

Arcspectro NIR THINFILM

Fibered NIR system for measuring Thin Films

Installation Guide and Operation Manual

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1. Quick start

The system is essentially composed of a NIR light source (powered by 12V) a NIR spectrometer (powered 12V) and a multi-core bifurcated fiber (picture below).



- 1) Install the Arcspectro THIN FILM Software (ARCSpectroTHINFILM_insallation_Package.exe) that is provided on the USB key shipped with the device on a windows 7 or 10 64 bits computer.
- 2) Connect (screw) SMA connectors to the lamp (multiple fibers) and spectrum (single central fiber). You should see a ring illumination at the output of the fiber when the light source is switched on.
- 3) Power light source and spectrometer with provided 12V power supplies. The light should come out of the fiber and you will hear ventilators running.
- 4) Connect USB from the spectrometer to a USB port of the computer
- 5) The computer should recognize the arcspectro NIR device (in case you can check in your device manager under USB devices if the spectrometer is listed)
- 6) Launch the Arcspectro THIN FILM software
- 7) Connect the software with the connect button in the up-left corner.

- 8) Place your fiber probe vertically (preferably with a stand) a few centimeters above your sample to be measured.
- 9) You are ready to measure (go to chapter 4 for more details about the software settings)

1.1 Specifications

Features	ARcspectro NIR THINFILM
Spectrometer Type	Scanning FT-NIR spectrometer (900-2500nm)
Spectral range	900nm-2500nm
Spectral resolution	2cm-1 equivalent to 2 nm (optical, reporting interval: 1nm)
Fiber	NA=0.25, SMA 905 connector. Bifurcated fiber with ring illumination and central fiber for collected light
Light source	Arclight NIR halogen lamp 20W
Measurement time	~ 10s (depending of the number of averages)
SNR (Full dynamic range- signle measurement)	> 10′000
Thickness repeatability measurement	10 nm (for 20 um thick kapton sample and 10s measurement time)
Measurable thickness range	2um to 800um (lower thickness possible with VIS-NIR spectrometer on demand)
Minimal refractive index step	< 0.01
Operating temperature	10°C-40°C
Power requirement	12V / 10W max
Communication Interface	USB 2.0
Software Interface	Windows 7/10
Dimensions	180mm x 160mm x 80mm
Weight	2 kg

2. Working principle

Due to the wave-like behavior of the light, the phenomenon of light interferences appears into a layer thinner than the half coherence length of the light. The light reflected at the first interface can interfere with the light reflected at the second interface and their interaction is dependant on the wavelength of the light and the refractive index of the layer. This effect leads to oscillations into the reflectance spectrum measured by this instrument. The frequency of this oscillation gives information about the thickness of the layer and its refractive index.





The first part of the incoming light is reflected at the interface n_1/n_2 . The amount of light reflected depends on the incidence angle, n_1 and n_2 . Some light passes through the first interface and is reflected at the second interface (n_2 /substrate). The two "rays" of light that are reflected back by the sample have a phase difference linked to the optical path difference (OPD).

At normal incidence (i.e. $heta_1=0^\circ$), the phase difference ($\Delta\phi$) between the two signal is:

$$OPD = 2 \cdot n_2 \cdot d \qquad \rightarrow \qquad \Delta \phi = \frac{2\pi}{\lambda} \cdot OPD = \frac{4\pi}{\lambda} \cdot n_2 \cdot d$$

If this difference is equal to a multiple of 2π , there is a constructive interference and it will lead to a maximum in the reflectance spectrum. If this difference worth $m \cdot \pi$ (with m an odd number), there is a destructive interference and it will result in a minimum in the reflectance spectrum. Finally, some wavelengths will lead to constructive interferences and some to destructive ones. Consequently, modulation with a certain contrast (depending on the phase step between the layers) of the measured spectrum is observed. For a single layer, the reflectance is given by the following equation:

$$R(\lambda, d) = R_{01}(\lambda) + R_{12}(\lambda) \cdot \left(1 - R_{01}^2(\lambda)\right) + 2 \cdot \sqrt{R_{01}(\lambda) \cdot R_{12}(\lambda) \cdot \left(1 - R_{01}^2(\lambda)\right)} \cdot \cos\left(\frac{4\pi}{\lambda} \cdot n_2 \cdot d\right)$$

The R coefficients are the modulus square of the Fresnel coefficients.

2.2 Example of single layer

This equation is used to calculate the reflectance of a 5um thick glass plate in the air. The simulated reflectance (Figure 1 - Theoretical reflectance spectrum of a 5um glass plate in air. (a) The reflectance is plotted in function of the wavelength. The oscillation frequency is not constant. (b) The wavelength is converted into Knum to obtain a homogenous oscillation.) has not a constant oscillation frequency over the wavelength range. To solve this problem, the lambda is converted into K_{num} variable with the following relation:

$$K_{num} = \frac{1}{\lambda} [cm^{-1}]$$

The theoretical reflectance equation can be rewritten with this variable:

$$R(\lambda, d) = R_{01}(\lambda) + R_{12}(\lambda) \cdot \left(1 - R_{01}^2(\lambda)\right) + 2 \cdot \sqrt{R_{01}(\lambda) \cdot R_{12}(\lambda) \cdot \left(1 - R_{01}^2(\lambda)\right)} \cdot \cos\left(4\pi \cdot K_{num} \cdot n_2 \cdot d\right)$$

The reflectance is replotted in function of wavenumber (Figure 1b), the oscillation is homogenous and has a constant frequency.



Figure 1 - Theoretical reflectance spectrum of a 5um glass plate in air. (a) The reflectance is plotted in function of the wavelength. The oscillation frequency is not constant. (b) The wavelength is converted into Knum to obtain a homogenous oscillation.

The frequency of this signal can be determined by looking at the cosine term of the above equation. If an analogy with the time-frequency domain is made:

$$Cos(\omega \cdot t) = Cos(2\pi \cdot f \cdot t) \rightarrow f = \frac{\omega}{2\pi}$$

The characteristic frequency of the layer is:

$$f = \frac{4\pi \cdot n_2 \cdot d}{2\pi} = 2 \cdot n_2 \cdot d$$

The characteristic frequency is the optical path difference (OPD) between both reflected rays. We can apply a Fast Fourier Transform (FFT) on the reflectance spectrum to extract the frequency content of the spectrum. The frequency axis is transformed into a thickness axis by dividing the frequencies by $2 \cdot n_2$. The intensity of the FFT transform is shown in Figure 2Figure 2 - FFT of the reflectance spectrum. We can see a predominant peak at 5 µm. The symmetric distribution of ripples around 5µm is due to the windowing function (Sinc convolution). If we

look attentively, there is a small peak around 10 μ m. This is due to the light that bounced two times in the layer and having at the output of the layer a total accumulated OPD of $4 \cdot n_2 \cdot d$.



Figure 2 - FFT of the reflectance spectrum

2.3 Multilayers

In the case of multilayers, each layer has its characteristic frequency. Furthermore, the light can also be modulated by the accumulation of two or more layers. In the end, the number of possible peaks in the FFT intensity will be given by the following relation where n is the number of layers.

$$Nb_{FFT \ peaks} = n \cdot \frac{n+1}{2}$$

Notice that the peaks due to the double reflection as seen in section 2.2 are not counted in this formula (since the intensity of such peaks is generally very low).

2.4 Example of two layers



In that case, three different paths of light are reflected from the sample. At normal incidence (i.e. $\theta = 0^{\circ}$), the optical path difference and respective frequencies are:

- Between I₁ and I₂:
- Between I₂ and I₃:
- Between I₁ and I₃:

$$OPD_2 = f_2 = 2 \cdot n_2 \cdot d_2$$

 $OPD_1 = f_1 = 2 \cdot n_1 \cdot d_1$

$$OPD_{12} = f_{12} = 2 \cdot (n_1 \cdot d_1 + n_2 \cdot d_2)$$

The following example shows all the frequencies that are obtained by measuring a multilayer sample. Notice that the 2mm thick glass substrate could be considered as a layer but its optical path difference, $(2 \cdot n_3 \cdot 2000 \ \mu m)$ is larger than the maximum measurable OPD by the Arcoptix NIR-THINFILM and intensity peaks due to these substrates will not be visible

The OPDs for this example are:

- $OPD_1 = f_1 = 2 \cdot n_1 \cdot d_1 = 150 \ \mu m$
- $OPD_2 = f_2 = 2 \cdot n_2 \cdot d_2 = 40 \ \mu m$
- $OPD_{12} = f_{12} = 2 \cdot (n_1 \cdot d_1 + n_2 \cdot d_2) = 190 \,\mu m$

Figure 4 shows the FFT of the reflectance spectrum of the sample described just above. In that case, we chose to plot in function of the OPD since the refractive index is not the same for the two layers. The 3 mains peaks that were predicted are easily visible in the figure. However, we observe other smaller peaks due to double reflections in the sample. A label aside each peak explains its origin.



Figure 4 - Reflectance spectrum's FFT intensity of the multilayers sample

In this example, all the peaks due to multi-reflections have a relatively small intensity compared to the three main peaks. Finally, we need to focus our attention on the main peaks since they contain all the information that we are looking for.

 Glass: 50 um
 n1 = 1.5

 Air: 20 um
 n2 = 1

 Glass: 2000 um
 n3 = 1.5

Figure 3 - Example of multilayers sample. Be aware

I₃

١₀

θ

that the proportions are not accurate.

The peak at 110 μ m is not trivial to understand. Figure 5Figure 5 shows what can happen. Let's write the optical path made by the orange and yellow intensities from where their paths differ for a normal incidence (i.e. $\theta = 0^{\circ}$):

Yellow optical path (YOP):

$$YOP = 2 \cdot n_2 \cdot d_2 + n_1 \cdot d_1$$

Orange optical path (OOP):

$$OOP = 3 \cdot n_1 \cdot d_1$$



Figure 5 - Graphical explanation for the peak at 110um

Then the optical path difference between these two optical paths is:

$$OPD = OOP - YOP = 3 \cdot n_1 \cdot d_1 - (2 \cdot n_2 \cdot d_2 + n_1 \cdot d_1) = 2 \cdot (n_1 \cdot d_1 - n_2 \cdot d_2) = OPD_1 - OPD_2$$

As said before, in real cases, the reflection coefficient of the interfaces is often low and the intensities that bounce twice in the same layer become nearly negligible.

2.5 Effective refractive index

Until now, the refractive index used for simulation was constant but in reality, this is not the case. Due to dispersion, the refractive index is wavelength dependant. Since a spectrometer with a relatively large range from 900nm to 2700nm is used, some variation of the refractive index will be observed and makes calculations and calibrations much more complicated. To solve this problem, an effective refractive index (n_{eff}) is used (kind of average refractive index over the measured wavelength range). One way to estimate this n_{eff} , is to use the refraction index at 900nm (λ_{min}) and 2700nm (λ_{max}) and enter these values in the following equation:

$$n_{eff} = \frac{\frac{n(\lambda_{min})}{\lambda_{min}} - \frac{n(\lambda_{max})}{\lambda_{max}}}{\frac{1}{\lambda_{min}} - \frac{1}{\lambda_{max}}}$$

This effective refractive index can also be determined by the Arcoptix THINFILM software by measuring a single-layer sample with a known thickness (see section 3.1.4).

3. Software overview

3.1 Measurement Tab

The reflected light is displayed in the "Spectrum" chart (Figure 6Figure 6 - Screenshot of the measurement tab.). This curve is transformed by a "Fast-Fourier Transform (FFT)" and the thickness of the layer can be retrieved in the frequency content of the spectrum. The characteristic frequency of a layer is:

$$f = 2 \cdot n_{eff} \cdot d$$

where d is the thickness of the layer and n_{eff} is the effective refractive index of the layer material in the wavelength range used by the spectrometer.

For a single thin film measurement, the FFT of the spectrum can be plotted directly in function of the layer thickness as seen in the "Thickness" chart (Figure 6Figure 6 - Screenshot of the



Figure 6 - Screenshot of the measurement tab.

measurement tab.).

3.1.1 Thickness Measurement

Notice here that every layer above 1mm thickness cannot be measured by the system and should be considered as substrate.

To determine the layer thickness, an effective refractive index is needed. This one can be entered:

- 1. Manually
- 2. By selecting a known material in the library of materials



3. By modeling the sample layers in a different tab. (Used for multilayers with a description of the sample in the "Parameter of the sample" tab.)

The measure can be done one time or continuously by clicking the respective button.

Single layer

The first and second options are made for single layer measurement and the FFT of the measured spectrum is plotted in function of the thickness of the layer. The maximum of the FFT intensity is indicated in the "Measured thickness". A cursor can also be used to detect the peaks above this threshold as shown in Figure 7.



Figure 7 - Peak at 24.96 um in the FFT intensity. The light can also bounce twice in the layer, it explains the second peak around 50 μm.

Multiple layers

For multilayer measurement, the sample needs to be described in the "Parameter of the sample" tab and the FFT of the measured spectrum is not plotted in function of the thickness but in function of the optical thickness $(n \cdot d)$ since each layer has a different refractive index. In this case, the software searches for a peak only in the corresponding ranges that are given in the layer table (by lower and Upper thickness and the material). Notice that these thickness range restrictions are intended to avoid confusion between main peaks and secondary peaks due to multiple reflections of inter-layer combinations. The tighter the ranges the more reliable will be the interpretation of the measured spectrum. Very loose range settings may lead to incorrect results (as explained in 2.4). If the user is not sure about the thickness range



Figure 8 - Optical thickness plot obtained for multilayers sample measurement. The three mains peaks are searched into the range of thickness given in the "Parameter of the sample" tab.

of the layers present on the sample, it is recommended to have an iterative approach by tightening the range successively. **Error! Reference source not found.**Figure 8 shows the measurement of a sample with 2 layers. More explanations are given in section 255.2.5.

3.1.2 Filter settings

A bandpass filter can be applied on the spectrum to limit the frequency content of the FFT of the spectrum. This operation permits to reduce the noise or other uninteresting frequencies (ghosts) in the measured spectrum. The bandpass filter will automatically filter out the frequencies that do not correspond to the expected thickness min and max. The range of expected layer thicknesses can be entered in the min/max thickness Edits.

Furthermore, if there is absorption at a specific wavelength in the spectrum, you may want to not consider this effect. In that case, you can specify which range of the spectrum curve needs to be taken for the FFT analysis (select the range where the oscillations are the most visible).

A triangular apodization can be performed before making the FFT by selecting the "Apodization" checkbox (this will affect the noise and sidelobes in the FFT of the spectrum). Once the measure is done, you can modify all those fields and click on "Apply" button to display the new re-calculated thickness spectrum.

Enable Filt	er 🗹 /	podizatio	n		
Bandpass	filter			_	
Thickness min	um Th	ickness m	nax [um]	Filter ord	ler
There is a thin					
20,0	-	30,00	-	3	+

3.1.3 Signal

If the "Show filtered spectrum" checkbox is checked, the spectrum filtered with the filter settings defined above is displayed.

Show filtered	spectrum	
Set Basel	ne Spectrum	Dark measurement
Absorption	Transmission	Dark substraction

Dark measurement

A Dark measurement (in principle measurement without sample) can be performed, and this measure will be subtracted for the following measurement if the "Dark subtraction" checkbox is checked. Be aware that a click on "Dark measurement" button save the last measurement as the dark measurement. It does not take a new measurement.

Baseline

A baseline can be defined to compute the absorption and transmission spectrum. As the dark measurement, the "Set Baseline Spectrum" button sets the last measure as the baseline. It does not take a new measurement. When a baseline is set, you can choose to display the absorption, transmission, or the classic spectrum by clicking respectively on the wanted spectrum. Making a baseline is useful because it permits correcting for the natural spectral shape of the illumination (halogen lamp). Usually, the baseline is obtained by measuring a bare cleaned substrate (without layer). Notice that for thick layers (more than 20 um) a baseline is not mandatory and good results can also be obtained with the raw spectrum.

3.1.4 Effective Refractive Index Measurement

If you precisely know the thickness of a single-layer sample, the effective refractive index of the layer material can be measured and saved into the material library. As before, a filter and spectral range selection can be applied on the spectrum to select only the range where the oscillation is clearly visible.

Ckness Measurement Refractive index Measurement Layer thickness [um]: 25.00 Measurement	Filter settings
Effective refractive index measured: 1.727	Bandpass filter n min n max Filter order 1.0 Cut spectral range Kmin [1 (cm] Knark [1 (cm]
Material name Save material	4500 🗢 10000 🌩 Apply

3.2 Parameter of the sample Tab

For multilayers, the sample is defined in the "parameters of sample" tab (figure below). An expected thickness range for each layer must be entered in the table. The materials of the layers can be selected from the list of known materials that are saved in the material library.

Measurement	Parameters of the sample	Material					
Sample's	parameters						
						Layer 2	
						Layer 1	
						Cubatanta	
						Subsuare	
			Number of layer(s)	2 🜲			
			Laver	Material		Lower thickness [um]	Upper thickness [um]
			Medium	Air (n=1)	~	*	
			Medium Layer 2	Air (n=1) Kapton (n=1,73)	>	- 50	- 60
			Medium Layer 2 Layer 1	Air (n=1) Kapton (n=1,73) NAO65 (n=1,53)	> > >	- 50 80	- 60 100

When this tab is used to describe the sample to measure, the third option of measurement in subsection 3.1.1 need to be selected.

3.3 Material Tab

In this tab, the library of all known materials is displayed. New materials can be created by clicking on the "Add new material" button and the following window appears.

New material can be added using Sellmeier's model or Cauchy's law if the constants are known. Otherwise, new material can be added manually but the effective refractive index needs to be calculated using the formula given in section 3.1. This library can be saved and loaded into/from a ".csv" extension file.

Add	d new material Refresh Load library Save	library Delete the materials selected
	Material	 Effective refractive index
•	Water	1,33
	NAO65	1,53
	Kapton	1.73
	Glass	1,5
	Air	1

NewMaterialWindow			-		>
New Material					
O Chauchy's law					
Name of the material	$n(\lambda)$	$=A+\frac{B}{\lambda^2}+\frac{C}{\lambda^4}$			
Value of constants:	A 1,00000 ‡	B 1.00000 🗘 C 1.0000)		
O Sellmeier's model					
Name of the material	$n^2(\lambda) - 1 = \frac{1}{\lambda}$	$\frac{B_1\lambda^2}{2-C_1} + \frac{B_2\lambda^2}{\lambda^2-C_2} + \frac{B_3}{\lambda^2-C_2}$	$\frac{\lambda^2}{C_3}$		
Value of constants:	B1 1,00000 🕀	82 1.00000 🗢 83 1.0000	0		
Manually add a material	C1 1.00000 🕀	C2 1,00000 🔃 C3 1,0000	0		
	Name of the material	Effective refractive index			
	Air	1,00000 🜩			
		Add to I	brary	Close	

3.4 Status bar field

|--|--|--|--|--|

Device status: Display if a device is connected or not.

Acquisition progress: shows the progress of the measurement.

Saturation level: gives the saturation level of the detector. If this bar is full, the detector is saturated, and the measured spectrum is not accurate. Please reduce the gain level or the output light intensity if the detector is saturated.

Scan status: Provide information about the last measurement. Green if the measurement is ok and red if a problem occurred during the measurement.

Tooltip: The remaining space is used to display tooltip information when the mouse passes over controls in the software.

3.5 Menu Bar

In the "File" menu, the data can be saved to an Excel Spreadsheet. It saves the spectrum measured and the FFT displayed in the software. If a baseline has been taken, the absorption and reflection data are also saved in the Excel sheet.

ARC	spectro API AODAQ Example
File	Device
	Export data to Excel

In the Device menu, menu items permit gathering information and setting some parameters of the spectrometer.



Device Status:

It opens a window where you can get some information about the spectrometer status.

🚽 Device Status 🛛 —			
Spectrometer resolutio cm-1	800		
Laser TEC Alarm Status	0		
Detector TEC Alarm Status	0		
Source Alarm Status	0		
Scanning Status	0		
Laser Mean Level	-907391022		
Device Frimware	2230		
Drive Frimware	1201		
Device Temp [C]	28,5		
Source Volage [V]	NaN		
Source Temp [C]	0.5		
Intem Status	ОК		
Serial Number ARCspectro	R510 (v2.230)SI		
Refresh	Close		

Device setting:

Connection setting:

The IP address used when you click on the "Connect" button is the one shown here.

Acquisition settings:

Sets the number of the averages that are performed by the NIR spectrometer. This value can be typically set between 1 and 30. Notice that the SNR is increased with the square root of the number of averages.

Spectrometers settings:

Interferogram apodization: Sets the apodization method (spectrum smoothing) for the NIR spectrometer. Setting to a stronger apodization level permits reducing the Noise and smooth the spectrum. In principle changing this setting has little influence on the result and it is recommended not to change it.

Set Resolution: Sets the resolution in cm⁻¹ of the acquisition. The maximum thickness measurable is defined by this parameter. Notice that the acquisition is slower and SNR lower if the resolution is higher.

Gain level: Sets the electronic gain of the detector. In principle, you need to set this always at "low". Be careful that the detector does not saturate (Warning in the status bar on the bottom of the window form)

Connection setting :			
Connect directly to followin	g IP addr	ess:	
127 0 0		1	
Acquisition settings :			
Number of averaging	1	*	
Constromator antipar			
opectrometer settings	1		
Interferogram apodization			~
Set resolution			~
Det researchers			
Gain Level			

4. Making a measurement

Here are the basic steps to follow to make a measurement. First, you need to launch the software and connect the spectrometer.

- 1. Launch the Arcspectro THINFILM software
- 2. Connect the spectrometer by clicking on the connect button in the up-left corner (IP address can be modified under device -> device settings)

The following steps depend if you want to measure the thickness(es) of a single layer sample or a sample with multiple layers.

Steps for single layer measurement with a material included in the material library

- 1. Go to the material tab and load the library
- Go back to the measurement tab and select the option "Single layer of known material" and choose the material of the layer in the list
- 3. Enable the filter under "Filter settings" and put the range of the expected thickness
- 4. Press the "Measure" button under "Measurement" and the thickness of the layer is displayed.

Steps for single layer measurement with known effective refractive index

1. Select the "Single layer with effective refractive index" option and enter the effective refractive index of the layer's material in the field

● Single layer with effective refractive index of 1,500 ÷

- 2. Enable the filter under "Filter settings" and put the range of the expected thickness
- 3. Press the "Measure" button under "Measurement" and the thickness of the layer is displayed.

Steps to measure thicknesses of the sample with multiple layers

- 1. Go to the material tab and load the library or add the material(s) that are not yet in the library
- 2. Go to the "Parameter of the sample" tab, put the layers' number of your sample, and select the material of the layer and the minimum/maximum of the expected thickness for each layer. Select the material of the incidence medium and the substrate. Notice that a substrate with an optical thickness smaller than 1250 µm can also be defined as a layer if you want to measure it. If you do so, put an air as substrate.
- 3. Go to the "Measurement" tab and select the "Sample layers defined in parameters" option
- 4. Press the "Measure" button under "Measurement" and the thicknesses of the defined layers are displayed.
- 5. If you want to check the results, the FFT of the theoretical reflectance spectrum can be plotted in the same chart. Check that the simulated peaks maximums are positioned

on the X-axis (wavenumber than the measured ones. To run this simulation, please press the "Theoretical Reflectance" button. If the peaks from measurement and simulation are not located at the same place, modify the range of thickness in the defined model. Notice that only the location of the peaks is important, the shape difference between the theoretical peaks and measured ones is principally due to sample roughness, light divergence and material dispersion (that are ideal in the simulation but not in reality). You can also click on the options button at the bottom-right corner of the simulation button to modify the thicknesses used for the simulation.

Steps to measure the effective refractive index of a single layer sample

- 1. Go to the "Refractive index measurement" tab in the "Measurement" tab
- 2. Enter the known thickness of the layer
- 3. Press the "Measure" button and the effective refractive index measurement is displayed

Global remarks to improve the measurement

If the oscillation is visible only in a specific range of the spectral range, you can apply a spectral range cut to select the range where the oscillation is well visible and press on the "Apply" button to plot the new re-calculated thickness plot. Notice that you can also use the "Dark reference measurement" and "Set baseline" features to improve the accuracy of the measurement. If the peaks are not visible (maybe because of a small index step), consider increasing the number of averages to improve the signal to noise ratio. To increase the number of averages, go to "Device" -> "Device settings" -> "Number of averaging". If the peaks are still not visible in the spectrum, try to change the distance between the end of the fiber probe and the sample. А short distance (2-3 mm) can be used for rather a thin film (below 100 um) measurement. If the thickness is in the order of hundreds of μ m, increase this distance up to 5 cm to have more collimated light and to reduce the angle dependency of the measurement.

5. Measurement examples

In this section, we present some measurement examples. This will give you a concrete inside how to handle different measurement configurations.

5.1 Effective refractive index measurement

5.1.1 Measurement of the Kapton's effective refractive index

A 50 um thick Kapton film is used to measure the effective refractive index of this material. As we can see in the spectrum graph, there are no significant oscillations for wavenumbers smaller than 4800 cm⁻¹. Thus, the FFT is applied only on the data between 4800 and 10000 cm⁻¹. The effective refractive index measured is 1.733. This value can be saved into the material library and is used in the example in section 215.2.1.



5.2 Thickness measurement examples

5.2.1 Measurement of an 8 μ m thick film of Kapton

The effective refractive index of Kapton is 1.733 and this material is already saved in the material library. An 8 μ m thick Kapton film is measured. We fix the bandpass filter between 5 and 15 μ m. The oscillation is clearly visible over the whole spectral range and the FFT can be applied on the whole spectrum. We see a clear peak at 7.84 μ m.



5.2.2 Measurement of a polypropylene adhesive tape

The effective refractive index of polypropylene for the wavelength range used is about 1.49. This value is directly entered in the numeric field in the first option of measurement. The thickness of this tape is unknown but visually it seems to be in the order of a few tens of micrometers. Consequently, the bandpass filter is set to let pass frequencies corresponding to thicknesses between 10 and 100 μ m. A first measurement is made and we see on the spectrum chart clear oscillation between 4500 and 7000 cm⁻¹. For optimal results, we recompute the FTT by keeping only the data in this range. Finally, the measured thickness is 27.34

Notice that we see in the spectrum some high frequencies around 5500 wavenumbers, this are absorption peaks of the water vapor always present in the air. These features will always be visible.



5.2.3 Measurement of a polyethylene packaging bag

A 100 μ m polyethylene packaging bag is characterized. Polyethylene has an effective refractive index of 1.51. The first measurement option is used and n_{eff} = 1.51 is entered in the numeric field. The bandpass filter is set between 80 and 120 μ m since we know that the expected thickness is around 100 μ m. A first measurement is taken and we can see that the oscillations after the 8000 cm⁻¹ are not usable. Thickness is recomputed after applying an adequate spectral range cut. Finally, the measured thickness is 100.14 μ m.



5.2.4 Measurement of PLA thin film on a glass substrate

A thin PLA film deposited on a glass substrate has an unknown thickness. PLA is a known material thus the second measurement option is chosen. PLA is selected in the material list. Since the layer thickness is unknown a large bandpass filtering range is used. The spectrum's data between 4500 and 8000 cm⁻¹ are used to compute the thickness. One clear peak is visible at 151.12 μ m.



5.2.5 Measurement of multilayers sample

In this example, approximately a 25 μ m layer of Norland adhesive 65 (NOA65) is spin-coated on a 550 μ m thick glass. The effective refractive index of these two materials is already in the loaded material library. The sample model is described in the "Parameter of the sample" tab (Figure 9). Here the glass plate is considered as a layer since its optical path is smaller than 1250 μ m (maximum optical length measurable for resolution set at 2 cm⁻¹) and we want to measure it. Air is put as substrate. Notice that this glass plate could also be considered as the substrate if we want to measure only the NAO65 layer.

Number of Imuncles	2	
Number of layer(s).	4	Ψ.

Layer Material		Lower thickness [um]	Upper thickness [um]		
Medium	Air (n=1)	~	2	-	
Layer 2	NAO65 (n=1,53)	~	20	30	
Layer 1	Glass (n=1,472)	~	530	570	
Substrate	Air (n=1)	~		-	~



Figure 9 - Description of the sample in the "Parameter of the sample" tab

From the given sample model, the optical thickness range of the layers can be calculated. They are shown in the table below.

	n _{eff}	Lower thickness [µm]	Upper thickness [µm]	Lower optical thickness [µm]	Upper optical thickness [µm]
Layer 2	1.53	20	30	30.6	45.9
Layer 1	1.472	530	570	780.16	839.04
Layer 1 + 2	-	-	-	810.76	884.94

Figure 10 - Optical thickness range for each layer of the defined model

A bandpass filter, from the lowest of the lower optical thickness (30.6 μ m) to the sum of the upper optical thickness (884.94 μ m), is applied on the measured spectrum. The software will search for a peak in each of these ranges. If the range of the layers' accumulation is in the measurement range of the instrument, it will also try to find a peak.

The sample's description is done, and the measurement can be computed by clicking on the "Measure" button. Notice that the option "Sample layers defined in parameters" need to be selected.

The software found three peaks (one for each layer and one for the accumulation of the two layers) and a label is put on them. Since only two peaks are needed to calculate the thickness of the two layers, the software will compute the thicknesses' calculation using the two peaks with the highest intensity. In Figure 11, the peak of layer 2 is a bit less visible. In that case, the software will use the first and third peaks to determine the thickness, and the measured thicknesses are displayed on the right.

To confirm these results, the FFT of the theoretical reflectance spectrum (using measured thicknesses) can be plotted on the same chart. The measured thicknesses are confirmed if the peaks of the simulation are located at the same position as the measured one. Since the software used the first and third peaks to determine the thicknesses these two peaks should be nicely fitted by the simulation. However, we need to see if the second simulated peak is located at a place where there is a peak in the measured spectrum. Looking at the zoom at the bottom of Figure 11, as predicted, the first and third peaks of the simulated spectrum fit nicely the measured peaks. For the second peak, we can see that the found peak is located at the same place as the simulated one so we can assume that the measured thicknesses are correct. If the second simulated peak was not on a peak in the signal, the measured signal needs to be improved by trying to increase the number of averaging, set a baseline or change the distance between the optical fiber probe and the sample.



Figure 11 – Software's screenshots of the sample's measurement described in Figure 9