

Training Manual



Broadband Optical Monitors

Optical Monitor Training Manual

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1. Getting started with the OMS

1.1 What is an optical monitor

An optical monitor's (OM) function is to provide in-process monitoring and termination in deposition processes.

The preferred configuration of an OM for precision optics applications is a broadband source, and a detector module.

The OM signal is obtained by optical interference within the growing film and is usually measured indirectly from a stationary test glass or witness in the process chamber. Alternatively it is possible to monitor directly from a workpiece by synchronising the measurement with the rotation of the calotte. The OM can be fitted in either T or R mode as required.

The Intellevation OM range incorporates design features which provide immunity of the signal from noise sources. Within the OM itself, variations in the output of the light are corrected in real time by providing a reference optical path using a flexible optical fibre.

Immunity against external sources of noise is provided by means of a four phase chopper (sample/dark/reference/dark) and synchronous detection using a single detector.

The processed signals from the detector module are digitised and passed to a computer which processes the raw data, taking into account the preset conditions for cut previously programmed onto the computer using *FilmMaker* software, and provides a CUT output via I/O to terminate the film. This process is repeated for each film in the stack.

The key differentiator between the OM and other methods of monitoring is that the OM uniquely monitors the optical thickness of the growing film and thereby takes into account the physical thickness 't' of the growing film, AND also its optical constants 'n' and 'k'.

Optical thickness= nt where $k=0$(1)

An OM which provides an automatic CUT capability such as the Intellemetrics range of OM's, follows the optical signal resulting from interference in the growing film and provides a CUT by acting on the optical signal processed by pre-programmed software. As such the OM is a shape recognition monitor. In the case of the Intellemetrics OMS the data associated with the process is preloaded into **FilmMaker** and saved as a coating project. This project is then passed to **FilmDirector** software for real time processing of the signal and to provide a CUT output. The software is resident on the computer provided with the Intellemetrics OM.

It is important to bear in mind that, bearing in mind that the OM operates by shape recognition mainly, it will only provide accurate process CUT performance when the operational parameters within the coating chamber are under a level of adequate control so that a smooth shape is achieved in the OM signal.

An OM should never be considered as a substitute for adequate control, of other key process variables such as deposition rate, densification, temperature, coating distribution etc.

1.2 Optical monitor signal from a growing film

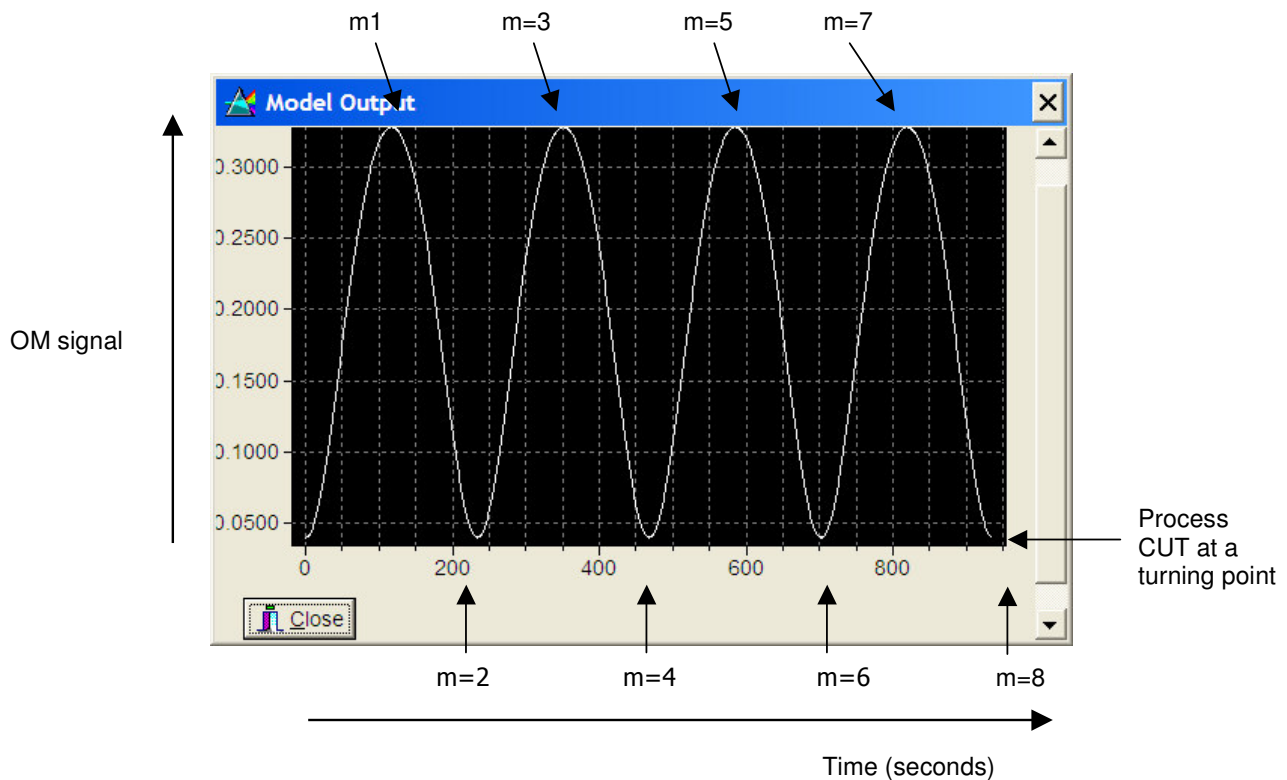
The optical signal from a growing film, monitored at a single wavelength, will be periodic in nature.

We can use the property that at the signal turning points (TP's) (maxima and minima) are represented by the equation.

$$nt = m\lambda/4 \text{ where } \dots\dots\dots (2)$$

- 'n' is the refractive index of the film material
- 'm' is an integer 1 or 2 or 3 or 4.....
- 'λ' is the probe or monitoring wavelength.
- The probe light is incident at normal incidence to the growing film

An example of the expected signal from a growing film is shown below provided by the **FilmMaker** Model function.



This is the predicted signal shape (model) of a growing single film of Titanium Dioxide (TiO₂) on glass monitored in reflection mode at a probe wavelength of 550nm.

The TP's shown above, $m=1, 2, 3, 4$ etc are described as optical quarter waves (QW).

In the thin film terminology used throughout this manual $m=1$ is equivalent to 1QW; $m=2$ is equivalent to 2 QW etc.

Another important quality of a single film is that at the thicknesses equivalent to $m=2, 4, 6, 8$, the optical effect, in the absence of any losses in the film ($k=0$), is such that the film has no effect. It is as if the film does not exist. This condition is normally referred to as an “absentee film”.

1.3 Programming of the process CUT

There is a wide range of OMS software CUT options available in the Intellemetrics OM range.

QW Cut

If the film being optically monitored is an integer QW then the OM software identifies each TP and counts down to zero providing a CUT output at 0. The CUT output is communicated through the instrument I/O to the customer system controller, to enable shutter closure and to set the source to idle.

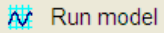
In the example shown previously the film was programmed into **FilmMaker** as 8QW and **FilmDirector** counted down as each TP was encountered.

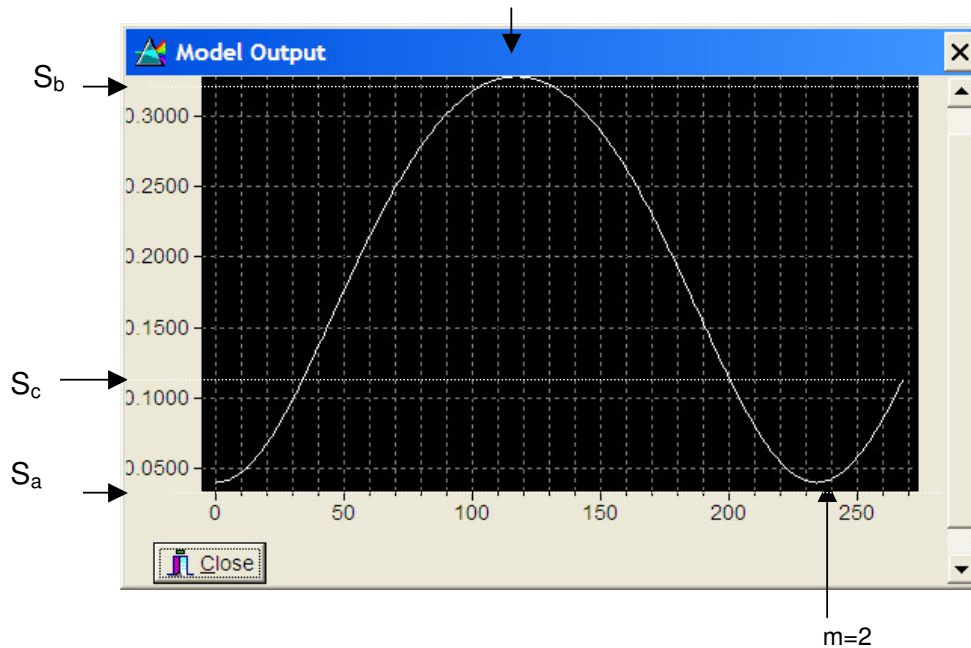
Benefits of the QW CUT approach are:

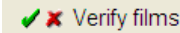
- The CUT is independent of the actual signal level (amplitude) since the OM is seeking a change in direction of the optical signal to establish a turning point.
- The TP's from (1) are determined by the refractive index and physical thickness of the film ONLY and the QW CUT approach is therefore responsive to any variations in material properties in the growing film. This level of monitoring is not available with quartz crystal monitoring, which is a mass measurement technique only.

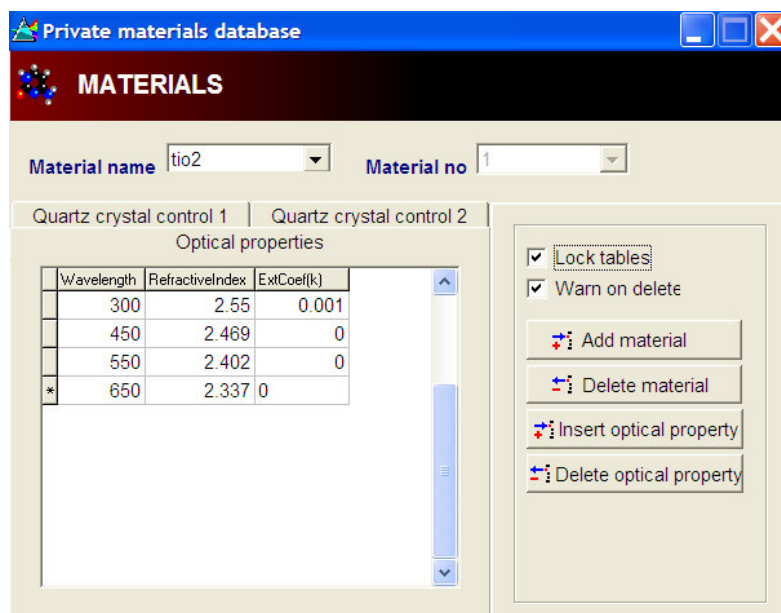
Non-QW Cut

An example of a non-QW cut is where the OM is programmed to provide 1.3QW of a film of TiO₂ at 550nm monitor wavelength. The **FilmMaker**

 is shown below.



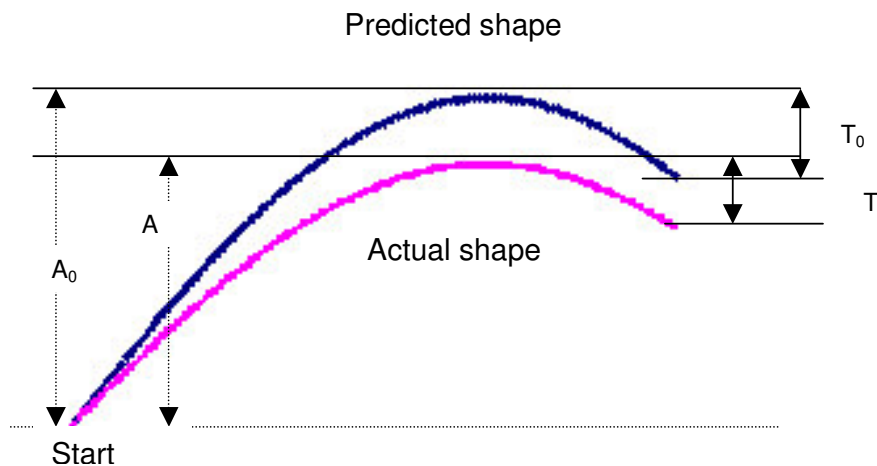
The predicted signal amplitude Sa, Sb and Sc associated with the growing film are obtained from the coating materials optical constants programmed into **FilmMaker MATERIALS**, when the  button is pressed. These values are then stored in the **FilmMaker** project



When the end point is predicted to be a non-QW position then the optical monitor will count down the first two turning points expected and finally terminate on the amplitude S_c .

The difficulty with this method is that the predicted signal value S_c will only be achieved if the programmed material optical properties match that of the completed film, and the detector response is absolutely linear.

To counteract these sources of error the Intellevation OM software provides an on-line correction by noting the value of each turning point reached in the film and comparing this with the predicted value.

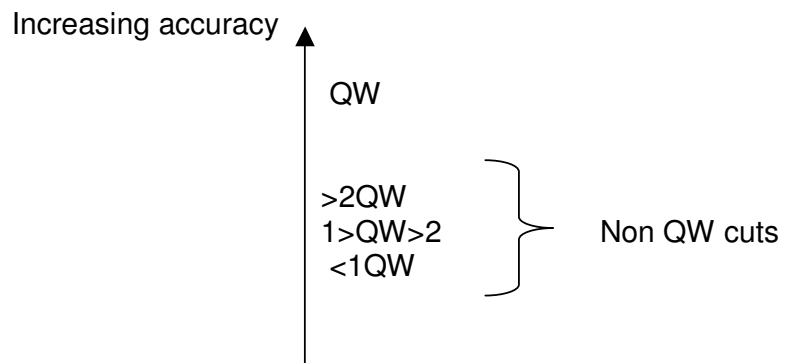


The corrected non-QW cut off point on the actual curve is inferred from
 $T = T_0 \times A/A_0$ (3)

In the example shown above the starting point for both predicted and actual shapes are identical. In practice this is not the case and there is often a discrepancy between the actual and measured starting points. Even in the case where the film is being deposited on an uncoated substrate, the actual reproducibility of positioning of witnesses will vary from witness to witness resulting in a slightly different start amplitude. To counteract this the Intellevation software re-calculates equation (3) at each turning point encountered in the film to provide the highest possible accuracy of cut.

The effectiveness of this on-line correction, in non-QW films, is best where there are at least two turning points. They cut accuracy is poorer if only one turning point is encountered before the cut, as illustrated above. A further degradation in accuracy occurs if the OM cut is a fractional QW (ie $<1\text{QW}$).

As a very general rule then the accuracy of cut on a film using an OM to cut can be summarised as follows:--



1.4 Multiple films considerations (alternate high low stacks)

One of the main advantages offered by an OM is the self-correction which occurs automatically when depositing a dielectric stack based on the HL building block.

Many precision optics film stacks have at their core the HL building block, and optical monitoring, which provides self correction of cut point as the stack builds, is the most accurate monitor technique available for the manufacture of these filter types.

The self-correction effect can be quantified by using *FILM SIMULATOR* to predict the effect of film cut accuracy as we progress through a stack.

An example is shown below of a simple HL stack consisting of TiO₂ and SiO₂ films.

Design: Glass/(HL)²/air where H and L are a single QW of TiO₂ and SiO₂ respectively at a design wavelength of 550nm.

Monitor scheme: Test glass/(HL)² monitored at a probe wavelength of 550nm



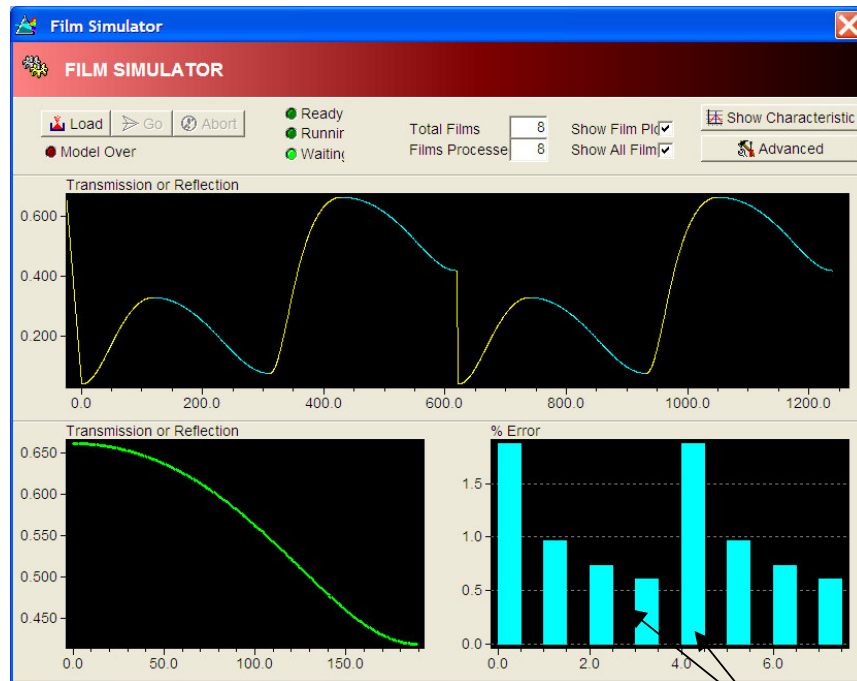
FILM SIMULATOR processes the films sequentially and outputs a bar graph in the bottom right of the screen indicating the predicted termination error of each film. You can see from the bar chart that there is a trend to reduced termination error as we progress through the film stack.

This self-correction only occurs under the following conditions:

- The films are deposited on the same substrate (witness).
- All films are integer QW's at the same monitor wavelength

We can demonstrate the poorer cut accuracy achieved when we split the coating between two test glasses.

Design: Glass/(HL)⁴/air at a design wavelength of 550nm
 Monitor scheme: Test glass No1/(HL)² + test glass No2/(HL)² both at probe wavelength of 550nm



Change of test glass between these films

FILM SIMULATOR predicts that the film termination errors shown above.

1.5 Setting up the OMS in a coater

The **coater** must be configured to conform to the following minimum requirements below:--

1. A method of controlling the film material deposition rate.
Normally For a coater using thermal deposition sources this requires the fitting of a quartz crystal rate controller.
2. A means of shuttering thermal sources to provide a sharp endpoint to the deposition process when a CUT output is provided by the OMS.
(Note that the 'lag' between receipt of the OM CUT signal and the shutter closed must be very small to minimise the lateness of cut. The CUT output delay from the OM is only a few millisecond!!).
3. Provision of suitably positioned feedthroughs and a test glass changer (or for direct monitoring a workpiece position on the calotte) to enable the OM optical path in the chamber.
(In the case of direct monitoring, the coater must be able to provide a trigger signal to the OM at the point on the calotte rotation when the measurement is to be taken.

The OMS is comprised of the following elements:

1. An optical broadband source
2. A detector module
3. A reference path to minimise source output fluctuations.
4. A stationary witness in the optical path of the OM, and referred to as **indirect monitoring**
or
A witness rotating with the parts being coated and normally held on the spinning calotte next to the parts being coated, referred to as **direct monitoring**.
(This section will only address **indirect monitoring** as the vast majority of coating installations in precision optics use **indirect monitoring**. Additionally **direct monitoring** places significant additional constraints on the scope of possible coating designs which can be monitored, and the engineering of the calotte hardware.)
5. A means of indexing the witness (**indirect monitoring**), where multiple films are being monitored under the control of the OM.

The OM system will have been installed by Intellevation engineers in either reflection or transmission mode, depending on customer preference. The angle of incidence at the witness is normally kept below 5°.

The detailed alignment and installation of the OM are covered in detail in the Intellevation User Manual provided with the OM and will not be covered here.

1.6 Establishing tooling factor at the witness for the coating materials

It is essential to establish the relationship between the thickness of material deposited in the coating zone (on the calotte), at the OM witness (indirect monitoring) and at the quartz crystal head. Ideally this should be a constant in each case established by performing a series of calibration runs.

All precision coaters using thermal deposition require a quartz crystal controller to provide a constant source deposition rate. It is necessary to establish in the early stages, the tooling factor/s associated with the QC head and the coated parts. In any event this is always required even in the case where an OM is not used.

The method of measurement of tooling factor for quartz crystal is covered in many texts and will not be addressed here.

We will assume that the quartz tooling factor between the workpieces and the QC head is already known for each source and material by prior calibration. We will refer to the indicated physical thickness at the quartz head as t_{Quartz} equivalent to a physical thickness at the workpiece t_{Part} .

The tooling factor between the crystal and the workpieces is normally defined as:--

$$TF = t_{\text{Part}} / t_{\text{Quartz}} \dots \dots \dots (4)$$

1.7 Procedure to establish the tooling factor between the QC head and witness position

Replenish the coating material in the source and complete any conditioning of the material required prior to deposition.

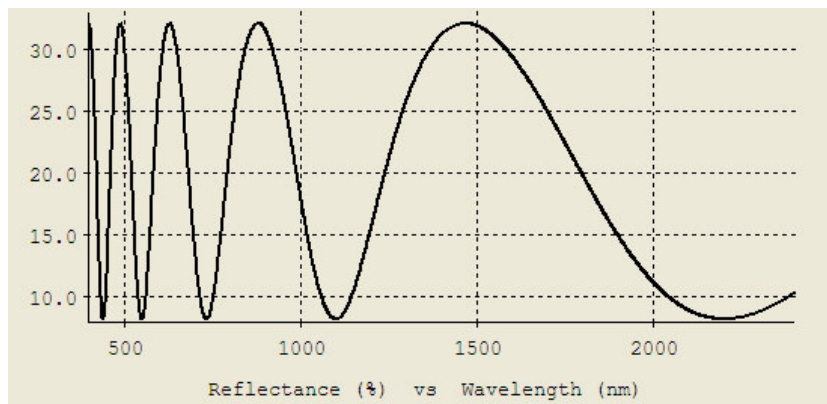
Ensure that sweep (in the case of EB gun deposition) and power settings are optimum and noted.

The test glass changer should be loaded with an uncoated glass and a fresh crystal is installed in the quartz crystal head.

Deposit a film of a high index material, say TiO_2 , at the expected process deposition rate, using the QC head to control the process and terminate the deposition. (The OM should be switched off during this test).

Note the final thickness reading on the quartz controller.

Remove the test glass and either measure the coating step at the edge using a profilometer or preferably scan the film on glass on a spectrophotometer to reveal the R v λ profile as shown below.



The maxima and minima occur at wavelengths where the condition applies.
 $m \times \lambda/4 = n \times t$(5)

When m is an odd integer the refractive index of the film n_f can be calculated from the equation

$$n_f = (n_s(1 + \sqrt{R/1-R}))^{0.5} \dots\dots\dots(6)$$

where n_s is the substrate refractive index; n_f is the film index and R is the reflectance.

In the above case $n_s = 1.52$. and n_f is calculated to be 2.28

In order to calculate the refractive index at other wavelengths we can use another feature associated with the scan above.

Starting at the longest wavelength TP which is a minimum, and has to be an even number, we determine an even number which multiplied by an even number will equal the product of the next higher integer times the next lower interference wavelength.

The table below illustrates this

λ	2192	1474	1098	876	730	628	547	487
Order	2	3	4	5	6	7	8	9
Product	4384	4422	4392	4380	4380	4396	4376	4383

If the Product is the same value in each case we have identified the correct order.

If we want to calculate the refractive index at the even orders, we can use the equation below.

$$n_x = (n_{(x+1)} m \lambda_x) / ((m+1) \lambda_{x+1}) \dots \dots \dots (7)$$

The example scanned above assumes no dispersion or loss in the film material. It is possible to establish the optical constants for dispersive and lossy single films using an extension of the above technique.

If the refractive index n_f is known then we can calculate $t_{\text{Test Glass}}$, the physical thickness of the coating on the test glass from equation (5).

Input formula.....

We can define the tooling factor for a the material (TiO₂ in this case) now to be

- Tooling factor between QC and workpiece $T_{\text{Quartz-Part}} = t_{\text{Part}} / t_{\text{Quartz}}$
- Tooling factor between QC and OMS $T_{\text{QC-OMS}} = t_{\text{Test Glass}} / t_{\text{Quartz}}$

Repeat the run a number of times to check reproducibility of TF.

Please note that it **cannot** be assumed that the tooling factor for a second material (eg silica) from the same source will be identical, and the tooling factors should be measured for each **material** and **source**

1.8 Importance of tooling factor between quartz crystal and OMS

An OM is always supported by a quartz crystal rate controller for deposition of precision optics coatings using thermal sources.

The deposition rate is a pre-programmed value and measured at the quartz crystal head.

However the actual deposition rate seen by the OMS will be the condensation rate at the witness:--

Film deposition/condensation rate at OM witness= Deposition rate programmed into the QC controller/ T_{QC-OMS} .

It is very important that this modified deposition rate at OMS is entered into the <i>FilmMaker</i> project.

The programmed deposition rate in FilmMaker influences the way in which other FilmMaker programmed variables function in such a way that a significant error in rate (>10%) will certainly have a detrimental effect on the CUT performance of the OMS.

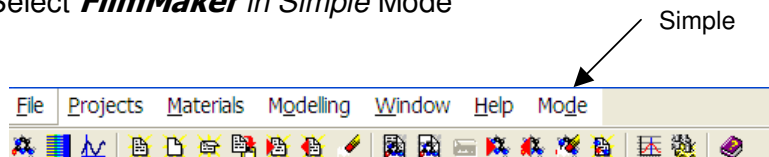
1.9 Reviewing Material Properties & QW Cut Performance & System Noise

Trial Runs Using the OMS and QC controller

In this series of runs we need to establish the quality of the material being deposited and the CUT performance of the OMS.

Each test will require:

- An uncoated substrate loaded into the test glass changer.
- The QC controller to be programmed to deposit at a controlled rate multiple quarter waves of the high index material.
- The CUT command must come from the OMS and therefore the CUT command for the QC must be inhibited. An alternative approach is to set the physical thickness on the QC controller to a very large value to prevent it being invoked.
- Select **FilmMaker** in Simple Mode

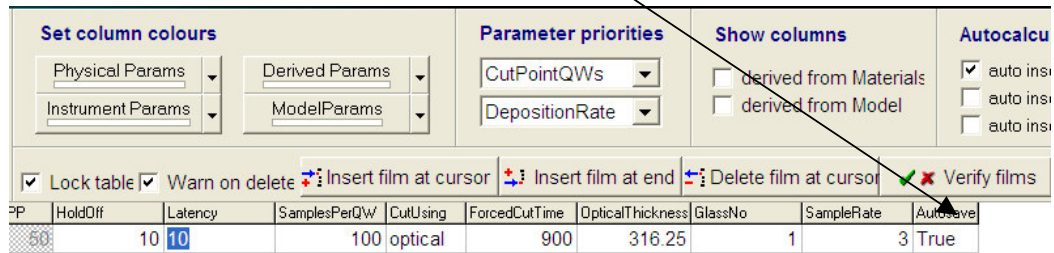


- Using **BUILD FILMS** create a project for a single film of high index material. Set the *Cut Point QW's* to 6, 7 or 8 and the monitor *Probe wavelength* in mid band for the detector module. The waveband for each Intellemetrics OM is shown below.

Detector module	Short edge (nm)	Mid band (nm)	Long edge (nm)
IL551	300	550	800
IL552	400	750	1100
IL553	550	1025	1500
IL554	800	1400	2000

- Set the *Analyser Mode* to *Normal* and *FilterCutOff* to 5. This is a high level of filtration and provides the highest probability that the run will complete in the presence of noise.

- Ensure in **FilmMaker** that the *Autosave* column is set to “True”



The screenshot shows the FilmMaker software interface. At the top, there are four main sections: 'Set column colours', 'Parameter priorities', 'Show columns', and 'Autocalcu'. Below these are several checkboxes and buttons for table management. At the bottom, there is a data table with columns: 'P', 'HoldOff', 'Latency', 'SamplesPerQW', 'CutUsing', 'ForcedCutTime', 'OpticalThickness', 'GlassNo', 'SampleRate', and 'Autosave'. The 'Autosave' column for the first row is set to 'True'.

P	HoldOff	Latency	SamplesPerQW	CutUsing	ForcedCutTime	OpticalThickness	GlassNo	SampleRate	Autosave
50	10	10	100	optical	900	316.25	1	3	True

This will ensure that the data collected during the process is saved for later analysis.

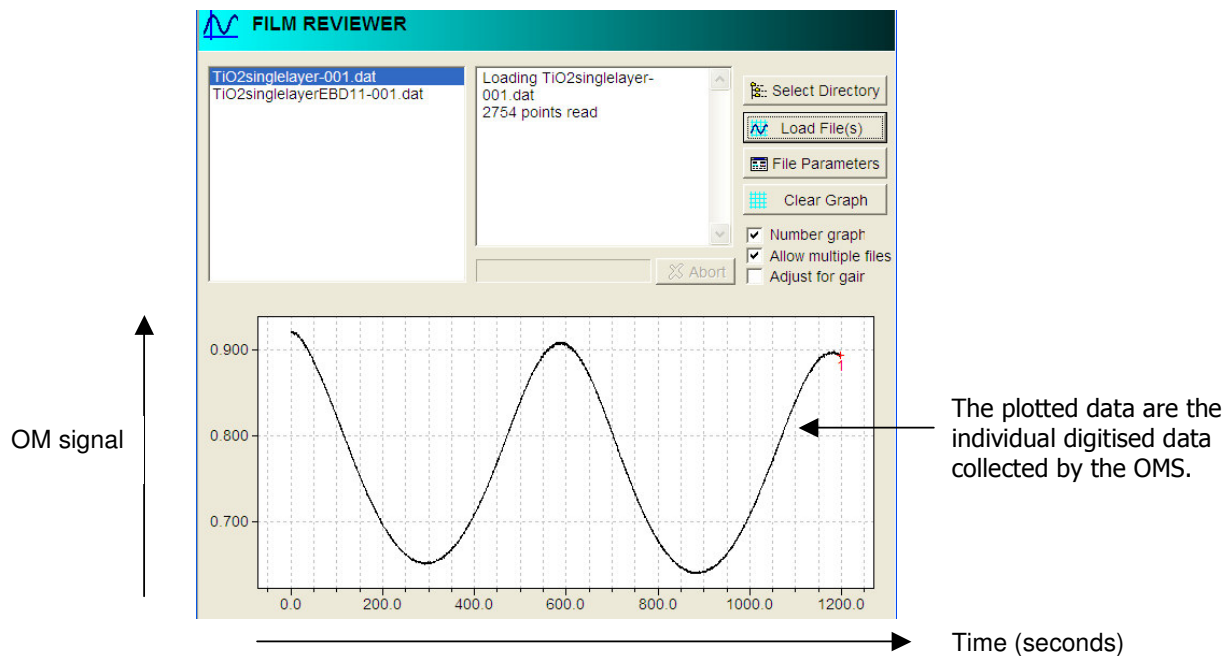
- Complete the coating.

The next stage is to review the data collected in the process to establish key process requirements.

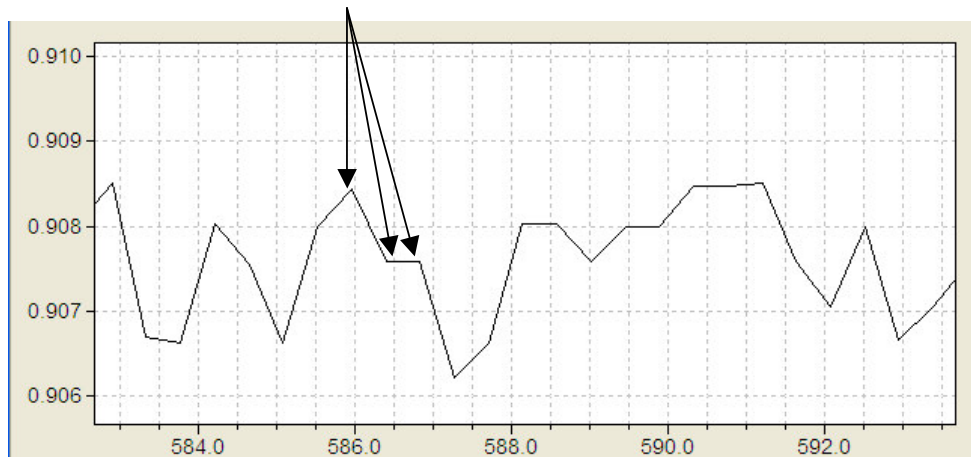
1.10 Assessing CUT performance, coater system noise level and filtration

Using **FilmReviewer**

As an example the run data “TiO2singlelayer-001.dat” file, collected on an Intelmetrics OM fitted in transmission mode, has been loaded into **FilmReviewer** below for analysis to illustrate the features available.

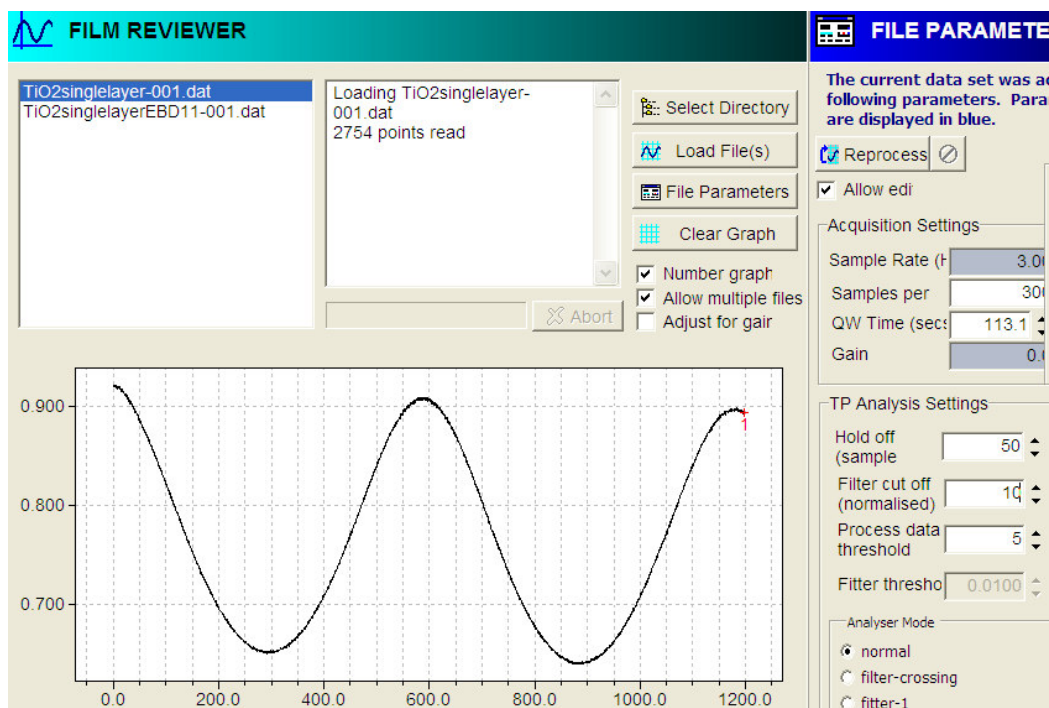


Using the zoom features we can resolve individual data points

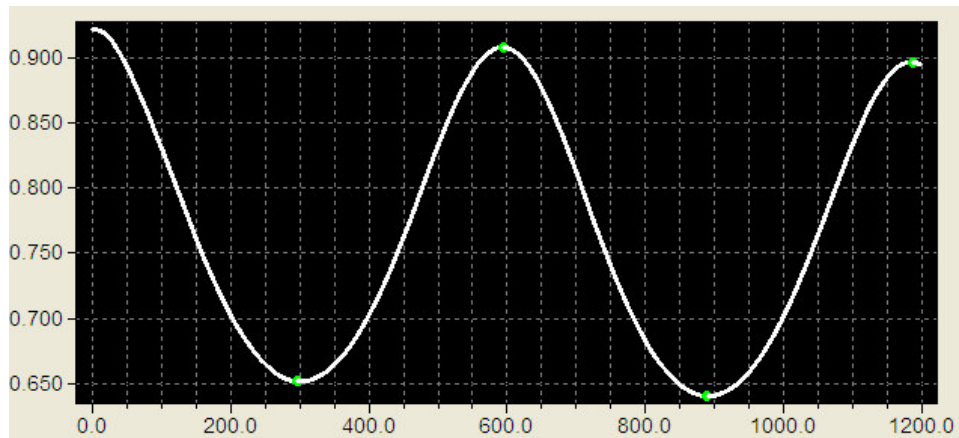


.....and infer a data acquisition rate of around 3 samples per second.

If we click on *File Parameters* the associated **FilmMaker** project values pop up.

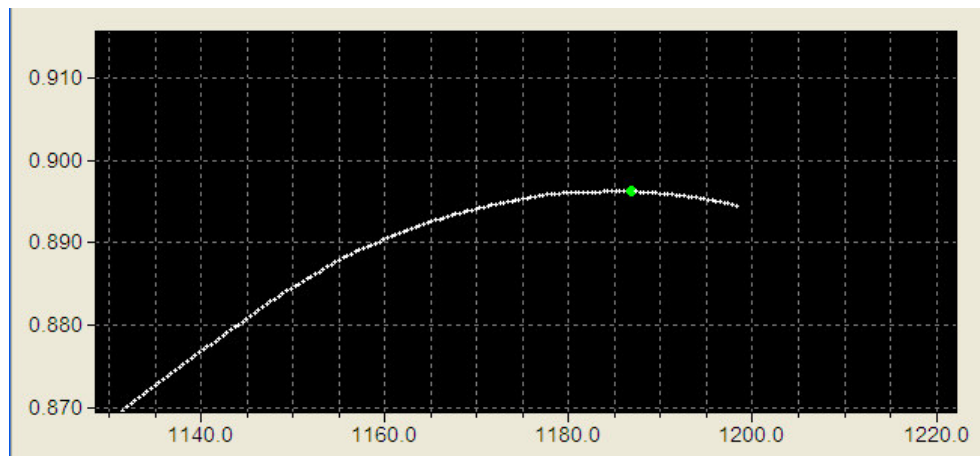


Now click on *Reprocess*



With no spurious turning points indicating that a filter setting of 10 was appropriate.

By using the zoom function, as shown below, we can assess how the multiple QW film terminated



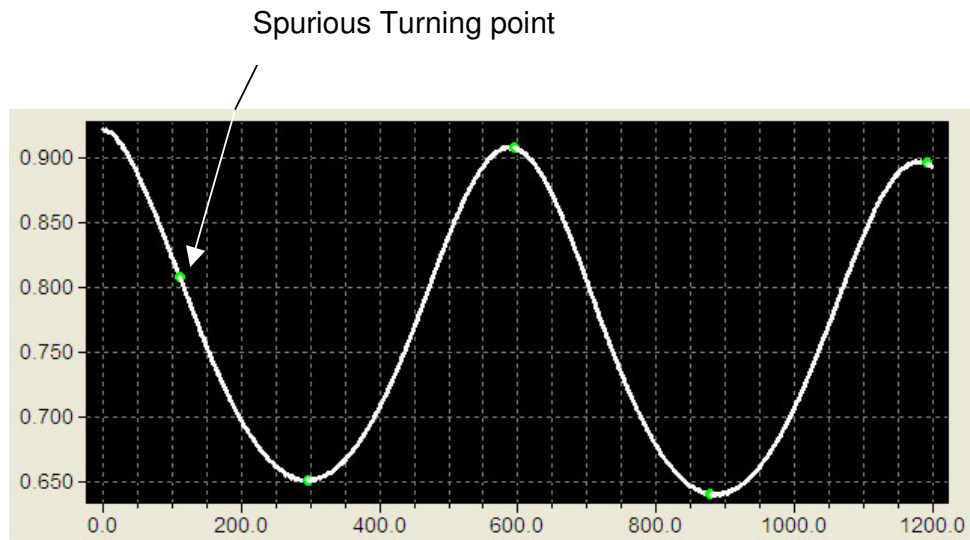
The final turning point marked by a coloured dot is seen to be late compared with the actual filtered data, which was set at a severity of 100 in this case.

The lateness of the cut point is dependant on the severity of the filter, and the filter analyser type, linear, quadratic etc. For each filter type and severity the delay in CUT is precisely predicable and reproducible from run to run.

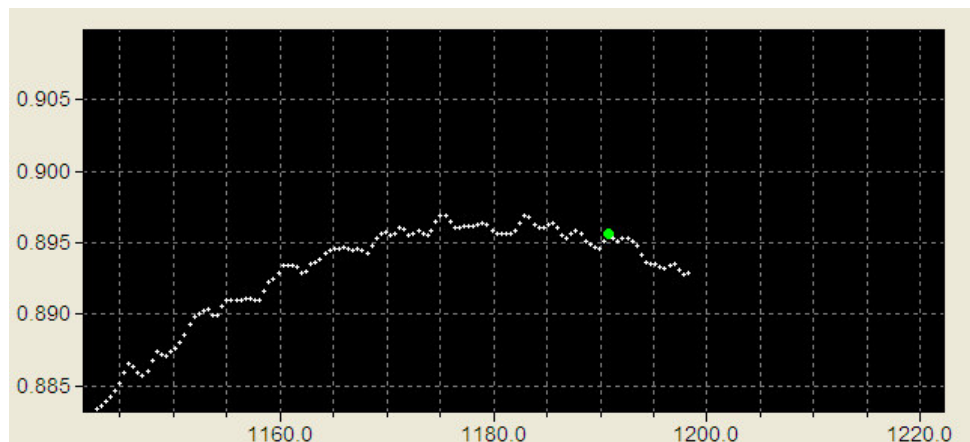
The conclusion from the above run is that the filter was set correctly and OMS terminated correctly.

To assess the level of noise and the appropriate filter setting we can use **FilmReviewer** to *Reprocess* the data with reduced filters until we encounter a fault condition where spurious turning points appear.

We find that with the analyser normal filter to 100 and reprocess we obtain the outcome below.



If we zoom in we can also see that there is inadequate filtering to produce a smooth curve.

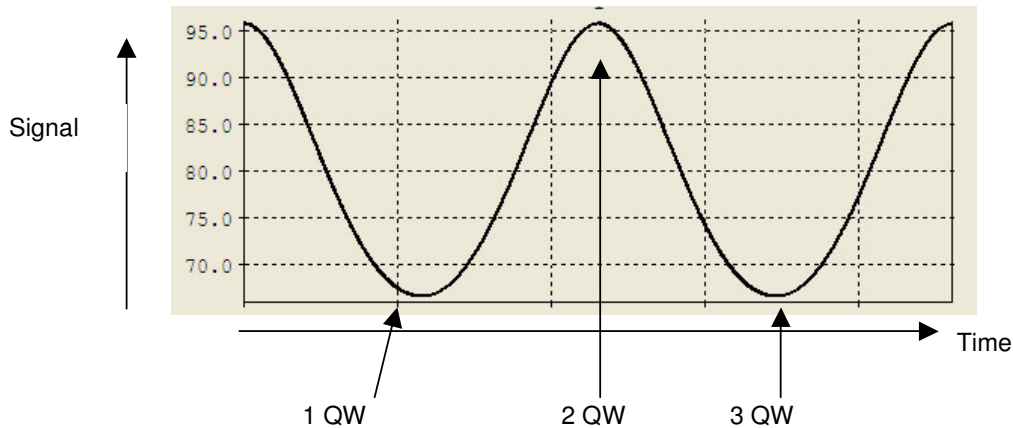


Our conclusion is that a normal filter of severity 10 was appropriate to this process and if the filter had been set to 100 it would have been inadequate resulting in the identification of spurious turning points and failure to complete the film successfully.

Further iteration of filters in **FilmReviewer** will identify the range of values where the filter performance is just adequate.

Note that setting the filter severity to a value which is just adequate can result in failure of the process if the instantaneous level of system noise generated varies slightly from run to run.
It is always prudent to leave a significant increased margin of filtration to deal with unexpected process noise spikes.

1.11 Inferring Material Properties from OMS data

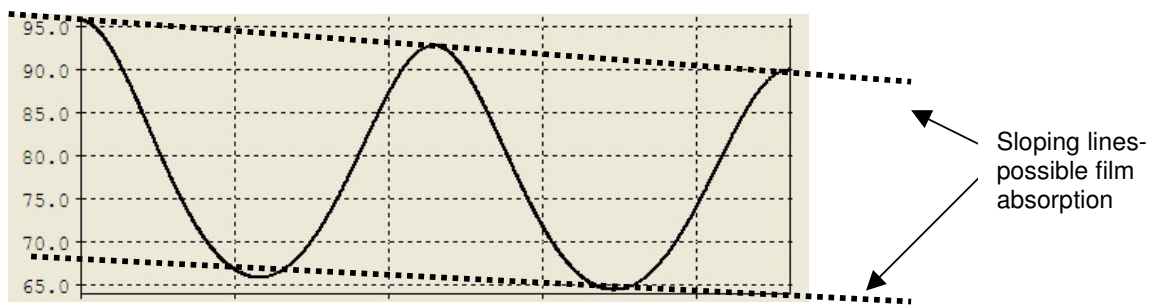


The effect of a film at the positions shown above of 2, 4, 6, 8 etc associated with an EVEN number of QW's is as though the film was not present (absentee as previously described), assuming that the absorption within the film is negligible.

Therefore we should be able to draw a line through these points which should have a value the same as the uncoated substrate. If the signal value is reducing as we increase the film thickness then we should be suspicious that there are losses in the film material. This will be the case for either transmission or reflectance mode monitoring although T mode only is shown above.

In the positions that represent 1, 3, 5, 7 etc associated with an ODD number of QW's the signal is influenced by the **refractive index** and **absorption** in the film.

Since the refractive index in the first instance should be constant or change only slowly, any significant slope in the lines drawn through the maxima and minima as shown below is as a general rule an indication of absorption in the film material at the probe wavelength.



Repeat the coating run and evaluation at both band edges wavelengths.

Repeat the coating runs for the second coating material, as required.
Intellevation can provide support in analysis of data collected during this phase.

When sending run data to Intellevation please also attach the associated **FilmMaker** project, saved with a *private materials database*.

For the characterisation of low index materials, particularly silica, it is advisable to use a test piece (witness) of a higher index glass $n_s \gg 1.52$ if possible. This will provide an increased signal swing in the process, which should improve the accuracy of film refractive index calculation.

1.12 Non QW CUT performance

In this series of runs we need to establish the performance of non-QW cuts on the OM.

We have already seen that the OM is best suited to termination of non-QW cuts where at least two turning points are encountered before the end of film non-QW>2QW.

Each test will require:

- An uncoated substrate loaded into the test glass changer.
- A control programme to be loaded onto the QC controller (see the operating instructions of you QC controller) to deposit at a controlled and steady rate multiple quarter waves of the high index material.
- The CUT command must come from the OMS and therefore the CUT command for the QC must be inhibited. An alternative approach is to set the CUT thickness on the QC controller to a very large value (eg 10 times the actual thickness required) to prevent it being invoked.
- Create a **FilmMaker** project built to deposit a single film of high index material non-QW and greater than 2QW.
- Monitor at a wavelength in mid band for the detector module from Section 1.9.
- Set the *AnalyserMode* to *Normal* and set the *FilterCutOff* value based on the outcome of the test undertaken in the previous section (if in doubt set the *FilterCutOff* to 5).
- Ensure in FilmMaker that the *Autosave* column is set to "True"

The screenshot shows the FilmMaker software interface. At the top, there are several tabs: 'Set column colours', 'Parameter priorities', 'Show columns', and 'Autocalcul'. Below these are various checkboxes and dropdown menus. A table is visible at the bottom with columns: 'HoldOff', 'Latency', 'SamplesPerQW', 'CutUsing', 'ForcedCutTime', 'OpticalThickness', 'GlassNo', 'SampleRate', and 'Autosave'. The 'Autosave' column for the first row is set to 'True'. An arrow points from the text 'Autosave column is set to "True"' in the list above to the 'Autosave' column in the table.

HoldOff	Latency	SamplesPerQW	CutUsing	ForcedCutTime	OpticalThickness	GlassNo	SampleRate	Autosave
10	10	100	optical	900	316.25	1	3	True

This will ensure that the data collected during the process is saved for later analysis.

- Complete the coating.
- Assess the coating in **FilmReviewer** and establish the degree of confidence in non-QW cuts.
- If required send the data to Intellevation for analysis.

Repeat the process at band edge wavelengths
Repeat the coating runs for the following films.

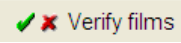
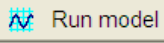
- 2QW>Film thickness>1QW
- Film thickness<1QW

1.13 Multiple QW's

In this series of runs we establish the capability of the OM to CUT multiple QW coatings.

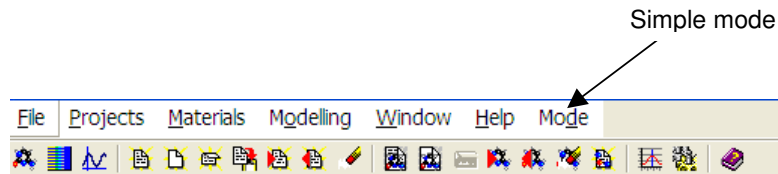
At this stage use Appendix A of this manual for Help on programming of **FilmMaker**.

Previously we have characterised the system tooling, single film QW and non QW cuts, performed some qualitative analysis of the film materials and achieved some understanding of the use of linear filters, and used **FilmReviewer** to review the process noise on data collected by the OM.

FilmMaker is a software package provided on the Intellevation OM product range. It comprises a front end *BUILD FILMS* input screen into which the user loads (types or transfers by csv file) his coating stack. On completion of data entry the next step is to click on  which checks the basic truth on the data entered. On completion of verification click on  and the expected OMS signal shape predicted is shown in *MODEL OUTPUT*.

Advanced packages **FilmSimulator** and **FilmReviewer** are included in **FilmMaker**.

1.14 BUILD FILMS: Creating the film stack



The key to the use of the *BUILD FILMS* form is to ensure that a new project is always entered in *Simple mode*.

Simple mode limits the number of variables that need to be entered to a minimum and will automatically set default values for the hidden parameter set.

The key film stack input required in *Simple mode* are:

1. *Material*
2. *Thickness* (physical thickness) or *CutPointQW's*
3. *ProbeWavelength*
4. *DepositionRate*
5. *QWTime*
6. *QWFactor*
7. *ForcedCutTime*
8. *GlassNo*
9. *SampleRate*
10. *Autosave*

Material:

Essential

This can be input as a *PrivateMaterialsDatabase*, or from a *PublicMaterialsDatabase*.

Thickness (physical thickness) or *CutPointQW's*

Essential

ProbeWavelength

Essential

DepositionRate

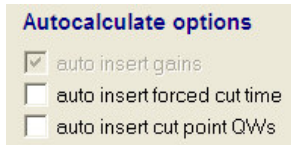
Essential

QWTime

Can be default

QWFactor
Defaults to 1

ForcedCutTime

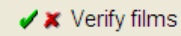


Only enabled if *Autocalculate options* ticked.

GlassNo
Defaults to 1 for all films

SampleRate
Defaults to 2 for all films

Autosave
Defaults to *True*

All other parameters are set to appropriate default values when the  button is pressed.

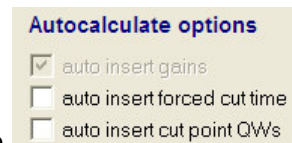
The complete set of *BUILD FILMS* parameters can be viewed by clicking on *Mode* and changing to *Advanced*.

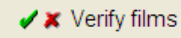


The remaining parameter set comprises:--

Gain, *SamplesperQW* and *Optical thickness*, *Holdoff* and *Latency* together with a number of parameters associated with setting of the filters which is covered in more detail in Appendix C.

Gain:

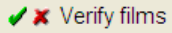


This is the signal gain which is enabled when the  box is clicked. **FilmMaker** will set the gain so that at the maximum expected signal is around 88% of the available signal headroom. This allows the instrument to work at optimum signal/noise for all films.

SamplesPerQW:

This is the number of samples that are collected in a quarter wave. The value is obtained from other **FilmMaker** programmed parameters as follows.

$$\text{SamplesPerQW} \leq \text{Thickness} \times \text{Sample Rate} / \text{Deposition Rate} \dots \dots \dots (8)$$

Note that if the number of *SamplesPerQW* is set to a higher value than the maximum **FilmMaker** will throw-up an error when the  button is pressed.

Holdoff

Holdoff applies at the beginning of each film and is programmed to ensure that the filter analyser does not find a turning point where the data is changing very slowly. At the end of the *Holdoff* the analyser is immediately able to act instantaneously on the filtered data and monitor for the CUT condition.

Latency

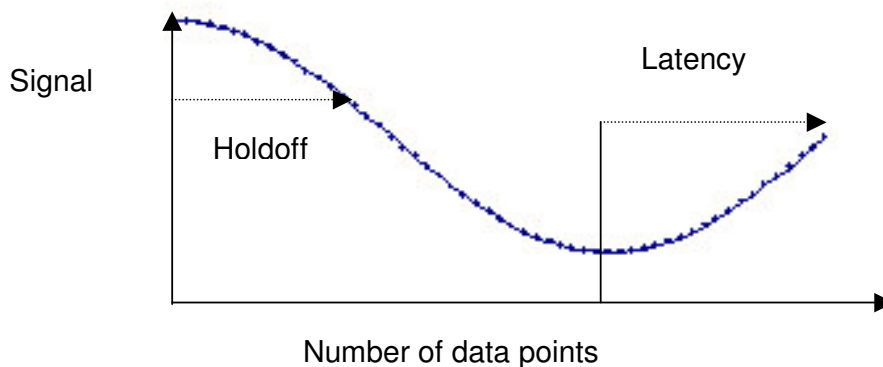
Latency behaves in the same way as *Holdoff* but only applies AFTER the first and subsequent turning points of a film, and is programmed in the same way as *Holdoff*.

Note that both *Holdoff* and *Latency* are programmed as the number of DATA POINTS and not as the time in seconds.

Note that if the *Holdoff* and *Latency* values are too high then real turning points will be missed.

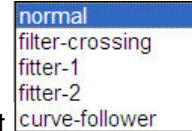
It is good practice to set *Holdoff* and *Latency* initially to about 1/3 the number of data points to complete the film.

An example is shown below.



1.15 Signal conditioning and filters

BUILD FILMS contains a suite of programmable signal filter options that enables reliable cut in a wide range of system noise environments. So far we have used only the linear (*normal*) filter. Filters are classed as either linear or



non-linear with options as shown in the attached pull down list except for curve-follower which is not yet implemented in the OM software. The severity of the filter in each case is fully programmable by the user.

The optimum programming of filters is a significant topic on its own and is covered in detail in Appendix C of this manual.

It is strongly recommended that a *normal* filter is set at the start of each new process using the OMS, as this filter when set to 5 is most likely, out of the filter set provided, to yield a robust end point to the process. Only after some data has been collected and reviewed should the user experiment with the use of alternative filters.

FilmReviewer, covered later in this manual, can be used to review the raw process data collected from the test run/s using the normal filter setting, and by using the reprocessing function, can establish the effect of different filter settings on the raw data and conclude if a change of filter would be more appropriate for subsequent coating runs.

1.16 OM process variables

Following on from the basic stack information, the user has a number of other process variables available. These two variables in this context are the test glass sequence where a test glass changer is provided, and the monitor wavelength. We note that the monitor wavelength features as a coating

design variable and it is only available here also because the software ensures that the relevant optical thickness remains unchanged with a change in monitor wavelength of a film. These two variables allow a high degree of flexibility to the user in combination with the use of **FilmSimulator**..

1.17 Data collection

The other programmable variables in **FilmMaker** which are instrument related include the sample acquisition rate, which can be up to 3Hz, and the number of samples collected in each quarter deposition.

The number of *samples per quarter wave* is determined from the predicted *quarter wave time* x the *sample acquisition speed*.

(Note that **FilmMaker** provides a data *Verify* function that must be used before a project can be considered as valid and the most frequently encountered reason for a project not to *Verify* is that the number of *sample per quarter wave* has been set too high).

Creating a valid **FilmMaker** project for a multilayer QW films stack.

This is an example of a design which could be considered as a valid test of the OMS/coater capability at this point in the programme.

Take the design: glass/film stack/air as $\text{glass}/(\text{HL})^3\text{H } 2\text{L H } (\text{LH})^3/\text{air}$:

Where H is an optical quarter wave (OQW) of the high index material of choice and L is an (OQW) of the low index material of choice.

The spectral characteristic of this design is shown below for the following conditions:--

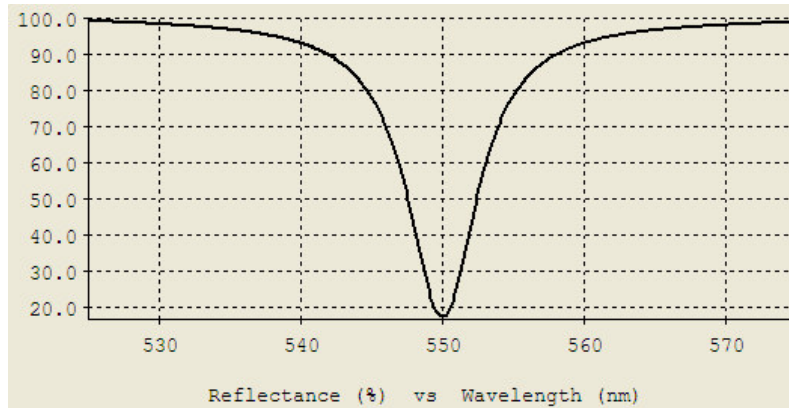
H is a QW of TiO₂ and L is a QW of SiO₂ and the monitor wavelength is 550nm.

For this test the optical constants of the materials have been chosen as

TiO₂: n=2.35, k=0

SiO₂: n=1.455, k=0

This theoretical ideal spectral response of the completed filter is as shown below.



The design produces a narrow passband filter at the monitor wavelength and a high reflection zone either side.

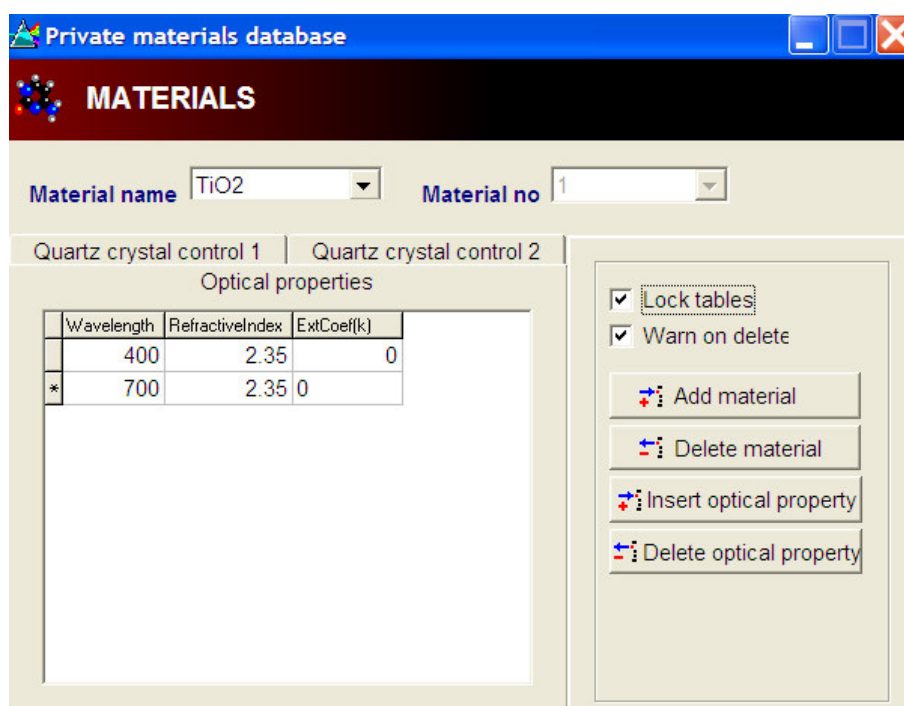
- Let us assume that the OMS is fitted in reflection mode and we have a test glass changer fitted in the chamber.
- The optical path of the OMS results in an angle of incidence of the collimated beam at the test glass is 5° .
- The *DepositionRate* for both materials set on the QC controller is 0.5nm/sec.
- The *SampleRate* is set to 3 Hz (maximum value)
- *GlassNo* is set to 1 for all films

Open **FilmMaker** and create a project name "test cavity". Go to the toolbar and click on *Mode* and choose *Simple mode*. This will enable you to input all the key information in the *BUILD FILMS* screen.

Create a *Private Materials Database* as shown below for the H and L index material. Insert the actual materials and values from your process measurements for 'n' and 'k'.

<i>Recommendation</i>	Ensure that you put wavelength values in for both extremes of the detector module waveband as shown in the table below, as this will prevent <i>Verify</i> errors occurring if at a later stage if you modify the <i>ProbeWavelength</i> .
-----------------------	--

Detector module	Short edge (nm)	Long edge (nm)
IL551	300	800
IL552	400	1100
IL553	550	1500
IL554	800	2000



Private materials database

MATERIALS

Material name: TiO2 Material no: 1

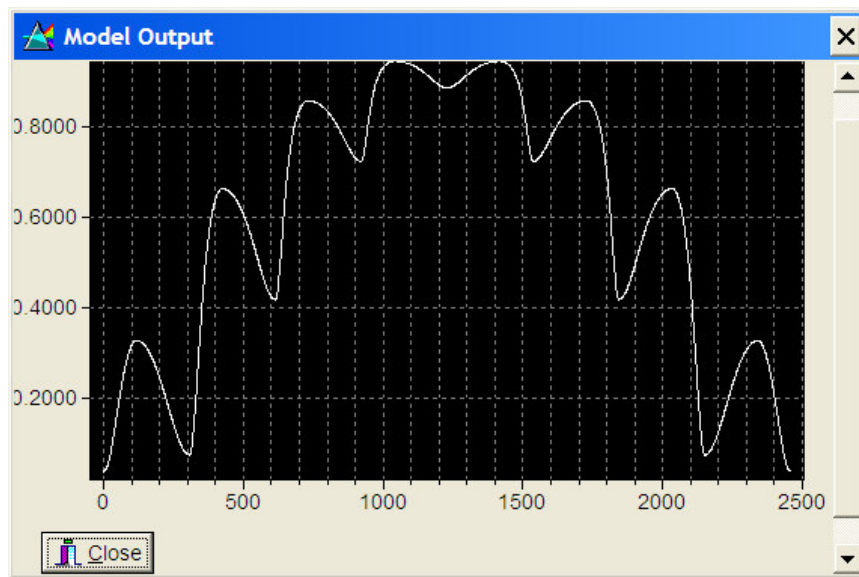
Quartz crystal control 1 Quartz crystal control 2

Optical properties

	Wavelength	RefractiveIndex	ExtCoef(k)
	400	2.35	0
*	700	2.35	0

☒ Lock tables
☒ Warn on delete

Press *Verify film* then the *Run model* buttons.. The predicted signal trace on the OMS is shown below.



We can infer from this trace that the signal swings are all reasonably large and that in principle we should be able to monitor this design on a single test glass.

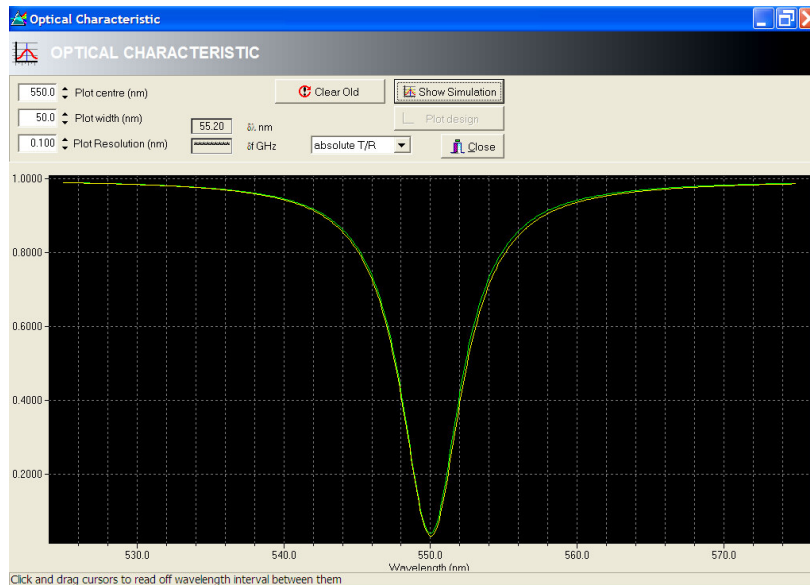
To assess this we can load the project directly into **Film Simulator**.



The filter used in this project is the default filter applied when using the *Simple* Mode data entry. This is a linear filter with a high level of filtration. The termination errors for each film are shown.

No system background noise has been applied.

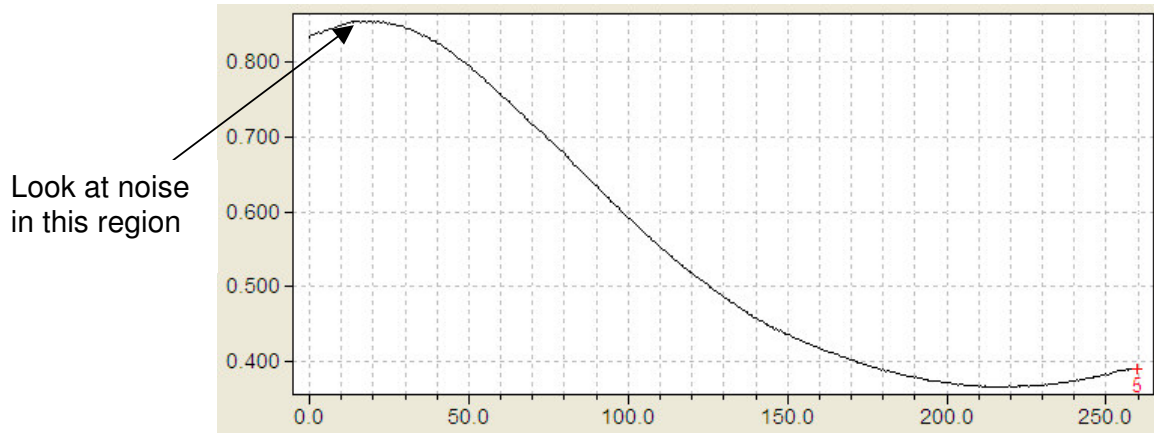
The output **Film Characteristic** for this process is shown below.



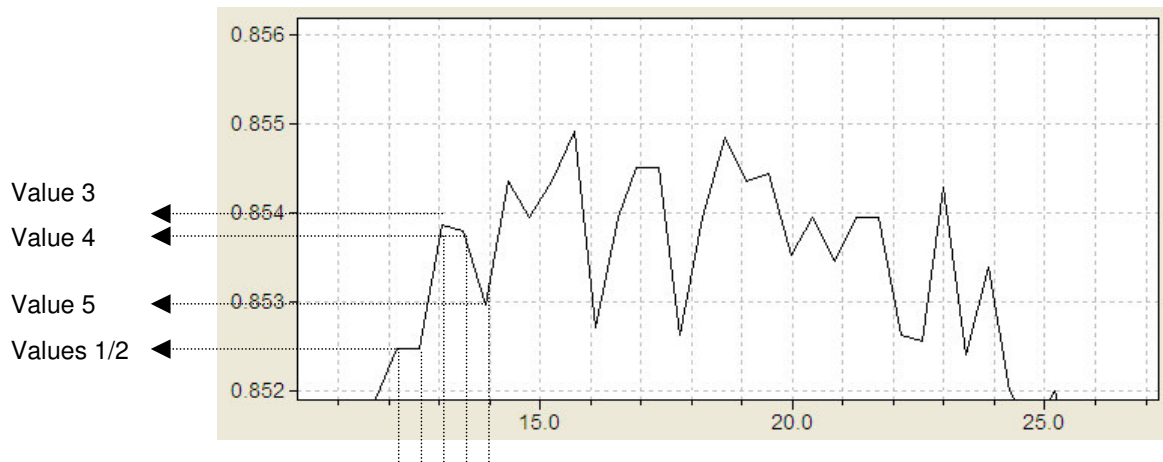
This is the predicted performance of the design where there is no noise present on the signal (ie an ideal case)

We can apply a level of noise and check how robust the design is to noise input.

- Set up the system to coat the project 'test cavity'.
- Set the monitor wavelength to mid band for the detector type as previously described.
- On completion of the coating remove the test glass and scan the test glass in transmission and compare the actual measured characteristic on the test glass with the ideal characteristic.
- Use **Film Reviewer** to review the run data and in particular assess the level of noise on the data.



Using the *Window, Zoom Drag and Pan* functions look at the data in the region shown above until you can read off the data as shown below.

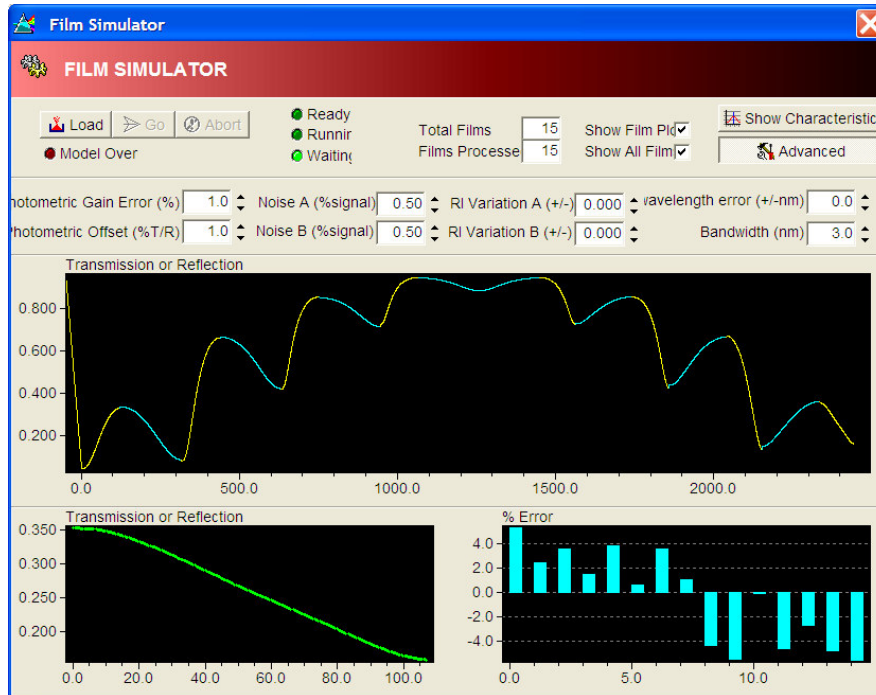


Raw Data point 1/2 3 4 5

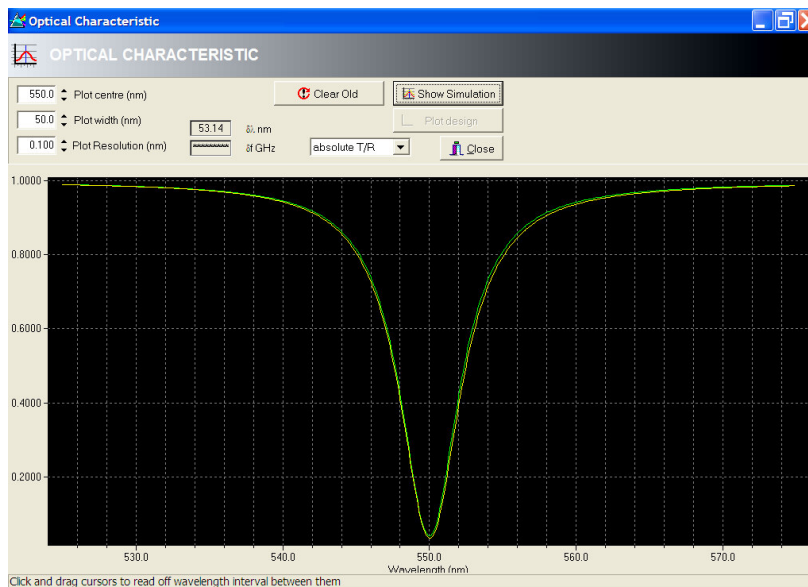
Read the value from each data point and using a least squares to fit the best curve to the data, determine the level of noise in the process, which can then be updated in **FilmSimulator** for further optimisation of process.

Typically the noise level intrinsic to the OMS detector will lie in the range 0.1% to 0.5%.

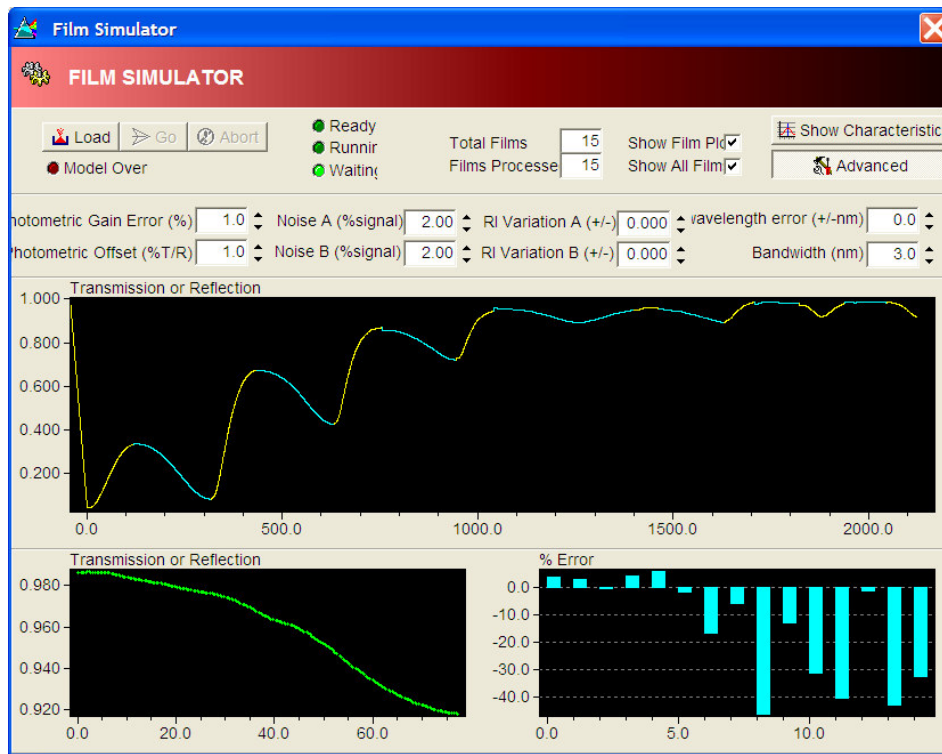
The *Noise A and B* figures below, which represent the signal noise associated with materials TiO₂ and SiO₂ respectively in our design have been set to 0.5% to take account of OM noise and some system noise.



The **Film Characteristic** of the filter is still very acceptable.

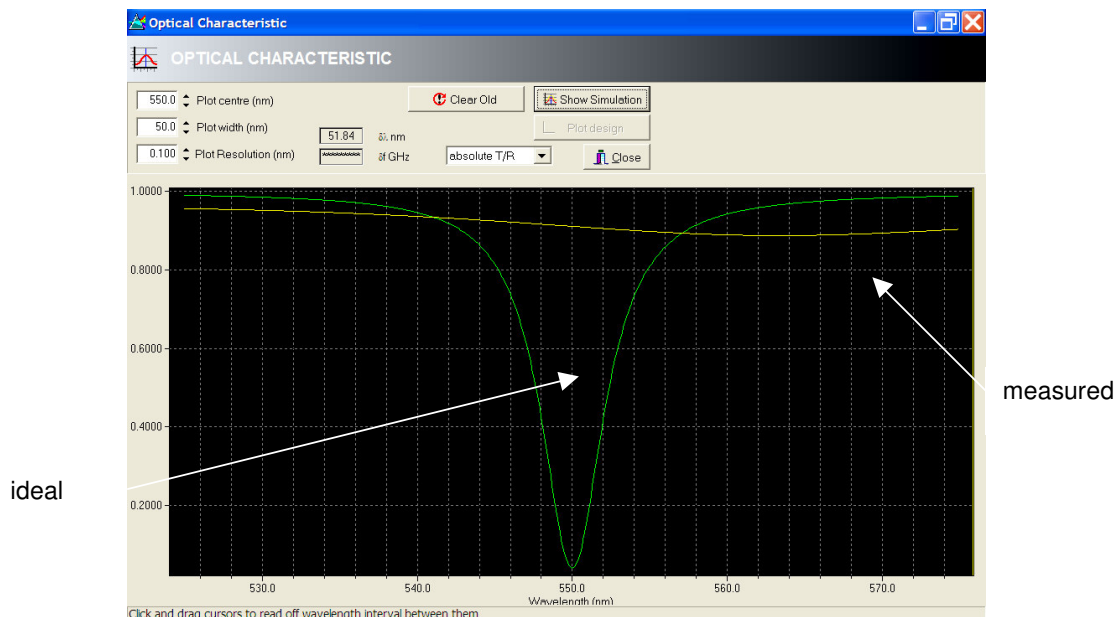


If we increase the *Noise A and B* figures below to 2%, the effect on the simulation can be seen below.



The simulation signal trace can be seen to poor in the second half of the cavity and film 10 shows a large error does not reduce as the stack build.

As expected the filter output trace as shown in **Film Characteristic** is also very poor.



The variables available to us provide an improved output are mainly:

1. Test glass sequence
2. Monitor wavelength
3. Signal filtration

In this case the film cut error has dramatically increased in the second half of the stack, in the presence of a high level of system noise, even with a high degree of linear filtration.

<i>Recommendation</i>	Modelled signal levels (in the absence of gain) above 60% are subject to progressively lower S/N performance, and are to be avoided for this reason, and a test glass change programmed to bring the signal level to within 0-60%.
-----------------------	--

Further simulation runs, incorporating modifications 1, 2 and 3 above, do not provide an OM scheme which will provide the desired filter output. In this case it is necessary to reduce the noise associated with the materials deposition before proceeding with the deposition.

1.18 Multiple films with non-QW CUT

In this series of runs we demonstrate the use of the OM for multiple film termination including non-QW cut.

If you are unfamiliar with programming the **FilmMaker** software package go to Appendix 1 which covers this in detail.

In the previous Sections we have completed setting up of the system tooling, characterisation of QW cuts, some qualitative analysis of the film materials, understanding of usable linear filter settings, demonstration of QW and non QW cut performance on single films and QW cut on multiple films.

Creating a valid **FilmMaker** project for a multilayer non-QW films stack.

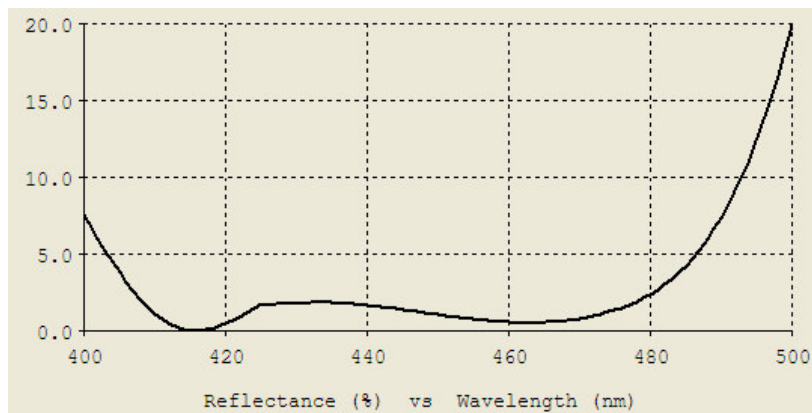
Take the design: glass/film stack/air as glass/3H 3L 1.5H L/air:
Where H is a quarter wave (QW) of the high index material (TiO₂) and L is a QW of the low index material (SiO₂) at a design wavelength of 550nm.
The spectral characteristic of this design is shown below for the following conditions:--

The optical constants of the materials are:-

TiO₂: n=2.358, k=0

SiO₂: n=1.455, k=0

The theoretical spectral response of the completed filter is shown below.



- Let us assume that the OMS is fitted in reflection mode.
- The optical path of the OMS results in an angle of incidence of the collimated beam at the test glass is 5°.
- The rate of deposition for both materials set on the QC controller is 0.5nm/sec.

Coating designs which combine several films and combine QW and non QW are sufficiently multivariate as to require a systematic approach to identify the best FilmMaker project scheme.

Open **FilmMaker** and create a project name “test non qw”.

Create a Private Materials Database as shown below for the H and L index material. Insert the measured materials values from your process for ‘n’ and ‘k’.

Go to the toolbar and click on *Mode* and choose *Simple mode*. This will enable you to input all the key information in the *BUILD FILMS* screen.

FilmNo	Tag	Material	Thickness	CutPointQW's	ProbeWavelength
1		TiO2	29.1561	0.5	550
2		SiO2	94.5017	1	550

Before *Verifying* ensure that the *Parameter Priorities* and *Autocalculate options* are set to *CutPointQW's* and *auto insert cut point QW's* respectively as shown below.

Parameter priorities CutPointQW's DepositionRate	Show columns <input type="checkbox"/> derived from Materials <input type="checkbox"/> derived from Model	Autocalculate options <input type="checkbox"/> auto insert gains <input type="checkbox"/> auto insert forced cut time <input checked="" type="checkbox"/> auto insert cut point QW's
---	---	--

By *verifying* the project in this way the software interprets the coating design and translates this into a CUT instruction for the OMS.

Following verification, if we *Model* the output will be seen to change from to

Before

FilmNo	Tag	Material	Thickness	CutPointQW's	ProbeWavelength
1		TiO2	29.1561	0.5	550
2		SiO2	94.5017	1	550

After

FilmNo	Tag	Material	Thickness	CutPointQW's	ProbeWavelength
1		TiO2	29.1561	0.5	550
2		SiO2	94.5017	1.77778	550

This is the required instruction to the OM to cut, so that to achieve a optical thickness of 1QW the OM must count 1 +.77776 quarter waves.

The background is covered in more detail in the section below.

It is important to ensure after this that the *Parameter Priorities* is set back to *Thickness* to 'lock' the values in the *Thickness* and *Cut Point QW's* columns, otherwise further iteration of *Verify*, which might be required later following **FilmSimulator** as this will cause the value in the *Cut Point QW's* column to be recalculated.

Note that the thickness value of Film 2 (94.5017nm) has not changed between the calculations.

Also note that the *Model* shape MUST be unchanged from before and after above, as the model indicates the predicted signal swing for the process.

If the model shape changes from *Verify* to *Verify* go back and check that values in the *Thickness* column are unchanged.

Note that the default values that FilmMaker has set for *Holdoff* are based on QW film terminations, and since we are now cutting on non-QW films, the *Holdoff* values will need to be reviewed down manually in some cases.

It is not necessary to do this before *verify* as this provides the predicted signal swing from the coating design, *probe wavelength* and *test glass* scheme only, but it is essential to review the *Holdoff* values before we FilmSimulate since the simulator mimics the OM behaviour in exact detail. If the *Holdoff* on a film is set beyond the required cut off value then the film will terminate with a positive error (late) or in extreme cases the simulation will hang.

At this stage consider each film in turn starting with Film1 and by using FilmMaker variables such as *probe wavelength*, *test glass*, and *QWF*, establish the best cut that can be achieved in FilmSimulator.

Do NOT change the *filter setting* from *Normal 10*.

Progressively build up the stack only moving forward to the next film when no further improvement in termination accuracy is achievable.

Keep the model signal swing below 60% by moving to a new test glass for films with a higher *model* signal swing, where possible, since *model* signal swings higher than 60% offer progressively lower signal to noise performance on the OM.

On completion of the whole stack in this way, then check the resultant filter performance by programming into *FilmSimulator* advanced mode the measured or expected process errors and inspect the expected spectral performance of the design by clicking on *FilmCharacteristic*.

As the above has been simulated with a high level of filtration, there is a high probability that the spectral output should be relatively immune to noise.

If this is the case then the design should be deposited at this stage using the *FilmMaker* project and the measured result on the test glass compared with the *FilmCharacteristic* output.

Note that *FilmCharacteristic* provides the expected output of the complete design, where multiple test glasses are used, and not of each individual test glass.

1.19 OMS interpretation of turning point

The OMS interprets the cut for QW films as a need to identify the requisite number of turning points.

So for example if a film is set to 2QW then the OM will monitor the signal swing and count down from 2 to 1 to zero as each turning point is encountered to provide a CUT output when the count reaches 0.

This interpretation is only true if the OMS signal level at the start of that film has been initiated from a true turning point from a previous film or has been initiated at a bulk medium, such as an uncoated glass.

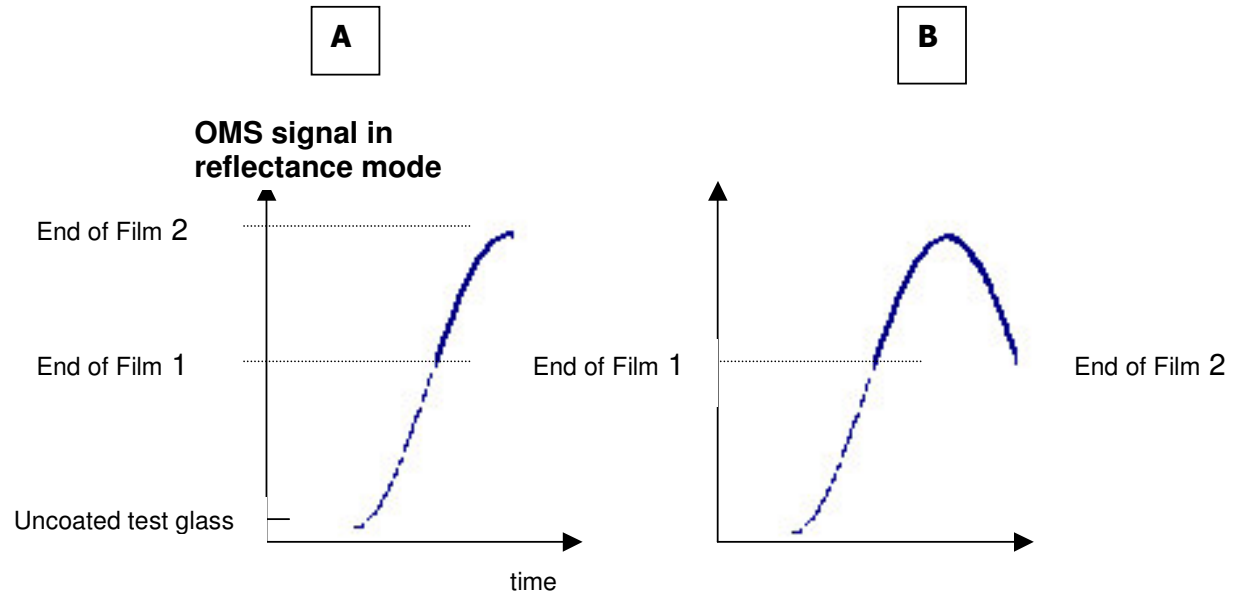
If the start point for the film is NOT a true turning point, because the previous film was a fractional QW or because the monitor wavelength has been changed, which has the same effect, then we need the software to re-interpret the coating design to provide a modified instruction for the OMS to cut.

This is shown graphically below.

In the example below we show the **Actual** and **Correct** interpretation for a film stack on a test glass of 0.5QW of TiO₂/1QW of SiO₂

In “A” the first film of 0.5QW of TiO₂ is terminated correctly. However the second film of SiO₂ on top of the TiO₂, is interpreted by the OMS as a command to CUT the film at the next turning point.

When we compare this to the required interpretation which is shown in “B” we can see how if we do not alter the instruction to the OMS the second film terminates early in A.



Appendix 1: *FilmMaker* software programming guide

A1.1 Some Definitions

We will refer to an individual deposited layer as a film, while a sequence of such layers will be termed a film stack. We can work on the definition of only one film stack at a time, so it makes sense to organise things on a project basis where a new project is assigned for each film stack we define. Thus we may talk about projects, and film stacks interchangeably.

About Databases

Each project or film stack definition is represented by its own unique database. A database is a collection of files contained within a folder and registered with a database engine using this folder name. The process of registration also allows us to associate a project name with each database. In everyday use, all we have to concern ourselves with is this straightforward project name, and let the database engine worry about the actual location of the database folder.

If you are unfamiliar with working with databases the following points should be noted.....

Don't expect to find a **File Save** or **File SaveAs** on the menu. Data is directly entered to the database as you work. Moving up or down on the grid or closing the form will post the data you have just entered to the underlying database.

Don't expect to be able to copy a design from one PC to another by simply putting a file on a floppy. You **can** transfer a project by floppy disc, or access a project on another PC via a network, but you need to move or access the entire folder, and then register it with your PC.

Loading a Design (Advanced Mode only)

Lets assume we are going to load a design that specifies a film stack comprised of alternating films of two different materials. We will assume that the materials we will be using have already been entered into a public materials database. Because many of the parameters that are needed will be common to all films, we can greatly ease the burden of typing all these numbers by setting up and using the *load from default* feature of **FilmMaker**.

In this case the basic steps we need to follow are -

1. Open a new project, selecting the *public materials database* that contains the materials we intend to employ.
2. In the *Select Materials* panel of the *BUILD FILMS* form select the materials that are to be used.

3. In the Parameter Priorities panel of the *BUILD FILMS* form select the *CutPointQWs* and *DepositionRate* options (the defaults).
4. Load the Default Values Grid of the *BUILD FILMS* form with one entry for each material.

The *probe wavelength* must be entered along with the *thickness in quarter-waves* and the *deposition rate*. Because of the *Parameter Priorities* we selected in step 3, we don't have to bother filling in the physical thickness, or the optical thickness, or the quarter-wave time, as these will be automatically calculated for us at a later stage.

5. Next fill in as many of the instrument parameters as are necessary for the application. Almost certainly we will want to set the *FilterCutOff*, the turning-point detection algorithm (*AnalyserMode*), the *SamplesPerQW*, and the *SampleRate*.

Note that we are not committed to these settings, and can edit them later on a film by film basis in the main data grid. Note also that as we change the turning-point detection mode (*AnalyserMode*), the analysis parameters that are inappropriate to the mode are greyed-out, and any data in these greyed-out columns will be ignored.

6. If we unlock the main data grid, we can now use these *Default Film Values* to load the main data grid according to the design. Thus clicking the 1-2 button enters default 1/2 pairs to the main grid, clicking the 1 button enters default 1 only, and so on. The *Tag* column can be filled in with comments as we go to help keep track of our position in the design.

7. When all films are loaded, we can click on the *VerifyFilms* button. The software then checks that the materials database has the correct data to satisfy the film stack and then fills in the *QWTime*, the *OpticalThickness* and the *PhysicalThickness*. It checks that the requested number of *SamplesPerQW* can indeed be generated for the given *SampleRate* and *DepositionRate*. Any verification errors are flagged.

9. The final step involves setting such parameters as may be peculiar to certain films. For instance, the cavity spacer film between two quarter-wave stacks will need to be, say, 4 quarter-waves thick, and can be typed in at this point. The shape difference between minima and maxima may dictate different turning-point parameters to be entered at certain points in the stack specification etc.

10. With all the films in place and verified, we can now model the film stack by clicking the *Run Model* Button on the *BUILD FILMS* form. The program calculates the theoretical response of the optical monitor as each film is built up, and displays it in a window. Further to this, it also loads the data grid with the starting signal level and its maximum and minimum excursions for each film in the stack. These can be viewed by enabling the *derived from Model* checkbox in the *Show Columns* panel of the *BUILD FILMS* Form.

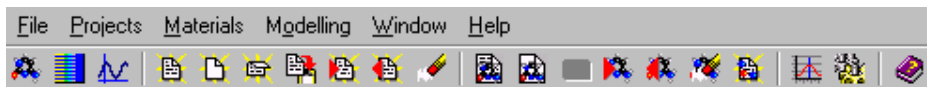
Most importantly, this operation calculates the correct *Gain* setting for the optical monitor as the stack builds up, and enters it in the data grid.

At this point the film stack is fully defined, and available for access by the optical monitor during a process run.

Main form

This is the menu and toolbar of the **FilmMaker** desktop.

Click on the screen image below for more information.



A1.2 Toolbar



opens the Materials form corresponds to **File Open Materials form**



opens the BUILD FILMS form corresponds to **File Open BUILD FILMS form**



opens an existing project corresponds to **Projects Open existing project**



creates a new project corresponds to **Projects Create new project**



closes an open project corresponds to **Projects Close project**



creates a copy of the open project corresponds to **Projects Copy project as ...**



makes a project accessible to a PC corresponds to **Projects Register project**



deletes reference to a project from a PC corresponds to **Projects Deregister project**



deletes a project corresponds to **Projects Delete project**



opens an existing public materials database corresponds to **Materials Open public materials database**



creates and opens a new public materials database corresponds to **Materials Create new public materials database**



closes an open public materials database corresponds to **Materials Close public materials database**



makes a public materials database accessible to this PC corresponds to **Materials Register public materials database**



deletes reference to a public materials database from a PC corresponds to **Materials Deregister public materials database**



deletes a public materials database corresponds to **Materials Delete public materials database**



associates a different public materials database with a project corresponds to **Materials Change materials database**



opens on-line Help

A1.3 Materials Form

This form is used for adding, deleting and editing the Materials and Optical Properties databases.

Click on the image below for more information.

Materials

MATERIALS

Material name: SiO2 Material no: 1

Quartz crystal control 1 Quartz crystal control 2

Optical properties

Wavelength	RefractiveIndex	ExtCoef(k)
1550	1.48	2.3E-8

Wavelength search precision: 2 (decimal places)

☒ Lock tables
☒ Warn on delete

+ Add material
- Delete material
+ Insert optical property
- Delete optical property

Material name and number

By selecting a material in the material name combo-box, it is possible to assign it a material number, as well as any of the physical and optical properties

Crystal control tabs

These tabs contain controls for entering and editing crystal control parameters in the materials database.

Optical properties grid

Use this grid for entering sets of optical properties data for each material.

Wavelength precision spin edit

Use the wavelength precision spin edit to set the precision used when probe wavelength values are checked during film verification.

Materials editing panel

- Lock materials tables check-box
- Materials warn on delete checkbox
- Add material button
- Delete material button
- Insert optical property button
- Delete optical property

Lock materials tables check-box

Check to protect data, uncheck to edit data

Materials warn on delete checkbox

Uncheck this box to suppress warning dialog every time an entry is deleted.

Add material button

Use the *add material* button to add new materials to your project's materials database.

Delete material button

Use the *delete material* button to delete unwanted materials from your project's materials database.

Insert optical property button

Use the *insert optical property* button to add a new set of optical properties to a material.

Delete optical property

Use the *delete optical property* button to remove unwanted optical property sets from a material.

A1.4 BUILD FILMS form

Click on the image below for more information.

Select Materials Panel

Use the controls on this panel to select the materials you want to use from the materials database associated with your project.

To select materials, click on material(s) required in the *Materials available* list box. Clicking the left arrow will move them to the *Materials selected*. All selected materials will appear in a pick list in the *Material* column of the *BUILD FILMS* and *Default Values* grids. To de-select, click on material(s) in *Selected materials* list box, and use the right arrow button.

Clicking the *Select material colours* button will open the *Select materials colour* dialog box, which you can use to set the background colours for your selected materials.

Select column colours

Use the colour picker buttons on this panel to select background colours for different types of film parameters.

When the down-arrow is clicked, a colour selection palette will open, and the colour selected will be applied as a background colour to all the columns of that parameter type in both *BUILD FILMS* grids and the *Default Values* grid.

Parameter priorities panel

Use the combo-boxes on this panel to set the order in which inter-dependent parameters will be evaluated when verifying films.

Show columns panel

Use the check-boxes on this panel to show or hide additional columns in the main grid. These columns refer to parameters derived either from the materials database or from the model.

Autocalculate options panel

Use the checkboxes on this panel to determine whether gains, forced cut time and cutpoint QWs should be calculated automatically. See Autocalculate Options.

BUILD FILMS editing panel

This panel contains the following:-

- Lock table check-box
- Warn on delete check-box
- Insert film at cursor button
- Insert film at end button
- Delete film at cursor button
- Verify films button
- Run model button

BUILD FILMS grids

Two identical grids, separated by a splitter, to enable two parts of the grid to be seen at the same time. Film data can be entered either directly or via the Default grid at the bottom of the form.

The columns within the grids can be moved and resized by using the header, as in a spreadsheet.

For details of editing procedures, see Data grids

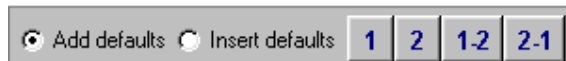
Insert film at end button

use to add a new film at the bottom of the grid

Default values edit panel

Lock table check-box
Warn on delete check-box
Insert row at cursor button
Insert row at end button
Delete row at cursor button

Enter defaults buttons



Use these buttons to enter new films with the values from the defaults grid into the *BUILD FILMS* grid.

Check either 'Add defaults' to enter new default films at the end of the film stack, or 'Insert defaults' to enter them at the film stack cursor.

The button marked '1' enters the first default film, the button marked '2' enters the second, the one marked '1-2' enters the first followed by the second, and the one marked '2-1' enters the second followed by the first.

Default values grid

Default values entered in this grid can be inserted into the main grid a row or more at a time by using the Enter defaults buttons

Column information

Displays additional information on grid columns, eg full name and units.

If the information is too long, it can be viewed by clicking the down arrow.

Lock default values table checkbox

Check to protect data, uncheck to edit data

Default values warn on delete checkbox

Uncheck this box to suppress warning dialog every time an entry is deleted.

Insert row at cursor button

Use to insert a new row of default values above the one that the cursor is on, and renumbers rows as necessary

Insert row at end button

Use to add a new row of default values at the bottom of the grid

Delete row at cursor button

Deletes the row of default values that the cursor is currently on, and renumbers rows as necessary

Lock film table checkbox

Check to protect data, uncheck to edit data

BUILD FILMS warn on delete checkbox

If checked, a dialog will be shown to ask for confirmation when deleting

Insert film at cursor button

Inserts a new film above the one that the cursor is on, and renumbers films as necessary.

Delete film at cursor button

Deletes the film that the cursor is currently on, and renumbers films as necessary

Verify films button

Checks that all necessary data has been entered in each film, performs calculations based on data entered by reference to the materials database, and enters verification status in *FilmNo* column

Run model button

Models the current film stack and displays the modelled data in a window. Also fills in the model parameters and sets the gains for each film.

Current film error

This display is blank until the films have been verified using the 'Verify films' button, after which it shows the error status of the film at the cursor in the main grid.

A1.5 Projects

FilmMaker's film stack and materials data are kept in project folders, one folder per film stack. A project name is associated with each folder, and used by the database engine to access the relevant data. Thus we can think of a film stack definition or workspace and a project as being interchangeable ideas.

You have the choice of using either existing *Public materials databases*, which can be shared by any number of projects, or *private materials databases*, which are stored with individual projects.

Projects created on another PC on a network, or copied onto a disk, **can** be registered and accessed from you PC.

The directory path of a project can be found by selecting **Projects Show path** from the main form menu.



Opening an existing project

Projects can be opened in any of the following ways:-

Select **Projects Open existing project** on the main menu

Click the **Open existing project** toolbar button

Pressing **Alt + P**, then **O** on the keyboard.

Choose an existing project from the 'Open Project' dialog box, and press OK to open. If another project or a public materials database is already open, it will be closed before the new project is opened.

When the project opens, the *Materials* form and *BUILD FILMS* form will open automatically, if they are not open already. The application window will display the project name in its caption, and the materials form will show the associated materials database name in its caption.



Creating a new project

Create a new project to start a new film stack specification. This does three things.

- a) It creates a new folder to hold all the files associated with the project
- b) It assigns a project name which will be used when you access the stack specification
- c) It assigns a materials database to the project.

New projects can be created in any of the following ways:

Select **Create new project** on the **Projects menu**

Click the **Create new project** Toolbar button

Press **Alt+P**, then **N** on the keyboard

Enter a folder name for your new project in the *Create FilmMaker Project* folder dialog, then enter a unique project name in the *Enter Project Name* dialog. Note that you don't have to use the same name for the folder and the project, but if you do, it will make life easier when you have large numbers of projects needing reorganisation.

The next dialog to open needs to know the materials database that will be associated with the project. You can choose an existing public materials database or choose to keep the materials data private to the project.

The new project will then be opened, closing any other project or materials database that happens to be open at the time. The Materials Form and *BUILD FILMS* form will open automatically if not already open. The new project name will appear in the caption of the *BUILD FILMS* form, and the materials database name or type will appear in the caption of the *Materials* form.



Closing projects

Projects can be closed in any of the following ways:-

Use the **Close project** Toolbar button

Select **Close project** from the **Projects menu**

Press **Alt+P**, then **C** on the keyboard

Open or create another project or a public materials database



Deleting projects

Projects can be deleted in any of the following ways:-
Selecting **Project Delete** project on the main menu
Clicking the Delete project Toolbar button
Pressing **Alt+P**, then **D** on the keyboard.

In the *Select Project to Delete* dialog, select the project that you wish to delete by typing in its name or select it using the down arrow.

NB Projects cannot be deleted while they are open. Use *Project Close* before proceeding.



Registering a project

Registering a project which resides on a disk or a networked PC will make it accessible from your PC.

Suppose you have a film stack design which you wish to export to another PC. There are two ways to do this.

1. Locate the folder that contains the project, and copy **all** the files onto a floppy disc. Take this disc to the second PC and copy from it into a new folder for the project. Note that the folder name can be different from the original if you so desire. Then follow the instructions below to register this folder as a project on the new machine.
2. If the PCs are connected by a network, and the second PC has access rights to the project folder in the first PC, all that is required is to click on the **register project** menu using the second machine, navigate through the network to the project folder in the first machine and proceed as per the instructions below.

Projects can be registered in the following ways:

- Select **Projects Register project** from the main menu
- Click the **Register project** Toolbar button
- Press **Alt+P**, then **R** on the keyboard
- Select the path of the project you want to register in the 'Browse for folder' dialog, and enter a name for the project in the 'Enter new project name' dialog
- Once a project is registered, it can be opened the same as any other project.



Deregistering a project

Projects whose name you want to remove from your PC, rather than deleting them entirely (eg. a project on the network or on a disk, which you have previously registered on your PC and no longer need to access) can be deregistered in the following ways:-

- Select **Deregister project** from the **Projects menu**
- Click the **Deregister project** Toolbar button
- Press **Alt+P**, then **G** on the keyboard

In the 'Select project' dialog, enter the name of the project you want to deregister, or select it from the drop-down list.

NB Projects cannot be deregistered while they are open. Use *Project Close* before proceeding. Note that deregistered projects can be re-registered at a later date.



Copy a project as ...

A copy can be made of an open project in the following ways:

- Select **Projects Copy Project As** from the main menu
- Click the **Copy project as ...** Toolbar button
- Press **Alt+P**, then **A** on the keyboard.

Enter a folder name for your new project in the *Create FilmMaker Project Folder* dialog, then enter a unique project name in the *Enter Project Name* dialog. Note that you don't have to use the same name for the folder and the project, but if you do, it will make life easier when you have large numbers of projects needing reorganisation.

If the project you are copying from was linked to a public materials database, then the new one will automatically be linked to the same one, otherwise a private materials database will be created for it.

The new project will then be opened, closing the original one. The *Materials* form and *BUILD FILMS* form will open automatically if not already open. The new project name will appear in the caption of the *BUILD FILMS* form, and the materials database name or type will appear in the caption of the *Materials* form.

Updating old format

Projects created in an older version of **FilmMaker** may not be able to be opened in this version. A message will be displayed to tell you this.

To update an old format project, select **Projects Update old** from the main form menu. If you attempt to update a project of the latest format, a message will be displayed to tell you that updating is unnecessary, and the project will be left unchanged.

Locating a project folder

For maintenance reasons you may want to locate the folder associated with a particular project. Because they need not share the same name finding the right folder can be difficult. However, there is a utility to simplify this task. In the main menu select **Projects/Show Path...** and the select project dialog will open. Select the project whose folder you wish to locate and a dialog will open displaying the full path.

A.1.6 Materials databases

Public materials databases are free-standing (not exclusive to a project), and can be accessed by any number of projects. Private materials databases are held within the project folder, and cannot be accessed by anything other than the project to which they belong.

The advantage of the public materials database is that you can build a library of materials and their properties for future use. The disadvantage is that any changes made to entries in the database will impact all projects that use them.

A private materials database, on the other hand, has the advantage that, being part of the project folder, it can be archived, moved about the place etc., with no impact on the inherent design. The only overhead is that you have to load the materials and their properties for each project you elect to use with a private materials database.

Unlike the private materials database, the public materials database can be created, opened, or deleted in its own right. However, because they are associated, each with their own folder, and have to be registered with the database engine in a similar manner to projects, you **cannot** freely copy them from one PC to another. Instead you have to follow the procedure described in registering a public materials database.

When a project is created, you have the choice of using an existing public materials database, or having a private one created within your project. You can also change to another materials database, either public or private, at a later stage.



Opening public materials databases

Public materials databases can be opened in the following ways:-

- Select **Materials Open public materials database** from the main menu
- Click the **Open public materials database** Toolbar button
- Press **Alt+M**, then **O** on the keyboard.

In the *Enter materials database name* dialog, enter the name of the materials database you would like to open, or select it from the drop-down list.

The *Materials* form will be opened automatically, and any other materials database or project which is open at the time will be closed. The name of the database is shown in the caption of the form.



Creating public materials databases

New public materials databases can be created in any of the following ways:

- Select **Create new public materials database** from the **Materials menu**
- Click the **Create new public materials database** Toolbar button
- Pressing **Alt+M**, then **N** on the keyboard

Enter a folder name for your new materials database in the *Create FilmMaker Public Materials Database* folder dialog, then enter a unique materials database name in the *Enter Materials Database* name dialog.

The new materials database will then be opened, closing any other materials database or project open at the time. The *Materials* form will open automatically if not already open. The database name will be shown in the forms caption.



Closing public materials databases

Public materials databases can be closed in any of the following ways:-

- Click the **Close public materials database** toolbar button.
- Select **Close public materials database** from the **Materials menu**
- Press **Alt+M**, then **C** on the keyboard
- Open or create another public materials database or a project

There is no explicit save operation required, as the data you have entered has been posted to the database as each entry is made.



Deleting public materials databases

Public Materials Databases can be deleted in the following ways:-

- Select **Delete public materials database** from the Materials menu
- Use the **Delete public materials database** toolbar button
- 3. Press **Alt+M**, then **D** on the keyboard.

In the Select Public Materials Database to Delete dialog, select the materials database that you wish to delete by typing in its name or selecting it using the down arrow.

Public materials databases cannot be deleted while they are open.

NB Deleting a public materials database which is in use by any existing projects will result in film verification errors in those projects. If you cannot be sure if you have any projects referencing a database, it is better not to delete it.



Registering public materials databases

Registering a public materials database which resides on a disk or a networked PC will make it accessible from your PC and available for use by any projects thereon.

Suppose you have a public materials database which you wish to export to another PC. There are two ways to do this.

1. Locate the folder that contains the database, and copy **all** the files onto a floppy disc. Take this disc to the second PC and copy from it into a new folder. Note that the folder name can be different from the original if you so desire. Then follow the instructions below to register this folder as a public materials database on the new machine.
2. If the PCs are connected by a network, and the second PC has access rights to the database folder on the first PC, all that is required is to click on the **Register public database** menu using the second machine, navigate through the network to the right folder in the first machine and proceed as per the instructions below.

Public materials databases can be registered in the following ways:-

1. Select **Materials Register public materials database** from the main menu
2. Click the **Register public materials database** Toolbar button
- 3 Press **Alt+M**, then **R** on the keyboard.

Select the path of the public materials database you wish to register in the 'Browse for folder' dialog, and enter a name for the public materials database in the 'Enter materials database name' dialog.

Once a public materials database is registered, it can be opened the same as any other public materials database.



Deregistering public materials databases

Public materials databases whose name you want to remove from your PC, rather than deleting them entirely (eg. a public materials database on the network or on a disk, which you have previously registered on your PC and no longer need to access) can be deregistered in the following ways:-

- Select **Deregister public materials database** from the **Materials menu**
- Click the **Deregister public materials database** Toolbar button
- Press **Alt+M**, then **G** on the keyboard

In the *Enter materials database name* dialog, enter the name of the materials database you want to deregister, or select it from the drop-down list.

Please ensure before deregistering a public materials database that no other projects registered on your PC are using it, as without the registration it will not be possible to open these projects.

NB Public materials databases cannot be deregistered while they are open. Use close public materials database before proceeding.



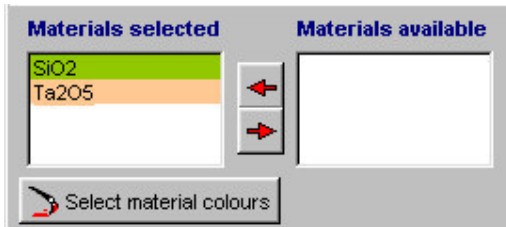
Changing materials database

A project can change its materials database from public to private, private to public or from one public one to another by any of the following:

- Select **Change materials database** from the **Project menu**
- Click the **Change materials database** Toolbar button
- Press **Alt+P**, then **H** on the keyboard

NB Care should be taken to ensure that the new database contains the correct materials and optical properties data for any film data already entered in the project.

Select materials panel



Use the controls on this panel of the *BUILD FILMS* form to select the materials you want to use from the materials database associated with your project.

To select materials, click on material(s) required in the *Materials available* list box. Clicking the left arrow will move them to the *Materials selected*. All selected materials will appear in a pick list in the 'Material' column of the *BUILD FILMS* and *Default Values* grids. To de-select, click on material(s) in *Selected materials* list box, and use the right arrow button.

Clicking the *Select material colours* button will open the *Select materials colour* dialog box, which you can use to set the background colours for your selected materials.

Entering and editing data

Materials and films data is entered by means of data grids, edit boxes and combo boxes, and is protected by checking the *Lock table* checkboxes.

The following topics are covered in this section:

- Edit boxes and Combo-boxes - Materials form only
- Data grids
- Default film values

Edit boxes and Combo boxes --Materials form only

Edit boxes

The only editable edit boxes are on the Quartz crystal control tabs on the Materials form. If the lock tables check box is checked they will be disabled to protect existing data. If it is unchecked, values can be entered or edited.

Combo boxes

As with the edit boxes, existing data is protected by using the lock tables check box.

The Material Name combo-box is used only for selecting the material that you want to look at or edit the details of. To add new materials, or delete ones that you no longer require, use the *Add material* and *Delete material* buttons. Values can be changed in all the other combo-boxes by selecting from the drop-down list, or by typing in the first letter or number of the value you want to enter.

Data grids

Data in all the grids is protected by using the *Lock table* check-boxes, which have to be unchecked to allow editing.

New rows are entered by using the *Insert row* or *Insert film* buttons on the *BUILD FILMS* form, or the *Insert optical property* button on the *Materials* form. Default films can also be entered into the *BUILD FILMS* grid by using the *Enter Default* buttons. Numbering of films and default rows is automatic.

Rows are deleted by using the *Delete row* or *Delete film* buttons on the *BUILD FILMS* form, or the *Delete optical property* button on the *Materials* form.

Once a row has been inserted, values can be typed straight in. Some columns in the *BUILD FILMS* form grids have pick-lists which are activated when the column is entered. Values can be entered in these columns by using the down-arrow, or by typing in the first letter or number. Moving materials from the *Materials available* list box to the *Materials selected* at the top of the *BUILD FILMS* form will make those materials available as a pick list in the *Material* columns.

Tips

Columns can be resized by moving the mouse over the border of the column title until the cursor changes to a double headed arrow, holding down the left mouse button and dragging.

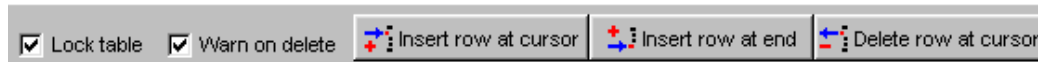
Columns can be dragged to a new position by holding down the left mouse button over the column title.

To apply a value to every row in a column in any of the grids on the *BUILD FILMS* form, select the value within the column that you want to use, and click on the column's title.

You can view two different sections of a film stack by moving the splitter between the two main grids.

All column properties are saved with your project when it closes, and will be the same next time you open it.

Default film values



The Default Values grid on the *BUILD FILMS* form can hold two default films which can then be inserted as required into the main films grid by means of the *Enter Default Film* buttons.

Before data can be entered the table has to be unlocked.

When rows are inserted in the *Default Values* grid, using the *Insert row* buttons, many of the values are entered automatically. However, *Material* and *ProbeWavelength*, as well as one of the inter-dependent thickness parameters (CutPointQWs, Thickness, Optical Thickness) and one of the inter-dependent deposition parameters (Deposition Rate, QWTime) must be entered before you can move onto or insert another row. Use the delete button to remove an entire row.

Importing and Exporting

The following import and export options are available.

Model data can be exported to CSV file by selecting **File Export Model data To CSV**

The data exported is identical to that shown in the *Model Parameters* columns of the *BUILD FILMS* form, and consists of *SigStartLevel*, *SigStartTrend*, *SigAtNextMax*, and *SigAtNextMin*.

Film stacks can be exported to and imported from Excel by selecting **File Export Film stack To Excel** or **File Import Film stack From Excel**.

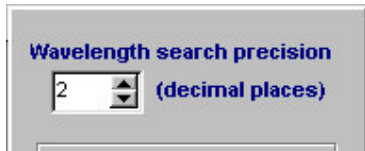
Export is complete with column headings, colours etc being exported. Import is likewise complete.

NB: The spreadsheet data to be imported has to exactly match the layout of the *BUILD FILMS* grid or the import will fail. It is recommended that the user export a blank grid to Excel, and to then work with this, so as to ensure successful importing.

Film stacks can be imported from CSV file by selecting **File Import Film stack From CSV**.

Any column of the *BUILD FILMS* grid can be imported from a CSV file provided its name appears in the first line of the file exactly as it is spelt in the column heading. Columns that are not imported are filled with the standard defaults.

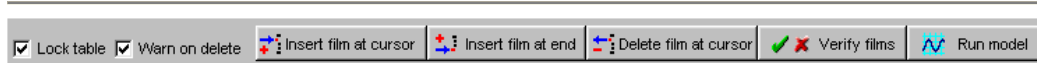
Wavelength precision

A screenshot of a software interface element. It features a title bar that reads "Wavelength search precision". Below the title bar is a small rectangular control with a white background. Inside this control, the number "2" is displayed on the left, followed by a small square button containing two vertical arrows (up and down). To the right of this control, the text "(decimal places)" is displayed in a smaller font.

The *Wavelength Precision* option on the *Materials* form sets the match precision used when the materials database is searched for wavelength entries, during *Film Verify*.

For example, if a *ProbeWavelength* entry for a tantalum dioxide film in the *BUILD FILMS* form calls for a wavelength of 1550.33nm, and the materials database contains an entry for tantalum dioxide with the wavelength 1550.30, the data for the latter wavelength will be used provided the 'wavelength precision' is set to 1 decimal place or lower.

A1.7 Verifying films



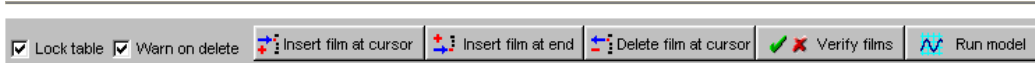
Before a film stack can be used, it must be verified using the *Verify films* button above the main grids on the *BUILD FILMS* form.

This procedure checks that the *ProbeWavelength* for each film is within the range required for the material being used, sets the refractive index and extinction coefficient, and completes or corrects parameters according to the values selected in the *Parameter Priority* combo boxes. It also checks that the sampling rate dictated by the *SampleRate* parameter is high enough to allow the specified number of samples per quarter-wave.

Verification may also calculate and insert a suitable value for the film timeout parameter *ForcedCutTime*. See Autocalculate Options.

If there are any errors in the stack, a message will appear in the status bar. Each film is marked with a tick or a cross in the 'Film no' column, and errors can be viewed in the 'Current error' box below the grids by clicking on each film.

A.1.8 Running the model



The *Run model* button on the *BUILD FILMS* form starts the modelling software which predicts the optical monitor output as each film in the film stack is deposited. A dialog opens into which we enter the following parameters -

1. Substrate refractive index
2. Whether the substrate is AR coated or not
4. The model step size in nm

Note that the model step size must be set to 0.1 nm for projects where including non-QW cuts. This is required to ensure that the model signal resolution is high. This is required as the model output is used to confirm the actual stopping condition (amplitudes) for some non-QW cuts.

5. The optical monitor mode, transmission or reflection

Changes to the above parameters are saved with the project.

The output of the model is displayed in a window. In addition, the model data is used to write a number of parameters to the grid. The signal start level, the level at any maximum or minimum and the signal trend at start may be used by the optical monitor software in determining cutpoints. To view these parameters in the grid you have to check the 'derived from Model' check box in the Show Columns panel.

A further output from the model is to fill in an appropriate instrument gain for each film in the stack. These gains, rounded down to the nearest 0.5 dB, are chosen to fully utilise the dynamic range of the detector.

A.1.9 Analyser Mode & Filter Parameters

So as to provide accurate termination in the presence of system noise, something which is present to some degree on all coaters, FilmMaker offers a set of noise filters and associated termination algorithms. These are selected from the pull down menu in the *AnalyserMode* column. The correct setting of these filters will largely determine the degree to which the deposited coating on the witness will replicate the design programmed into the OMS.

Basic Noise Filtration... setting the *FilterCutOff* parameter

The sinusoidal-like data stream coming from the detector has a fundamental frequency associated with it. This can be derived at setup from the estimated quarterwave time. The filter needs to pass this frequency and reject higher frequencies. A normalised setting of 1.0 would achieve this perfect filtering, but, unfortunately, the consequential phase delay would be far too large. To get workable phase delays, we normally have to use settings of 7.5 or higher (ie cutting off frequencies 7.5 times the signal fundamental and higher). The linear algorithms require more filtering (7.5 to 15) than the curve fitting filter algorithms (25 to 100) discussed later.

Note that the filter cutoff parameter is normalised, and a given parameter value will have much the same effect regardless of the actual film being built. However, the quarterwave time needs to be estimated to within +/- 20% for this to be so.

The main benefit of filtration is in improving the reliability of the termination. On the negative side, filtration introduces a phase delay in the monitored signal that results in late (but reliable) termination. The phase delay can be predicted as follows....

FilterCutOff	Delay (QWs)	Error on 1QW (%)
1	0.5	+50
5	0.1	+10
50	0.01	+1
500	0.005	+0.5

As a general rule of thumb, the best results are achieved when filtration is reduced to a point where the filtration is set just high enough to prevent system noise from causing unreliable termination of layers.

However, with a new process/project the best way of achieving success is to initially set a high level of filtration and thereby ensure that the OMS proceeds through the process without error, and then to repeat the coating build with progressively reduced filter sets.

Termination Algorithms.... setting the *AnalyserMode*

Normal Mode (linear)

This is a simplex algorithm that looks for a number of sample points (as set in the *PCD Threshold* column) to be distributed across an extremum. For example, when *PCD Threshold* equals five, then a maximum will be detected if two points are going up slope, two going down slope, and the remaining point is at the top.

Increasing the *PCD Threshold* improves the ability to reject noise spikes, but a phase delay of at least half the *PCD Threshold* setting is inevitable.

The data set must be monotonic, ie that is smoothly increasing to the maximum, then smoothly decreasing to the minimum and so on, with no backward steps. This demands quiet data, which often means high levels of filtering and thus phase delay.

A typical starting set up would be:--

Samples per QW = 100

Normal = 10

PCD Threshold = 5

Filter Crossing (bi-linear)

This employs a second noise filter that runs slower than the main filter by the ratio set in the *Crossing Ratio* column.

The point at which one filtered signal crosses over the other occurs at a reproducible place after each extremum, and this is the cut point. The delay here is very consistent so that the error introduced is truly systematic and can be calibrated out.

The positioning of the crossover point is relatively immune to drifts in signal baseline, but does introduce a phase delay. The higher the *Crossing Ratio*, the better the noise rejection, but also the greater the phase delay.

Fitter 1 (quadratic)

Fitter 1 employs a parabolic curve fitter that operates over window of the most recent data points to determine extrema in the optical monitor signal. The size of the analysis window is set by the *Filter Buffer Size* column. The greater the buffer size, the better the inherent filtering of the fitter, and thus the better the ability to handle noisy data. However, typical OM curves approximate parabolic for only a limited extent either side of the extrema, so will give erroneous results if the buffer size is too large.

A good rule of thumb is that the buffer should be somewhere between one fifth and one third of the *Samples Per QW* column.

Because this algorithm inherently filters, the *FilterCutOff* column can be increased to very much higher values than you would use with *Normal* or *Filter Crossing* modes. A good rule of thumb is to increase the *FilterCutOff* by a factor of at least the square root of the buffer size.

The *FitterThreshold* parameter is applied to the quality-of-fit, and thus sets the point at which the fitter will consider itself 'locked' to the incoming signal. Only for very noisy data is there any point in increasing this value.

The fitter is predictive, and 'knows' when an extremum is approaching. It writes its prediction of the time of the next turning point to the Process Screen. Because the fitter is predictive, it creates absolutely no phase delay. However, because it is being fed filtered data, there will still be the phase delay of the basic noise filter.

Therefore, by setting the *FilterCutOff* some 10 to 20 fold higher than is usual, and compensating for the noisier data by using a large *Filter Buffer Size*, it is possible to terminate in this mode with almost no delay.

A typical starting setup would be:--

Samples per quarter wave = 400

Filter = 100

Filter Buffer Size = 100

Filter Threshold = 0.01

Fitter 2 (quadratic)

Similar to Type 1 fitter with the exception that it works on the reciprocal of the data stream. The reason for this being, that in certain specialised cases, it fits over a wider extent at the extremum than the Fitter 1 algorithm, and thus allows larger buffer sizes to be employed without the size introducing errors discussed above.

Use Fitter 2 in situations where the maxima are clearly much sharper than the minima. A typical application where this occurs is when building filters which employ pairs of QW stack reflectors to produce a high finesse resonant cavity. Where the maxima and minima are similar in terms of sharpness, use fitter 1.

Curve Follower (shape recognition)

Curve follower depends upon a process generating an optical trace absolutely identical to that modelled. It is capable of positioning the current signal on the model trace with high accuracy, but it is computationally intensive and can be used only at sample rates of 2Hz and less. It is quite a specialised filter, and should be used only when none of the conventional filters will work. It is particularly appropriate to non-QW designs, when these have to be laid down on the one witness. The length of the deposition must exceed 0.8 of a QW before curve follower will 'lock' to the signal and will give best results when the optical trace traverses at least two successive extrema before seeking a cutpoint. Increasing the **FollowerGPP** improves accuracy but drastically increases the computational power required. The **FollowerBufferSize** parameter smooths the output of the fitter and thus its stability, but increases phase lag.

A typical setup would be :-

Samples per quarter wave = 200

Filter = 100

Follower Buffer Size = 4

FollowerGPP = 50

A1.10 Increasing the Robustness of Turning Point Detection

All four turning point detection algorithms are sensitive to noise spikes to some degree, and erroneously assigning a turning point to a noise spike effectively ruins the run. Because we know in advance the approximate timing of the extrema, it is possible to block out all turning points until one is due. The **Holdoff** parameter sets the delay after the start of the run before the algorithm accepts a turning point. It is set in units of sample points. The **Latency** parameter sets the interval after finding an extremum that must expire before another turning point will be accepted. It is set in units of sample points.

Although these parameters suppress the acceptance of turning points, they do not suppress processing, and thus the recovery from the **Holdoff** and **Latency** periods is instantaneous. For example if we have set 100 **Samples per QW**, we can happily set the **Holdoff** at 80 and still be sure of picking up the first extremum.

A1.11 Setting *BUILD FILMS* form preferences

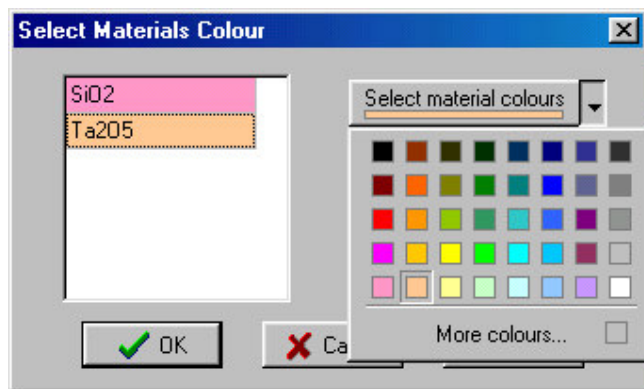
Various display and parameter preferences can be set on the *BUILD FILMS* form.

The following topics are covered in this section:

- Selecting material colours
- Setting column colours
- Setting parameter priorities
- Showing and hiding columns
- Setting autocalculate options

Selecting material colours

By using the controls in the Select materials panel of the *BUILD FILMS* form, you can select the materials that you want to appear in the drop-down lists of the Materials columns in all the *BUILD FILMS* form grids, and also apply a background colour for each material.



To apply background colours to selected materials, click the 'Select material colours' button. This will open the 'Select material colours' dialog. Select the material you want to apply a colour to, and click the down-arrow of the colour selector, which will open a colour palette. For additional colours click the 'More colours...' button.

Selected materials and associated colours will be stored with the project.

A1.12 Parameter priorities panel



Use the combo-boxes on this panel in the *BUILD FILMS* form to set the order in which inter-dependent parameters will be evaluated when verifying films.

For example, if *CutPointQWs* is selected, then the current values of this parameter will be used to calculate the other 'thickness' parameters, ie *optical thickness* and *physical thickness*. Thus we can set up the thickness of each film in terms of quarter-waves, make changes to the probe wavelength etc, and on verifying the design, the new values for optical thickness and physical thickness will be written into the grid.

The two sets of inter-dependent parameters in **FilmMaker** are

- a) the thickness parameters
 - physical thickness
 - optical thickness
 - quarter-wave thickness
- b) the deposition parameters
 - deposition rate
 - quarter-wave time

Note that the correct setting of the *Parameter Priorities* Panel



in combination with *Autocalculate options* is essential prior to and after *Verify films* and *Run Model* operation. This is to ensure that the non-QW films are interpreted correctly by the Intellevation OM. This is covered in more detail in Section 1.18 of this manual.

Showing and hiding columns

A screenshot of a grey rectangular control box. At the top left of the box is the text "Show columns" in a bold, dark blue font. Below this text are two vertically stacked checkboxes, each followed by a label. The first checkbox is unchecked and is followed by the text "derived from Materials". The second checkbox is also unchecked and is followed by the text "derived from Model".

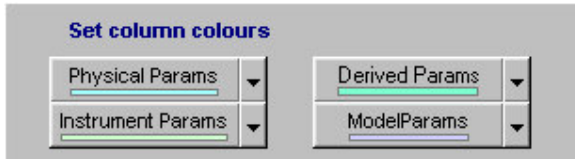
Show columns

☐ derived from Materials

☐ derived from Model

Two sets of columns in the *BUILD FILMS* main grid are hidden by default, those derived from materials and those derived from a model. To view these columns, use the *Show columns* check boxes at the top right of the form.

Select column colours

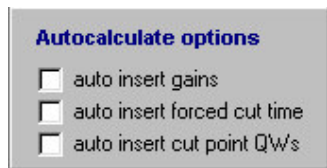


Use the colour picker buttons on this panel to select background colours for different types of film parameters.

When the down-arrow is clicked, a colour selection palette will open, and the colour selected will be applied as a background colour to all the columns of that parameter type in both *BUILD FILMS* grids and the *Default Values* grid.

The colours selected will be saved automatically with the project.

A1.13 Autocalculate options



Auto insert gains:

During modelling, the default behaviour of **FilmMaker** is to calculate the correct gain for use during the deposition of each film, and write it back into the main data grid. If you wish to preserve any gains which you may have inserted, uncheck the *auto insert gains* checkbox.

Auto insert fixed cut time:

During verification, the default behaviour is to calculate the process run time for each film, and writes a value of 2.0 times this value into the timeout parameter *ForcedCutTime*. This avoids the frustration of having a process-run time-out inadvertently. However, if you wish to exactly prescribe the cut time, eg if you intend to terminate on time rather than optically, then unchecking the *Auto insert cut time* checkbox will enable you to do this.

Auto insert cutpoint QWs:

During modelling, the default behaviour of **FilmMaker** is to leave the *CutPoint QWs* parameter of the main grid unchanged. However, if the *auto insert cutpoint QWs* checkbox is checked, a new set of *CutPoint QWs* parameters are calculated suitable for interpretation by optical monitors that use integral turning points to estimate film thickness.

Software Version 1.0.2 enhancements

Enhancement of Modelling Capabilities

Multiple test glass modelling

The model can now handle those cases where multiple test glasses are being used during a coating run. It correctly interprets the insertion of any number of new test glasses during the process, as well as the situation where test glasses used earlier in the process are reinserted at a later point. This works over and above the possibility of changing probe wavelength on a film by film basis.

Correction for OMS interpretation of films not starting at a turning point

For fractional quarter-wave work, starting a film other than on a turning point has been a problem up till now, as the analysis algorithms start counting thickness after the first turning point encountered, whilst the model uses the true thickness. The thickness of the film following a fractional quarter-wave cut, therefore, has to be adjusted to allow for this. The new modelling software, if requested, will make this calculation for you.

Minor Enhancements

- The default value that is written to the *ForcedCutTime* during *Verify films* has been increased to twice the process run time.
- The film stack can be exported to, and imported from Excel.
- The model derived parameters can be exported to a csv file.

You can now locate the folder associated with a project using *Project Show Path...*

*NB: This version uses a new format for the films database. Projects created with earlier versions of **FilmMaker** can be converted to this new format using the main menu pick *Project/Update Old**

Software Version 1.0.3 enhancements

Support for CurveFollower analysis mode:

This advanced analysis mode will be used by the new releases of FilmDirector. It provides superior accuracy when monitoring non-QW designs on the one witness. Both **FilmSimulator** and **FilmReviewer** are now curve-follower aware.

Change in the way sample rate is handled:

Previous versions used a Rotation parameter to specify the sampling rate of the system. Whilst, this makes sense when monitoring a witness on a rotating carrier, as is done for WDM applications, it is not true of a lot of other precision optical coating applications. To this end, we have renamed the Rotation parameter SampleRate. The units have been changed from rpm to Hz, and all internal calculations have been adjusted. If you load a project built in an earlier version of **FilmMaker** you will receive a notification that the units are changing, and then the system will convert the old rpm figures to Hz.

Import Design from CSV

A flexible csv file import function has been added. This allows designs generated by third party software to be loaded into **FilmMaker**.

Software Version 1.0.4 enhancements

Version 1.0.4 addresses a few minor bug fixes, but, from the user point of view, brings no major changes over Version 1.0.3. However, this new version implements underlying structural changes that have been made to support on-going development.

Software version 1.0.5 enhancements

Further Support for Non- QW Designs:

Hitherto, the turning point counting analysis modes (all modes except *Curve Follower*) have estimated fractional QW thickness by linear interpolation between turning points. For all optical monitoring profiles, this leads to substantial systematic error, especially with values close to the integral QWs. This software release solves the foregoing problem by utilising the monitor curve shape predicted by the model when it interpolates between turning points. Provided the process follows that modelled, then systematic errors for any fractional QW estimate are now less than 0.2% of the fractional part.

QW factor

A new column *QW Factor* has been added to the main grid. This number allows the design *CutQWs* figure to be adjusted by some user calculated factor. By this means it is possible to factor-out systematic errors due to the filter, poor shape fit and so on.

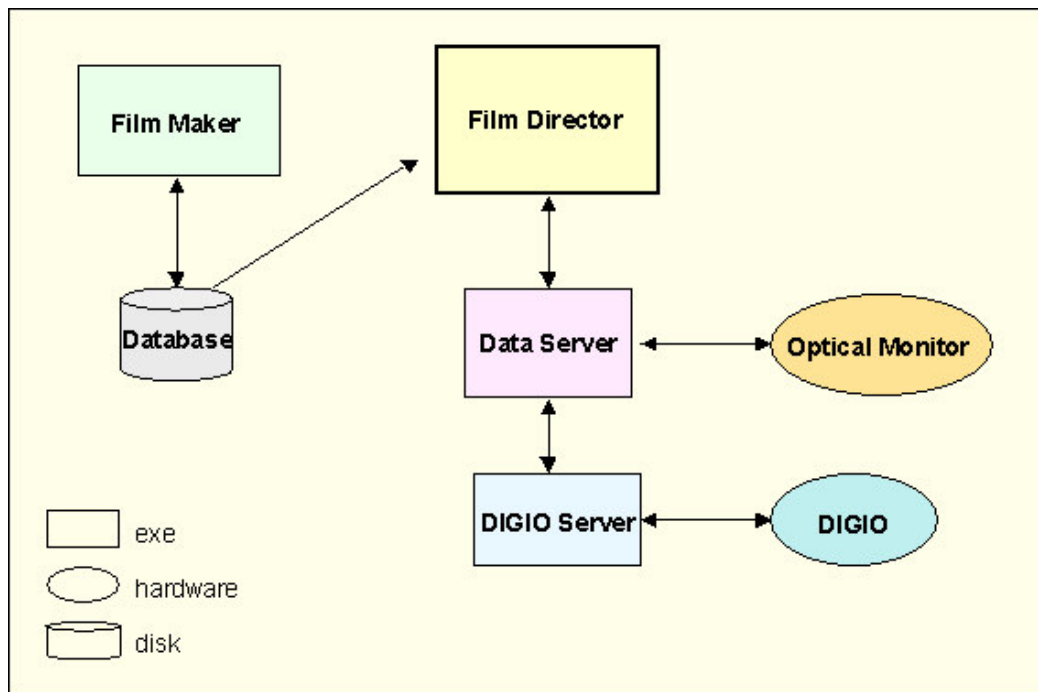
Appendix B: *FilmDirector* software programming guide

B1.1 Overview

FilmDirector controls the operation of the optical monitors used by precision optical coating processes. It uses information stored in a database to set-up the instrument parameters of the optical monitor. This it does on a layer by layer basis. It also processes the signal returned by the optical monitor and, guided by parameters loaded from the database, will send a cut signal to the process controller when it determines a given layer has reached target thickness.

FilmDirector requires two other elements of software in order to function, namely, a hardware data server and a film-stack database. The first is a program, which encapsulates the optical monitor hardware implementation being used, is started automatically by **FilmDirector**, and normally runs in the background. The second is a database which contains a comprehensive design and build specification for the filter being manufactured. This is normally output by a package like **FilmMaker**.

A typical installation is illustrated below.



In this example, **FilmMaker** is used to load a design, verify its integrity and calculate the instrument parameters that the optical monitor will require.

FilmMaker can then be closed because all that is needed is now in the database.

When **FilmDirector** starts, it also starts the hardware data server, which in turn starts a digital I/O server that provides access to the hardware digital input-output lines which, in turn, provides communication with the main process controller. The hardware data server sets up the optical monitor hardware and verifies that it is functioning correctly. The user connects **FilmDirector** to the database by loading the project just created by **FilmMaker**.

When driven by the process controller, the commands appearing at the digital I/O interface cause **FilmDirector** to proceed stepwise from one film to the next, fetching the next set of instrument parameters as required, until the entire stack has been built. This orderly sequencing is one of the main roles performed by **FilmDirector**, and is formally defined in the section on the Sequencer.

The other major role carried out by **FilmDirector** is detection of a cut point condition. To do this, **FilmDirector** employs an identical analysis engine to that used by **FilmMaker**. Projects set up and verified in **FilmDirector** are transferred in their entirety when they are loaded into **FilmDirector**.

<p>There is no provision for altering parameters once they have been loaded.</p>

The data from process runs can be saved and reprocessed in **FilmMaker** with a view to improving cut point precision.

B1.2 Getting Started--Projects and Processes

Projects and processes have special meanings within **FilmDirector** - **Project** refers to the **FilmMaker** project that **FilmDirector** will use. It is the name of a database which describes a film stack.

Process refers to a name, which **FilmDirector** will associate with a given process run. It is a single file, but you should be aware that **FilmDirector** would use this name as the basis for the other process related files it will produce. It maintains the status of a process, and contains such information as the name of the associated project and the current film being processed. Processes can be reloaded so that they start from the first film, or so that they continue at the film following that when the process was stopped. Though not obligatory, it is recommended that you place every new process in a new folder.

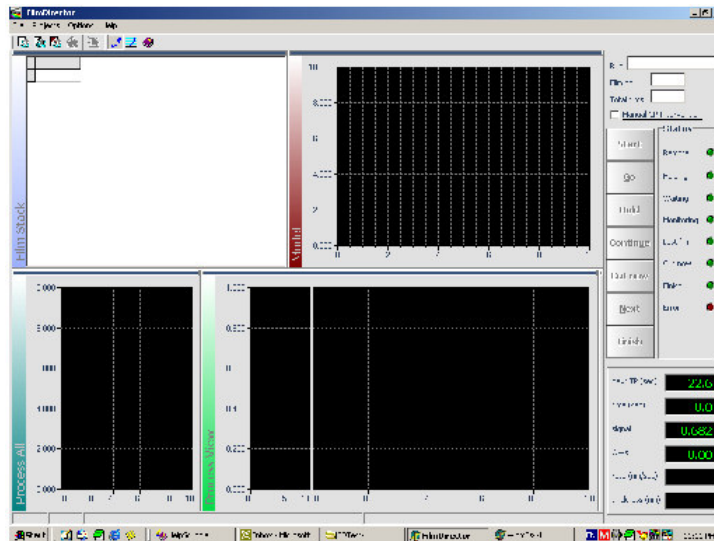
Is There a Valid **FilmMaker** Project Available?

If you have not yet created a **FilmMaker** project, do that now. Open **FilmMaker** and follow the online help. Make sure the project has been verified and modelled before closing **FilmMaker** and proceeding.

Now Start **FilmDirector**:

In the Windows start-up menu, click **Programs** then **FilmDirector** to start the application. If **FilmDirector** has never been run before, the desktop will be empty. Clicking the thin blue line at the top of each panel will display the sub-window menu. From this menu you can choose one of several possible display windows. See Operating Sub-windows for details. Select the *Film stack* window for the top left hand panel, and then open the *Model* window to the right of that. At the lower left open the *Process All* window, and to the right of that the *Process View* window. Use the vertical splitter to push the unused far right window out of sight. Note that this window arrangement will be preserved next time **FilmDirector** starts, but you are not committed to it in any degree, and windows can be closed, opened, and rearranged at any time during the process.

At this stage your desktop should look something like the following -



Are the Servers Running?

Film Director needs to have the data server running before it can function. This will happen automatically when **Film Director** is started. In addition to the data server, it is likely that a digital I/O server will also be running. If they are, you will see the following icons displayed in the system tray.




You don't need to set up the digital I/O server until such time as you wish to control **Film Director** externally from the main process controller.

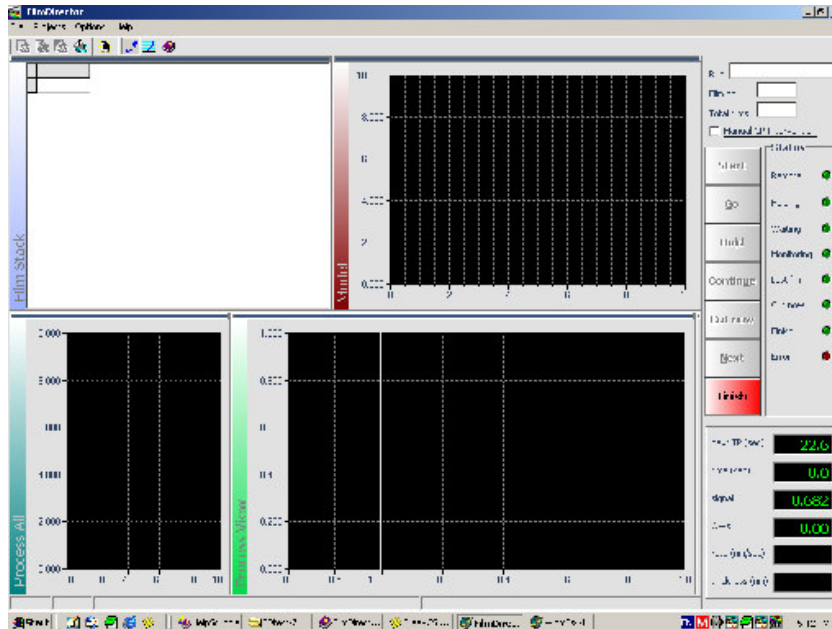
However, the data server will need to be set up and should be producing valid data before attempting to proceed


Click on the data server's icon to open it, then make sure the optical monitor is functioning correctly. Refer to its online help if necessary.

Start a New Process:


Click  on the toolbar to open the select process directory dialog. Choose the option to create a new folder. Name it *FD-Test*, and click OK. Enter *Test1* for the name of the process when prompted by the next dialog, and then OK. For a more detailed description see, Creating a new process.

At this stage your desktop should look something like the following -

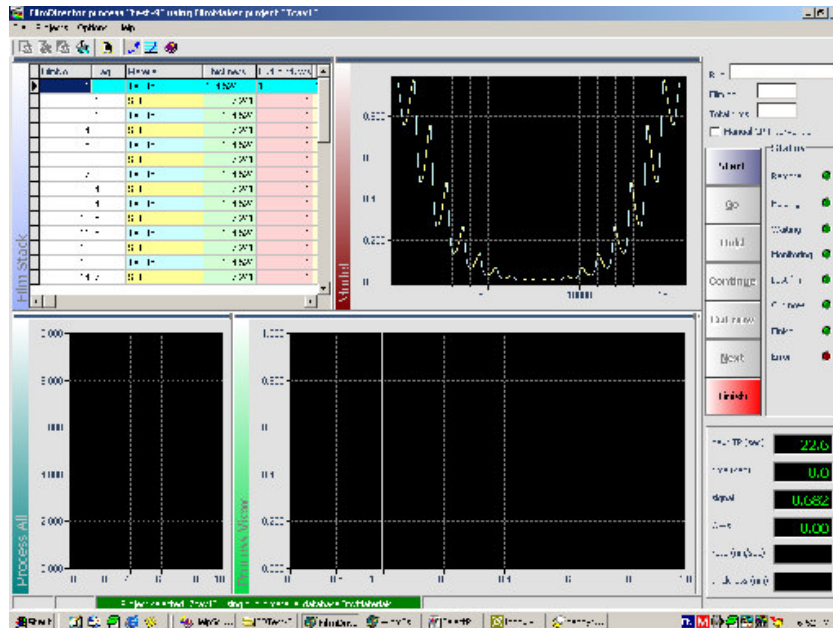


You will note that the **Finish** button on the control panel is now enabled. This is so that you can abort the process at this early stage, and close the application should you need to. Of greater importance is the fact that the load project icon  is now enabled, and we can proceed with associating a **FilmMaker** project with the new process.

Load a Project

Click on the load project icon  to open the select project dialog. Here you will see all the **FilmMaker** projects registered with this PC. Select the one you wish to use and click OK. For a more detailed description see Opening a **FilmMaker** project.

At this stage your desktop should look something like the following -



Four things should have happened -

The film stack window should be showing the loaded project in much the same way as it is in **FilmMaker**. If you attempt to change any of the displayed values, you'll find that this cannot be done. *This is a read-only data display.* However, the cursor can be moved around the display in an identical manner to within **FilmMaker**. Also if you right click on the window you'll see that some of the display options available in **FilmMaker** have been made available here. For more information see Film stack window.

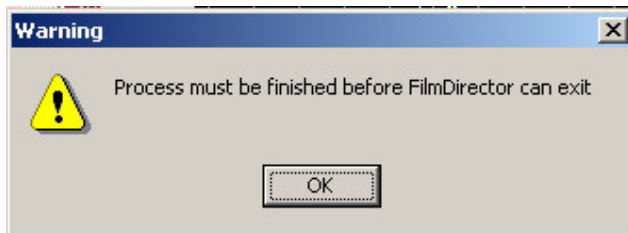
The model window should be showing the model data calculated by **FilmMaker**. Note that the material colours assigned in **FilmMaker** are carried over to **FilmDirector**. Right clicking the window will bring up extensive options for zooming and panning the display. For more information see Model window.


The process name, and the project it is using, now should be showing in the main window title bar. Also, if the project loaded correctly, there will be a message in the status bar at the bottom of the main window to that effect.

The **Start** button in the control panel should be enabled indicating **FilmDirector** is ready to run.

Closing a Process:


At this stage **FilmDirector** is ready to run the process, but, before we do that, it is worth considering the state that **FilmDirector** is now in. If, for example, you decide to close **FilmDirector** in order to do something else, you will get the following warning dialog -




What this means is that **FilmDirector** won't let you leave the program until it is in a finalized state. You can press the **Finish** button on the control panel, or use the **process close** button  on the tool bar to the same effect. The current process context will be stored, and both process and project data will be unloaded as can be seen by the appearance of the **FilmDirector** desktop. Now you can exit the program without problem. See Closing a process for more details.

Re-opening a Process

Having closed the process, how can we re-open it? The tool bar offers two different ways in which this can be done -

the **restart existing process** button  loads the process for starting at the first film.

the **open existing process** button  loads the process for starting at the next film after that at which it the process was closed.

Because we have never run the process, it doesn't matter which one we choose, so click the restart icon , select a file, and we should be back to the **FilmDirector** desktop state we had earlier with the project loaded and the **Start** button enabled. See Continuing a process which has been interrupted and Restarting a process from the beginning for more details.

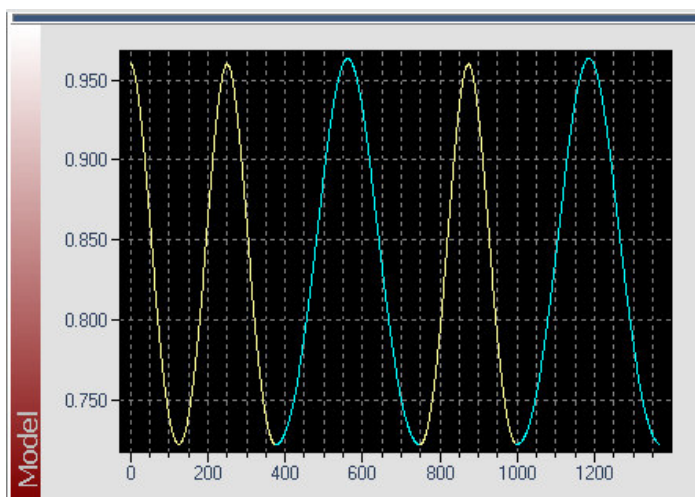
B1.3 Start the Process:

For purposes of illustration we will follow the deposition of a number of quarter waves of Tantalum Oxide alternating with Silica on a glass substrate, monitoring the process in transmission.

The project we are using can be seen in the film stack window. The current film marker (magenta) is on the first film, and the last film marker (red) is on the fourth and last film.

FilmNo	Tag	Material	Thickness	CutPointQWs	Pr
1		Ta2O5	187.5	3	55
2		SiO2	185.811	2	
3		Ta2O5	125	2	
4		SiO2	185.811	2	55

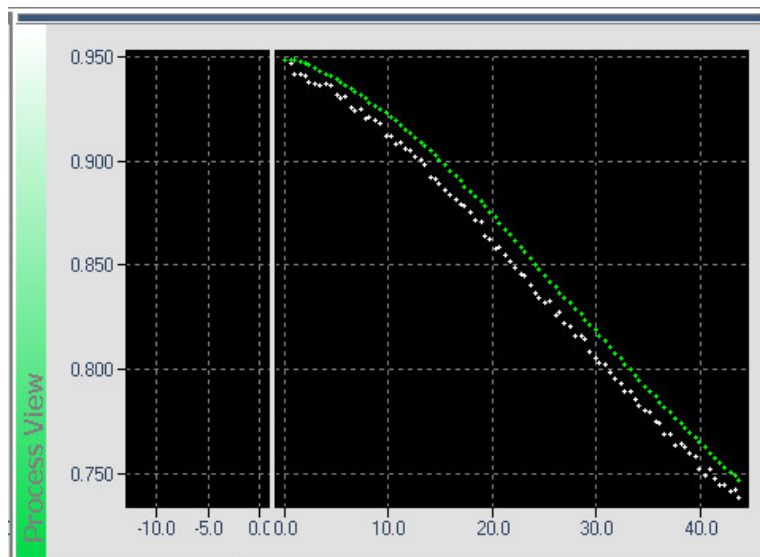
The model derived from the project can be seen in the model window. An initial three QWs of Tantalum Oxide are followed by alternating half waves of silica then Tantalum Oxide.





1. We are assuming the process will be run manually, so we start by clicking the **Start** button. The **Waiting** LED on the control panel will begin flashing and all buttons will be temporarily disabled as the optical monitor is moved to the monitoring wavelength for the first film, as gains are set, and so forth.

2. When the optical monitor is ready to proceed, the **Go** button is made active. At this point **FilmDirector** is waiting for the process controller to signal that the shutter has been opened and deposition is under way. We can do this manually by opening the shutter and immediately clicking the **Go button**. On doing so, the Monitoring **LED** will begin to flash indicating data acquisition has commenced, and the data will appear in the right-hand pane of the process-view window. The digital displays in the control panel also begin to update, with the run time, the current signal, and an estimate of the thickness deposited in units of quarter waves. The other displays are pertinent to certain of the analysis modes and will remain blank except for when a particular mode is employed. See Control panel for more details.

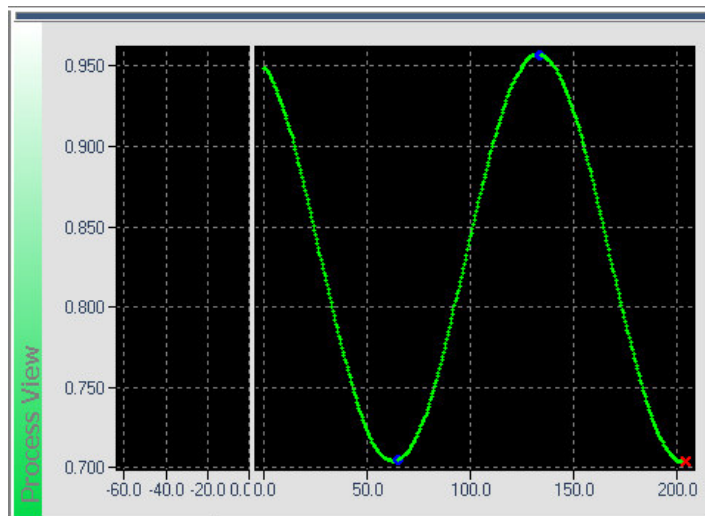
3. Depending upon how various options have been set, you will see something like that shown below.



In this particular case we see two traces separated by a small time lag. The white trace is the unfiltered data, and the somewhat delayed, green trace is the filtered data. The amount of filtration and thus lag depends upon the value entered for the layer in **FilmMaker**. See **FilmMaker** help for details of how to apply filtration to the signal. You can turn the display of either signal on or off as you wish using the  or  buttons on the tool bar. Note these buttons have immediate effect on the entire trace up to the current point.

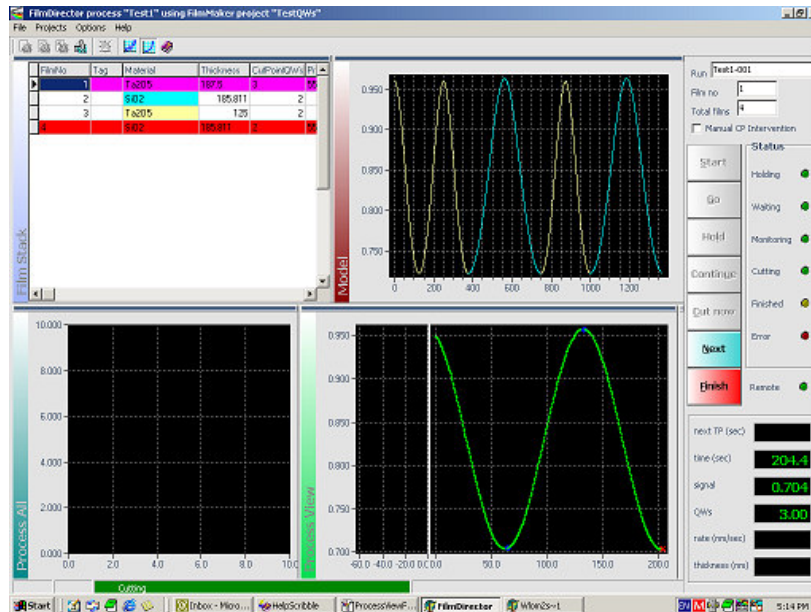
At this point ignore the left hand pane of the process-view window. Simply note that the vertical bar can be used to set the relative size of the two panes.

Turn off the unfiltered trace, leaving the filtered data showing. As the deposition continues and the signal crosses a turning point, the latter will be marked with (in this case) a blue dot. On the third turning point, the analyser will cut the deposition, and mark the event with a red cross (in this case) on the trace. If **FilmDirector** has not been set up for automatic operation, the transition to the cutting state will still occur, but the operator will have to close the shutter manually.



There are a number of preferences such as the chart colours which the user can freely alter, even when the process is running. These preferences are automatically saved for when **FilmDirector** next opens. For more details see Process view window.

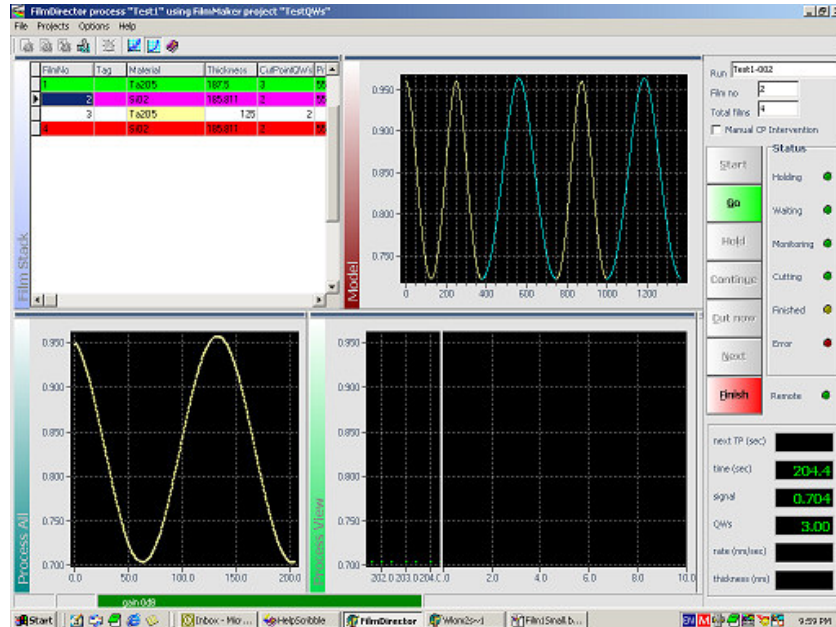
4. After cutting the **FilmDirector** desktop looks as follows –



The status of the desktop is maintained until the **Next** command is received. So the digital displays on the control panel show that we are still on film 1 of 4, that the thickness is 3.00QWs and that the run time is 204.4 seconds. However, no status LED's are lit, and the Next button is enabled showing we are simply idling waiting for the **Next** command.

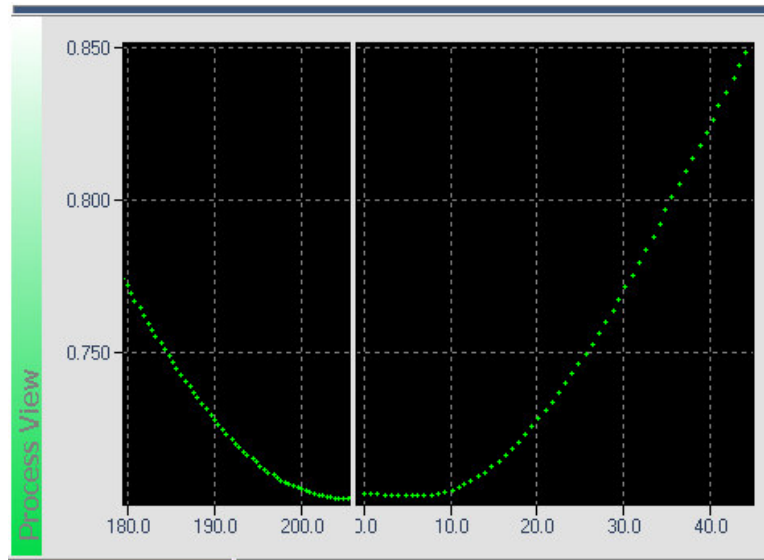
5. In the case of an automatic system, the process controller would now issue a **Next** command. In manual mode, we simply click the **Next** button. On doing so it will be noted **FilmDirector** indexes its status to the next film in the database. The current film marker in the film stack window moves onto film 2, the signal plot from the last film is removed from the right-hand pane of the process-view window and appended to the data in the process-all window. In this case, it is the only data in that window. Note that only filtered data is shown in the process-all window, and note also that it is colour-coded according to the material colours that were assigned in the **FilmMaker** project.

All buttons are disabled, and the **Waiting** LED starts blinking as the optical monitor moves to the new wavelength, and sets the new gain required for this film. It also emits the number of the material to be used for this layer at the DIGIO. When the optical monitor is ready, the **Go** button is enabled, and **FilmDirector** waits for the system controller to indicate it is ready by issuing the **Go** command.

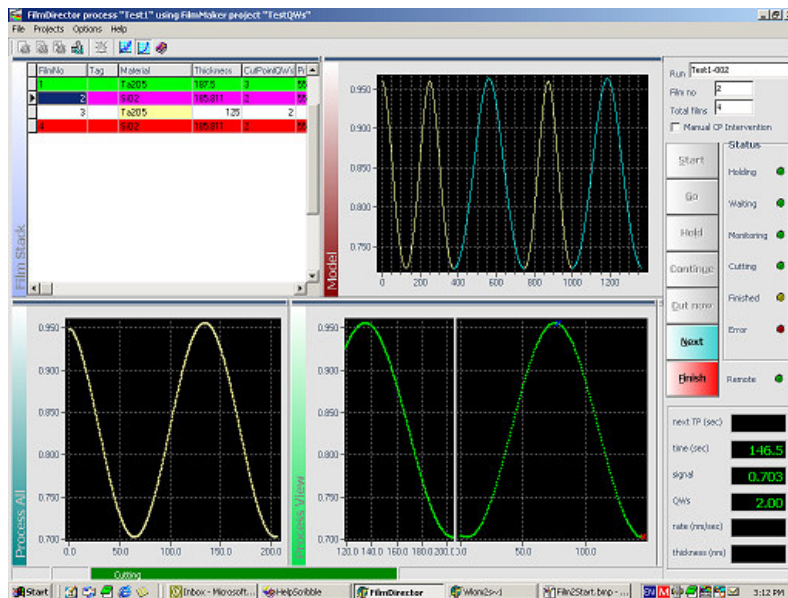


6. From this point onwards, deposition of the next layer proceeds much like the last. The system controller opens the shutter to begin deposition and simultaneously issues a **Go** command, or, we can manually open the shutter and click the **Go** button on the control panel. On doing so, the **Monitoring** LED will begin to flash indicating data acquisition has commenced, and the data will appear in the right-hand pane of the process-view window.

The digital displays in the control panel also begin to update, with the run time, the current signal, and an estimate of the thickness deposited in units of quarter waves. However, there is one difference, the final portion of the last signal trace is showing in the left hand pane of the process-view window, and as the right-hand active trace auto scales, so the scaling of the last trace is adjusted. This allows you to judge how well the current layer has built upon the last one deposited. In this particular example we can note a small anomaly at the start of deposition of the current film as if the deposition proper was slightly slow in commencing.

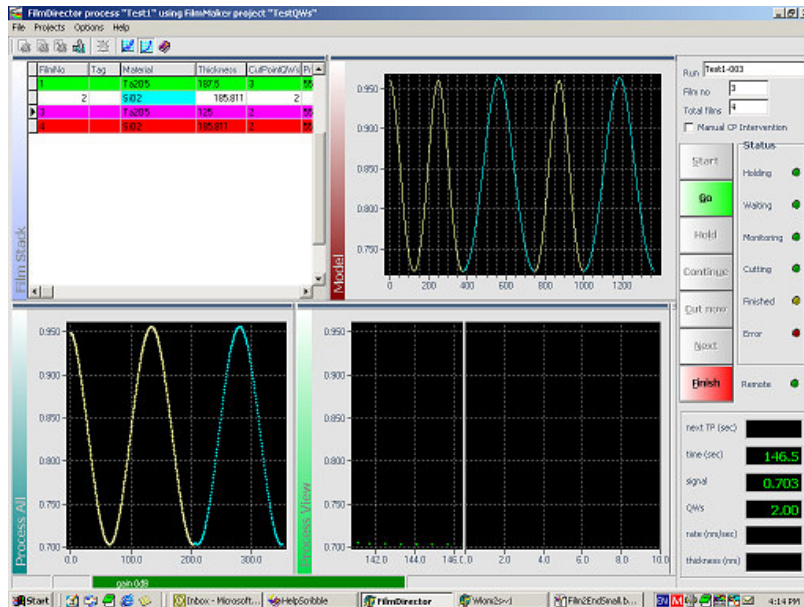


7. In our example, deposition of silica continues for two quarter waves before being cut by the analyser. Now the desktop will look like the following -

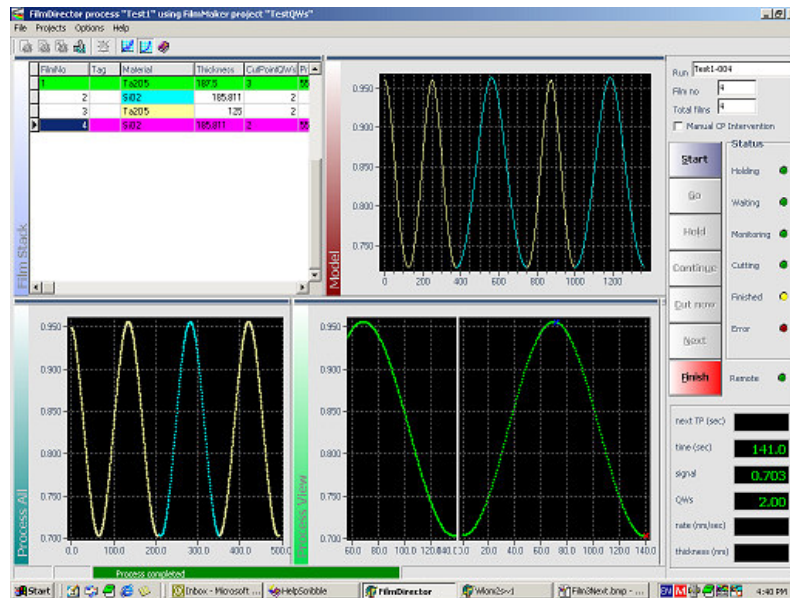


The digital displays show a run time of 146.5 seconds, and a thickness of 2.00 quarter waves. The signal trace is still in the right-hand pane of the process-view window, while the left hand pane holds the final portion of the previous film's data. The process-all window holds the trace for film 1. However, no status LED's are lit, and the Next button are enabled showing we are simply idling waiting for the **Next** command.

8. Clicking **next** loads film 3 from the database. So as we have already seen, film 2 data is cleared from the right-hand pane of the process-view window, and appended, suitably colour coded, to the data in the process-all window. The final section of it is plotted into the left hand pane of the process-view window. The current film marker in the film stack window is moved on, the **Waiting** LED starts to blink, and the optical monitor is instructed to move to its new values of wavelength and gain.



9. Films 3 and 4 are deposited in the same manner as already described for films 1 and 2. When the final film is cut, however, **FilmDirector** holds the display status for the last film, but is in fact ready to repeat the entire build from the start. This is signified by the fact the **Finished** LED is flashing, and the **Start** button is enabled.



Notice that the process-all window now contains the data for all films but the last. If the process has built the stack faithfully, then the data in the process-all window should mirror that in model window. The process-all window has a right click menu that allows you to zoom and pan the data, copy it to clipboard and so forth. For more information see Process All window.

B1.4 Toolbar



Creates a new process, equivalent to **File New Process**



Opens a previously interrupted process for continuation, equivalent to **File Open Process**



Opens an existing process ready to restart at the beginning, equivalent to **File Restart Process**



Closes the current process if it hasn't yet completed, equivalent to **File Close Process** or Control panel **Finish** button



Use to select a **FilmMaker** project for a new process, equivalent to **Projects Open**



Select to view raw data in the *Process View* window, equivalent to **Options View Data Raw Data**



Select to view filtered data in the *Process View* window, equivalent to **Options View Data Filtered Data**

B1.5 Control panel

Click on the pictures below for more information.

Run:

Film no:

Total films:

☐ Manual CP Intervention

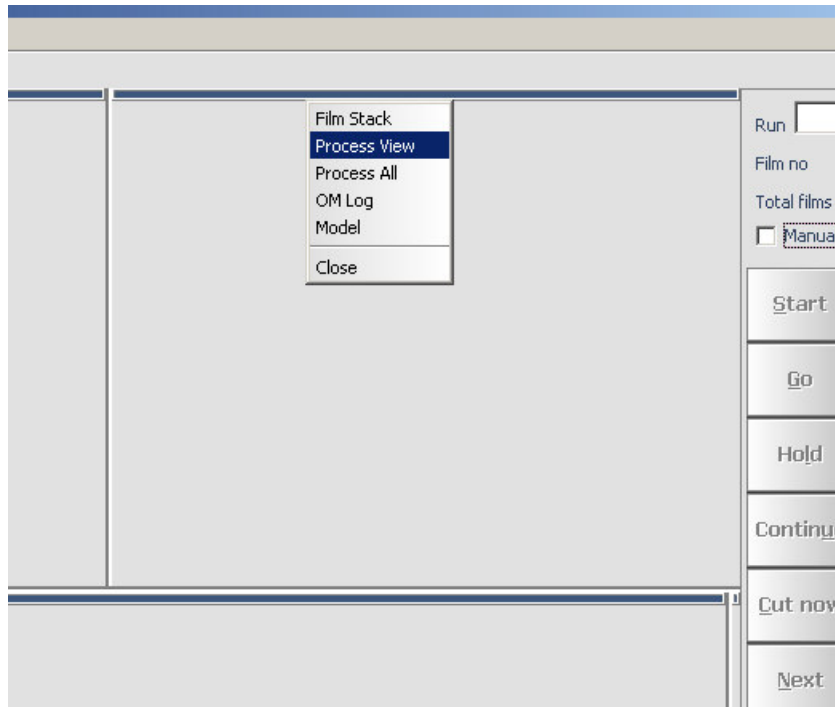
Status	
Start	Holding ●
Go	Waiting ●
Hold	Monitoring ●
Continue	Cutting ●
Cut now	Finished ●
Next	Error ●
Finish	Remote ●

next TP (sec)	<input type="text" value=""/>
time (sec)	209.7
signal	0.702
QWs	3.00
rate (nm/sec)	<input type="text" value=""/>
thickness (nm)	<input type="text" value=""/>

B1.6 Operating Sub-windows

The **FilmDirector** desktop consists of the Control Panel on the right, plus five panels which can be resized by means of the vertical and horizontal splitters, and into which any of the available **FilmDirector** sub-windows can be opened.

Click on the relevant parts of the picture below to get more information.



FilmDirector remembers which windows were open and their relative sizes and positions for next time the application is opened.

The user is free to open or close a sub window at any point whatsoever. For example, plotting sub-windows like the process view window does not have to be open at the start of a process to show all the data acquired. It can be opened or shut freely during the deposition of a film without any impact on the final cut point. When opened it will always show the complete up-to-date picture.

Thus for any sub window, the functionality that it represents is always in place and active even if the window itself is closed.

B1.7 Preferences applicable to all sub-windows

All sub-windows have a right click menu, which provides access to a number of user preferences specific to the particular window.

However, all sub-windows have the following user options in common.

Each sub-window has a coloured sidebar so that it can be identified at a glance. The following properties can be changed using the pop-up menu on each form (right mouse-click)

Visibility Select **Preferences Sidebar Show**

Colour Select **Preferences Sidebar Colour**

Font colour Select **Preferences Sidebar Font Colour**

B1.8 Filmstack window

FilmNo	Tag	Material	Thickness	CutPointQW's	ProbeWavelength	Depos
1	1	Ta2O5	184.524	1	1550	1.8
2	1	SiO2	267.241	1	1550	
3	2	Ta2O5	184.524	1	1550	
4	2	SiO2	267.241	1	1550	2.1
5	3	Ta2O5	184.524	1	1550	
6	3	SiO2	267.241	1	1550	
7	4	Ta2O5	184.524	1	1550	
8	4	SiO2	267.241	1	1550	
9		Ta2O5	184.524	1	1550	
10	cav	SiO2	1068.97	4	1550	
11		Ta2O5	184.524	1	1550	
12	1	SiO2	267.241	1	1550	
13	1	Ta2O5	184.524	1	1550	
14	2	SiO2	267.241	1	1550	
15	2	Ta2O5	184.524	1	1550	
16	3	SiO2	267.241	1	1550	
17	3	Ta2O5	184.524	1	1550	
18	4	SiO2	267.241	1	1550	

FilmMaker functionality

The film stack window replicates the one used by **FilmMaker** with the one exception, it is a read-only display. The display enhancements such as material colours and column colours are all inherited from the **FilmMaker** project. As are the options for the display of column data.

Cursor navigation is the same as for **FilmMaker** -

- arrow up/down, left/right moves the cursor one cell
- home/end moves the cursor to the extreme left hand or extreme right-hand cell
- ctrl home/end moves the cursor to topmost or bottommost cell
- pageUp/pageDown scrolls the contents by one window's worth

Cut and paste is not available, and if you need a copy of the stack for documentation, it is recommended you use **FilmMaker**'s export to Excel capability.

FilmDirector functionality

The film stack window marks three films as deserving of special attention by colouring them differently to the rest. These are the **First Film**, the **Last Film** and the **Current Film**. In the example illustrated above, the First Film is coloured green, the Current Film is coloured light blue and the Last Film is not shown.

The Current Film colour is used to indicate the film currently being deposited by the process. However, that's where the similarity ends. The First Film is not necessarily the first film in the stack, nor is the Last Film the last, although, by default, these associations are the ones made when a project is loaded. Before the process is actually started, the user has the possibility of selecting start and end points anywhere within the stack so as to run the process for a limited number of layers. You can access the First and Last Film edit options from the windows right click menu.

Film stack window preferences

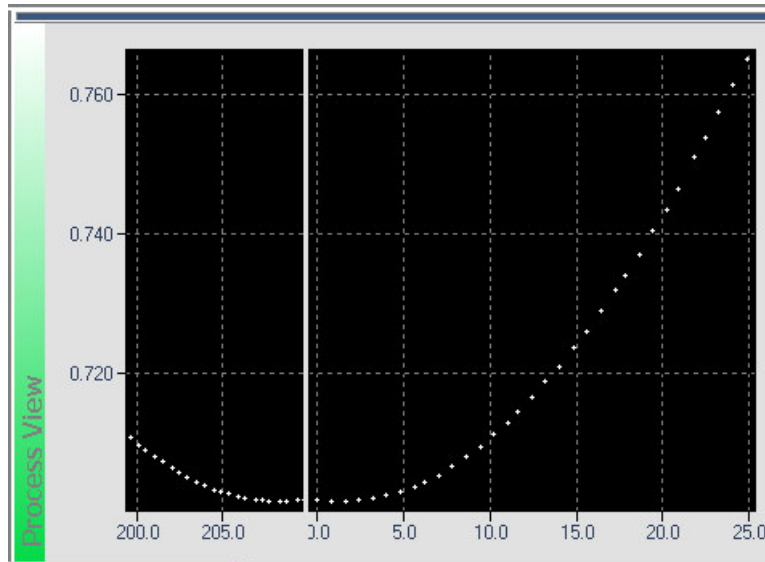
Apart from the preferences common to all sub-windows, see operating sub-windows, the right click menu permits the setting of the following user preferences -

include/exclude data columns derived from the materials database

include/exclude data columns derived by **FilmMaker**'s modelling engine



- set the colour of the First Film
- set the colour of the Last Film
- set the colour of the Current Film

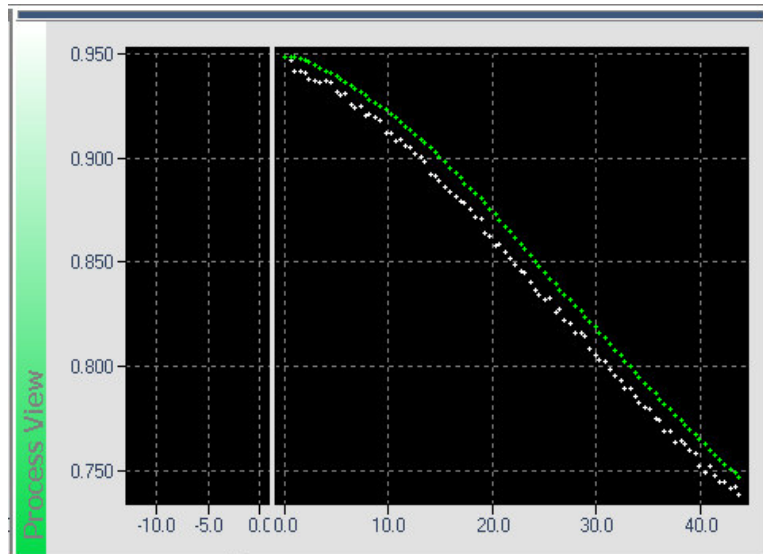
B1.9 Process View window



The process-view window provides two independent graphs placed side by side. In the right-hand pane is plotted the data from the film currently being deposited. In the left hand pane is plotted the final section of the preceding film. The scaling is chosen so that the two plots can be juxtaposed with a view to estimating how well the termination of the preceding film and the start of the new film has been accomplished. Process related issues, such as substrate temperature shift on switching materials, might well be highlighted by this method of display. Likewise, with a quarter-wave stack, process problems become very obvious when one quarter-wave fails to meld seamlessly into the next at material changeover.

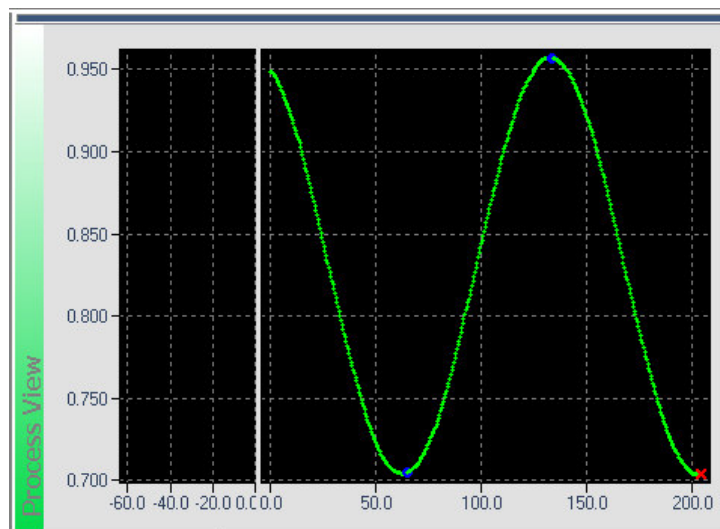
When the mouse is placed over the vertical bar between the panels, the cursor will change to indicate that the bar can be dragged with a left click, thereby altering the relative sizes of the two panels. The user is free to resize the two panels even while data is being acquired to the graph. The position chosen will be remembered next time **FilmDirector** opens.

The process-view window can show two signal streams in the right-hand pane, but only one in the left. Depending upon the toolbar buttons  and  either or both the raw and filtered data can be displayed in the right-hand pane. The left hand pane, however, only shows the filtered data. The following picture illustrates the two data streams running in the right-hand pane.



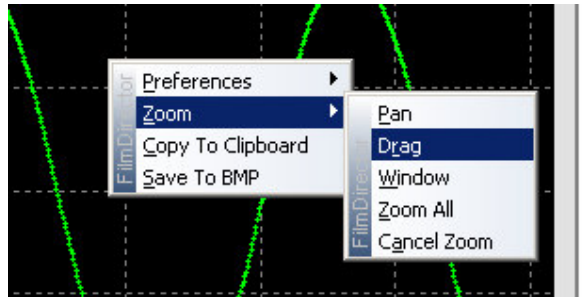
The position of turning points and the cut point determined by the analyser are plotted in the right-hand pane as they are encountered. They are positioned with reference to the filtered data stream and **will be visible only if filtered data is being displayed.**

The following picture shows a filtered data stream with the turning points marked in blue and the cut point in red.



Zoom and pan functions

The right-click menu has an extensive range of zoom and pan functions. Note that because the scaling of the left hand and right-hand panels is linked, zoom operations acting on one will affect the other. Note also that **when actively acquiring data, auto-ranging algorithms are operational, and will overrule any user scaling activity**. However, if you wait until the end of the run you can freely rescale the data using zoom and pan.



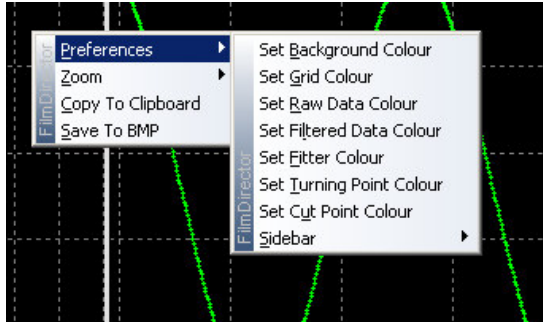
- zoom **pan left**, clicks and drags to move the plot within the window
- zoom **drag left**, clicks and drags to continuously scale along any axis
- zoom **window left**, clicks and drags to drop a zoom-to marquee
- zoom **zoom all**, **fits** the data to the window
- zoom **cancel zoom**, **cancels** zoom mode for the window

Copy functions

The right click menu has options to save the plot in either pane to clipboard or *.bmp file.

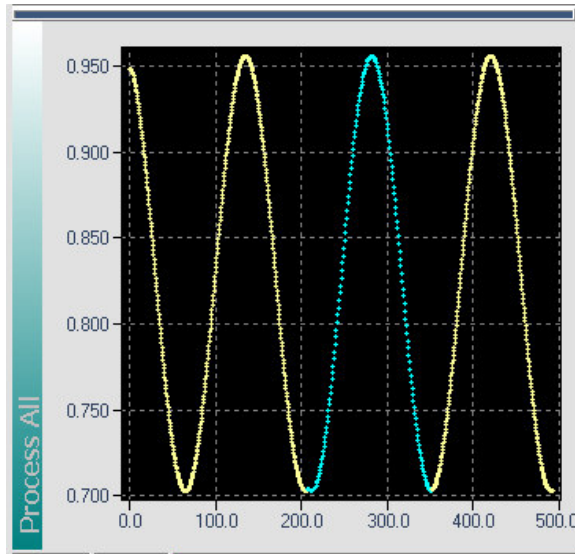
Process-view window preferences

Apart from the preferences common to all sub-windows, see operating sub-windows, the right click menu permits the setting of the following user preferences -



- set the background colour of both left hand and right-hand panes of the window
- set the colour of the grids of both left hand and right-hand panes of the window
- set the plot colour used for raw data
- set the plot colour used for filtered data
- set the plot colour used for the fitted parabola (fitter-1 and fitter-2 analysis modes only)
- set the colour used for the turning point
- set the colour used for the cut point

B1.10 Process all windows

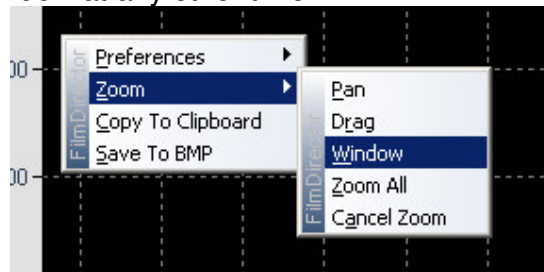


This window displays the data acquired for all films processed thus far, but does not include the film currently being deposited, or, if deposition has just ceased, the most recent film. Each film's data is coloured according to the materials colours allocated in **FilmMaker**.

The data in the process-all window should faithfully mirror that in the model window if the build has run according to the specification provided in **FilmMaker**.

Zoom and pan functions

The right-click menu has an extensive range of zoom and pan functions. Note that when running, **auto ranging algorithms are operational, and will overrule any user scaling activity**. However, these don't normally operate except when a **Next** command is processed, so you can freely zoom and pan this window at any other time.



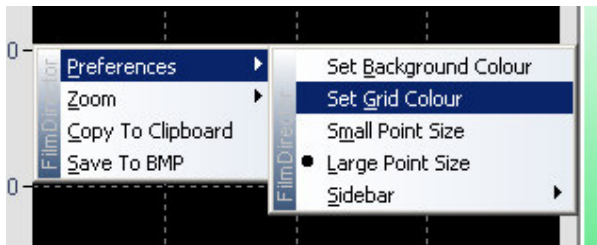
- Zoom pan; left click and drag to move the plot within the window
- Zoom drag; left click and drag to continuously scale along any axis
- Zoom window; left click and drag to drop a zoom-to marquee
- Zoom all; fits the data to the window.
- Zoom cancel zoom; cancels zoom mode for the window

Copy functions

The right click menu has options to save the plot to clipboard or *.bmp file.

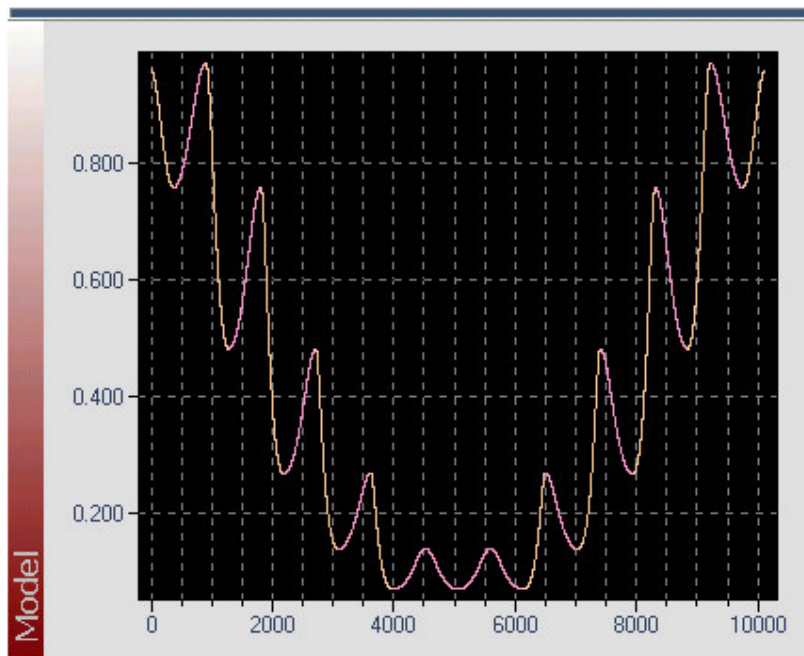
Process-all window preferences

Apart from the preferences common to all sub-windows, see operating sub-windows, the right click menu permits the setting of the following user preferences -



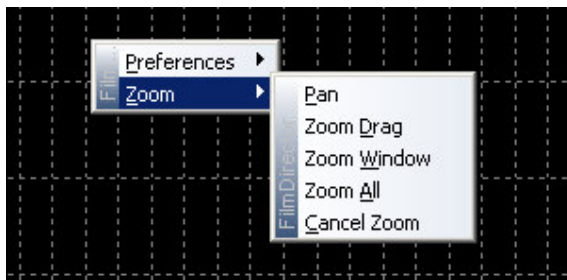
- Set the background colour of the window
- Set the colour of the grids of the window
- Set the point size used by the plot

B1.11 Model window



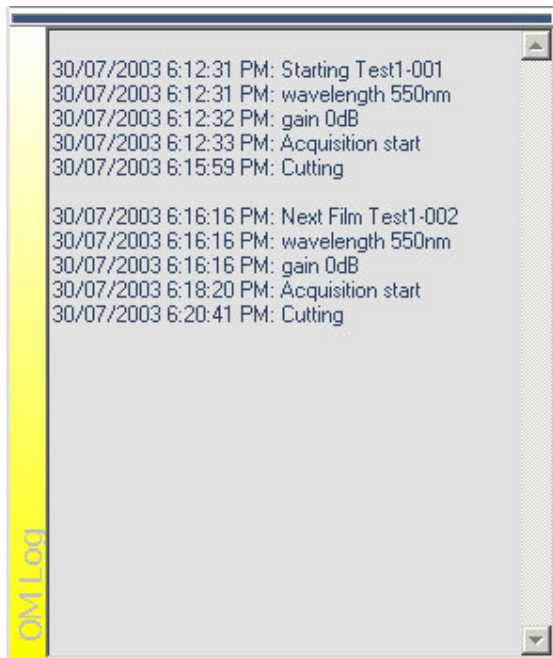
The model window displays a model of the progress of the optical signal as calculated by **FilmMaker** for the loaded project. Material colours assigned in **FilmMaker** are carried over to **FilmDirector**. *Note that this data has been created by **FilmMaker**, so if you wish to make changes to, say, the substrate RI or the model step size, this would have to be done in **FilmMaker** and the project reloaded into **FilmDirector**.*

The right click menu provides for the setting of preferences common to all sub-windows, see Operating sub-windows, and in addition, provides extensive zooming and panning capability.



- Zoom pan; left click and drag to move the plot within the window
- Zoom drag; left click and drag to continuously scale along any axis
- Zoom window; left click and drag to drop a zoom-to marquee
- Zoom all; fits the data to the window
- Zoom cancel; cancels zoom mode for the window

B1.12 Process log




As **FilmDirector** goes through the sequences involved in the deposition of a film stack, it notes the principle activities in the log. It does this regardless of whether the log window is open or not. When the log window is opened, the log for the process complete up to the current film is displayed. Thus you don't have to maintain an open log window if you want the desktop space for something else.

When a process is finished, the log is written to a log file, and can be access with a normal text editor like NotePad. The log file will be found with the other files pertinent to the particular process

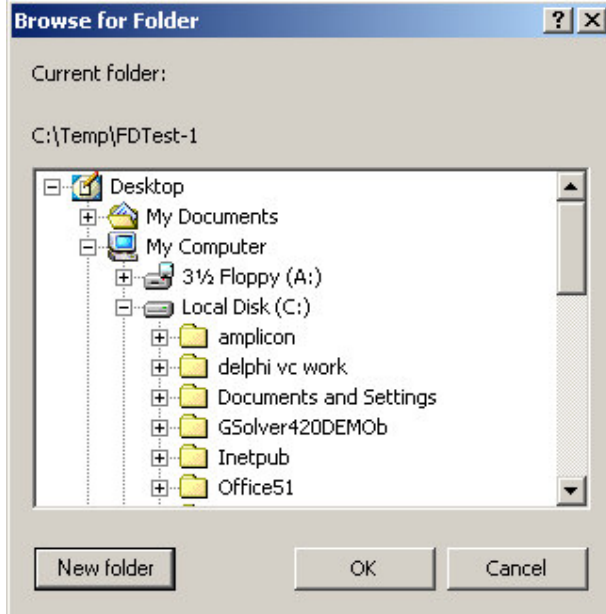
The right click menu provides just the user preferences common to all sub-windows.

Text can be selected in the log window, and copied to clipboard using **ctrl-C**, and pasted into a text document using **ctrl-V** in the normal manner.

B1.13 Creating a new process

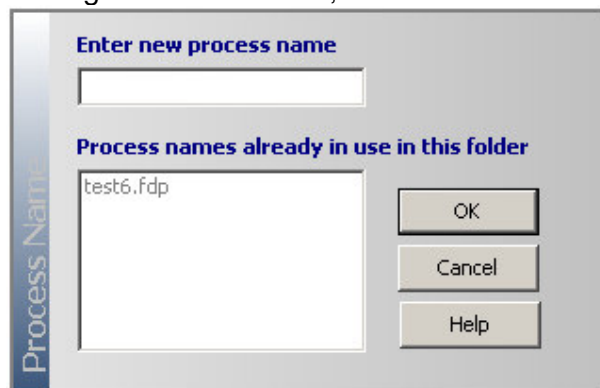
New **FilmDirector** processes are created by selecting **File New Process** from the main menu, or by using the **New Process** toolbar button .

This action opens the **Browse for Folder** dialog -




Navigate to a suitable location, and click the **New Folder** button to create and name a new folder for the process files. A process can generate a number of files, and, although not obligatory, it is neater if all the files for one process are located in the one folder.

Having selected a folder, the **Process Name** dialog opens -



If the one folder has been used for multiple processes, they will be listed in the lower panel. However, if you have elected to use a new folder for the process then this panel will be blank. Enter the process name in the edit box and click the **OK** button.

Having created the process, the next step is to associate a **Project** with it by selecting **Projects Open** from the main menu, or by using the **Open Project** toolbar button . The process is now ready to run. For more information on opening projects see the section Opening a Project.

Note that if you have created a new process, but have not yet associated a project with it, closing the process will delete it.

Likewise if you attempt to close **FilmDirector** before a project has been associated with the new process, **FilmDirector** will require you to click the **Finish** button on the control panel before allowing you to exit. The effect of this is to delete the empty process you have just created.


B1.14 Running a process

The basic sequence of events involved in running a process are proscribed by **FilmDirector**'s sequencer.

Once a process and its project are loaded, the following basic sequence applies. Note that commands can be input via the DIGIO hardware ports or the buttons on the control panel as described in the overview.

1. **FilmDirector** awaits a **Start** command.
2. On receiving a **Start**, **FilmDirector** loads the parameters for the first film from the database, sets up its analyser and instructs the optical monitor according to these parameters. When the optical monitor signals that it is ready, **FilmDirector** moves to the *waiting* state.
3. **FilmDirector** awaits a **Go** command from the process controller indicating that deposition has started.
4. On receiving a **Go** command it enters the *monitoring* state, instructs the optical monitor to clear its acquisition buffer, and commences feeding the optical signal through its analyser looking for the cutpoint.
5. **FilmDirector** awaits a **CutNow** command. Normally this will be issued by its analyser when the latter establishes that the correct film thickness has been attained.
6. On receiving a **CutNow** command it ceases data acquisition, saves the run data if required and waits for a **Next** command.
7. On receiving a **Next** command, **FilmDirector** loads the parameters for the next film from the database, sets up its analyser and instructs the optical monitor according to these parameters. When the optical monitor signals that it is ready, **FilmDirector** moves to the *waiting* state.
8. **FilmDirector** then repeats steps 3 to 7 for however many films are to be deposited. On the final film, however, it loops back to step 1 ready to recommence the process.

B1.15 Continuing a process which has been interrupted

To continue running a process from the point at which it was closed or aborted, select **File Open Process** from the main menu, or use the **Open Process** toolbar button .


The question of whether or not context is preserved across a close and subsequent reopen of a process depends upon the point in the cycle at which the close was made.

Example 1: *FilmDirector* has just cut film 3 correctly and is now waiting for the **Next** command. The operator closes the process by pressing **Finish**. This is the ideal point at which to break the process. On doing an open process, *FilmDirector* will be in an identical state to where it left off with the plotted data present in the *Process All* and *Process View* windows, and with the current film marked in the Film stack window and so forth. On receiving a **Next** command *FilmDirector* will load film 4 parameters from the database, and continue the process.

Example 2: *FilmDirector* has just cut film 3 correctly, has received a **Next** command and loaded film 4 parameters and is now waiting for a **Go** command. At this point the operator aborts the process by clicking the **Finish** button. Once again, there is no problem in continuing this process. On doing an open process, *FilmDirector* will roll back to waiting for a **Next** command, then reload film 4 parameters on getting one, and proceed with film 4 deposition.

Example 3: *FilmDirector* is in the middle of film 4 deposition when the operator aborts the process. Now we have a problem caused by the fact film 4 has never completed, and if we attempt to continue by using open process, *FilmDirector* will wait for a **Next** command and then restart film 4. There is no easy way to salvage the run, unless we can make a good estimate of the amount of material deposited in layer 4 before the process was aborted. If this can be done, then we can edit film 4 in *FilmMaker* by splitting it into two films, one representing the material deposited so far, and one the material yet to be deposited. This will keep the model correct for the ensuing films in the stack. Then instead of doing an open existing process, use restart existing process to open the process, and then manually set the first film to film 5, ie the yet to be completed section of the original film 4.


B1.16 Restarting a process from the beginning

To restart an existing process from the beginning, select **File Restart Process** from the main menu, or use the **Restart Process** toolbar button .

The process will open ready to run, with the film 1 as the first film. This is the preferred way of opening an established process with a view to starting a new deposition run.


B1.17 Closing a process


To close a process before the last film has been run, select **File Close**

Process from the main menu, use the **Close Process** toolbar button , or the **Finish** button on the Control Panel.

The current process context will be stored, and both process and project data will be unloaded. At this point the application may be closed, or another process loaded.


A process may be closed pretty well anytime during its course. In this sense, close acts as an abort function. Depending upon when a close is made, the context of the process is saved to some degree with a view to it being recoverable at a later point.

If the process is reopened with the restart existing process button  then the context is lost entirely, and the ensuing process will start all over again.

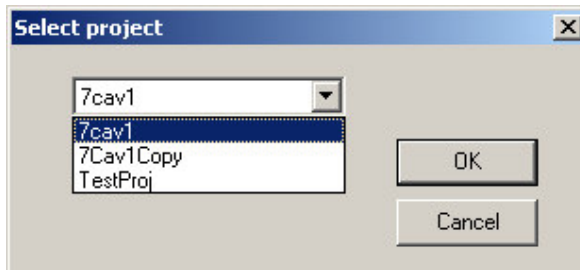
If the process is reopened with the open existing process button  then the context is not lost, and the process will continue with the next film in the stack.

*If a process is aborted by pressing **Finish** or by using the tool bar **Close Process** button while it is in the middle of depositing a film, re-continuing the process will restart the same layer, and cannot easily compensate for the fact the aborted layer is of uncertain thickness. See *Continuing a process which has been interrupted**

B1.18 Opening a **FilmMaker** project

To open a **FilmMaker** project for use with a process, select **Projects Open** from the main menu or use the **Open Project** toolbar button .

This opens the Select Project Dialog –



The drop-down list contains all projects registered with **FilmMaker** on the current PC. If you wish to access a project that is on another machine, either by copying the appropriate folder to floppy disk, or by using a network connection, that project will have to be registered with **FilmMaker** on the current PC before it will be recognized and will appear in the available project list. See Registering Projects in **FilmMaker** help.

Select the project you wish to use and click OK. Several actions will occur -
 If the Filmstack window is open, the project will appear in this window.
 If the Model window is open, the model generated by **FilmMaker** for this design will be plotted there.
 The name of the process and its associated project will be displayed in the **FilmDirector** title bar.
 The status bar will show a success message with the name of the project and its associated materials database.

*Note that projects are 'read only' as displayed in **FilmDirector**.*


Interactions with FilmMaker

FilmDirector accesses the project database as needed during the running of the process. The project that is loaded cannot be accessed by **FilmMaker** until the process closes. **FilmMaker** can access other projects, but if it attempts to access the one being used by **FilmDirector**, a **directory is locked** error is reported.

Conversely, if **FilmDirector** attempts to load a project that currently is open in **FilmMaker**, the load will fail and **FilmDirector** will report **project open in FilmMaker** in its status bar.

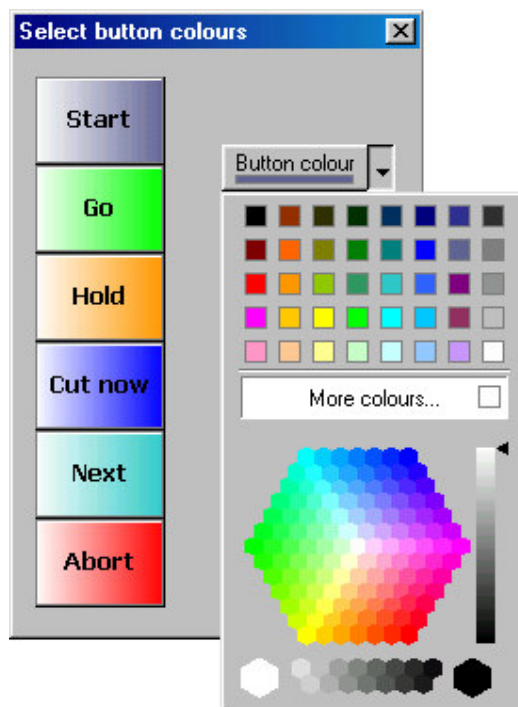
B1.19 Changing to a different *FilmMaker* project

A **FilmMaker** project can only be changed if the process has not yet been started (the Control Panel **Start** button will still be active).

Simply select **Projects Open** from the main menu, or use the **Open Project** toolbar button .

Changing control panel button colours

To change the colours of the Control Panel buttons, select **Options Button Colours** from the main menu. This will open the 'Select button colours' dialog.



Click on the button that you want to change, and select a colour from the colour picker.



Viewing raw and filtered data

These two toolbar buttons dictate whether the process-view window will display raw data, filtered data or both.

B1.20 Client-server architecture

FilmDirector uses a client-server architecture to allow it to function in a hardware-independent way. The client, **FilmDirector**, is always the same executable, while the server is hardware implementation specific. This latter software element we call the hardware data server. It is an executable that can be run quite independently of **FilmDirector**. It contains all the hardware controls such as wavelength, gain, calibrate and so on.

FilmDirector, on the other hand, is a data client, and looks to the optical monitor hardware for a data server which will respond to generalised optical monitor commands of the type SetWavelength, SetGain and so forth. In itself, it knows nothing about these parameters and always defers to the film stack database for their correct value. Likewise, it accepts signal data from the server, and expects it to be correctly scaled. **FilmDirector** is purely a slave to the layer by layer instructions held in the database.

Film stack database

FilmMaker employs a separate database for each new project. The database is registered with the database engine under the project name.

FilmDirector uses this registration to determine which database it will access. The database contains, on a film by film basis, the composition, target thickness, optical monitor settings, cutpoint analyser settings, amongst a host of other parameters.

Note: It is important to understand that a true database is employed, and its contents cannot be casually manipulated from Windows Explorer.

Digital IO server

This is a freestanding executable file that provides client programs with access to the digital in/out resources of a PC. It provides a high degree of flexibility in allocating these resources, and is typically used to interface to the process controller, optical monitor or test glass changer. Being a server means that it will automatically start and run when its services are requested by a client program.

Sequencer

One of the key roles performed by **FilmDirector** is to provide the sequences whereby film information is loaded from a database, appropriate parts of it are fed to the optical monitor's hardware data server, data is streamed in from the optical monitor until a cutpoint is recognized, and a cut output is activated. The behaviour, in this regard, is controlled by a software sequencing engine.

The sequencer responds to a finite set of commands. These can be generated by button presses on **FilmDirector**'s control panel, or, equally well, arise from an external source. The DIGIO server provides a means of mapping such commands to a digital input line for activation by a process controller.

The sequencer, at any one time, can adopt only one of a set of well defined states. These states are shown on the LED display on the control panel, but are identically available for external use. The DIGIO server provides a means of mapping such states to a digital output line for use by a process controller.

The possible commands and states are enumerated below.

Inputs:

State	Input Button	Name	DIGIO Tag
process-load	<i>none</i>	<i>not mapped</i>	
project-load	<i>none</i>	<i>not mapped</i>	
start	Start	mcStart	
go	Go	mcGo	
last	<i>none</i>	<i>Not mapped</i>	
hold	Hold	mcHold	
continue	Continue	mcContinue	
cut	Cut now	mcForceCut	
next	Next	mcNext	
abort	Finish	mcAbort	
error	<i>none</i>	<i>not mapped</i>	

Outputs:

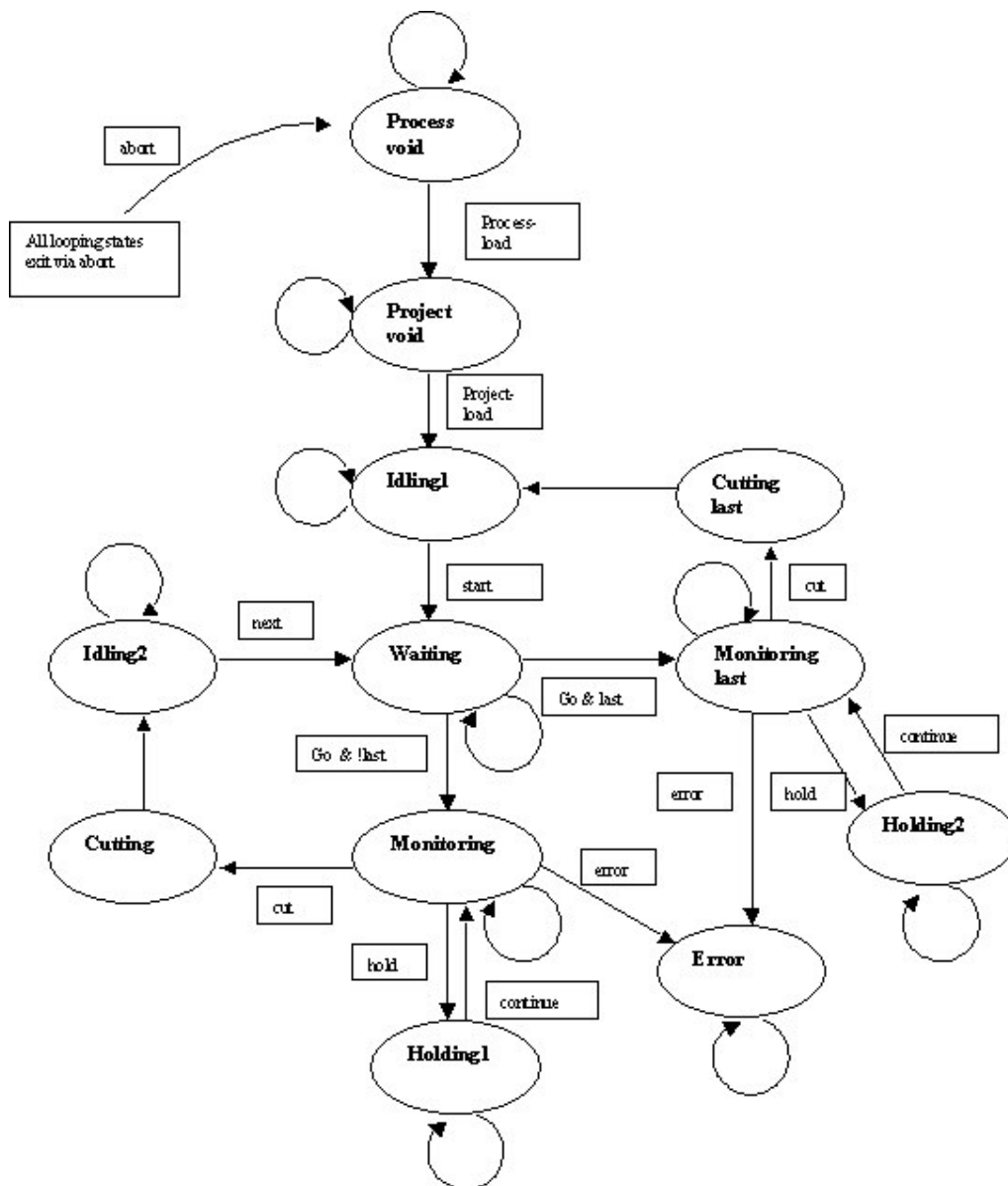
Machine State	DIGIO Tag
process-void	<i>not mapped</i>
project-void	<i>not mapped</i>
idling1	msIdling
waiting	msWaitingForGo
monitoring	msMonitoring
monitoring-last	msMonitoring
holding1	msHolding
holding2	msHolding
cutting	msCutting
cutting-last	msCutting
idling2	msIdling
error	msError

The DIGIO Tag, is the tag used by the DIGIO server to associate a particular physical port with a specific state or command.

Note: at this level, we do not consider the implementation details of the physical ports.

All this and more is handled by the DIGIO Server. See the help provided with it for details.

The behaviour of the sequencer can be formalised by means of the following state diagram.



Vertical splitter

As the mouse moves over this region, the normal cursor will change to the resizing cursor, and if you left click at this point, the division between the left and righthand windows can be dragged to suit your personal preferences. This preference is saved automatically when the application closes.

Combined menu bar and horizontal splitter

If the cursor is moved carefully over the horizontal division between windows, two different cursor shapes can be observed. One of these, the resizing cursor indicates that a left-click and drag operation can be used to horizontally reposition the division between the upper and lower windows.

The 'finger' cursor indicates that a left-click will open the sub-window menu. This menu can be used to select a sub-window to open in the panel immediately below the blue menu bar.

These preferences are saved automatically when the application closes.

Menu bar

If the cursor is moved carefully over the thin blue bar of the topmost windows, the normal cursor changes to a 'finger' cursor to indicate that a left-click will open the sub-window menu. This menu can be used to select a window to open in the panel immediately below the bar.

This preference is saved automatically when the application closes.

Subwindow menu

The submenu is opened by clicking on the thin blue menu bar. The menu displays the windows which can be opened into the panel below the menu bar. You do not have to close a window before opening another. The window you have opened into a particular panel will be reopened automatically next time you use the application.

Process files

If, for example, a process is named Test4 then the following files will be generated -

Test4.fdp the process file proper

Test4_cl.bin plot status file

Test4_cr.bin plot status file

Test4_fl.bin plot status file

Test4_fr.bin plot status file

Test4_ll.bin plot status file

Test4_lr.bin plot status file

Test4_log.txt log file

Note that plot and log files are generated regardless of whether the windows they reference are open or not.

Run name edit box

Each layer is given a unique run name to identify its files. This is done automatically by appending the film number to the process name. This occurs on **Start and Next**, however, if desired, the run name can be forced by entering it in the edit box sometime before the final cut is made.

Current film number

This is the number of the film currently being deposited. It is updated after **Start** or **Next**. It is also indicated by the current film marker in the film stack window it cannot be edited.

Total film number

This is the total number of films which will be run during the current process. It is the inclusive difference between the start and last film markers in the film stack window. It cannot be edited. To change the films over which the process will operate, use the first and last markers in the film stack window.

Manual cutpoint intervention checkbox

Check this box to enable manual intervention in automatic cutting of the film. Normally, the setting of the analysis parameters in **FilmMaker** determines how the cutting of the process will be done, and the analyser will cut the film without warning when it determines the correct film thickness has been reached. When this checkbox is checked, the analyser will alert the operator that it is about to signal a cut, by popping a dialog box. This box allows the operator the option of cancelling the cut and using his own judgment if he so wishes. If the dialog is ignored, the cut will be made anyway.

Note: this option not available on this software release

Start button

Pressing the start button (assuming it is enabled at this point) sends a **Start** command, in response to which **FilmDirector** will load the parameters for the first film.

This means -

- Instructing the optical monitor to move to specified wavelength.
- setting a specific gain in the optical monitor.
- Loading the selected endpoint parameters into **FilmDirector's** analyser.
- Outputting the selected material number to the DIGIO

Having done the above, **FilmDirector** will idle awaiting a **GO** command from the system controller or operator.

Go button

Pressing the go button causes the **Go** command to be issued. Normally, this command would be sent from the system controller via the DIGIO when the system controller opens the shutter to start deposition. On receiving a **Go** command **FilmDirector** does the following -

- Instructs the optical monitor to clear its data acquisition buffer.
- Commences plotting the data stream from the optical monitor to the process view window.
- Commences analysing the data stream from the optical monitor with a view to finding a cutpoint.

Hold button

Pressing the hold button causes a **Hold** command to be issued. On receiving a **Hold** command **FilmDirector** does the following -

The analysis and plotting of the data stream from the optical monitor is stopped.

Continue button

Pressing the continue button causes a **Continue** command to be issued.

FilmDirector responds as follows -

- The optical monitor is instructed to clear its acquisition buffer.
- The timebase is adjusted back to the time the **Hold** command was received.

If the deposition was, indeed, halted when **Hold** was issued, and then recommenced with the **Continue** command, then the data trace will not show a dislocation due to the temporary cessation of the process, and the analyser will cut at the correct point.

Cut now button

Pressing the cut now button causes the **CutNow** command to be issued.

Normally this command is issued by the analyser when it determines the required film thickness has been attained. However, the operator can force a termination of the deposition run at any point by clicking the cut now button.

FilmDirector responds in the following manner -

- The cut signal is sent to the DIGIO.
- Data acquisition ceases.
- The run data is saved to a file of the same name as the run name, and in the same folder as that used by the current process. This will only occur if the AutoSave option has been enabled for the particular layer in **FilmMaker**.

Next button

Pressing the next button causes a **Next** command to be issued. Under normal circumstances, the **Next** command is issued by the system controller when it is ready to setup for the next layer in the film stack. **FilmDirector** responds to the command by loading the parameters applicable to the next film to be deposited from the database.

This means -

- Instructing the optical monitor to move to specified wavelength.
- Setting a specific gain in the optical monitor.
- Loading the selected endpoint parameters into **FilmDirector**'s analyser.
- Outputting the selected material number to the DIGIO.

In addition to the above, **FilmDirector** will adjust the data plots to reflect the move onto the new film.

It will -

- Copy the righthand panel into the lefthand panel of the process view window such that only the final fragment of the plot is showing in that window.
- Clear the right hand panel of the process view window.
- Append the data of the last film to that already in the plot all window, colour coding it in a manner appropriate to the material that was being deposited.

Having done the above, **FilmDirector** will idle awaiting a **GO** command from the system controller or operator.

Finish button

Pressing the finish button causes the **Finish** command to be issued. This command causes the following actions to be taken by **FilmDirector** - if the system is monitoring, ie. acquiring data, the run and its data are abandoned and the process terminated at the previous layer. If the system is idling waiting for a **Next** command, the process is terminated at the current layer. The status of the system is saved so that it can be reopened ready to run from the last completed film.

Status LEDs

The status LEDs track the state of **FilmDirector**'s sequencer. They have the following meanings -

- Holding - system is holding acquisition waiting for a **Continue** command.
- Waiting - system is waiting for either the optical monitor or the system controller
- Monitoring - system is acquiring data and looking for a cutpoint

Cutting - system is sending cut output to DIGIO. Note that this state is transitory and will not always be obvious. It does, however, always occur.

Finished - the last film in the stack has been cut.

Error - an irrecoverable error has occurred.

Click the finish button to terminate the process.

Remote LED

The remote LED is used to indicate that the system is in its remote control mode. Under these circumstances, the normal command buttons are inoperable, and **FilmDirector** will respond only to commands from the process controller. However, all display functionality is still operable.

Note: this option not available on this software release

Digital displays

Next TP (sec) - estimated number of seconds to the next turning point. This information is available only when *fitter-1* and *fitter-2* analysis modes are employed for cutpoint detection. See **FilmMaker** help for details of these analysis modes.

Time (sec) - time since the start of the current film. This time is the true deposition duration and does not include time spent in the hold state.

Signal - current value of the optical signal in units of absolute T/R

QWs - estimate of current film thickness in units of quarter-waves. This information is not available in the *curve-follower* analysis mode. See **FilmMaker** help for details of these analysis modes.

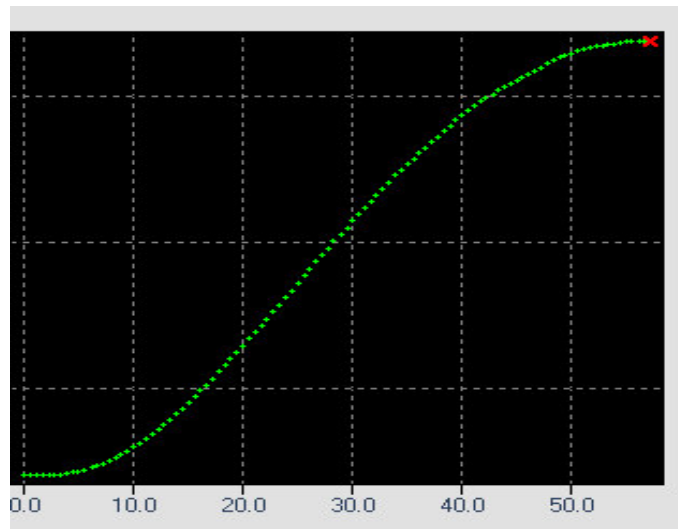
Rate (nm/sec) - estimate of the instantaneous deposition rate that is available only when the *curve-follower* analysis mode is in operation. See **FilmMaker** help for details of these analysis modes.

Thickness (nm) - estimate of current film thickness that is available only when the *curve-follower* analysis mode is in operation. See **FilmMaker** help for details of these analysis modes.

Appendix 3 Application of Filters in the Intellevation OM range

Importance of Turning Points

Turning points (TP) are important features of the optical signal. They allow us to gauge the optical film thickness in a manner that is independent of instrument factors such as optical gain and offset. They are readily detected by software, and thus lend themselves to robust methods of process automation.



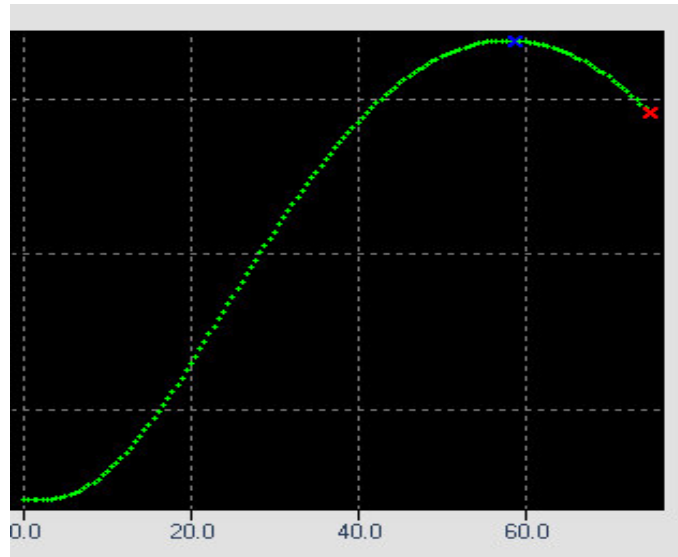
We know this trace represents the deposition of a single quarter wave (QW) of material. This will be true regardless of:

- The calibration of the OM
- The rate control and calibration of the deposition sources

Extrapolation From the TP

Gauging the film thickness for points beyond a TP is more difficult.

Whilst the extremum of the optical signal represents a distinct physical singularity, this is not true of any other points on the optical trace. The shape of the optical signal can be predicted by modelling the reflectance of the film stack, and the resulting prediction used to extrapolate from the last TP encountered.



We know the trace represents the deposition of an amount over 1QW, but by how much?

We can make an estimate based on an expected curve shape and by reference to the signal excursion and QW time encountered so far.

Accurate cutting of fractional QW films is dependent on precise process control and accurate optical measurement.

Methods of TP Detection

Film cut accuracy is underpinned by accurate TP detection.

FilmMaker offers a choice of TP detection methods depending upon the setting of the *AnalysisMode* parameter.

Normal; filter crossing are point by point extremum detectors
Fitter 1; fitter 2 are shape fitting detectors

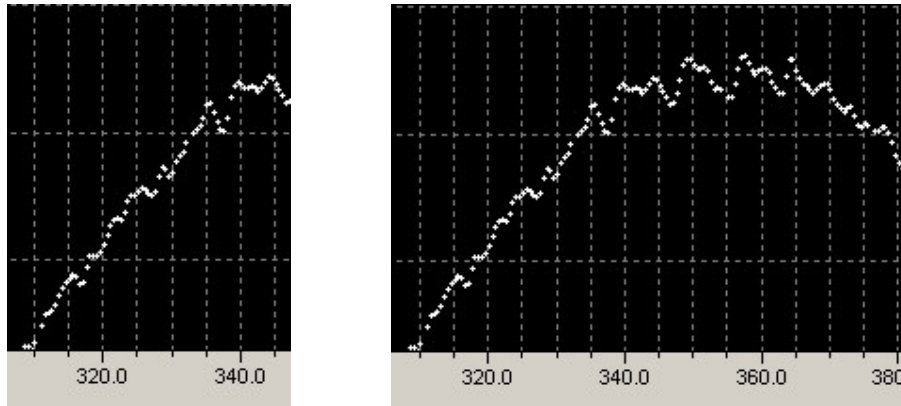
: film at cursor		Insert film at end	Delete
FilterCutOff	AnalyserMode	CrossingRatio	
10	normal	1.5	
0.5	normal	1.5	
4	filter-crossing	1.5	
5	fitter-1	1.5	
1.5	fitter-2	1.5	
2.5	curve-follower	1.5	
2.5	normal	1.5	

There are two classes of TP detection algorithm, point by point detectors and shape fitters. **FilmMaker** provides both types. No one analysis mode is better than the other. The best choice is situation dependant.

Note that the *curve- follower* mode is a specialised analysis mode that does not rely on the detection of turning points.
 Its application will not be discussed here.

Point by Point Detectors

Point by point detectors look for a change in the signal trend on a point-by-point basis. You know you have crossed an extremum only when the event has passed.

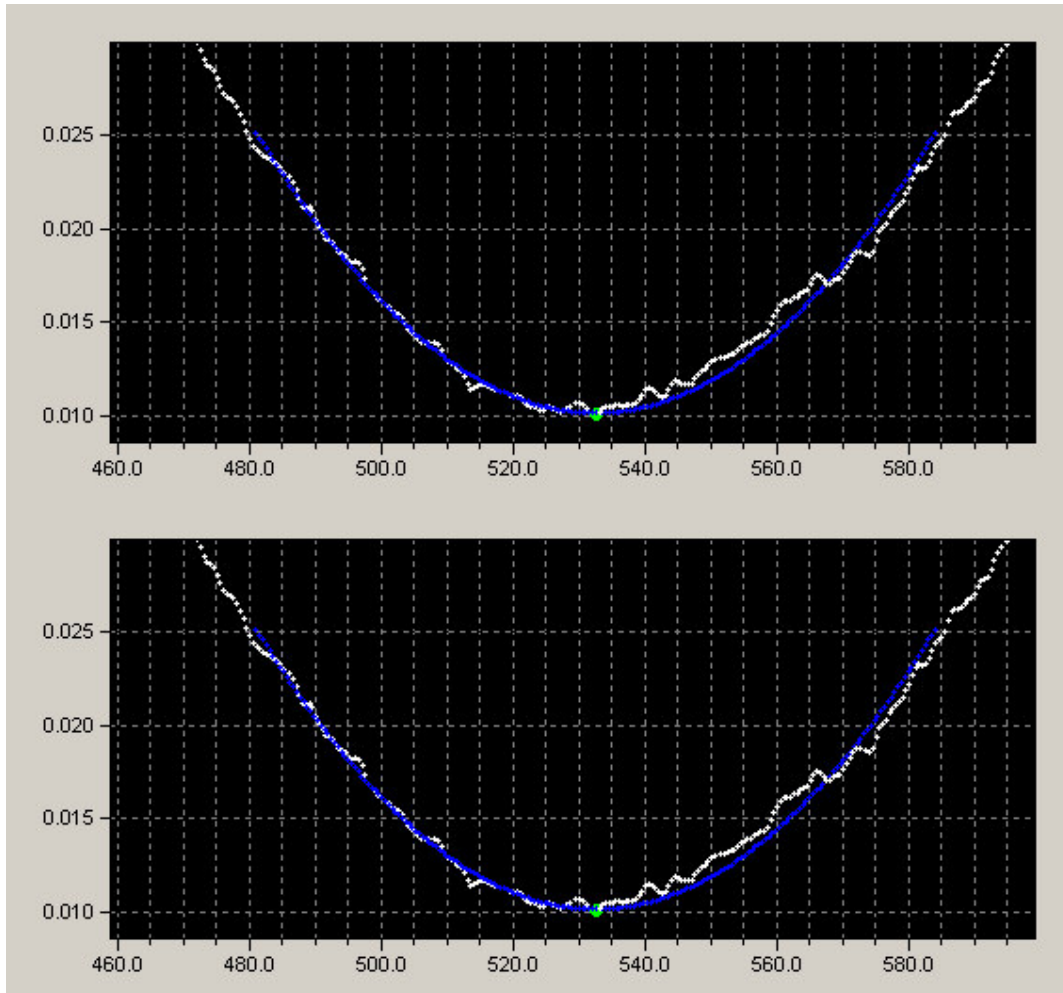


With a noisy signal this means being well past the TP before it can be detected with confidence.

Point by point detectors are incapable of cutting a deposition process exactly at an integral QW thickness.

Shape Fitters

Fitters can predict the occurrence of a TP well before it occurs. Fitters are less perturbed by short term noise than point by point detectors.



Fitters depend upon the signal shape matching an expected shape. Choosing the wrong fitter type leads to large errors.

Long-term noise due to undamped deposition rate fluctuations can render fitters unusable.

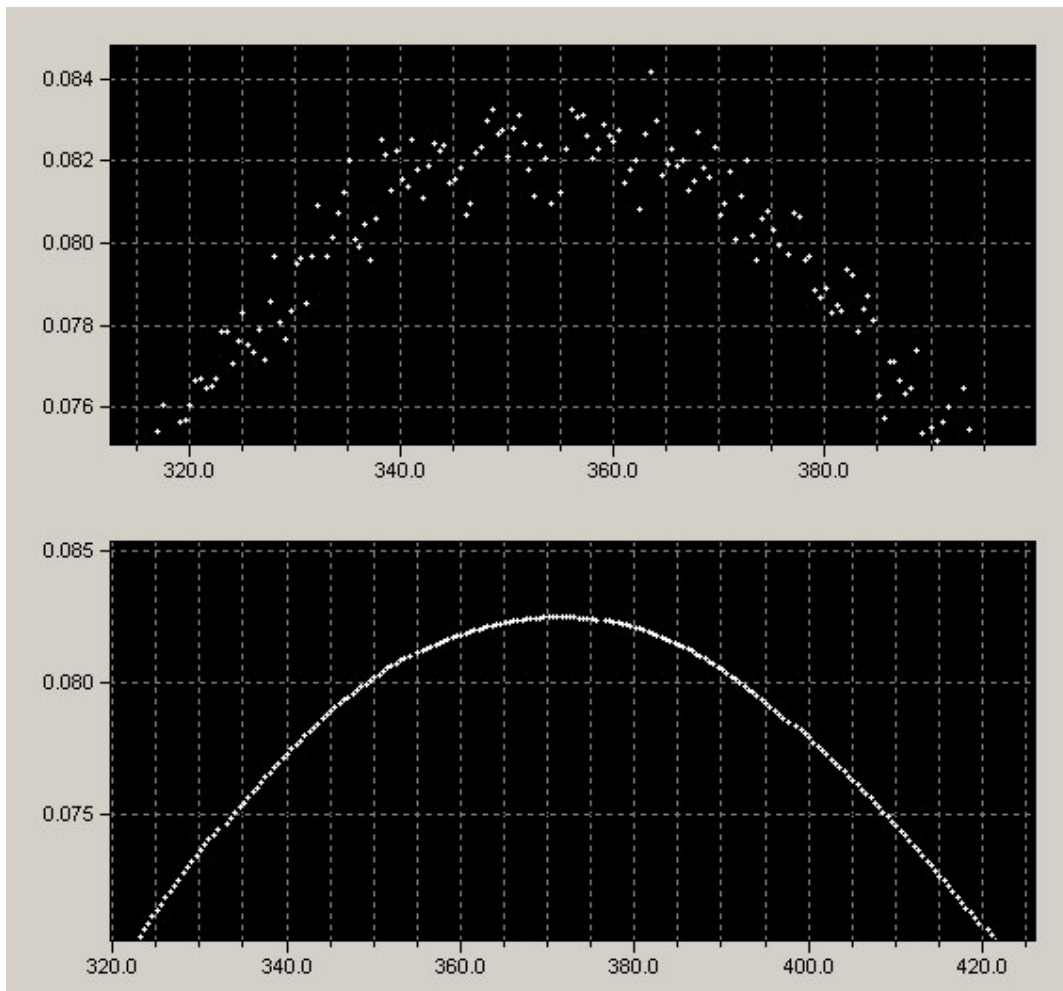
The Role of the Noise Filter

The raw optical signal is too noisy for reliable TP detection, regardless of the method used.

FilmMaker provides a 4th order Butterworth filter which pre-processes the data stream before TP detection occurs.

It operates quite independently of the TP detection process.

It is always active, even when a fitter is operating.



Setting the Noise Filter

Two parameters contribute to the Butterworth filter
QWTime must be close ($\pm 20\%$) to that actually achieved.
 Usually this means setting the *DepositionRate* to match that achieved at the test glass.
FilterCutOff is used to set the upper cutoff frequency of the filter. The lower the value the more aggressive the filtering that is applied.
 Provided the *QWTime* is entered correctly, a given value of *FilterCutOff* has the same effect regardless of the situation in which it is used.

			<input type="checkbox"/> Lock table	<input checked="" type="checkbox"/> Wait
DepositionRate	QWTime	FilterCutOff		
0.5	125	10		
0.5	188.356	10		
0.5	125	10		
0.5	188.356	10		
0.5	125	10		

- A value of 10 will smooth all but the noisiest signals.
- A value of 500 will have no noticeable effect.

The Meaning of the Filter Value

The *QW time* of the optical signal provides a measure of its fundamental frequency. The cut off frequency of the filter is set higher than the fundamental frequency by a factor equal to the *FilterCutOff* parameter.

Filter Phase Lag

The filtered signal lags real time in a determinate manner. The process will be cut late as a result of this phase lag. The more aggressive the filter the greater the phase lag. The phase lag measured in QW's, will be exactly $0.5/\text{FilterCutOff}$.

FilterCutOff	Phase Lag (QWs)	Error on 1QW (%)
1	0.5	50
5	0.1	10
10	0.05	5
50	0.01	1
100	0.005	0.5
500	0.001	0.1

Although the effect of the filter is to cut late, the cut is made with greatly increased consistency due to the reduced noise level. Consistency of cut is the critical outcome.

Other methods can be applied to compensate for the over-build of the film

The Normal Analyser

A robust point- by- point analyser requiring only one parameter.

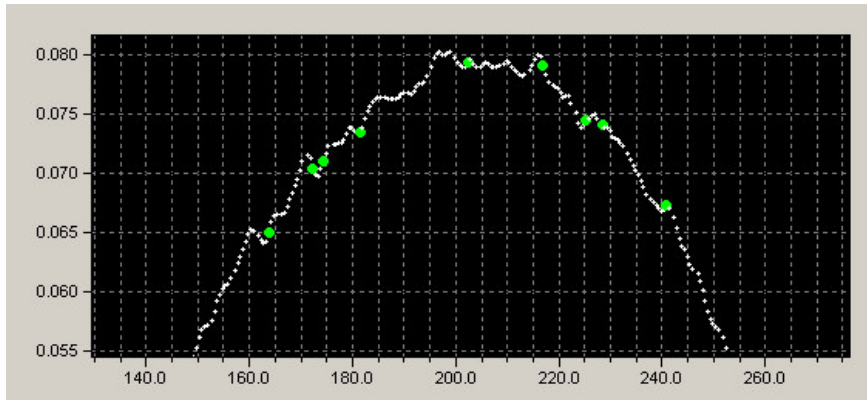
The *PCD threshold* is the only parameter involved in this mode, and normally can be left at the default value of 5. Setting the *PCD threshold* to 5 means 5 successive data points will be used in the TP detection process.

Insert film at end		Delete film at cursor		✓	✗
FilterThreshold	PCDThreshold	FollowerBufferSize	FollowerBufferSize	FollowerBufferSize	FollowerBufferSize
0.001	5	20	20	20	20
0.001	5	20	20	20	20
0.001	5	20	20	20	20

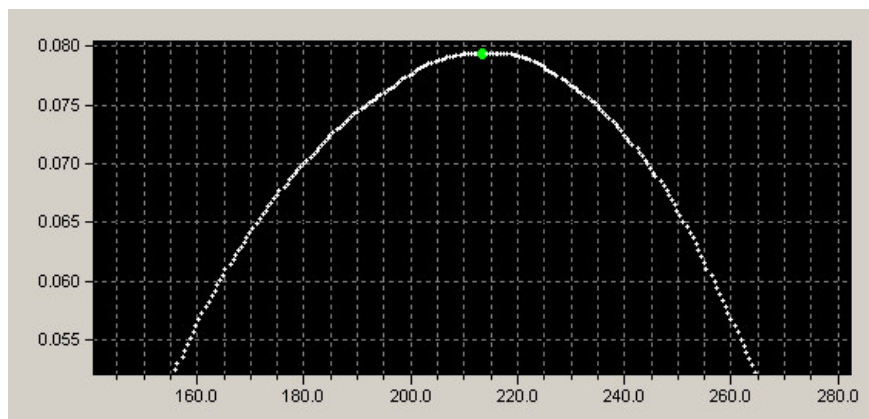
- A maximum is detected if $5 < 4 < 3$ and $1 < 2 < 3$
- A minimum is detected if $5 > 4 > 3$ and $1 > 2 > 3$
- The *PCD threshold* is always an odd number, and will be reduced to the nearest odd number if necessary.
- The TP is detected $(PCD\ threshold - 1) / 2$ data points late.

Robustness of *Normal Mode*

The *normal* analysis mode requires a monotonic signal, but is robust to deposition rate induced shape changes.



The signal must trend smoothly across the extremum. If not, spurious TP's will be detected.



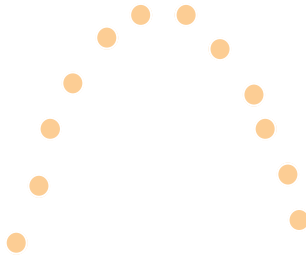
When the *FilterCutOff* is set sufficiently low that the signal is monotonic, this mode handles problems like shifting deposition rate better than any other methods.

The *FilterCrossing* Analyser

A point by point analyser similar to the Normal mode but differing in detecting the TP at the flank of the extremum.

Two parameters are required.

AnalysersMode	CrossingRatio	PCDThreshold	Fi
filter-crossing	1.5	7	
normal	1.5	3	
normal	1.5	5	



A second Butterworth filter is set up whose cut-off frequency is *CrossingRatio* times greater than the main filter. Its output leads that of the main filter in terms of phase.

The *PCDThreshold* provides the criteria by which one filter output is deemed to have crossed the other.

- Maximum $1' > 1$ and $2' > 2$ and $4' > 4$ and $5' > 5$
- Minimum $1' < 1$ and $2' < 2$ and $4' < 4$ and $5' < 5$.

Detecting the TP at a point where the signal is changing faster should improve cut-point precision. In practice the improvement is slight, and this method is more susceptible to deposition rate fluctuation.

The Fitter1 Analyser

A parabolic curve fitter is best suited to low finesse applications such as single layer, or off band multilayer applications.

Two parameters are required. The last *FitterBufferSize* data points (green) are held in the buffer, and fitted to a parabolic curve (yellow).

When the residual, which is a measure of what does not fit, exceeds the *FitterThreshold* the fitter is deemed to out of lock, and no attempt is made to interpret the data. When a good fit is obtained the fitter predicts the time at which the TP will occur, and this estimate is updated as each new data point is received.

The moment the current time exceeds the predicted time, the TP is called.

The TP is only **one** point late

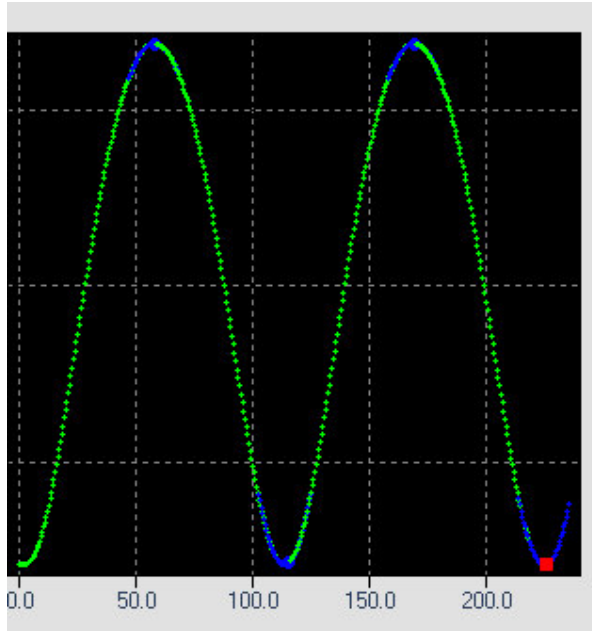
AnalysersMode	FitterBufferSize	FitterThreshold
fitter-1	50	0.01
fitter-1	50	0.01
fitter-1	50	0.01

The *Fitter2* Analyser

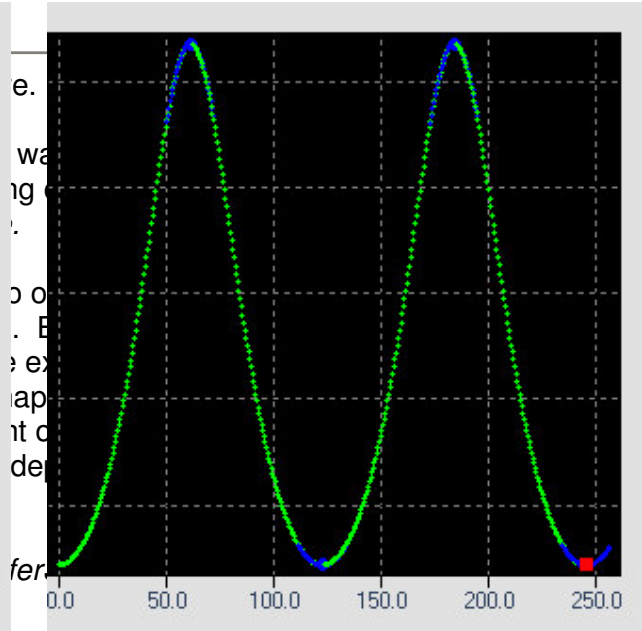
A parabolic curve fitter suited to high finesse applications such as Fabry-Perot structures.

It uses an inverse parabolic fit, but in all other ways is setup and used like a *Type1* fitter

Fitter 1



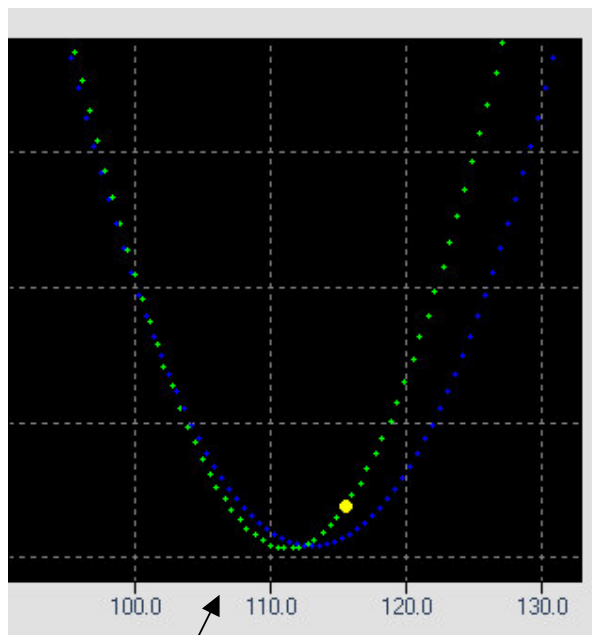
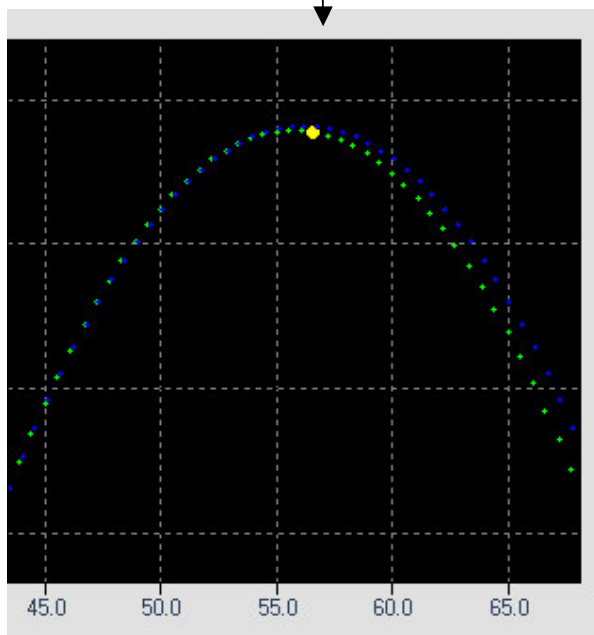
Fitter 2



It is necessary to use **FilmSimulator** for further optimisation.

Reflectance monitoring of TiO₂ on glass
SamplesPerQW=100
FitterBufferSize= 50
The shape of maxima and minima is different.

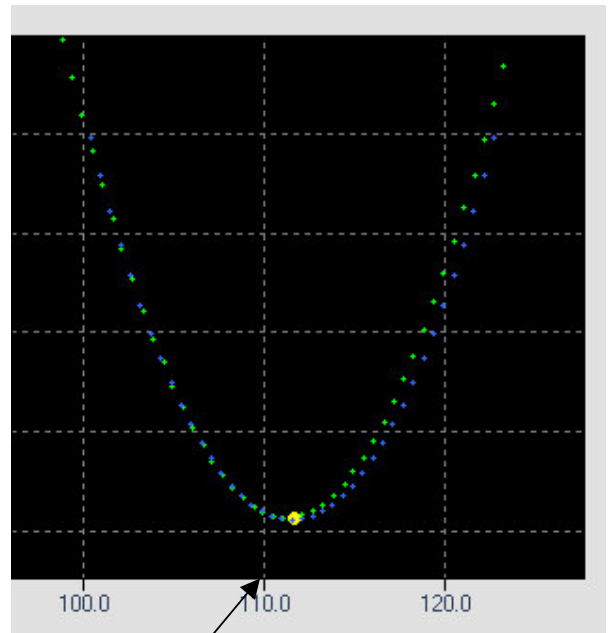
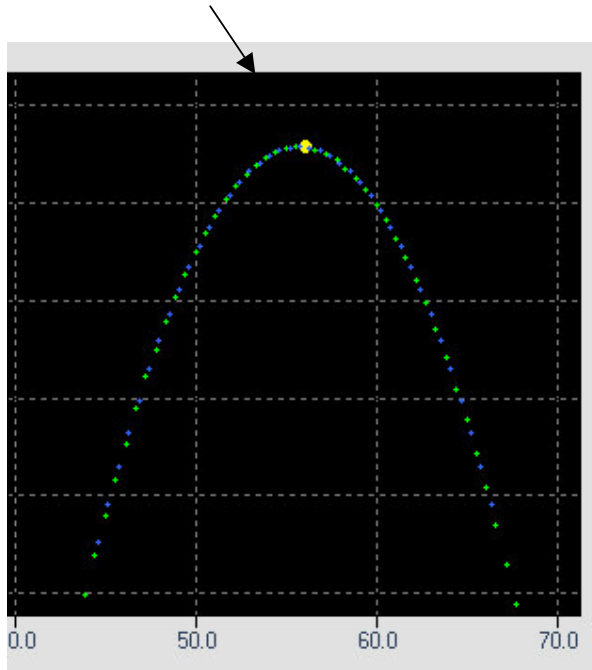
Shape fit of maximum is OK and TP is only 1 point late.



hape fit of minimum is poor and 8 points late

Reflectance monitoring of TiO₂ on glass
SamplesPerQW=100
FitterBufferSize=20

By fitting less of the curve, maxima and minima
can be treated the same.



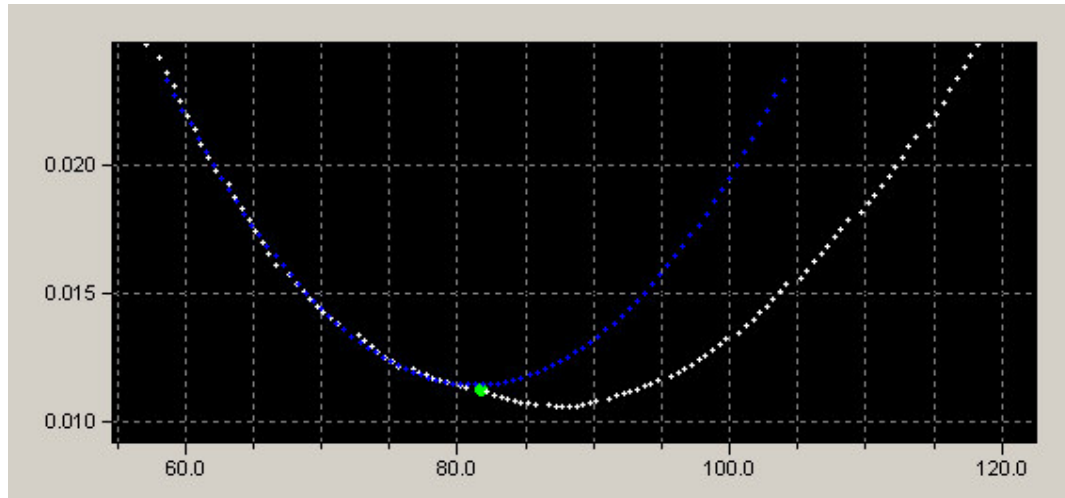
The shape fit of maximum is perfect and the TP is one point late

When the QW shape is perturbed by rate fluctuations, setting the fitter parameters becomes difficult.

Reflectance monitoring of TiO₂ on glass where

SamplesperQW=200

FitterBufferSize=40



- With the buffer size only 1/5 of the QW, the shape match should be good, nevertheless, a substantial TP error is generated.
- This error will not be consistent as it is a function of low frequency noise components
- The *Normal* analyser mode will yield superior results.

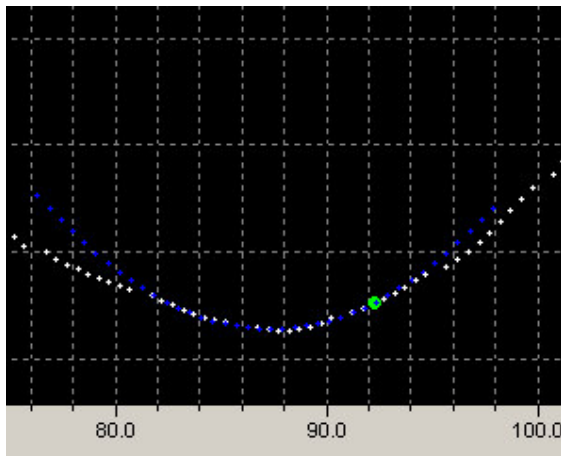
The *FitterThreshold* rarely needs to be changed from its default value of 0.01

When the shape fit is poor, the fitter will fail to lock over much of the extremum with the result that the TP will be assigned late compared with the fitted parabola.

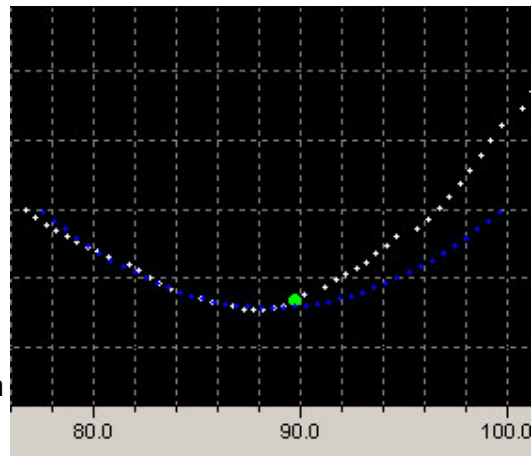
Increasing the *FitterThreshold* improves lock at the expense of precision.

It is always better to improve the process rather than attempt to handle poor optical data in this manner

FitterThreshold=0.01



Fitter threshold=0.1

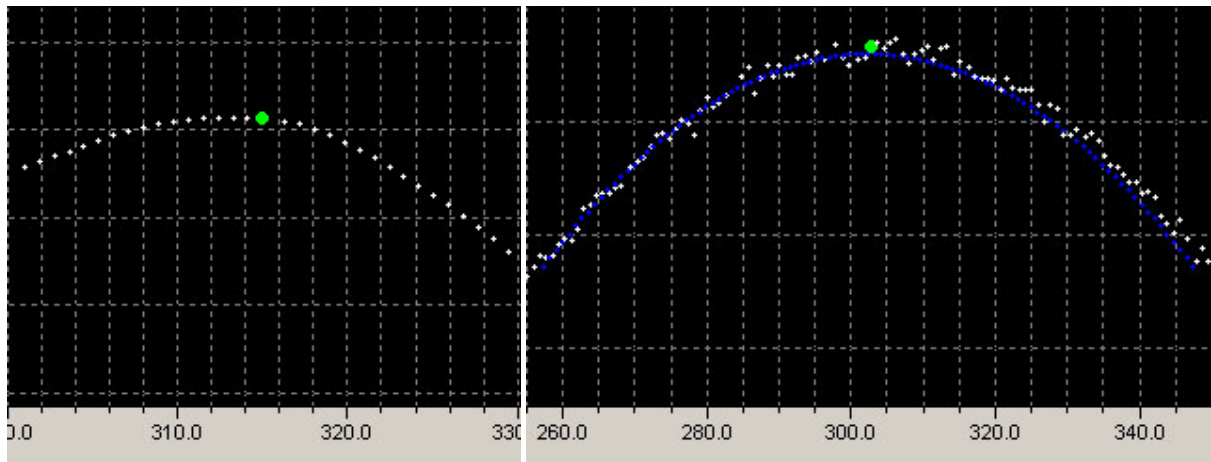


Fitters are noise tolerant

Provided the QW shape is not perturbed, fitters cope well with noisy signals.

Mode=*normal*
FilterCutOff=10
Phase lag error=5%

Mode=*fitter1*
FilterCutOff=500
Phase lag error =0.1%



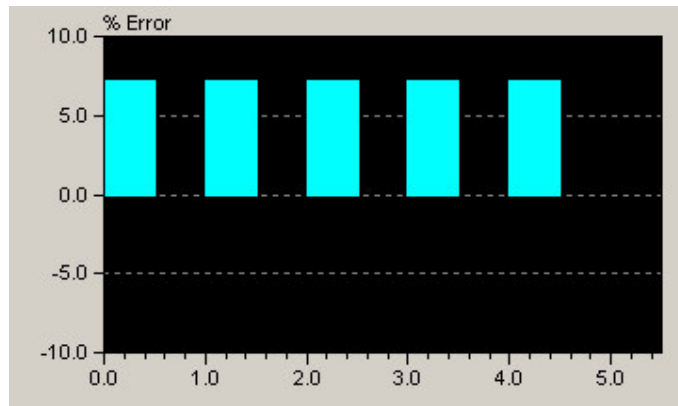
Less aggressive filtration is required compared with the *Normal* mode resulting in less phase lag.

Errors Cutting on the QW

Using the default parameters set up by the Simple user mode for reflectance monitoring of 1QW of TiO₂ on glass.

FilterCutOff=10
SamplesPerQW=100
PCDThreshold=5

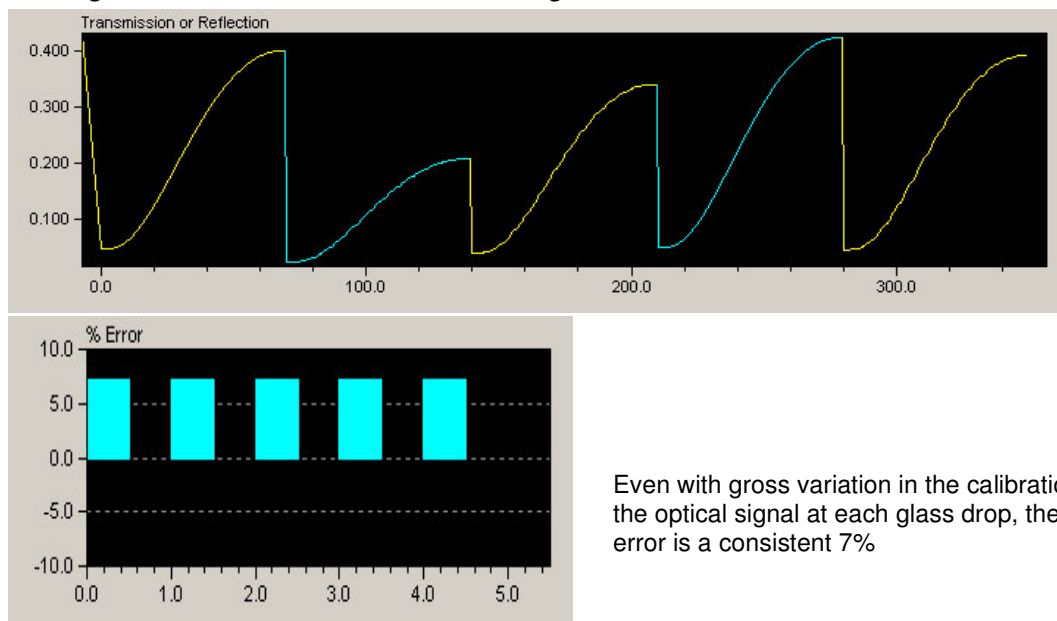
Film Simulator error results from 5 separate runs are:--



Note the error is identical each time

Film overbuilds up to 7%. 5% of this for filter phase lag and 2% from the fact that *normal* analysis mode cuts 2 points late and there are 100 *SamplesPerQW*.

Cutting on the QW is free of errors arising from instrument calibration.



Even with gross variation in the calibration of the optical signal at each glass drop, the cut error is a consistent 7%

Noise impacts the precision of TP detection

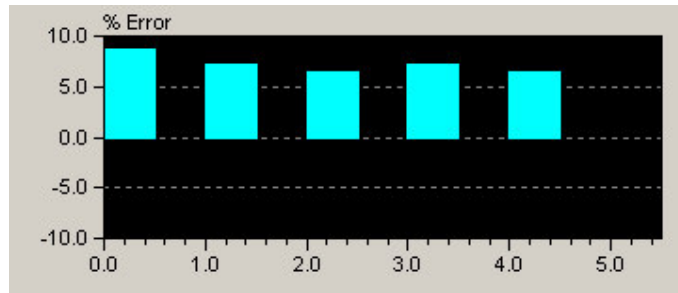
Reflectance monitoring of 1QW of TiO₂ on glass

Analysis mode=*normal*

FilterCutOff=10

SamplePerQW=100

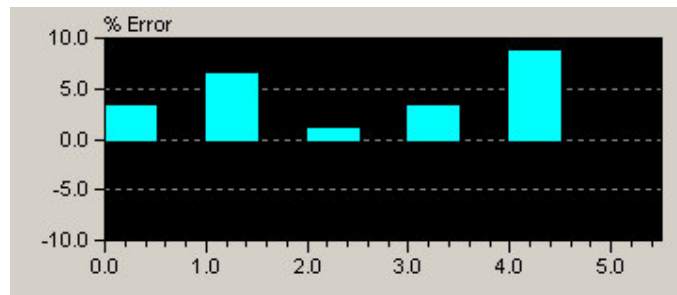
PCDThreshold=5



With a noise level of +/-1% superimposed on the signal, loss of cutting precision becomes obvious

Depending upon the design, this degree of error may or may not be significant

An optimally aligned OM typically exhibits half this noise level.



With a noise level of +/-4% imposed on the signal, the precision will be unacceptable for most applications.

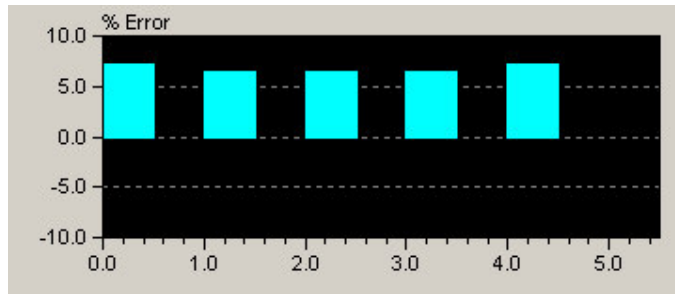
Note that noise is a function of signal level, and best cutting precision is obtained at low signal levels.

OM schemes are best if designed to restrict the signal to noise levels below 60%.

Fitters show superior precision in the presence of noise

Reflectance monitoring of 1QW of TiO₂ on glass.

AnalysisMode=fitter1
FilterCutOff=10
SamplesPerQW=100
FitterBufferSize=50
FitterThreshold=0.01

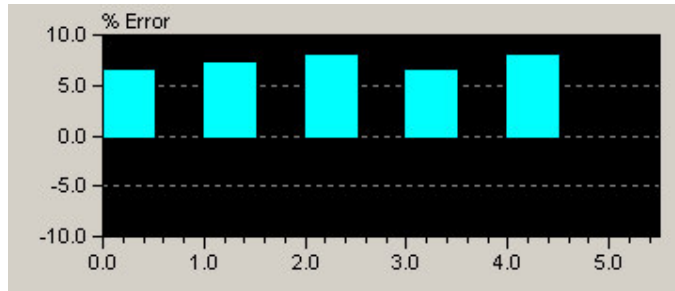


+/-1% noise on signal.

The constant error term is comprised of:--

5% from *FilterCutOff*

1% from the 1 point delay fitter 1 causes when there are 100 *SamplesPerQW*



+/-4% noise on signal

This level of performance can be further improved, if the deposition rate permits the setting of a higher *SamplesPerQW* figure. This in turn allows the *FitterBufferSize* to be set correspondingly higher with an improvement in the cut-off precision.

Reducing Phase Lag

It is impossible to avoid some degree of phase lag error on a QW cut

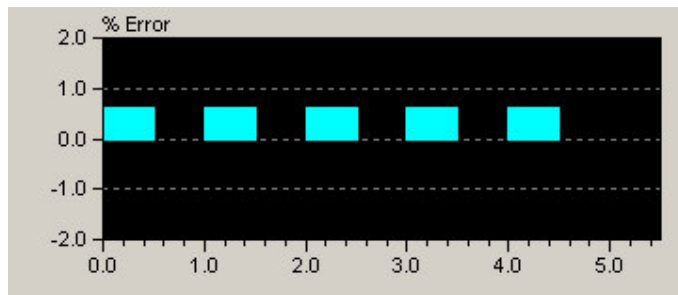
The *normal* mode will not function without considerable filtration thus phase lag.

Fitter1 and *Fitter2* can operate with very little filtration provided the *FilterBufferSize* is set high enough. However there are distinct limits to what can be achieved.

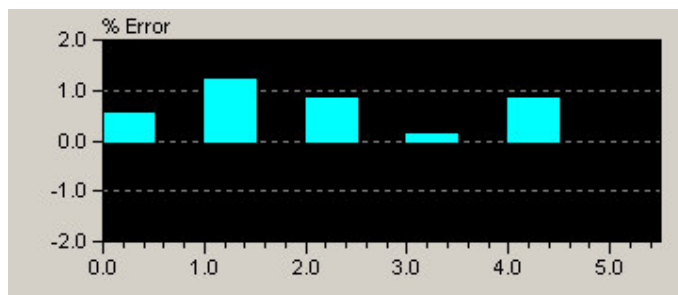
When QW times are of the order of 60 seconds, a typical *SampleRate* of 2Hz will yield 120 *SamplesPerQW*. This means keeping *FitterBufferSize* less than 24 if shape fit errors are not to become dominant. This size of buffer will not help much with noise, and considerable filtration will still need to be applied. It is not possible to compensate for phase lag by setting the *QWFactor* to a value of say 0.95 as this simply forces the analyser to cut at a point short of the full QW. Something that results in large errors/

Processes using low deposition rates can be cut on the QW with very little phase lag due to the possibility of setting *SamplePerQW* to a large number.

AnalysisMode=fitter1
FilterCutOff=100
SamplesPerQW=1000
FitterBufferSize=200
FitterThreshold=0.01



Film overbuild amounts to 0.6% with 0.5% from filter phase lag and 0.1% from the fact that the fitter1 analysis mode cuts 1 point late and there are 100 *SamplesPerQW*.



1% noise superimposed on signal. The large filter buffer provides noise filtering in its own right and allows the filter cut off to be increased to 100. The phase lag can be reduced without noise performance suffering.

Cutting Fractional QW's

Cutting fractional QW's is less than 1 is difficult.

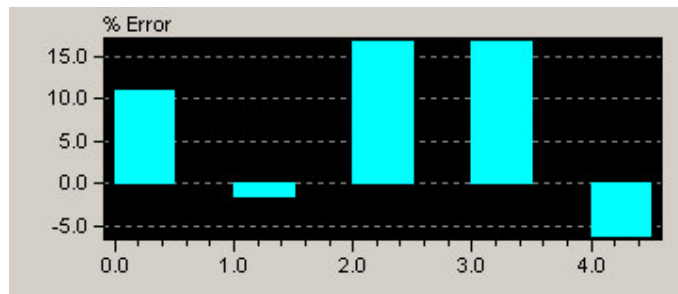
Without the first TP to 'anchor' the optical signal to the model, the cutpoint is determined by extrapolation from the starting optical signal using the curve shape derived from the model. Errors in calibration are directly transposed to errors in the cut point.

Reflectance monitoring of 0.8QW of TiO₂ on glass.

AnalysisMode=normal

FilterCutOff=10

SamplePerQW=100



The optical monitor calibrates itself using the new test glass prior to starting the run. This means calibrating to a low value of 4%. The error on this could easily be +/-0.4%, which will result in a percentage gain error of +/-10%.

FilmSimulator shows the sort of cut accuracy that can be expected under these circumstances.