Semiconsoft,Inc

Thin Film Measurement solution
Software, sensors, custom development
and integration

MPROBE® SPECTROSCOPIC REFLECTANCE SYSTEM: MEASURING THICKNESS OF THICK FILMS

MPROBE® system is used for a wide range of applications: practically any translucent film in 1nm -1mm range can be measured quickly and accurately. There are two basic methods of data analysis – model fitting/curve fitting and FFT decomposition of the measured spectrum. Model fitting is, typically, used for thin films: 1nm to 1 μm, FFT decomposition is used for thicker films. In the 1μm to 20 μm range, either FFT or model fitting can be used, depending on the application requirements.

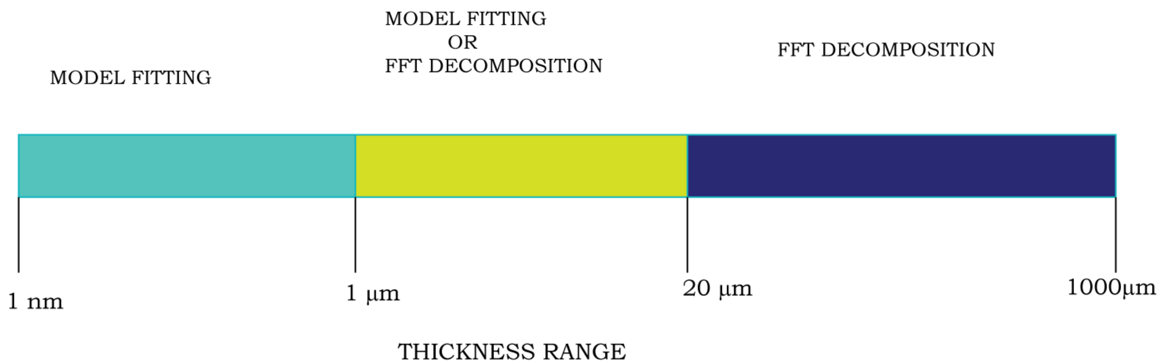

Fig. 1 Data analysis method depending on the thickness range.

FFT decomposition approach is a very powerful and convenient method: it is fast, has low requirements for calibration (intensity drift/variations do not affect the results) and it requires minimum information about the measured sample. FFT decomposition main drawbacks are a need for R.I. (refractive index) information and, until recently, lower accuracy, as compared to direct model fitting.
Recent improvements in TFCompanion software have dramatically improved the accuracy and resolution of the FFT decomposition algorithm. In most cases, thickness measurement accuracy of better than 0.1% is achieved.

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I. THICKNESS RANGE OF THE PRACTICAL FFT USE

FFT is using the fact that interference in the thick films creates a periodic function of intensity vs. the wavelength (interference fringes). The measurement wavelength range and refractive index of the material determine the minimum thickness of practical FFT use. Sampling one period or a fraction of the function period results in deterioration of the FFT accuracy and places a limit on the minimum thicknesses that can be practically determined with the FFT. **Table 1** shows FFT measurement errors depending on thickness and wavelength range.

Thickness/ Walength range		200nm	500 nm	700 nm	1000nm
400-1000nm	Error(absolute value)	92nm	36nm	6 nm	0.6nm
	Error (%)	46%	7%	0.9%	0.06%
400-1700nm	Error (absolute value)	49 nm	2nm	1.2 nm	0.4nm
	Error (%)	24%	0.4%	0.017%	0.04%

Table 1. FFT measurement errors.

Simulated reflectance spectra for 200nm, 500nm, 700nm and 1000nm oxides were analyzed using FFT and measurement errors (absolute and relative) were calculated. Spectra were generated for 400-1000nm and 400-1700nm measurement ranges.

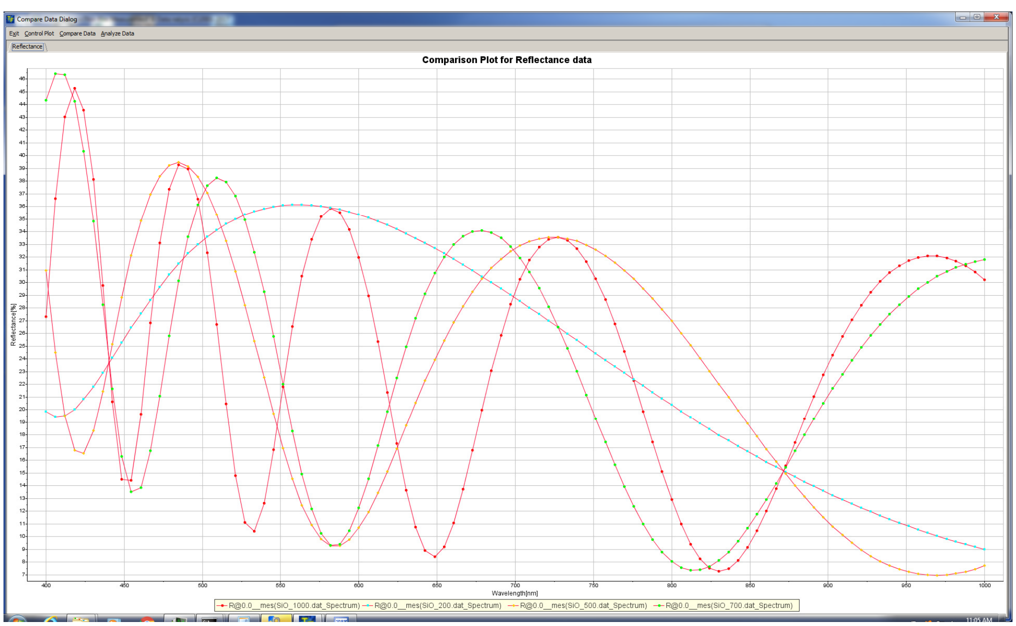

Fig. 1 Simulated reflectance spectrum (wavelength range: 400-1000nm) of the SiO2/Si. Oxide thicknesses: 200nm, 500nmm, 700nm and 1000nm (Oxide thickness corresponding to one period in visible range is ~ 320 nm)

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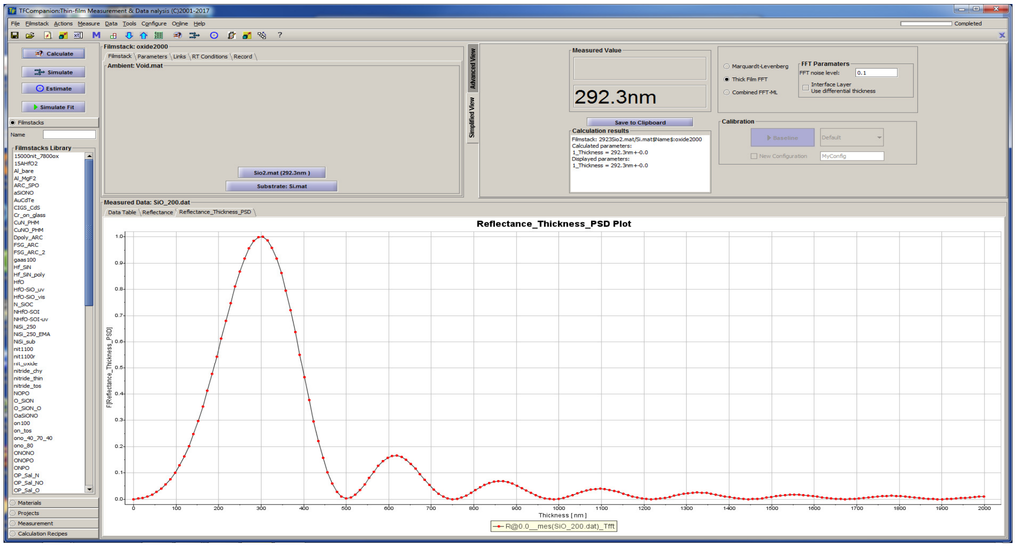

Fig. 2 Thickness of the 200nm oxide determined using FFT (400-1000nm wavelength measurement range). A large thickness measurement error (92nm) shows that FFT maybe not practical for this thickness

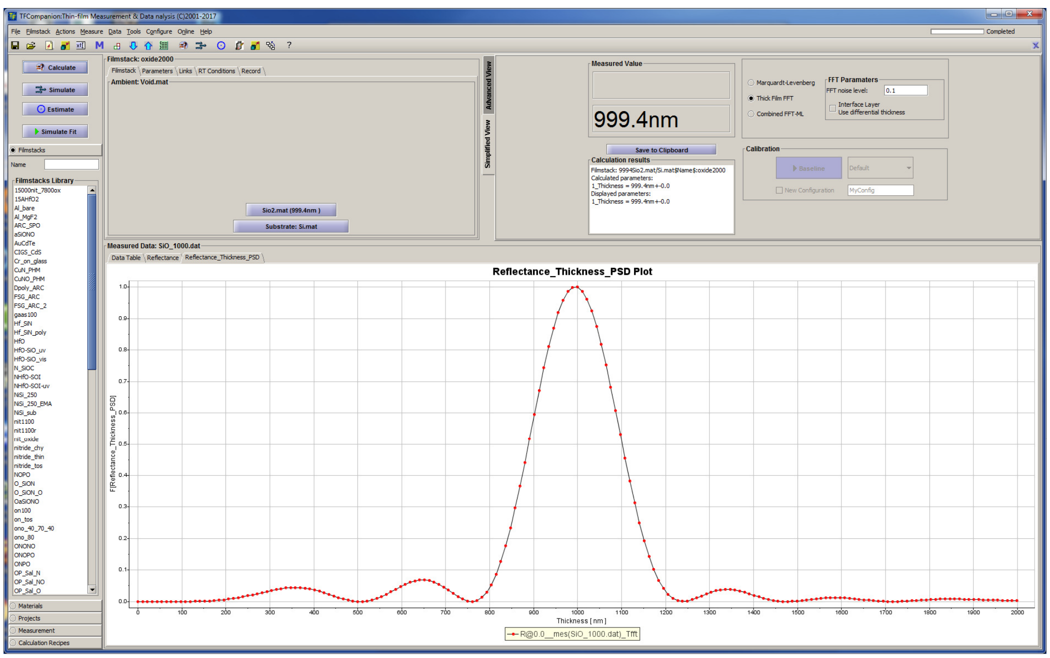

Fig. 3 Thickness of the 1000nm oxide determined using FFT (400-1000nm wavelength measurement range). A very small measurement error (0.6 nm) shows that FFT can be used successfully for this thickness

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II. PRACTICAL EXAMPLES OF FFT ANALYSIS USE

2.1 MULTILAYER POLYMER WEB/FILM

Multilayer polymer films are used for many application e.g. food packaging, stickers/labels, etc.

In this example we will review a 4 layer polymer web with the following structure: Separator/Silicon/Adhesive/PET film (substrate). Silicon is a thin film (<1 μm) that enables "peel-off" separator to expose adhesive of the sticker (PET film).

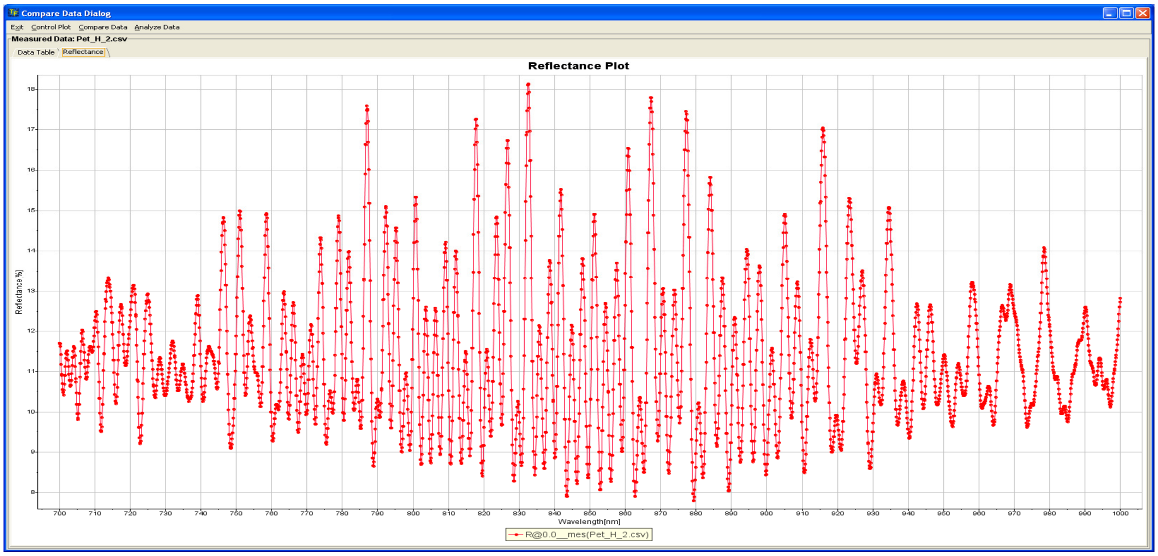

Fig. 4 Reflectance spectrum measured with MProbeVisHR (700nm -1000nm wavelength range). Sample 1 is a 4 layer polymer web (sticker).

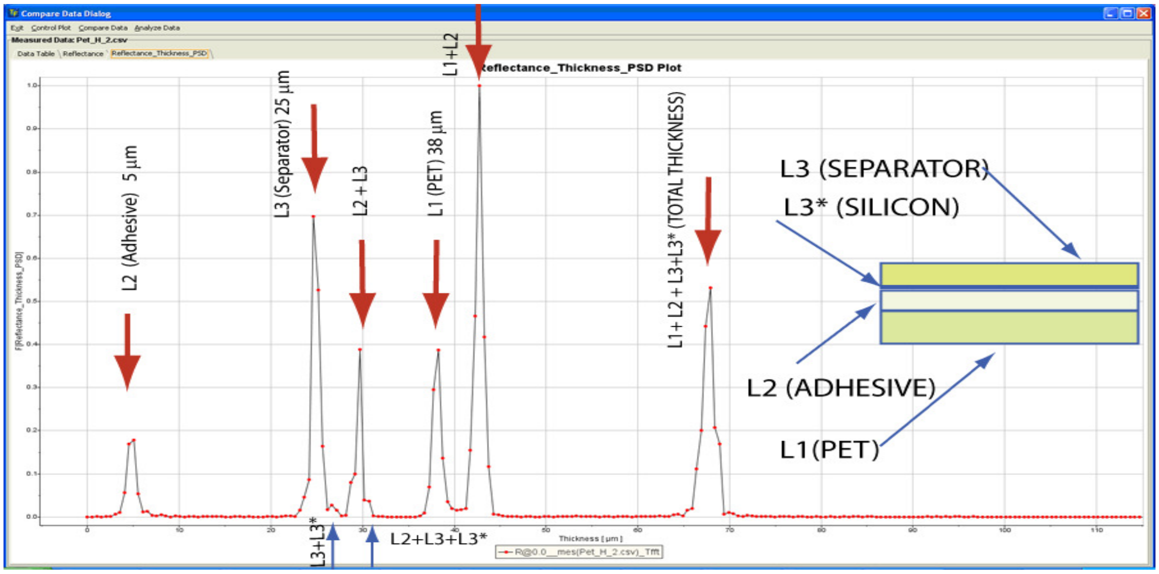

Fig. 5 FFT decomposition data analysis of the data (Fig. 4). Position of the peaks indicate the thickness of the layers.

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FFT decomposition analysis creates a peak(layer) for every pair of interfaces, the position of this peak indicates the thickness of the layer and the height of the peak indicates the "quality" of the interface. This means that a 3 layer stack should have 6 peaks (last peak being the total thickness). These peaks are visible on Fig. 5. The Silicon layer (3*) peak is not displayed separately (the thickness is too low < 1µm), but it is displayed in a combination with Separator and Separator +Adhesive layers. The total thickness peak is also broadened because of the Silicon layer. MProbe TFCompanion software can automatically identify the peaks and match them to the layers. It helps to know the structure of the measured product and the range of expected thicknesses. However, this information can also be gleaned, in most cases, from the FFT decomposition itself and fed back in the model. Layers thickness constraints help software to identify peaks easily.

FFT decomposition on Fig. 5 shows all the layers directly (except silicon layer). Frequently, some of the layers are "hidden" or corresponding peak are too small to detect accurately.

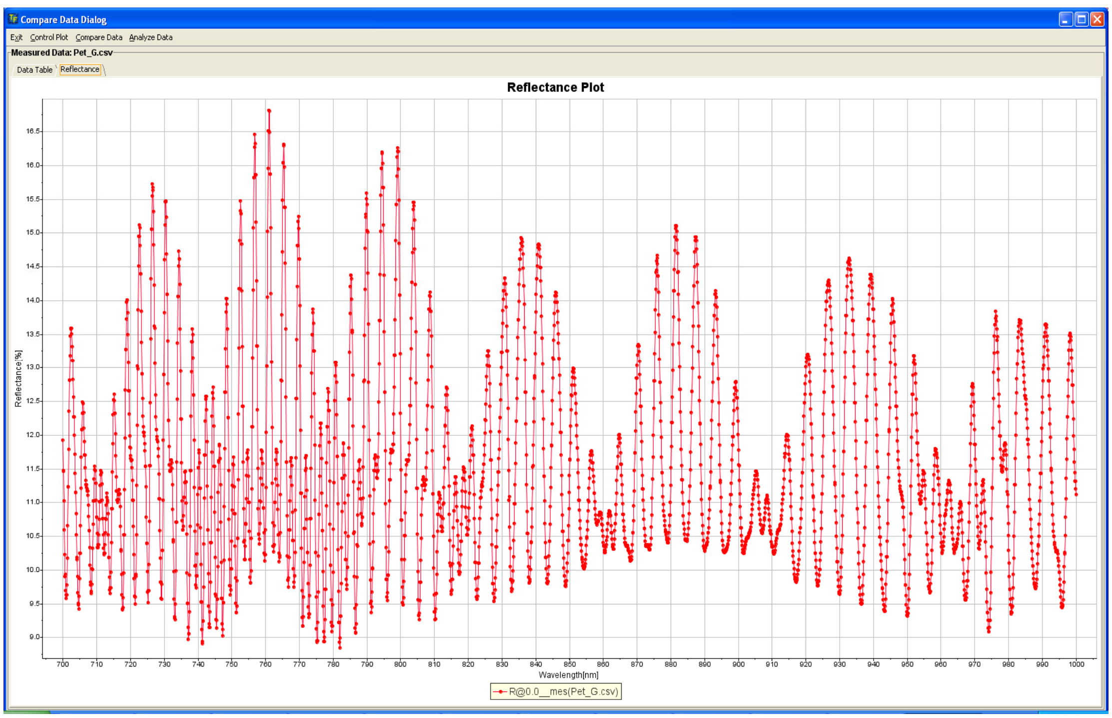

Fig. 6 Reflectance spectrum measured with MProbeVisHR (700nm – 1000nm wavelength range). Sample 2 is a 4 layer polymer web (sticker). Sample 2 has the same structure as Sample 1 but, in this case, the thicknesses of the Separator and PET (Substrate) layers are similar.

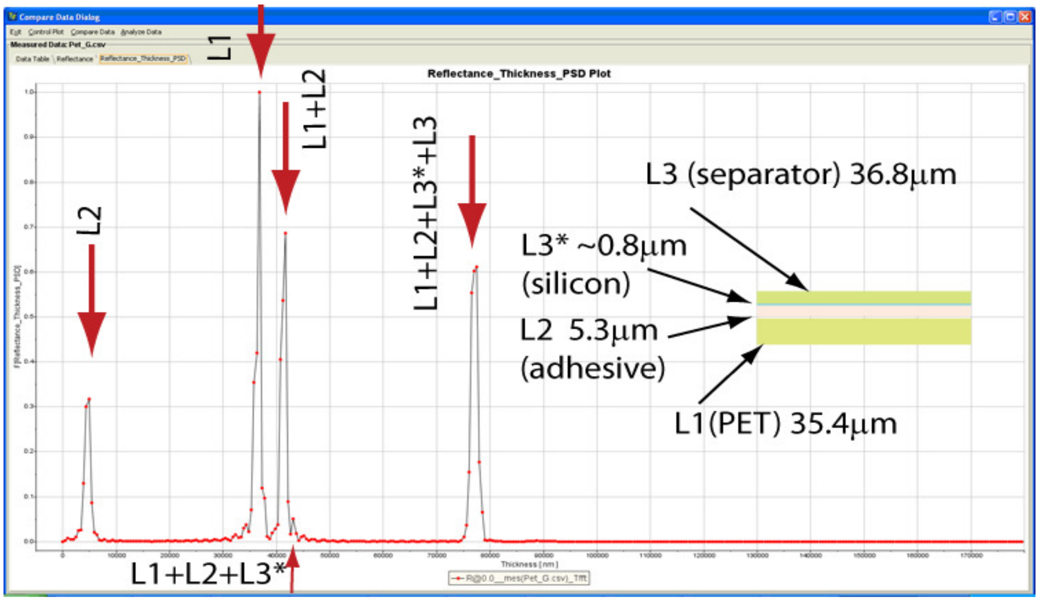

Fig. 7. FFT decomposition data analysis of the data (Fig. 6).

FFT deconvolution of Sample 2 measurement (Fig 7) does not show Layer 3 directly – it manifests itself in the broadening of the L1 peak. It is possible to deconvolute L1 peak to determine L3 but a better way is to use the total thickness and L1+L2 information to determine L3.

Differential thickness option can be activated in the software to determine "missing" thickness from the total thickness (see Fig. 8)

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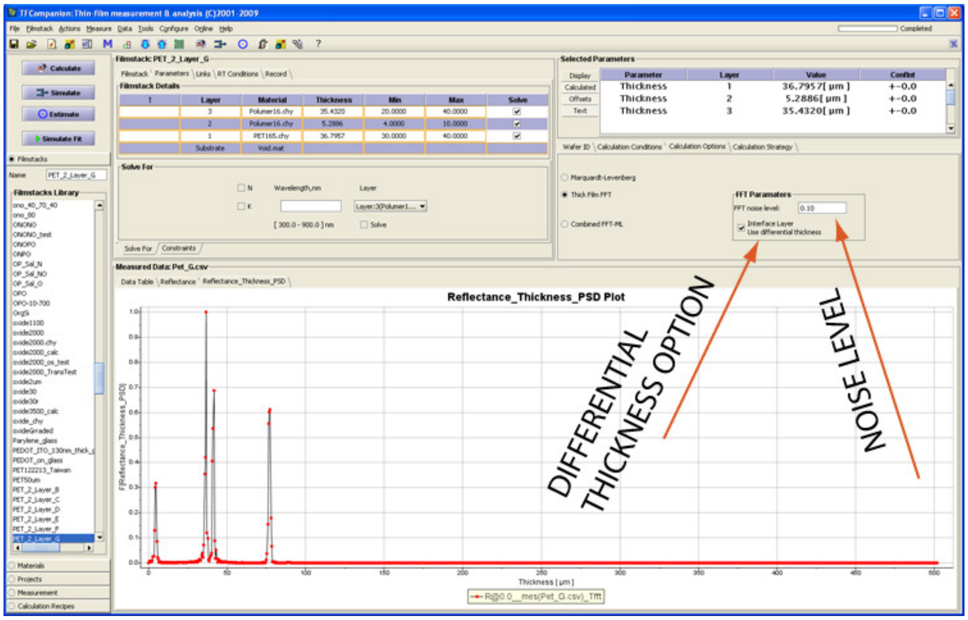

Fig. 8 Setting differential thickness option to determine thickness of the "hidden" layer/interface from the total thickness. Noise level setting helps separate Layer thickness data from the noise.

2.2 ALUMINA (SAPPHIRE) LAYER MEASUREMENT.

Alumina, parylene, yttrium oxide and many other thick layers have R.I. depending on deposition conditions. Using a library, stoichiometric material, optical properties with FFT decomposition can result in inaccurate thickness reading.

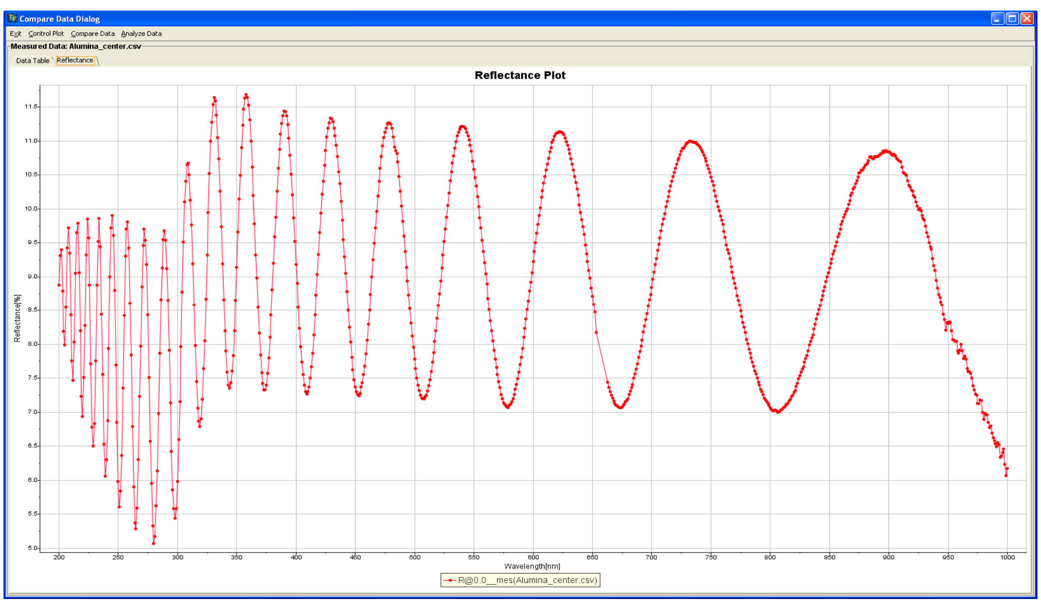

Fig. 9. Reflectance of Alumina on glass measured with MProbe UVVisSR system (wavelength range: 200nm -1000nm)

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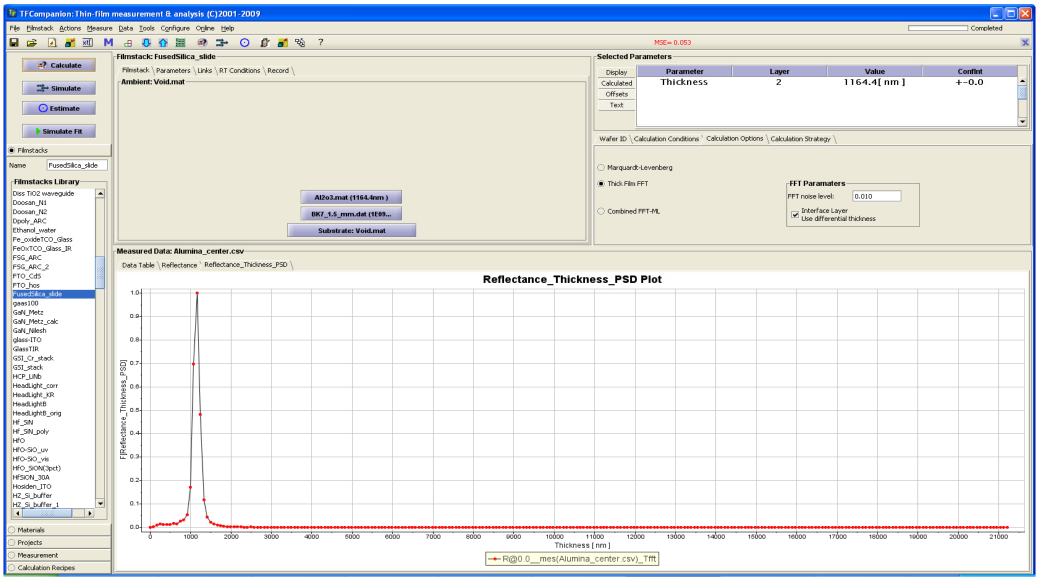

Fig. 10 FFT decomposition of the data on Fig. 8. using library Alumina material properties. The peak position indicates the thickness of 1164nm

Direct comparison of the model vs. measured data using FFT decomposition results shows that refractive index (R.I.) value used in the model is not accurate (Fig. 11)

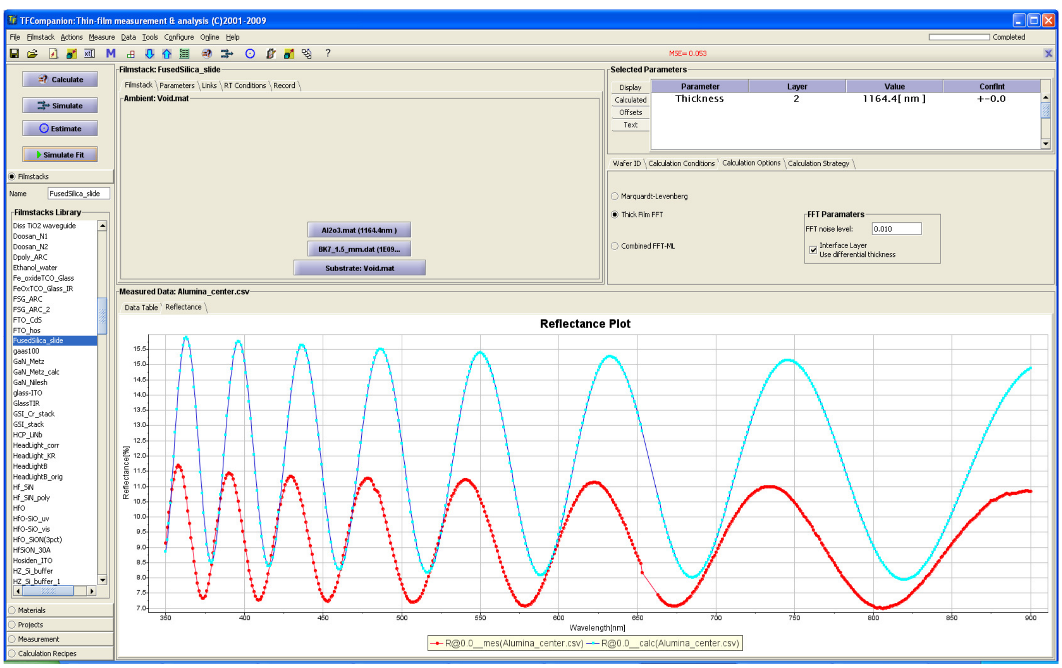

Fig. 11 Direct comparison of the FFT results model (red) and measured data (blue) shows that R.I. is not correct.

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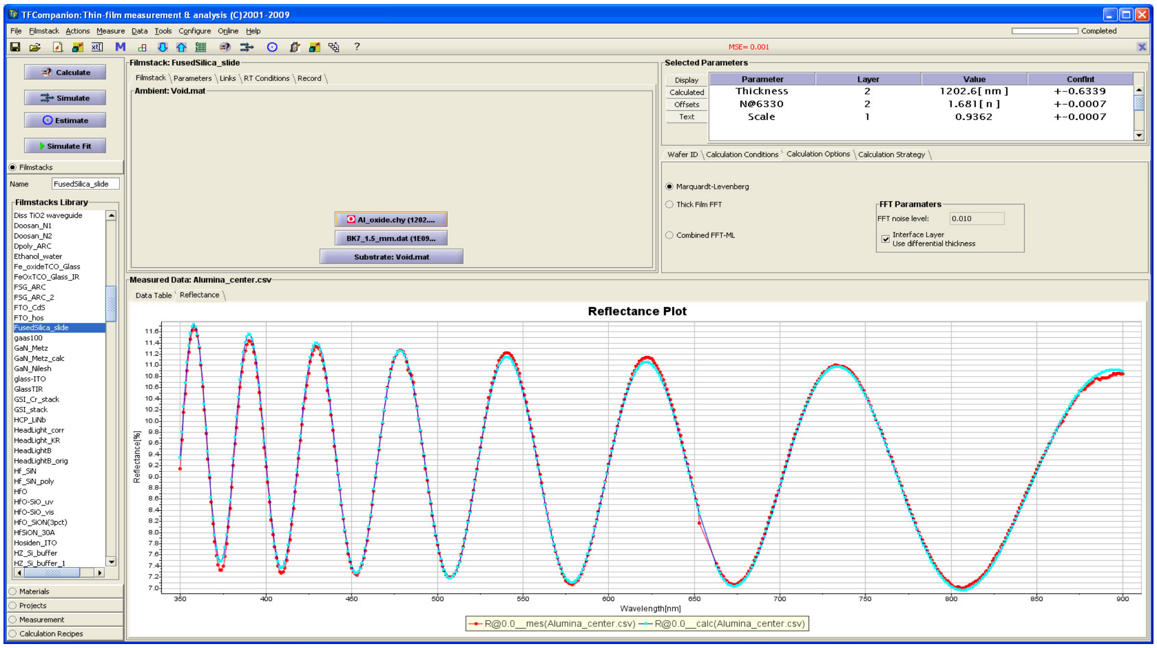

Fig. 12. Direct fit of the model to measured data to determine the thickness and R.I. of alumina. Thickness 1202 nm.

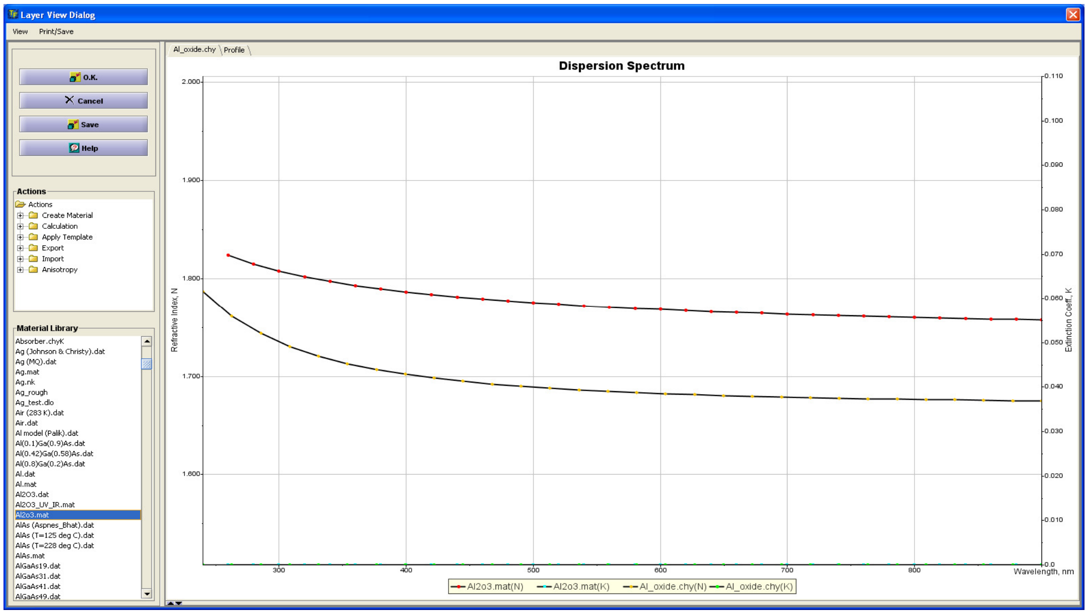

Fig. 13. Alumina R.I. determine from the measurement (yellow) and library alumina R.I. (red)

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2.3 HARD COATINGS

Hard coating has many applications, in particular, it is deposited on the surface of polycarbon products like eyeglass lenses and headlight/taillight covers of the cars. When hardcoating is deposited it creates an Inter Penetration Layer (IPL) in polycarbon. IPL is, typically, fairly thin (~ 1 µm). It is important for quality control to measure both the thickness of the IPL and hard coat layers.

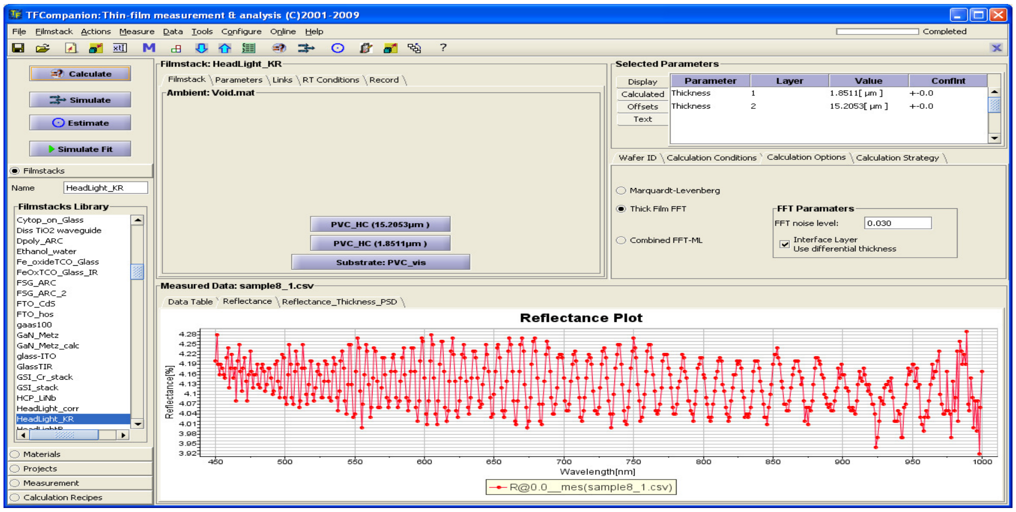

Fig. 14 Reflectance spectra of polycarbon with hardcoat sample (headlight). Measurement is taken with MProbe Vis system (wavelength range: 400-1000 nm)

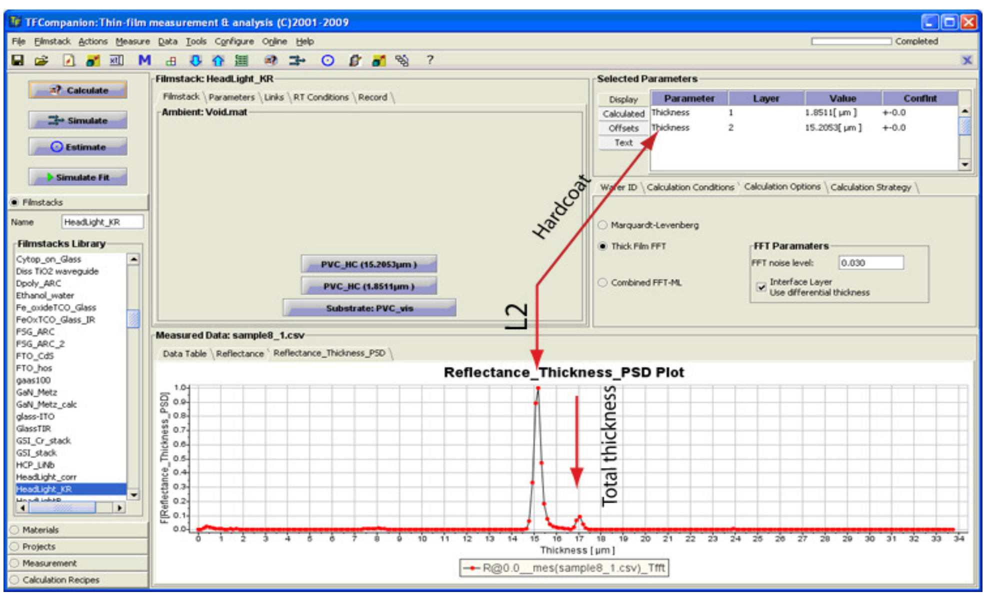

Fig. 15. FFT decomposition of the measurement data (Fig. 14). A differential thickness option is activated and IPL is determined from total thickness. Hard coat: 5.2 µm, IPL: 1.85 µm

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IPL layer has a R.I. in between polycarbon and hardcoat optical properties, so the optical contrast between IPL and both material is weak. As a result, direct peak from the IPL is very weak (on the noise level). Using differential IPL thickness determination from the total thickness solves the problem and gives accurate results.

III. FFT ANALYSIS ACCURACY OPTIONS

The accuracy of the thickness measurement with FFT algorithm depends on how accurately the position of the peak can be determined.
The maximum error of the measurement can be determined as $(X_{n+1}-X_n)/2$, where X_n and X_{n+1} are points adjacent to a peak (Fig. 1)

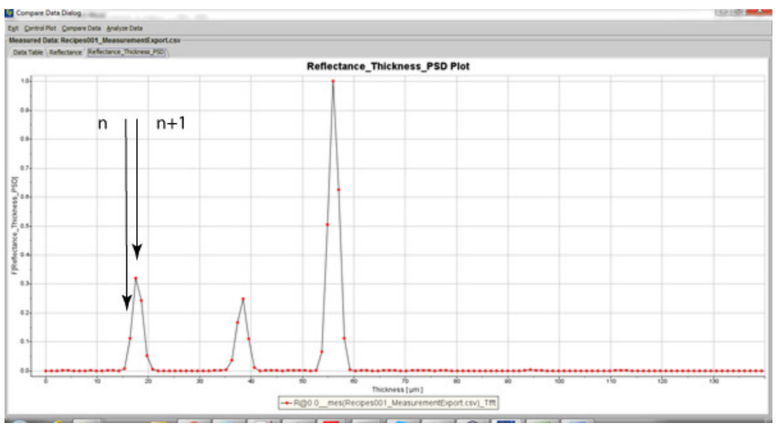

Fig. 16. FFT points resolution. Distance between adjacent FFT points (bins) determines maximum error.

To improve accuracy one can:

1. Increase the number of points
2. Interpolate between the points
3. Fit a Gaussian to a peak and determine position from the fitted function.
4. Apodization (filter the data). It does not, in most cases, improve accuracy directly but helps avoid aliases and additional peaks, especially in noisy signals

All these options are available in TFCompanion software and are reviewed here using an example of a coating on polymer film.

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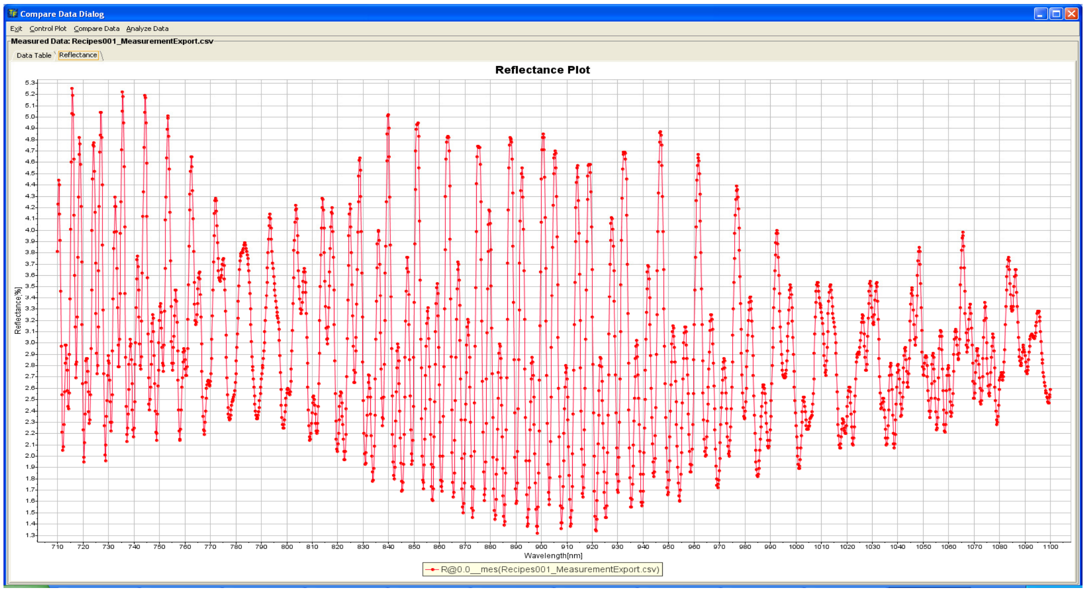

Fig. 17 Measured reflectance spectrum of coating (~ 18 µm) on 38 µm PET

3.1 INCREASING THE NUMBER OF POINTS

FFT points are spread in the maximum measurable thickness range. Frequently, only part of the thickness range is of interest. In our example, the maximum measurable thickness is 280 µm but the thicknesses of the sample are 18 µm and 38 µm.
We can increase the number of points using a method that is sometimes called "oversampling".

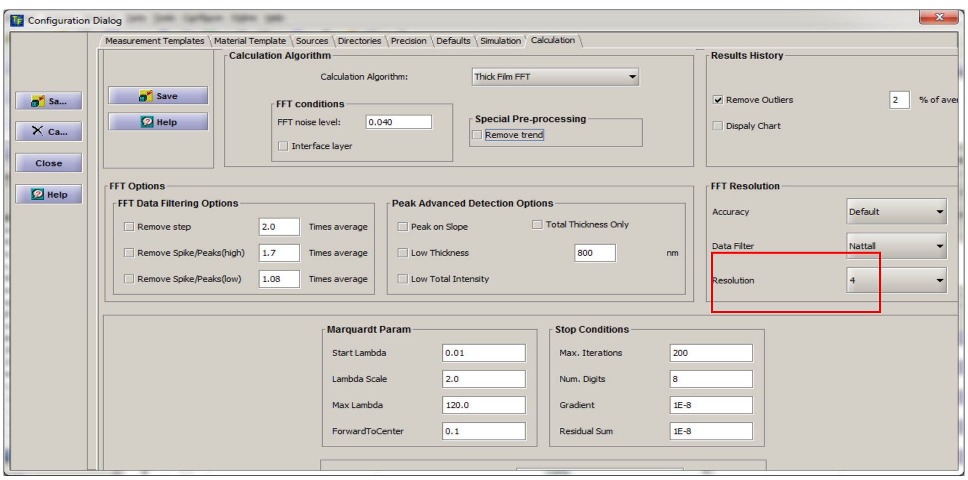

Fig. 18. **Resolution improvement by using increased number of FFT points. 1 is default resolution, 5 – maximum resolution**.

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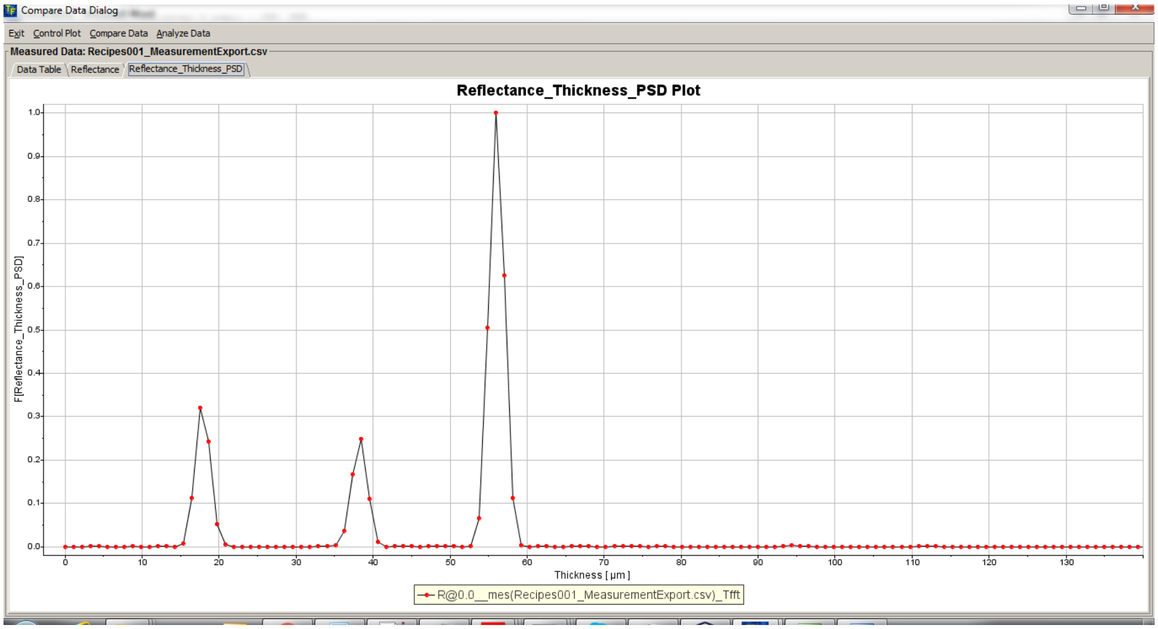

Fig. 19 Peaks using default resolution (1)

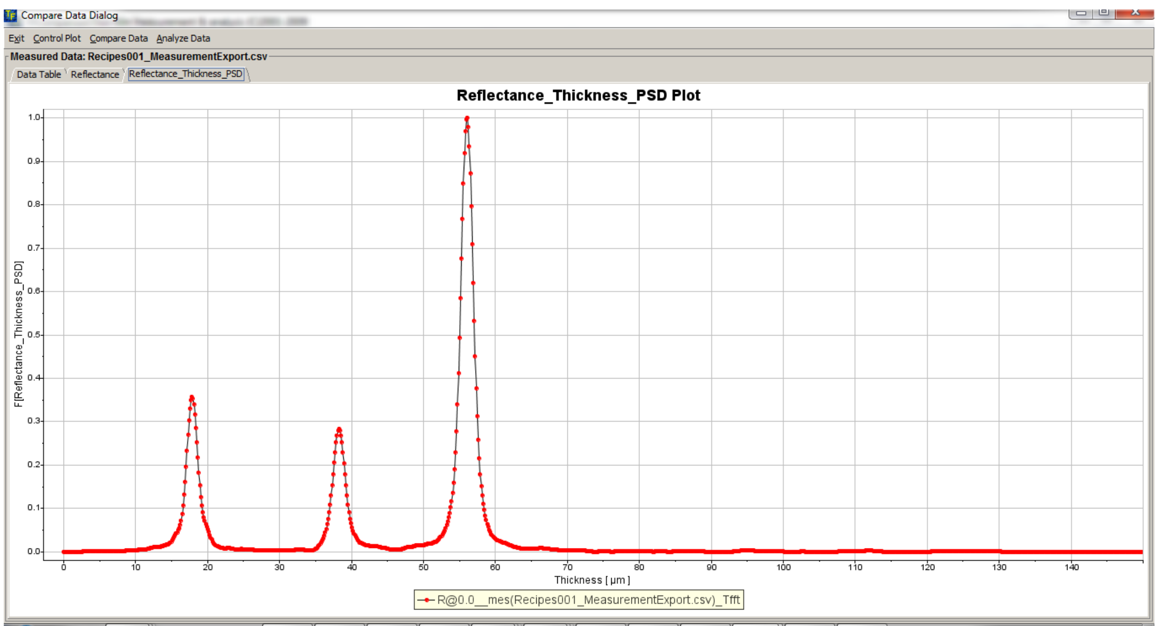

Fig. 20 Peaks using high resolution (4)

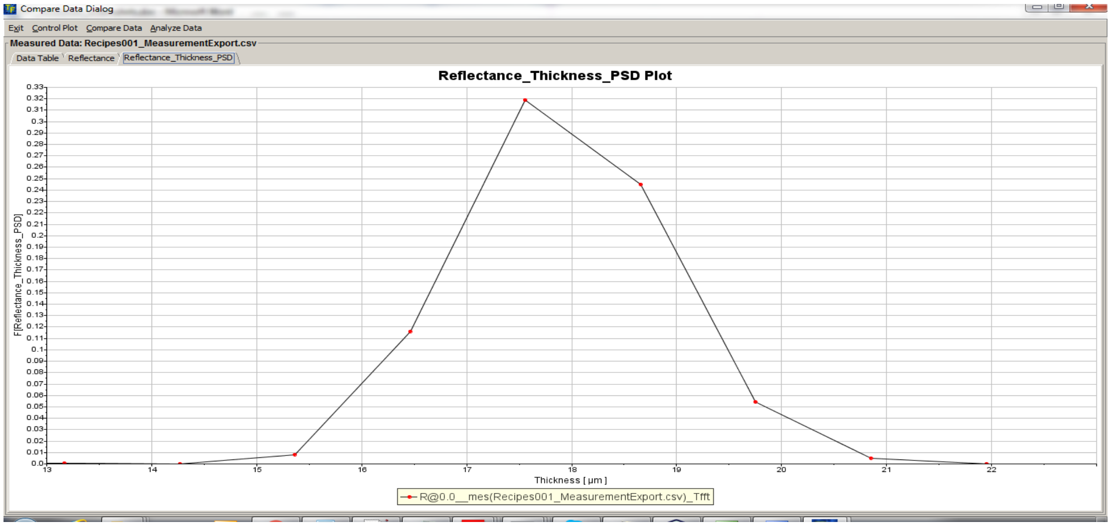

Fig. 21 Peak detail from fig. 19 (default resolution - 1)

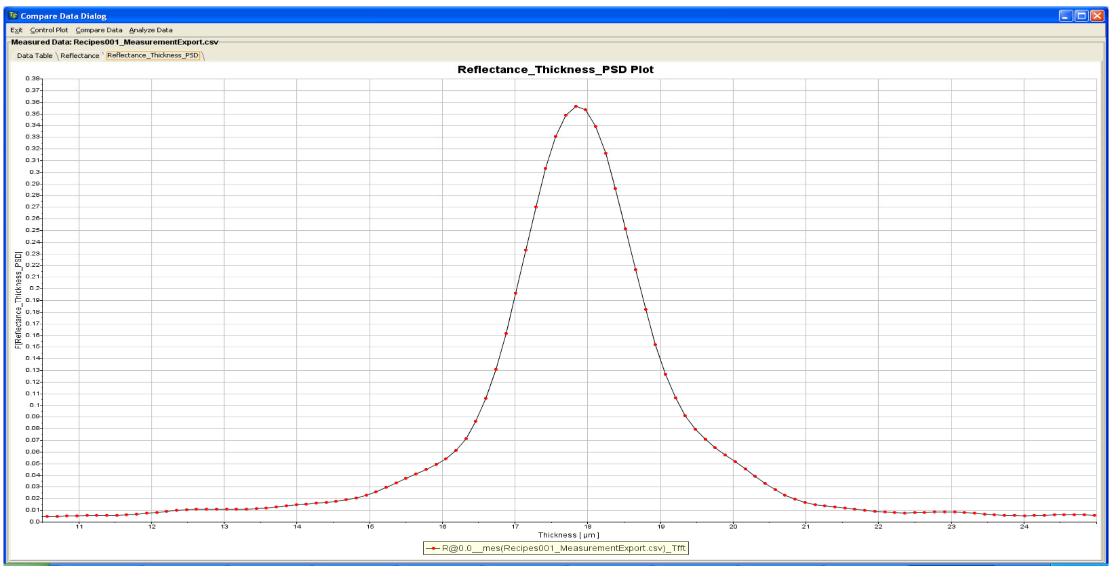

Fig. 22 Peak detail from Fig. 19 (high resolution -4)

Resolution	1	2	3	4
Maximum possible error (µm)	0.548	0.274	0.137	0.068

Table. 2 Maximum possible absolute measurement error depending on the resolution for this measurement

3.2 INTERPOLATION BETWEEN THE POINTS AND GAUSING FIT

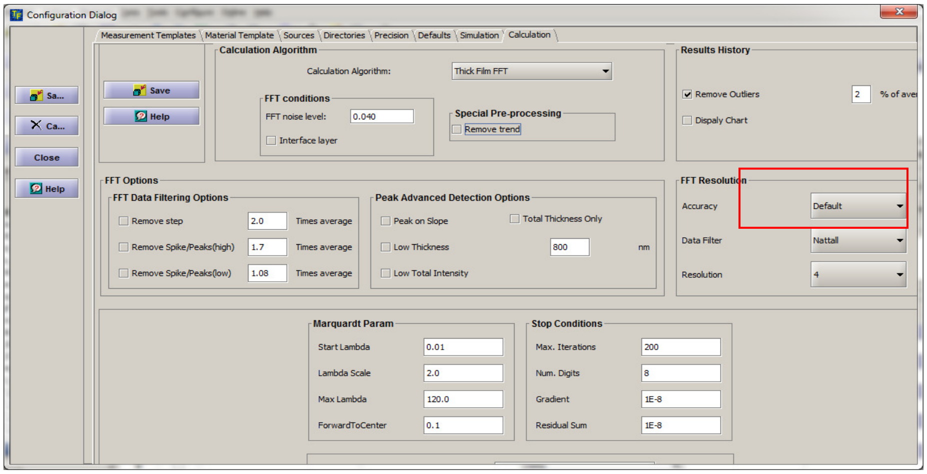

Fig. 23. Selecting accuracy level.

Three levels of accuracy are available:
a). Default – no interpolation or fit
b). High accuracy. Gaussian interpolation between the points
c). Maximum accuracy. Gaussian curve fit to the peak.

3.3 APODIZATION- DATA FILTERING

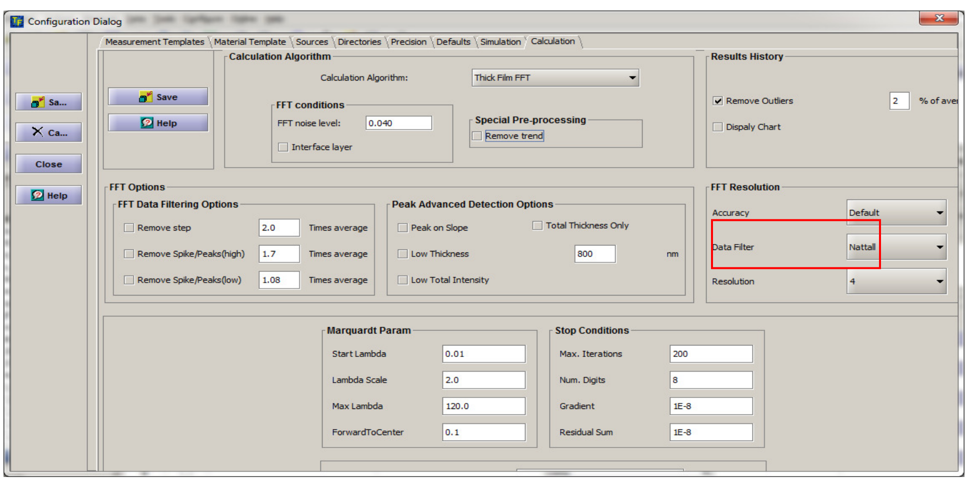

Fig. 24 Apodization filter selection

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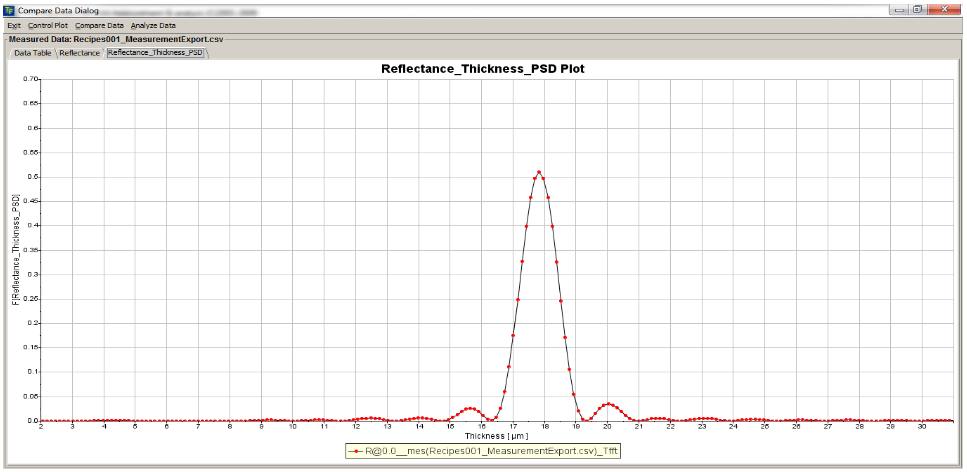

Fig. 25. Peak without data apodization/ Two aliases are visible.

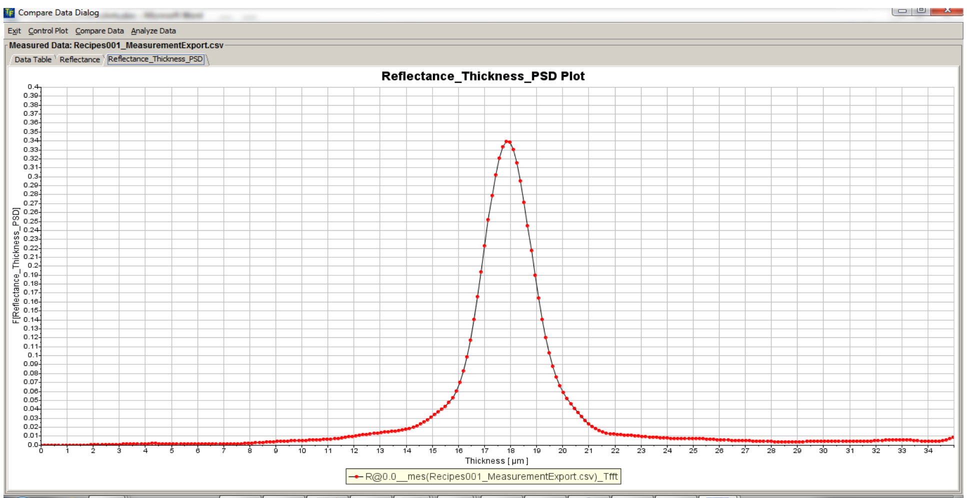

Fig. 26 . Peak with data apodization (peak is the same as on Fig. 25)

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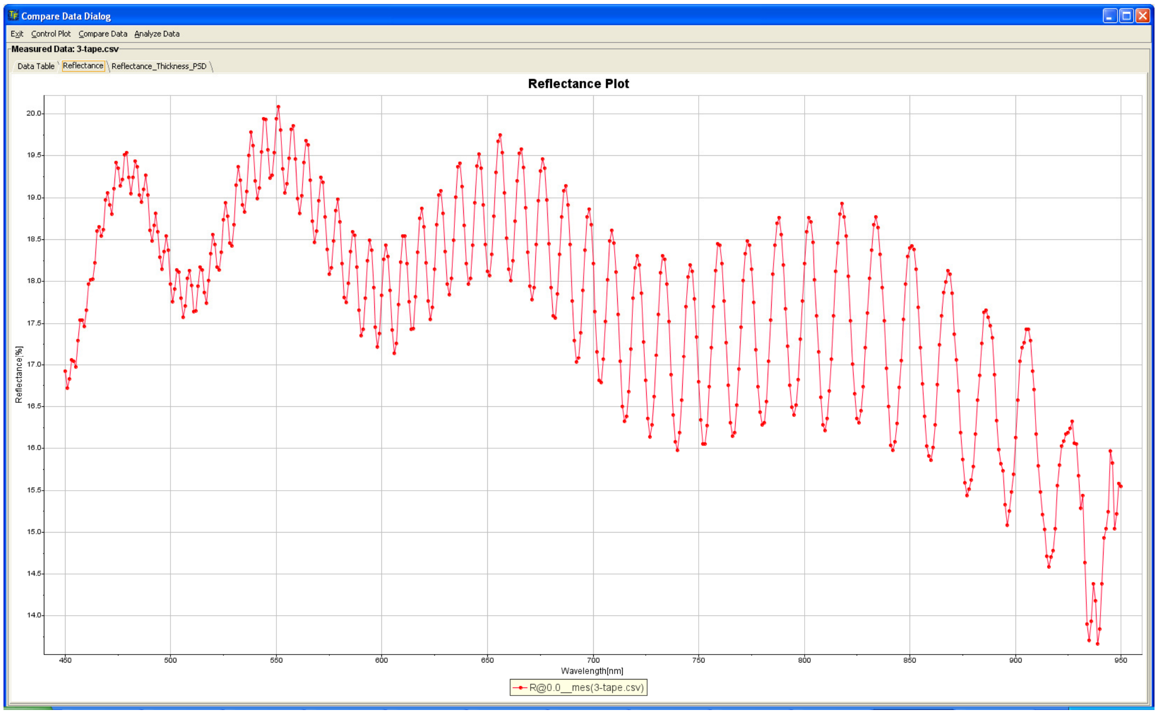

Fig. 27. Reflectance spectrum of GaN on sapphire (400-1000nm wavelength range)

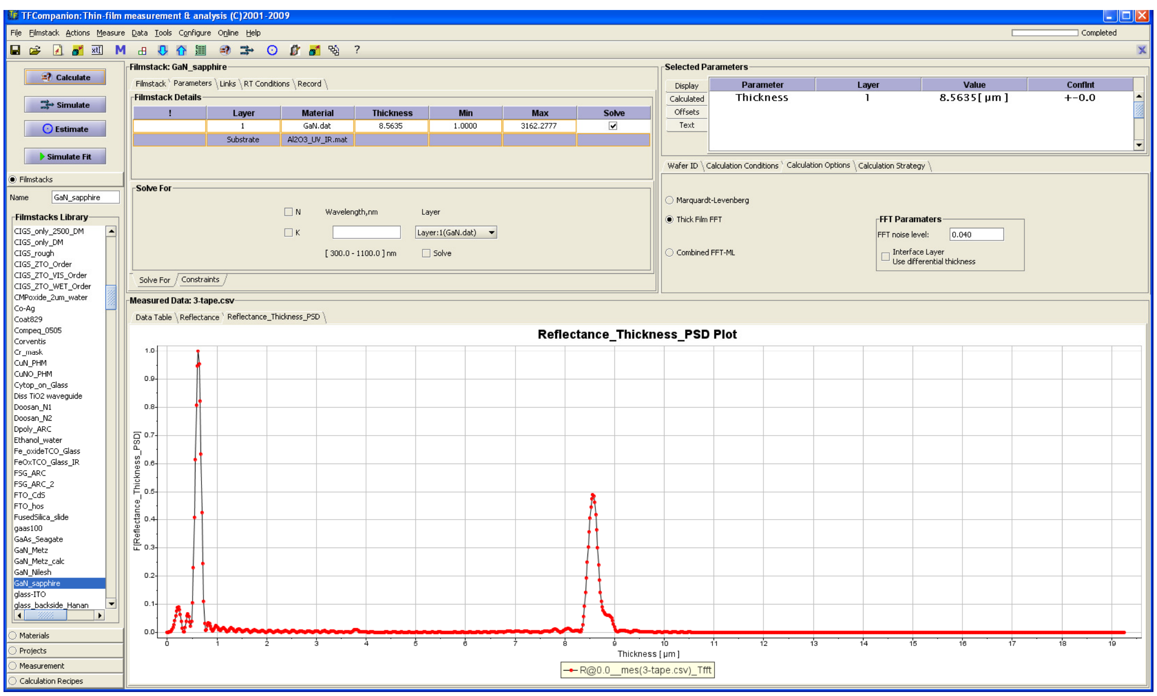

Fig. 28 Measurement of GaN (fig. 27) without data apodization

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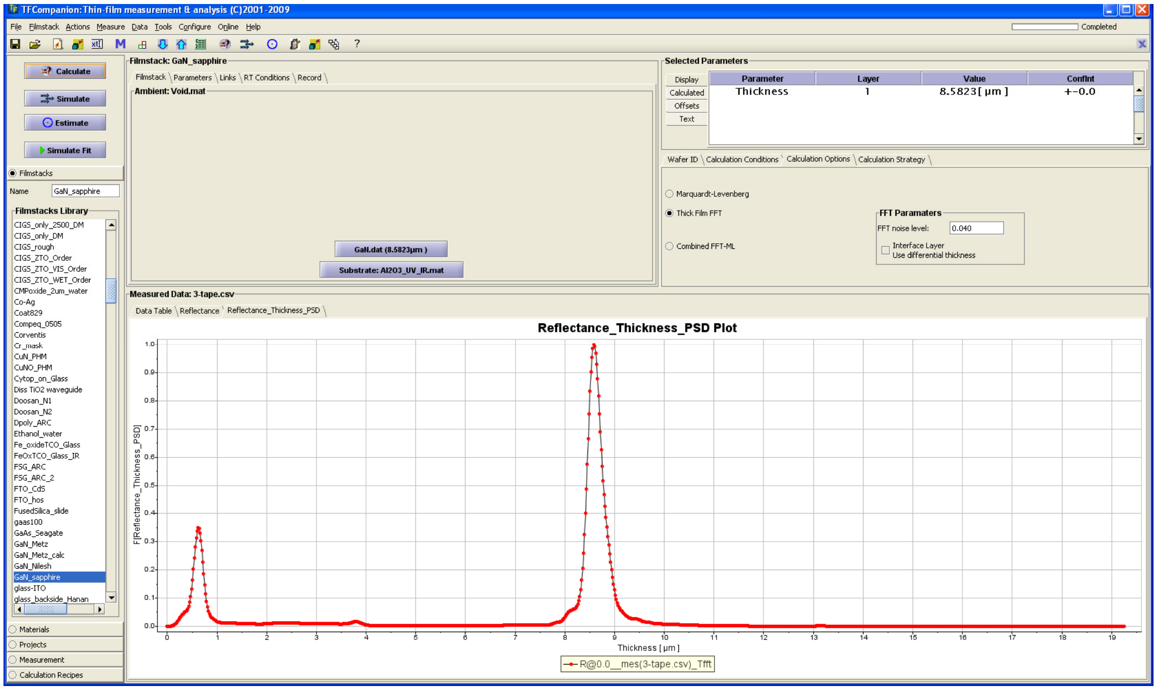

Fig. 29 Measurement of GaN (Fig. 27) with data apodization

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