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

Thickness Range Limits for MProbe System

I. Introduction

MProbe is using spectroscope reflectance measurement principle. The phase (φ) of the light propagating in the material is changing as a function of the wavelength (λ), refractive index of the material (n) and the length of the path (d).

$$\varphi = \frac{2\pi}{\lambda} nd \quad (1)$$

When the light is reflected from the measurement sample it is a combination of the beams reflected from different interfaces - each having a different phase (Fig. 1). In the measurement process, the phase differences are being converted in intensity variations as a function of the wavelength.

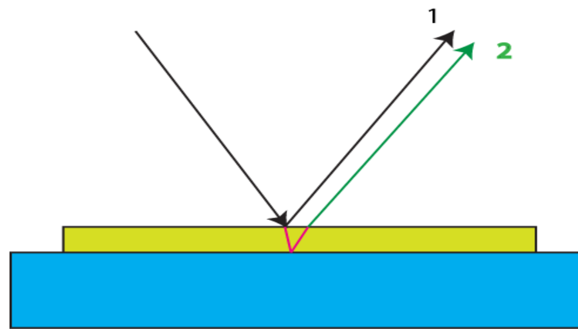

Fig. 1 Light reflectance from the filmstack. Beam 1 is reflected from the top interface, Beam 2 is propagated though the layer and reflected back from the layer/substrate interface.(multiple reflection in the layer are not shown for clarity)

3 nm

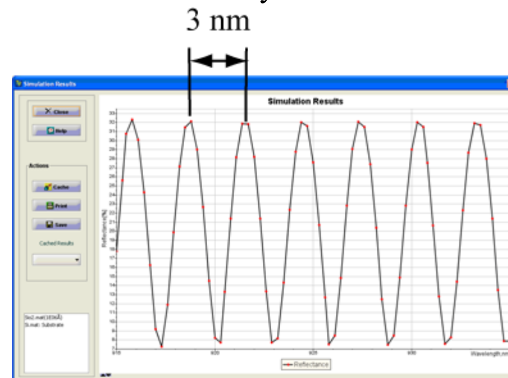

Fig. 2. Simulated reflectance spectrum (visible range) for 100µm SiO2 film (on Si substrate) .

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In case of the thick films (Fig. 2), the resulting reflectance spectrum shows a distinct interference pattern. Measuring the distance between the fringes allows determining the thickness of the layer. In order to determine film thickness from pattern on Fig. 2, measurement system needs to have enough wavelength resolution to resolve peaks. MProbe Vis system has <2 nm (FWHM), it can measure 100 µm SiO2 assuming that interface between the film and substrate is perfect, there is no roughness (< 1nm), etc. If conditions are not perfect – the amplitude of the fringes will decrease and it will be next to impossible to resolve. So, one can call 100µm a detection limit of the system. For a precise measurement on real samples – the measurement range will be ~ 75 µm

Measurement precision degrades between the maximum thickness and detection limit. If we use a different material with higher refractive index – the maximum measurable thickness will be reduced. For example, if R.I. is 2 times higher than SiO2 /(quartz) – the thickness will be reduced 2 times as well.

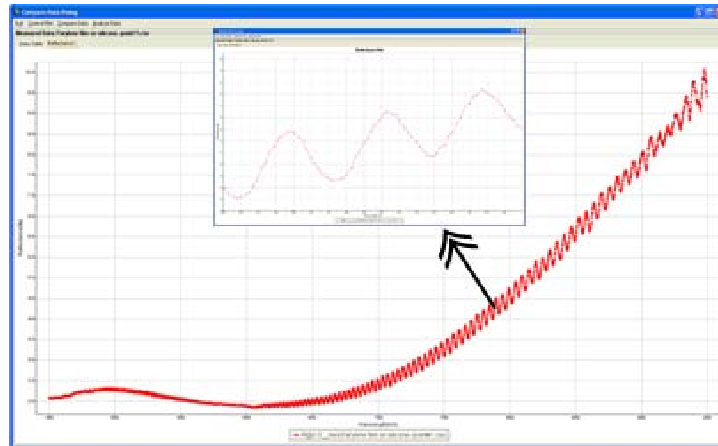

Fig. 3 Measured reflectance (400-950 nm) of the Silicon rubber film (~ 50 µm thick) with thin Parylene layer. Interference fringes are clearly resolved at longer wavelength (600nm +)

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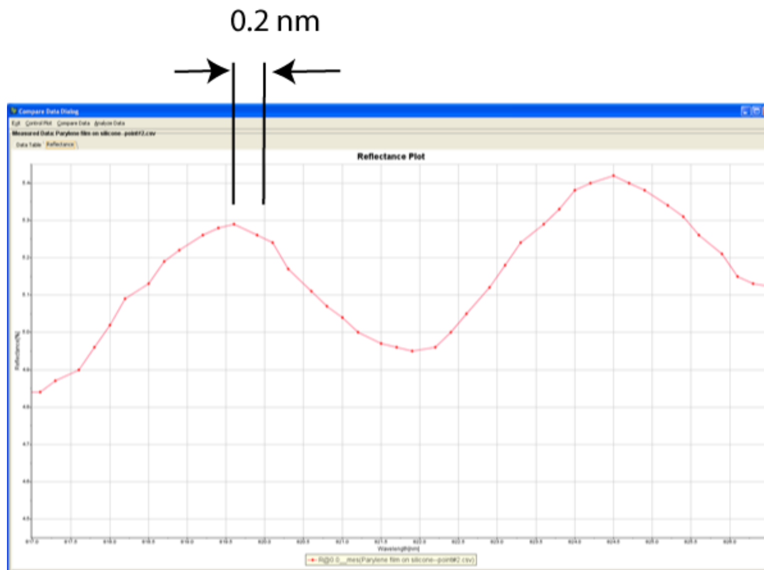

Fig. 4. Fragment of Fig. 3 plot showing "pixel resolution" i.e. wavelength distance between individual pixels of the CCD (measurement points) for MProbe Vis system

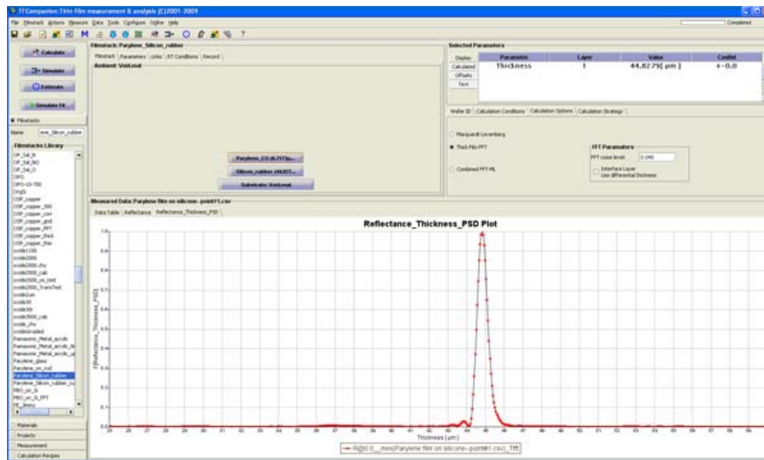

Fig. 5 Analysis of the measurement data from Fig. 1 (limited wavelength range 600-950nm is used). The peak position Indicates the layer thickness.

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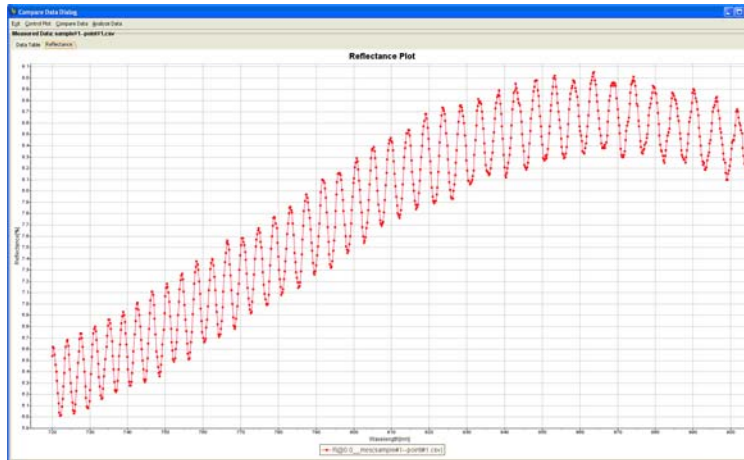

Fig. 6. Measurement data using MProbeHR (wavelength resolution <0.35 nm). In 700-1000nm wavelength range.

Comparing measurement data with high-resolution MProbeHR (Fig. 6) and MProbe Vis (Fig. 3) - we can determine the effect of the wavelength resolution on the amplitude of the interference fringes: ~ 0.7% (VisHR) and ~ 0.4% (Vis). There is no effect on measurement accuracy – signals down to 0.1% can be clearly determined.

II. Thickness ranges (R.I. = 1.5)

System	Wavelength Resolution, nm	Pixel resolution, nm	Maximum thickness, µm	Detection limit, µm
MProbe Vis	<2.0	0.2	75 µm	100 µm
MProbe Vis-E	<1.0	0.2	150 µm	200 µm
MProbe UVVis	<2.0	0.22	75 µm	100 µm
MProbe VisHR	<0.35	0.2	420 µm	550 µm
MProbeNIR	<3.5	1.6	150 µm	250 µm
MProbe VisHRX	<0.1	0.035	1200 µm	1900 µm
MProbe NIRHR	<0.3	0.1	1800 µm	2000 µm

Table I. Measurement thickness: maximum limits.
Thicknesses determined for material with Refractive index ~1.5.

Minimum thickness limit is determined by the sensitivity of the system. Sensitivity increases at shorter wavelengths as can be seen from equation 1.

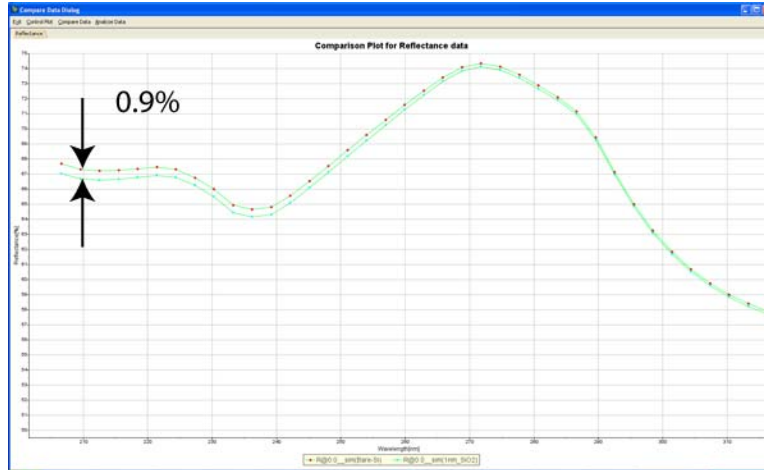

Fig. 7. Reflectance simulation for bare Si and 1nm SiO2 on Si.in UV range. Two curves can be clearly distinguished in UV.

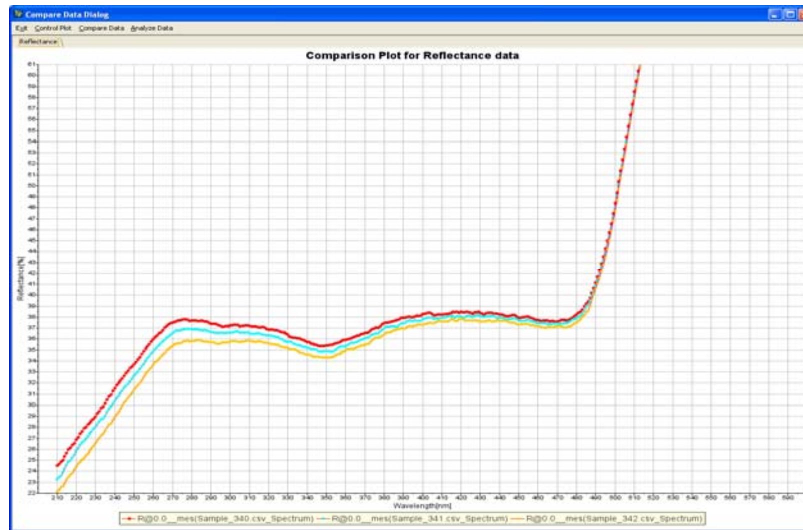

Fig. 8 Measured reflectance: Polymer monolayers on gold subsatrate Gold (red), 1.3 nm monolayer (Green) , 2.6 nm (yellow)

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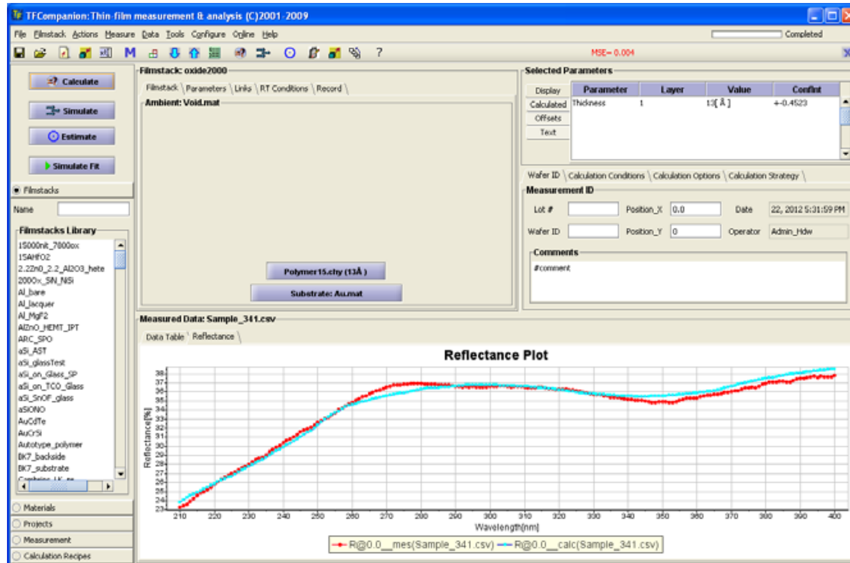

Fig. 9. Measurement of 1.3 nm polymer on gold .
Model vs. measured data

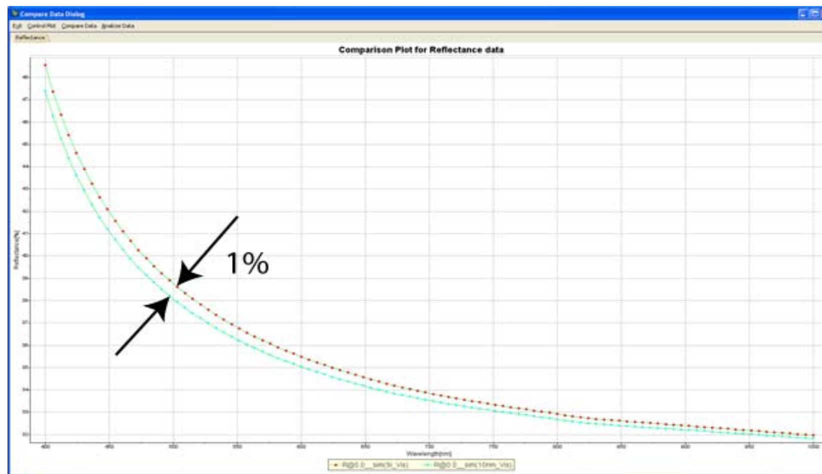

Fig. 10 Reflectance simulation for bare Si and 10 nm SiO2 on Si in visible range. Two curves can be clearly distinguished

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Thin films do not have distinct interference pattern – spectrum is a smooth curve that shifts down as thickness increases. Accurate calibration and measurement conditions have stronger effect on the measurement as compared to the thick films. For that reason, minimum thickness is determined at the 1% level i.e. change in thickness that cause ~1 % change in reflectivity. Smaller difference at the 0.1% level can be measured but require perfect interfaces and measurement conditions, so we define it as a detection limit (possible to measure but difficult to achieve in practice). Accuracy deteriorates between the minimum thickness and detection limit.

System	**Wavelength Range, nm**	**Minimum thickness**	**Detection limit, µm**
MProbe Vis	400-1000 nm	10 nm	1 nm
MProbe Vis-E	400-1000 nm	10nm	1 nm
MProbe UVVis	200 -1000nm	1nm	0.1 nm
MProbe VisHR	700-1100 nm	1 µm	100 nm
MProbeNIR	900 – 1700 nm	50 nm	10 nm
MProbe HRX	800 -870 nm	10 µm	1 µm
MProbe NIRHR	1500 -1550 nm	10 µm	5 µm

Table II. Measurement thickness: minimum limits.
Thicknesses determined for material with Refractive index ~1.5.

III. Thickness ranges on Si (R.I.= 3.4 in NIR)

Si is transparent in NIR range (wavelength >1000nm) and becomes measurable with the MProbe system (very thin Si can be also measured in the Visible range). Only two MProbe configuration cover NIR range: MProbe NIR and MProbe NIRHR. MProbe NIR HR is primarily used for thicker Si samples and small spot measurement is used to mitigate effects of roughness and thickness non-uniformaty common in thick Si samples.

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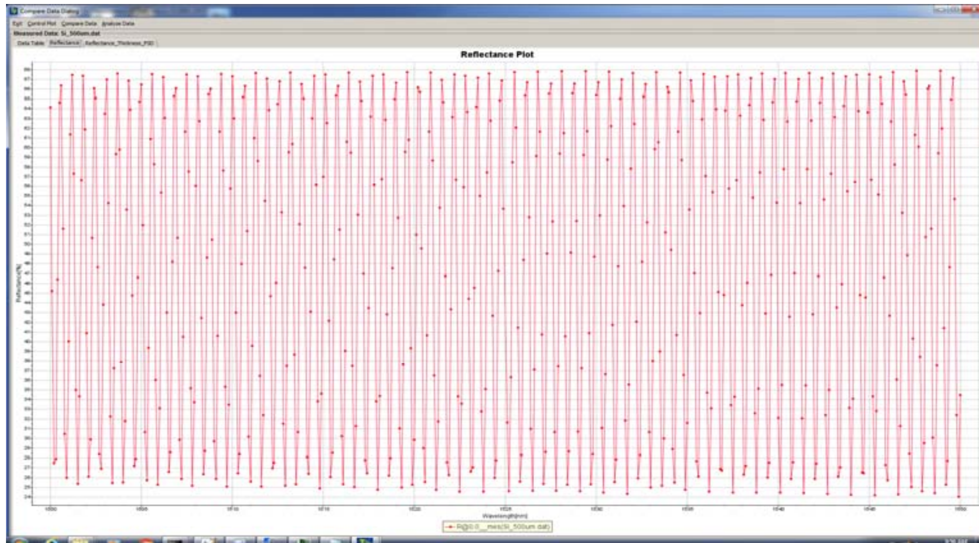
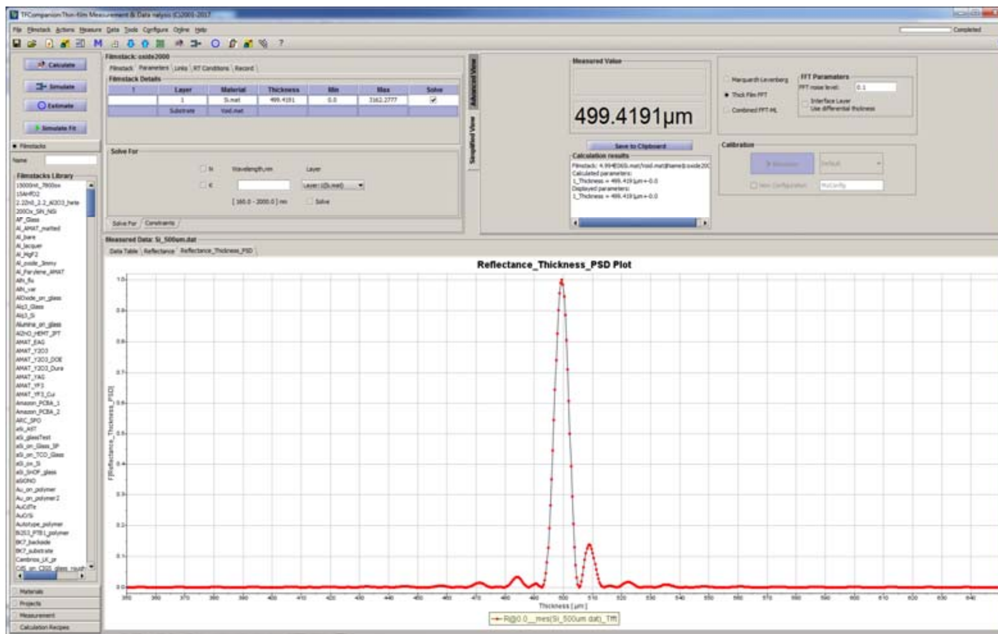


Fig. 11. Reflectance spectrum (simulation) of 500 µm Si (1500-1550nm range with 0.3nm resolution) corresponding to MProbe NIRHR



Fig, 12 Data analysis results (data from Fig. 11)

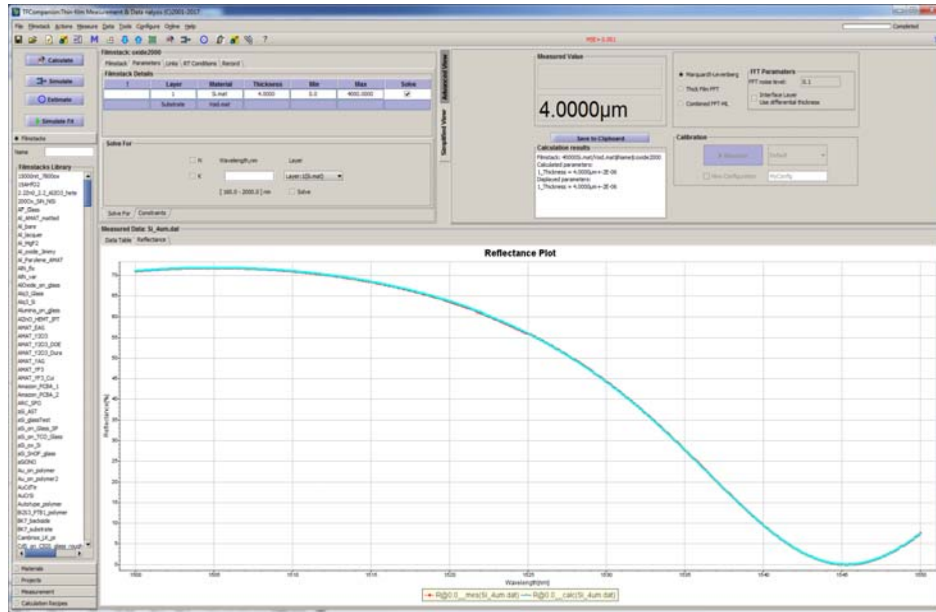


Fig.13. Data analysis results of 4 µm (MProbeNIRHR)

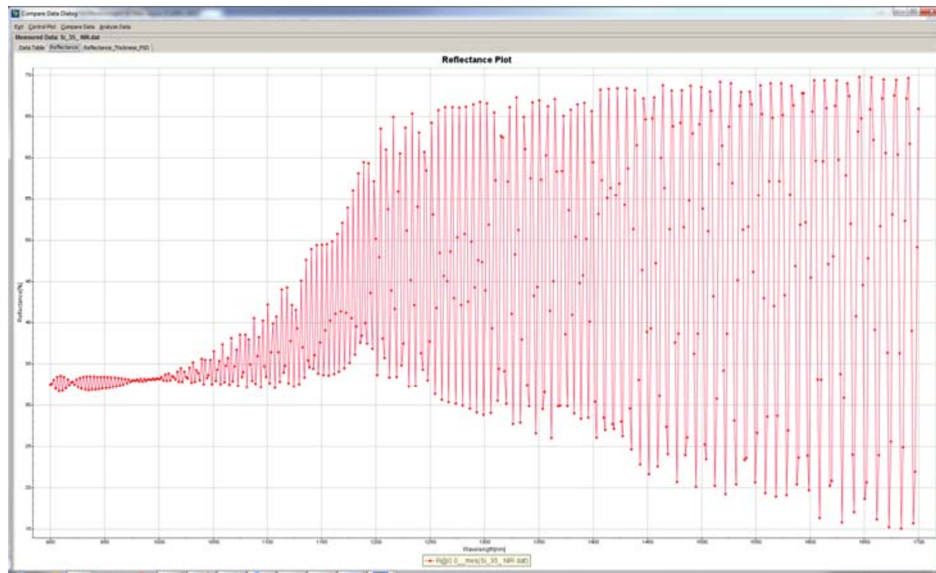


Fig. 14. Reflectance spectrum (simulation) for 35 µm Si (MProbe NIR)

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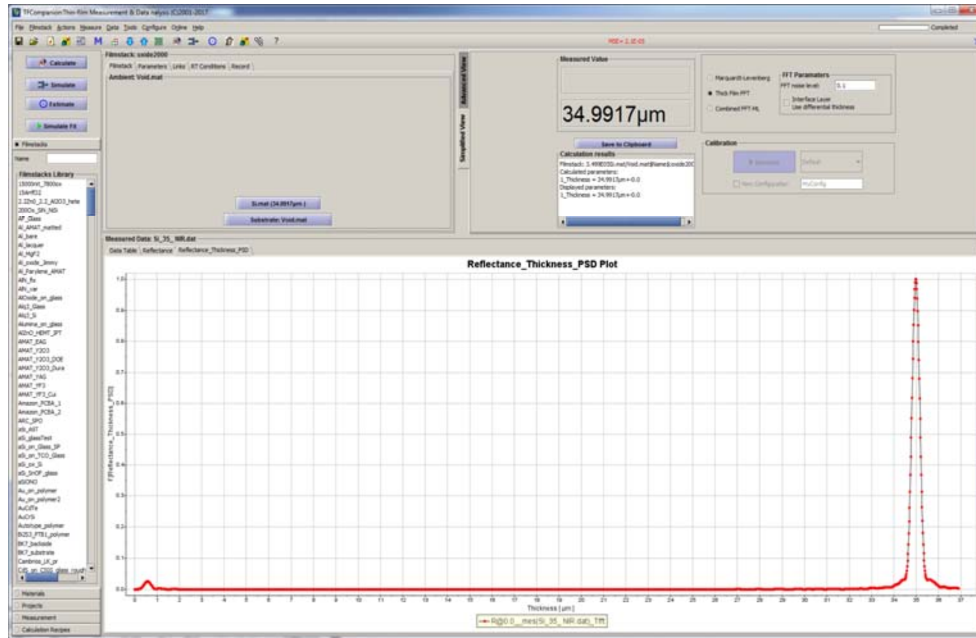

Fig, 15 Data analysis results for 35 µm Si -MProbe NIR
(data from Fig. 14)

System	Wavelength Range, nm	Minimum thickness	Detection limit
MProbeNIR	900 – 1700 nm	100 nm	50 nm
MProbe NIRHR	1500 -1550 nm	4 µm	2 µm

Table III. Minimum thickness range on Si

System	Wavelength Range, nm	Maximum thickness	Detection limit, µm
MProbeNIR	900 – 1700 nm	30 µm	40 µm
MProbe NIRHR	1500 -1550 nm	500 µm	800 µm

Table IV. Maximum thickness range on Si

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