to angle of incidence for a measurement. While the nominal angles for the alpha-SE are 65°, 70°, and 75°, the actual machined angles can vary from these values by tenths of a degree. Thus, it is very critical that the actual angles are calibrated to ensure accurate ellipsometry analysis. To calibrate the angle of incidence, measure the reference sample (25nm thermal SiO_2 coating on silicon). While the thickness is not precisely 25nm, it can be fit using a standard model, at the same time that the actual angles of incidence are fit. Thus, the analysis of this sample provides the correct angles, which are then saved to the hardware configuration file. When collecting new data at the nominal angles, the calibrated angle will be recorded in the data file, so that analysis will have this correct information.

For routine measurements, the angle calibration is adequate for ellipsometry measurements at multiple angles. In other words, the reproducibility of the source and detector unit position when moving from one angle to another is typically within 0.02° or better. Thus, the angle does not need to be recalibrated for standard ellipsometry measurements unless the alpha-SE has just been moved or installed, or after mounting the sample chuck. The following procedure is used to calibrate the angle of incidence for all three Off-Sample positions.

From the ***Hardware*** tab, click the 'Angle Offsets' button from the **Calibration:** panel.

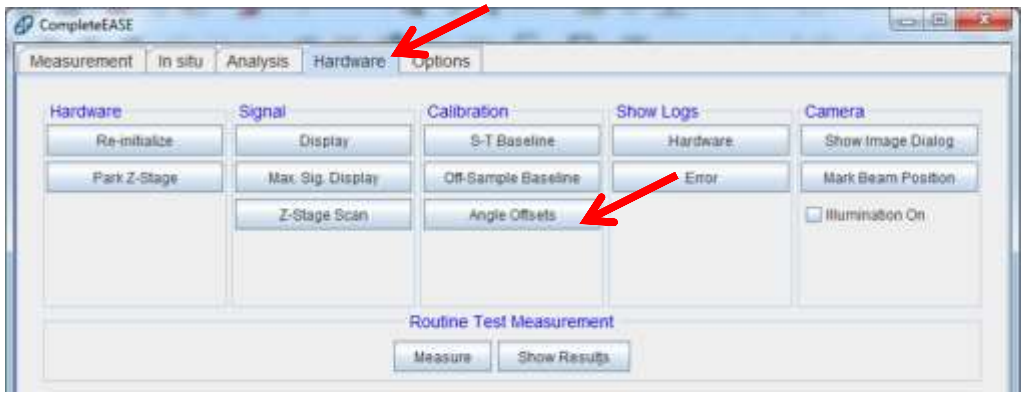

Figure 4-19. Angle Offsets button.

CompleteEASE will prompt you to load the reference wafer (25nm SiO_2 on Si), as shown in Figure 4-20.

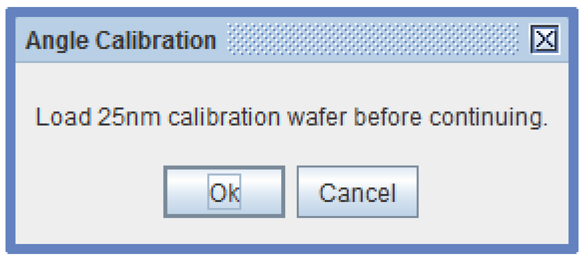

Figure 4-20. Load the reference wafer.

After loading the reference wafer and securing it to the sample stage with vacuum, CompleteEASE will prompt to move to the first angle of incidence, which is 65°. Move both Source and Receiver heads to this position and click ‘Ok’, as shown in Figure 4-21.

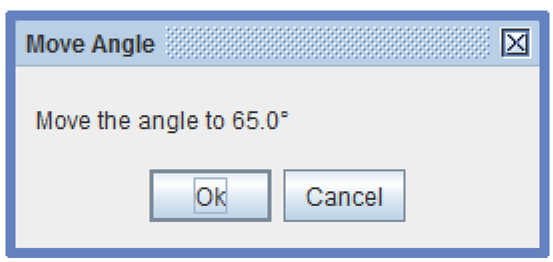

Figure 4-21. Angle offset calibration starts with 65°. Move both source and receiver to this angle of incidence.

The nominal angle of incidence (65°) is entered for the measurement and the experimental data are analyzed using the standard reference sample model description (SiO2 – Interface – Si). The thickness of the SiO2 layer is allowed to vary, along with the angle offset. This angle offset becomes the correction to 65° for future measurements and is saved in a configuration file. The software then prompts to move to 70°, where it again begins with the nominal angle, fits the new measurement, and saves the new angle offset information. After completing all three angles of incidence, the angle offsets should be correctly calibrated and saved for future measurements.

Figure 4-22. After measurement is finished at 65°, the data are analyzed using the nominal angle of incidence to establish the offset specific for this angle. Then, the software will ask to move to the next angle, 70°, where it will continue the procedure.

In Figure 4-23, the fit to the final angle of incidence (75°) is shown from the ***Analysis*** tab. You can see the model used to analyze the data, along with the Angle Offset fit to 0.11 degrees. This means the data collected at 75° nominal angle were actually measured at 75.11 degrees. To improve future accuracy, this corrected angle of incidence will be used when measuring at this hardware position.

To demonstrate, the reference sample was re-measured immediately after the "Angle Correction" procedure. Figure 4-24 shows the three angles of incidence that were now measured and recorded. The data fit using the "Si with Thermal Oxide" model from the Basic file location is shown in Figure 4-25. The resulting angle offset is now in the low third decimal place. In practice, the "Angle Correction" can be considered successful if the angle offset for a follow-up measurement is within ± 0.02°.

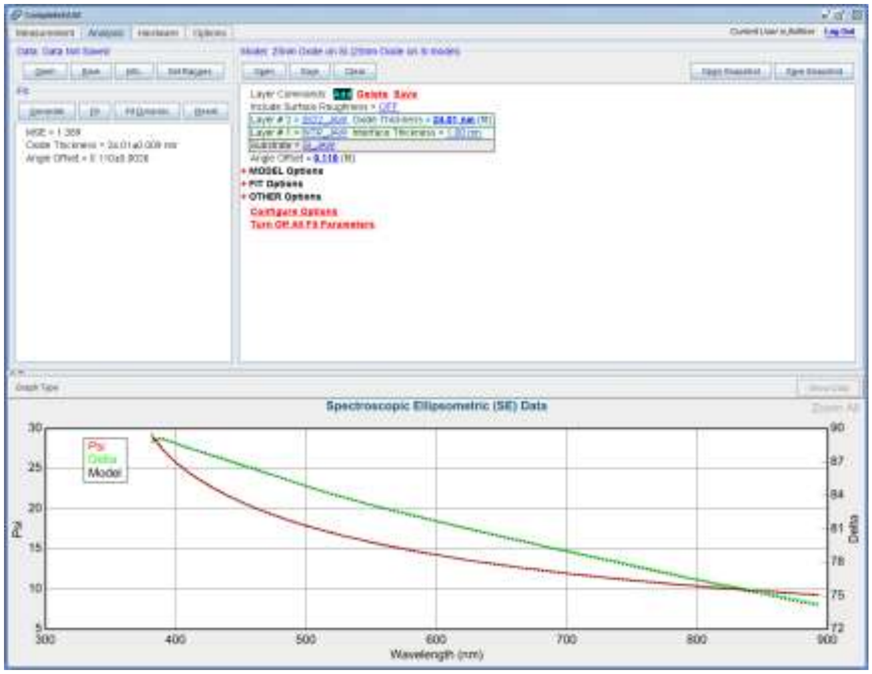

Figure 4-23. The final angle (75°) is shown, along with the model from Analysis tab to demonstrate that the Angle Offset is being fit for this angle alone. This offset from the nominal 75° is recorded in the configuration file to correct for future measurements.

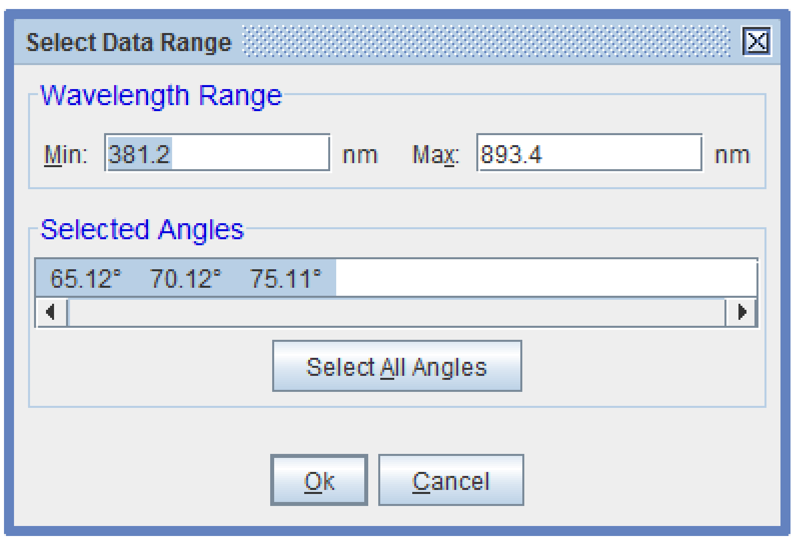

Figure 4-24. Measurements collected after Angle Offsets are calibrated will show the corrected angle of incidence. Note that all three angles shown for this measurement are over a tenth of a degree from their nominal positions.

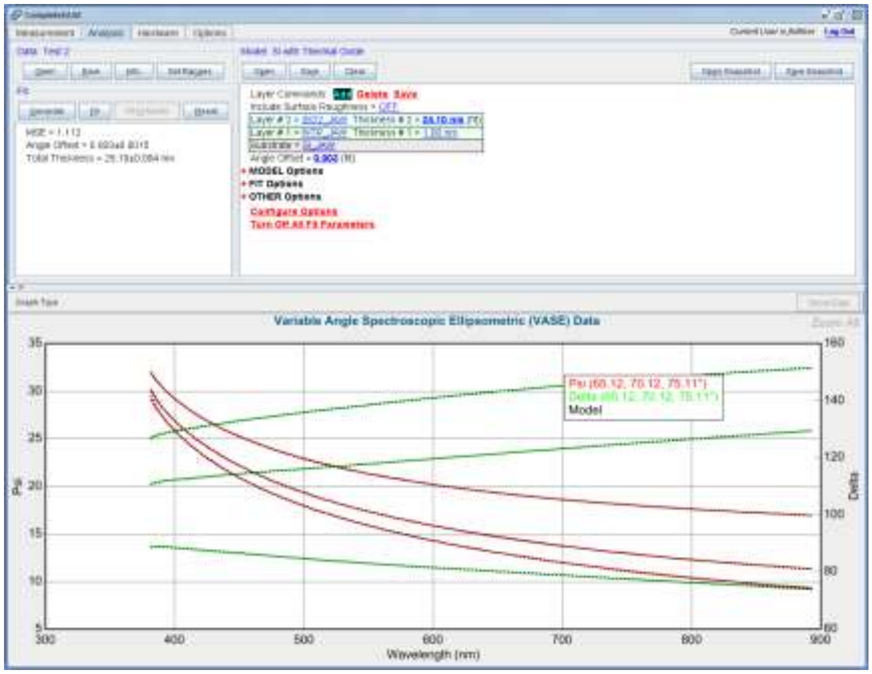

Figure 4-25. A measurement taken on the same reference wafer after Angle Offsets are calibrated show the Angle Offset to be near zero –as the model calculates data for the corrected angles rather than the nominal angles. Note the actual angles are listed in the Graph Legend.

4.9. Powering Down

The alpha-SE system can be left on continuously if desired. However, the Quartz-Tungsten-Halogen (QTH) lamp has a rated lifetime of 1500 hours. To maximize lamp life, turn off the system when not in use for extended periods of time. To power down the system:

- Close software
- Press power button off.

Note: The accuracy and precision are lower for a "cold" system. Thus, it is suggested to turn system & software ON for 30 minutes before taking measurements.

5. Data Collection

The first step to any ellipsometry experiment is collection of data with the ellipsometer. The most common measurement is standard Spectroscopic Ellipsometry (SE) Off-Sample, which is discussed in the Section 5.2. Less common measurements, including Intensity Transmission and Mueller-matrix Ellipsometry are described in Sections 5.3 and 5.4, respectively.

The next step, after collecting experimental measurements, involves the data analysis procedures. These modeling methods are discussed in a separate manual, titled "CompleteEASE Software Manual". A PDF copy of this manual is included with the software, installed in the main C:\CompleteEASE directory and accessible by pressing the "F1" key from within the software.

5.1. Measurement Tab Overview

The ***Measurement*** tab for an alpha-SE will appear as in Figure 5-1.

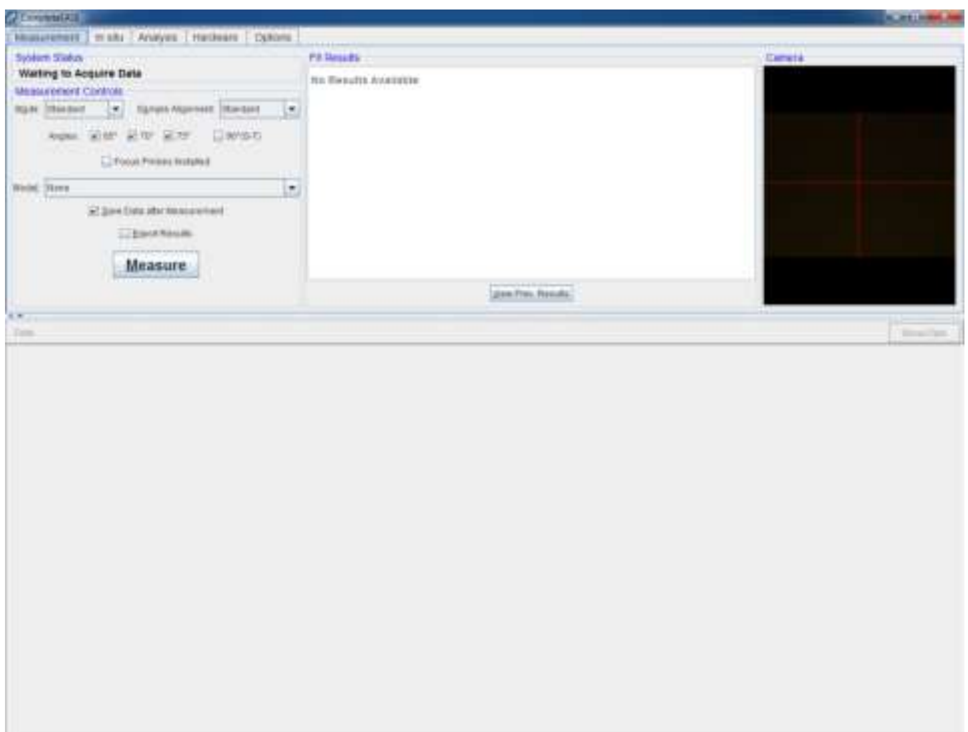

Figure 5-1. Measurement tab for alpha-SE systems. Camera panel only available if optional camera was purchased with the system.

Prior to collecting data, the user selects measurement “Mode”, type of “Sample Alignment”, measurement angles, “Model” to use for data analysis, and whether to “Save Data after Measurement” and/or “Export Results”. Three of these options provide a drop-down menu, as shown in Figure 5-2. Table 5-1 provides details for each of these choices.

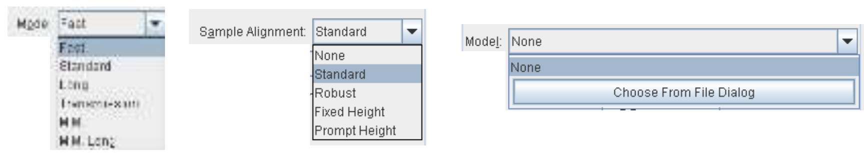

Figure 5-2. Options for measurement Mode, Sample Alignment, and Model.

Table 5-1. Measurement Settings for an alpha-SE.

Category	Option	Description
Mode	Standard	Use for most measurements (~ 10 seconds)
	Fast	Quick measurements (~ 3 seconds)
	Long	Low reflectivity samples or high precision measurements (~30 seconds)
	Transmission	Collects Intensity Transmission measurements
	M.M.	Mueller-matrix measurement – for anisotropic and depolarizing samples
	M.M. Long	High Accuracy Mueller-matrix measurement
Sample Alignment	None	Stage location is below beam for Straight-Through (90°) measurements.
	Standard	Use for standard reflected measurements. This setting does a quick search for the light beam near the previous alignment position.
	Robust	A thorough alignment of the light beam that searches over the full translation range. Use for glass substrates with multiple reflected beams or when substrate thickness varies significantly from previous sample.
	Fixed Height	Moves sample stage to height described in hardware configuration file.
	Prompt Height	Allows user to enter the sample stage height for measurement. It is often helpful to first perform a Z-stage scan from the ***Hardware*** tab.
Model	None	Collects data only, allowing analysis at a later time.
	“Choose from File Dialog”	All default models are saved within various folders including: *Common*, *Advanced*, *Basic*, and *Calibration Wafers*. Only models in the COMMON folder will appear in the drop-down list.

Note: For most measurements, the “Standard” Mode and “Standard” Sample Alignment are sufficient.

If “Save Data after Measurement” is selected, the software will prompt the user for filename and location after the measurement is complete.

If “Export Results” is selected, the software also saves the results to a text file in the same location.

5.2. Off-Sample Measurements

The most common measurements with an alpha-SE involve collecting SE data from reflection Off-Sample. Measure one, two, or all three angles (65°, 70°, and 75°) within a single measurement procedure. The alpha-SE stores calibration information and does not need to be calibrated before typical operation. If you question the accuracy of the SE data, please consult Chapter 4.

Measuring a Sample

Once the measurement choices are selected, you can press the 'Measure' button to begin. As the alpha-SE has automated sample height alignment, the system will align the Z-height to detect reflected light from the sample (using selected Sample Alignment) and then collect measured data (using selected Mode). Finally, if a Model was selected, the data will be analyzed to determine the resulting film properties.

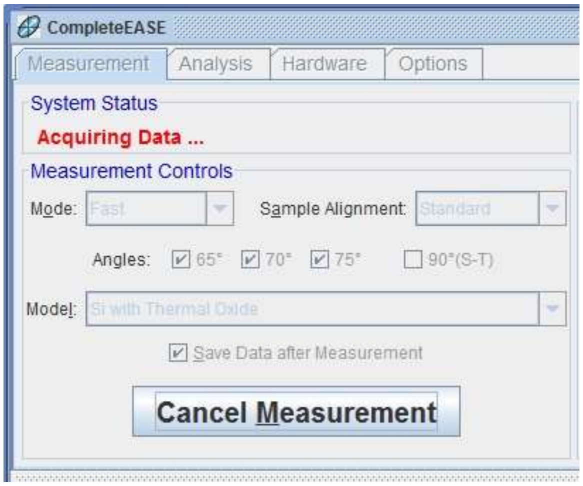

Figure 5-3. Pressing 'Measure' will start the data collection procedure. The ***System Status*** *will be updated to show the current hardware operation.*

If the "Save Data after Measurement" check-box was selected, a dialog box will appear, as shown inFigure 5-4. Find the location you wish to save. You can choose folders from the Recent, Projects, or Library (not recommended) tabs. If the desired folder does not appear, use the "Browse File System" (under Recent tab) or "Add Folder Link" (under Projects tab). Folders linked to the Projects tab will remain visible until removed, regardless of recency.

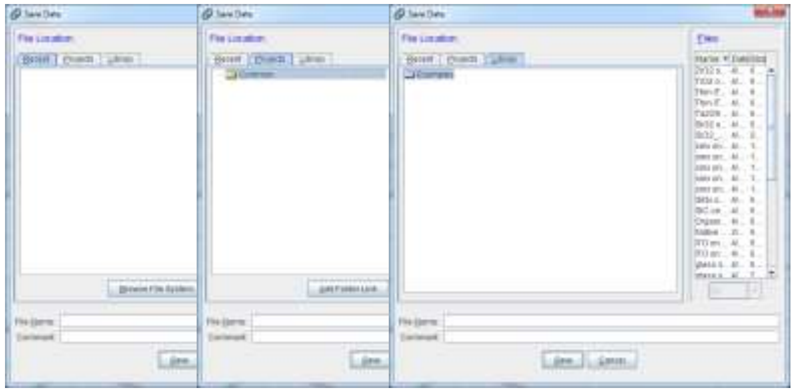

Figure 5-4. Save Data dialog box.

Note: CompleteEASE data files are encrypted & saved with ".SE" or ".iSE" extensions. These files are only accessible by the CompleteEASE program.

If a model was selected prior to measurement, the model analysis will be performed and the fit parameters displayed in the **Fit Results:** panel. The model fit to the measured data is also displayed in the graph: the black dashed "Model" curves should lie essentially on top of the colored Psi and Delta measured data curves if the model fits the data well. If this is not the case, the wrong model was selected to analyze the data. The final result for a thin oxide on silicon is shown in Figure 5-5. The model parameters will be reported in the ***Measurement*>Fit Results:** panel, while a graph of Psi and Delta versus wavelength are displayed at the bottom of CompleteEASE – along with corresponding Fit curves from the model.

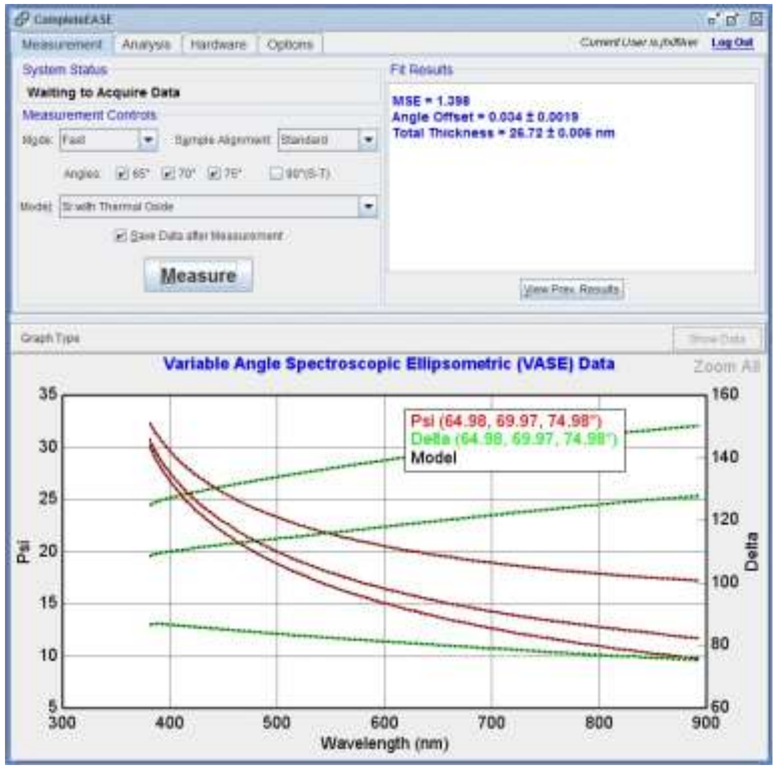

Figure 5-5. Successful measurement of thin oxide film using an alpha-SE system.

5.3. Straight-Through Measurements

Note: Straight-Through measurements are used for measuring i) transmission intensity data on samples with transparent substrates or ii) retardance of birefringent samples.

Straight-Through measurements on the alpha-SE are performed by placing the Source and Receiver Units at 90° (Straight-Through position) and holding the sample in the beam path. Thus, measurements are performed at 0° relative to the sample surface normal, rather than 90° as listed on the source/receiver arms.

Normal incidence Intensity transmission measurements characterize the amount of light that travels through the sample. The remaining light is reflected, absorbed, or scattered. CompleteEASE can model the first two, but does not consider scattering from a sample.

To measure transmission intensity:

1. Move the alpha-SE source and receiver units to the Straight-Through (90°) position.

2. Perform "S-T baseline" if needed as described in Section 4.6. Measurement accuracy is best when an "S-T baseline" has been performed within the last hour.

3. Hold sample in the beam path, with sample surface normal to beam.

Note: Make sure the sample is at correct height with respect to the light beam as the stage will not move for alignment during this measurement.

4. Press ***Measurement***>'Measure' with the selections shown in Figure 5-6. Note 'Mode' = Transmission.

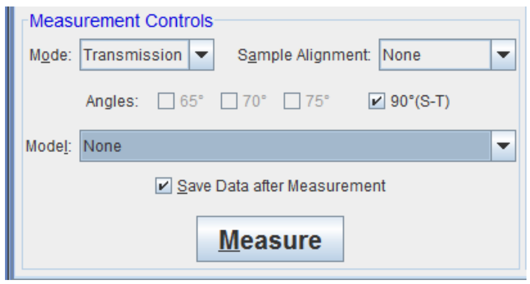

Figure 5-6. Measurement settings for Transmission Intensity measurement. Note 'Mode' = Transmission.

When finished, data will show in the graph panel. An example of transmitted Intensity through a Chromium coated glass substrate is shown in Figure 5-7.

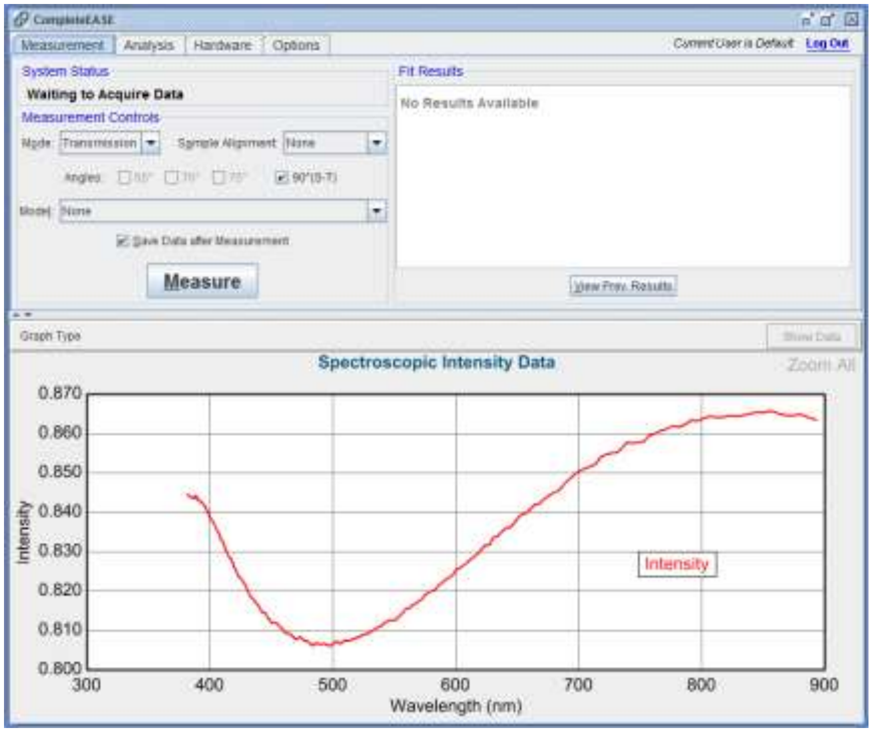

Figure 5-7. Transmission Intensity data measured through a thin chromium coating on glass.

Measuring SE data ('Mode' = Standard, Fast, or Long) at normal incidence is not very common, as isotropic samples do not produce any polarization change in this configuration. Anisotropic samples, however, will produce a polarization change at normal incidence. Such materials are best studied with Mueller-matrix measurements. See Section 5.4 for more details.

5.4. Mueller-matrix Measurements

Mueller-matrix measurements can be acquired in reflection Off-Sample or in transmission via the Straight-Through configuration on an alpha-SE. Because Mueller-matrix measurements probe the anisotropic nature of a material, they can be useful when studying a variety of advanced thin films and substrates. This section discusses the measurement of Mueller-matrix data in more detail.

Note: Measurement accuracy is best when a baseline has been performed within the last hour. This is described in Section 4.6 for Straight-Through measurements and Section 4.7 for Off-Sample reflected measurements.

For a Straight-Through Mueller-matrix measurement (to characterize retardance of a substrate, for example), press ***Measurement***>'Measure' with the following selections.

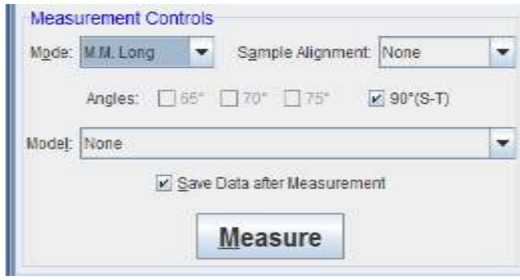

Figure 5-8. Measurement settings for Mueller-matrix measurement in transmission.

For an Off-Sample Mueller-matrix measurement, press ***Measurement***>'Measure' with the following Mode and Sample Alignment selections. Choose any or all three of the Off-Sample angles (65°, 70°, and 75°).

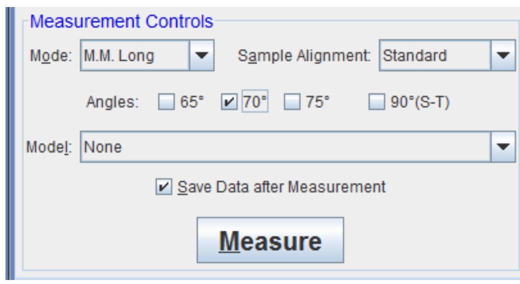

Figure 5-9. Measurement settings for Mueller-matrix measurements in reflection.

After the measurement is complete, several viewing options are available from the graph panel. Click "Data" and select "Show Mueller items" to view Mueller-matrix data options. Mueller-matrix diagonals, off-diagonals, or any of the 12 measured Mueller-matrix elements can be graphed. An example of transmitted Mueller-matrix elements through an anisotropic plastic is shown in Figure 5-11.

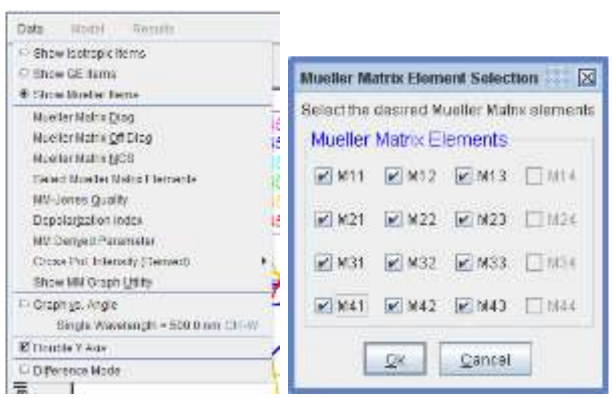

Figure 5-10. Menus for selecting Mueller-matrix Data Graphs.

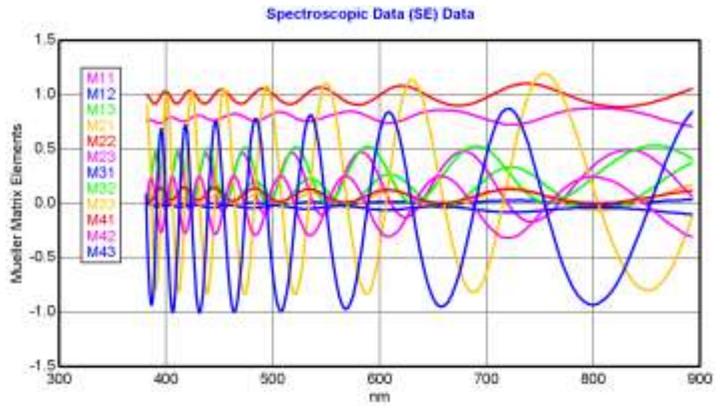

Figure 5-11. Mueller-matrix elements measured through an anisotropic plastic sheet.

6. Hardware Tab

The ***Hardware*** tab for an alpha-SE is shown in Figure 6-1. This tab consists of multiple panels: **Hardware**, **Signal**, **Calibration**, **Show Logs**, **Camera** (optional), and **Routine Test Measurement**.. A brief description of all commands within this tab is provided.

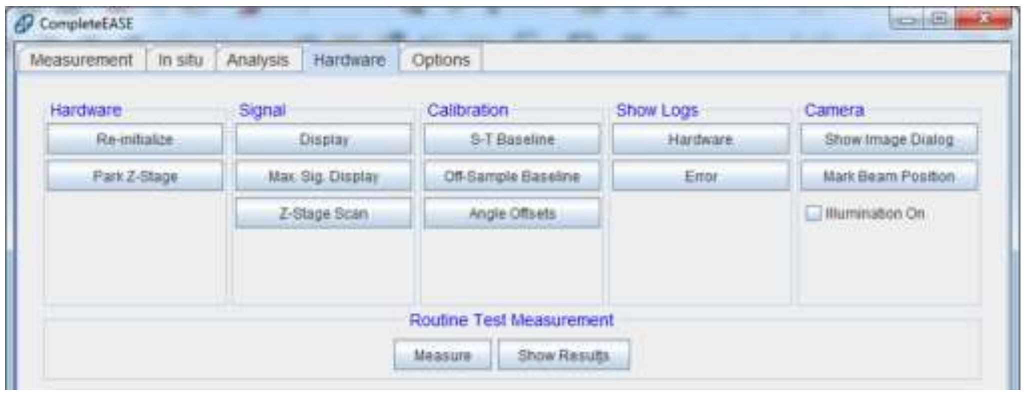

*Figure 6-1. CompleteEASE software with the **Hardware** tab selected.*

6.1. Hardware

Re-initialize

This button re-initializes the ellipsometer hardware, which initiates communication through the USB link, scans the spectrometer, moves the motors to home position, and tests the motors. Details of any errors that occur during hardware initialization can be found in the "Hardware" and/or "Error" logs.

Park Z-Stage

Moves the Z-stage to the "park" position such that the Z-stage shipping lock can be engaged. This should be done before moving/shipping the alpha-SE unit to avoid damage to the Z-stage motor.

6.2. Signal

Display

Displays signal intensity of the light collected by the spectrometer. Average, maximum, UV, and IR intensity values are also reported in the status box, along with the current spectrometer "Dark Count" and electronics "Temperature". An example is shown in Figure 6-2.

Max. Sig. Display

Same as Display, except that the polarizer and compensator optics are adjusted to find the maximum signal intensity. Window will appear as shown in Figure 6-2, after the maximum signal is found.

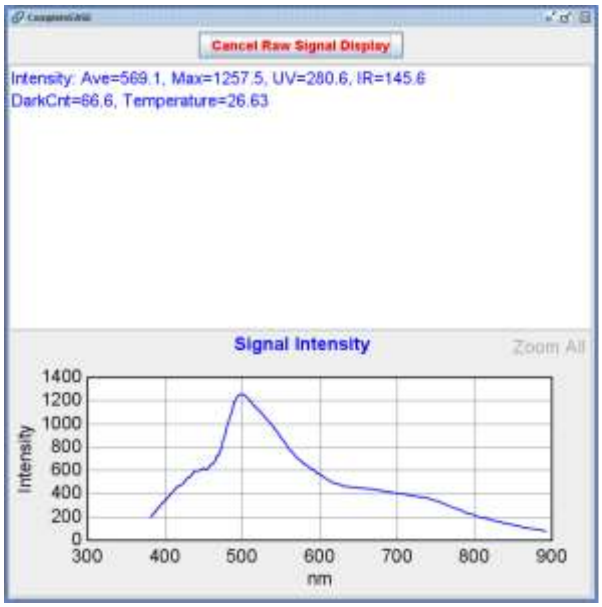

Figure 6-2. CompleteEASE "Signal Display" screen.

Z-Stage Scan

Scan the Z-stage to generate intensity vs. sample height profile. A sample should be mounted and the ellipsometer unit set to the Off-Sample configuration before clicking this button. The resulting signal intensity profile should appear symmetrical, similar to the graph shown in Figure 6-3. The black dashed curve is a polynomial fit to the measured profile, and the reported "MSE=" value quantifies the symmetry of the profile. If the MSE value is greater than 0.02, contact your J.A. Woollam Co. representative.

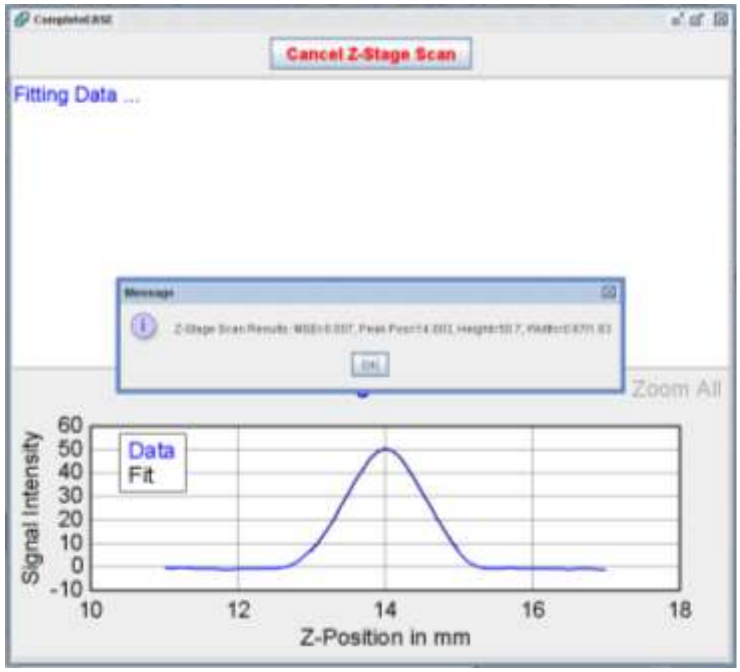

Figure 6-3. Results of a typical Z-Stage scan.

6.3. Calibration

S-T Baseline

The S-T Baseline acquires baseline spectra for the Straight-Through configuration such that accurate transmission intensity and Mueller-matrix data can be acquired. For best data accuracy, always perform an S-T Baseline after moving the ellipsometer optics, or if it has been >1 hour since the previous baseline.

The S-T Baseline will collect data from the measurement beam as the polarizer and compensator positions are rotated. This will provide details to correct for any misalignment of the optical element azimuths relative to each other and more importantly measure the baseline intensities at various optical element combinations.

Note: The S-T Baseline procedure is described in Section 4.6

Off-Sample Baseline

The Off-Sample Baseline acquires data at the current angle of incidence over a range of optical element (polarizer and compensator) positions to improve data accuracy, especially for Intensity and Mueller matrix measurements. This option also calibrates and stores the angle of incidence which is used for subsequent measurements. Because this baseline is angle dependent, the best Intensity and Mueller-matrix data follow an Off-Sample Baseline at the angle of incidence intended for measurement.

Note:	**The Off-Sample Baseline procedure is described in Section 4.7**

Angle Offsets

Spectroscopic Ellipsometry is very sensitive to angle of incidence for a measurement. While the nominal angles for the alpha-SE are 65°, 70°, and 75°, the actual machined angles can vary from these values by tenths of a degree. Thus, it is very critical that the actual angles are calibrated to ensure accurate ellipsometry analysis.

Note:	**The Angle Offsets procedure is described in Section 4.8.**

6.4. Show Logs

Hardware and Error Logs

These buttons display the Hardware and Error logs, which contain information useful for diagnosing and debugging problems with the instrument. An example Hardware Log is shown in Figure 6-4 and an example Error Log is shown in Figure 6-5. Use the 'Copy to Clipboard' button to paste the log information in another program such as Microsoft Word.

If the instrument is not working properly, J.A. Woollam Co. may require information to diagnose the problem. From the ***Options*** tab, click the "Create Debug File" button (see Figure 6-11), and then email the generated file (C:\CompleteEASE\CompleteEASE_Debug.zip) to J.A. Woollam Co.

Note:	**The Debug File packages all hardware and software configuration files, along with the current Error Log into a single ZIP file.**

Figure 6-4. Hardware Log.

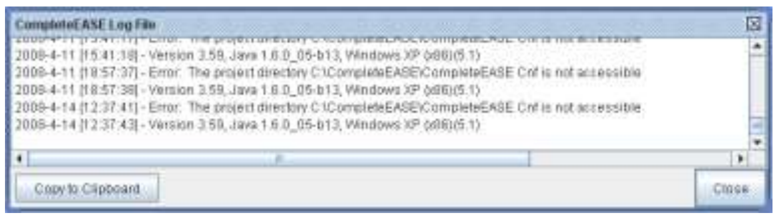

Figure 6-5. Error Log.

Note:	**When CompleteEASE starts, it checks the size of the ErrorLog.txt file. If greater than 5MB, then it is saved to the Archive folder and a new file is created.**

Note:	**Old ErrorLog.txt files are archived in the "\CompleteEASE\cnf\Archive" folder. They are zipped to save space.**

6.5. Camera

The camera is an optional accessory for the alpha-SE that may or may not have been purchased with your system. See Section 7.2 for more details.

Show Image Dialog

Click “Show Image Dialog” to open the camera image.

Note:	**Measurement beam will not be visible on smooth, specular surfaces, but the beam position can still be identified in the software (see following section).**

Figure 6-6. Show Image Dialog.

Mark Beam Position

The measurement beam position can be marked such that users can identify where the beam is located, even for smooth, specular samples.

1. Mount and align the calibration wafer to set stage to correct Z position for measurements.
2. Remove calibration wafer and replace with non-specular sample of similar thickness such as the reverse unpolished side of the calibration wafer or a business card.
3. Click "Mark Beam Position" to open the dialog box shown in Figure 6-7. Follow the instructions in blue: Use the mouse to drag a rectangle over the measurement spot to mark the current beam position and size. This process can be repeated as many times as necessary. When finished, click 'Close', and the software will recall this marked location.

Figure 6-7. Mark Beam Position.

Illumination On

Check this box to illuminate the area under the camera.

Figure 6-8. Illumination On.

6.6. Routine Test Measurement

Routine test measurements can be used to monitor the stability of the tool using the 25nm calibration wafer.

Note: For this feature to be useful, it is important to always use the same sample for the measurements.

Measure

Click this button to start the routine test measurement. The software assumes that the 25nm calibration wafer has been loaded and aligned.

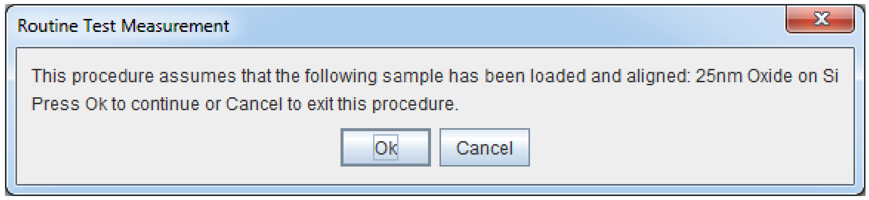

Figure 6-9. Routine test measurement.

Show Results

After completing at least two routine test measurements, the user will be albel to view the results by clicking the 'Show Results' button to graph history of the routine test measurements.

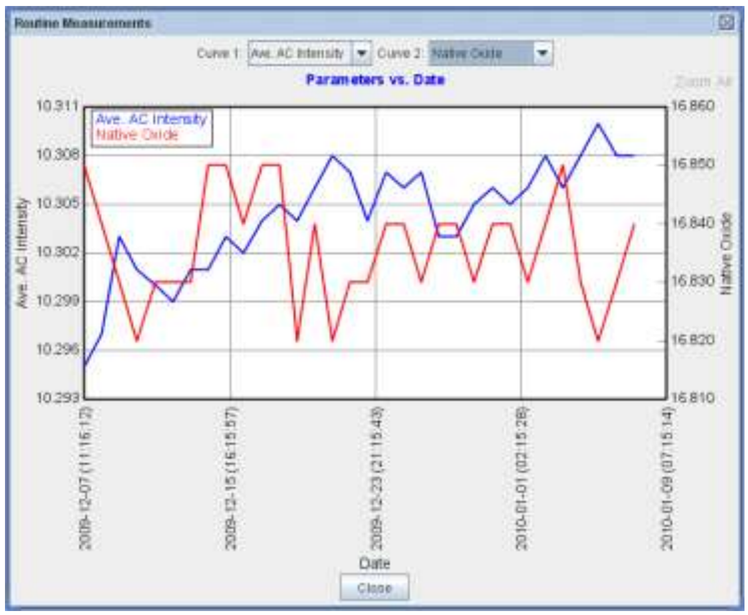

Figure 6-10. Routine test measurement results.

6.7. Configuration Files

The CompleteEASE software determines the hardware configuration based on the "cnf" files that are located in the C:\CompleteEASE\cnf folder. These files may include the following:

hardware.cnf

Describes the hardware configuration and options available with the current system.

Privileges.cnf

User privileges when set up for password-protected user log-in.

Alpha-cal.cnf

Describes the most recent calibration and intensity baseline values for the hardware, based on recent System Calibrations and Baseline measurements.

Motorinfo.cnf

Saves information regarding the calibrated angle of incidence for alpha-SE.

CompleteEASE.cnf and CompleteEASEhard.cnf

Configuration files for user settable software and hardware parameters. These parameters are accessed by choosing 'Edit Configuration' button from the ***Options*** tab (see Figure 6-11).

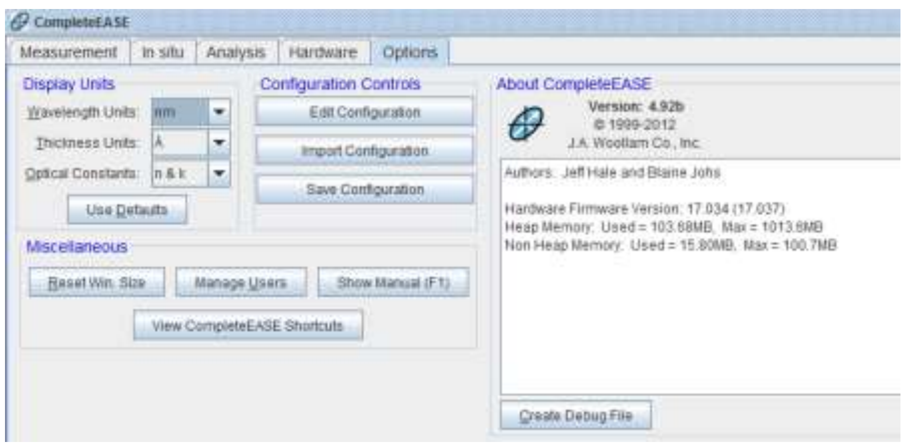

Figure 6-11. The ***Options*** *tab.*

7. Accessories

7.1. Focusing

The focus probes included with this system are designed to decrease the spot size of this alpha-SE from approximately 3 by 9 mm to 0.3 by 1 mm. They can be used to target a specific area of the sample or to reduce the effect of backside reflections. They are designed to work best at an angle of incidence of 70 degrees.

The magnetic bases of the probes attach to magnets in the arms of the alpha-SE, allowing them to be installed and removed easily. During normal use, the probes can be removed and reinstalled without requiring alignment or calibration. However, due to rough handling or other factors, it may occasionally be necessary to re-align the focus probes for optimal performance. A set of hex keys was included with this system for this purpose.

Figure 7-1. alpha-SE with optional focusing accessory installed.

Tips when using focus probes:

1. Handle the probes carefully.
2. When installing a probe, the lip on the base of the probe should be towards the front of the system. Holding the probe by its base, gently place it onto the arm of the system. When positioned correctly, the probe will magnetically lock into place.

3. To remove a probe, simply grip the base and tip it downward to disengage the magnet.
4. Each probe can only be used on one side of the system. The magnets' polarities prevent incorrect installation.
5. It is recommended that all sample alignment be done without the probes installed. This reduces the risk of large, thick samples contacting the probes and causing damage. In addition, it usually results in a more repeatable alignment. The following steps outline this procedure:
    a. Take a measurement of the sample without the focus probes installed using "Sample Alignment: Standard".
    b. Install the focus probes and set "Sample Alignment" to "None". This prevents the z-stage from changing position. Then take the final measurement.
6. Whether or not the focus probes are installed during alignment, selecting "Focus Probes Installed" will result in a more precise alignment, and should always be done when focus probes will be used for the measurement.

How to test focus probe alignment:

1. Place a reference sample on the sample chuck.
2. Take a measurement at 70 degrees with the focus probes NOT installed. This will move the sample to the correct position.
3. Select Max. Sig. Display in the hardware tab and record the average intensity.
4. Install the focus probes and record the new average intensity.

Some intensity will be lost when the focus probes are installed. If the average intensity drops by less than 25%, the focus probes are aligned well. If the intensity drops by more than 25% when the probes are installed, they may have become misaligned.

Before attempting to align focus probes:

1. Ensure that both probes are seated securely onto the alpha-SE. There should be no gap between the probe and the system arm.
2. Wipe off the mating surfaces of the probes and the alpha-SE. Dust or debris can become stuck under the probe, causing it to mount incorrectly.

3. If these steps do not improve performance, the focus probes will need to be re-aligned.

Aligning focus probes:

1. Remove the focus probes and install a calibration wafer.
2. Take a measurement at 70 degrees. This will move the sample to the correct position. Make sure that the “Focus Probes Installed” box is checked.
3. Install the source (left) probe. Adjust the two gold adjustment screws on the base of the probe to center the beam onto the receiver (right) aperture. This will require a 1/16” hex key.

Figure 7-2. Source probe installed.

Figure 7-3. Receiver aperture.

4. Replace the sample with a piece of paper. The beam should appear small and uniform. If not, the lens of the focus probe may be adjusted. To adjust the focus, first loosen the set screw on the lens tube and slide it to minimize the spot size.

Retighten the set screw to lock it in place. Replace the paper with the original calibration wafer.

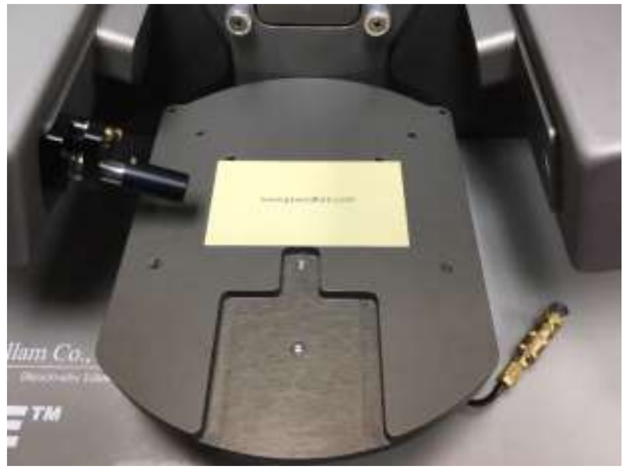

Figure 7-4. Use paper to view focused measurement beam.

Figure 7-5. Focused beam should appear small and uniform.

5. Repeat step 3 if lens position was adjusted.
6. Select “Max. Sig. Display” in the “Hardware” tab. Then install the receiver (right) probe. Adjust the two gold adjustment screws on the probe to maximize the signal. This will require a 1/16” hex key. The lens position can be adjusted at the same time to maximize signal, as in step 4. This is usually not necessary.
7. Once the signal is maximized, the focus probes are aligned and can be used normally.

7.2. Camera

The camera is an optional accessory for the alpha-SE which can be used to view the light beam location or patterned features on samples. The actual light beam will not appear on smooth, specular surfaces, but the location can be identified based on reference location. The field of view is approximately 10 mm x7 mm and camera view is integrated within CompleteEASE.

Figure 7-6. alpha-SE with optional camera accessory.

Installation

Installation of the camera is simple. Align the Camera Mounting Plate to the Z-Stage Post and slide down until fully seated. Connect cable.

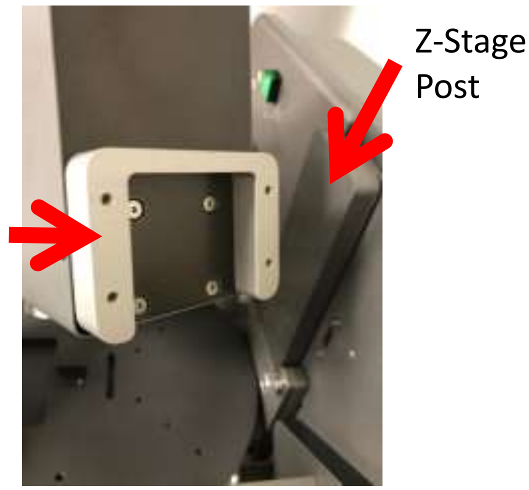

Figure 7-7. Camera Mounting Plate and Z-Stage Post.

Figure 7-8. Align Camera Mounting Plate with Z-Stage Post.

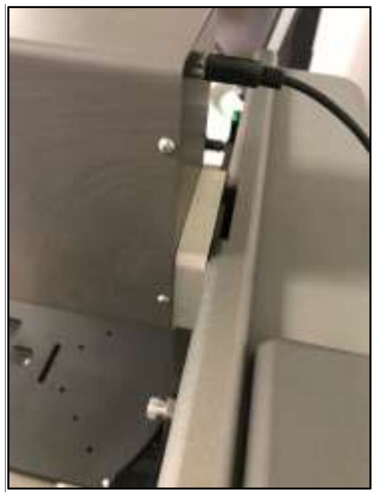

Figure 7-9. Connect cable.

Note: The camera should be fully seated on the mount plate with no gap in the rear.

The camera is attached to the Z-stage assembly such that the camera moves as the Z-stage moves. The adjustable lens can be used to focus the camera and compensate for varying sample thicknesses.

The camera image is viewed from the Measurements tab. Additional camera functions are found in the Hardware tab, as described in Section 6.5.

7.3. Liquid Cell

The alpha-SE liquid cell is used to measure samples under liquid ambient. It has 500 µL capacity and is designed for glass slides and 1” or 2” wafers (other sample sizes may be accommodated, contact J.A. Woollam Co. for details). Instructions for the alpha-SE liquid cell are contained in a supplemental manual.

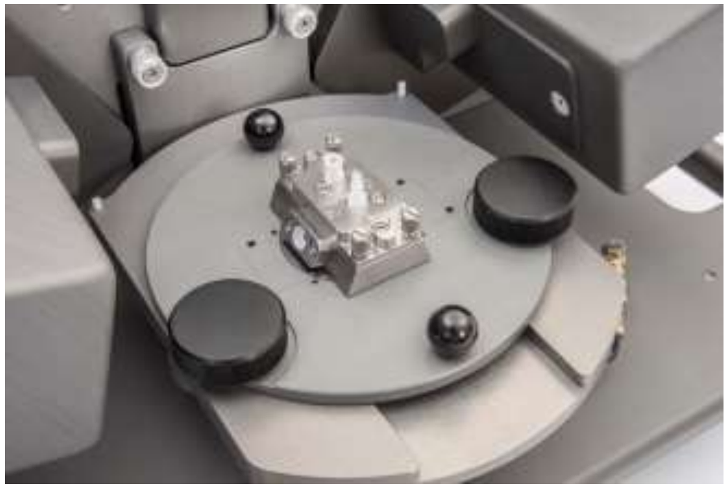

Figure 7-10. alpha-SE with optional liquid cell accessory.

7.4. Transmission Mount

The transmission mount is used to hold samples vertically for normal incidence transmission measurements. The transmission mount should be installed similarly to the standard stage as described in Chapter 3, section "Attaching the Sample Chuck".

Figure 7-11. alpha-SE with optional transmission mount.

7.5. Manual Translation

12mm XY manual translation uses graduated micrometers with 0.001" resolution for fine sample adjustment. The manual translation stage should be installed similarly to the standard stage as described in Chapter 3, section "Attaching the Sample Chuck".

Note: The vacuum tube for the stage needs to be routed down under the base plate before plugging into the main plate to avoid interfering with the stage.

Figure 7-12. alpha-SE with optional translator installed.

7.6. QCM Adaptor

The QCM Adaptor is a tilt stage designed to hold Q-Sense QCM-D Quartz Crystal Microbalance. J.A. Woollam provides the adaptor plate only. QCM-D and Cell provided by Q-Sense. The QCM Adaptor should be installed similarly to the standard stage as described in Chapter 3, section "Attaching the Sample Chuck".

Figure 7-13. alpha-SE with optional QCM adaptor plate and QCM-D from Q-Sense.

8. Service and Troubleshooting

8.1. Lamp Change Procedure

1. Close CompleteEASE and turn off the alpha-SE power. Allow lamp to cool
2. Open the lamp access door, as shown in Figure 8-1.
3. Disconnect the white electrical connector, and pull the lamp out of the holder. Use caution when removing lamp; lamp may be hot.

Warning: Lamp may be hot.

4. Insert the new lamp into the holder, taking care not to touch the glass bulb with bare hands. Seat the lamp firmly into the holder.
5. Connect the white electrical connector.
6. Close the lamp access door. Turn on the alpha-SE power and start the CompleteEASE software. Allow lamp to warm up.
7. Check the Straight-Through beam alignment and intensity, as described in Sections 4.2 and 4.3. The bulb may need to be rotated to optimize signal.

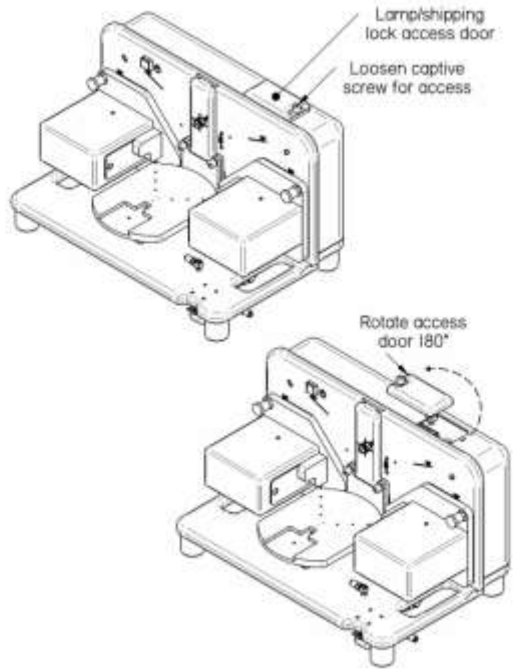

Figure 8-1. Opening the lamp access door to change the lamp.

8.2. Upgrading CompleteEASE

If your software is newer than version 4.47, simply run the setup program and follow the on-screen prompts, as described in Section 2.4.

If your software is older than version 4.47, contact J.A. Woollam Co. for instructions.

Note: Do not copy configuration files from the original installation CD if your system is already operating with CompleteEASE, as this will overwrite your latest calibration and return it to factory settings. This may require recalibration of your instrument.

8.3. Troubleshooting Guide

Consult Table 8-1 for advice on troubleshooting alpha-SE problems or resolving error messages. If this table does not contain a solution for the problem, please contact your J.A. Woollam Co. representative.

Table 8-1. Potential alpha-SE problems and error messages.

PROBLEM	SOLUTION
Error: "Calibration data does not match current system"	Copy the **MOTORINFO.cnf**, **alpha-Cal.cnf**, and **Hardware.cnf** files from the cnf folder of the CompleteEASE directory on the original installation CD into the C:\CompleteEASE\cnf directory. Exit and restart the CompleteEASE program.
Error: "Could not find alpha-SE S/N xxxxx"	Check USB cable connections. Verify that the alpha-SE device driver is properly installed. Make sure that the correct configuration files are installed (see above problem).
Error: "No alpha-SE systems attached to the computer's USB port"	Exit the CompleteEASE software; turn OFF alpha-SE power button. Disconnect both power supply cable and USB cable. Reboot/restart the computer. Connect the USB cable to a *different* USB port on the computer. Connect the power cable back into instrument and turn the alpha-SE power button ON. Verify driver installation as described in Section 3.5; Figure 3-14, Figure 3-15, and Figure 3-16. Start the CompleteEASE software.
Error: "Please turn the alpha-SE power ON"	Press the green power switch on the alpha-SE unit. If the switch light does not come on, check the power supply connections.
Error: "The light source is not operating correctly; please check connections or replace the lamp"	Do as the error message suggests; see Section 8.1 for instructions to install new lamp.
Motor moving, homing, or limit switch errors	Verify that the Z-stage shipping lock is released as described on pg 3-5; Figure 3-5 and Figure 3-6. Exit the CompleteEASE software and turn OFF the alpha-SE power button. Disconnect the USB cable from the instrument. Wait 30 seconds. Reconnect the USB cable back to the instrument and turn the alpha-SE power button ON. Restart the CopmleteEASE software; if an error message occurs again, contact your J.A. Woollam Co. representative.
Beam is not centered on the receiver unit aperture or signal intensity is out of spec	Check that the Angle of Incidence (AOI) indexers are fully seated in their slots as described in Section 4.1. Verify signal intensity as described in Section 4.3. If the problem persists, contact your J.A. Woollam Co. representative.

Creating a Debug file

To reduce support time, please create and email a debug file before contacting your representative.

From the ***Options*** tab, click the "Create Debug File" button (see Figure 6-11). This will generate the following file: *C:\CompleteEASE\CompleteEASE_Debug.zip.* Email this file to your J.A. Woollam Co. representative to aid in debugging problems with your alpha-SE system.

Note:	**The Debug File packages all hardware and software configuration files, along with the current Error Log into a single ZIP file.**

9. Appendices

9.1. Spectroscopic Ellipsometry

The alpha-SE is designed to acquire accurate spectroscopic ellipsometry measurements. This optical measurement technique, commonly used to determine thin film thickness and optical constants, is discussed briefly in this section. In addition, the alpha-SE can collect Intensity measurements and Mueller-matrix measurements, which are also discussed briefly.

Ellipsometry is a non-destructive optical technique in which the sample to be characterized is illuminated with a beam of polarized light, as shown in Figure 9-1. Ellipsometry measures the change in polarization state of the measurement beam induced by reflection from the sample. The change in polarization state is commonly characterized by the ellipsometric Psi (Ψ) and Delta (Δ) parameters defined in Eqn. (1-1):

$$\tan(\Psi)\cdot e^{i\Delta} = \rho = \frac{r_p}{r_s} \qquad (1\text{-}1)$$

In this equation, rho (ρ) is defined as the ratio of the reflectivity for p-polarized light (r_p) divided by the reflectivity for s-polarized light (r_s). The amplitude ratio, tan(Ψ) and the relative phase difference, Δ, are measured by comparing the effects of light in p- and s- directions respectively. In this manner, the measurement is self-referencing and can be highly accurate.

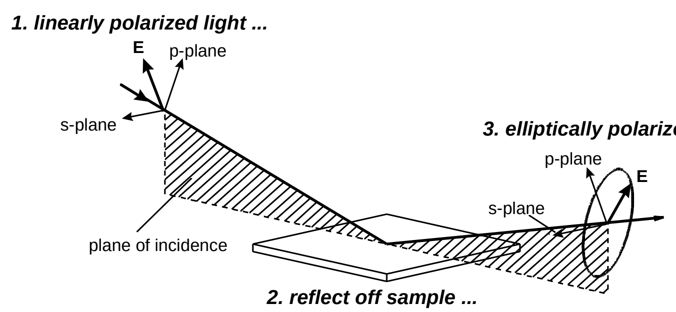

Figure 9-1. Interaction of polarized light with a sample.

This description of the polarization state measured from light reflecting off a surface is based on the 2x2 Jones matrix description of a sample, where the off-diagonal elements are zero (which holds for isotropic samples).

$$\begin{pmatrix} E_p \\ E_s \end{pmatrix}_{out} = \begin{bmatrix} r_p & 0 \\ 0 & r_s \end{bmatrix} \begin{pmatrix} E_p \\ E_s \end{pmatrix}_{in} \qquad (1\text{-}2)$$

Thus, a standard ellipsometry measurement does not involve any cross-coupling between p- and s- polarization directions.

Ellipsometry Advantages

Ellipsometry offers three main advantages over simple intensity-based reflection or transmission measurements:

1. **Precision:** As the change in polarization state is defined by a ratio, ellipsometry is not sensitive to changes in the absolute intensity of the measurement beam (i.e., the sample itself is the 'reference' for the measurement). Thus, it can remain accurate without knowing "absolute" intensity values.
2. **Sensitivity:** The phase information contained in the ellipsometric Δ parameter provides enhanced sensitivity to ultra-thin films, even down to sub-nm thickness.
3. **Information:** Ellipsometry measures 2 values (Psi and Delta) at each wavelength, doubling the information content compared to an intensity reflection or transmission measurement.

The high accuracy, precision, and sensitivity of the ellipsometric measurement make it highly suited for demanding thin film metrology applications.

Intensity Measurements

In addition to ellipsometry measurements, which measure the polarization change, the alpha-SE can also collect intensity-based (spectrophotometric) measurements. This includes both reflectance and transmittance (R&T) data. R&T are generally less accurate than ellipsometry measurements, as they require knowledge of the incident intensity and the intensity measured after reflection or transmission. In contrast, SE measurements are self-referencing, where one polarization direction is compared to another but within the same reflected or transmitted beam. Thus, SE measurements will not suffer degraded accuracy from intensity fluctuations, scattered light, or partial collection of the measurement beam.

Intensity measurements relate the amount of light reflecting or transmitting from a surface to the incident light intensity. The alpha-SE software represents this as a ratio from 0 (no light) to 1 (all of the light). The Intensity measurements rely on a Baseline measurement of the total light without a sample (or reflected from reference sample) for the preliminary intensity of "incident light". If the intensity fluctuates, or if a different portion of measurement beam is collected during sample measurement compared to the baseline measurement, the intensity values will be inaccurate. Thus, Intensity measurements are considered secondary to SE measurements.

Mueller-matrix Measurements

Standard ellipsometry measurements assume 1) the measurement beam remains 100% polarized and 2) the off-diagonal elements are zero (no cross-coupling between p- and s- polarizations). These assumptions are appropriate for a large variety of materials characterization problems. Thus, SE measurements are the standard measurement used by alpha-SE. However, the alpha-SE is also able to collect the more general Mueller-matrix measurement when handling samples that may be anisotropic or depolarizing or both.

Mueller-matrix ellipsometry replaces the standard 2x2 Jones matrix description of the sample with a more general 4x4 matrix. The Mueller-matrix maps the Stokes parameters for incoming to outgoing light, using the following notation.

$$\begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix}_{OUT} = \begin{bmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \\ M_{41} & M_{42} & M_{43} & M_{44} \end{bmatrix} \cdot \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix}_{IN} \qquad (1\text{-}3)$$

To determine all 16 elements of the Mueller-matrix would require a compensator before and after the sample. Fortunately, there is symmetry within the Mueller-matrix elements that allows a complete characterization of difficult samples without measurement of all 16 elements.

For example, the standard Mueller-matrix for an isotropic sample is shown in the following equation, where N, C, and S are related to Psi and Delta.

$$\begin{bmatrix} 1 & -N & 0 & 0 \\ -N & 1 & 0 & 0 \\ 0 & 0 & C & S \\ 0 & 0 & -S & C \end{bmatrix} = \begin{bmatrix} 1 & m_{12} & 0 & 0 \\ m_{21} & 1 & 0 & 0 \\ 0 & 0 & m_{33} & m_{34} \\ 0 & 0 & m_{43} & m_{44} \end{bmatrix} \qquad (1\text{-}4)$$

The last row/column of the Mueller-matrix requires probing and detection of the handedness of the polarization. Because the alpha-SE has a compensator after the sample, it can collect the first 3 columns of the Mueller-matrix, but no information from the 4th column, as shown below.

$$M_{alpha\text{-}SE} = \begin{bmatrix} \bullet & \bullet & \bullet & \times \\ \bullet & \bullet & \bullet & \times \\ \bullet & \bullet & \bullet & \times \\ \bullet & \bullet & \bullet & \times \end{bmatrix} \qquad (1\text{-}5)$$

Determining Sample Properties (Data Analysis)

Data analysis is a very important part of spectroscopic ellipsometry (SE): without data analysis, SE only measures the ellipsometry parameters Psi and Delta versus wavelength.

Data analysis is used to determine optical constants, layer thickness, and other material properties. The basic steps of this approach include:

1. SE data is measured on the sample.

2. A model describes the measured sample using layers for each material. Thickness and optical constants (n and k) describe each layer over the measured wavelength range, with estimates for any unknown properties.

3. The unknown properties of the sample are defined as model "fit" parameters. The software automatically adjusts these parameters to improve the agreement between the measured and model-generated data.

4. The results of the fit are evaluated. If results are not acceptable, the process can be repeated with a new model or different "fit" parameters until the best description is found.

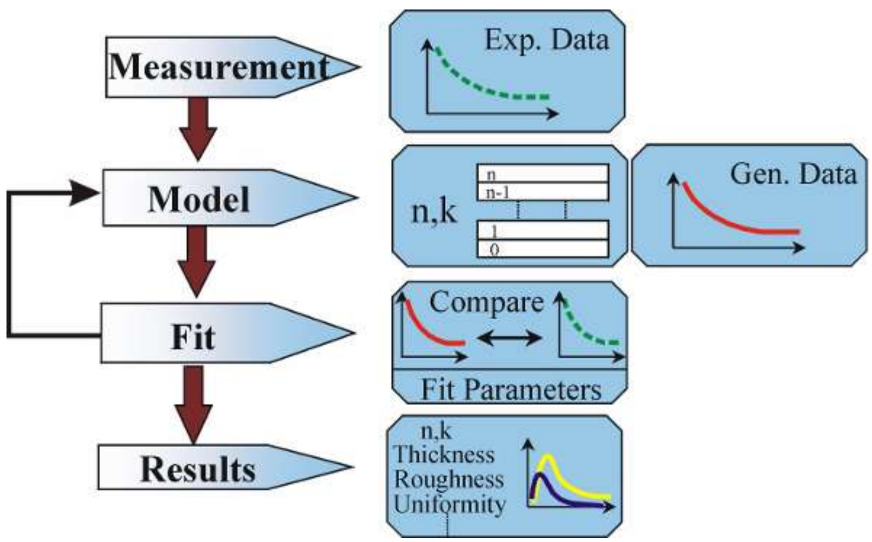

Figure 9-2. Flowchart for SE data analysis.

The CompleteEASE software provides a graphical user interface for building models and displaying measured data and model fits. The fundamentals and theory of data analysis is explained in more detail in the "CompleteEASE Software Manual". To access this manual, press the F1 key from within CompleteEASE or find the PDF from the C:\CompleteEASE folder after installation on your computer.

Film Thickness

Spectroscopic Ellipsometry is commonly used to measure both the film thickness and refractive index for transparent films. As the film thickness increases, there is an increasing separation between the light reflected from the surface and the light that travels through the film, as shown in Figure 9-3. This causes a delay that is related to both the physical thickness and the index of refraction (which describes the phase velocity in a material). Thus, spectroscopic ellipsometry measurements contain the information to accurately measure both thickness and index.

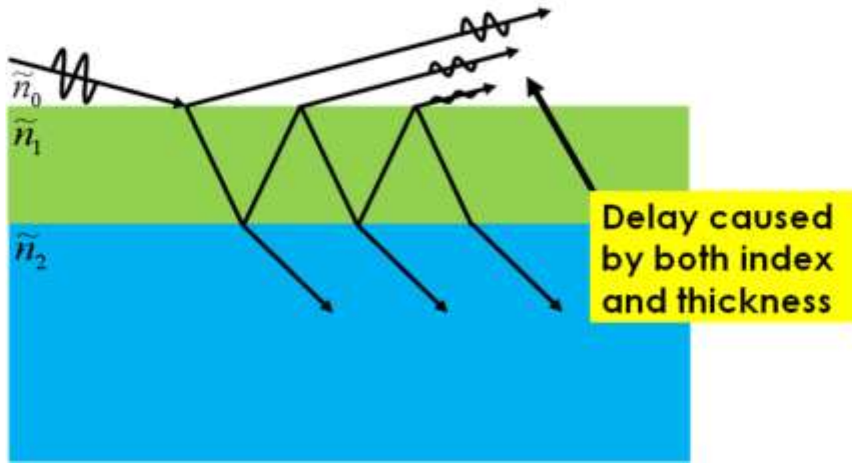

Figure 9-3. Reflection of SE measurement beam from surface of thin film interferes with light that travels through the film – providing information about the film thickness and optical properties.

The measured spectroscopic ellipsometry data provide information about the thickness based on the position and number of interference oscillations. Figure 9-4 shows the Psi curve for a series of thin SiO_2 films of different film thickness. As the thickness (T) increases, the interference oscillations shift toward longer wavelengths. In addition, the shape of the interference oscillations is dependent on the film index of refraction.

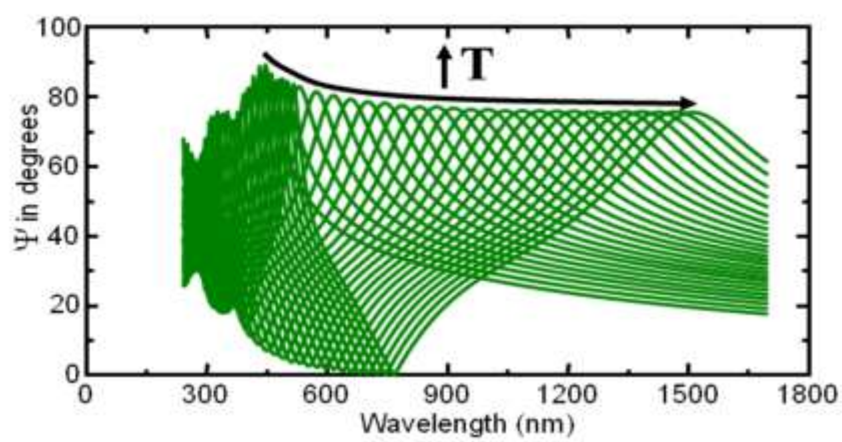

Figure 9-4. Interference oscillations in SE data will shift as thickness increases.

Ultra-Thin Films (<10nm)

Spectroscopic Ellipsometry is very sensitive to the presence of surface layers on the order of just a fraction of a nanometer. The primary sensitivity comes from changes in phase (Delta), as is shown in Figure 9-5 for a series of thin oxides on silicon substrate. However, the interaction of light and these ultra-thin layers does not provide adequate sensitivity to simultaneously determine both thickness and refractive index. For this case, it is safest to assume an approximate refractive index (often measured from a thicker film) and then only determine the film thickness.

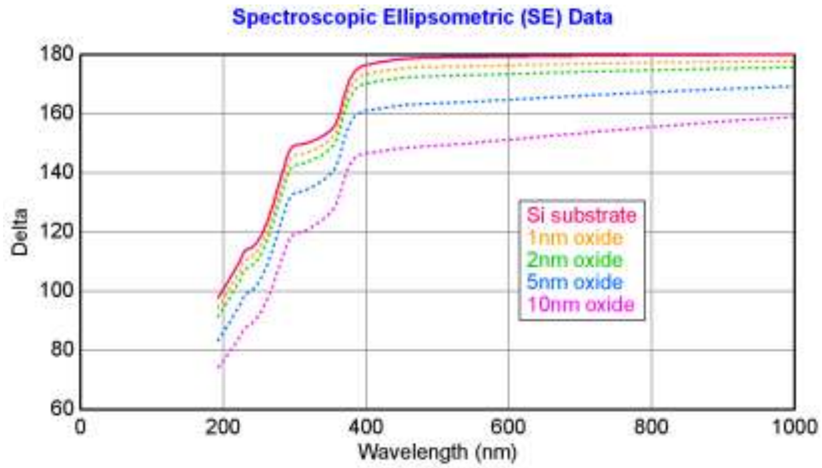

Figure 9-5. Delta (phase) is very sensitive to thickness changes at the sub-nm level for ultrathin films.

Optical Constants

Optical constants of isotropic materials can be described using two parameters. These values characterize how a material responds to excitation by light of a given wavelength. One representation is the complex index of refraction, $\tilde{n}$, where the real part *n* is the index and the imaginary part, *k,* is the extinction coefficient.

$$\tilde{n} = \mathrm{n} - i\mathrm{k} \tag{1-6}$$

The index, n, describes phase velocity of light in a material compared to propagation in vacuum. The absorption of light is governed by the extinction coefficient, k. These quantities also determine the amount of light reflected and transmitted at an interface between two materials. A large index difference will reflect more light at the interface.

Alternately, the optical constants can be described using the complex dielectric constant, given as:

$$\tilde{\varepsilon} = \varepsilon_1 - i\varepsilon_2 = \tilde{n}^2 \quad (1\text{-}7)$$

Additional References

For more information on ellipsometry theory, see the following references:

1. H. Tompkins and E. Irene, eds. Handbook of Ellipsometry, William Andrew Publishing, New York, 2005.
2. H. Fujiwara, Spectroscopic Ellipsometry Principles and Applications John Wiley & Sons, West Sussex, England 2007.
3. J.N. Hilfiker and J.A. Woollam, *Ellipsometry*, in Encyclopedia of Modern Optics, edited by Robert D. Guenther, Duncan G. Steel and Leopold Bayvel, Elsevier, Oxford, 2004.
4. J.A. Woollam et al., "Overview of Variable Angle Spectroscopic Ellipsometry (VASE), Part I: Basic Theory and Typical Applications", *SPIE Proc.* **CR72** (1999) 3.
5. B. Johs et al., "Overview of Variable Angle Spectroscopic Ellipsometry (VASE), Part II: Advanced Applications", *SPIE Proc.* **CR72** (1999) 29.
6. H.G. Tompkins and W.A. McGahan, Spectroscopic Ellipsometry and Reflectometry, John Wiley & Sons, 1999.
7. R.M.A. Azzam, and N.M. Bashara, Ellipsometry and Polarized Light, North Holland Press, Amsterdam 1977, Second edition 1987.

9.2. Conventions Used in this Manual

The CompleteEASE software is written in JAVA with a Tab-interface to conveniently organize software features. Figure 9-6 shows the front screen of CompleteEASE.

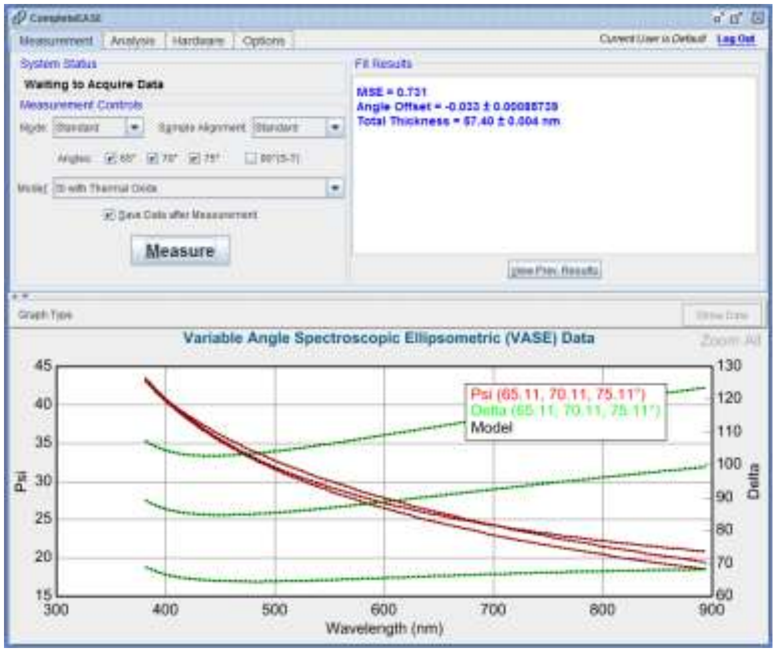

Figure 9-6. CompleteEASE Software

To help the user navigate this manual, the following conventions will be followed to describe features in the CompleteEASE software.

Tabs

When the software is used with an alpha-SE system, there are typically four Tabs, as shown across the top of the software screen: ***Measurement, Analysis, Hardware,*** and ***Options***. Tabs will be written in bold and italics.

Screen Panels

Within each Tab, there are screen areas referred to as panels. From the ***Measurement*** tab shown in Figure 9-6, the panels include **System Status**, **Measurement Controls**, and **Fit Results**. Throughout this manual, panels will be written in bold, blue text.

Buttons

Figure 9-7 shows the ***Hardware*** tab. Within panels are buttons. Buttons will be designated with single 'quote' marks, such as 'Align Sample' and 'Display Signal'.

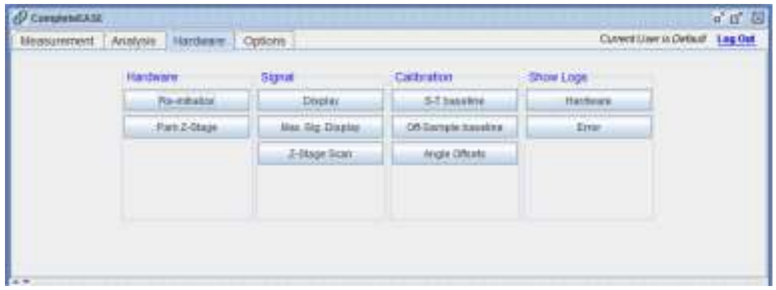

Figure 9-7. ***Hardware*** *Tab showing Screen Panels and Buttons.*

9.3. Short-cut Guide

There are two types of short-cuts within CompleteEASE. First, like other software, if a letter is underlined, the short-cut for that command is to hold ALT button and press that letter. Additional short-cuts that are more global incorporate the CTRL, SHIFT, and ALT buttons. These additional short-cuts are listed in Table 9-1.

Table 9-1. Short-cut reference.

Short-Cut	Function
CTRL+M	Go to Measurement Tab
CTRL+A	Go to ***Analysis*** Tab
CTRL+I	Go to ***In situ*** Tab
CTRL+H	Go to ***Hardware*** Tab
CTRL+O	Go to ***Options*** Tab
CTRL+P	Graph the Psi data curves
CTRL+D	Graph the Delta data curves
CTRL+N	Graph the “N” data curves (N,C,S format)
CTRL+C	Graph the “C” data curves (N,C,S format)
CTRL+S	Graph the “S” data curves (N,C,S format)
CTRL+1	Graph the <e1> data curves
CTRL+2	Graph the <e2> data curves

CTRL+I	Graph the Intensity data
CTRL+Z	Graph the Depolarization data
CTRL+L	Add to Fit Log
CTRL+ALT+L	View Fit Log
CTRL+R	Copy Analysis Report to Clipboard
CTRL+Y	Toggle between single and double-Y axis.
CTRL+ALT+O	Toggle Default Optical Constant units between “e1 & e2” and “n & k”
CTRL+ALT+W	Toggle Default wavelength units between “nm” and “eV”
CTRL+ALT+S	Show graph statistics
CTRL+ALT+SHIFT+I	Add the ***In Situ*** Tab
SHIFT+Mouse roller	When positioned over model parameter, it will increase or decrease this parameter.
CTRL+SHIFT+Mouse roller	Same as SHIFT-Mouse roller, but with smaller parameter increments.

9.4. Contacting J.A. Woollam Co.

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