Frequently Asked Questions

1. What kind of samples can be characterized by FR-tools?

In FR-tools the White Light Reflectance Spectroscopy is employed for the characterization of supported or unsupported films in terms of thickness(es), refractive index, colour etc. The sample under characterization can be either planar or curved (with radius of curvature ≤ 20 mm). There are certain requirements that should be fulfilled in order to characterize successfully the samples of interest.

- The substrate could be transparent (e.g. glass, quartz, dielectric …) or non-transparent (Si wafer, GaAs wafer, Stainless steel, …).
- The coating on the substrate could be a single film or multiple films. The films could be either transparent or semi-transparent e.g. polymers, resists, dielectrics, semiconductors, liquid crystals, antireflective coatings etc. If the absorbance is high (e.g. metals) the film thickness range in which the methodology can be applied is limited to very few tens of nanometers.
- The refractive index contrast between the film(s) and the substrate (or the top film with the surrounding environment – e.g. air – in free standing structures) should be adequate high to produce interference. The minimum required refractive index contrast depends on the film thickness. If the film thickness is high (several microns at least) then the refractive index contrast could be as low as 0.02. If the film thickness is small then the refractive index contrast should be higher.
- In addition FR-Tools are able to measure film thickness of un-supported samples e.g Si membranes, polymer membranes, liquid membranes, …
- The roughness of the substrate or the film(s) causes diffuse scattering. Since WLRS is based on specular reflectance, high roughness causes blurring and the interference fringes might be not be identified by the fitting algorithms. This effect becomes more pronounced in the case of thick films.
- The non-uniformity of the film thickness may alter the accuracy of the measurements, e.g. the film thickness varies in the measurement spot (350-400um OD). In FR-Monitor, special algorithms have been implemented to measure the non-uniformity of the film thickness.
- In case of curved substrates, the focusing accessory should be mounted on the reflection probe to decrease the spot size.

2. What affect the measurement performance of the tool (FR-pOrtable or FR-pRo)?

The thickness measurement range depends on:

a) the spectrometer's spectral range
b) the spectrometer's resolution and
c) the emission spectrum of the light source.

In all FR-tools the emission spectrum of the light source is wider than the spectral range covered by the embedded spectrometer. Thus FR-pOrtable and FR-pRo VIS/NIR are covering the same spectral range because they are equipped with the same spectrometer. FR-pRo UV/VIS can measure the thickness of thin layers.

3. How spectrometer resolutions affect the accuracy of the film measurements?

The accuracy of the film measurements vs. spectrometer resolution and its spectra range is a trend between 2 poles a) as the interference fringes are more dense (e.g. in very thick films) there is need of higher resolution in order to be able to distinguish the dense fringes peaks b) as the spectral range goes to NIR range the interference fringes become less dense. So, in order to measure very thick films (very dense interference fringes) we need to go to very narrow NIR spectral range. In order to measure very thin films (too few or no one interference fringes) we need to perform measurements in the UV spectral range.

4. How the resolution of the spectrometer is determined?

For each CCD, the resolution of the spectrometer is determined with the combination of two parameters a) the width of the entrance light slit of the spectrometer b) the grating that analyze the light. The standard version of the FR-tools (FR-pOrtable, FR-pRo VIS/NIR) is equipped a Flame-T spectrometer from OceanOptics with 25μm entrance slit and 600line/mm grating resulting a spectra range 350nm-1050nm with resolution 1.0nm. That resolution is suitable enough for most common film thickness measurements from 10nm up to 90μm. In certain configurations, the grating is denser (1200lines/mm, 1800lines/mm etc.) and then the spectral range become narrower and so the resolution improve. E.g. with 1800lines/mm and spectral range 600nm-760nm the resolution with 25μm slit becomes 0.32nm, suitable for measurements of very thick films. As the entrance slit become narrower (e.g. 5μm or 10μm) the resolution of the spectrometer further improves, but the photon flux that enters into the spectrometer becomes lower.

Following our studies at our labs with a wide range of diverse samples that cover a wide thickness range, the spectrometer configuration that cover a large number of applications is the 600lines/mm and 25um slit. Under special sample requirements, this combination can be tailored to specific measurements needs.

5. Why there are various fitting algorithm options in FR-Monitor?

In FR-Monitor there are three algorithms implemented: the Levenberg-Marquardt, the Fourier and the Trust. The Levenberg-Marquardt is the most generic algorithm and is can be used for the vast majority of applications for the calculation of film thicknesses and refractive index (Lorenz model is excluded). When the film under characterization is thick, e.g. >5um, it is advised to apply first the Fourier algorithm and then apply the Levenberg-Marquardt for higher accuracy. The Trust model is advised to be used in cases where the Lorenz model should be used for the measurement of the refractive index. In all cases the fitting is performed by pressing a button only.

Algorithm	Thickness	Refractive Index
Levenberg-Marquardt	Single Layer Multiple Layers	Cauchy model Sellmeir
Fourier	Single thick layer	No
Trust	Single Layer	Cauchy model Lorenz model Sellmeir

6. What about the materials range and refractive index information that is included in FR-Monitor software?

Our materials library has 350+ materials. The materials library is enriched in every newer version of FR-Monitor. However, new materials can be easily imported or created/added to the library. Support for a wide range of parameterized materials (from Cauchy to Lorentz, etc.) is included.

7. What about the flexibility of FR-Monitor Software?

FR-Monitor is stand-alone software tools developed by ThetaMetrisis for the control of all FR-tools (i.e. FR-Portable, FR-pRo, FR-Scanner, FR-Liquid, FR-Thermal, FR-Education and FR-μProbe) configurations and further signal processing. FR-Monitor is designed as a general software platform to fully control all FR-tools subsystems: spectrometers, light sources, X-Y stages, supporting electronics modules such as temperature controller, shutter, humidity sensors etc. Furthermore, thanks to its open architecture is easily upgradeable to control new features. FR-Monitor performs all optical measurements supported by FR-tools namely absorbance, transmittance, reflectance and fluorescence. Additionally, state-of-the-art algorithms for the real time characterization (both thickness and optical properties) of transparent or semitransparent films (single or stacked) and the recording of films variations under dynamically change conditions, e.g. dissolution, temperature treatment, ambient changes etc. are implemented. Reflectance and transmittance spectral data can also be used as a raw measurement (for example, as in spectrophotometer) or for further processing.

FR-Monitor can be used either on-line or off-line i.e. the user can process the measurements on any PC without the need to be connected to the FR-tool. FR-Monitor is upgraded twice a year at least with enriched material library, new models and characteristics.

8. What about for more complicated measurements as multi-layers or refractive index measurements?

FR-Monitor implements a smart fitting algorithm that is able to calculate more than one fitting parameter at a time:

For Refractive index calculation + film thickness (e.g. for a Cauchy material) we have a total of 4 calculated parameters (film thickness + 3 Cauchy parameters). Due to the complexity of the fitting procedure the samples must be high grade in term of roughness and non-uniformity.

For a stack of films, FR-Monitor is able to calculate the film thickness of all layers at the same time, when the refractive index of its layer is known. Software is also able to measure a stack consists of periodic layers of materials by assuming the same thickness for the same type of material. In our labs we have successfully measure the individual film thicknesses in a stack consisting of SiO_2/Si_3N_4/poly-Si/PMMA and ophthalmic lens with a hard coat and six antireflective layers.

9. How long does the fitting process of FR-Monitor software last?

The fitting process of FR-Monitor software is a quite quick procedure (~ ms to sec). Its duration depends on the number of parameters have to be calculated e.g. the number of the measured layers, refractive index, non-uniformity, the selected fitting algorithm parameters….

10. What about the light source?

The light source has to be in-line the spectral range specifications of the spectrometer that is embedded in the tool. For example it is meaningless to equip the tool with a spectrometer operating in the 200-850nm spectral range and a tungsten light source (emit light at >350nm). Furthermore the light source should couple high optical power to the optical probe and the emission spectrum should be stable both in terms of spectral content and intensity for long period in order to support long-term operation. All these specifications are fulfilled in FR-tools.

Due to electrical power specifications of FR-pOrtable, it is not possible to equip it with deuterium-tungsten light source and thus it is not possible to operate the tool at wavelengths <350nm.

11. What is the difference in term of accuracy between FR-pOrtable and FR-pRo.

FR-pOrtable is a USB powered compact version of the FR-pRo VIS/NIR version (spectral range 360 – 1050nm). The light source of the FR-pOrtable is a hybrid LED – incandescent, while FR-pRo VIS/NIR uses a conventional halogen tungsten light source. The requirements of both light sources are suitable for film thickness measurements. The spectrometer's configuration is the same for both instruments. In conclusion in standard range measurements (10nm – 90µm) **both tools offer the same high accuracy results**. FR-pOrtable is a handy unit with no moving optical fibers, extremely long light source lifetime of 20000h and is appropriate for Point-of-Need applications, such as: industrial environment for on-line coating thickness measurement, thickness measurement at the field, etc. On the other hand, FR-pRo can be upgraded with a wide range of accessories for various diverse applications such as real-time monitoring of swelling/dissolution of coatings, characterization of physicochemical properties of polymers, absorbance of liquids etc.

12. So, what are the differences between FR-pOrtable and FR-Basic?

FR-pOrtable offer a specific spectra range 360nm – 1050nm with specific optical power suitable only for film measurements applications. In other words FR-pOrtable is a dedicated generic film measurements tool with 360nm – 1050nm spectra range and 20nm – 10µm film measurement range. In the contrary FR-Basic follows a different philosophy in its implementation, is a modular and reconfigurable bench top optical instruments, suitable for many more optical measurements. Therefore FR-pRo

- can be combined with more optical sources to full fill other requirements spectra ranges, e.g. FR-pRo UV/VIS 200nm – 850nm.
- The optical power of the light source could be much stronger, so it can be used with measurements involved integrating spheres (diffused/specular reflectance calculation, haze calculations etc.)
- It can be combined with much more modules, as hot plate, gas chambers, liquid vessels etc. for measurements under special environments
- can accommodate highly stabilized spectrometers (back-thinned, cooled) for applications as monitoring bio-reactions, in which the experiment can be last for long time.

	FR-pOrtable	FR-pRo VIS/NIR	FR-pRo UV/VIS
Spectral range	360nm – 1050nm	360-1050 nm	200nm – 850nm
Light Source	hybrid LED	halogen tungsten	Deuterium & tungsten
Stability	Yes	Yes	Yes
Thickness range	10 nm-90µm	10 nm-90µm	1 nm-90µm
Power	USB	Powered plug	Powered plug
Portability	Yes	No	No
Extendibility	limited	Yes	Yes
Cost	+	++	+++