

Operations Manual
for the
Filmetrics F20
Thin-Film Analyzer

Revision 4.81
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CE Mandated Warnings



Please read the following instructions carefully to prevent potential shock or fire hazards. This manual should be retained for future use.



Bitte lesen Sie die nachstehende Anleitung sorgfältig durch um Stromschlag und Feuergefahr zu vermeiden. Diese Betriebsanleitung sollte für späteren Gebrauch sorgfältig aufbewahrt werden.



Preghiamo di leggere accuratamente, le sequenti Istruzioni, per evitare Prossimi Incendi e Correnti.



1.

Shock Hazard – Do Not Enter

Achtung Hochspannung – Nicht Berühren

Attenzione Corrent-Forte – Prego non toccare



2.

The front panel's switch is not the power disconnect device. The power cord should be removed after use.

Der Kippschalter an der Vorderseite unterbricht nicht die Stromzuführung. Das Stromkabel sollte nach Gebrauch aus dem Gerät herausgezogen werden.

L'interuttore nella parete frontale non blocca le Corrente. La Corrente viene.



3.

Never expose the unit to water or liquids. Avoid direct sun.

Bringe das Gerät nicht mit Wasser oder einer anderen Flüssigkeiten in Berührung. Vermeide direkte Sonneneinstrahlung.

Evitare contatto con acqua oppure liquidi Infiammabili al Macchineggio. Anche entrate di Sole.

4.



Do not insert any objects into the unit.

Keinen Gegenstand in das Gerät einbringen. Do non inseriamo any obietta into gli unità.

Non mettere ogetti dentro la Macchina.

5.



Do not use near open flame or heat.

Das Gerät nicht in der Nähe einer offenen Flamme oder Hitze benutzen.

Non mettere la Macchina vicino a fuochi oppure Riscaldamenti.

6.



The unit should never be enclosed or blocked.

Das Gerät darf nicht eingeschlossen oder blockiert werden.

La Macchina non chinderla per nessun motivo.

7.



Connect unit only to a properly measured supply. Use only three wire cord which is provided with the unit.

Schließen Sie das Gerät nur an eine ordnungsgemäss vermessene Stromversorgung an. Verwende nur ein dreiadriges Kabel, wie es auch mit dem Gerät ausgeliefert wird.

Montare solo con misura normata. Adoperando solo 3 cavi elettrici cosi come e fornita la Macchina.

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1 Getting Started

What is the F20 used for?

The Filmetrics F20 is used to measure the thickness and optical constants (n and k) of dielectric and semiconductor thin films. Measured films must be optically smooth and within the thickness range set by the system configuration requirements specified in Appendix B, Performance Specifications. Commonly measured films include semiconductor process films such as oxides, nitrides, resists, and polysilicon, optical coatings such as hardness and anti-reflection coatings, flat panel display films such as polyimides, resist, and cell gaps, and the various coatings used in CD and DVD manufacture. Films that cannot be measured include very rough films and metal films.

* * Note * * Most of this manual, plus additional user information, is located in the FILMeasure software help. Select **Help>FILMeasure Help...** from the menu bar.

Installation

The following steps assume that the F20 system, cables, and accessories have been unpacked and that you have a Pentium-based (100 MHz or greater) computer with a Windows 98 or later operating system and a USB or parallel port.

* * Note * * Windows NT computers do not support USB and must use the parallel port F20 system electronics.

Installation Note for European countries:

Change the computer's regional settings to use decimal points.

Step #1: Install software

Insert the supplied CD into the CD drive and run setup.exe to install the software. If a floppy disk was supplied, install the files on this disk only after the FILMeasure software from the CD has been successfully installed. The floppy disk contains custom software settings pertinent to your measurement application or system configuration.

Step #1: Connect the F20 Spectrophotometer to the Computer

With the computer power off and the power cord to the F20 spectrophotometer unplugged, connect the F20 to a USB or parallel port of the computer with the supplied cable.

Step #2: Connect power to the F20



Plug the F20 spectrophotometer into a 100-240 VAC ~ outlet with the supplied cable. Power to the light source is controlled by the front panel switch.

Step #3: Test software

From the **Start** menu on the taskbar, select **Programs** and then select **FILMeasure** to begin program execution. If a "No Spectrometer Detected" message is issued, check that the power cord and interface cable are connected correctly. If using a parallel port connection, verify that no other programs or drivers conflict with the parallel port. If the computer is a desktop PC, a plug-in ISA parallel port card should be added and used for the F20. Contact Filmetrics for further assistance.

Step #4: Connect Fiber-Optic Cable to the F20

Follow the instructions on the following pages for setting up your particular measurement hardware:

System Setup

Several accessories are available for the F20 series systems. Please refer to the following list to find different applications for the configuration provided with your system. If you would like information on purchasing additional accessories not included, please contact Filmetrics.

- **Fixed Stage (SS-1):** The SS-1 stage is our standard stage for the F20 system. This is the most versatile stage, which is shipped with each system unless otherwise specified.
- **Rotating Sample Stage (WS200, WS300):** This stage allows for rotation for manual thickness mapping.
- **Small Spot Stage (SS-2):** The SS-2 stage is used to achieve a smaller spot size for measurement. This is also useful for nonuniform or rough samples. This accessory comes standard with the F20-XT system.
- **Contact Probe (CP-1):** The contact probe is useful for measuring coatings on curved surfaces, such as ophthalmic lenses. This accessory comes standard with the F20-HC, in place of the SS-1.
- **Contact Probe for Cylindrical Samples (CP-C):** This contact probe is used for measuring coatings on cylindrical samples, such as test tubes and rods.
- **Contact Stage Option (CS-1 Option):** The contact stage option is used to measure the thickness of freestanding films and coatings on glass samples where eliminating the backside reflection of the glass is necessary. Use of the contact stage requires that the sample be flat.
- **Transmission Option (T1 Option):** This option is used to make transmission measurements for transparent samples.
- **Reduced Kinematic Mount with lens assembly (LA1-RKM):** This assembly is used for inline applications, or when a longer working distance is required.

If using fixed (SS-1) or rotating (WS-200, WS-300) sample stage:

Connect the fiber-optic cable between the F20 front panel and the stage as shown in Figure 1.1. The fiber-optic cable should be fully inserted into the arm on the stage. The screw on the end of the stage arm is actually a spring-loaded ball plunger, and does not require tightening.

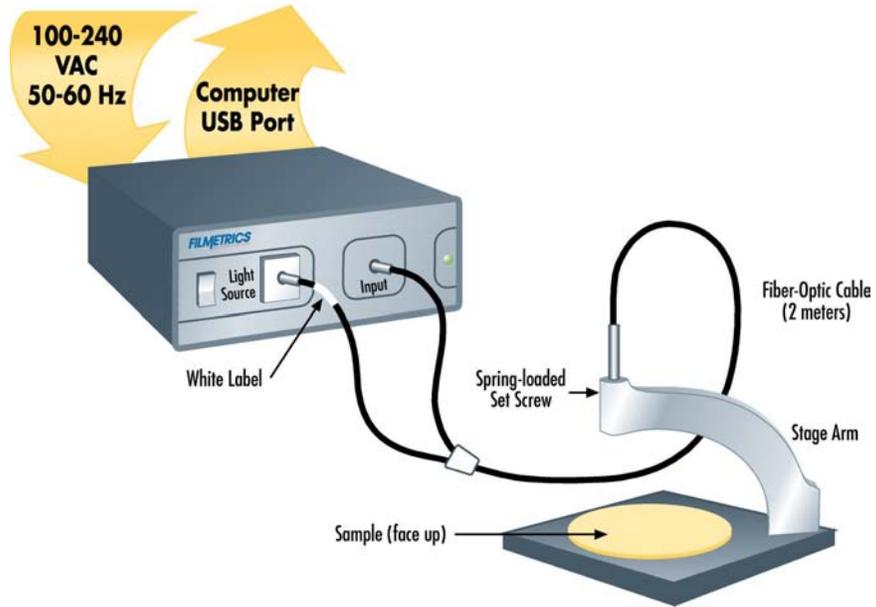


Figure 1.1: Setup Configuration for SS-1 stage.

The fiber-optic cable contains 7 fibers – a single detection fiber surrounded by 6 illumination fibers. The measurement spot size is not the illuminated area, but rather the intersection of the illuminated area with the projected image of the detection fiber. When focused for maximum signal, the measurement spot size is roughly half the diameter of the illuminated area. The SS-1 sample stage is already optimized for maximum focus when the fiber is fully inserted into the stage arm.

If using the Small-Spot sample stage (SS-2):

Connect the fiber-optic cable between the F20 front panel and the stage as shown in Figure 1.1. If the fiber does not have a white label indicating "Light Source", then the two fiber ends are identical, so they can each be attached to either the light source or spectrometer. Start with the fiber-optic cable fully inserted into the arm on the stage.

Instructions for focusing for maximum signal are as follows:

- a. Turn on the light source and start the FILMeasure program.
- b. Go to the **Set Up>Data Acquisition** dialog box from the menu bar. Set the integration time for 50 milliseconds, and make sure **Subtract Dark** and **Use Reference** are de-selected.
- c. Select **Acquire>Start Continuous Acquire...** from the menu bar.
- d. Place a reflecting sample, such as a silicon wafer, at the sample position. You should now see a trace on the screen. If the signal saturates, reduce the integration time (see step b).
- e. Optimize the focus to maximize the measured signal by adjusting the fiber-optic cable position in the stage arm. To achieve this, move the fiber-optic cable slightly up the lens tube until maximum signal is obtained. When finished, tighten the setscrew that secures the fiber.
- f. The set up is now complete. Now select **Acquire>Stop Continuous Acquire....**

If using Contact Probe (CP-1):

Connect the Contact Probe to the F20 front panel as shown in Figure 1.2. The two fiber ends leading from the Contact Probe are identical, so they can each be attached to either the light source or spectrometer.

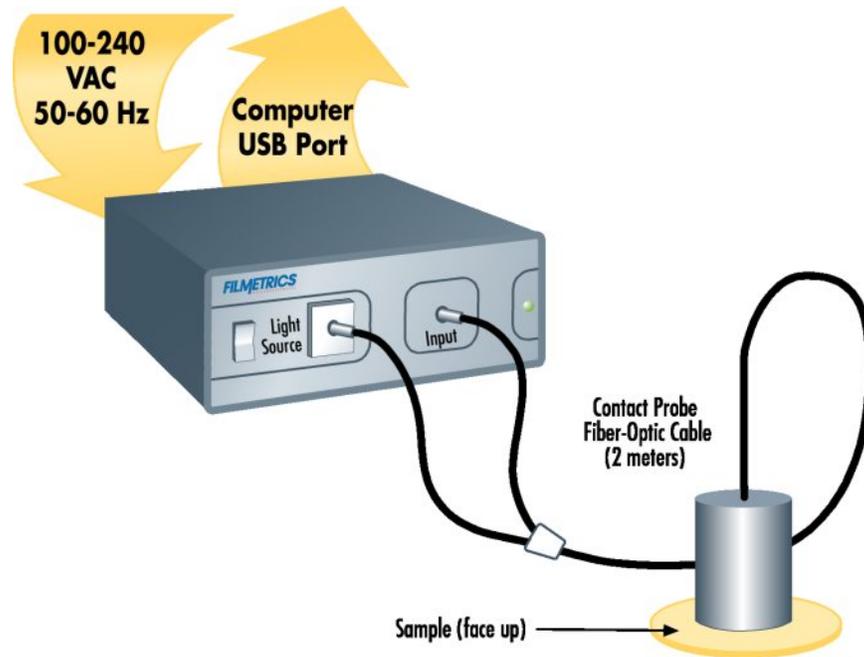


Figure 1.2: Setup Configuration for Contact Probe.

If using Contact Stage (SS-1 with CS-1 option):

Connect the contact stage fiber optic cable to the F20 front panel as shown in Figure 1.3. The two fiber ends leading from the common end of the fiber are identical, so they can each be attached to either the light source or spectrometer. Connect the four 3" legs to the bottom of the SS-1 Sample Stage. Remove the tilted mirror insert in the SS-1 stage using the supplied 1/16" hex socket driver. Screw the fiber optic cable common end into the black contact adapter, and then fully insert the contact adapter into the bottom hole in the SS-1 stage, fastening it with the 1/16" hex driver.

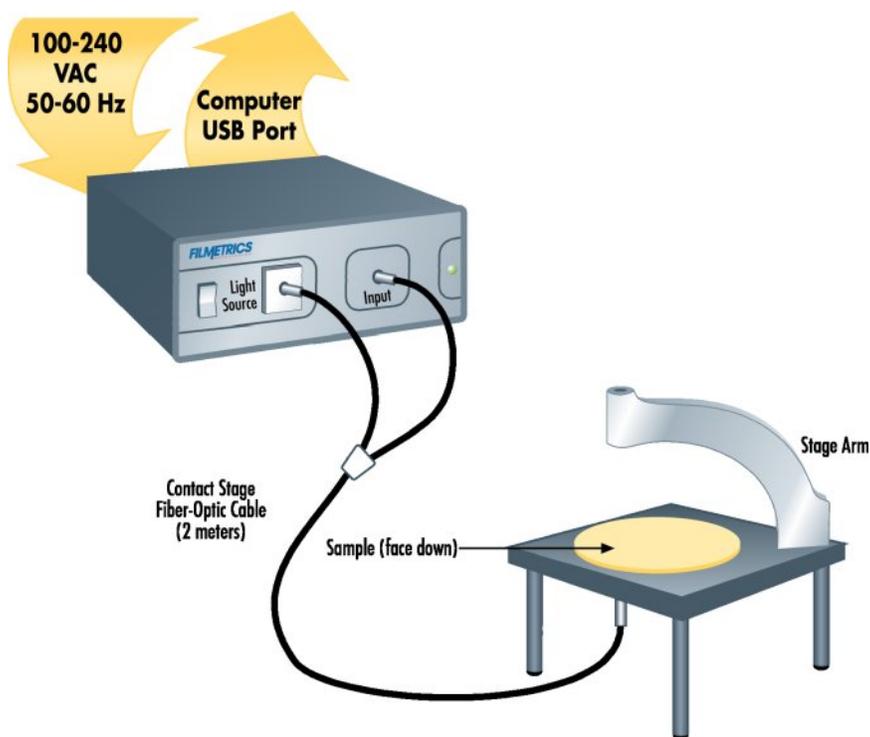


Figure 1.3: Setup Configuration for Contact Stage.

If using Transmission Option (SS-1 with T-1 option):

Connect the fiber-optic cable between the F20 front panel and the stage as shown in Figure 1.4. The fiber-optic cable should be fully inserted into the arm on the stage. The screw on the end of the stage arm is actually a spring-loaded ball plunger, and does not require tightening. Connect the four 3" legs to the bottom of the SS-1 Sample Stage. Remove the tilted mirror insert in the SS-1 stage using a 1/16" hex socket driver. Screw one end of the single fiber optic cable into the black adapter, and then fully insert the adapter into the bottom hole in the SS-1 stage, fastening it with the 1/16" hex driver. Before taking a baseline measurement, be sure to set the mode of operation to transmittance. See Chapter 3 Making Measurements, Example #6 for more information on transmittance measurements.

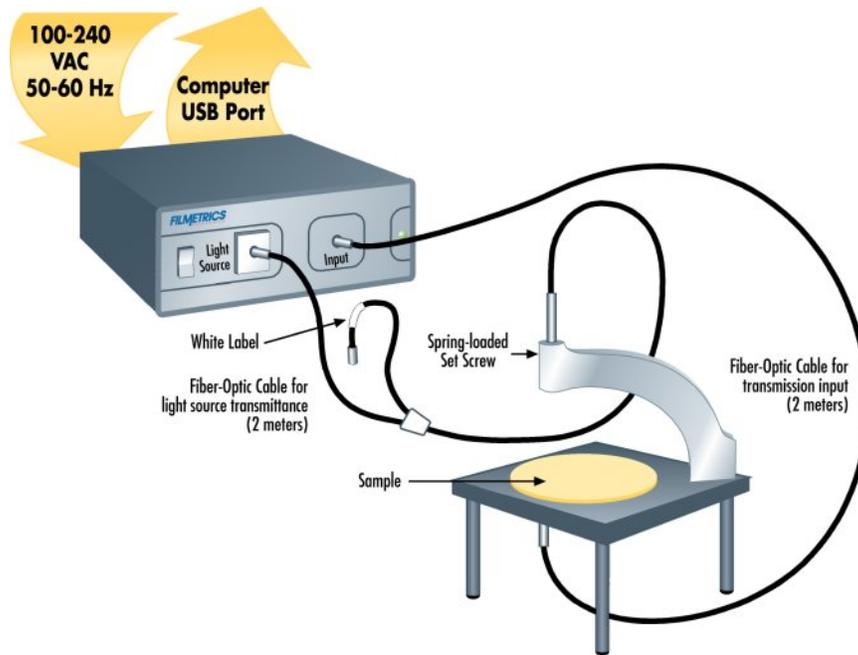


Figure 1.4: Setup configuration for T-1 Transmission option.

If using Reduced Kinematic Mount with lens assembly (LA1-RKM):

Step #1: Connect Fiber-Optic Cable to the F20

Connect the fiber-optic cable between the F20 front panel and the LA1-RKM as shown in Figure 1.5. Slide the fiber-optic cable part way into the lens assembly. The spring-loaded setscrew should be adjusted so that the fiber-optic cable is held in place, yet it may be moved in and out for focus adjustments.

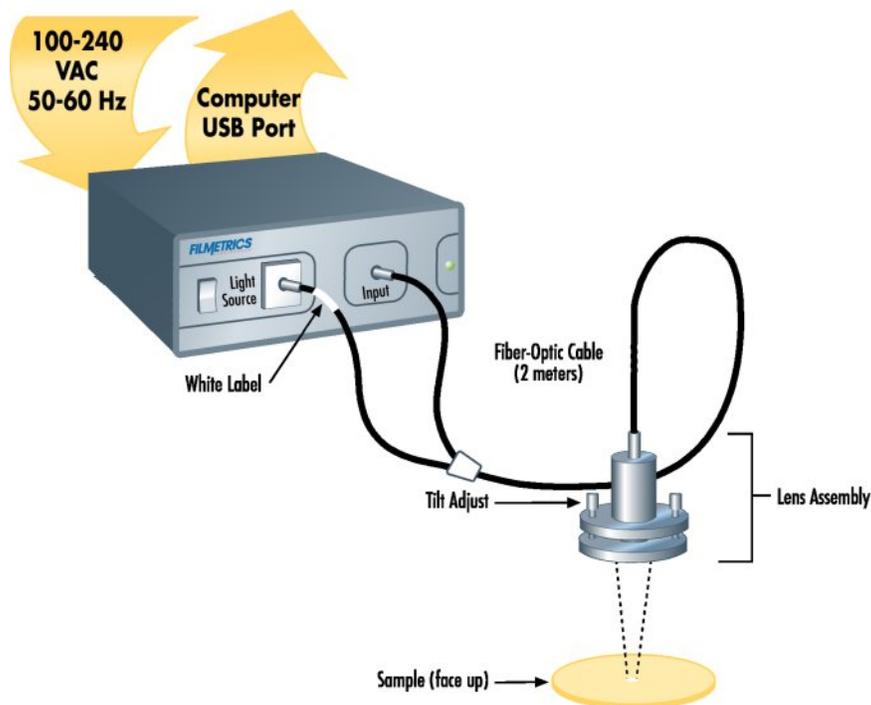


Figure 1.5: Setup configuration for LA1-RKM lens assembly.

Step #2: Adjust the lens assembly:

This step involves adjusting the focus and tilt of the lens assembly for maximum signal and assumes that the lens assembly has been mounted on a fixture approximately 6 inches above the sample surface, and the "read" return fiber from the lens assembly to be adjusted is connected to the spectrometer input. The idea here is to adjust the tilt and focus for maximum signal. To do this,

- Turn on the light source with the front panel switch and start the FILMeasure program.
- Go to the **Set Up>Data Acquisition...** menu item. Set the integration time for 100 milliseconds, and make sure the **Subtract Dark** and **Use Reference** checkboxes are de-selected.

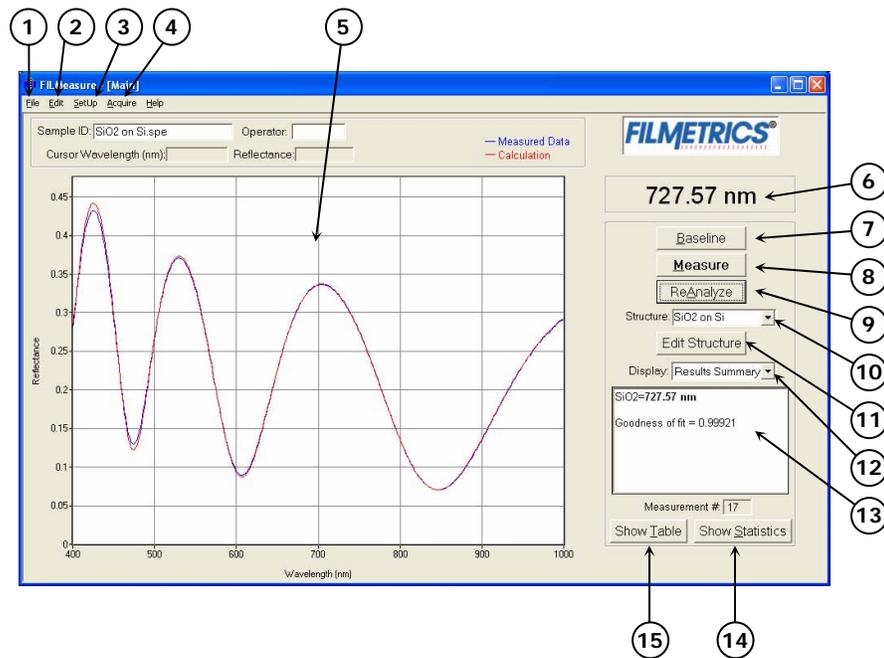
- c. Select **Acquire>Start Continuous Acquire** from the menu bar.
- d. The fiber-optic cable contains 7 fibers – a single detection fiber surrounded by 6 illumination fibers. Do a rough focus adjustment by placing a diffuse surface (a business card works well) at the sample position and then focus the light beam on the sample position by sliding the fiber-optic cable inside the lens tube. (The diffuse reflector will allow you to see the beam.) When 6 individual spots can be seen, slide the fiber-optic cable farther into the LA1-RKM until the spots merge into the center of the illuminated area.
- e. Place a reflecting sample, such as a silicon wafer, on the sample stage, under the lens assembly. You should now see a trace on the screen. Turn the tilt adjustment screws to maximize the signal. If the signal saturates, reduce the integration time (see step b).
- f. Optimize the focus to maximize the measured signal by adjusting the fiber-optic cable position in the lens assembly. Focus the light beam on the sample by sliding the fiber-optic cable inside the lens tube. To see the beam, it may be necessary to place a diffuse surface, such as a business card, over the sample. Ideally, the best focus adjustment is when the beam is just under focused. To achieve this, focus the beam on the reflecting sample, and then move the fiber-optic cable slightly down in the lens tube until maximum signal is obtained. When finished, tighten the socket head set screw that secures the fiber. Once again, if saturation occurs, it may be necessary to reduce the integration time.
- g. Repeat steps e) and f) to make certain the adjustments are optimal.
- h. The set up is now complete. Now select **Acquire>Stop Continuous Acquire** from the menu bar.

2 Software Overview

The way that light reflects off of a thin film is determined by the characteristics of the film, such as its thickness, optical constants, and roughness. The F20 is able to determine thin-film characteristics by first carefully measuring the amount of light reflected from the thin film over a range of wavelengths (i.e., by measuring the reflectance spectrum), and then analyzing this data by comparing it to a series of calculated reflectance spectra. Most of the features of the FILMeasure software that runs the F20 can be divided into reflectance acquisition and reflectance analysis functions. The following pages outline the main features of the FILMeasure software.

The basic steps for any F20 measurement are selecting and editing the film structure, taking a baseline measurement, and then making and evaluating the measurement. The details of each of these steps are explained below, followed by descriptions of other FILMeasure functions.

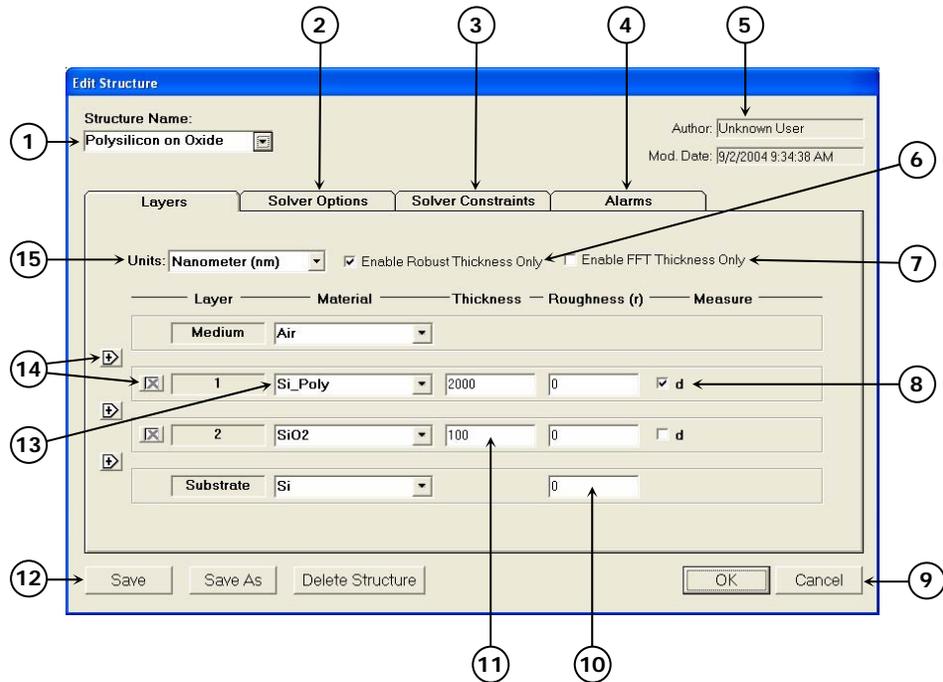
FILMeasure Main Window



1. Standard Windows **File** menu for saving and retrieving data, printing, etc.
2. The **Edit** menu is used for viewing and editing the material library.

3. Used to set up reflectance acquisition parameters and the graphic display.
4. For starting and stopping continuous reflectance acquisition and data measurement. Convenient for setting up hardware.
5. Graphical display for measured and calculated reflectance, as well as measured optical constants. Change display limits by double-clicking in the display area. A click of the right mouse button while the cursor is within the graphical display activates a blue line (one click for measured curve) and red line (2 clicks for calculated curve) for easy reading of cursor values in the main FILMeasure window. Keyboard up/down and right/left arrows move the line to a desired location.
6. The measured film thickness is displayed here.
7. The baseline measurement sequence, which is required before measurements are made, is initiated by pressing the **Baseline** button.
8. This button causes a reflectance spectrum to be acquired and then analyzed in one step.
9. Performs analysis on the displayed reflectance spectrum. Usually used when trying different analysis settings on a previously acquired spectrum.
10. Used to select the film structure that is to be measured.
11. This is where the selected film structure is described, and the analysis parameters are set.
12. Used to select the information displayed in the results box below.
13. The results box summarizes the most recent measurement results.
14. Statistical tabulation of all measurement results is accessed by pushing this button.
15. Complete calculated results of the most recent measurement are accessed by pushing this button.

Edit Structure Window



A structure defines the film to be measured, the substrate and any underlying films, the approximate thickness of the film, and the quantities to be measured:

1. The name of the film structure is listed here.
2. Advanced measurement parameters can be accessed by clicking on the **Solver Options** tab.
3. Constraints on the possible measured values are selected here.
4. Used to set alarms to notify the user of measurements that are outside of a user-specified thickness range or have a poor GOF.
5. Author, as defined by user login name and structure modification date are indicated here.
6. A very robust thickness measurement routine is enabled by selecting this box.
7. Another very robust thickness measurement routine used for measuring very thick films or thick multi-layer stacks, where the total thickness is greater than 5 microns. See **Fast Fourier Transform Thickness Only Mode (FFT TO mode)** on page 47 for more information.
8. The values to be measured are selected by checking the appropriate boxes.

9. **OK** closes the **Edit Structure** box, retaining any changes made. Changes will not be permanently saved unless **Save** or **Save As** is selected. The **Cancel** button closes the **Edit Structure** box without retaining changes.
10. Known film roughness for films not being measured, and the initial guess for the film(s) being measured are entered in this column.
11. Known film thicknesses for films not being measured, and the initial guess for the film(s) being measured are entered here.
12. The structure can be saved as a new structure, deleted, or changes can be saved.
13. The film layers are listed here. Common films can be selected from the pull-down menus.
14. Layers can be added or deleted using these buttons. Up to 8 layers may be present in the structure.
15. The thickness (length) units are chosen here. The choices include nanometers (nm, $10e-9$ m), microns (μm , $10e-6$ m), angstroms (\AA , $10e-10$ m), and kilo-angstroms ($\text{k}\text{\AA}$, $10e-7$ m).

Taking a Baseline

The baseline measurement allows the FILMeasure software to take into account the response inherent to the F20 reflectance measurement hardware. It does this by measuring a reference sample and by taking a “dark” reading. If optical constants or very thin films (< 1000 Å) are to be measured, the light source should be allowed to stabilize at least ten minutes before the baseline is taken, and then periodically re-taken every 20-30 minutes. For thicker films, a new baseline can be taken less often.

Baseline measurements may be started two ways:

1. Select the **Baseline** button in the main FILMeasure window, which will guide the user through the baseline procedure, or
2. Select **Set Up>Data Acquisition** from the menu bar for manual access to the baseline functions.

The first step of the baseline measurement is to take a reference spectrum. This is done by placing a reference sample of similar reflectance to the test sample (usually silicon or BK7 glass) on the sample stage and clicking **OK** when prompted. The reference material that is used should be selected from the **Reference** list. For reference materials not in the list, reflectance versus wavelength values should be entered into a text file with the extension “.rrr” (stored in the Material subfolder).

The dark scan should be taken with no sample on the stage and the light turned on (so that the light output remains stable). Most stages have a built-in tilted mirror or other reflector that is used to re-direct the incident light away from the collection optics. If you are using a movable stage, move this reflector under the light beam. Click on **OK** to take the dark reading.

After acquiring a baseline the F20 is ready to begin making measurements. To verify that the system is working properly, you may select **Acquire>Do Single Acquisition** from the menu bar, with the reference sample in place. You should see the reflectance spectrum of the reference material.

Editing Film Structures

The description of the nominal film structure, as well as the measurement parameters, is specified in the **Edit Structure** dialog box. Dozens of different film structures and their measurement specifications may be saved using the **Edit Structure** dialog box.

The **Edit Structure** dialog box is accessed with the **Edit Structure** button on the right-hand side of the main FILMeasure window. The **Edit Structure** dialog box lists an initial guess at the specifications of the

film structure to be measured. These specifications include the name of the film structure (which identifies it in the **Structure:** list), the number of films in the structure, the specifications of individual films, and the quantities to be measured.

Edit Structure > Adding, Changing, or Deleting a Structure

When the **Edit Structure** dialog box is opened, it shows the stored specifications of the structure selected from the **Structure:** list, along with any changes made since the program was started. Changes to the structure selected can be permanently stored by making the desired changes and then clicking on **Save**. New structures may be added to the **Structure:** list by opening the **Edit Structure** dialog box, setting the desired specifications, and then clicking on **Save As**. Similarly, a structure may be deleted (removed from the **Structure:** list) by clicking on **Delete Structure**.

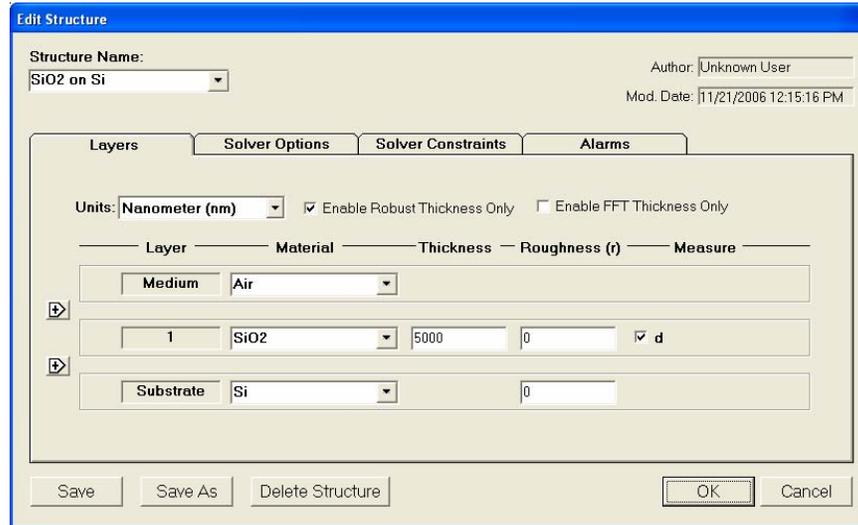


Figure 2.1: **Edit Structure>Layers** window.

Edit Structure > Layers: Setting Up a Film Structure

When measuring a layer, the specifications (d , n , k , roughness) of the known films (including the incident medium and substrate) must be entered into the proper fields in the **Edit Structure** dialog box, as well as initial guesses for the values to be measured. The refractive index (n) and extinction coefficient (k) values for common materials can be selected automatically with the pull-down menus on the left-hand side of the **Edit Structure** dialog box.

If a material is being measured which is not present in the pop-up material list there are three possible approaches: a) choose a material in the list which is similar, b) if the material is transparent, select **“Enter Refractive Index Value”** from the material list and enter a value for

the refractive index (n will automatically be varied by FILMeasure to account for dispersion effects, with the entered value being n at 632 nm), or c) in the **Edit>Material Library...** dialog box from the menu bar, enter the refractive index values for n and k as a function of wavelength and save the files so that they may be selected as in a). See page 23 for more information.

Edit Structure > Layers: Measuring Thickness

To measure a film thickness, check the appropriate box on the right-hand side of the Layers field in the **Edit Structure** dialog box. When no boxes are checked, and Analyze (or Reanalyze) is selected from the main FILMeasure window, the theoretical spectrum for the specified layer structure and thicknesses will be displayed.

Edit Structure > Layers: “Enable Robust Thickness Only”

If thickness, of films greater than 1000 Å, is the only property to be measured, then the **Enable Robust Thickness Only** mode is recommended. This mode can oftentimes allow for successful measurements to be made when the reflectance data is affected by non-ideal film properties, such as non-uniformities and birefringence. The range of thicknesses tested is constrained by the limits set in the **Constraints** field in the **Constraints** tab. Selecting this feature will limit the **Options** tab settings available.

Edit Recipe > Layers: Enable FFT Thickness Only

If thickness, of films greater than 5 microns, is the only property to be measured, then the **Enable FFT Thickness Only** mode is recommended. This mode is oftentimes the most effective technique when the sample has multilayer stacks. Selecting this feature will limit the **Options** tab settings available.

Edit Structure > Solver Options

Correct setting of the following options will help ensure accurate measurements. Many of the options are set automatically when film information is supplied in the **Edit Structure** dialog box, and all of them can be saved so that subsequent measurements can be made as quickly and easily as possible.

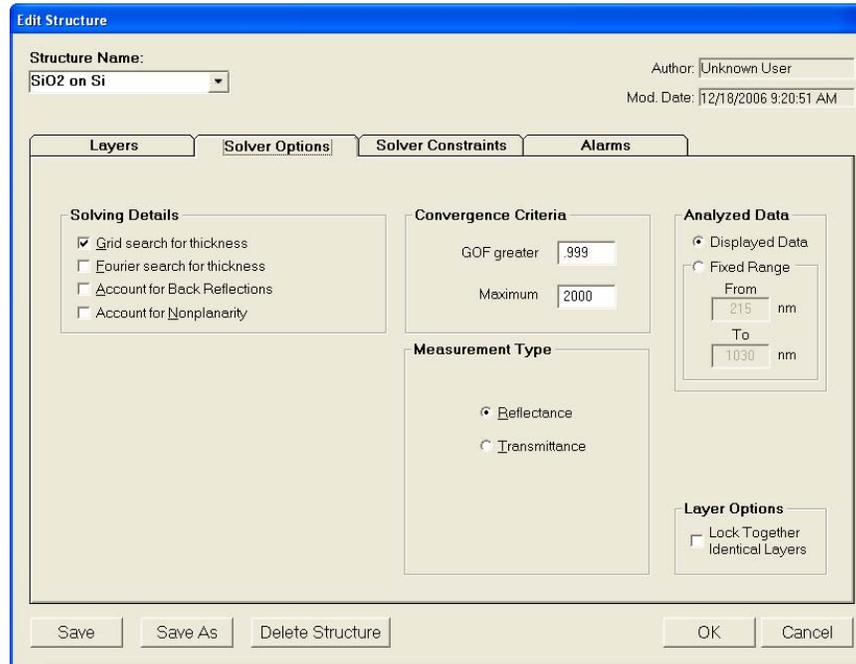


Figure 2.2: **Edit Structure**>**Options** window.

Edit Structure > Solver Options: Grid search for thickness

There are a number of methods that FILMeasure can use to determine thickness. None is perfect – each is a different trade-off between speed, accuracy, and robustness (i.e., the ability to find the best solution among many that are nearly as good). Because thickness can vary over many orders of magnitude and many near-solutions exist, it is often best to use a very robust method to get close to the best solution, and then let a more accurate method take over. One very robust method is the Grid method, which can be activated by selecting the **Grid search for thickness** checkbox. The Grid method searches the entire allowed thickness range (as defined by the initial guess and the constraints) to find the best initial thickness. However, on some very complex multilayer spectra, it is possible for the Grid method to become confused and give the wrong answer. In such cases it is best to use the Fourier Transform method to determine initial thicknesses (see below), or to provide them manually.

Edit Structure > Solver Options: Fourier search for thickness

The **Fourier search for thickness** checkbox is an alternative option to let FILMeasure choose an initial thickness for analysis. The Fourier Transform method analyzes the oscillations present in the spectrum and determines the film thicknesses based on the periodicity of those oscillations. It is somewhat less robust than the Grid method, but is better at finding the correct thickness in cases where the shape of the

initial theoretical spectrum is different than the measured data (i.e., the reflectance spectrum is non-ideal in some way) or in cases where there is more than one film thickness is being measured.

Edit Structure > Solver Options: Account for Back Reflections

When measuring films in transparent substrates, reflectance off of the backside of the substrate may occur. **Account for Back Reflections** allows the software to shift the intensity of the reflectance curve to account for the additional light. This feature should not be used when measuring very thin films (< 100 nm).

Edit Structure > Solver Options: Account for Non-Planarity

Samples with nonplanar surfaces scatter some of the light away from the collection optics. This option automatically compensates for the light lost due to nonplanarity.

Edit Structure > Solver Options: Convergence Criteria

This sets the minimum **GOF** between the measured and calculated spectra that is attained before the measurement routines consider the solution final. In most cases a value of 0.999 is sufficient. For cases where the desired **GOF** is not attainable, the value in the **Maximum Iterations** field limits the number of iterations performed by the analysis routine.

Edit Structure > Solver Options: Measurement Type

Specify here whether the data to be analyzed is **Reflectance** or **Transmittance**.

Edit Structure > Solver Options: Analyzed Data

This sets the range of data that is to be analyzed. It may be either the range displayed on the current graph or a fixed range.

Edit Structure > Solver Options: Lock Identical Layers

Samples comprised of repeating layers can be more accurately measured by activating this option. Once the option is active, all properties of any layers that initially have the same material and thickness are locked together.

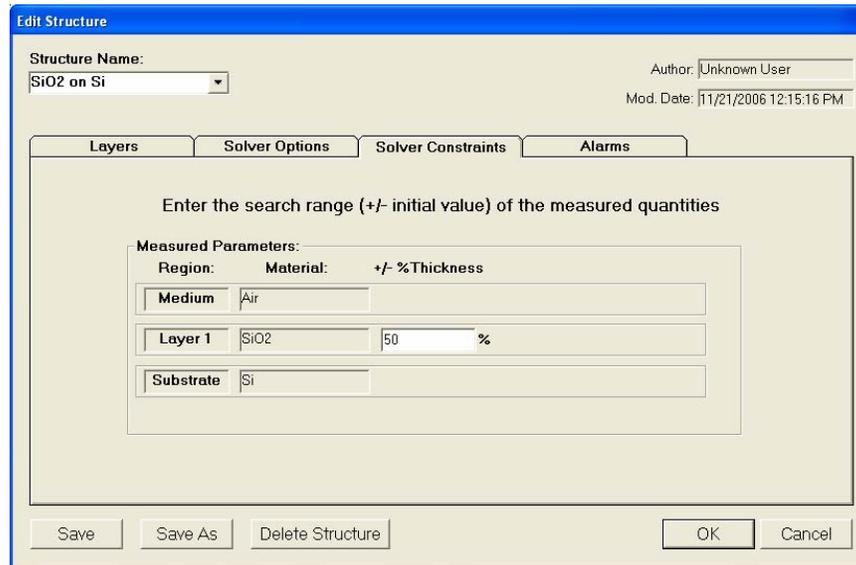


Figure 2.3: **Edit Structure>Solver Constraints** window.

Edit Structure > Solver Constraints

By setting constraints, the user can limit the possible values of the measured film properties. The constraints are set in conjunction with the values entered in the **Edit Structure>Layers** dialog box. For example, if the initial guess of the measured thickness of a film is 1000 Å and the thickness constraint is set at $\pm 50\%$, FILMeasure will only consider possible thicknesses in the range 500 Å to 1500 Å. Constraining the measurement range can speed up the measurements and can also help exclude non-physical solutions.

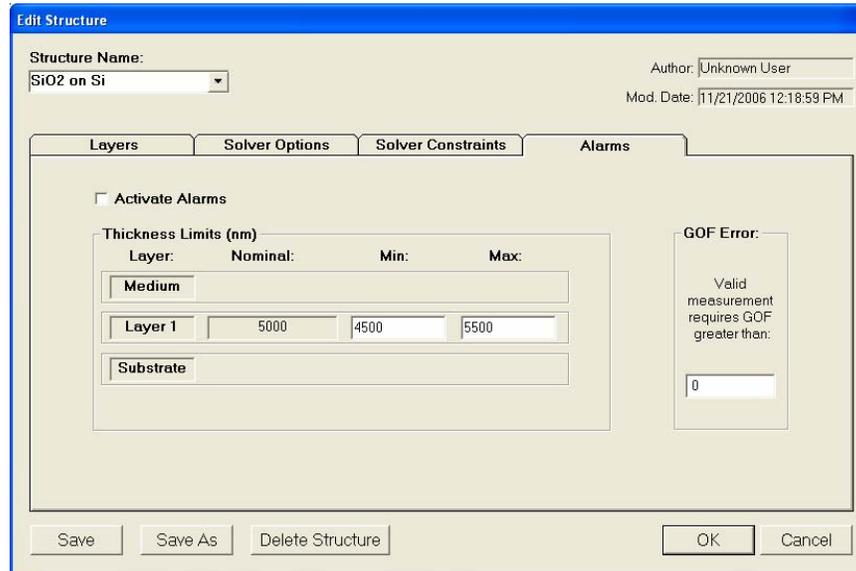


Figure 2.4: **Edit Structure>Alarms** window.

Edit Structure > Alarms: Activate Alarms

When **Activate Alarms** is selected, an alarm will trigger if the measured thickness of the sample is outside the specified **Thickness Limits**.

Edit Structure > Alarms: Thickness Limits

Setting the minimum and maximum allowable thickness limits will trigger an alarm if the measured thickness is outside the limits when **Activate Alarms** is selected.

Edit Structure > Alarms: GOF Error

Constraining the **GOF Error** will exclude measurements where the calculated GOF does not reach the specified limit. A warning or **Invalid** result will appear if the GOF constraint is not met. Specify 0 to have all solutions reported. More information on GOF may be found on page 22.

Understanding and Evaluating Measurement Results

Display of Measured Data

Once film structure and measurement information have been entered and baseline spectra taken, measurements may be made by clicking on the **Measure** button. After measurement, the measured and calculated reflectance spectra are displayed on the graph. The thicknesses of the films are listed in the results box. If any of the thickness values were measured, they are displayed in bold numbers.

The values of the calculated reflectance versus wavelength are listed in the grid that is viewed by clicking on the **Show Table** button at the lower right-hand corner of the screen. The calculated n and k values may be viewed by scrolling through the grid. Clicking on a column containing measured data will cause it to be plotted on the graph.

Selected data from the results grid may be copied to the clipboard by clicking on the **Copy Selected Data** button. The wavelength data is copied along with the selected reflectance, n , and/or k data.

Goodness of Fit (GOF)

The accuracy of a calculation fit, and thus the reliability of the measurement, can be judged by the match between the measured and calculated spectra, which is quantified by the GOF value. GOF is a number between 0 and 1. 0 is a poor fit.

A perfect match between measured (blue) and theoretical (red) spectra will result in a GOF of 1.0. To ensure accurate results the user may set a minimum acceptable GOF value by entering a number between 0 and 1 into **GOF Error** on the **Constraints Tab** in **Edit Recipe**. A warning message will be displayed after each measurement where the GOF falls below the user-specified **GOF Error**. If the GOF is less than 1.0 there are several possible causes as follows:

a) Nonuniformity – Any variation of layer thickness, or presence of roughness, within the measurement spot will result in a reduction in reflectance. In severe cases the interference peaks may disappear entirely.

b) Incorrect Structure Definition – If the refractive index of one or more layers in the structure is different from what is described in the layer structure, there may be some mismatch between the blue curve and the red curve.

c) Graded Interfaces – The amplitude of the peaks in the spectrum depends on both the size of the change in refractive index at each interface in the layer structure and the sharpness of the interface. In many hardcoat samples you will find that there is some degree of layer intermixing at the interface, leading to a weaker than expected reflectance at that interface. In severe cases the peaks may disappear entirely.

Window Menu Items

File > Open Reflectance Spectrum...

This command is used to open stored reflectance spectra, which are then displayed and can be analyzed for film properties.

File > Save Measured Spectrum...

This command is used to save measured reflectance spectrum for export or later analysis. All data is saved along with the corresponding wavelength data in comma-delimited format.

File > Save Calculated Spectrum...

This command is used to save the calculated reflectance spectrum for export or later analysis. All data is saved along with the corresponding wavelength data in comma-delimited format.

Edit > Material Library...

The files that FILMeasure uses to describe n and k of different materials can be edited and created by selecting **Edit>Material Library...** from the menu bar. The files that are used to describe n and the material type (e.g., dielectric, semiconductor, metal) are designated index files and have the extension ".nnn". The files that describe k have the extension ".kkk".

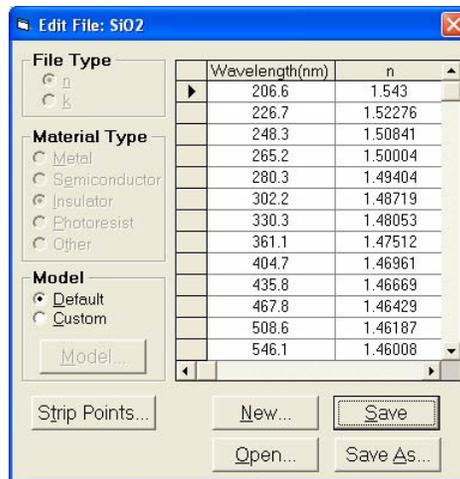


Figure 2.5: **Edit>Material Library...** dialog box.

A new material may be entered into the material library using manually if refractive index (n) and extinction coefficient (k) are known as a function of wavelength for the new material, they may be manually added to the library. For each material there is a file that contains index values as a function of wavelength. This file is named material.nnn. Optionally, a .kkk file may be created. If no .kkk file is created, k is assumed to equal zero over the entire spectrum. To create a new material file:

- Select **Edit>Material Library...** menu item. The **Edit Material** dialog box will appear.
- Click **New...** to create a new material.

- c. Select the type of file and type of material you are ready to create (.nnn or .kkk).
- d. Optimize the functionality of the file by entering index values over the entire wavelength spectrum of the system. The wavelength unit is nanometers. Enter index information every 20 to 50 nm, depending on the complexity of the data. In areas where n or k is quickly changing, more densely spaced the points should be entered.
- e. Alternatively, select on the **Model>Custom** option button and click the **Model** button. A **Custom Model Information** dialog box will appear. Select the appropriate model. Enter in the known coefficients and click **OK**. Cauchy coefficients are displayed in microns. If they are entered in Å, FILMeasure will automatically detect it and convert them to microns.

Set Up > Data Acquisition: Integration Time

This control is used when manually setting the integration time (i.e., when not using **Auto Integration Time:** feature). To set the integration time, make sure that the **Subtract Dark** and **Use Reference** checkboxes are not selected. Enter a time into the **Integration Time (ms)** field and click **OK**. A value of 100 ms is a good starting point. To facilitate rapid adjustment of the integration time, select **Acquire>Start Continuous Acquisition** from the main FILMeasure window menu bar. FILMeasure will now be continuously acquiring and displaying scans. If the scan is off-scale, select **Set Up>Graph Options** from the menu bar. Activate **AutoScale Maximum** to rescale the y-axis. The vertical scale of the spectrum extends from zero to 4095. Thus, a good working level is when the peak height of the sample being measured, or the reference sample, whichever is greater, is 3000-3500 counts. (Note: if the reference measurement saturates – Detector Saturation error – then spurious final measurements will result.) If the maximum signal is too low, increase the integration time. Too large an integration time will result in excessive dark current, so it is sometimes necessary to accept a smaller signal level to limit the dark current.

* * Note * * If the integration time is changed, it will be necessary to re-acquire the dark and reference scans.

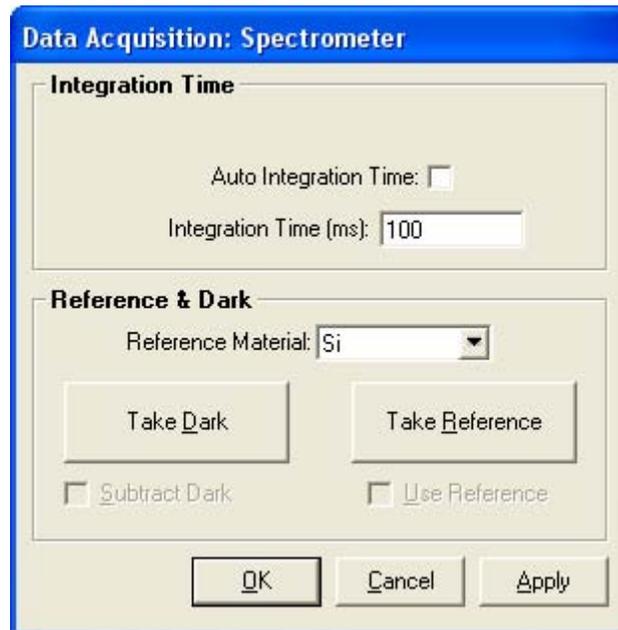


Figure 2.6: **Set Up>Data Acquisition** dialog box.

Set Up > Data Acquisition: Reference Material

Enter here the reflectance (or transmissivity if in transmittance measurement mode) value of the reference sample used. For transmittance measurements referencing with air, enter 1.0. For reflectance measurements, the reflector should have known reflectance characteristics over the region of interest. The reflectance versus wavelength values should be entered into a text file with the extension ".rrr" (stored in the `FILMeasure\Material` subfolder). Materials that already have ".rrr" extensions are available by selecting from the list in the **Reference Material:** field.

Set Up > Data Acquisition: Take Dark

This button allows the dark portion of the baseline measurement to be taken without having to re-take the reference measurement.

Set Up > Data Acquisition: Take Reference

This button allows the reference portion of the baseline measurement to be taken without having to re-take the dark measurement.

Set Up > Data Acquisition: Subtract Dark

This feature allows the dark subtraction portion of the baseline correction to be disabled.

Set Up > Data Acquisition: Use Reference

This feature allows the reference portion of the baseline correction to be disabled.

Set Up > Data Analysis: Data Smoothing

This function averages together a number of data points on either side of each measured data point. For example, if the **Smoothing Points** field is set to 5 then each data point displayed on the screen is actually an average of five data points (the data point plus the two data points on either side). This function can be used to reduce noise when reflectance signals are very weak.

Set Up > Data Analysis: Scans to Average

In order to get the low noise spectrum it is occasionally necessary to acquire a number of reflectance spectra and display their average. This is readily accomplished by setting the Scans to Average field.

Set Up > Graph Options: Axis Fields

The **Graph Options** dialog box may also be accessed by double-clicking on the graph display. The **Horizontal Axis Minimum** and **Maximum** fields are used to control the wavelength range displayed on the screen. Use the **Vertical Axis Minimum** and **Maximum** fields to control the vertical-axis display. Check the **Autoscale Maximum** checkbox to activate y-axis autoscaling. The lower value is always 0 for autoscaling; the maximum y-axis upper limit is 5000.

Set Up > Significant Figures

Select the number of significant figures for FILMeasure to display, between 4 and 7, with a maximum of 0.1 Å resolution.

Set Up > Reflectance Mode (Transmittance Mode)

Choose the correct mode of operation before beginning a baseline measurement. The measurement settings are stored for each of the two possibilities. After taking a baseline in reflectance and in transmittance, this feature allows for switching between reflectance and transmittance with out taking any other baselines.

Set Up > Contact Probe Mode: Activate

If using the contact probe (CP-1), enabling the **Contact Probe Mode** allows spectra to be taken and measured continuously while the probe is depressed on the sample. Continuous measurement can be stopped by pressing the **Stop Measurement** button or by removing the probe from the sample. Once measurement is stopped, a window will appear listing the measurements made since contacting the sample. The software will automatically highlight the second-to-the-last measurement. If the automatically selected measurement is unacceptable, a different

measurement can be selected by clicking on it. The acceptability of the selected measurement must be confirmed by clicking the OK button or by starting another measurement by placing the probe in contact with a sample.

Set Up > Contact Probe Mode: Activate Template Mode

By selecting **Activate Template Mode**, the user can edit and measure to a user-defined template. For more information on editing and measuring templates, go to **Contact Probe – Template Mode** on page 49.

Set Up > Access Control...

The software for the F20 incorporates password protection to limit access to the measurement software and settings. When the software is initially installed the access control is turned off. The software will automatically boot up with Engineer level access that enables access to all features of the program except turning on and off access control and adding and deleting users.

Turning on access control requires Supervisor level access. The software is delivered with one user, a supervisor, in the list of authorized users as shown below:

UserID: filmsuper

Password: filmetricsfff

To turn on access control, log in as filmsuper using the password shown above. The **Activate Access Control** checkbox should now be enabled. By placing a check mark in the **Activate Access Control** checkbox access control will be active. User ID and Password are case-sensitive.

To add an operator level user, select operator from the **Access Level** list box, type a user name and type an initial password for that user. Then click the **Add User** button. To add an engineer or a supervisor user follow the same procedure, but pick the appropriate access level from the list box before pressing the **Add User** button.

To Delete a user, enter the **UserID** and press the **Delete User** button.

Operator and Engineer level users can change their passwords when they are logged in by entering their password into the password box and pressing the change button. Supervisor-level users can change their password or the password of any other user by selecting the appropriate access level, entering the appropriate **UserID** and the new password and pressing **Add User**. If the program finds that a user already exists, it will delete the old entry for that user and create a new entry.

We recommend that you create a new supervisor level user and delete the filmsuper user for maximum security. If all supervisor level users

forget their passwords, it will be necessary to re-install the software and add all the users again.

Set Up > Configuration...

Users can set this to point to the location of layer structure files. The default configuration is set to C:\Program Files\FILMeasure.

Set Up > Show Measured Spectrum

Deselect this function to hide the blue (measured) curve from the graph.

Set Up > Show Calculated Spectrum

Deselect this function to hide the red or gray (calculated) curve from the graph.

Acquire > Start Continuous Acquire (Stop Continuous Acquire)

This feature collects real-time data from the spectrometer. It is useful when searching for a specific location to measure (for example, locating a more uniform area of the sample that exhibits interference fringes).

Acquire > Start Continuous Measure (Stop Continuous Measure)

This feature collects real-time spectrum data and analyzes it – similar to pressing the **Measure** button over and over.

Acquire > Do Single Acquisition

This function collects a single spectrum, blue curve, without performing any analysis.

3 Making Measurements

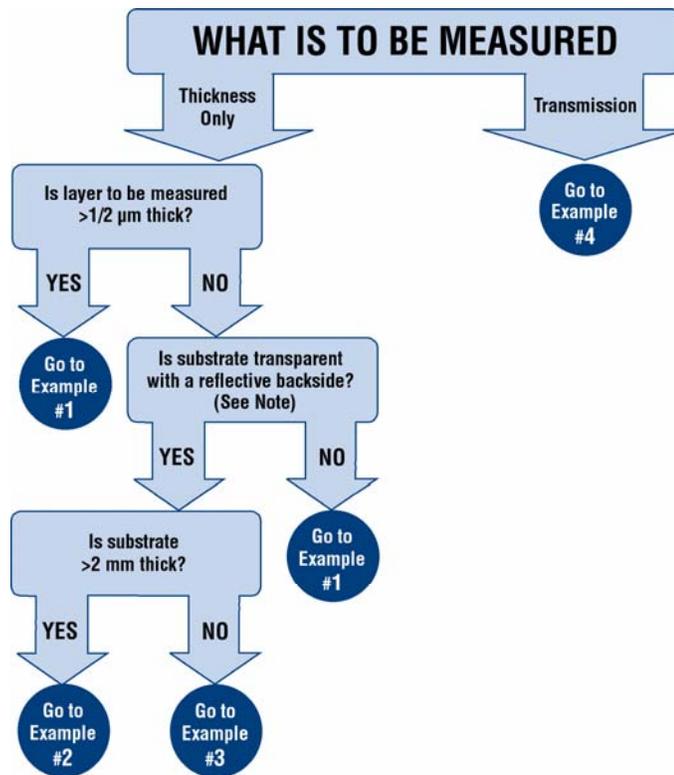
Types of Measurements

Accurate measurements with the F20 rely on using the proper measurement setup. The type of setup that is used depends upon whether both thickness and optical constants are being measured, or just thickness alone. Also important are the thickness of the film and the type of substrate.

The basic steps for any F20 measurement are: 1) selecting and editing the type of film to be measured, 2) taking a baseline measurement, and 3) clicking on the **Measure** button to make the measurement. Each example below will take you through this sequence of steps. In each example it is assumed that the hardware has been set up as described in Chapter 1 Getting Started, and that you have first read through Chapter 2 Software Overview to familiarize yourself with the basic controls.

The “Measurement Assumptions”, “Hints for Improved Accuracy”, and “Troubleshooting” sections describe techniques that should be followed for the most accurate measurements.

Examples that describe the most common measurement setups are described in this section. Use Figure 3.1 to find the proper example for your application.



Note: Transparent substrates are considered to have a reflective backside unless the backside is specially prepared to absorb light incident from the frontside.

Figure 3.1: Selection tree for identifying the example for specific measurements.

Examples

Example #1: Thickness of Films Greater Than ½ Micron Thick: SiO₂ on Silicon

For this example we will demonstrate only the measurement of SiO₂ on silicon (the SiO₂ on Silicon Test Sample provided with the F20 may be used), but this type of measurement has an extremely broad range of applications, including hardcoats, polysilicon, and LCD cell gaps, to name just a few.

Hardware:

If the sample to be measured is flat, any standard or rotating sample stage will work fine. If the sample is curved, or is transparent with films on its backside (such as eyeglass lens applications), a hand-held contact probe measurement device (e.g., Part# CP-1) may be necessary.

Step 1: Select the film structure

Select the film structure to be measured, in this case "SiO₂ on Si", from the **Structure:** list box on the main screen. If the structure to be measured does not exist, a new structure must be defined (see "Editing Film Structures").

Step 2: Edit the film structure

To edit the structure, click the **Edit Structure** button to open the dialog box. Check to see that the film sequence matches that of the actual sample. If not, different films can be selected. Also enter your best guess for the thickness of the film to be measured, and check that only the SiO₂ layer thickness is being measured.

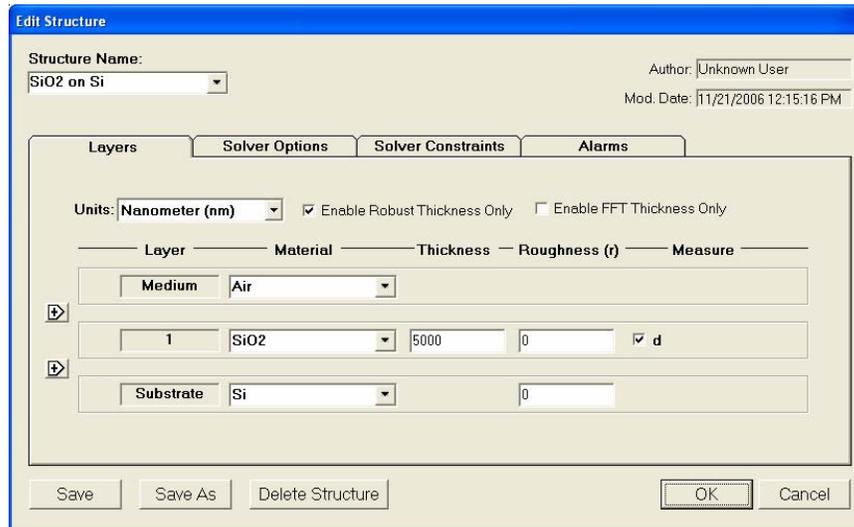


Figure 3.2: Example **Edit Structure>Layers** window for measuring the thickness of a thin film greater than ½ micron thick.

Step 3: Take a Baseline Measurement

Take a baseline measurement by first clicking on the **Baseline** button on the main screen. A dialog box will appear to step you through the process. In the **Take Baseline** dialog box, make certain the **Autoscale Integration** checkbox is selected, and choose the reference material that will be used ("Si" in this case). Then put the reference sample on the measurement stage and click **OK**. A new dialog box will appear with further instructions for the dark measurement: remove the reference sample from the stage (or tilt the sample at an angle) and click **OK**. (In the case of a contact probe, place the probe on the baseline sample and click **OK**, and then remove the probe from the sample and click **OK**.)

Step 4: Make the Measurement

Make the measurement by placing your sample on the stage (or the contact probe on your sample) and click on the **Measure** button. FILMeasure will then acquire the reflectance spectrum and calculate the corresponding thickness. If the measurement was successful, the minima and the maxima of the calculated reflectance (the red line on the graph) will coincide in wavelength with the minima and the maxima of the measured reflectance (the blue line on the graph). In most cases they will not overlap, but will be separated in amplitude.

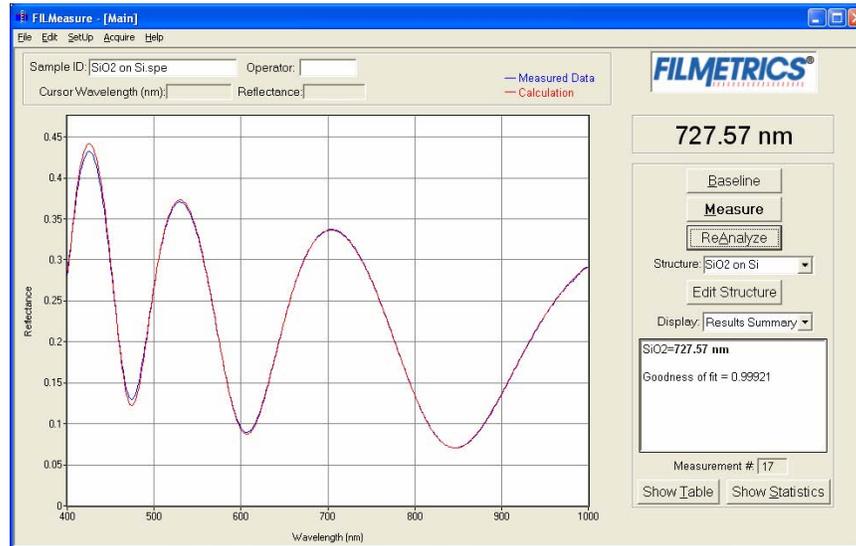


Figure 3.3: Measured and calculated reflectance spectra when measuring the thickness of SiO₂ on silicon.

If the calculated (red) and measured (blue) minima and maxima do not coincide, then the measurement was not successful. There are several possible causes of an unsuccessful measurement. The most common for this type of measurement are described in Cases #1, #2, #3, and #4 in the "Troubleshooting" section.

Example #2: Thickness of Films Less Than ½ Micron Thick on Thick Transparent Substrates: TiO₂ on Glass

This example demonstrates the measurement of TiO₂ on glass. This type of measurement has a broad range of other applications, most commonly optical coating and flat-panel display process films.

Hardware:

If the sample to be measured is flat, the contact sample stage should be used. If the sample is curved, the hand-held contact probe (e.g., Part# CP-1) may be necessary.

Step 1: Select the film structure

Select the film structure to be measured, in this case “TiO₂ on Glass”, from the **Structure:** list box on the main screen. If the structure to be measured does not exist, a new structure must be defined (see “Editing Film Structures”).

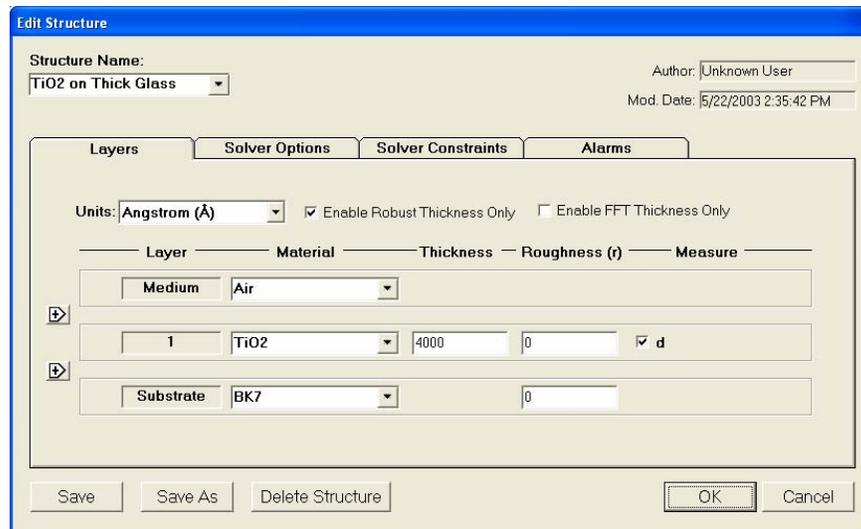


Figure 3.4: Example **Edit Structure>Layers** window for measuring the thickness of a film less than ½ micron thick on a thick, clear substrate.

Step 2: Edit the film structure

To edit the structure, click the **Edit Structure** button to open the dialog box. Check to see that the film sequence matches that of the actual sample. If not, different films can be selected. Also enter your best guess for the thickness of the film to be measured, and check that only the TiO₂ layer thickness is being measured.

Step 3: Take a Baseline Measurement

Take a baseline measurement by first clicking on the **Baseline** button on the main screen. A dialog box will appear to step you through the process. In the **Take Baseline** dialog box, make certain the **Autoscale Integration** checkbox is selected, and choose the reference material that will be used ("BK7" in this case). Then put the reference sample on the measurement stage and click **OK**. A new dialog box will appear with further instructions for the dark measurement: remove the reference sample from the stage (or tilt the sample at an angle) and click **OK**. (In the case of a contact probe, place the probe on the baseline sample and click **OK**, and then remove the probe from the sample and click **OK**.)

Step 4: Make the Measurement

Make the measurement by placing your sample on the stage (or the contact probe on your sample) and click on the **Measure** button. FILMeasure will then acquire the reflectance spectrum and calculate the corresponding thickness. If the measurement was successful, the minima and the maxima of the calculated reflectance (the red line on the graph) will coincide in wavelength with the minima and the maxima of the measured reflectance (the blue line on the graph). In most cases they will not overlap, but will be separated in amplitude.

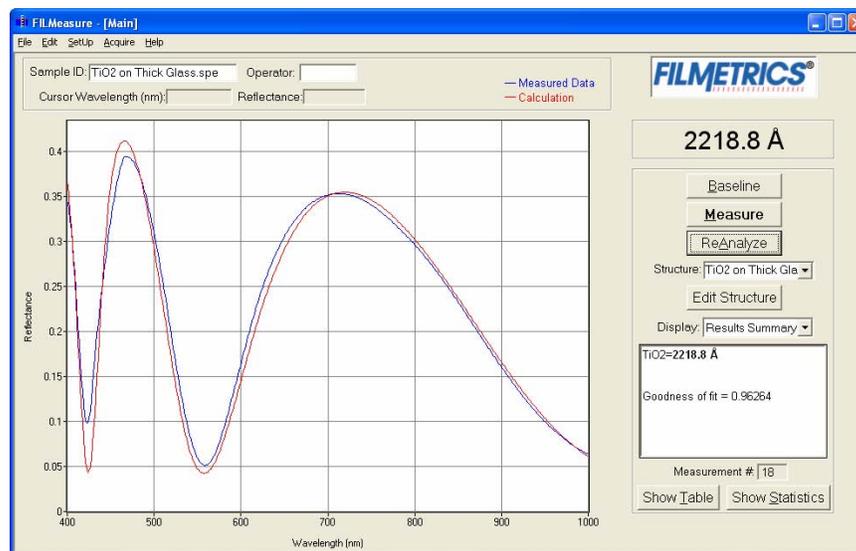


Figure 3.5: Measured and calculated reflectance spectra when measuring the thickness of TiO₂ on glass.

If the calculated (red) and measured (blue) minima and maxima do not coincide, then the measurement was not successful. There are several possible causes of an unsuccessful measurement. The most common for this type of measurement are described in Cases #1, #2, #3, and #4 in the "Troubleshooting" section.

Example #3: Thickness of Films Less Than ½ Micron on Thin Transparent Substrates: MgF₂ on Glass Slide

In this example we will demonstrate the measurement of MgF₂ on a glass slide.

Hardware:

For this type of measurement the sample must be flat, with the front and backsides parallel. The standard SS-1 sample stage is required. The contact stage option is recommended. If you are able to take the baseline measurements with an uncoated substrate, then follow the film structure setup instructions in Example #2.

Step 1: Select the film structure

Select the film structure to be measured, in this case “MgF₂ on Glass”, from the **Structure:** list box on the main screen. If the structure to be measured does not exist, a new structure must be defined (see “Editing Film Structures”).

Step 2: Edit the film structure

The screenshot shows the 'Edit Structure' dialog box with the 'Layers' tab selected. The 'Structure Name' is 'MgF2 on Glass Slide'. The 'Units' are set to 'Micron (µm)'. There are two checkboxes: 'Enable Robust Thickness Only' and 'Enable FFT Thickness Only', both of which are unchecked. The layers are defined in a table:

Layer	Material	Thickness	Roughness (r)	Measure
Medium	Air			
1	MgF2	0.14	0	<input checked="" type="checkbox"/> d
2	BSG	2000	0	<input type="checkbox"/> d
Substrate	Air		0	

At the bottom of the dialog are buttons for 'Save', 'Save As', 'Delete Structure', 'OK', and 'Cancel'.

Figure 3.6: Example **Edit Structure>Layers** window for measuring the thickness of films less than ½ micron thick on a thin transparent substrate.

To edit the structure, click the **Edit Structure** button to open the dialog box. Check to see that the film sequence matches that of the actual sample. If not, different films can be selected. Also enter your best guess for the thickness of the film to be measured, and check that only

the MgF₂ layer thickness is being measured. The “Enable Robust Thickness Only” checkbox should be deselected.

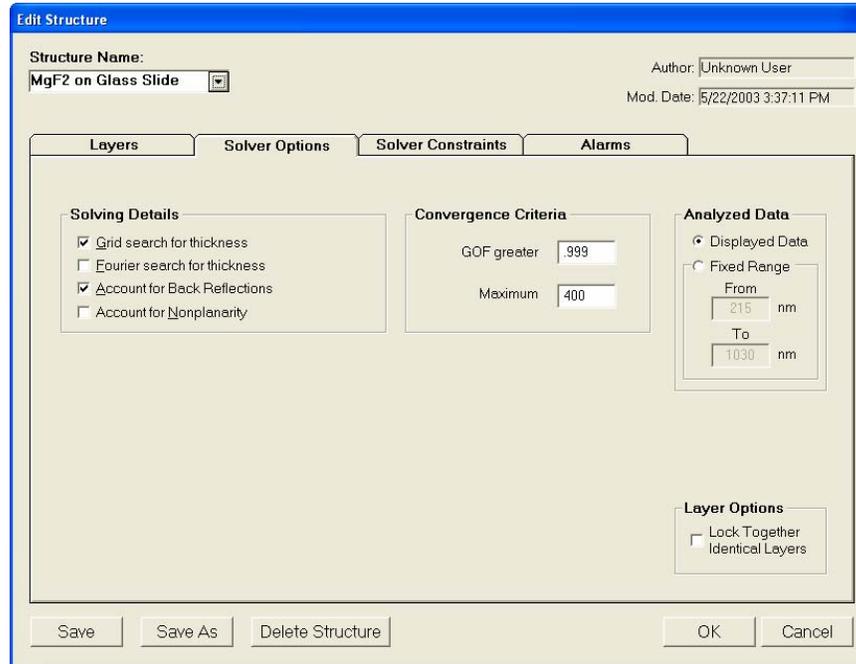


Figure 3.7: Example **Edit Structure**>**Options** window for measuring the thickness of films less than ½ micron thick on thin transparent substrate.

Step 3: Take a Baseline Measurement

Take a baseline measurement by first clicking on the **Baseline** button on the main screen. A dialog box will appear to step you through the process. In the **Take Baseline** dialog box, make certain the **Autoscale Integration** checkbox is selected, and choose the reference material that will be used (“BK7” in this case). Then put the reference sample on the measurement stage and click **OK**. A new dialog box will appear with further instructions for the dark measurement: remove the reference sample from the stage (or tilt the sample at an angle) and click **OK**. (In the case of a contact probe, place the probe on the baseline sample and click **OK**, and then remove the probe from the sample and click **OK**.)

Step 4: Make the Measurement

Make the measurement by placing your sample on the stage (or the contact probe on your sample) and click on the **Measure** button. FILMeasure will then acquire the reflectance spectrum and calculate the corresponding thickness. If the measurement was successful, the minima and the maxima of the calculated reflectance (the red line on the graph) will coincide in wavelength with the minima and the maxima of

the measured reflectance (the blue line on the graph). In most cases they will not overlap, but will be separated in amplitude.

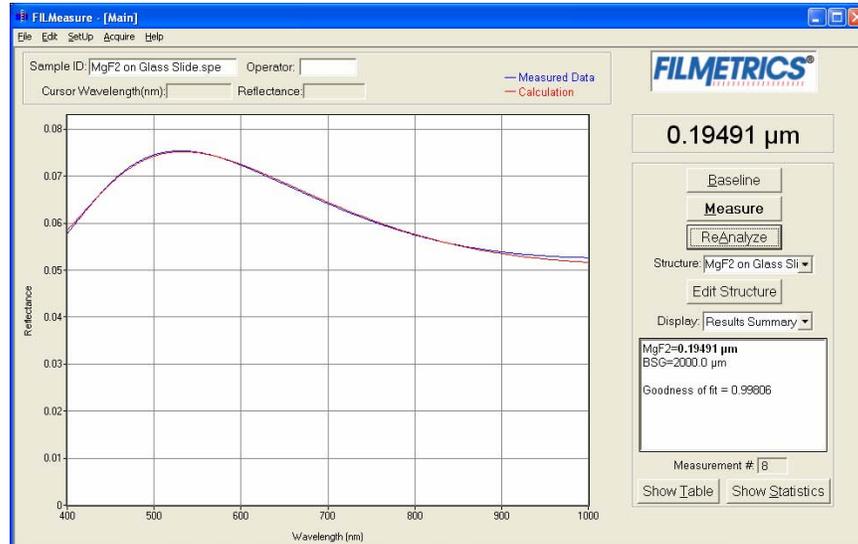


Figure 3.8: Measured and calculated reflectance spectra when measuring the thickness of MgF_2 on a glass slide.

If the calculated (red) and measured (blue) minima and maxima do not coincide, then the measurement was not successful. There are several possible causes of an unsuccessful measurement. The most common for this type of measurement are described in Cases #1, #2, #3, and #4 in the "Troubleshooting" section.

Example #4: Transmittance Measurements

For this example we will demonstrate the acquisition of a transmittance spectrum. If analysis is to be performed on the measured transmittance spectrum, be sure to specify "Transmittance" in the **Options>Measurement Type** section of the **Edit Structure** dialog box.

Hardware:

For this type of measurement the sample must be flat, with the front and backsides parallel. The standard sample stage equipped with the T-1, Transmission Option, is required. When measuring very thin films, use of a vacuum plugged into the vacuum port is recommended.

Step 1: Specify Transmittance Mode

Under the Set Up menu, activate Transmittance Mode.

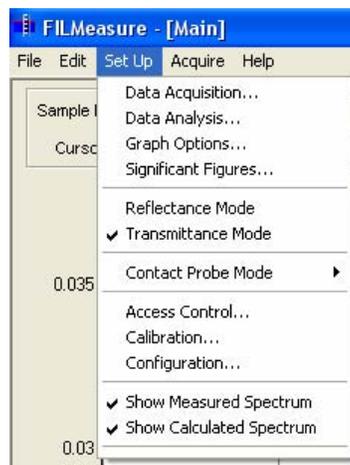


Figure 3.9: Transmittance Mode Setup

Step 2: Take a Baseline Measurement

Take a baseline measurement by first clicking on the **Baseline** button on the main screen. A dialog box will appear to step you through the process. In the **Take Baseline** dialog box, make certain the **Autoscale Integration** checkbox is selected. In the list box, choose the reference sample material that will be used. Be sure the file represents transmittance data. Place the bare substrate on the stage in the light beam and click **OK**.

If measuring layers on a very thin substrate (less than 1 mm), select "Enter Constant..." and enter "1" to use air as the reference. Then click **OK** while the beam is unblocked.

A new dialog box will appear with further instructions for the dark measurement: place an opaque object on the stage to block the beam and click **OK**. Note: Most glasses and plastics absorb UV light below 350 nm, displayed as a sudden drop in transmittance at those wavelengths.

Step 4: Make the Measurement

Make the measurement by placing your sample on the stage. Under the **Acquire>Do Single Acquisition** from the menu bar.



Figure 3.10: **Do Single Acquisition** collects the measured spectrum (blue curve) off of the sample.

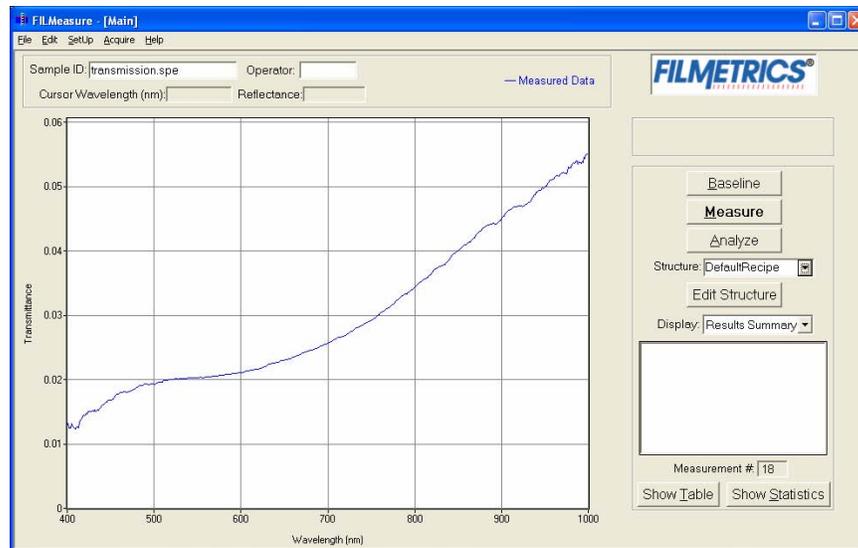


Figure 3.11: Transmittance spectrum.

Measurement Assumptions

The following assumptions must be valid if accurate measurements are to be made with the F20:

1. Every film present in the structure is specified in the **Edit Structure** dialog box. This includes *every* film present in the sample including so-called adhesion films, oxide films (unless they are less than 20 Å or greater than 500 microns thick), and films on the bottom surface of the substrate if the substrate is transparent.
2. The thickness of the measured film is uniform over the spot being measured.

In addition, the following assumptions are made if optical constants and/or very thin films (<500 Å) are to be measured:

3. Each film in the structure is homogeneous and uniform (i.e. the refractive index and extinction coefficient are constant as a function of depth and constant over the entire spot being measured).
4. No significant scattering of the light incident on the sample is occurring, unless it is caused by slight surface roughness that is being accounted for in the structure definition.
5. The top surface of the sample under test is at the same height as the reference sample that was used to make the reference calibration measurement.
6. The sample is flat. (The vacuum chuck may help in this case when samples are warped.)
7. No changes to the measurement system (such as fibers moved) or light source have occurred since the acquisition of the most recent baseline.
8. The light source has been allowed to warm up for approximately 15 minutes.
9. No significant changes in room temperature (> 10 degrees F) have occurred since acquisition of the most recent baseline.

If any of the above assumptions are not true, it may still be possible to make a measurement, but accuracy may be degraded.

Hints for Improved Accuracy

Roughness

Slight amounts of surface or interface roughness may be present that will decrease the GOF value for a measurement. Entering a value for or solving for roughness can account for this roughness, so that a better GOF may be achieved. Generally, roughness is only present when the sample surface looks hazy at the measurement spot. The fact that this haze can be seen means that there is scattered light. (A perfectly smooth surface will scatter no light, and thus the measured spot will not be visible.) Usually roughness less than 25 Å will not be visible, while roughness greater than about 200 Å will be extremely hazy.

Restricting the wavelength range of the analyzed reflectance spectrum

Occasionally the reflectance spectrum from measured films is adversely affected by factors such as absorbing dyes, birefringence, or non-uniformity, none of which can be properly modeled. It may be possible to still make accurate thickness measurements of these films by analyzing only the portions of the spectra that contain valid, uncorrupted thickness information (i.e., oscillations). The portion of the reflectance spectrum that is used to calculate film properties is determined by the graphic display, i.e., only the data shown on the screen is used in the calculations. Therefore, to measure values using a restricted wavelength range, simply select a narrower range by double-clicking on the screen to bring up the **Graph Options** dialog box. An example is shown in Figure 3.12 and Figure 3.13.

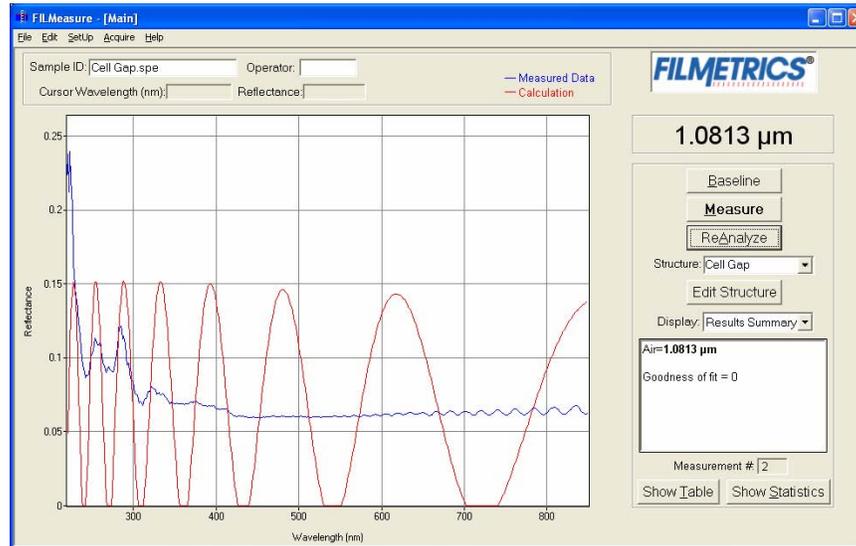


Figure 3.12: Example of non-ideal film (spectrum with no oscillations at lower wavelengths) that requires reduced wavelength range for accurate measurement.

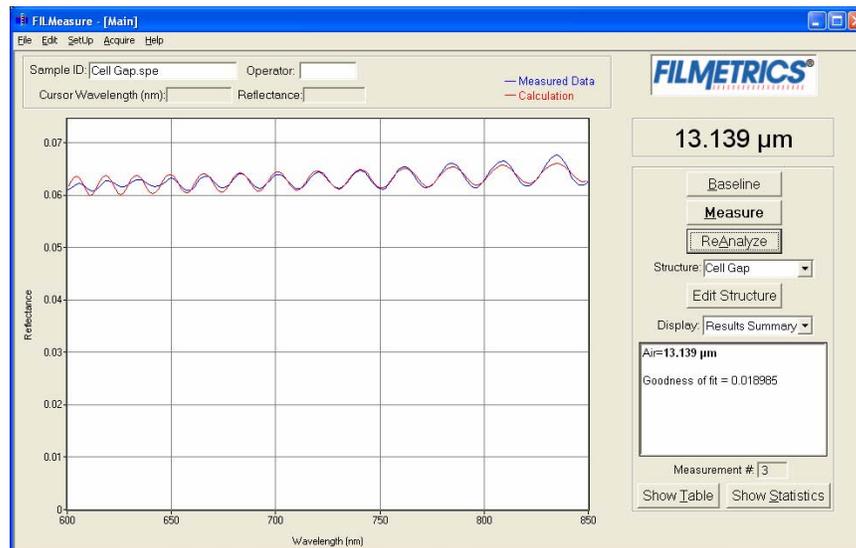


Figure 3.13: Example of reduced wavelength range for measuring thickness of non-ideal films.

Measuring thickness when the approximate thickness is not well known

Unless otherwise specified, FILMeasure will determine a film's thickness by finding the best answer within about 1000 Å of the initial (user supplied) value. If the approximate thickness of the film is not known to

better than about 1000 Å, then the Grid method or the Fourier Transform method of determining approximate thickness may be applied. See “Editing Film Structures” for more details. A Fast Fourier Transform analysis technique is also available. See page 47 for more information.

Measuring photosensitive films

For layers such as unexposed photoresist that can not be exposed to short-wavelength light, a filter may be inserted in the slot on the light source.

Troubleshooting

Incorrect or unreasonable measurement results can be caused by a number of different factors. Below are listed some of the more common symptoms of and solutions for poor measurement results. In all cases it has been assumed that the user has read the “Measurement Assumptions” section listed above, and that each criteria has been met.

Case #1: No oscillations, or portions of oscillations, are present in the measured reflectance spectrum.

There can be several causes of this. The simplest is that the film may just be very thin (<200 Å). Also, if the film is very rough, non-uniform in thickness over the measurement area, or has a graded interface, it may not support coherent optical interference, and thus it may not be able to be measured. Another cause of no oscillations can be an improper baseline measurement, so usually the first step when no oscillations are seen is to carefully retake the baseline.

Case #2: The measured reflectance spectrum has periodic oscillations across the entire screen, but its minima and maxima do not match up with the calculated reflectance.

The most common cause is that the initial thickness guess was considerably different than the actual film thickness, and due to the constraints on possible thicknesses, FILMeasure was not able to look for an answer in the region of the actual thickness. To understand this, it helps to know that the number of oscillations on the screen is proportional to the film thickness. For example, if the measured spectrum has roughly twice the number of the oscillations that the calculated spectrum has, then the measured film is roughly twice the thickness of the calculated thickness. Using this information, the initial thickness guess and the thickness constraints can be set more appropriately in the **Edit Structure** dialog box. Another possible cause is found in case #3 (incorrect dispersion).

Case #3: Two or more different, but nearly the same, thickness readings are obtainable from the same measurement location.

When this occurs usually the measured and calculated spectra match somewhat, but not very well across the entire spectra (i.e., the measured and calculated spectra match only over a small wavelength range and then gradually walk off one another outside this wavelength range). When thickness is the only value being measured, this is normally caused by the refractive index of the measured layer not matching that used by FILMeasure, especially when the film is greater than one micron thick. Unless more accurate index values can be obtained, the best way to solve this problem is to restrict the wavelength range used in the analysis.

Case #4: Not all of the measured spectrum display oscillations.

Some regions of the spectrum are strangely curved (thickness greater than 1 micron). This can be a symptom of non-uniformity in thicker films. In this case simply restrict the wavelength range used in the analysis.

4 Advanced Features

Fast Fourier Transform Thickness Only Mode (FFT TO mode)

The FFT TO mode tends to be more robust when measuring very thick films or thick multi-layer stacks, where the total thickness is greater than 5 microns.

To activate FFT TO mode, select the **Enable FFT Thickness Only** located on the **Layers** tab in the **Edit Structure** box.

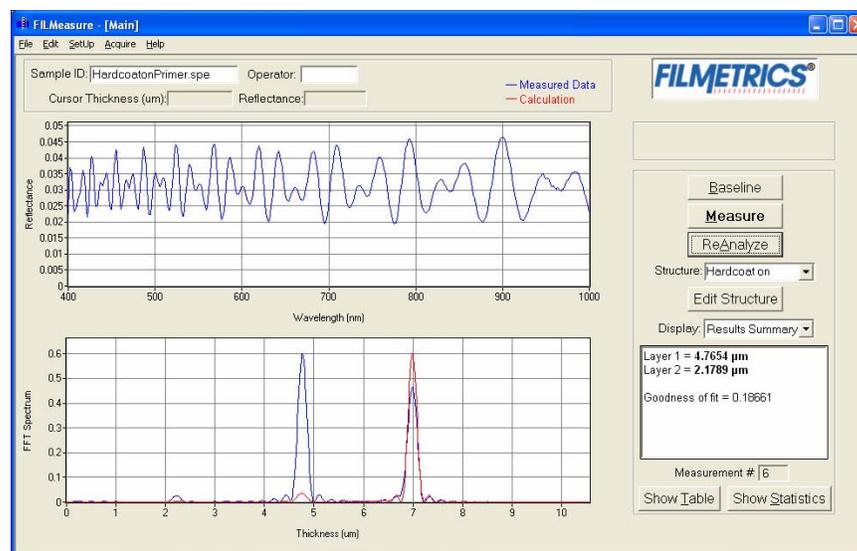


Figure 4.1: The main FILMeasure window shows a split screen with the measured spectrum on the top graph and the FFT spectrum on the bottom graph.

In FFT TO mode, instead of matching the measured reflectance spectrum with a calculated reflectance spectrum, FILMeasure identifies the peaks in the FFT Spectrum and uses them to compute the layer thicknesses. The number of possible FFT peaks is $n*(n+1)/2$ where n is the number of layers. Thus, for a two layer structure, we expect to see three peaks in the FFT spectrum.

Figure 1.1 shows the screen just after measurement of a two layer stack using FFT TO Mode. The upper graph shows a blue curve representing the reflectance spectrum of the sample. The lower graph shows a blue and red FFT spectrum. The blue FFT spectrum is computed from the measured reflectance. The red FFT spectrum is computed from the theoretical reflectance spectrum of a layer stack with the measured layer thicknesses. The small side lobes visible on either side of the two tall

peaks are artifacts of the FFT process and can generally be ignored. The only time the side lobes will cause a problem is if a weak peak from a multi-layer sample is very close to a much stronger peak. If this case occurs FILMeasure may lock onto one of the side lobes by mistake and it may not be possible to measure the layer thickness associated with the weak peak. Reducing the Constraint and/or increasing the guess for the thickness for the layer with the weak peak may be helpful in getting FILMeasure to lock onto the weak peak. If the peak is too weak to reliably measure it is best to change the layer structure definition so that the layer corresponding to the weak peak is eliminated.

Along with the measured layer thicknesses, the Results Text Box also displays the goodness of fit (GOF). More information about the GOF is given below.

Discussion of GOF:

A perfect match between measured and theoretical FFT spectra will result in a GOF of 1.0. To insure accurate results the user may set a minimum acceptable GOF value by entering a number between 0 and 1 into **GOF Error** on the **Constraints Tab** in **Edit Structure**. A warning message will be displayed after each measurement where the GOF falls below the user-specified **GOF Error**. If the GOF is less than 1.0 there are several possible causes as follows:

a) Nonuniformity – Any variation of layer thickness within the measurement spot will result in a reduction in the FFT peak heights. In order to permit easy visual interpretation of the FFT results FILMeasure always scales the amplitude of the red curve so that it matches the blue curve. However, if the scaling factor is not 1.0, FILMeasure reports a reduced GOF even if the red curve appears to exactly match the blue curve on the screen.

b) Incorrect Structure Definition – If the refractive index of one or more layers in the structure is different from what is described in the layer structure, the FFT peak amplitudes in the blue curve will not match the peak heights in the red curve. The software will attempt to scale the red curve, but if there is more than one FFT peak present, the scaling will only result in one correct peak height. If you wish to view the impact of changing the refractive index of one or more layers, simply change the refractive index in the Edit Structure dialog box and click **Analyze (ReAnalyze)**. If there is only a single layer you will notice that the GOF will change, but the red curve should not change much. If there are multiple layers in the structure you will notice that the relative peak heights in the red curve will change when you click **Analyze**.

c) Graded Interfaces – The amplitude of the peaks in the FFT spectrum depends on both the size of the change in refractive index at each interface in the layer structure and the sharpness of the interface. In many common samples you will find that there is some degree of

layer intermixing at the interface, leading to a weaker than expected reflectance at that interface. The FFT peak(s) associated with the intermixed interface will suffer a reduced amplitude and in severe cases the peaks may disappear entirely.

Contact Probe – Template Mode

Contact Probe Template Mode can be activated by selecting **Setup>Contact Probe Mode>Activate Template Mode**. When this option is selected, options will appear on the bottom right corner of the main screen allowing the user to **Edit Template** and **Measure to Template**. Saved templates can be selected from the **Template:** pull-down menu.

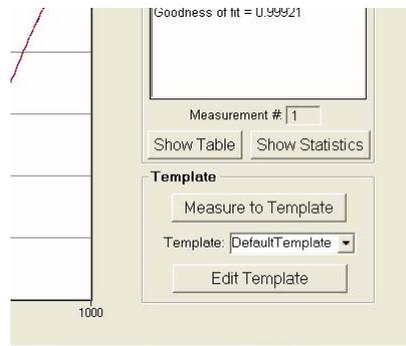


Figure 4.2: To activate **Template Mode**, select **Setup>Contact Probe Mode> Activate Template Mode**.

Template Window

While **Template Mode** is activated, if **Measure to Template** is selected, the **Template Window** will display with the saved template loaded (selected from the **Template:** pull-down menu).

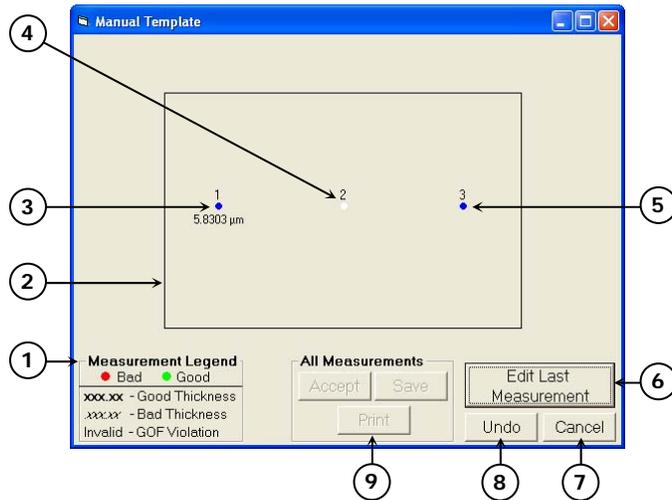


Figure 4.3: The **Template Window** appears when the **Measure to Template** Button is selected.

1. The **Measurement Legend** is displayed on the **Template Window** when **Alarms** are activated.
2. The outline represents the template pattern and shape.
3. When **Alarms** are not activated, points that have been measured are indicated by a blue dot with the measured thickness values. Points that fall outside the thickness range as specified in the **Alarms** section of the **Edit Structure** dialogue are marked according to the **Measurement Legend**. All points must be measured in the numbered order given on the pattern.
4. The next point to be measured is indicated by a blinking dot. All points must be measured in the numbered order given on the pattern.
5. Points that have not been measured are indicated by a blue dot. All points must be measured in the numbered order given on the pattern.
6. **Edit Last Measurement** allows the user to choose the best measurement for the last measured point.
7. Selecting this closes the **Manual Template** window.
8. Selecting this removes the thickness value of the last measured point, so it can be re-measured.

- Once all measurements have been made, the user can accept the measurement results, save the template with measurements, or print the template with the measured values.

Measuring to a Template

Measurements are continuously taken for the active point while the probe is depressed on the sample. Removing the probe from the sample will stop measurement for the active point.

Once measurement is stopped, the template will be updated with the measured thickness of the point. Points that are invalid or are outside of the thickness range specified in the **Alarms** section of the **Edit Structure** window will display as red dots.

To accept the thickness and measure the next point, the probe can then be placed on the next measurement location.

Editing Template

Selecting **Edit Template** while **Template Mode** is activated will bring up the **Template Structure** window. This window allows the user to edit and create new templates by changing the template outline and moving, adding, or removing measurement points on the template.

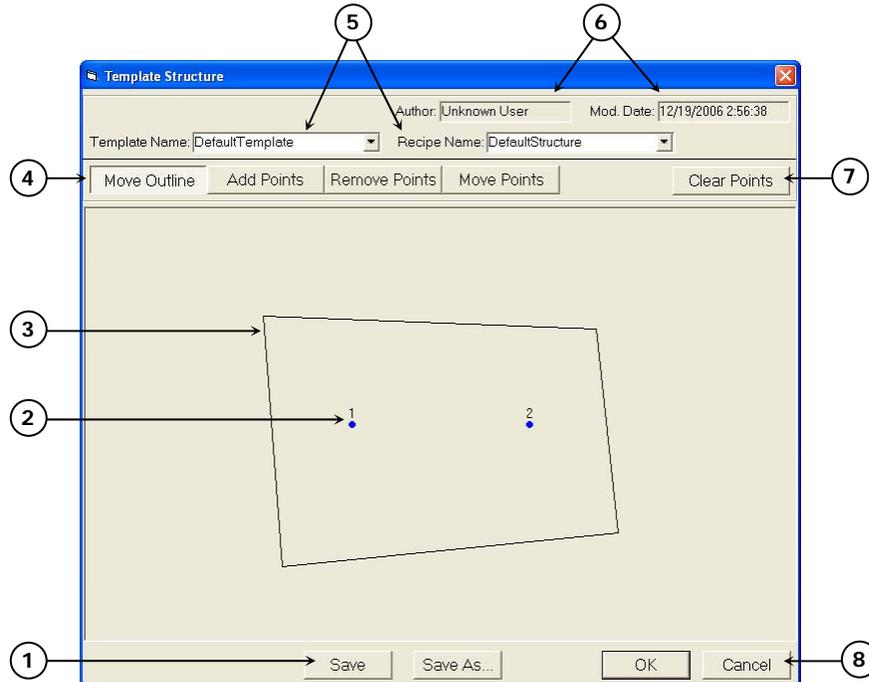


Figure 4.4: Template Structure Window.

- The **Template Structure** can be saved as a new structure, or changes can be saved.

2. Location of measurement points are indicated by blue dots and are labeled by the order in which they will be measured.
3. The outline of the template can be changed to match the pattern of the sample.
4. Selecting **Move Outline** allows the user to click and drag the corners of the polygon to create new shapes. **Add Points**, **Remove Points**, and **Move Points** allow the user to add, remove, and click and drag existing points, respectively. Points are added sequentially, and when points are removed, the measurement order is automatically renumbered.
5. The name of the **Template Structure** is listed here, as well as the layer structure that is currently in use.
6. Author, as defined by user login name, and structure modification date are indicated here.
7. Clears all measurement locations on the template.
8. **OK** closes the **Template Structure** box, retaining any changes made. Changes will not be permanently saved unless **Save** or **Save As** is selected. The **Cancel** button closes the **Edit Structure** box without retaining any changes.

Software Overview for n and k Enabled Systems

For users who have n and k enabled software, certain modifications to the standard FILMeasure software have been made to allow users to accurately determine the index of refraction and extinction coefficient of a film.

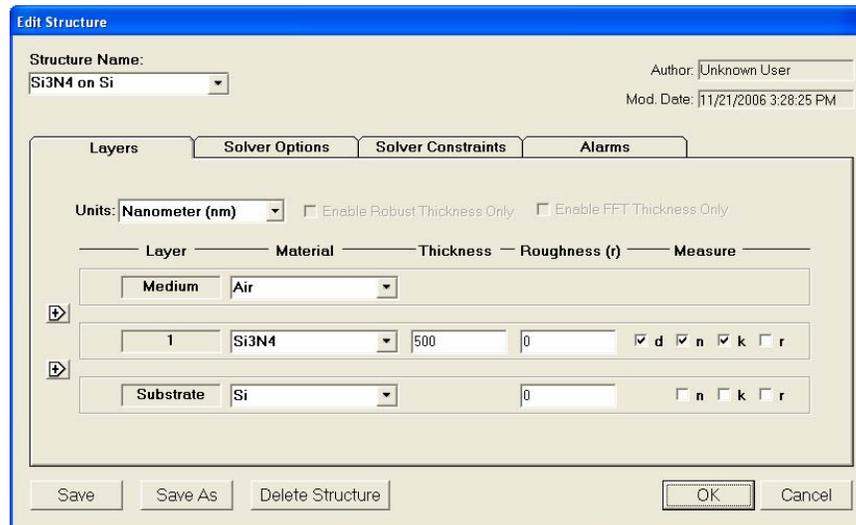


Figure 4.5: **Edit Structure**>**Layers** window for n and k enabled systems.

Edit Structure > Layers: Measuring Optical Constants

For n and k enabled users, n and k can be measured by checking the appropriate box on the right-hand side of the Layers field in the **Edit Structure** dialog box. When an optical constant is selected for measurement, **Enable Robust Thickness Only** and **Enable FFT Thickness Only** cannot be selected.

In general, thickness values can be measured independently if the n and k of the layer are specified. However, unless the thickness is extremely well known, n and k cannot be measured without also measuring thickness. Also, unless the material is a dielectric ($k=0$), n and k must be measured together.

As with most measurements, the uncertainty of the measured data increases as the number of simultaneously measured values increases. This is especially true here, as changes in d , n , and k can often affect the measured reflectance spectrum in similar ways. Thus it is best to provide as much information about the film structure as possible.

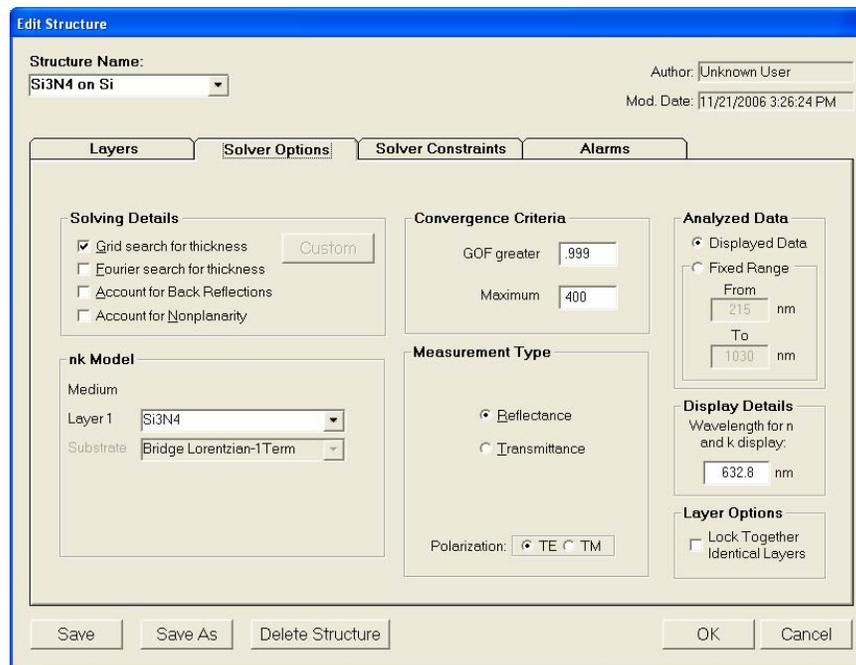


Figure 4.6: **Edit Structure>Solver Options** for n and k enabled systems.

Edit Structure > Options: nk Model

When measuring n and k for a film, the general dependence of these values upon wavelength must be specified. This dependence is determined by the type of material to be measured. For example, insulators, semiconductors, and metals all have a unique type of n and k wavelength dependence. Dozens of models for these different

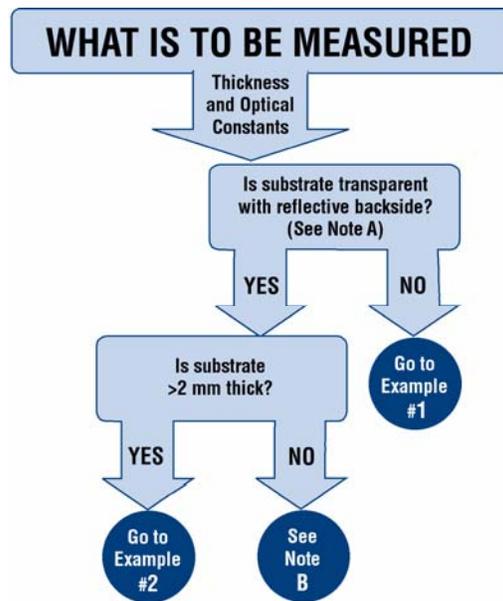
dependencies have been proposed and used over the years. FILMeasure uses a few of the most versatile and accepted of these models. For insulators, the Cauchy model is used, for semiconductors, either the Amorphous or Bridge-Lorentzian model, and for metals, the Drude model. These models, and starting coefficients values, are selected automatically when a material is chosen for the **Material** lists in the **Edit Structure** dialog box. Other models may also be specified by selecting them from the **nk Model** box in the **Options** tab.

Edit Structure > Options: Display Details

When solving for n and k , the film values displayed in the **Results Summary** box of the main FILMeasure window will be the values determined for the wavelength entered here.

Measurement Examples for n and k Enabled Systems

Examples that describe the most common setups for index and thickness measurement are described in this section. Use Figure 4.7 to find the proper example for your application.



Note A: Transparent substrates are considered to have a reflective backside unless the backside is specially prepared to absorb light incident from the frontside.

Note B: These samples may require special preparation to reduce backside reflections in order to be measured accurately.

Figure 4.7: Selection tree for identifying the example for specific measurements.

Example #1: Thickness and Optical Constants of Films on Opaque Substrates: Si₃N₄ on Silicon

For this example we will demonstrate the measurement of Si₃N₄ on silicon but this type of measurement has an extremely broad range of applications, including the measurement of oxides, polysilicon, and optical coatings.

Hardware:

Any standard or rotating sample stage should work fine. The sample frontside must be flat. If the sample backside is not flat and parallel with the frontside, then the contact stage must be used.

Step 1: Select the film structure

Select the film structure to be measured, in this case "Si₃N₄ on Si", from the **Structure:** list box on the main screen. If the structure to be measured does not exist, a new structure must be defined (see "Editing Film Structures").

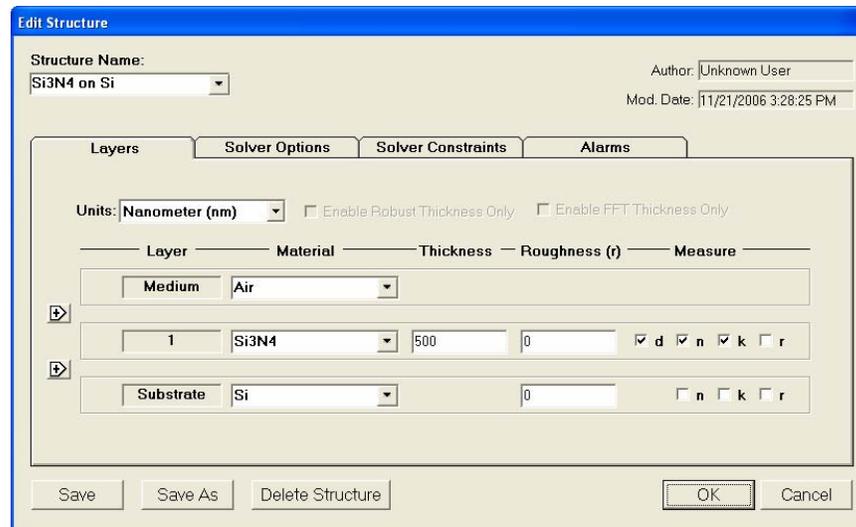


Figure 4.8: Example **Edit Structure>Layers** window for measuring the thickness, n , and k of films on an opaque substrate.

Step 2: Edit the film structure

To edit the structure, click the **Edit Structure** button to open the dialog box. Check to see that the film sequence matches that of the actual sample. If not, different films can be selected. Also enter your best guess for the thickness of the film to be measured. Also check that thickness, n , and k of the Si₃N₄ layer are selected to be measured.

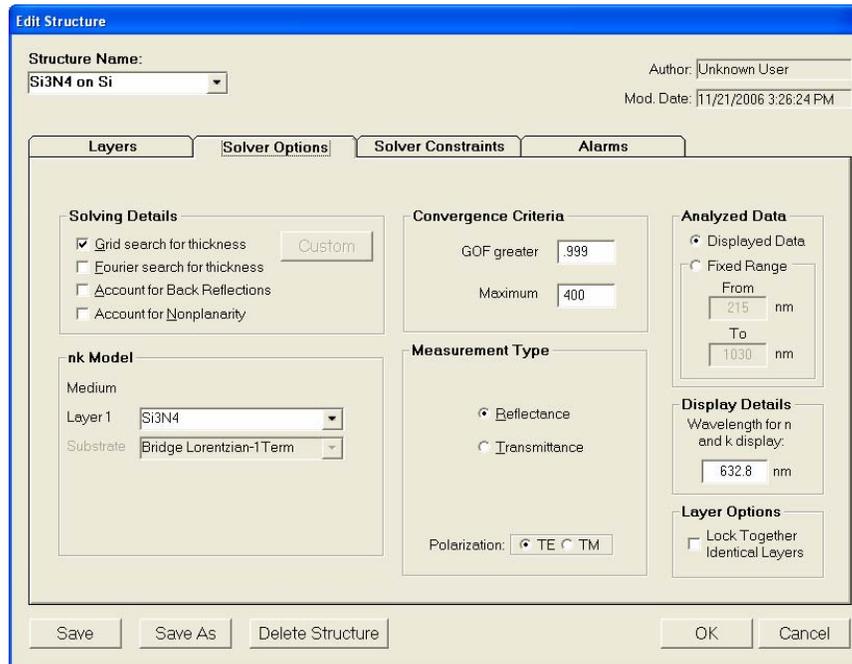


Figure 4.9: Example **Edit Structure>Options** window for measuring the thickness, n , and k of films on an opaque substrate.

Step 3: Take a Baseline Measurement

Take a baseline measurement by first clicking on the **Baseline** button on the main screen. A dialog box will appear to step you through the process. In the **Take Baseline** dialog box, make certain the **Autoscale Integration** checkbox is selected, and choose the reference material that will be used ("Si" in this case). Then put the reference sample on the measurement stage and click **OK**. A new dialog box will appear with further instructions for the dark measurement: remove the reference sample from the stage (or tilt the sample at an angle) and click **OK**.

Step 4: Make the Measurement

Make the measurement by placing your sample on the stage and click on the **Measure** button. FILMeasure will then acquire the reflectance spectrum and calculate the corresponding thickness. If the measurement was successful, the calculated reflectance (the red line on the graph) will coincide with the measured reflectance (the blue line on the graph).

If the measured and calculated spectra do not fall on top of each other, the resulting thickness, n , and k values are incorrect. If the mismatch between measured data and calculation is only slight, the results reported will only be off by a small amount. If the measured and calculated spectra match, but the results are implausible, there may be a

problem with the sample positioning and light collection. Causes and corrective actions to improve the measurements are listed in Cases #1 and #2 in the “Troubleshooting” section.

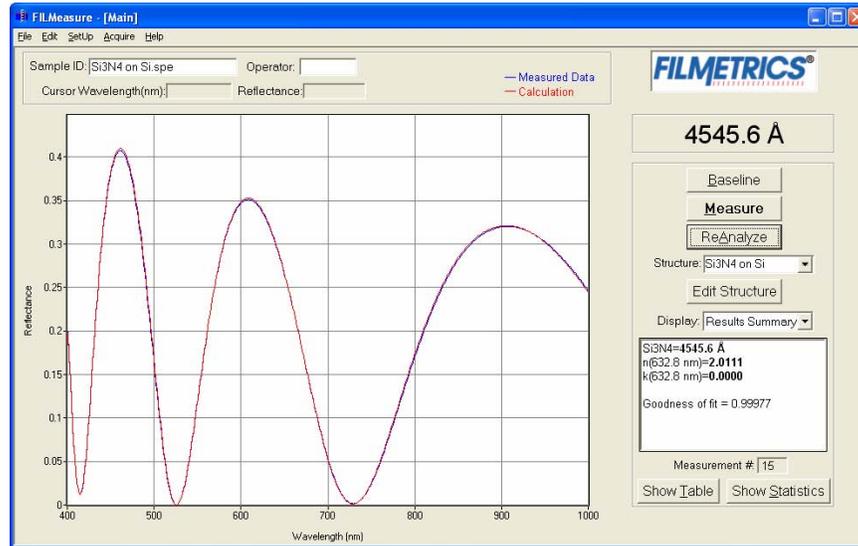


Figure 4.10: Measured and calculated reflectance spectra when measuring the thickness, n , and k of Si_3N_4 on silicon.

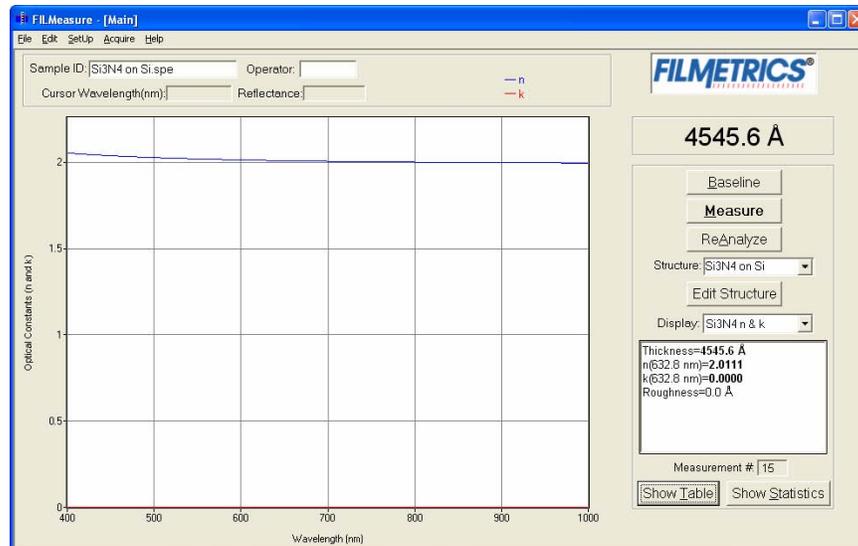


Figure 4.11: Calculated n and k curves may be selected from the **Display** list

Example #2: Thickness and Optical Constants of Films on Thick Transparent Substrates: MgF₂ on BK7

This type of measurement is typically applied to optical coatings on glass substrates, as well as anti-reflection coatings on various transparent substrates.

Hardware:

The contact stage must be used when measuring the thickness and optical constants of films on a thick transparent substrate (see Chapter 1 for setup of the contact stage). Use of the contact stage means that the front side of the sample must be flat.

Step 1: Select the film structure

Select the film structure to be measured, in this case “MgF2 on BK7”, from the **Structure:** list box on the main screen. If the structure to be measured does not exist, a new structure must be defined (see “Editing Film Structures”).

The screenshot shows the 'Edit Structure' dialog box with the 'Layers' tab selected. The 'Structure Name' is 'MgF2 on BK7'. The 'Units' are 'Angstrom (Å)'. The 'Layer' is 'Medium', 'Material' is 'Air', 'Thickness' is '2000', and 'Roughness (n)' is '0'. The 'Substrate' is 'BK7', 'Material' is 'BK7', and 'Thickness' is '0'. The 'Measure' checkboxes for 'd', 'n', 'k', and 'r' are checked. The 'Author' is 'Unknown User' and the 'Mod. Date' is '8/16/2006 8:15:17 AM'. Buttons for 'Save', 'Save As', 'Delete Structure', 'OK', and 'Cancel' are visible at the bottom.

Figure 4.12: Example **Edit Structure>Layers** window for measuring the thickness, n , and k of films on a thick transparent substrate.

Step 2: Edit the film structure

To edit the structure, click on the **Edit Structure** button to open the dialog box. Check to see that the film sequence matches that of the actual sample. If not, different films can be selected. Also enter your best guess for the thickness of the film to be measured.

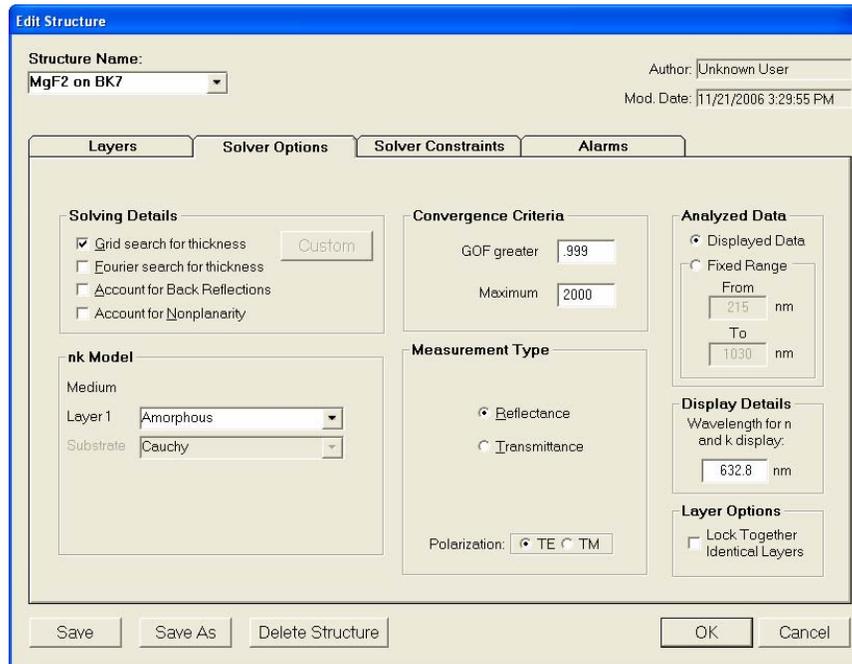


Figure 4.13: Example **Edit Structure>Options** window for measuring the thickness, n , and k of films on a thick transparent substrate.

Step 3: Take a Baseline Measurement

Take a baseline measurement by first clicking on the **Baseline** button on the main screen. A dialog box will appear to step you through the process. In the **Take Baseline** dialog box, make certain the **Autoscale Integration** checkbox is selected, and choose the reference material that will be used ("BK7" in this case). Then put the reference sample on the measurement stage and click **OK**. A new dialog box will appear with further instructions for the dark measurement: remove the reference sample from the stage (or tilt the sample at an angle) and click **OK**. (In the case of a contact probe, place the probe on the baseline sample and click **OK**, and then remove the probe from the sample and click **OK**.)

Step 4: Make the Measurement

Make the measurement by placing your sample on the stage and click on the **Measure** button. FILMeasure will then acquire the reflectance spectrum and calculate the corresponding thickness. If the measurement was successful, the minima and the maxima of the calculated reflectance (the red line on the graph) will coincide in wavelength with the minima and the maxima of the measured reflectance (the blue line on the graph).

If the measured and calculated spectra do not fall on top of each other, the resulting thickness, n , and k values are incorrect. If the mismatch

between measured data and calculation is only slight, the results reported will only be off by a small amount. If the measured and calculated spectra match, but the results are implausible there may be a problem with the sample positioning and light collection. Causes and corrective actions to improve the measurements are listed in Cases #1 and #2 in the “Troubleshooting” section.

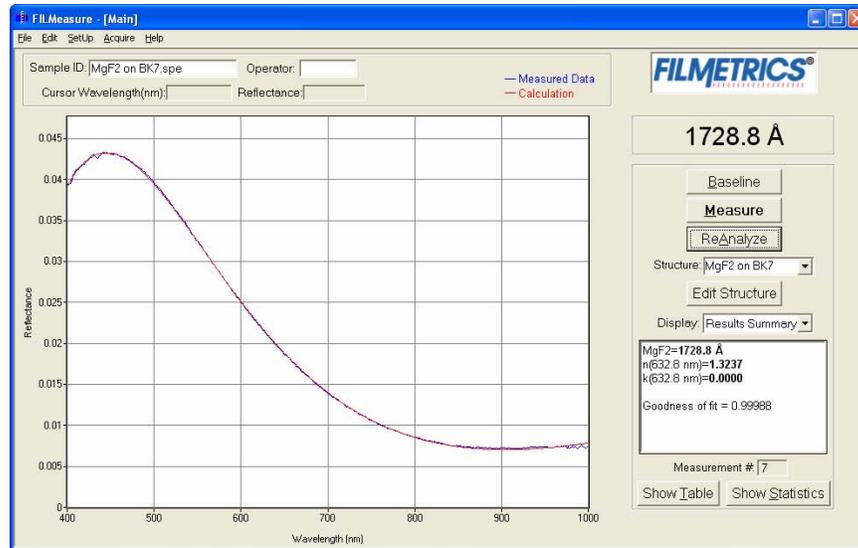


Figure 4.14: Measured and calculated reflectance spectra when measuring the thickness, n , and k of MgF₂ on BK7 glass.

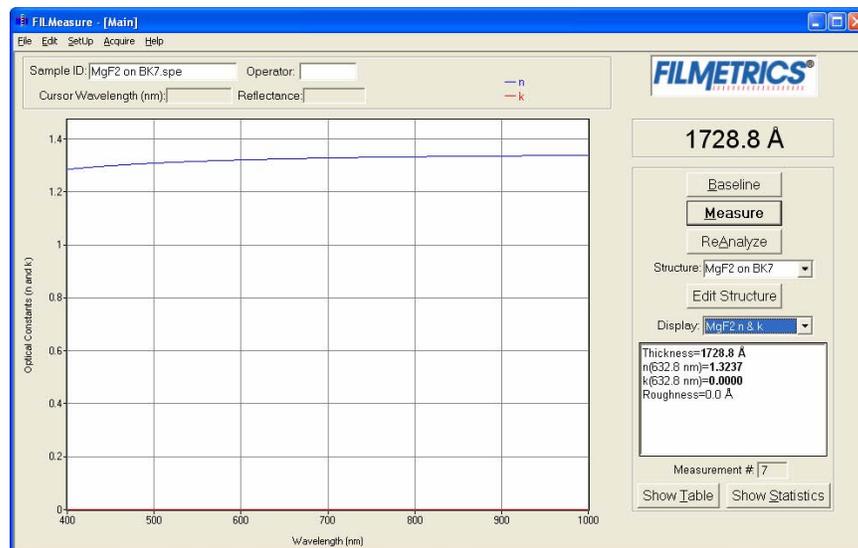


Figure 4.15: Calculated n and k curves may be selected from the **Display** list.

Troubleshooting

Case #1: Poor matches between the measured and calculated reflectance spectra when measuring thickness and optical constants.

There can be many causes of this problem, including those listed in Case #1 and Case #2 above. Most commonly when a poor fit between the spectra occurs, it is because 1) the components of the film structure are not all included in the **Edit Structure>Layers** dialog box, 2) very inaccurate initial guesses for the film thickness(es) have been listed, 3) the optical constants listed in the **Edit Structure>Layers** dialog box are far from the actual optical constants in the material, or 4) the film being measured has properties that are not taken into account by FILMeasure. Examples of these properties are graded interfaces, non-uniform films, and voids.

Case #2: Several different answers, or one unreasonable answer, are found when measuring thickness and optical constants, even though a good match is found between the measured and calculated reflectance spectra.

This normally occurs when a large number of properties are being measured on a very thin film. In general, the thinner a film is the less unique information that can be obtained from it. To understand this, read Chapter 5 Theory of Operation. To solve the problem, one must usually reduce the number of properties being measured.

Hints for Improved Accuracy

Roughness

Slight amounts of surface or interface roughness may be present that will decrease the accuracy of the measurement of optical constants. Entering a value for or solving for roughness can account for this roughness, so that optical constants can be measured. Generally, roughness is only present when the sample surface looks hazy at the measurement spot. The fact that this haze can be seen means that there is scattered light. (A perfectly smooth surface will scatter no light, and thus the measured spot will not be visible.) Usually roughness less than 25 Å will not be visible and will have little effect on measurement results. Roughness greater than about 200 Å will be extremely hazy to the point accurate measurement of optical constants will not be possible.

Restricting the wavelength range of the analyzed reflectance spectrum

Restricting the wavelength range can also be helpful in optical constant measurements if n and k are not accurately described over the whole wavelength range by a single model. If n and k are saved to file when measured with a restricted wavelength range, n and k versus wavelength data will only be saved for that specified range.

Creating and Editing Material Files

Creating n and k files from a calculated spectrum (n and k enabled systems only)

Files for n and k can be created directly from a calculated spectrum, where n and k are measured. Once a spectrum is analyzed, go to **File>Save n and k to files...** and save the files in C:\Program Files\FILMeasure\Material\. This will save your n and k files as a custom material which can be loaded into the layer structure.

Creating new n and k files

New n and k files can be created by going to **Edit>Material Library...** Clicking the **New** button will allow the user to define a new material file. Once clicked, while the **Default Model** is selected, the user can manually enter wavelength versus n or wavelength versus k values.

The user can also select **Custom Model**. While this is selected, clicking on the **Model...** button allows the user to create n and k files using predefined mathematical models.

Once completed, clicking **Save As...** will save the new file as a custom material for later use.

Editing n and k files

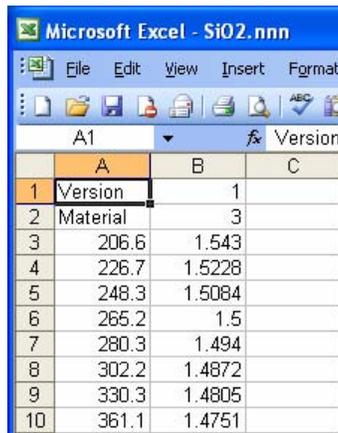
Existing material files can be edited by going to **Edit>Material Library...** There, the user can load a material file by clicking **Open**. Values can then be changed manually. Clicking **Save** will save the file for later use.

Converting Microsoft Excel files into FILMeasure n and k files

For wavelength versus n or wavelength versus k data saved in Excel (*.xls) format, the data can be directly saved as material files that can be read by FILMeasure.

For both n and k files, the data should follow the format of figure 4.3, where the wavelength values, in units of nanometers, are in the first column, and the n or k values are in the second. Note that the version number (cell B1) refers to version of the file. For this cell, you can use 1. The material number (cell B2) refers to what material category the file corresponds to. The material categories (and their corresponding numbers) are: metal (1), semiconductor (2), insulator (3), photoresist (4), and other (5). By putting the correct value for the material number, the file will automatically be sorted into the correct category when selecting the material in the **Edit Recipe** window.

To save the file created by Microsoft Excel, go to **File>Save As...** For **Save as Type:** choose **CSV (Comma delimited) (*.csv)**. For n files, save the file as "**FILENAME.nnn**", and for k files, save the file as "**FILENAME.kkk**" (FILENAME represents the name you wish to call the file; note that quotation marks must be used to enclose the filename in Excel to force the extension to **.nnn** or **.kkk**). The file should be saved in the directory **C:\Program Files\FILMeasure\Material**. Clicking **Save** will save the material files for later use.



	A	B	C
1	Version		1
2	Material		3
3	206.6	1.543	
4	226.7	1.5228	
5	248.3	1.5084	
6	265.2	1.5	
7	280.3	1.494	
8	302.2	1.4872	
9	330.3	1.4805	
10	361.1	1.4751	

Figure 4.3: Creating n file using Microsoft Excel.

5 Theory of Operation

Measurement Theory

The F20 measures thin-film characteristics by either reflecting or transmitting light through the sample, and then analyzing this light over a range of wavelengths. Because of its wave-like properties, light reflected from the top and bottom interfaces of a thin-film can be in-phase so that reflections add, or out-of-phase so that reflections subtract. Whether the reflections are in- or out-of-phase (or somewhere in between) depends on the wavelength of the light, as well as the thickness and properties of the film (e.g., reflections are in-phase when $\lambda = (2 * n * d) / i$, where λ is the wavelength, n is the refractive index, d is the film thickness, and i is an integer). The result is characteristic intensity oscillations in the reflectance spectrum (see Figure 5.1). In general, the thicker the film, the more oscillations there are in a given wavelength range.

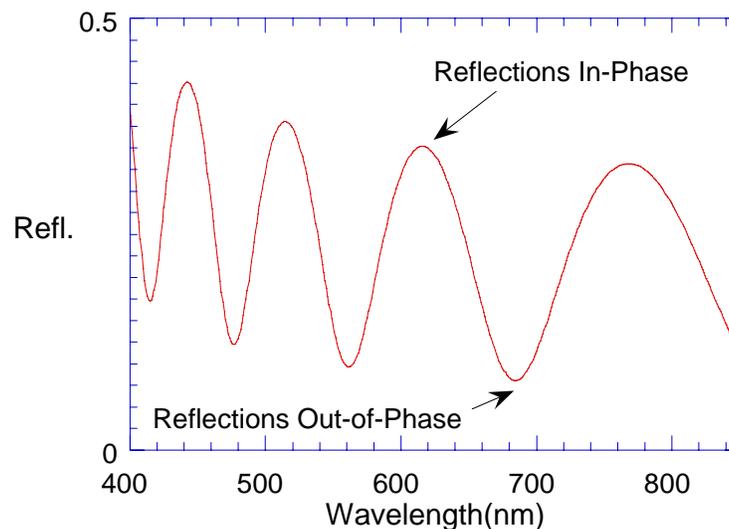


Figure 5.1: Example of reflectance spectrum with oscillations.

The amplitude of the oscillations is determined by the refractive index and extinction coefficient of the films and substrate. Therefore, by analyzing the period and amplitude of these oscillations, the F20 can determine thickness and optical properties (n and k) of multiple thin-films.

Thickness Measurement Details

Optical thin-film thickness measurements require the successful completion of two tasks: acquisition and then analysis of an accurate reflectance spectrum. To determine film thickness, FILMeasure calculates a reflectance spectrum that matches as closely as possible the measured spectrum. FILMeasure begins with an initial guess for what the reflectance spectrum should look like theoretically, based on the user's input of a film structure for the sample. Then FILMeasure varies the parameters it is solving for until the calculated reflectance spectrum matches the measured data. Mathematically, this procedure is complicated by the fact that as the thickness of the films in the calculation is varied there can be many near matches. Therefore, an approach that simply homes in on a solution by finding successively better approximations will not work unless the starting guess for optical thickness is within approximately 1000 Å if the actual thickness.

In measuring thickness only, FILMeasure avoids homing in on a false solution by searching the entire acceptable thickness range to determine the thickness that gives the best possible match between the measured and calculated spectra. The thickness range searched is determined by the initial guess for thickness together with the thickness constraint. If no thickness is entered for an initial guess, FILMeasure will search the entire thickness range from 0 to 100 microns. Since the time to find a solution is proportional to the range of thicknesses being searched it is beneficial to provide an initial guess for the thickness of the films to be measured.

Optical Constants (n and k) Measurement Details

Measurement of optical constants (refractive index and extinction coefficient, also called n and k) requires a simultaneous determination of film thickness. The exception to this is for measurement of a bare substrate. The approach used by FILMeasure to determine film thickness and optical constants is the same as that used to measure thickness alone, except that now n and k are also varied to optimize the match between calculated and measured reflectance spectra.

Since n and k vary as a function of wavelength, it is necessary to solve for them at every wavelength. For a completely unknown material it is not possible to do this using a reflectance spectrum only since at each wavelength only one known parameter (reflectance) is known and there are two unknowns (n and k). However, n and k are not independent, but are related to each other via what is known as the Kramers-Kronig relation. If n were known at all wavelengths, k could be computed solely from n . Since it is only possible to measure n over a finite wavelength range, k cannot be computed directly from n .

In reality, however, there is plenty of data present from a single reflectance spectrum to determine both n and k simultaneously. This is due to the fact that the refractive index at any given wavelength is not independent of the refractive index at adjacent wavelengths, but follows a smooth dependency that can be accurately modeled by a theoretical equation. Furthermore, if there is an equation for refractive index it can be transformed using the Kramers-Kronig relations to yield k . Thus, if the equation for refractive index has three adjustable parameters it is only necessary to adjust these three parameters, plus the thickness in order to match the calculated and measured spectra.

Therefore, the measurement of n and k has been reduced to choosing an appropriate model for n and k as a function of wavelength and then adjusting the parameters in the model to obtain a good fit to the measured data. FILMeasure uses different models depending on the type of material being measured.

The parameter space being searched to find a solution is potentially quite large since it involves thickness plus the adjustable parameters of the model. Furthermore, since there are many near-matches as the thickness in the model is varied, it is important to reduce the parameter space being searched. This is done by homing in on the match closest to the initial guess. This will only be the correct solution if the initial guess for thickness is within about $\frac{1}{2}$ wavelength of the correct value. To permit more robust solution FILMeasure can search the entire constrained thickness range to determine the correct thickness before it begins solving for n and k . This initial search feature is enabled by checking one of the appropriate search mechanisms in the **Edit Structure>Options** dialog box.

F20 Hardware Operation

The F20 performs two distinct functions: data acquisition and data analysis. Data analysis specifics are discussed in Chapter 2 Software Overview. In this section we describe how the F20 acquires accurate spectral reflectance data.

Light is supplied by a tungsten-halogen bulb that generates light from approximately 375 nm to 3000 nm. This light is delivered to and collected from the sample through a fiber-optic cable bundle and a lens. The intensity of the reflected light is measured at 512 different wavelengths with a spectrometer. The F20 spectrometer uses a diffraction grating to disperse the light and a linear photodiode array to measure the light at the different wavelengths. The photodiode array operates by integrating the current generated by light falling on each of the 512 pixels. After a user-selectable integration time, the accumulated charge in each photodiode is read by the computer. Because a longer integration time results in a larger charge, it is the integration time that

determines the sensitivity of the spectrometer. Adjustment of the integration time is used to obtain the proper signal level. Too short an integration time results in a weak, noisy signal, while too long of an integration time results in a saturated signal.

The Baseline Measurement

The baseline measurement allows the FILMeasure software to take into account the response inherent to the F20 reflectance measurement hardware. It does this by measuring a reference sample and by taking a "dark" reading. In any optical system there are many components whose characteristics vary with wavelength (e.g., the output of the light source and the sensitivity of the spectrometer). However, when reflectance measurements are made, only variations in reflectance vs. wavelength due to the sample under test are of interest. Therefore, FILMeasure must perform a calibration to determine the spectral response of the system. This is done by making a measurement of a "reference" sample that has known reflectance characteristics. Note that it is not necessary for the reference sample to be the same as the substrate upon which films to be measured reside. The only purpose served by the reference sample is to permit calibration of the optical system. For example, it is possible to use a Si wafer as the reference sample and then measure films on GaAs, InP, glass, plastic, etc.

After the reference measurement is made a dark reading is taken. A non-zero dark level is due to current leakage inherent to photodiodes, which causes each photodiode in the array slowly charges up even when no light enters the spectrometer. Thus, in order to make an accurate measurement of the light entering the spectrometer, it is necessary to subtract this "dark" current contribution. This is the purpose of the "dark" reading, which measures the magnitude of the dark current for a given integration time. When a "dark" measurement is made, a spectrum is measured that represents the signal generated by the spectrometer when a sample of zero reflectance is measured. To simulate a sample with zero reflectance during a "dark" measurement, a specularly reflecting sample can be held at an angle with the light source turned on, or in many cases the light source may simply be turned off momentarily during the dark measurement.

Due to drift in the light source and temperature of the spectrometer electronics, it is a good idea to take a baseline periodically.

Appendix A How to Contact Us

We welcome suggestions from our users on ways to improve our software and hardware. Please send us any suggestions you may have for improvements in the manual or new features you would like to see in the software.

We may be reached by phone at 858-573-9300, by fax at 858-573-9400, or by e-mail at support@filmetrics.com.

Appendix B Performance Specifications

	Thickness Range	Thickness Range when measuring <i>n</i> and <i>k</i>	Accuracy ¹	Precision ²	Stability ³
F20	150 Å to 50 μm	1000 Å to 5 μm	The greater of 0.4% or 10 Å	1 Å	0.7 Å
F20-UV	30 Å to 20 μm	500 Å to 3 μm		2 Å	1.2 Å
F20-NIR	1000 Å to 250 μm	3000 Å to 10 μm		1 Å	0.7 Å
F20-EXR	150 Å to 250 μm	1000 Å to 10 μm		10 Å	10 Å
F20-HC	150 Å to 50 μm	N/A			
F20-XT	1000 Å to 450 μm	N/A	0.4%	2 Å	25 Å

¹ Thermally grown SiO₂ on Si (except for F20-XT: Si on SiO₂ on Si).

² Standard deviation of 100 thickness readings of 500 nm SiO₂ film on silicon substrate. Value is average of standard deviations measured over twenty successive days. F20-XT values are based on 7 μm Si on SiO₂ on Si sample.

³ Two sigma based on daily average of 100 readings of 500 nm SiO₂ film on silicon, measured over twenty successive days. F20-XT values are based on 7 μm Si on SiO₂ on Si sample.

Appendix C Application Note: Si₃N₄

Theoretical Underpinnings

The refractive index of a single layer film is related primarily to the depth of the minima found in the measured reflectance. The reflectance at the interference fringe minima of a film deposited onto Si is zero when the refractive index is near 1.97. The reflectivity at the fringe minima for a film with a refractive index of 2.00 is the same as that for a film with a refractive index of 1.94. Therefore, it can be difficult to unambiguously determine the refractive index from a reflectance measurement. However, for most films the user knows that the refractive index is either always greater than or always less than 1.97 so there is no uncertainty. Silicon nitride is one of the few rare films whose refractive index spans this critical range. Fortunately, there is a solution for silicon nitride that allows us to determine which of the two possible refractive index values is correct. This is done by measuring both n and k for silicon nitride and by realizing that silicon nitride with a refractive index larger than 1.97 has measurable absorption (non-zero k) at wavelengths less than 420 nm. Thus, to get good results for n the widest possible wavelength range should be used (especially going down to short wavelengths) and the user should simultaneously measure both n and k .

Discussion of Si₃N₄ n and k Measurement

Silicon nitride is a dielectric material commonly used in semiconductor fabrication processes. The refractive index of stoichiometric Silicon Nitride is 2.05 at 633 nm. However, in practice the refractive index of deposited films can vary from 1.7 or less (films containing excess hydrogen or oxygen) to as high as 2.5 or more (Si rich films). The measurement of n and k is complicated by the fact that this refractive index range (1.7 to 2.5) spans a critical range for films deposited on Si substrates. In order to get an unambiguous result for measurement of n , the structure description should be set by choosing "Si₃N₄ (Si Rich)" as the material for the silicon nitride layer. To confirm that the proper model is chosen, go to the options tab and note that the model displayed is "Si₃N₄". If the Si₃N₄ model is not displayed in the **nk Model** list and Si₃N₄ is not in the list of models, then newer software is required. It is important that both n and k be measured simultaneously (put a check mark for n and for k in the **Edit Structure>Layers** dialog box). When using the Si₃N₄ model the constraints for n and k should be set to large values (at least 5). If the film is very thin (less than 50 nm), it may be necessary to set the material to "Si₃N₄" or "Si₃N₄-thin", instead of "Si₃N₄ (Si Rich)", to get reproducible results, but this should only be used as a last resort.

Step-by-step instructions for measuring silicon nitride on Si:

1. Start FILMeasure and click the **Edit Structure** button.
2. Set the material for the **Medium** to "Air".
3. Set the material for **Layer 1** to "Si₃N₄ (Si Rich)".
4. Enter a guess for the layer thickness of the silicon nitride into the thickness box for **Layer 1**.
5. Put check marks in the *d*, *n*, and *k* check boxes for **Layer 1**.
6. Set the material for the **Substrate** to "Si".

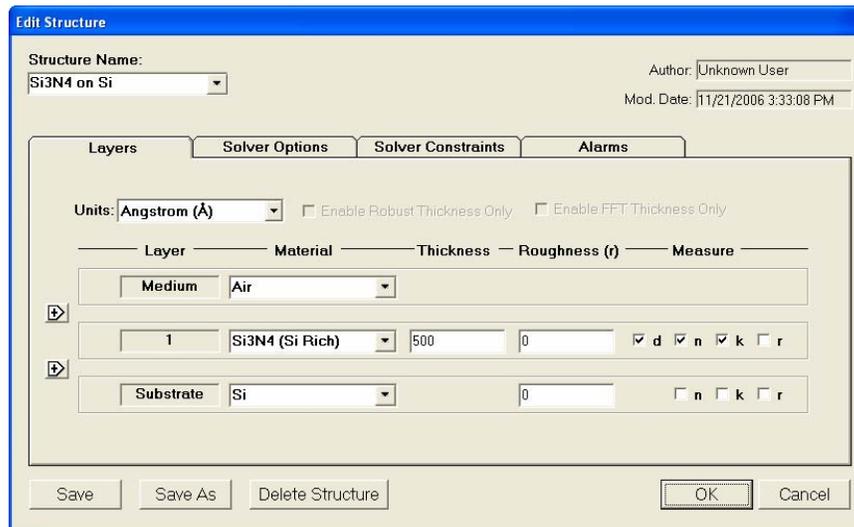


Figure A.1: Settings for steps 1-6.

7. Click on the **Options** tab.
8. Click on **Grid search for thickness** under **Solving Details**.
9. Make sure there is no check mark for **Account for Back Reflections**.
10. Under **Convergence Criteria**, set the number of **Maximum Iterations** to "600" and set **GOF greater than** to "0.999".
11. Under **Analyzed Data** select **Fixed Range** and enter "From: 200" and "To: 1100".
12. Under **Measurement Type** select **Reflectance**.

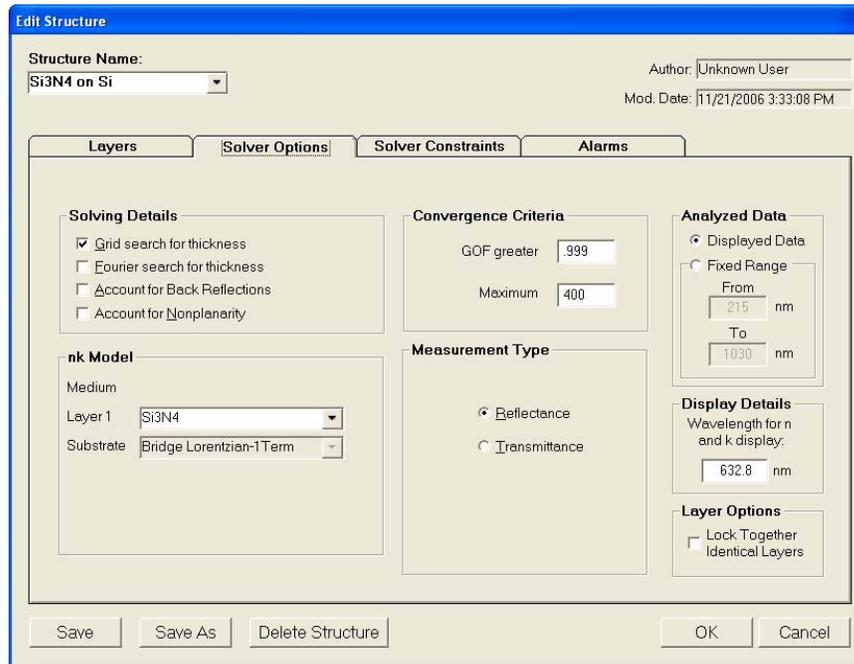


Figure A.2: Settings for steps 7-12.

13. Click on the **Constraints** tab.
14. Set the constraint for d to 75%.
15. Set the constraint for n to 5 and the constraint for k to 5.

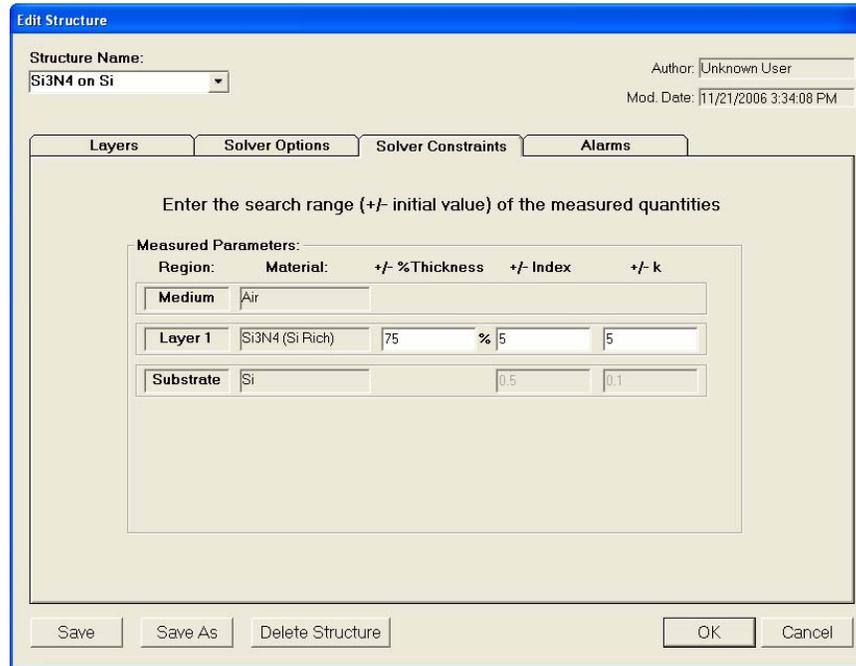


Figure A.3: Settings for steps 13-15.

16. Click **Save As** and give the structure a name.
17. Follow the instructions in the manual for measuring dielectric layers.

Appendix D Optional Features

D.1 Measuring Optoelectronic Devices

VCSEL cavity resonance dips and distributed Bragg reflectors (DBRs) may be measured by selecting **Opto Values** from the **Measure:** list box. To measure laser cavity resonance dips, select **Cavity Dips** from the **Find** list box. This routine works by finding the wavelength that corresponds to the minimum reflectance in a pre-determined wavelength range. The wavelength range that is searched can be restricted in one of two ways, which are selectable in the **Cavity Dip Setup** dialog box. The simplest way to restrict the wavelength range is to manually specify the range. The second is to restrict the search to the range between the lowest wavelength above a given reflectance value and the highest wavelength above a second (usually identical) reflectance value. The upper and lower limits of the search are displayed on the screen, along with the cavity dip location.

The location of the center wavelength and the bounding reflectance minima of a DBR may be measured by selecting **DBR Center** from the **Find** list box. The reflectance threshold for finding the mirror minima can be specified with the **DBR Center Setup** box. This is especially useful when measuring multiple and convoluted DBR structures.

D.2 Measuring Filters

The cut-off wavelengths of high-pass, low-pass, band-pass, and notch filters may be measured by selecting **Filters** from the **Measure:** list box. Filter measurements are made by taking appropriate reference and dark readings as described in the "Taking a Baseline" section, and clicking on **Measure**. Measurement parameters are set on the main screen. The wavelength range searched is restricted to that displayed on the screen, which is determined by the **Set Up>Graph Limits** dialog box from the menu bar.

D.3 Correlation Function

While it is always best to use accurate material index information, the FILMeasure software may be set up to correlate thickness results to targeted values using a binomial expression ($y=Ax+B$), when measuring films >1000 nm. This option can be activated upon customer request. Contact Filmetrics for details. If access to correlation parameters is user specific, you may wish to activate **Set Up>Access Control...** from the menu bar. Supervisor and Engineer levels have access to the correlation parameters.

Correlation parameters are stored with each structure. Settings and activation are specific for each structure.

To set up the correlation parameters, perform the following:

1. Enter the **Edit Structure** dialog box.
2. Click the **Edit Correlative Coef.** button.
3. Enter at least 3 measured and 3 target thicknesses. For best results, enter many measurements at varying thicknesses.
4. Click the **Calculate Coefficients** button.
5. Click the **Apply Updated Coefficients** button to apply and close the dialog box.

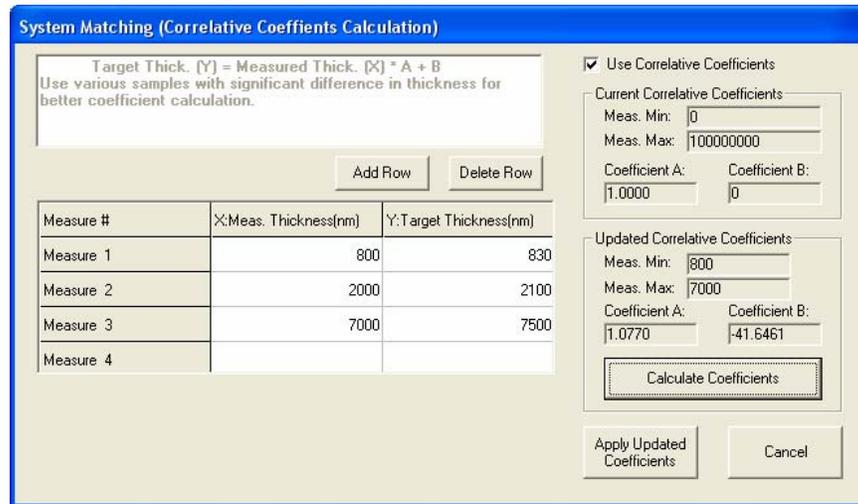


Figure A.4: **Correlation Coefficients** window.

Measurements reported will be automatically adjusted. A “Correlation Active” note will appear in the results box after an analysis has taken place. Measured thickness values must be within the range of thicknesses specified in the correlation table.

To deactivate the correlation parameters, go to the Correlation dialog box and deselect the **Use Correlative Coefficients** checkbox and press **Close**.

Appendix E Light Bulb Replacement



* * Warning: * * Hazardous voltages are present within the unit. Never attempt any maintenance without disconnecting the power cord.

Step by step:

1. Exit FILMeasure program and turn off your computer.



2. Disconnect power cable from the back of the unit.



3. Disconnect fiber optic cables from the front of the unit.
4. Turn the unit over and remove the four recessed screws opening the two halves of the enclosure.



* * Warning: * * Caution, avoid touching any interior components, other than the lamp, lamp base, and housing.

5. Loosen lamp set screw (counter clockwise to loosen).
6. Insert new lamp fully into lamp housing. Do not touch the lamp glass.
7. Secure lamp with setscrew (clockwise). Do not over tighten.
8. Plug new lamp into the lamp power connector. Do not test lamp with lid removed.
9. Replace the unit's top cover and screws. Insert cord into wall supply and test light.

Appendix F Automation and Data

Measurements can be automated and additional data analysis can be performed by user-supplied software that communicates with FILMeasure via use of an ActiveX object or by Dynamic Data Exchange (DDE). The ActiveX automation approach is the preferred method. The DDE automation is included only for backward compatibility with older software. An example ActiveX program written in Visual Basic 6.0 is located in `Program Files\FILMeasure\ActiveXClientVB`. An example program illustrating how to use DDE with FILMeasure is located in the `Program Files\FILMeasure\Client\VC` folder.

Although the ActiveX example program is written in Visual Basic, the ActiveX communication can be done in any programming environment that supports ActiveX. The FILMeasure program exposes an ActiveX object called `FMRemoteControl`. The object has one function called `.Execute(strCommand, intCancel)`. You pass in a string-based command in `strCommand` for FILMeasure to execute. The `Execute` function returns a string in response to the command. You can also check the result of the execute command separately using the property `.Response`. See the example program for information about how to instantiate the `FMRemoteControl` object.

The syntax for each command includes a command keyword followed by a left parenthesis followed by one or two arguments followed by a closing parenthesis. If the command has no arguments (like **GetGOF**, for example) the parentheses are not needed. Some commands have arguments which are optional. Optional arguments are denoted with the use of `{}`.

Some examples of valid commands are:

```
ActiveSpectrometer(1)
```

```
ActiveSpectrometer(1, 52DCB3F6C6E04622871DA36251D35DE4)
```

Although all commands are listed below, commands that refer to measurement options not included with a particular system will not function. For example, the commands dealing with `OptoValues` measurements are only available in FILMeasure versions containing the **Measure: OptoValues** option. The commands understood by FILMeasure are as follows:

ActiveSpectrometer(`<arg1>,{<arg2>}`) – Sets the current active spectrometer used for data acquisition to `<arg1>`. If the system has two spectrometers then a value of 3 may be used for `<arg1>` to activate both spectrometers simultaneously. USB versions may have more than one system connected and a GUID is required as `<arg2>` to specify a system box. If only one system is connected to the computer then

<arg2> is optional. To associate a GUID with a system serial number use the GetSystemGUID command.

AnalyzeLayer – Equivalent to pushing the thickness analyze button. This command can be useful for testing DDE applications.

AnalyzeOpto – Equivalent to pushing the OptoValues analyze button. This command can be useful for testing DDE applications.

AuthenticateRefBac – Recovers previously stored Reference and Background spectra taken during baseline procedure.

ContinuousAcquire(<arg1>) – If <arg1> is 1, it will start continuous acquire mode. 0 stops continuous acquisition.

CopySpectrum – Copies currently displayed spectrum onto the clipboard.

GetActiveSpectrometer({{<arg1>}}) - Returns the active spectrometer in the system with the GUID specified in <arg1>. <arg1> is optional if only one system is connected.

GetGOF – Returns the GOF resulting from the last measurement.

GetGOFThreshold - Returns the threshold used to calculate GOF.

GetK – Returns the value of K resulting from the last measurement.

GetLastBaselineDate - Returns the date the most recent baseline was performed. Returns 0 if no baseline exists.

GetN – Returns the value of N resulting from the last measurement.

GetNumSpectrometers({{<arg1>}}) – Returns the number of spectrometers in the system with the GUID specified in <arg1>. <arg1> is optional if only one system is connected.

GetNumSystems - Returns the number of systems connected.

GetRoughness(<arg1>) – Returns the measured roughness of the layer specified by <arg1>.

GetSerialNumber({{<arg1>}}) – Returns the serial number of the system with the GUID specified in <arg1>. <arg1> is optional if only one system is connected.

GetSystemGUID(<arg1>) – Returns the GUID of the system with the SystemID specified in <arg1>. SystemID must be a number from 1 to the number returned by GetNumSystems.

GetSystemType({{<arg1>}}) – Returns the system type with the GUID specified in <arg1>. <arg1> is optional if only one system is connected.

GetThickness(<arg1>) – Returns the measured thickness of the layer specified by <arg1>.

MeasureLayer – Equivalent to pushing the **Measure** button. Returns the measured thickness of layer 1.

MeasureOpto – Equivalent to pushing the OptoValues **Measure** button. Returns the measured position of DBR or FP parameter specified.

MeasureSpectrum – Equivalent to pushing the Spectrum **Measure** button. Copies measured spectrum to the clipboard.

OpenSpectrum(<arg1>) – Opens the spectrum whose name and path are specified in <arg1> and displays it on the graph. Note that since quotation marks are not used, filenames cannot contain commas or parentheses.

OptoDBRThreshold(<arg1>) – Sets the percentage threshold for DBR measurements to the value specified by <arg1>.

OptoDBRThresholdMode(<arg1>) – use 0 in <arg1> to specify percentage of absolute reflectivity, use 1 to specify percentage of maximum reflectivity.

OptoFPMeasurementMode(<arg1>) – use 0 in <arg1> to specify measuring based on a percentage of the maximum or absolute reflectivity, use 1 to specify measuring restricted by wavelength.

OptoFPReflectanceLimits(<arg1>,<arg2>) – use <arg1> and <arg2> to specify the lower and upper reflectivity limits.

OptoFPReflectanceThresholdMode(<arg1>) – use 0 in <arg1> to use the Absolute option, use 1 to use the Maximum option.

OptoFPWavelengthLimits(<arg1>,<arg2>) – used to set the lower and upper wavelength limits.

OptoMeasurementMode(<arg1>) – use 0 to select cavity dip, use 1 to select DBR peak.

PasteSpectrum – Paste spectrum from clipboard and graph it.

PasteSpectrumRaw – Paste spectrum from clipboard, use reference and dark if selected, and graph it.

QuitProgram – Exit FILMeasure program

SaveCalculation(<arg1>) – Save calculated spectrum to file specified in <arg1>.

SaveNK(<arg1>,<arg2>) – Saves n and k data to the name and path specified in <arg1> for layer <arg2>. Do not include the 3-digit extension. They will default to *.nnn and *.kkk.

SaveRefVsTime(<arg1>,<arg2>) – Saves the current Reflectance vs. Time plot to the name specified in <arg1> for wavelength ID specified in <arg2>. <arg1> should only be a filename, do not include a path or the

3-digit extension. It will default to *.vst. The saved filename and path will be displayed in the DDE box.

SaveSpectrum(<arg1>) – Saves the current measured spectrum using name and path specified in <arg1>. Note that since quotation marks are not used, filenames cannot contain commas or parentheses.

SetDConstraint(<arg1>,<arg2>) – Sets the thickness constraint for layer <arg1> to +/-<arg2> percent.

SetIntegrationTime(<arg1>,{<arg2>}, {<arg3>}) – Sets the integration time to <arg1> milliseconds for SpectrometerID <arg2>. For a single spectrometer system, the SpectrometerID is "1" and <arg2> is optional. USB versions may have more than one system connected. If more than one system is connected to the computer SpectrometerID, <arg2>, must be supplied and a GUID is required as <arg3> to indicate which system. If only one system is connected to the computer then <arg3> is optional. To associate a GUID with a system serial number use the GetSystemGUID command. If <arg2> is not supplied <arg3> must not be supplied.

SetMat(<arg1>,<arg2>) – Set material for layer <arg1> to material <arg2>.

SetMatMedium(<arg1>) – Set material for incident medium to material <arg1>.

SetMatSubstrate(<arg1>) – Set material for substrate to material <arg1>.

SetMode(<arg1>) – Set measurement mode to <arg1> (<arg1> must be either transmittance or reflectance)

SetNA(<arg1>) – Set numerical aperture for measurement optics (only used in F40 systems).

SetReferenceMaterial(<arg1>) – Set reference material to material <arg1>

SetStartWavelength(<arg1>) – Set starting wavelength for data analysis to <arg1>.

SetStructure(<arg1>) – Set structure to <arg1>. Note Arg1 must exactly match the name of an existing structure in the list of structures. Valid structure names cannot contain parentheses.

SetRecipe(<arg1>) – Set recipe to <arg1>. Note Arg1 must exactly match the name of an existing recipe in the list of recipes. Valid recipe names cannot contain parentheses.

SetStopWavelength(<arg1>) – Set stop wavelength for data analysis to <arg1>.

SetThickness(<arg1>,<arg2>) – Sets the initial guess thickness of the layer specified by <arg1> to the thickness value specified by <arg2>. Returns the thickness value given in <arg2>.

Start – Starts a Reflectance vs Time plot. Only support Reflectance vs.Time.

Status – Verify the system is ready for commands.

Stop – Stops a Reflectance vs Time plot.

StoredSpectraAcquire({<arg1>},{<arg2>}) – Acquires a spectrum and stores into array in memory, where <arg1> is the argument for ActiveSpectrometer and <arg2> is a GUID to select a system box. Return value is SpectrumID that can be used to analyze or retrieve the spectrum. Before switching between spectrometers using <arg1> and <arg2> you must first execute ActiveSpectrometer at least once for each spectrometer after program startup. The ActiveSpectrometer command is slower than using StoredSpectraAcquire with <arg1> and <arg2> present, so it is preferable to use <arg1> and <arg2> to switch between spectrometers when doing high speed measurements.

StoredSpectraAnalyze(<arg1>) – Analyzes a stored spectrum. <arg1> is the SpectrumID that determines which spectrum to analyze. Valid SpectrumID is from 1 to the number of stored spectra.

StoredSpectraClear – Clear all stored spectra and free associated memory.

StoreSpectraRetrieve(<arg1>) – Retrieve a stored spectrum and load into graph for possible analysis, saving to file, etc. <arg1> is the SpectrumID that determines which spectrum to retrieve. Valid SpectrumID is from 1 to the number of stored spectra.

TakeBackground – Take a fresh background (sometimes called a dark) measurement.

TakeRefBackground – Take a background measurement to be subtracted from the reference. You should normally execute TakeRefBackground each time you call TakeReference.

TakeReference – Take a reference measurement. See TakeRefBackground.

UseReference(<arg1>) – If <arg1> is 1 then Use Reference is activated. 0 deactivates (unchecks) Use Reference.

UseBackground(<arg1>) – If <arg1> is 1 then Use Background (Subtract background or dark spectrum from measured data) is activated. 0 deactivates (unchecks) Use Background.

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