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| <b>Document:</b> Woollam                             | <b>Revision:</b> A | <b>Release Date:</b> 9/7/22 |
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## 1. Equipment Purpose

- 1.1. The Woollam tool uses ellipsometry to characterize thin films. Ellipsometry detects the phase change in polarized light as it reflects from, or is transmitted through samples. The Woollam Ellipsometer does not directly measure thickness and optical constants. Rather, it uses collected data to solve models which estimate the thickness and optical parameters of interest.

## 2. Equipment Specifications

- 2.1. Location: West side of SNF cleanroom, near Fiji 1 and 2
- 2.2. Maximum sample diameter: 8 in
- 2.3. Spot size: 2mm normal, 1.1-11.5mm depending on angle of incidence
- 2.4. Minimum sample size: Must be larger than spot size for reliable result
- 2.5. Max sample height: 20mm
- 2.6. Wavelengths of light: 210-1680 nm
- 2.7. Lamp type: Xe arc lamp
- 2.8. Calibration frequency: During lamp replacement. See staff for last calibration date

## 3. Cleanliness Standard

- 3.1. The Woollam is compatible with all three levels of cleanliness. Clean, Semi-Clean, and gold contaminated

## 4. Processing Capabilities

- 4.1. Measures reflected or transmitted polarized light.
- 4.2. Fits models of optical constants against measured data to determine the thickness and optical constants of a film.
- 4.3. Complex models of optical data are available. Contact staff for a copy of the manual.
- 4.4. The Woollam DOES NOT directly measure thickness or optical constants!

## 5. Becoming a User

- 5.1. Read and understand all material on SNF website concerning the Woollam M2000 Spectroscopic Ellipsometer.
- 5.2. Shadow a lab user using the Woollam. If you do not know a current Woollam user, check the badger reservation schedule and see if a current user is willing to let you shadow.
- 5.3. Contact staff for qualification. Qualification consists of a written quiz and an in lab practical.

## 6. Safety

- 6.1. Do not place hands near pinch points.
- 6.2. Do not expose eyes to the beam of light.

## 7. Required equipment

- 7.1. Cleanroom garments as are compatible with SNF Cleanroom.

## 8. Operating Procedure

### 8.1. Starting Procedure

- 8.1.1. “Enable” the Woollam in Badger.
- 8.1.2. Turn on the lamp by pressing the “Lamp Ignition” button. **Figure 1.**



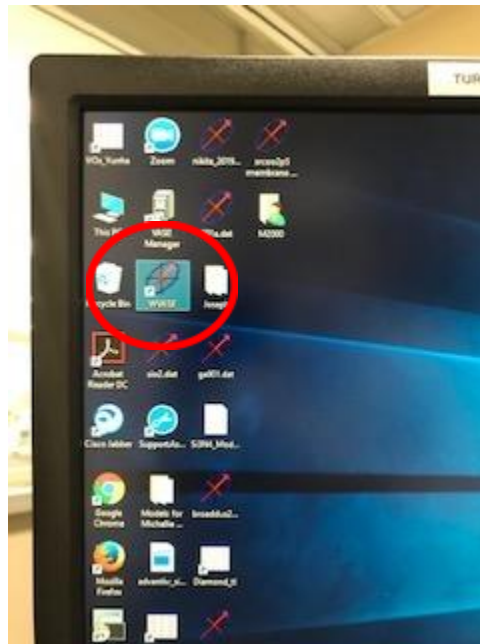
***Figure 1: Lamp Ignition Button circled in red***

- 8.1.3. Load wafer on sample chuck.
- 8.1.4. Turn on the vacuum switch. **Figure 2.**
  - 8.1.4.1. Even if your sample is not large enough to cover the vacuum ports, it is still good practice to turn on the vacuum switch.

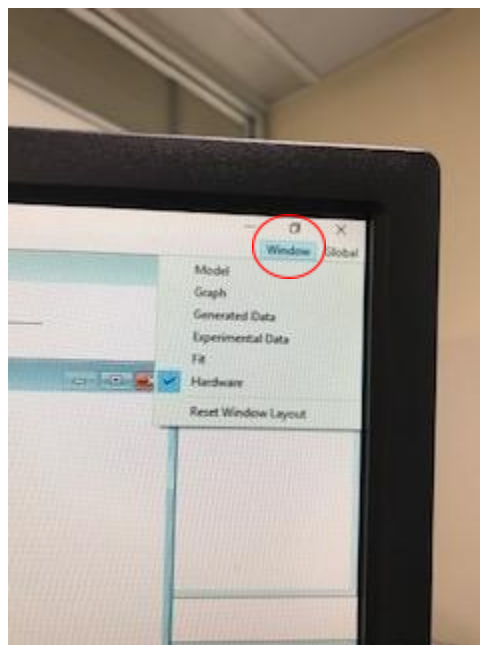


**Figure 2: Location of vacuum switch, lower left corner. Sample stage upper right.**

- 8.1.5. Log On to the computer. Password: temp2000.
- 8.1.6. Open WVase software. **Figure 3.**
  - 8.1.6.1. Do not open WVase Manager, it is a completely different program.
- 8.1.7. Once the software opens, some program windows may not be visible. To view the program window you need, select “Window” in the upper righthand corner. **Figure 4.**



**Figure 3: WVase application on Desktop**

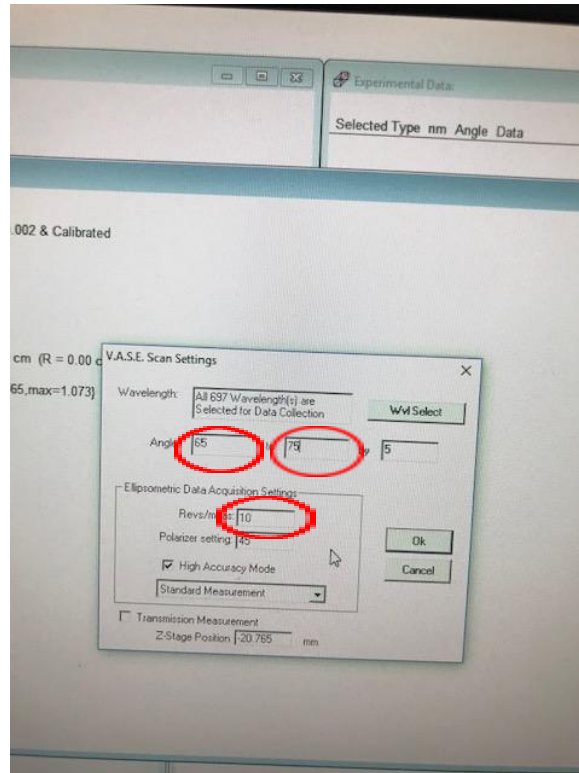


**Figure 4: Window tab to select or reveal different windows**

## 8.2. Acquire Data: Hardware Window

8.2.1. In the Hardware window, right click and select "initialize".

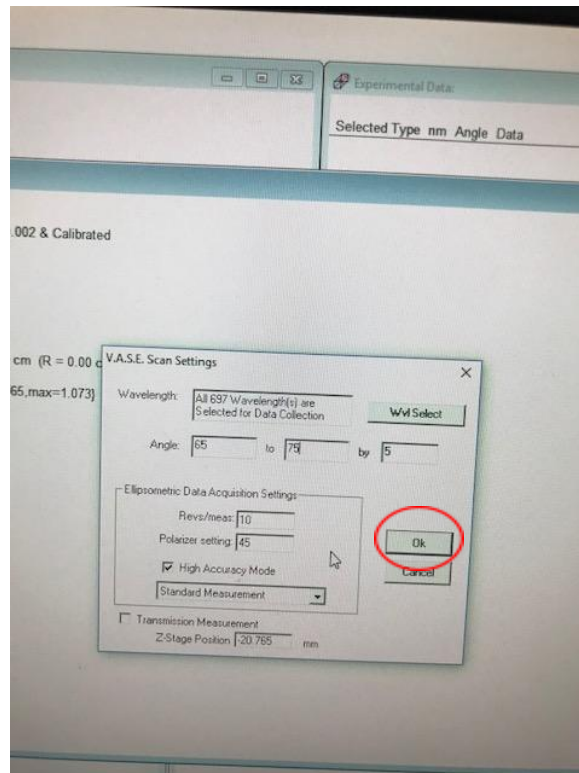
- 8.2.1.1. Do not calibrate system, calibrations are done by staff
- 8.2.2. Right click and under “Acquire data” select “Align sample”.
  - 8.2.2.1. Samples should be aligned even if they are not 4” or uniform in diameter.
- 8.2.3. Right click and under “Acquire Data” select “Spectroscopic Scan”. **Figure 5.**



**Figure 5: Parameters to be modified for a spectroscopic scan**

- 8.2.4. In the scan window, you may need to change some of the parameters:
  - 8.2.4.1. Select angle: In order to reduce the polarization shifts from the substrate it is best to choose angles near the Brewster Angle for your substrate. (Typical selection for Si is 65-75 degrees).
  - 8.2.4.2. Translator move: if you wish to measure a different spot on the wafer, use the arrows to jog the sample table. The default movement is 1mm per click, but there is a window available to change the distance/click.

- 8.2.4.3. Angle step size: More angles will give you more data and improve confidence in the results, but will also take more time. (Typical selection for a single thin film on silicon is 3 angles, so the angle step size would be 5 to measure at 65, 70, and 75 degrees).
  - 8.2.4.4. Revs/measurement: The default setting is 10. More revs/measurement will decrease the amount of noise in the data collection but will also take longer. (Typical value is 40 revs/measurement).
  - 8.2.4.5. DO NOT CHANGE POLARIZER SETTING. This is a hardware setting that is fixed.
- 8.2.5. Select "Ok" to start the scan **FIGURE 6.**



**Figure 6: Click "Ok" to start scan**

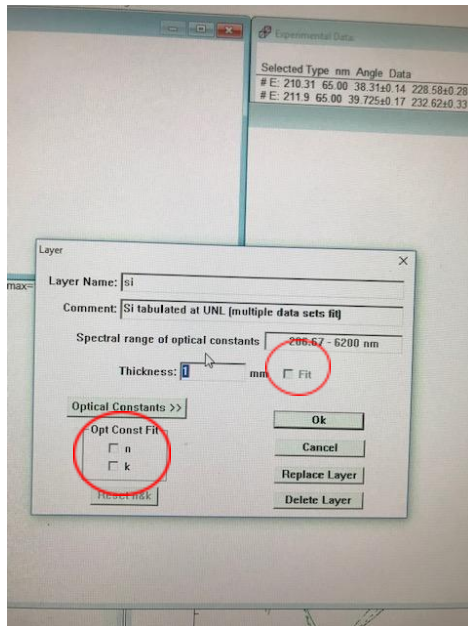
- 8.2.6. Once the scan is complete, you will have the option to save your scan.
  - 8.2.6.1. Scans should be saved to a flash drive, as the computer is not connected to the internet.



- 8.2.6.2. Scans may be saved to the desktop, but this is not recommended as the computer may be replaced or wiped at any time.
- 8.2.7. Verify Data is visible in the Data window and curves are displayed in the Graph Window. Default settings for graph are  $\Psi$  and  $\Delta$  on the y-axes and nm on the x. Right clicking on the graph will show options for changing the data that is graphed and the axes.

### 8.3. Create a Model: Model Window

- 8.3.1. Click in the Model Window to select the window.
- 8.3.2. Select Add layer. For Si wafers, use Si.mat, 1mm default thickness.
- 8.3.3. Add layers to the model in the same order as they are on your sample, from bottom to top.
  - 8.3.3.1. In the pop up box, select which layer you would like to be fit. Select parameters for fitting in the pop up box. Note some layers will not have data for the entire range of the Woollam spectrum. Data outside of the range will be extrapolated. If you do not wish to have the data extrapolated, go back to the Data window and use the menu options to select the range desired.
  - 8.3.3.2. The same material may have several different files. These are different mathematical models. It can be helpful to iterate through several different models to achieve the lowest MSE. It is often a good idea to start with the most recent model.
- 8.3.4. For the layer to be fit (i.e. the layer of unknown thickness, n or k), select “fit”. **Figure 7.**



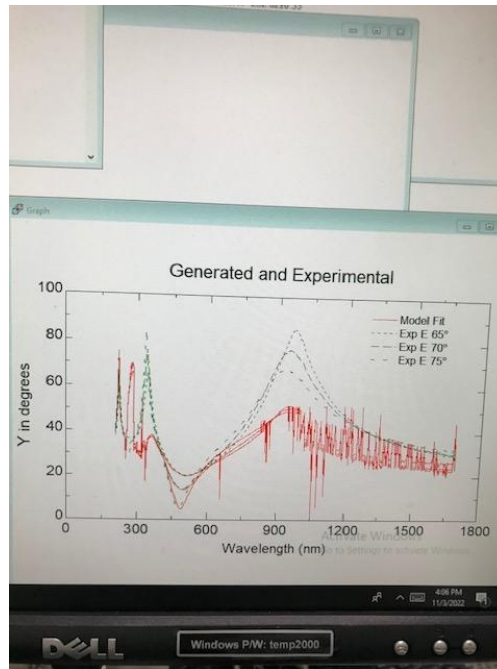
**Figure 7: By selecting these boxes when creating a layer, the software will “fit” these parameters to match the data**

#### 8.4. Generate Data: Generate Data Window

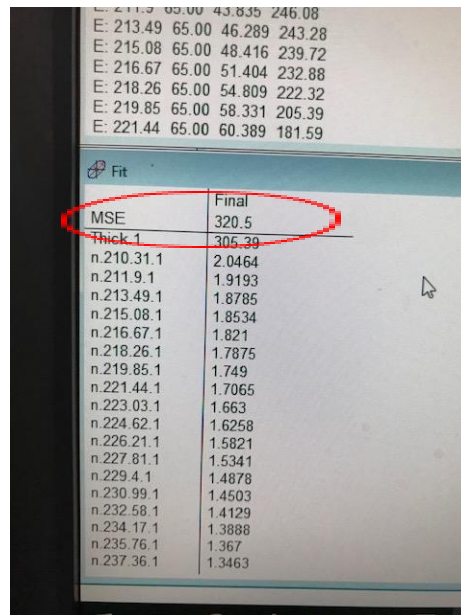
- 8.4.1. Click the Generate Data window to select the window.
- 8.4.2. Right click in the window and select “Generate Data”. Model data will be displayed in Graph Window with measured data.
- 8.4.3. A curve will be generated and appear overlaid on the data curve. It should be reasonably close, but is not the final curve. Do not worry if the fit is not exact. A more precise curve will be fitted to the data in the next step

#### 8.5. Solve for Fit Parameters: Fit Window

- 8.6. Click in Fit Window to select the window.
- 8.7. Right click to select “Normal Fit”. Woollam will generate an answer for the fit parameters. Verify fit curves against measured data and check MSE. **Figure 8 and 9.**
  - 8.7.1. MSE is the Mean Squared Error. A value less than 10 is good, though not always possible depending on the complexity of the model.
  - 8.7.2. MSE can be seen in the top line of the “Fit” window



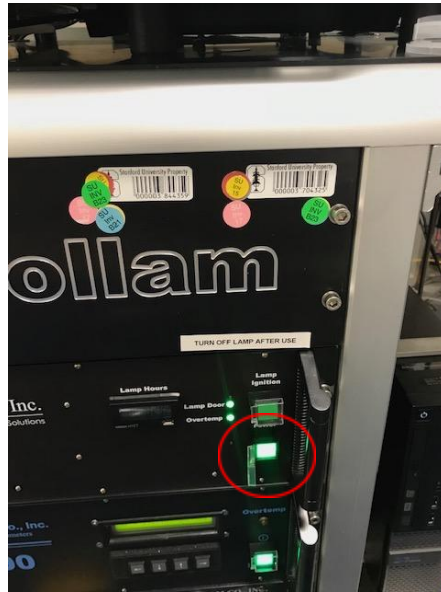
**Figure 8: Example of a bad fit. Notice the red fit curve does not match the green data curve**



**Figure 9: Example of large MSE**

8.8. Modify the model if necessary, then repeat steps 8.3-8.5 until you have minimized the MSE value, or are satisfied with the result.

- 8.9. Turn off the vacuum and remove the wafer.
- 8.10. Turn off the lamp by pushing the “Power” button. Once the tool is off, immediately push the “Power” button again to turn it back on. **FIGURE 10.**
  - 8.10.1. This power cycle is the only way to turn off the lamp.



***Figure 10: Power Button Circled in Red***

- 8.11. Close Vase software and lock the computer screen.

# WOOLLAM ELLIPSOMETER

## 9. Operating Guide

- Right clicking in a given window will show the same menu available at the top
- If you cannot find the window you need, click the “Window” button in the upper right hand corner of the screen

- Select the window you would like to see/use

9.1. Enable Woollam in Badger

9.2. Push Lamp Ignition button to turn on lamp

9.3. Load sample onto stage

9.4. Turn on vacuum switch

9.5. Open WVase software

9.6. Hardware Window

9.6.1. Select “Initialize”

9.6.2. Select “Acquire Data” -> “Align”

9.6.3. Select “Acquire Data” -> “Spectroscopic Scan”

9.6.3.1. Edit Scan angles, and revs/meas

9.6.3.2. DO NOT change Z height or polarizer angle

9.6.4. Click “Ok” to run the scan.

9.7. Model Window

9.7.1. Select “Add Layer” to create your model from the bottom layer up

9.8. Generate Data Window

9.8.1. Select “Generate Data”

9.9. Fit Window

9.9.1. Select “Normal Fits” -> “Normal Fit”

9.10. Close software

9.11. Turn off sample vacuum

9.12. Remove sample

9.13. Turn off lamp by turning off Woollam, and immediately turning it back on

## 10. Definitions and Process Terminology

- 10.1. MSE: Mean Squared Error. This is the difference between the calculated fit and the experimental data. Less than 10 is a good value for MSE.
- 10.2. Revs/Meas: The number of analyzer revolutions averaged for each point. Typically a value between 10-50. For low reflectivity samples this value can be set as high as 100. More revs/measure will increase the quality of your data to a point, but will slow the acquisition rate.

## 11. Troubleshooting

| Symptom                         | Issue   | Resolution   |
|---------------------------------|---|--|
| Polarizer Error                 | <ul style="list-style-type: none"> <li>Not Enabled in Badger</li> </ul>   | <ul style="list-style-type: none"> <li>Enable in Badger</li> </ul>   |
| Bit Locker                      | <ul style="list-style-type: none"> <li>Computer Requires Bit Locker Password</li> </ul>   | <ul style="list-style-type: none"> <li>See Appendix</li> </ul>   |
| Cannot Align/<br>Z height error | <ul style="list-style-type: none"> <li>Stage out of range</li> </ul>  | <ul style="list-style-type: none"> <li>See Appendix</li> </ul>   |
| Failure to Enable               | <ul style="list-style-type: none"> <li>Badger malfunction</li> </ul>  | <ul style="list-style-type: none"> <li>Unplug the Badger box on the side of the Woollam, wait 30 seconds before plugging in. Wait one minute for Badger to establish a connection. Then enable the Woollam again.</li> </ul> |
| Changing Units                  | <ul style="list-style-type: none"> <li>Would like to change units</li> </ul>  | <ul style="list-style-type: none"> <li>See Appendix</li> </ul>   |
| High MSE                        | <ul style="list-style-type: none"> <li>Model doesn't match material</li> <li>Too wide of scan wavelengths</li> <li>Other</li> </ul> | <ul style="list-style-type: none"> <li>Verify deposited material and model match</li> <li>Reduce wavelengths scanned over</li> <li>See staff</li> </ul>  |

## 12. Appendices, Figures & Schematics

- **Changing Units**
  - Click “Global” In the upper right hand corner of the WVASE software
  - Click “Defaults”
  - Change units to your preferred units
  
- **Z height error**
  - Close and re-open the WVase software
  - In the Hardware window, select “initialize”
  - Under “setup” select “load sample”
  - Remove your sample as prompted
  - Click “OK”
  - Enter 1mm est. thickness
  - Click “OK”
  - Place sample on stage
  - Do not adjust translator, click “Ok”
  - Sample loading and alignment are complete, a scan can be run without additional alignment.
  
- **Bit Locker Password:**
  - When you are first prompted for the Bit Locker press “Esc”
  - The Bit Locker password is:
    - If you are unable to enter all of the digits, you are on the wrong password screen. Press “Esc”

- **Transmission Scan**
  - Find the Transmission Scan holders located near the Woollam
  - Open WVASE and initialize software as normal.
  - In the Hardware window, select “Acquire Data” -> “R&T Data”
  - Select “Background and Sample Scan”
  - Ensure scan angle is “90 to 90” degrees
  - Click “Ok”
  - Follow prompts for scan, first a background scan will be collected
  - Then insert sample in Transmission scan holder, click “Ok”
  - A graph should now appear of your transmission

### 13. Revision Block

| Revision | Date       | Description of Change  | Author   |
|----------|------------|--|----------|
| A        | 12/1/2022  | Initial Release  | A.Denton |
| B        | 08/15/2023 | Added Transmission Scan, Bit Locker, Changing Units, Z Height Error. | A.Denton |