Chapter 5

Details of Operation

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.

5.1 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 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. A baseline measurement is taken by clicking on the Baseline button on the main screen and following the prompts. The steps for taking the baseline are explained in detail here.

The first step is to take a reference spectrum. This done by placing the reference sample (usually silicon or BK7 glass) on the sample stage and clicking OK when prompted. The reference material that is used should be selected in the Reference list. If the film structure to be measured has already been selected from the "Structure:" list, then Autoscale Integration Time can be selected. In some instances this will not be possible and the instructions for setting the integration time with the Setup > Data Acquisition box will have to be followed.

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 with the reference sample in place. You should see the reflectance spectrum of the reference material.

5.2 Editing Film Structures

The film characteristics that are to be measured, and the description of the sample film structure are 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 screen. 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 Changes". New structures may be added to the "Structure:" list by opening the "Edit Structure" dialog box, entering the name of the new structure in the "Name:" field, setting the desired specifications, and then clicking on "Save As New". Similarly, a structure may be deleted (removed from the "Structure:" list) by clicking on the "Delete" button.

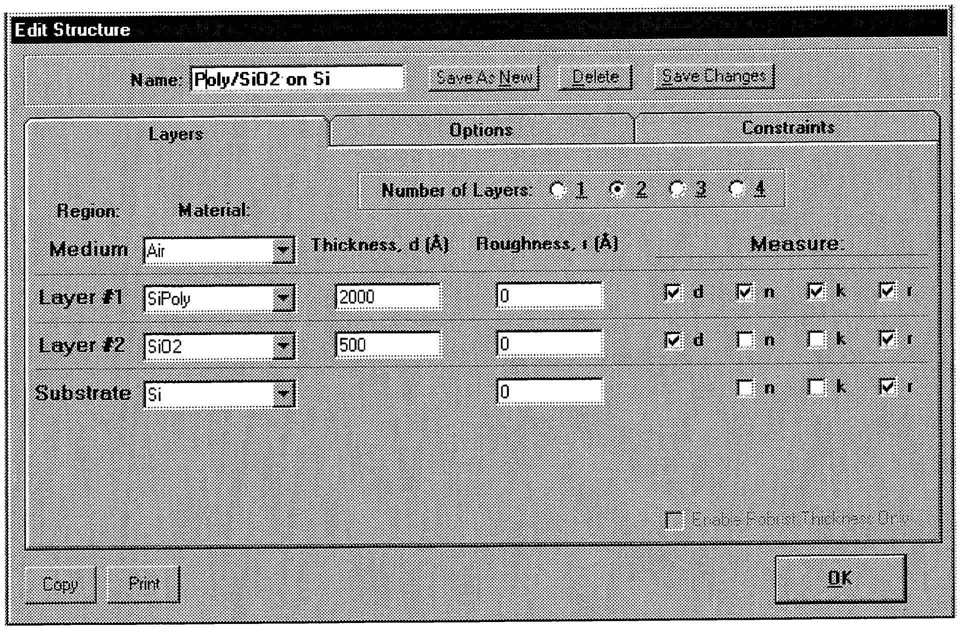

Figure 5.1: Edit Structure > Layers window

Edit Structure > Layers: Setting Up a Film Structure

When solving for a parameter, 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 (an insulator), select "Enter Refractive Index Value" from the material list and enter a value for the refractive index (*n* will automatically be varied by FILMeasure, with the entered value being *n* at 632 nm), or c) in the Edit > Edit Material Library dialog box, 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).

Edit Structure > Layers: Choosing Film Properties to be Measured

To measure a film property, check the appropriate box on the right-hand side of the "Layers" field in the Edit Structure dialog box. 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* can not be measured without also measuring thickness. Also, unless the material is a dielectric (k=0), *n* and *k* must be measured together.

As with any measurement, the accuracy of the measured data decreases as the number of 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.

Edit Structure > Layers: "Robust Thickness Only" Mode

If thickness is the only property to be measured and the film to be measured is greater than 5000 Å thick, the "Robust Thickness Only" mode may be used. 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 birefringce. In this mode, if the thickness entry field is empty, FILMeasure will search for the best thickness fit between approximately 20 Å and 100 µm (Caution: Measuring thickness in this mode may take a considerable amount of time.) If a thickness value is entered, the range of thicknesses tested is constrained by the limits set in the "Constraints" field.

Edit Structure > Options

Correct setting of the following options will help insure 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.

Most of the options are self-explanatory: measurements may be made in reflection or transmission mode; the angle of the incident light may be varied, with normal incidence defined as zero degrees; and transverse electric and magnetic polarization may be selected when the incident angle is not zero.

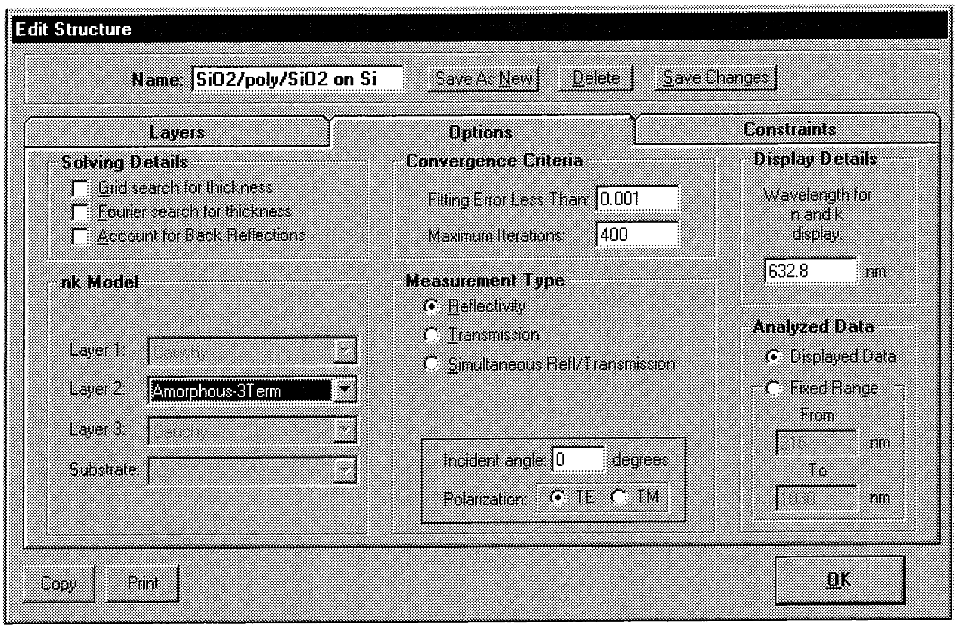

Figure 5.2: Edit Structure > Options window

Edit Structure > Options: Grid Search for Thickness

There are a number of methods that FILMeasure can use to determine thickness, *n,* and *k.* 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 "Grid Search for Thickness." 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 spectra, it is possible for the Grid method to become confused and give the wrong answer. In such cases it is best to measure without the Grid method by using accurate initial guesses to get close to the final solution.

Edit Structure > Options: Fourier Search for Thickness

The Fourier Transform method 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 > Options: Convergence Criteria

This sets the maximum error between the measured and calculated spectra that is attained before the measurement routines consider the solution final. In most cases a value of 0.005 is sufficient (for how this is calculated, see Fitting Error in Section 5.3.) For cases where the desired Fitting Error is not attainable, the value in "Maximum Iterations:" limits the number of iterations performed by the analysis routine.

Edit Structure > Options: Models for *n* and *k*

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 are selected automatically when a material is chosen from the Material lists on the "Edit Structure..." dialog box. Other models may also be specified by selecting them from the "nk Model" box in the "Options..." dialog box.

Edit Structure > 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 +/- 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.

5.3 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 thickness of the films are listed in the boxes labeled "Layer 1:", "Layer 2:", etc. (actual material names are used if entered in the index box for each film layer). 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 “Show Table” 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 "Copy Selected Data". The wavelength data is copied along with the selected reflectance, *n,* and/or *k* data.

Fitting Error

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 Fitting Error value. The Fitting Error is a normalized average RMS difference between the measured and calculated spectra points. Of course, the smaller the error value, the better the fit, and the more reliable the measured values. The actual value of the Fitting Error is quite dependent upon the type of measurement being made, but, as a general guideline, a good measurement of thickness and optical constants occurs when it is in the neighborhood of 0.01 or less.

5.4 The File Menu

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.

5.5 The Edit Menu

Edit > Copy Measured Spectrum...

This command is used to copy the Measured reflectance spectrum and corresponding wavelength data in comma-delimited format.

Edit > Copy Calculated Spectrum...

This command is used to copy the calculated reflectance spectrum and 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 by selecting Edit > Material Library... 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".

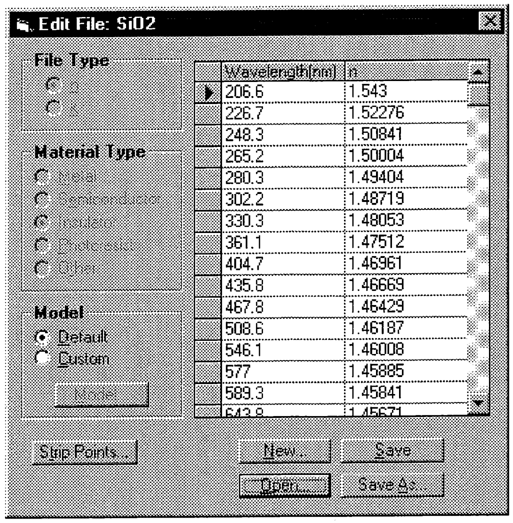

Figure 5.3: The Edit > Material Library dialog box

Edit > Units...

The thickness (length) units used to describe structures and display results are chosen here. The choices include nanometers (nm, 10e-9 m), microns (µm, 10e-6 m), angstroms (Å, 10e-10 m), and kilo-angstroms (kÅ, 10e-7 m).

5.6 The Setup Menu

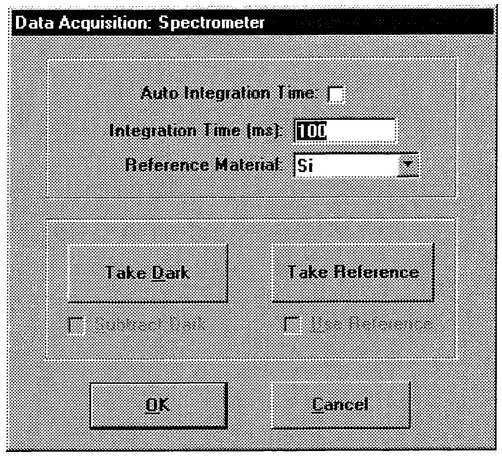

Figure 5.4: The Setup > Data Acquisition dialog box

Setup > Data Acquisition: Integration Time

This control is used when manually setting the integration time (i.e., when not using Automatic Integration Time.) To set the integration time, make sure that "Use Background" and "Use Reference" are not checked and enter a time into the “Integration Time” 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. FILMeasure will now be continuously acquiring and displaying scans. If the scan is off-scale select Setup > Graph Options... and “AutoScale Y axis” to rescale the axes. Now turn the light source on and insert a test sample. The vertical scale of the spectrum extends from zero to 4095 (since the A-to-D conversion uses 12 bits). Thus, a good working level is when the peak height of the sample being measured, or the reference sample, which ever is greater, is 3000-3500 counts (Note: if the reference measurement saturates, spurious final measurements will result). If the maximum signal is too low, increase the integration time.

Setup > Data Acquisition: Reference Material

Enter here the reflectance (or transmissivity if in transmission measurement mode) value of the reference sample used. For transmission measurements, 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 "Material" subfolder). Materials that already have “.rrr” extensions are available by selecting from the list in the "Reference Material" field.

Setup > 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.

Setup > 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.

Setup > Data Acquisition: Subtract Dark

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

Setup > Data Acquisition: Use Reference

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

Setup > Data Analysis: Data Smoothing

This is essentially a function that averages together a number of data points on either side of each measured data point. For example, if the "Smoothing Points" 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.

Setup > Data Analysis: Scans to Average

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

Setup > 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 which enables access to all features of the program except turning on and off access control and adding and deleting users.

The access control options are accessed from the Set Up menu. 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" check box should now be enabled. By placing a check mark in the Activate Access Control check box access control will be active.

You should also create some users at this time. 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.

Setup > 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. The selected range also controls the range of wavelengths that FILMeasure analyzes when determining film properties. Use the Vertical Axis Minimum and Maximum fields to control the vertical-axis display. Check the Autoscale Y axis box to activate y-axis autoscaling. The lower value is always 0 for autoscaling, the maximum y-axis upper limit is 5000.

Setup > Graph Options: Display *n* and *k* on One Graph

Check this box to cause *n* and *k* to be graphed together on the same plot. If this option is not checked *n* will be graphed along with the initial guess for *n* and *k* with the initial guess for *k*. Scroll the spreadsheet displaying wavelength, *n* and *k* left or right to plot *n* or *k* on the graph.

Chapter 6 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 619-554-0005, by fax at 619-554-1311, or by e-mail at support@filmetrics.com.

Appendix A Performance Specifications

Thickness Measurement Range

F20	150 Å to 50 µm
F20UV	50 Å to 50 µm

Optical Constant Measurement Range

F20	1000 Å to 10 µm
F20-UV	200 Å to 5 µm

Spot Size

Adjustable 500 µm to 1 cm

Thickness Accuracy[1]

+/- 1 nm at 500 nm thickness

Precision[2]

0.1 nm

Repeatability[3]

0.07 nm

[1] Thermally grown SiO_2 on Si.

[2] Standard deviation of 100 thickness readings of 500 nm SiO_2 film on silicon substrate. Value is average of standard deviations measured over twenty successive days.

[3] Two sigma based on daily average of 100 readings of 500 nm SiO_2 film on silicon, measured over twenty successive days.

Appendix B 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 Fig. B.1.) In general, the thicker the film, the more oscillations there are in a given wavelength range.

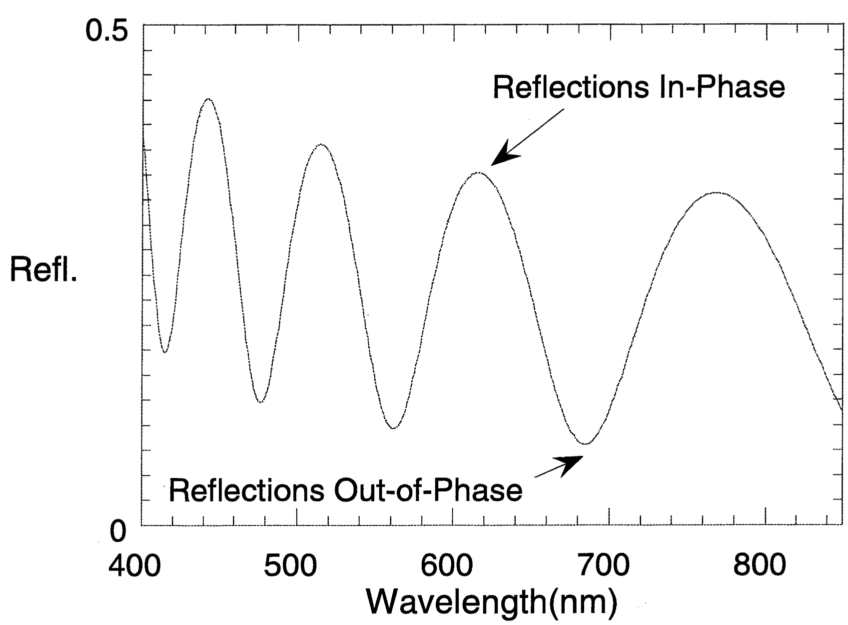

Figure B.1: Example of Reflectance Spectrum with Oscillations

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 which 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 Constant (*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 reflection spectrum only since at each wavelength only one know 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 reflection 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 ½ 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 5. 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 400 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 C Optional Features

C.1 Measuring Optoelectronic Devices

VCSEL cavity resonance dips and distributed Bragg reflectors (DBRs) may be measured by selecting "Opto Values" from the "Measure:" list. To measure laser cavity resonance dips, select "Cavity Dips" from the "Find:" list. 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. 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.

C.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. Filter measurements are made by taking appropriate reference and dark readings as described in Section 6.1, 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 "Graph Limits" dialog box, which is found under the "Setup" menu.

Appendix D

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 F20/30/40/50, and the DB25 signal 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 set screw (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 E Automation and Data I/O

Measurements can be automated and additional data analysis can be performed by user-supplied software that communicates with FILMeasure via Dynamic Data Exchange (DDE). An example program illustrating how to use DDE with FILMeasure is located in the "Client" folder, which is inside the "FILMeasure" folder. Although the example program is written in Visual Basic, DDE-based automation software can be written in any language that supports DDE. A single data entry is linked and is used to return information from FILMeasure to the client application. Once the link is set up, FILMeasure will also execute commands specified by the client application. To set up a link to FILMeasure set up a DDE conversation as follows:

LinkTopic = "FILMeasure|FILMeasureDDE"

LinkItem = "DDESourceBox"

Although all commands are listed below, commands that refer to measurement options not included with a particular system will not be available. 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:

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.

CopySpectrum - Copies currently displayed spectrum onto the clipboard

GetRMSError - Updates the linked data to be the RMSError resulting from the last measurement.

GetThickness(<arg>) - Updates the linked data to be the measured thickness of the film specified by <arg>.

MeasureLayer - Equivalent to pushing the thickness Measure button. Updates the linked data to be the measured thickness of film 1 when finished measuring.

MeasureOpto - Equivalent to pushing the OptoValues Measure button. Updates the linked data to be the measured position of DBR or FP parameter specified.

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

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 reflectance, use 1 to specify percentage of maximum reflectance.

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

OptoFPReflectanceLimits(<arg1>,<arg2>) - use <arg1> and <arg2> to specify the lower and upper reflectance 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.

SetThickness(<arg1>,<arg2>) - Sets the initial guess thickness of the film specified by <arg1> to the thickness value specified by <arg2>. Updates the linked data to be the thickness value given in <arg2>.