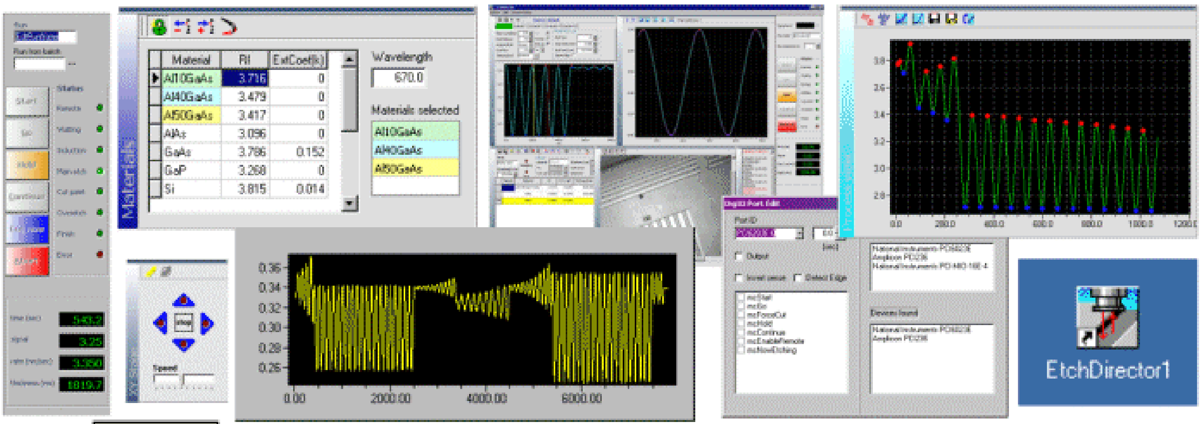
Etch*Director*©

for the Intellevation LEP400

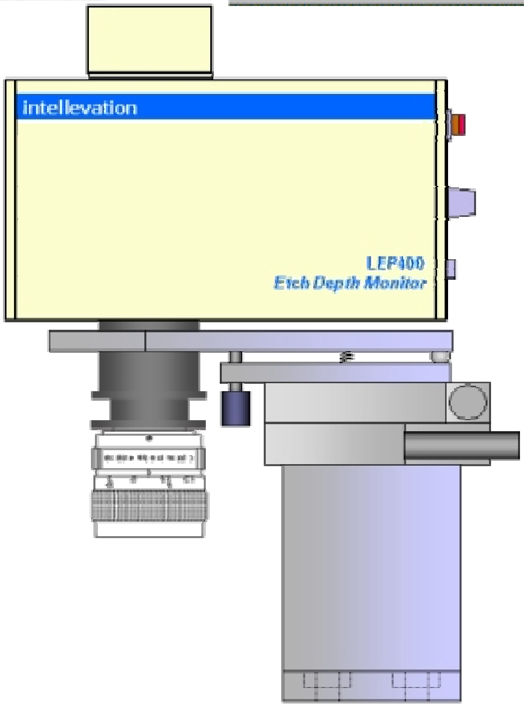
Software Help Manual

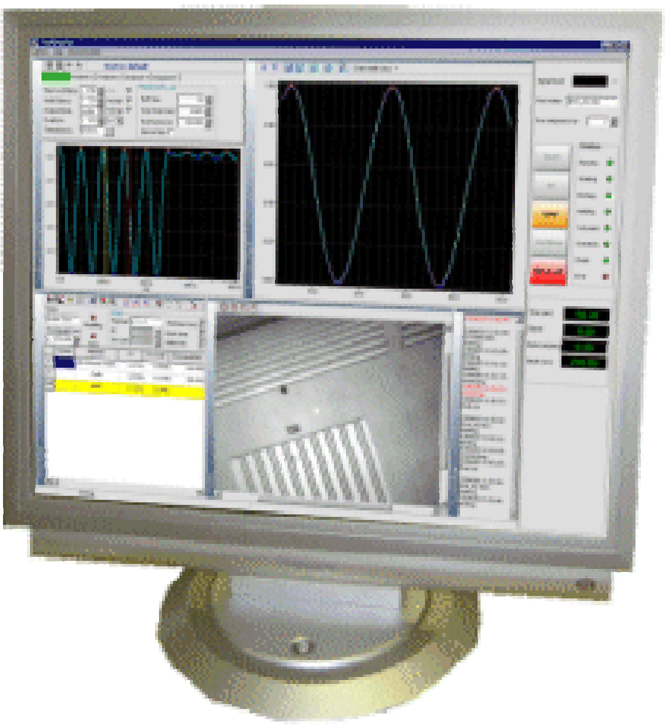


Material	RI	ExtCoef(k)
Al10GaAs	3.716	0
Al40GaAs	3.479	0
Al50GaAs	3.417	0
AlAs	3.096	0
GaAs	3.786	0.152
GaP	3.268	0
Si	3.815	0.014

Wavelength: 670.0

Materials selected:
- Al10GaAs
- Al40GaAs
- Al50GaAs





Overview

This document is a version of the online help file that has been transformed into a continuous format to enable printing. As a consequence of converting from hypertext, the page links are no longer active and the reader should ignore any reference to them.

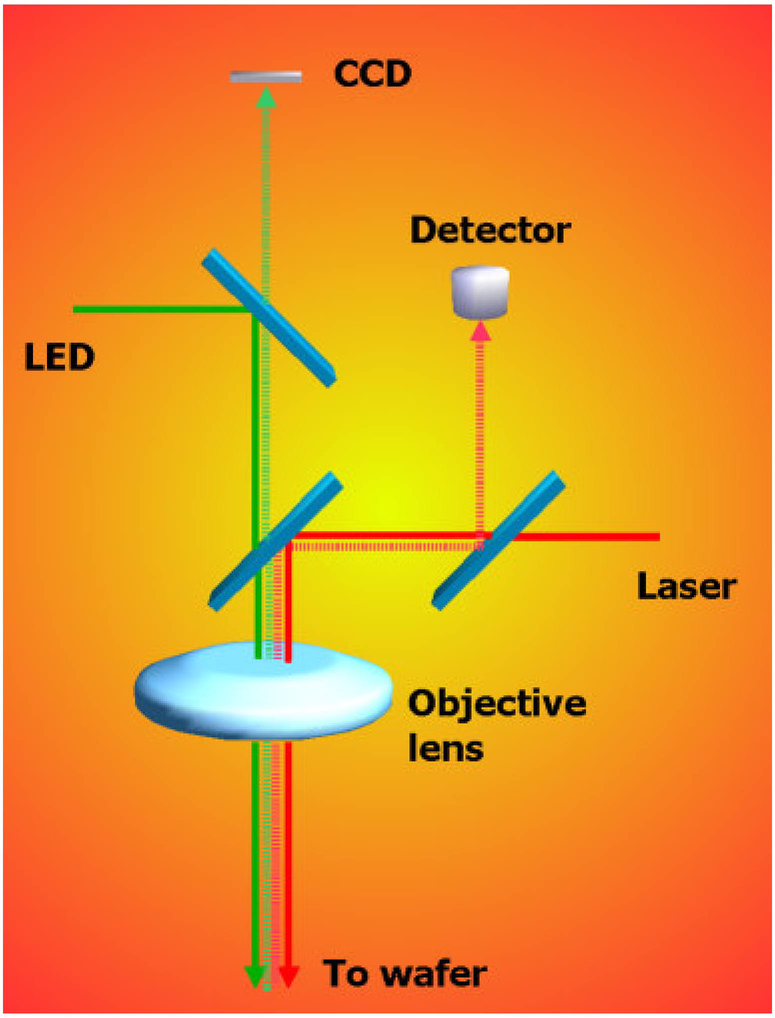
Welcome to Intellevation **Etch*Director*©** Help. This online help is aimed at guiding you through the software required to operate the Intellevation LEP400 laser endpoint detector. Another key resource is the hardware instruction manual, which is located with the instrument and in electronic format (Installation manual.pdf) on the Windows desktop.

Etch*Director*© is the software interface to your LEP400 laser endpoint detector for dry etching. The application displays the endpoint process data and enables you to configure the system for automatic endpoint detection by utilising the range of termination algortims provided. **Etch*Director*©** includes a powerful modelling feature that predicts the endpoint waveform in advance of the etch, thereby saving on set up costs. In addition, electronic communications are included that enable the endpoint detector to be interfaced to the etch process controller, for further automation.

Etch*Director*© Help
June 2007

Principle of operation

The LEP400 series is a range of interferometers, based on a laser source (detailed in the hardware installation manual). Laser light is focussed via two beam splitters and an objective lens onto a tiny spot on the surface of the wafer. The main optical axis is aligned perfectly normal to the wafer, so that light reflected from the surface under study returns via the same path back to the first beam splitter which then diverts it to the detector. The signal generated by the detector forms the basis for endpoint detection.



A confocal vision system is provided so that the position of the laser spot on the wafer surface can be monitored. It consists of an LED which illuminates the wafer surface via two beam splitters and the objective lens, the returning light being focussed onto a CCD.

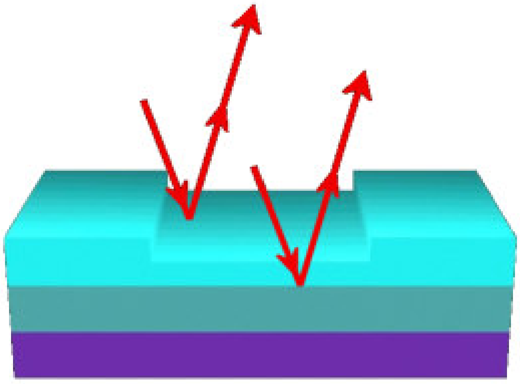
The variation of the reflected signal with time is determined by the optical and physical properties of the wafer materials, which contribute to the phenomenon of interference.

Interference

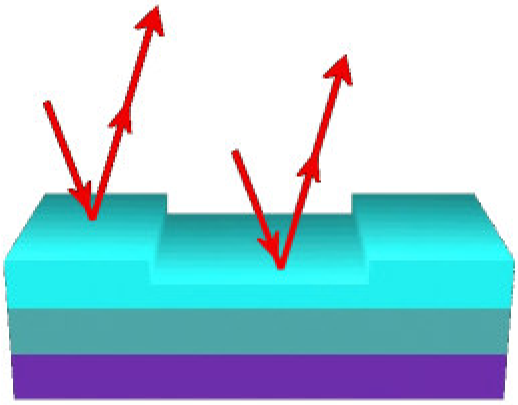
In the beam leaving the laser, the light waves are coherent. When the beam strikes two surfaces a distance apart, there is a phase difference between the two sets of reflected waves. These two groups of waves may add together ('interfere') constructively or destructively. If the distance between the two surfaces changes with time (as in an etch), the strength of the combined reflected signal oscillates generating maxima and minima intensity levels. The number of these 'fringes' characterizes the change in distance between the surfaces - etch depth.

The laser spot can be positioned on an open area of transparent material (1) or over a step on the wafer (2) to obtain interference fringes during an etch.

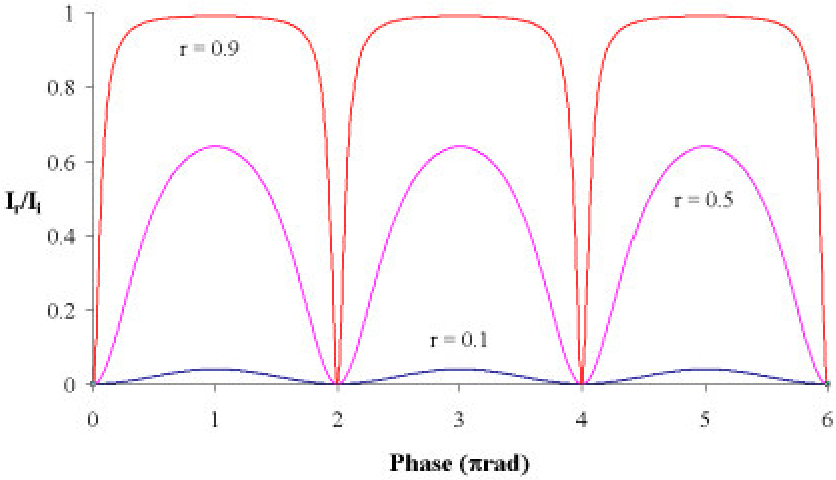
(1) Intra-layer interference: Laser light is reflected from top and bottom of the film being etched and from any reflecting film interfaces in the stack below. This is the preferred means of operation of the LEP400.



(2) Stepped-level interference: Laser light is reflected from the surface of the mask and top of the material being etched (also known as stepped level interferometry). This method is susceptible to a larger degree of error, as two different materials are being considered - two different etch rates and two thickness tolerances. Reflections from the side of the trench and from within the mask also complicate interpretation of the data.



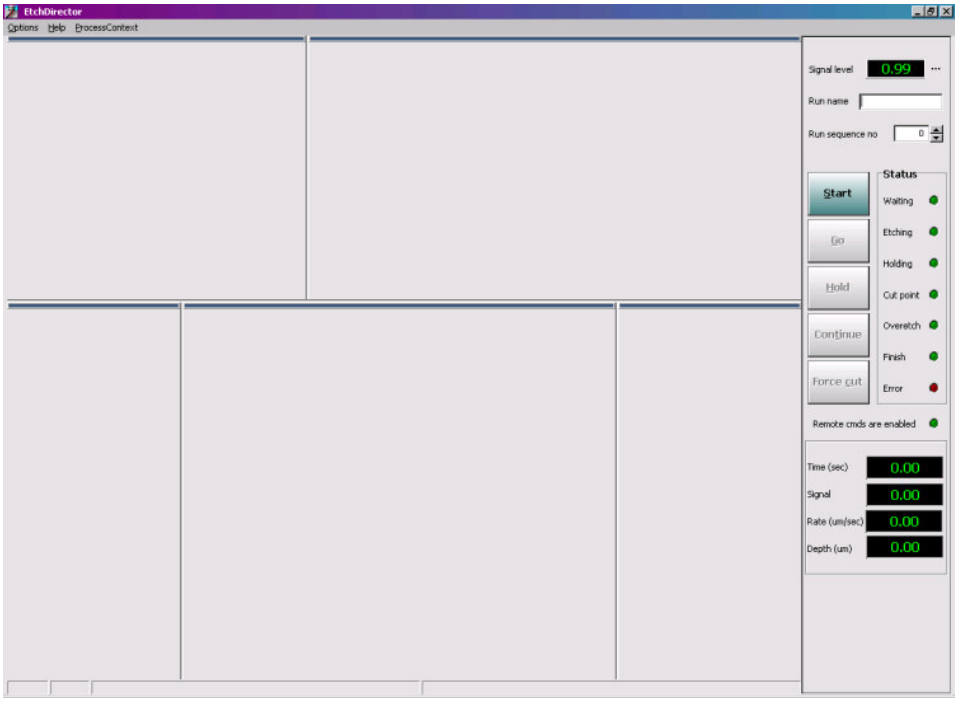
The reflected intensity (I) depends on the reflectivity (r) of the wafer materials. The intensity variation with phase thickness ($\delta=4\pi nd/\lambda$), n = refractive index, d = physical thickness, λ = laser wavelength, is shown below.



The interference signal observed as a film is etched is cyclical, with etch period corresponding to the removal of a thickness of λ/2n, or two 'quarter wavelengths'. The shape of the interference pattern depends on the reflectivity of the film surfaces.

Getting started

To open **Etch*Director***©, double click on the icon on the Windows desktop. To enter the program proper you will then be prompted to read the license agreement, which must then be accepted. This will bring up the main **Etch*Director***© desktop. Click on the image, below, for a definition of the various sections.



Signal level 0.99
Run name
Run sequence no 0
Time (sec) 0.00
Signal 0.00
Rate (um/sec) 0.00
Depth (um) 0.00

General settings

Computer setup
Window panels
Options menu
Color customisation
Instrument profile
Batch parameters
Directory structure
Process contexts
Control panel
Process data display
Real-time signal display
Status bar
Sidebars
Zooming and panning
Units
Exporting chart images
Exporting data as .CSV

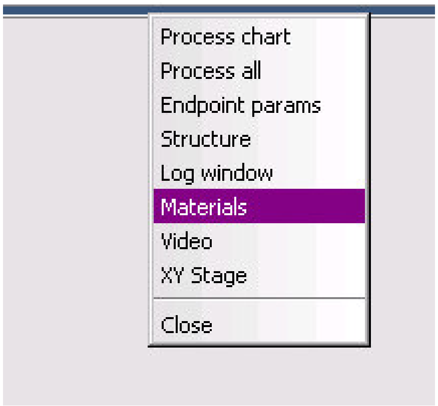
Computer setup

In order to ensure uninterrupted operation during an endpoint run, the power schemes should be disabled. In the 'Power Options' menu in Control Panel, the turn off monitor, turn off hard disks and system standby options should be set to never (factory settings).

For the **Etch*Director*©** screens to be displayed correctly, the computer VDU should be operated at a minimum resolution of 1024 x 768 and in High Color (16 bit). These settings are adjusted on the 'Display' menu in Control Panel.

Window panels

The main **Etch*Director*©** screen consists of five re-scalable panels in which any of the **Etch*Director*©** windows may be opened in any of the panels at any time. A window is opened in one of the panels by moving the cursor over one of the horizontal bars across the top of the panel, until it appears as a hand and then left clicking to bring up the window menu.



The window is the opened by clicking on the appropriate option - Process chart, Process all, Endpoint params, Structure, Log window, Materials, Video, XY stage. Similarly, a window can by closed by selecting the 'Close' option.

Windows can be resized by moving the cursor over the frame of a panel until it appears as two parallel lines and a pair of arrows. Then by holding down the left mouse button, the frame can be moved.

Upon opening **Etch*Director*©**, the panels will display the same windows that were active when the program was last closed, including the files that were loaded at the time. In addition, any customization of the windows (such as colors or units) are remembered and set as the default.

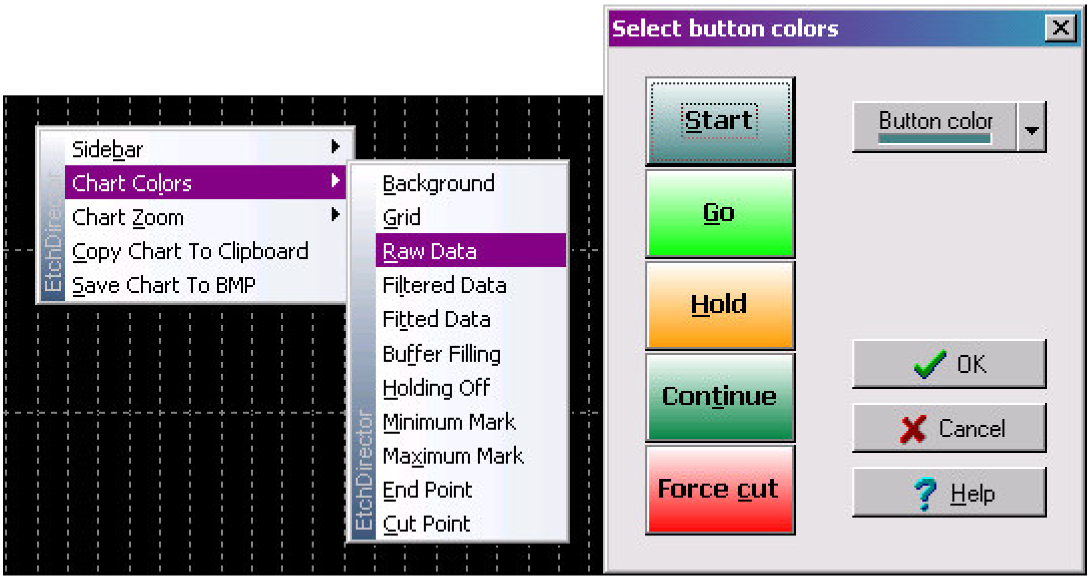
Options menu

The options menu allows the operator to adjust general **Etch*Director*©** settings relating to appearance, data collection and data storage.

The options are:
Button colors
Instrument profile
Directory structure

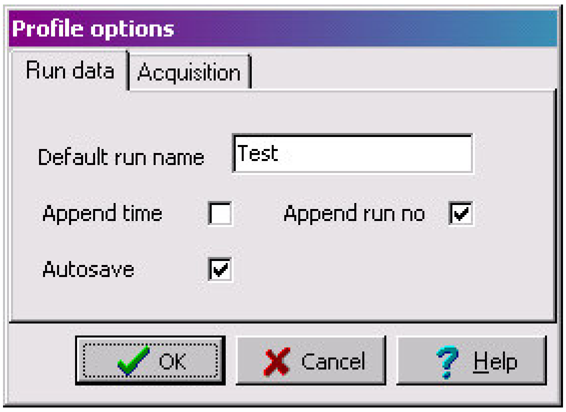
Color customisation

The colors of tabs, lines and markers on the sub-windows can be altered by right clicking on the window and selecting the 'color' option. The colors of the control panel buttons can be edited by selecting the 'Button colors' from the Options menu on the main toolbar.



Instrument profile

The instrument profile menu enables the auto-save function to be set up for process data. By checking the 'Autosave' box, every process is automatically saved in the specified directory once the endpoint run is finished. The file name consists of the characters entered in the 'Default run name' panel and appended with the clock time (in seconds) and/or run number according to the boxes checked. The file name is also displayed in the batch parameters display on the main **Etch*Director***© desktop. Take care not to choose a file name that already exists, as the old data will be overwritten.

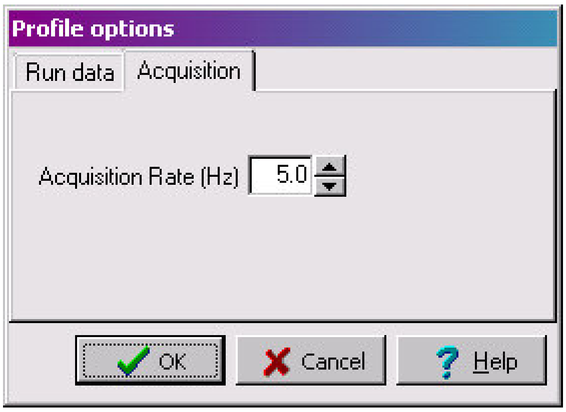


Default run name: Test

Append time ☐ Append run no ☑

Autosave ☑

On the second tab, the data sampling rate (in Hertz) can be specified up to a maximum of 20Hz. The sample rate should be sufficiently high to obtain at least 10 data points between signal maxima and minima. However, excessively high sample rates require more computer resource, 5-10Hz should be adequate for most processes.



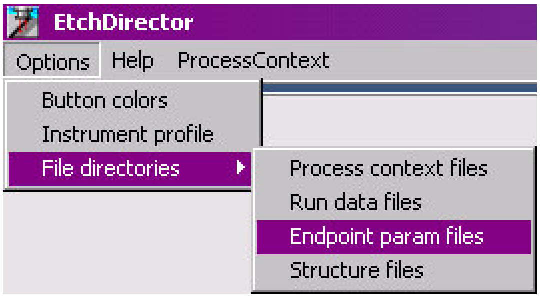
Acquisition Rate (Hz) 5.0

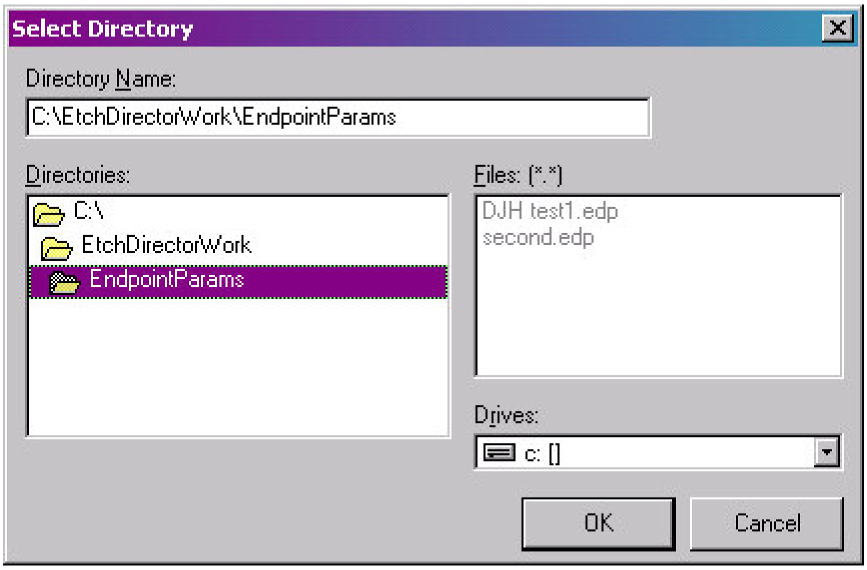
Batch parameters

The autosave file name as specified in the instrument profile and the run number are displayed on the application desktop. Upon opening **Etch*Director***©, the run sequence number is reset to 0 and is automatically incremented by 1 every time the process 'Start' button is activated.

File directories

When an **Etch*Director***© file is saved, the save window opens at a default path, which are user defined in the 'File directories' option. To change the default directory for a file type, navigate to the data type on the pull down 'File' menu and select a new path using the dialogue box that is opened.

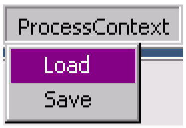




C:\EtchDirectorWork\EndpointParams

Process contexts

A Process context file stores the Instrument profile and Endpoint params settings, enabling the complete acquisition settings for a given process to be stored in one location. Files (with the .edc extension) are loaded and saved directly from the Process contexts on the main toolbar.

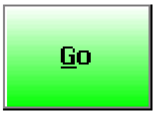


Control panel

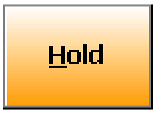
The Control panel contains the main operator controls used for running an endpoint process. The input controls and status indicators correspond to the digital I/O states.

Control panel inputs

Initialize a process run.



Begin data acquisition.



Pause data acquisition.

Continue data acquisition.

Terminate the endpoint step currently running. This will cause an error output to be sent and an error displayed in the Log window and in the Status bar, as the software has not found the endpoint, but subsequent endpoints will proceed unaffected by **Etch*Director*©**.

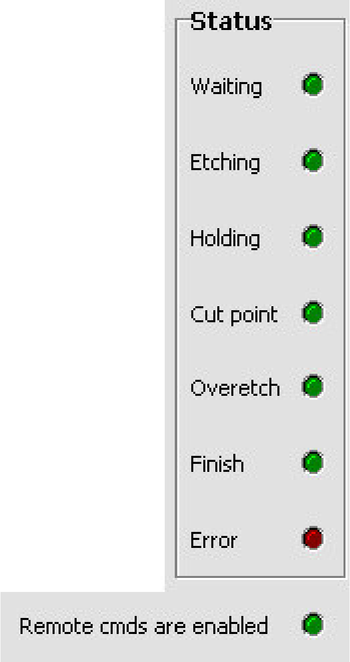
Each input functions is only available at particular stages during the process (e.g. you cannot 'Continue' a run until you have put it in 'Hold'), at which time the buttons are displayed in color. When they are not available the buttons are greyed.

Control panel status display

The status of the endpoint process is indicated by a flashing light beside one of the steps on the control panel. When active, they indicate the following:

WAITING - The endpoint process has been initiated and the system is waiting for the 'Go' command.
ETCHING - The system is collecting data and looking for the next endpoint.
HOLDING - Data acquisition has been paused.
CUT POINT - The current endpoint has been found and over-etch completed.
OVERETCH - The process is in overetch.
FINISH - The final endpoint and overetch specified has been found.
ERROR - **Etch*Director*©** has encountered an error before completing the current endpoint run.
REMOTE CMDS ARE ENABLED - The remote enable is active, allowing the digital I/O to control the endpoint detector.

The change in state is also displayed in the Log window and in the Status bar.



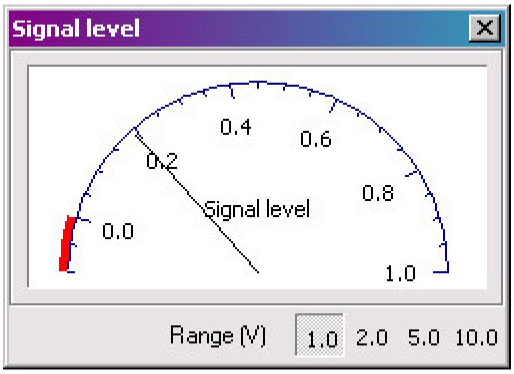
Process data display

During an endpoint run, key process parameters are displayed in real time - Process time (seconds), reflected signal level (Volts), Etch rate and etch depth (both user definable units).

The etch rate and depth are only displayed, if an analysis mode has been selected in the Endpoint params window that involves identification of interference fringes. If this is the case, the rate and depth will only be calculated once the software has locked on to the process signal, after two turning points.

Real-time signal display

This displays the real-time detector signal level, useful for setting up the offset and gain, as detailed in the installation manual. Clicking on the '...' button opens the analogue display window with scalable axis.



Status bar

The current endpoint process status and any error messages that occur are displayed in the status bar at the bottom of the application window. The change in process status is also displayed in the Log window.

Sidebars

Each sub-window is identified by a sidebar along its left hand edge. This sidebar can be edited by right clicking on the sub-window and highlighting the 'Sidebar' option. The sidebar can be removed by deselecting the 'Show' option. The sidebar background and font color can be chosen by clicking on 'Color' or 'Font color'.

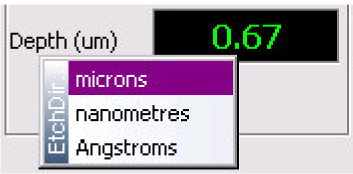
Zooming and panning

Data displayed in **Etch*Director*©** charts (Model, Process and Process all precision view) can be studied in more detail using the zoom and pan functions. Right clicking on the graph and selecting the 'Chart zoom' function displays the available options:

Pan: Displays the hand cursor. Holding down the left mouse button and moving the mouse scrolls the data through chart window.
Drag: Displays the zoom cross-hairs. Holding down the left mouse button and moving the mouse in the positive axis direction (i.e. up or right) enlarges the chart scale in that direction. Moving the mouse in the negative axis direction (i.e. down or left) reduces the chart scale in that direction.
Zoom window: Displays the zoom window cursor. Clicking and dragging a box on the chart rescales the contents of the box to fill the chart window.
Zoom all: Returns the chart display to the original size, but the current zoom mode is still active.
Cancel zoom: Returns the chart display to the original size and cancels the current zoom function.

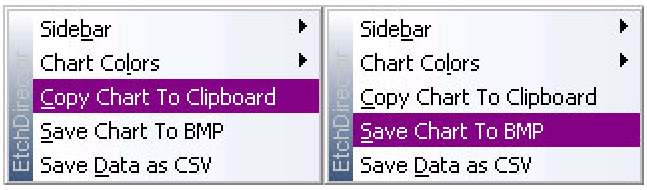
Units

The units of physical thickness or depth or etch rate can be set locally on any screen. Right clicking on the number window or thickness column header in the case of the structure window presents the units available, which can be activated by left clicking on. The units of thickness available are microns (um), nanometres (nm) and Angstroms (A). The units of etch rate available are microns per second (um/sec), nanometres per second (nm/sec), Angstroms per second (A/sec) and microns per minute (um/min).



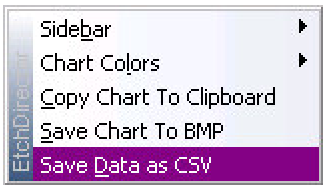
Exporting chart images

Etch*Director*© charts may also be exported as graphical images. Right clicking on the chart enables two options. 'Copy Chart To Clipboard' will export an image of the chart to the Windows clipboard. This image can then be imported into a graphics application (e.g. Paint), edited and saved as required. To do this simply open the graphics software and click on 'Paste'. Alternatively the chart may be saved as a bitmap (.BMP file) directly from **Etch*Director*©**. Selecting the 'Save Chart To BMP' option opens a save dialogue box allowing the file name and path to be entered.



Exporting data as .CSV

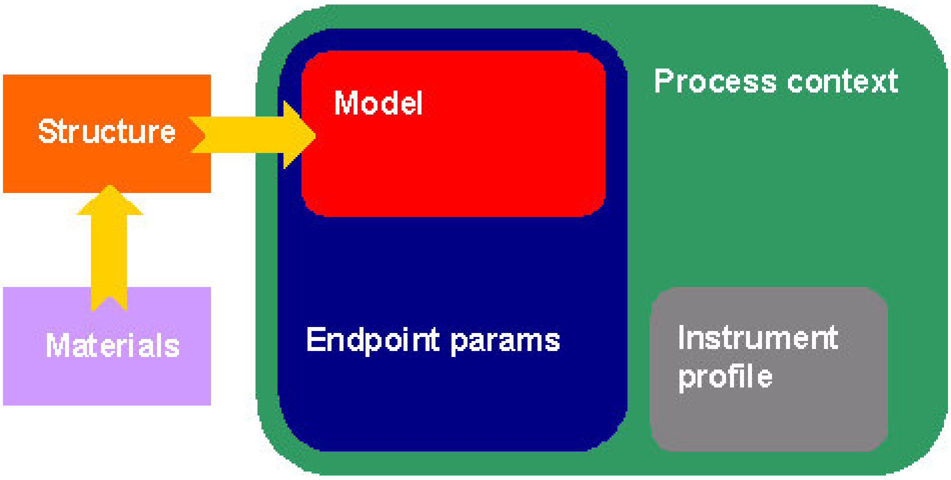
Etch*Director*© model and process data may be exported to .CSV (comma separated variable) format for display in other applications, such as Microsoft Excel. Data can be exported from the Process all window, Precision view screen, Model window and the model view in th Endpoint params window. Right-click on the chart and select the 'Save Data as CSV' option ot open the Save as dialogue box, then enter the required file and path name.



The process data exported is the filtered dataset. If the raw data is required, the process run should first be reprocessed at the maximum filter cut off level.

Window & file type overview

As you begin to use **Etch*Director*©**, it will become apparent that there are a number of different files to which various settings can be saved to and loaded from. Each file stores different discrete endpoint information or other types of endpoint files, enabling the user to choose the level to which a process endpoint is defined. The inter-relationships between the types of data is shown in the diagraml, below. For more detail on a file/window click on the appropriate box.



Etch*Director*© files can be identified from their file extensions:

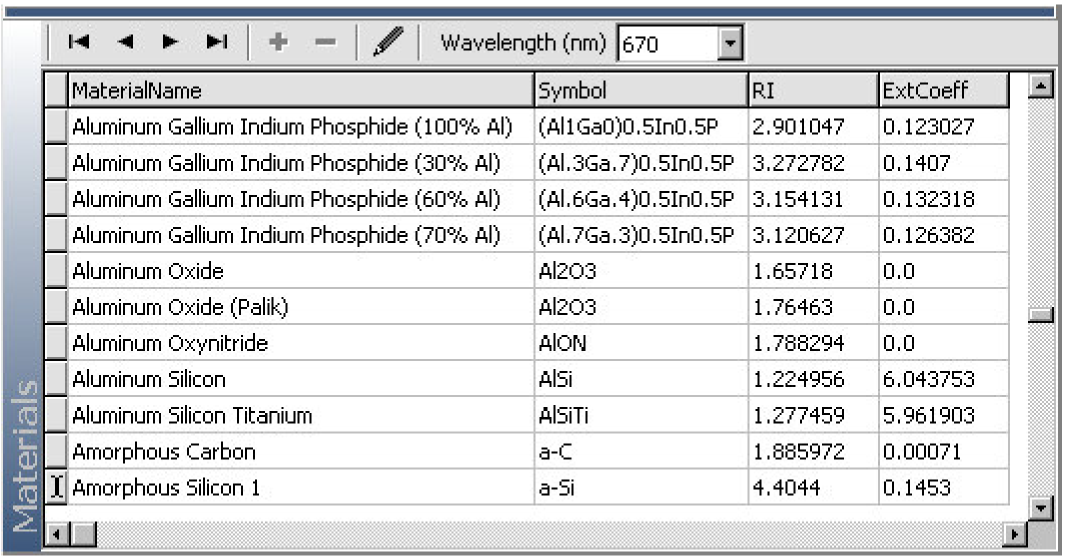
.eds Structure file
.mod Model file
.edp Endpoint params file
.edc Process context file
.edd Process data file

Each has a user defined default file directory, which is opened when a 'save as' command is activated.

Materials database

In order to interpret the measured endpoint signal, it will often be required to input the optical properties of a material. **Etch*Director*©** contains an online database of this information.

The Materials database is opened by moving the cursor over the top of a window frame (until it is displayed as a hand) and left clicking to open the window menu and then selecting the 'Materials' option. To close the window, repeat this process, but select 'Close' from the window menu.



Wavelength (nm) 670

MaterialName	Symbol	RI	ExtCoeff
Aluminum Gallium Indium Phosphide (100% Al)	(Al1Ga0)0.5In0.5P	2.901047	0.123027
Aluminum Gallium Indium Phosphide (30% Al)	(Al.3Ga.7)0.5In0.5P	3.272782	0.1407
Aluminum Gallium Indium Phosphide (60% Al)	(Al.6Ga.4)0.5In0.5P	3.154131	0.132318
Aluminum Gallium Indium Phosphide (70% Al)	(Al.7Ga.3)0.5In0.5P	3.120627	0.126382
Aluminum Oxide	Al2O3	1.65718	0.0
Aluminum Oxide (Palik)	Al2O3	1.76463	0.0
Aluminum Oxynitride	AlON	1.788294	0.0
Aluminum Silicon	AlSi	1.224956	6.043753
Aluminum Silicon Titanium	AlSiTi	1.277459	5.961903
Amorphous Carbon	a-C	1.885972	0.00071
Amorphous Silicon 1	a-Si	4.4044	0.1453

The database contains a list of materials, their symbol notation and their optical properties (refractive index (RI) and extinction coefficient) for a range of wavelengths. The optical properties of materials vary with wavelength, so it is important to select the correct operating wavelength from the toolbar menu before you begin using the database.

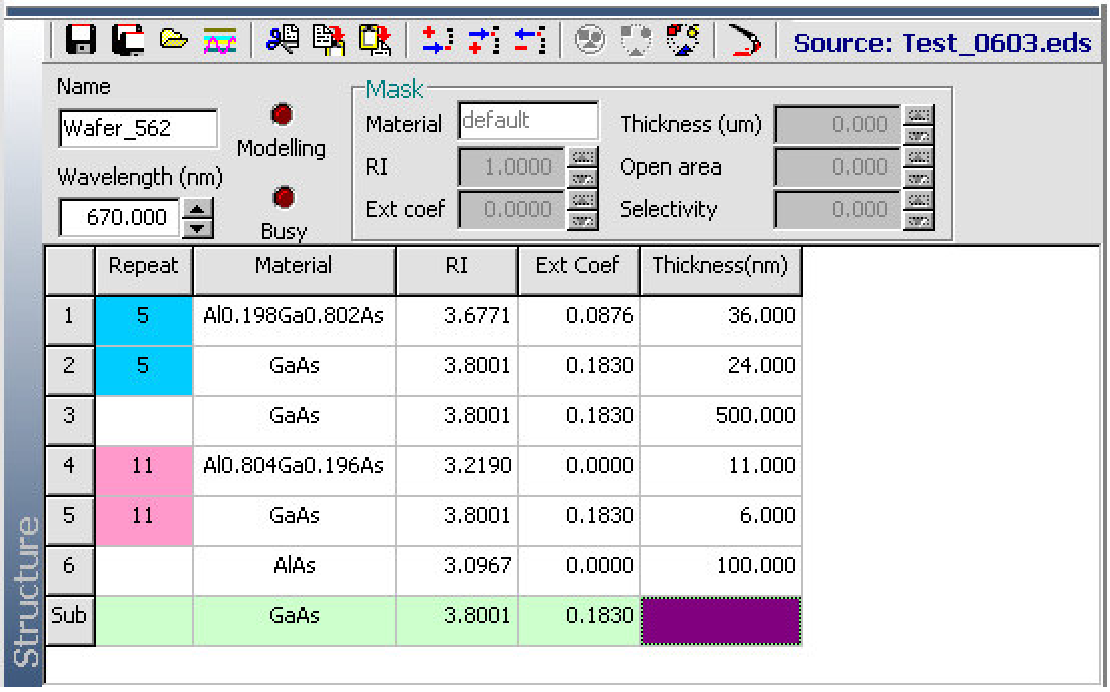
The database may be manually edited in **Etch*Director***©, allowing user-defined materials to be added. To enable editing, click on the edit icon on the toolbar. Then manually click on a row or use the arrow keys on the toolbar to move the row mark in the furthest left column to the desired position. Then the '+' button can be used to insert a blank row at that position, which should then be filled in manually or the '-' button can be used to remove the selected row. Be careful when removing rows, as once data is erased, it cannot be recovered. Once editing is complete, deactivate the edit button on the toolbar.

The default wavelength value for the database is factory set, with service access provided in the registry. The standard sidebar customisation options are available for the Materials database.

Structure window

For multiple layer etches, the software uses a theoretical model curve to calculate the etch depth. In order to generate a model, the operator must first define the composition of the wafer - materials, thicknesses and refractive indices. This is done in the structure window.

The Structure window is opened by moving the cursor over the top of a window frame (until it is displayed as a hand) and left clicking to open the window menu and then selecting the 'Structure' option. To close the window, repeat this process, but select 'Close' from the window menu. The standard sidebar customisation options are available for the Structure window.



Source: Test_0603.eds

Name: Wafer_562

Wavelength (nm): 670.000

Mask
Material: default
RI: 1.0000
Ext coef: 0.0000
Thickness (um): 0.000
Open area: 0.000
Selectivity: 0.000

	Repeat	Material	RI	Ext Coef	Thickness(nm)
1	5	Al0.198Ga0.802As	3.6771	0.0876	36.000
2	5	GaAs	3.8001	0.1830	24.000
3		GaAs	3.8001	0.1830	500.000
4	11	Al0.804Ga0.196As	3.2190	0.0000	11.000
5	11	GaAs	3.8001	0.1830	6.000
6		AlAs	3.0967	0.0000	100.000
Sub		GaAs	3.8001	0.1830	

Toolbar buttons

Save the current structure to a file. The structure file currently open will be overwritten.

Save the current structure as a new file.

Load a saved structure file.

Model the current structure.

'Cut' the highlighted cell(s) or row(s). This function writes the data to the clipboard, while erasing the information from the cells in the structure window

Copy the highlighted cell(s) or row(s). This function writes the data to the clipboard, while leaving the information in the structure cells unchanged.

Paste the contents of the clipboard to the highlighted cells.

Insert a blank layer directly above the substrate.

Insert a blank layer directly above a highlighted cell.

Remove the layer in which a cell is highlighted.

Group together the highlighted rows.

Separate the rows in a group currently highlighted.

Separate the rows in all the groups in the structure.

Select the color of the substrate layer.

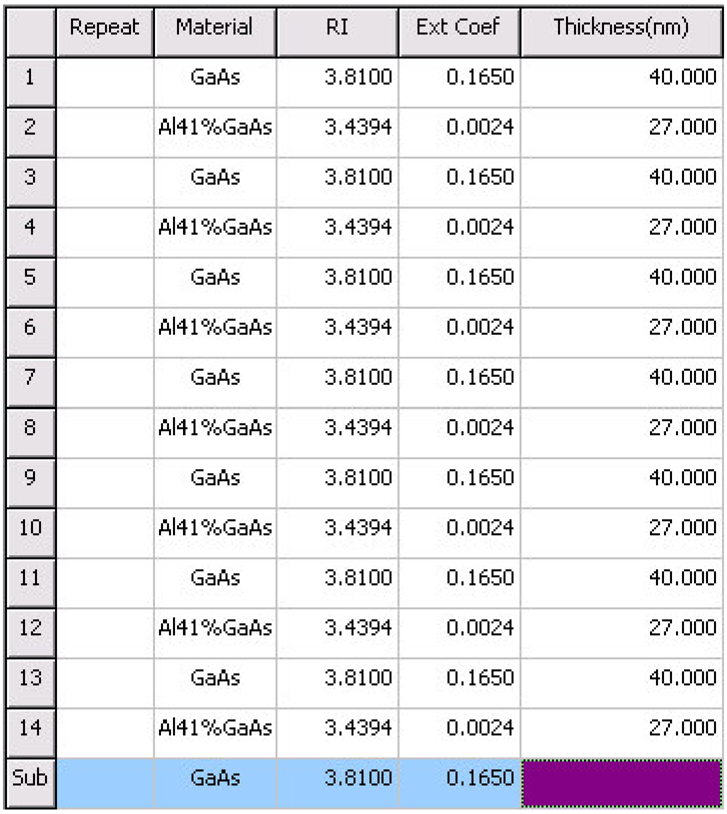
Building a structure

The wafer structure table represents the material layers as if the wafer is being viewed in cross-section; layer one being the top film, with the layer number increasing until the bulk wafer is reached (substrate).

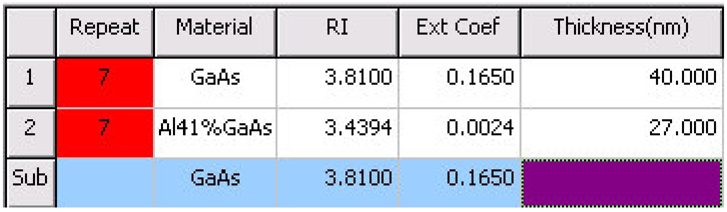
The process of building a structure starts by adding empty layer rows to the table, using either one of the insert buttons on the structure window toolbar. Alternatively, this can be done by right clicking on the structure and navigating to the 'Layers' sub-menu. You will be prompted to input how many layers you wish to insert, thus enabling multiple rows to be entered at once.

The next step is to 'fill in' the empty boxes. The materials' name and refractive indices can be entered directly from the Materials database by double-clicking on the material name box. This opens the database in a new window from which materials can be highlighted, either manually or using the arrow keys on the toolbar, and entered directly into structure by clicking on the 'Select' button. However, before choosing any materials, be sure the wavelength in the database (displayed on the top on the window and in the left hand column) matches the laser wavelength you are working with. If this is not the case the wavelength should be changed by opening the materials database in one of the standard window panels. Alternatively, the materials names and refractive indices can be entered manually by clicking on the empty boxes. Then the layer thickness should be entered, baring in mind the units setting, displayed in the column header. On very complicated structures (100+ layers), a higher level of computer resource is required to read structure edits, which may result in the 'Busy' indicator becoming momentarily illuminated.

The cut/copy and paste options on the toolbar may be used to manipulate cells or groups of cells. Where the structure has a film stack consisting of duplicate sets of layers, the repeat column can be used to simplify the structure display. To use the repeat function, the layers that constitute the unit of repetition must be grouped. This is done by highlighting one or more columns of cells covering all the rows requiring grouping and clicking on the 'group' button on the toolbar. You will then be prompted to assign a color to the group, that will be displayed in the repeat cells on the structure table. The repeat value may then be edited as any other cell to achieve the required structure.



	Repeat	Material	RI	Ext Coef	Thickness(nm)
1		GaAs	3.8100	0.1650	40.000
2		Al41%GaAs	3.4394	0.0024	27.000
3		GaAs	3.8100	0.1650	40.000
4		Al41%GaAs	3.4394	0.0024	27.000
5		GaAs	3.8100	0.1650	40.000
6		Al41%GaAs	3.4394	0.0024	27.000
7		GaAs	3.8100	0.1650	40.000
8		Al41%GaAs	3.4394	0.0024	27.000
9		GaAs	3.8100	0.1650	40.000
10		Al41%GaAs	3.4394	0.0024	27.000
11		GaAs	3.8100	0.1650	40.000
12		Al41%GaAs	3.4394	0.0024	27.000
13		GaAs	3.8100	0.1650	40.000
14		Al41%GaAs	3.4394	0.0024	27.000
Sub		GaAs	3.8100	0.1650	🟪



	Repeat	Material	RI	Ext Coef	Thickness(nm)
1	7	GaAs	3.8100	0.1650	40.000
2	7	Al41%GaAs	3.4394	0.0024	27.000
Sub		GaAs	3.8100	0.1650	🟪

In addition, grouping may be used to color code regions of the wafer structure that are not repeated, so that they are more easily identified.

If stepped level interferometry is being used, the mask properties should be set.

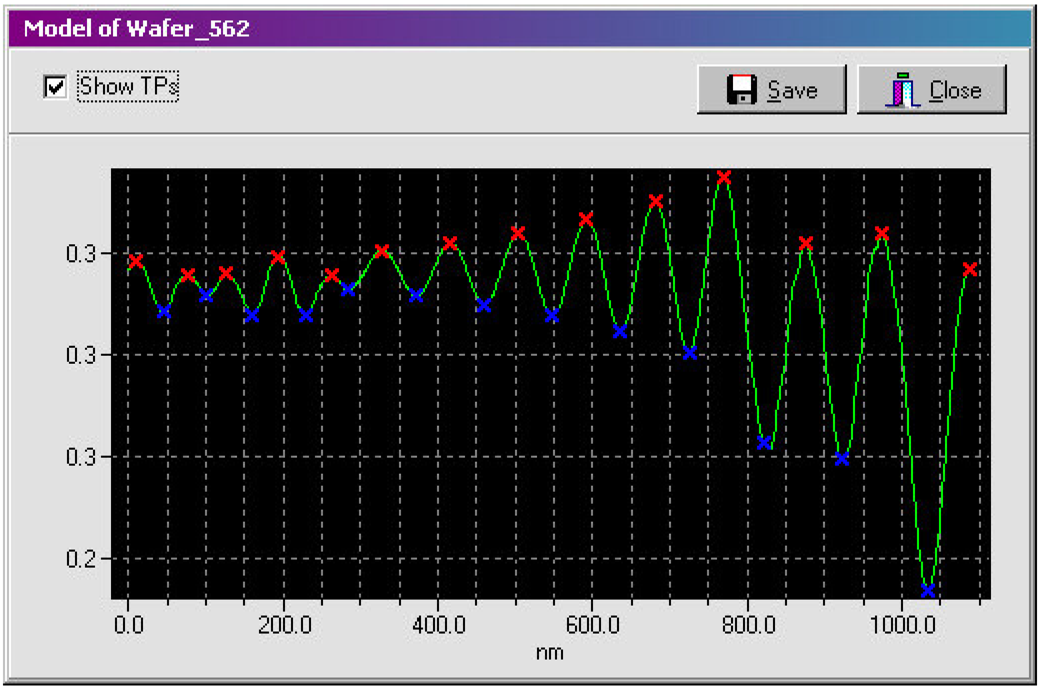
Finally, the operating wavelength should be entered. If unsure, this value will be listed on the Configuration Record page of the instruction manual and on the optical head itself.

Mask properties

This feature is not yet available.

Generating a model

Once the structure has been entered, the model waveform can be calculated by clicking on the button on the Structure window toolbar. The trace is plotted on to a new window.



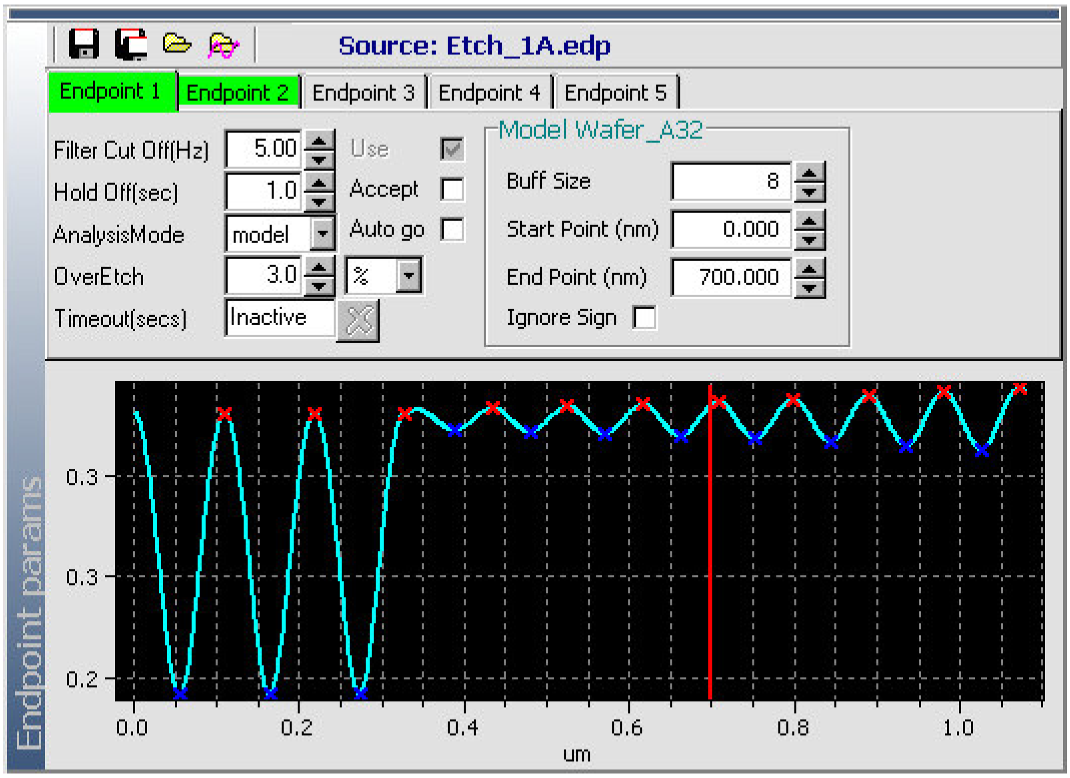
Checking the 'Show TPs' box marks identified turning points. The 'Save' option enables the model to be saved in **Etch*Director***© model format (*.mod) that can be used in the Endpoint params window. The trace may also be exported as a .CSV file.

The usual zooming and panning, image export and color and unit customisation options are available.

Endpoint params window

The Endpoint params window stores the measurement parameters that define the endpoint. An endpoint recipe may utilise up to five separate endpoint events, programmed with a range of analysis modes, over etch filter and pre-etch settings.

The Endpoint params window is opened by moving the cursor over the top of a window frame (until it is displayed as a hand) and left clicking to open the window menu and then selecting the 'Endpoint params' option. To close the window, repeat this process, but select 'Close' from the window menu.



Source: Etch_1A.edp

Filter Cut Off(Hz) 5.00
Hold Off(sec) 1.0
AnalysisMode model
OverEtch 3.0 %
Timeout(secs) Inactive
Use ☑
Accept ☐
Auto go ☐

Model Wafer_A32
Buff Size 8
Start Point (nm) 0.000
End Point (nm) 700.000
Ignore Sign ☐

The standard sidebar customisation options are available. In addition, the endpoint tab colors are also set from the menu opened by right-clicking in the main body of the window.

Toolbar buttons

Save the current endpoint parameters. The endpoint params file currently open will be overwritten.

Save the current endpoint parameters as a new file.

Load a previously saved set of endpoint parameters for which the file name will be displayed on toolbar.

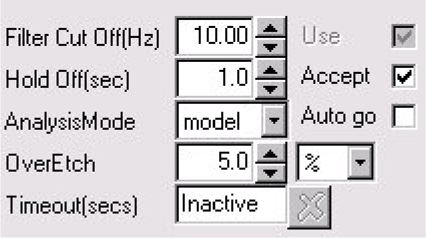
Load a model file (only active when in Model analysis mode)

The name of the endpoint params file currently in use (Source) is displayed on the right hand side of the toolbar. When **Etch*Director*©** is opened, the parameter values which were last in use are loaded, but not the file in which they are saved. This allows new users to use optimised settings without being able to overwrite another users file.

General endpoint settings

Use

An endpoint step is activated by checking the 'Use' box, which then causes the endpoint tab to become highlighted. For most processes just a single endpoint step is required (Endpoint 1 is always set active, and the box is greyed). However, occasionally multiple steps may be required, be it to allow for a cool-down step, change in process chemistry or compensate for layer thickness variations. In such circumstances the endpoint steps must be run sequentially, ie you cannot jump a step.



Filter Cut Off(Hz) 10.00
Hold Off(sec) 1.0
AnalysisMode model
OverEtch 5.0 %
Timeout(secs) Inactive
Use ☑
Accept ☑
Auto go ☐

Accept

Checking the 'Accept' box causes the software to react to a detected endpoint by ceasing data acquisition and sending a 'Cut' digital output. This is the usual method of operation, however, sometimes the operator may wish to observe the signal and terminate the process manually by clicking on the 'Force cut' Control panel input. While this box is uncheck, data will continue to be acquired until the operator ends the run manually or the process timeout (below) is reached. The calculated endpoint will be marked on the Process chart as usual, but no digital 'Cut' output will be sent. The 'Accept' box status may be changed during the endpoint process if required.

Auto Go

Checking the 'Auto Go' box ties the 'Go' input to the 'Start' input, so when a 'Start' command is received, data acquisition begins immediately.

Filter Cut Off

The acquired process data is passed through a [software] Butterworth filter to increase the signal to noise ratio. Such smoothing reduces the risk of signal noise being incorrectly interpreted as interference fringes by **Etch*Director***©, leading to inaccuracies in the calculated etch depth, rate and ultimately endpoint. The 'Filter Cut Off' value determines the degree of filtering applied to the raw process data. The lower the set frequency, the more smoothing the information occurs. However, beware over-smoothing, as it can lead to the loss if information, which is also detrimental to the performance of the instrument. In addition, the filtered signal will time-lag the raw data signal (something which can be observed on the Process chart window), resulting in an overetch. If high levels of noise occur persistently, the cause of the problem should be sought. Signal noise may occur from roughening of the wafer, degradation of the chamber window condition, mechanical clamping stability of either the optical head or wafer, optical interference from the plasma or electrical interference.

Hold off

The first few seconds of an etch may often exhibit more noise than the rest of the process, due to a surface contaminants or plasma stabilization. Rather than reducing the filter cut off frequency, which would make it unnecessarily low throughout the main part of the etch, a hold off can be set. This is the number of second at the start of the process which are not analysed by **Etch*Director***©. The data collected during the hold off period is shown in a different color on the Process chart window.

Analysismode

The endpoint data collected can be process by any one of several analysis modes: Model, Simplex, Kink.

Overetch

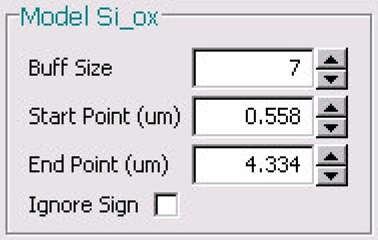
Etch*Director*© can also be used to apply an overetch time to an endpoint process. This is set in the 'Overetch' box in either seconds or as a percentage of the process time (between receiving 'Go' and the endpoint being detected) according to the selection in the adjacent units box. When an overetch is active the 'Cut' output is sent once the over etch is complete, when the endpoint is found.

Timeout

An endpoint process timeout can be set, which will terminate the run after a specified time, if the endpoint has not been found. A timeout setting is cleared by clicking on the red cross to the right of the box.

Model analysis mode

In model analysis mode, **Etch*Director*©** compares the measured process data with a pre-defined model trace. A model is loaded from the toolbar on the Endpoint params window and the trace displayed in the chart area beneath the endpoint parameter settings. The standard chart color, zoom, units, image export and CSV data export options are available. Aside from the general endpoint settings, specific model endpoint parameters must also be set. The name of the currently active model is displayed next to these parameters.



Model Si_ox

Buff Size: 7

Start Point (um): 0.558

End Point (um): 4.334

Ignore Sign ☐

Buff Size

This box specifies the buffer, which is the size of the data point window analysed for turning points. The optimum value depends on the etch rate, sample rate and the signal to noise ratio. Ideally it should be made as small as possible in order to reduce the time lag between collecting data at the turning point and actually identifying the turning point. However, if the buffer size is too small, noise may be erroneously identified as interference fringes. The buffer size is discussed in more detail in the frequently asked questions section of the help.

Start point

This defines the start position from which the etch will be monitored, and is set by typing the depth or by clicking and dragging the green vertical bar on the model plot. Normally this will be set to zero, but moving the start position can help to compensate for wafer-to-wafer variations in starting thickness, see frequently asked questions.

End point

This value is the target endpoint depth and is set by either entering the required figure into the box or clicking and dragging the red vertical bar on the model plot. This endpoint must be set beyond the second turning point, see below. The units of 'End point' and 'Start point' can be changed by right clicking on the value box and selecting from the available options (A, nm, um).

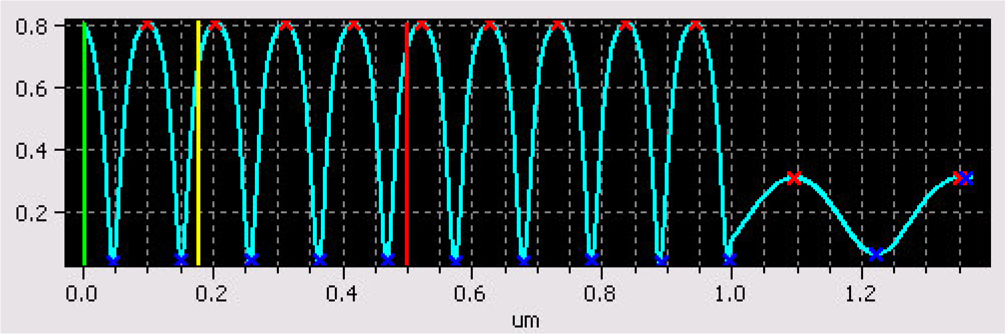
Ignore sign

If this box is checked, when **Etch*Director*©** compares the turning points identified in the process signal with those in the model, it will not distinguish between their sense (maximum or minimum). Therefore, it will lock on to the model after the first two turning points, whatever their form. If this option has to be activated, then it is an indication that the model is not a true representation of the wafer, and thickness and refractive indices used in the structure should be checked.

Endpoint detection

In order to calculate the etch depth in real-time, **Etch*Director*©** must compare the process data with the model. To do this it must find an initial point of comparison between the two traces. This point is when two turning points (fringes) are found in the process data that match the first two fringes in the model. The sense of the turning points must match those of the model, i.e. if the model begins with a maxima followed by a minima, **Etch*Director*©** must identify a maxima followed by a minima in the process data in order to begin a depth measurement. Consequently, the endpoint must be set after the second turning point of the model.

If a turning point of a different sense to the model is identified first, then it will be ignored until a matching pair is found. In this case, the ignore sign check box may be used, however, it does indicate a discrepancy between the actual wafer composition and the model structure, which should be checked.

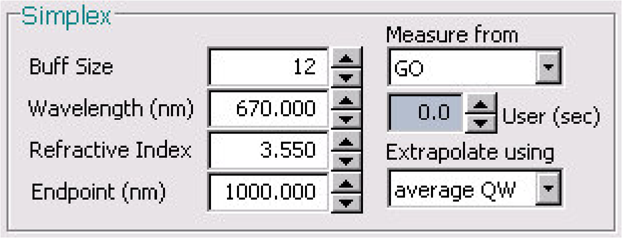


Once 'lock on' to the model has been achieved, the calculated etch depth and rate are displayed in the data display in the lower right hand corner. In addition, a vertical yellow bar is displayed on the model chart, illustrating the progress of the etch. Every turning point measured on the process trace is compared to the model and the depth re-corrected if necessary.

The etch rate is calculated by dividing the quarterwave thickness (the depth between turning points on the model) by the quarterwave time (time between subsequent turning points). This rate is then used to extrapolate the etch depth in the subsequent quarterwave, until the next model reference point is identified in the process data (i.e. the next turning point). Therefore, it is clear that any noise detected could be erroneously by identified as genuine, closely packed interference fringes and give rise to a larger than actual etch rate being calculated. This in turn would cause the calculated depth to increase rapidly and premature endpoint detection. Likewise, if the etch rate slow considerably, it will not be detected by **Etch*Director*©** until the next turning point is identified. This can also lead to premature endpointing if the etch rate calculated in the previous quarterwave will extrapolate the calculated depth to the set endpoint before the next turning point is detected.

Simplex analysis mode

The simplex analysis mode provides a more basic tool enabling endpoints to be found on single layer etches, without the complication of using a model. Aside from the general endpoint settings, specific simplex endpoint settings must also be set. In addition to the data processing parameters, basic information about the wafer is also stored here.



Buff Size 12
Wavelength (nm) 670.000
Refractive Index 3.550
Endpoint (nm) 1000.000
Measure from GO
0.0 User (sec)
Extrapolate using average QW

Buff Size

This box specifies the buffer, which is the size of the data point window analysed for turning points. The optimum value depends on the etch rate, sample rate and the signal to noise ratio. Ideally it should be made as small as possible in order to reduce the time lag between collecting data at the turning point and actually identifying the turning point. However, if the buffer size is too small, noise may be erroneously identified as interference fringes. The buffer size is discussed in more detail in the frequently asked questions section of the help.

Wavelength

This value is the wavelength of the laser being used to probe the wafer. The laser wavelength is listed in the system configuration record in the instruction manual and on the side of the optical head itself. The units of wavelength are changed using the menu opened by right clicking on the value box.

Refractive Index

The refractive index of the material layer being etched should be entered here. If not known, it can be looked up in the **Etch*Director***© Materials database. In order to operate in this mode, clear interference fringes must be detectable, so the material must be transparent (i.e. the extinction coefficient is zero).

Endpoint

This value is the target endpoint depth and is set by either entering the required figure into the box. This endpoint must be set beyond the second turning point, so that 'lock on' can be achieved. The units of 'End point' can be changed by right clicking on the value box and selecting from the available options (A, nm, um).

Measure from

This enables the operator to select from where in the process trace the etch depth measurement is begun, allowing compensation for RF-matching delays or surface contamination which may prevent normal etch rates being achieved directly after a plasma is struck. The available measurement triggers are:
GO - from when the 'Go' command is received
HOLDOFF - from the end of the 'hold off' time
User defined - from a user-specified time (in the box below) after the 'Go' command is received.

Extrapolate using

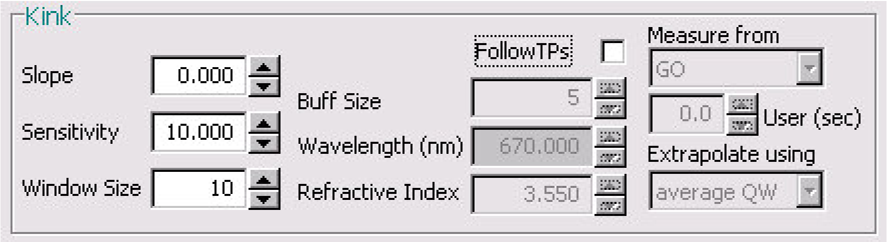
Between turning points, the etch depth is extrapolated using the previously calculated etch rate. This can be the rate average calculated over all the detected interference fringes (average QW) or the rate calculated from juts the last quarterwave (nearest QW). The latter makes the measurement more sensitive to changes in the etch rate, but the former is less sensitive to signal noise being erroneously identified as genuine fringes.

Endpoint detection

Since only one material is being etched, the depth can be calculated using just the laser wavelength and refractive index, since the distance between turning points is one quarterwave (wavelength/(4 x refractive index)). With the quarterwave time also known, the etch rate can be calculated and used to extrapolate the real time etch depth. Therefore, in order to begin measuring, **Etch*Director*©** must measure two turning points.

Kink analysis mode

Model and simplex analysis modes compare process data to a predicted curve in order to terminate at a specified depth. However, sometimes this may not be the most suitable technique for end pointing. For example, etching through an interface is often indicated by a distinct change in the measured signal level due to the variation in reflectivity. It can be useful to endpoint on these features rather than monitoring the interference fringes, as it will be less sensitive to variations in material thickness, refractive index and etch rate. Also, when etching wafers containing materials that are absorbing to the laser wavelength, characteristic signal changes are measured that can be identified by the software. These signal level changes (i.e. the signal gradient) are detected by the 'Kink' analysis mode. Aside from the general endpoint settings, specific kink endpoint parameters must also be set, see below. These parameters should be tuned by reprocessing previously obtained data.



Kink

Slope 0.000

Sensitivity 10.000

Window Size 10

FollowTPs ☐

Buff Size 5

Wavelength (nm) 670.000

Refractive Index 3.550

Measure from GO

0.0 User (sec)

Extrapolate using average QW

Slope

This parameter is in units of rate of change of the signal. The signal must consistently maintain or exceed the steepness of the reference slope over the extent of the data window in order to be accepted as an endpoint. Make sure you include the negative sign for downward trending features. For flat line detection (when etching down to an opaque layer, e.g. a metal) use a slope of 0.0. If the endpoint feature is going down rapidly, then use a value like -0.1, if the feature is going up rapidly then use a value like 0.1.

Sensitivity

This parameter determines the degree to which the data set within the window has to meet the slope criteria. The larger the number, the less critical the matching.

Window size

This parameter has units of sample points, and indicates the width of the sample window that will be used to establish that 'kink' has occurred. The endpoint is assigned to a point in the middle of the window. So, if the sample rate has already been set to 2Hz then 'Points in Window' of 15 means that a 7.5s period will be used to judge if a 'kink' has occurred in the data.

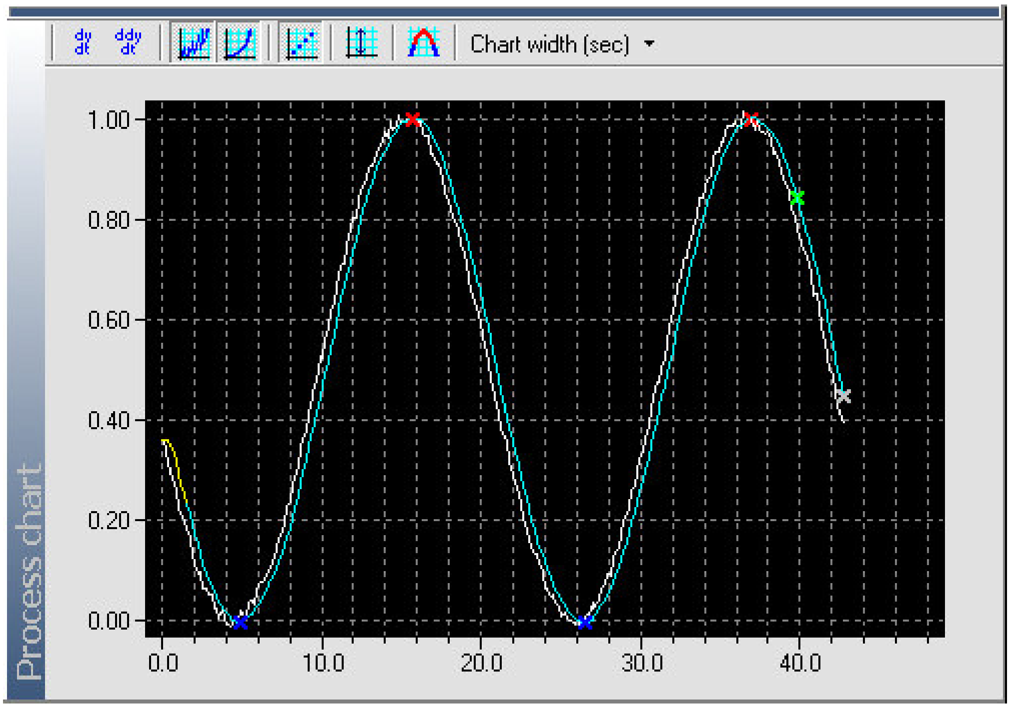
Follow TPs

If this box is checked, **Etch*Director*©** will, in addition, calculate the etch depth and rate in the simplex mode of operation. In this case, the depth calculation parameters that then become active should be set accordingly, as outlined under the Simplex analysis mode section.

Process chart window

The Process chart window displays the most recently acquired process data over a user-specified time interval. Displaying a narrow section of data enables the operator to study the fine detail of the process data and the performance of the software data-fitting algorithms. The complete process trace is displayed in the Process all window.

The Process chart is opened by moving the cursor over the top of a window frame (until it is displayed as a hand) and left clicking to open the window menu and then selecting the 'Process chart' option. To close the window, repeat this process, but select 'Close' from the window menu.



Toolbar buttons

The toolbar on the Process chart window contains buttons that control the way in which the process data is displayed. Click on the icons to activates the function and click once more to deactivate.

Displays the first derivative (or gradient) of the process data (feature not yet available).

Displays the second derivative of the process data (feature not yet available).

Displays the raw (unfiltered) process data.

Displays the smoothed (software filtered) process data.

Toggles the display between data points and joined line

Holds the y-axis (signal) at the current maximum and minimum values, so that if the process data range exceeds these limits, the axis will not rescale.

Displays the turning point curve fit, allowing the buffer size and filter frequency to be optimised.

Chart width (sec) ▾ A drop down menu allows the displayed time window to be selected, buy clicking on the appropriate value.

Chart display

The chart window shows measured voltage on the y-axis and time in seconds on the x-axis. The data plotted on the chart is coloured, depending on the phase of the process or function of the indicator. The colour legend is displayed (and customised) by right-clicking on the chart and selecting 'Chart colors'. Selecting an entry from the drop down menu will display the colour indicating that meaning and allows it to be changed. Similarly, the sidebar can be edited.

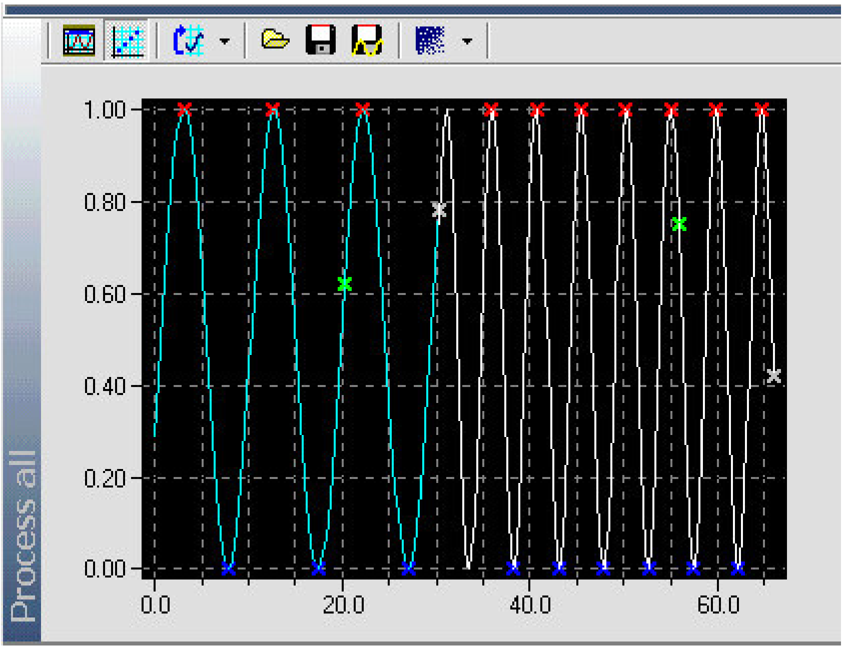
At the start of the process, the filtered data will be displayed in a different colour, indicating the size of the buffer and the hold off (if one has been set in the Endpoint params window). Marker crosses indicate identified maxima and minima, the endpoint and the cut point (after the overetch period if one has been set in the Endpoint params window).

The process data is auto-saved to a default directory, to a file name format defined in the instrument profile menu. However, the process data can be reprocessed and saved to a specific file on the Process all window. The zoom and pan functions can be used to study obtained data in more detail and the chart image can be exported.

Process all window

The Process all window displays a representation of the entire filtered data stream acquired during all the active endpoints specified in the Endpoint params window. A more detailed view of the most recently obtained data is displayed in the Process chart window.

The Process all chart is opened by moving the cursor over the top of a window frame (until it is displayed as a hand) and left clicking to open the window menu and then selecting the 'Process all' option. To close the window, repeat this procedure, but select 'Close' from the window menu.



Toolbar buttons

Plots the Precision view, showing all the data collected.

Toggles the data display between data points and a joined line.

Reprocesses a specified endpoint according to the settings in the Endpoint params window.

Load a previously saved process run.

Save the current process run in **Etch*Director***© format (*.edd). The data can also be exported as a CSV file.

Save the current process run as a model file.

Specify the data point density to plot on the process all chart.

Chart display

In order to efficiently manage the information, only a fraction of the acquired data points are displayed on the Process all chart. The point density is defined on the toolbar. During the process, the software prioritizes displaying data points at identified maxima and minima and displays selected intervening points with even spacing in order to obtain the specified point density. As the process progresses the number of data points displayed at turning points increases and consequently the number of data points displayed between turning points decreases, so the interference waveform becomes less well defined. Therefore, on long etches it is advisable to select the line display in order to show a clear process trace.

The complete data stream can be displayed by opening the Precision view panel.

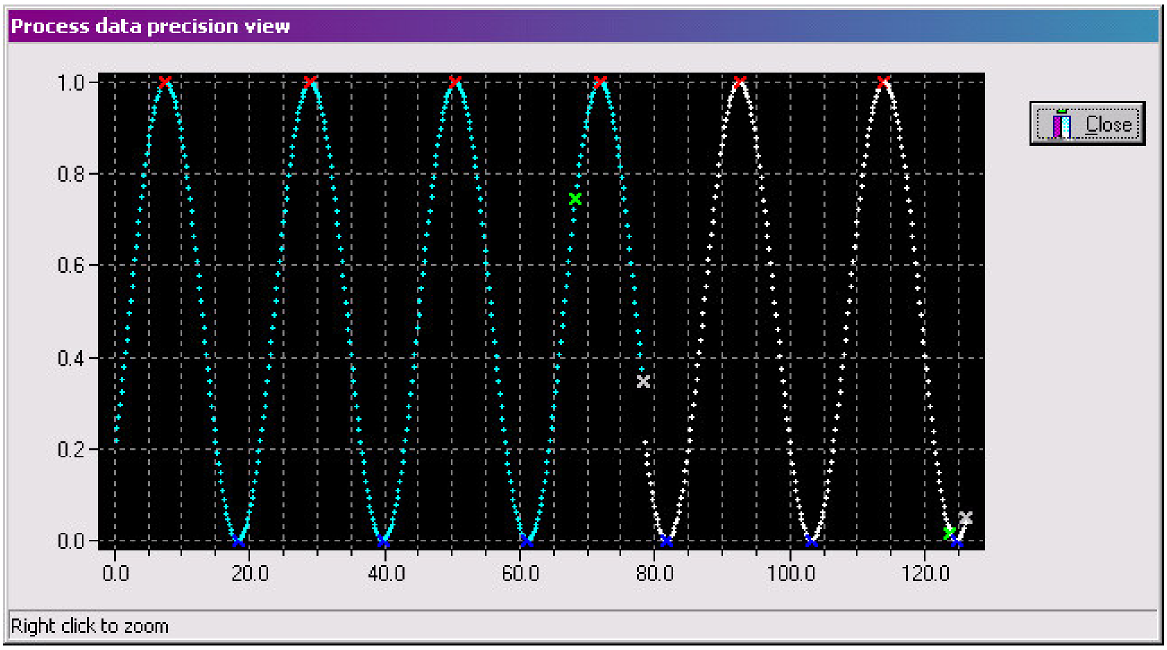
The process data is auto-saved to a default directory, to a file name format defined in the instrument profile menu. However, the process data can also be manually saved to a specific directory. Data files saved in the **Etch*Director*©** process format (*.edd) can be opened in the process all screen. The data will be loaded, endpoint1 reprocessed and the file name displayed next to the toolbar buttons.

As with the Process chart window, identified maxima, minima and other endpoint events are shown by distinct markers. In addition, data for different endpoints in the Endpoint params window is displayed in different colors.

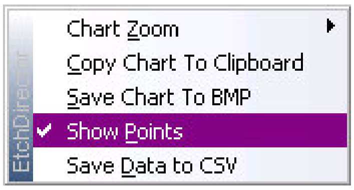
The standard sidebar and color edit and chart image export options are available. The zoom function is only available on the Precision view panel.

Precision view panel

Clicking on the precision view icon on the Process all window opens a new window displaying all the filtered data from the last endpoint run, as opposed to the decreased density plot on the process all chart. Turning points, endpoints and cut points are marked on the data.

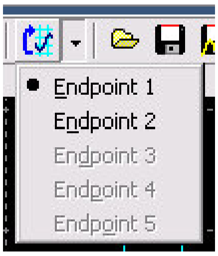


Right-clicking on the chart opens a menu enabling zooming, chart image export and CSV data export options. In addition, the data display can be toggled between point and line plot views.



Reprocessing data

Once process data has been obtained, the endpoint parameters can be fine tuned by reprocessing this already acquired information, removing the need to test adjustments on actual etches. To reprocess data, first load the process file and select the endpoint to be reprocessed from the pull down menu on the Process all window toolbar.



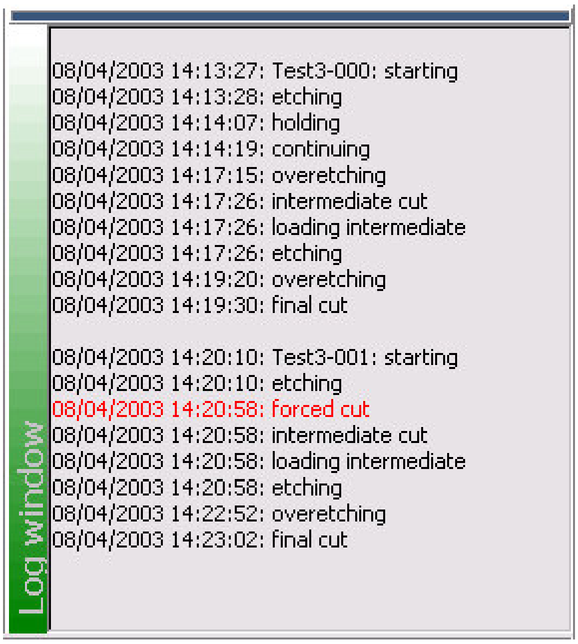
The Endpoint params settings at which the data was collected will be loaded along with the process run. Any of these values may now be changed, before clicking on the reprocess button on the Process all window. The data will then be displayed as it would have appeared had the new settings been applied before the etch.

When using reprocessing to optimise the endpoint parameters, it is advisable to apply new setting to several data sets to be sure they account for wafer-to-wafer variations.

Log window

The Log window tabulates the control panel status changes throughout the process.

The Log window is opened by moving the cursor over the top of a window frame (until it is displayed as a hand) and left clicking to open the window menu and then selecting the 'Log window' option. To close the window, repeat this procedure, but select 'Close' from the window menu.



```
08/04/2003 14:13:27: Test3-000: starting
08/04/2003 14:13:28: etching
08/04/2003 14:14:07: holding
08/04/2003 14:14:19: continuing
08/04/2003 14:17:15: overetching
08/04/2003 14:17:26: intermediate cut
08/04/2003 14:17:26: loading intermediate
08/04/2003 14:17:26: etching
08/04/2003 14:19:20: overetching
08/04/2003 14:19:30: final cut

08/04/2003 14:20:10: Test3-001: starting
08/04/2003 14:20:10: etching
08/04/2003 14:20:58: forced cut
08/04/2003 14:20:58: intermediate cut
08/04/2003 14:20:58: loading intermediate
08/04/2003 14:20:58: etching
08/04/2003 14:22:52: overetching
08/04/2003 14:23:02: final cut
```

Changes in process status are displayed automatically, there is no 'start' or 'stop' button. Even if the Log window was not open during a process, the entries will be displayed when the window is next opened during that **Etch*Director*©** session. The log entries are erased every time **Etch*Director*©** is shut down.

Each entry line is date- and time-stamped according to your computer settings at the instant the new status becomes active. The first entry for a new process is also labelled with the run name.

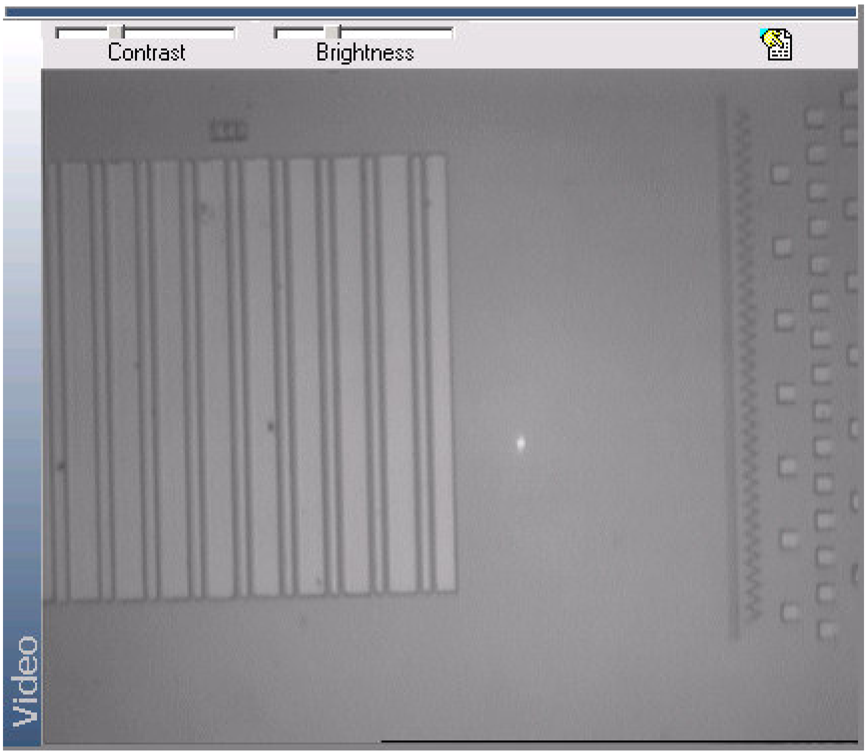
Any errors or manual interventions that impact the endpoint detection (eg a 'Force cut' command) are displayed in red.

The standard sidebar customisation options are available for the Log window.

Video window

If your system has a video capture card fitted, the Video window will display the camera image of the wafer in the **Etch*Director*©** software. Two types of video board are fitted as standard. This section describes the IDS Falconplus implentation, alternatively the National Instruments PCI 1407 board may be fitted. The specification of the video board fitted to your machine is described in the configuration record page of the installation manual.

The Video window is opened by moving the cursor over the top of a window frame (until it is displayed as a hand), left clicking to open the window menu and then selecting the 'Video' option. To close the window, repeat this process, but select 'Close' from the window menu. Once opened, the window will automatically begin acquiring video data from the card. The size of the video image can be changed by clicking and dragging on the frames of the window.



The contrast and brightness properties of the image and be changed using the sliders at the top of the video window. Right-click on the video window and select 'Tools' from the menu box to display the sliders.

The button on the toolbar activates the click and move calibration overlay.

The standard sidebar edit options are also available.

Errors

'video drivers not located...option not available' displayed on opening the video window indicates the video board or drivers are not installed. If you believe the board should be fitted to your system, please contact Intellevation.

If a blue screen is displayed instead of the camera image, either

- The video cable is not connected to the camera
- The video cable is not connected to channel one on the video board (bottom BNC connector).
- The camera is not receiving a supply voltage.

Video window (NI PCI-1407)

This section concerns the operation of the video display in **Etch*Director***© if a National Instruments PCI-1407 board is fitted (see installation manual).

The Video window is opened by moving the cursor over the top of a window frame (until it is displayed as a hand) and left clicking to open the window menu and then selecting the 'Video' option. To close the window, repeat this process, but select 'Close' from the window menu. Once opened, the window will automatically begin acquiring video data from the card. The size of the video image can be changed using the four icons on the window toolbar.

Measurement
& Automation

The image contrast can be optimised and image files exported using the National Instruments utility, Measurement & Automation Explorer, accessed via a shortcut on the Windows desktop. More details are given in the hardware installation manual. Remember, attempting to capture video data in more the one application simultaneously will create errors, to the **Etch*Director*©** Video window should be closed before running Measurement & Automation Explorer.

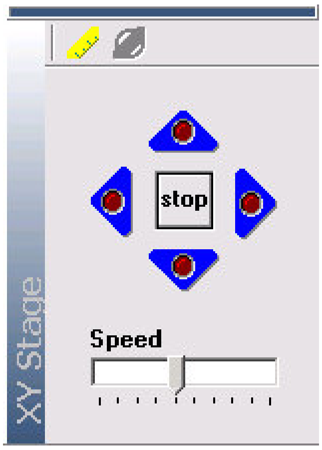
The standard sidebar edit options are available.

Errors

If the video card drivers are not installed or the board is being used by another software application, then a warning message will be displayed in the camera image area. If the camera is not attached to the board or there is no power supply to the camera (i.e. instrument cable not plugged in) the software will report an error locking on to the video source.

XY stage window

In order to use this window, the motorised translation stage hardware should be installed on the endpoint system. The XY stage window is opened by moving the cursor over the top of a window frame (until it is displayed as a hand) and left clicking to open the window menu and then selecting the 'XY Stage' option. To close the window, repeat this process, but select 'Close' from the window menu.



The stages are moved by clicking on and holding down one of the direction arrows. The current motion status is displayed in the status bar at the bottom of the application screen. The red lights on the arrows are activated when the stage has reached the limit of the travel range in that direction. The speed of motion is set using the speed slider - moving the slider right increases the speed.

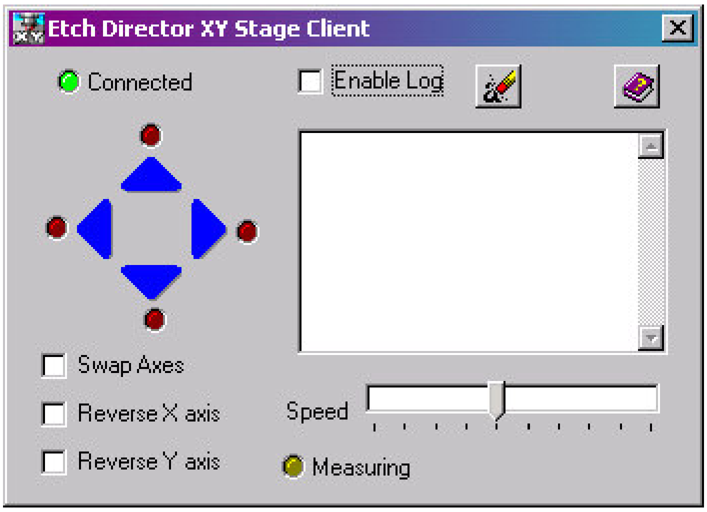
The buttons on the toolbar are used to calibrate click and move laser spot repositioning.

Additional motorised XY settings and diagnostics can be found in the XY Stage client.

The standard sidebar edit options are also available.

XY stage client

The motorised XY client collects information from the XY controller board and makes it accessible to **Etch*Director***© through a COM interface. When **Etch*Director***© opens, the client opens automatically, displaying the icon, above, in the Windows tray (beside the clock). Clicking on the client icon opens the window. The client is minimised to the tray by clicking on the cross in the top right hand corner. Closing **Etch*Director***© also closes the client.



The green indicator light shows the client is connected to **Etch*Director***©. The direction arrows, limit indicators and speed slider may be utilised as in the **Etch*Director***© XY stage window.

All error messages are logged to the message screen on the right hand side. To record all other XY stage events, the 'enable' box should be checked. Right clicking on the message screen enables selected text to be copied. Clicking on the eraser icon clears the message box.

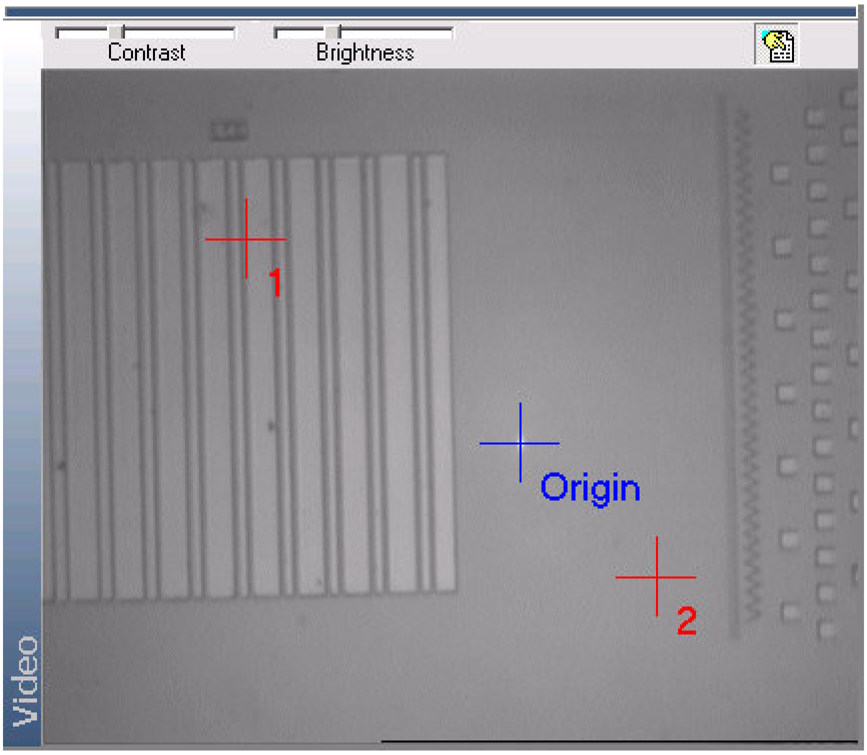
The direction of translation can be manipulated to account for the relative positioning of the stages and the video camera using the three axes check boxes.

The 'Measuring' light indicates when click and move is being calibrated.

Click and move laser positioning

If a video card and motorised XY stages are fitted, then the laser spot can be repositioned by double-clicking at the target position on the video window. To use this feature, first the system must be calibrated:

- First open the calibration overlay by clicking on the button on the video window.



- Position the stages so that the crosshairs of point 1 are over a distinctive feature on the wafer.

- Click on the 'measure' button in the XY stage window.

- Move the stages so that the crosshairs of point 2 are on the feature previously marked by point 1.

- Click on the 'stop measure' button in the XY stage window.

- Double click on the laser spot, so that it is marked by the origin cross.

- This completes the calibration procedure, so the video overlay can be deactivated by reclicking the video toolbar button.

Now the laser spot can be automatically positioned by double clicking at the target location on the video image.

The calibration parameters remain stored in **Etch*Director***© until the procedure is carried out again. If there is a change in the set up of the LEP400 hardware (such as a change in wafer to lens distance or rotation of the optical head) then click and move positioning may no longer be accurate and recalibration will be required.

Data servers

When **Etch*Director***© opens, the data server opens automatically, displaying the icon, above, in the

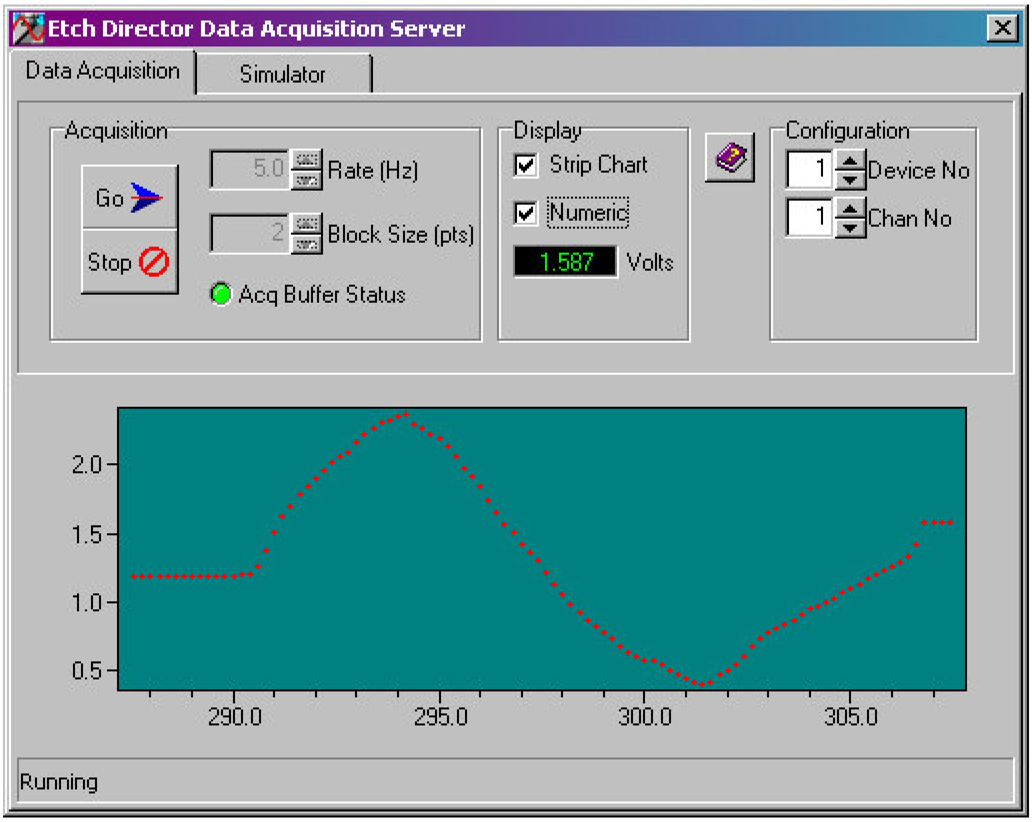
Windows tray (beside the clock). The data server collects process data from the acquisition source and publishes it to a COM interface, which is then accessed by the client, in this case, **Etch*Director*©**.

Clicking on the data server icon opens the window. On instrument software versions, this will display the hardware data server settings applied to and defining the data acquisition board. In addition, for desktop machines and service use, a simulator mode is also available, access to which is configured in the registry.

The data server is minimised to the tray by clicking on the cross in the top right hand corner. Closing **Etch*Director*©** also closes the data server. If the data server is opened separately or a system error causes it to remain open it can be closed by right clicking on the icon in the tray and selecting 'Close server' from the pop up menu.

Hardware data server

The hardware data server collects information from the acquisition board and makes it accessible to **Etch*Director*©**. The data server parameters are factory set and should not require editing.



Etch Director Data Acquisition Server

Rate (Hz): 5.0

Block Size (pts): 2

☑ Strip Chart

☑ Numeric

1.587 Volts

Device No: 1

Chan No: 1

Running

Acquisition settings

The Go/Stop control data passing through the server. When the application is opened it will automatically start acquisition, so the operator does not need manually start the system. The rate and the block size are greyed while acquisition is in progress. The acquisition rate value is taken from the setting in the instrument profile menu of **Etch*Director*©**. The block size is the amount of data read from the hardware buffer on the acquisition board for each sample point. The minimum value of 2 is the optimum setting to provide the quickest response time. The buffer status LED indicates how efficiently data is flowing through the server buffer. A green status light means the system is comfortable with the current flow rate of data. A yellow or red light indicated the server is struggling to empty the buffer as quickly as it is being filled. Consequently, the data displayed in **Etch*Director*©** will time lag actual process events. The load on the buffer can be reduced by decreasing the acquisition rate in **Etch*Director*©**.

Display settings

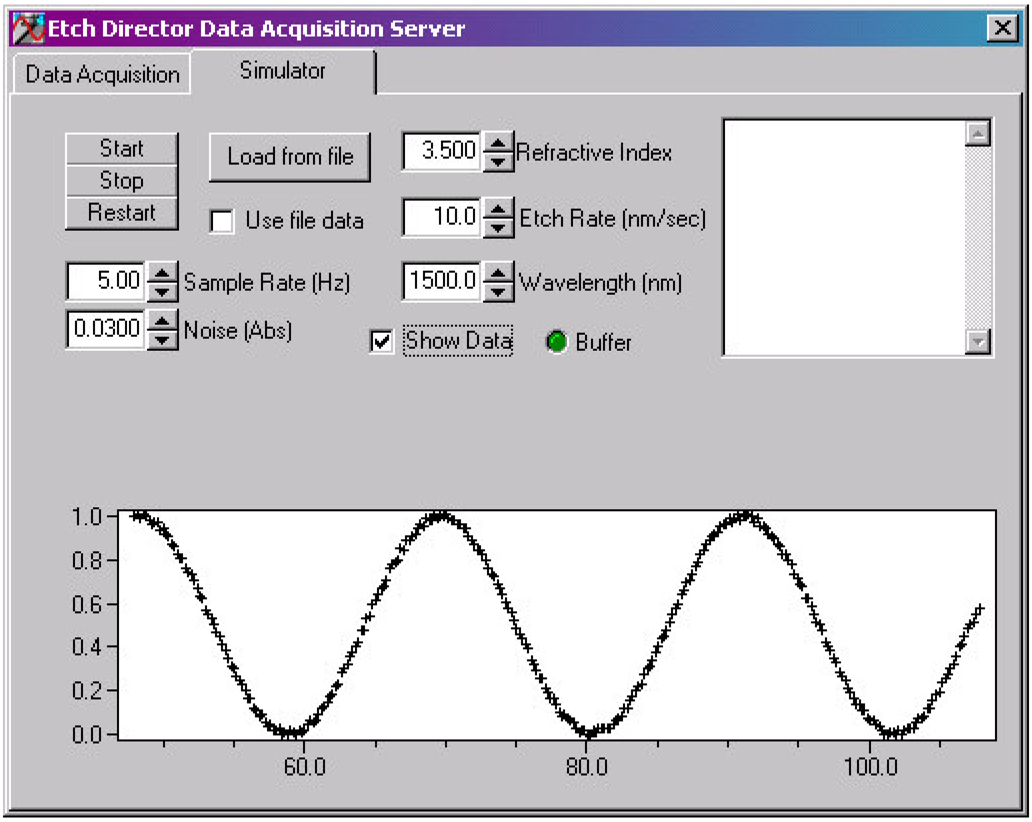
The data read from the acquisition card can be shown on a numerical and/or chart display by checking the appropriate box in the display menu. This provides a useful check that the data is being reproduced faithfully in **Etch*Director*©**.

Configuration settings

The location of the data acquisition board (device number) and the analogue input address (channel number) must be defined in order for the server to sample data. For all non-modulated systems these are both set to '1'.

Simulator

A software data server (or simulator) is availale for service use or desktop machine installations of **Etch*Director*©**. This enables data files to be processed by **Etch*Director*©** in real time, thereby simulating a real etch. Access to the simiulator must be configured in the registry.



3.500 Refractive Index

10.0 Etch Rate (nm/sec)

1500.0 Wavelength (nm)

5.00 Sample Rate (Hz)

0.0300 Noise (Abs)

☐ Use file data

☑ Show Data

General settings

The flow of data is controlled using the Start/Stop/Restart buttons. Data acquisition is automatically initiated when the server is opened, so there is no need for the operator to press 'Start'. The sample rate is set to the value entered in the instrument profile in **Etch*Director***©. The buffer status LED indicates how efficiently data is flowing through the server buffer. A green status light means the system is comfortable with the current flow rate of data. A yellow or red light indicated the server is struggling to empty the buffer as quickly as it is being filled. Consequently, the data displayed in **Etch*Director***© will time lag actual data set being passed through the simulator. The load on the buffer can be reduced by decreasing the acquisition rate. Checking the 'Show data' box displays the simulator data in the lower screen.

Processing saved file data

To run previously obtained process data through the simulator, click on the 'Load from file' button and open the required data set (saved in .csv format). The trace will be displayed on the lower screen. Then check the 'use file data' box and the file information will be passed through the server.

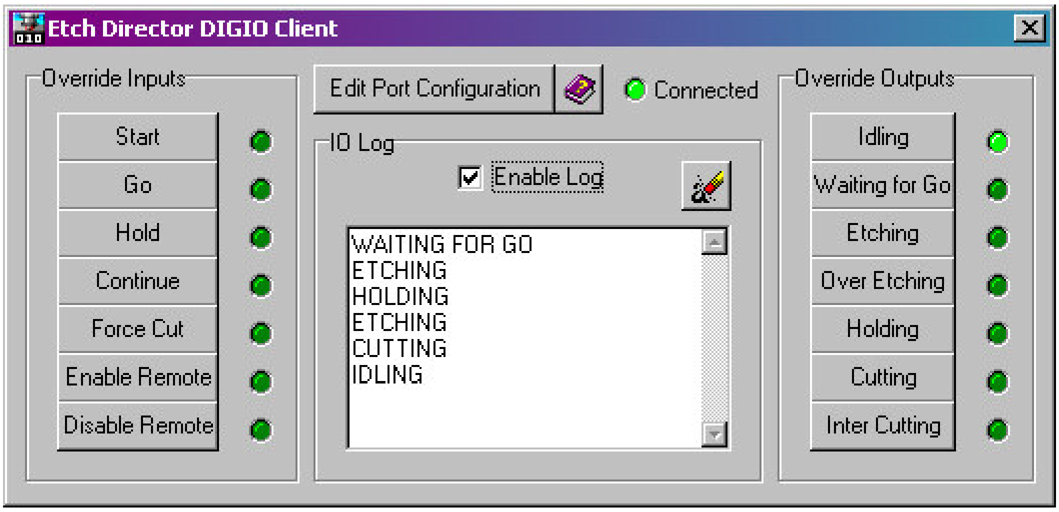
Processing a test data set

Alternatively, a simulated sinusoidal data trace may be calculated by specifying a few basic processing parameters. The 'Refractive Index', 'Etch Rate' and 'Wavelength' all determine the periodicity of the signal. Noise may also be added to the trace. This test data trace will always run when the simulator is active, unless the 'use file data' box is checked.

Digital I/O client

The Intellevation LEP400 provides several digital I/O ports that can be used as an electronic interface between the instrument and the process controller. This link can be used to communicate simple, 'on/off' commands, such as 'Start' data acquisition and 'turn off the plasma'. The interface is configured in the software through the digital I/O client.

When **Etch*Director***© is opened, the digital I/O client is automatically activated and minimised to the Windows tray (beside the clock). The digital I/O client configures the hardware I/O board to the control panel commands, publishing a COM inteface to **Etch*Director***©. The client is opened by clicking on the icon in the tray and minimised by clicking on the cross in the top right hand corner. The client is closed automatically with **Etch*Director***©, however, if it has been opened individually or an error has prevented automatic closure, the client can be closed by right-clicking on the icon in the tray and selecting 'Shut Down Digio Client' from the pop-up menu.



☑ Enable Log

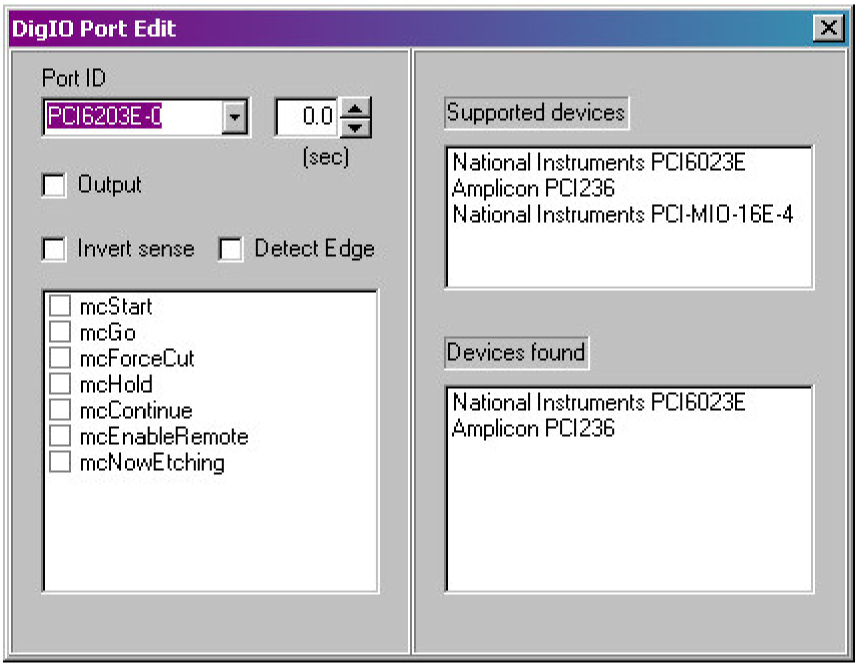
```
WAITING FOR GO
ETCHING
HOLDING
ETCHING
CUTTING
IDLING
```

The client enables the digital inputs and outputs to be manually overridden, for the purposes of testing. Checking the box activates a log of all digital IO events, which can be cleared by clicking on the eraser icon.

The configuration of the IO ports is factory set and should not require user modification. However, service access to these settings is provided by clicking on the 'Edit Port Configuration' button, provided access has be granted in the registry.

Editing digital I/O ports

The digital I/O port configuration menu is opened from the main digital I/O client screen. However, port edit access is only required for service use and must be set in the registry.



Port ID: PCI6203E-0

0.0 (sec)

☐ Output

☐ Invert sense ☐ Detect Edge

☐ mcStart
☐ mcGo
☐ mcForceCut
☐ mcHold
☐ mcContinue
☐ mcEnableRemote
☐ mcNowEtching

Supported devices:

National Instruments PCI6023E
Amplicon PCI236
National Instruments PCI-MIO-16E-4

Devices found:

National Instruments PCI6023E
Amplicon PCI236

The right hand side of the menu lists the supported IO hardware and the supported hardware detected by the digital I/O client. The left hand side of the menu enables the ports to be configured.

To configure an IO, first select a port from the pull down list at the top of the screen. The port name describes the device and the port number. The pinout of the IO port is detailed in the hardware installation manual supplied with the instrument. Then define it as either an output (check the 'output' box) or input (ensure the box is unchecked) type and select the required function from the list in the lower half of the screen. Finally configure the type of signal to be sent/received when the IO is active. The IO can be triggered on a changing signal edge (check 'Detect edge' box) or from a sustained pulse (set the timer at the top of the screen). The default sense of the IO is for it to be active when the pin voltage is high (5V) and inactive when it is low (0V). However, this can be reversed by checking the 'Invert sense' box.

Remember, in order for the digital inputs to be able to control the endpoint detector, the 'Enable remote' input must be active.

SECS (optional)

The Intellevation LEP400 provides a SECS communications interface, which enables commands to be sent between the endpoint detector and the process controller via a serial port. The addition to the simple 'on/off' commands that can be sent using the digital I/O, SECS can issue more complex commands, such as loading files and changing parameter values. The SECS command traffic logs and settings can be accessed using the SECS client.

The message types utilised by the protocol are summarised below, in the order which they may be typically sent during a process.

Type3

The reset command. Sent to the endpoint detector, it stops the process in progress (if the 'Force Cut' command is active) and enables the remote inputs to the system.

Type2

Enables and disables the mouse and keyboard over the **Etch*Director***© Window panels and Control panel. Any attempt to use the mouse and keyboard in these areas while local access is disabled will result in an explanatory message being displayed on the screen.

Type4

Sent to the endpoint detector to load a Process context file from the specified context folder.

Type1

Sends the 'Start' command to the endpoint detector to begin the endpoint run.

Type5

SECS will send a type 5 message to the process controller when either **Etch*Director***© finds an endpoint ('endpoint announcement') or when the process is stopped before an endpoint is found ('endpoint alarm').

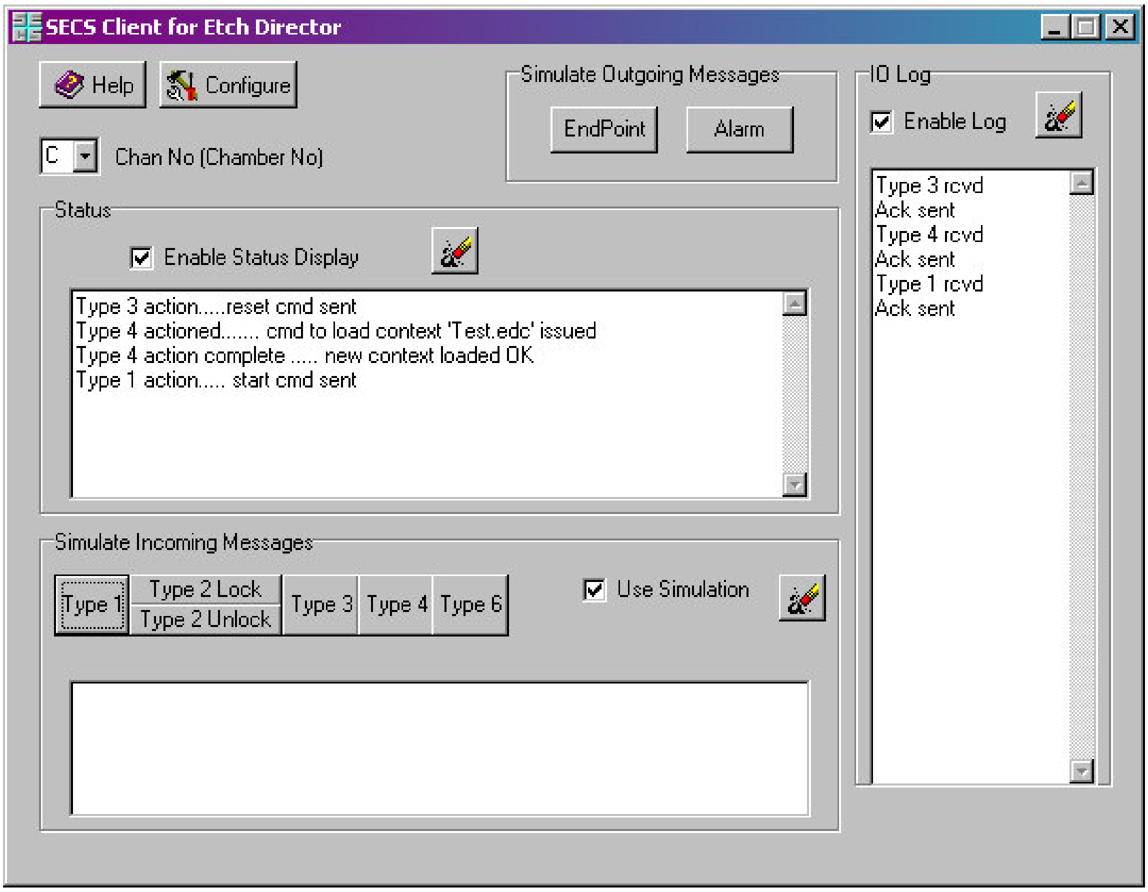
Type0 and type6

Type 0 and 6 messages are options which can be enabled on the SECS configuration menu. They are polling commands, which enable the process controller to keep track of the endpoint status (no error, busy, etc) when no other SECS commands are being sent. In between other commands, the process controller will continue to send type 6 messages and the endpoint detector will respond with type 0 messages. This is particularly useful for establishing when the endpoint detector has completed time-consuming commands, such as loading a context (type4).

There is also a standard handshaking procedure in place. After any message is sent, the receiving party will either send an 'ACK' to acknowledge the message or 'NAK' if the message is not recognised. If the transmitting side receives a NAK or no response within 1seconds of sending the message, it will resend the message. This is repeated until an ACK is received or for a maximum of four failed attempts.

SECS Client

When **Etch*Director***© opens, the SECS client is automatically activated and minimised to the Windows tray (beside the clock). The client is opened by clicking on the icon in the tray and minimised by clicking on the cross in the top right hand corner. The client is closed automatically with **Etch*Director***©, however, if it has been opened individually or an error has prevented automatic closure, the client can be closed by right-clicking on the icon in the tray and selecting 'Shut Down SECS' from the pop-up menu.



C Chan No (Chamber No)

☑ Enable Status Display

```
Type 3 action.....reset cmd sent
Type 4 actioned....... cmd to load context 'Test.edc' issued
Type 4 action complete ..... new context loaded OK
Type 1 action..... start cmd sent
```

☑ Enable Log

```
Type 3 rcvd
Ack sent
Type 4 rcvd
Ack sent
Type 1 rcvd
Ack sent
```

☑ Use Simulation

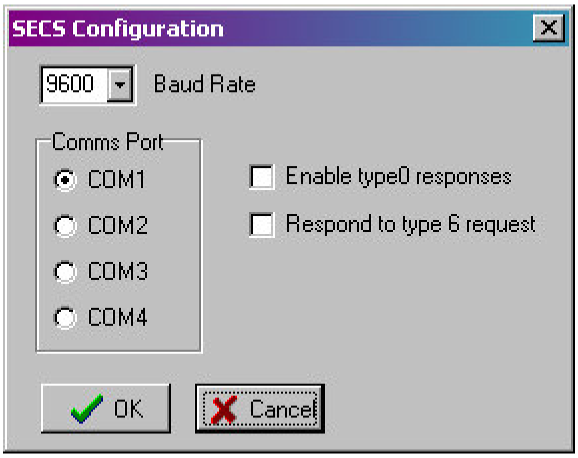
On the SECS client screen the Channel number (or Chamber ID) should be set to the letter which the endpoint detector is referred to in the SECS protocol. This parameter is incorporated in the SECS messages. Other parameters are set up on the SECS Configuration window, accessed by clicking on the 'configure' button on the client.

The client contains two log displays. The SECS status log, lists the actions carried out by Etch **Etch*Director***© as a result of SECS commands being passed and the IO log, which records all the SECS message types sent and received. The logs are activated by cheking the enables boxes and clears by clicking on the eraser buttons.

There is also a manual override to simulate SECS messages. To use this, the 'Use simulation' box must be checked. The 'Endpoint' and 'Alarm' buttons will send outgoing type 5 messages. Likewise incoming commands can be simulated using the appropriate numbered buttons. The type 4 command simulation will attempt to load a process context call Test.edc. Therefore, in order for it to successfully load, a file of this name should be saved in advance to the process context folder. The log window displays the content (Message ID, Chamber ID, Status, etc) of the simulated incoming SECS messages called.

SECS Configuration

Access to the SECS configuration menu is only required for service use and is restricted using settings in the registry.


SECS Configuration

9600 Baud Rate

Comms Port
● COM1
○ COM2
○ COM3
○ COM4

☐ Enable type0 responses
☐ Respond to type 6 request

This menu enables the Baud rate and interface COM port to be selected. In addition, type 0 and type 6 polling messages for SECS can be turned on or off.

Registry settings

Some **Etch*Director***© settings cannot be changed from within the software itself, but are defined in the machine registry. These concern parameters that are factory-set for a particular hardware configuration. However, access to these settings maybe required for service, such as in the case of a hardware upgrade.

CAUTION: The system registry is crucial for the correct operation of the computer. Intellevation

Limited take no responsibility for errors in machine operation as a result of user-made changes to the registry.

Before editing the registry ensure that **Etch*Director***© and all associated programs are closed. To open the registry, click on 'Run...' on the Windows Start menu. In the dialogue box that opens type in 'regedit' and click on 'OK'. This will open an explorer-style interface. On the left hand window under 'My Computer', navigate to 'HKEY_LOCAL_MACHINE\SOFTWARE\Intellevation Ltd'. How to change the **Etch*Director***© settings is described below. Once the changes are complete, close the Registry Editor window before reopening **Etch*Director***©.

Materials database

To change the default wavelength of the materials database, open the ' **Etch*Director***©\Materials folder'. Then on the right hand screen, double click on the setting 'Lambda' and in dialogue box that opens enter the new wavelength in nanometres.

Data server

To change data server setings, open the 'LHDS' folder. To set the data server to open in simulator mode (rather than the hardware data server), double click on 'OpenInSimulator' and in the dialogue box that opens enter '1' (as opposed to '0'). To enable the operator to change between the two modes double click on 'PermissionToChange' and in the dialogue box that opens enter '1' (as opposed to '0' to prohibit changes).

Digital I/O

To enable access to the digital IO pin asignment, open the 'DIGIO' folder. In the right hand side window, double click on 'PermissionToEdit' and in the dialogue box that opens enter '1' (as opposed to '0' to prohibit editing).

SECS

To enable access to the SECS Configuration window, open the 'SECSClient' folder. In the right hand side window, double click on 'PermissionToEdit' and in the dialogue box that opens enter '1' (as opposed to '0' to prohibit editing).

Frequently asked questions & troubleshooting

Please select an area on which to ask a question:

Modelling
Process data
Endpoint termination
Communications

Modelling questions

Why do I get an error trying to calculating a model from a structure?

'Error calculating model. Model size exceeds allocated memory.' A model can exceed the allocated memory size if the material thickness or probe wavelength are set to excessively large values. Check they are set correctly - including units. If a thick film layer is being etched, it may be more convenient to use the Simplex analysis mode in conjunction with other endpoint steps if there is more than one layer in total being processed.

'Structure verification error.' This error occurs when an illegal entry is read in one of the structure cells. This most often occurs when cells have been 'cut' and new values not entered in the spaces that are left. The verification error dialogue box that is displayed automatically in these circumstances will indicate the row and column position of any illegal cells.

'Attempting to flatten an empty structure object.' This error is displayed when an attempt is made to model a structure with no layers, i.e. just the substrate. The model assumes the wafer has a rough back surfaces, so even if it the material is transparent, no interference will occur. There are several alternatives, if the objective is to etch into the substrate.

Why is no trace displayed on the model chart created from my structure?

If no error is created in modelling the structure, but the model window is empty, it is almost certain that no film thickness values have been entered into the structure window.

Can I display my model data in other software programs?

Yes. Model traces can be exported as BMP graphic files or copied to the clipboard for pasting directly into documents such as reports and presentations. The model data can also be exported as a .CSV file for use in spreadsheet applications such as Microsoft Excel, that enable further user-manipulation. Process data can be exported in a similar way.

Process data questions

Why is the color of the filtered process data different at the start of a run?

At the start of a process, the data points required to fill the buffer are shown in a different color to provide a visual illustration of the window size being used to identify turning points. In addition, if a holdoff is being applied, this time will also apear in a different color. The meaning of each color displayed can be found from right clicking on the chart and opening the color customisation menu.

What signal level amplitude should I see?

The amplitude of the measured signal will depend on the composition of the wafer being processed. When etching silicon dioxide on bulk silicon, the contrast in refractive index is large (approximately 1.45 and 3.55), which gives rise to a large signal swing - typically about 1V peak to peak. However, other materials show less or very little contrast, such as doped InP on bulk InP. Consequently, the observed signal variation is much less and in such a case the hardware voltage gain (see installation manual) can be used to increase the amplitude, which may be as little as 0.1V peak to peak. In addition, the signal level is affected by the transparency of the material to the probe wavelength and other requirements for intra-layer monitoring. The variation in amplitude can be esitmated before the etch by modelling the process - but remember the y-axis of the model is the fraction of reflected light intensity, not Volts. The alignment of the optical head (tilt, focus - see installation manual) and condition of the window can also effect the intensity of the reflected light.

Can I display my process data in other software programs?

Yes. Process traces can be exported as BMP graphic files or copied to the clipboard for pasting directly into documents such as reports and presentations. The process data can also be exported as a .CSV file for use in spreadsheet applications such as Microsoft Excel, that enable further user-manipulation. Model data can be exported in a similar way.

The process chart time axis scrolls during a run, but why can't I see the data?

On the process chart window ensure the y-axis range has not been locked using the toolbar button. If this as been selected, any signal level outwith the scale limits when the lock was applied will not be displayed. Also check the data and background colors have not been set alike, by using the color customisation menu.

How do I set up the data sampling rate and buffer values?

First select the sampling rate. There should be a sufficient number of data points between turning points so that a sufficient depth resolution is achieved. As a rough guide this should be at least 10 data points per quarter wave. Given the quarter wave time is t = Thickness/Rate = $\lambda/4nR$, to achieve more than ten points per quater wave, the sample rate must be at least $10/t = 40nR/\lambda$. Typically, 6Hz will suit most ICP applications (non silicon), while 2Hz will be adequate for the etch rates observed in RIE chambers.

Secondly set up the buffer size. The buffer size is the window of most recently acquired data points that is analysed for turning points and is therefore determined in part by the sample rate. If the buffer is too small, there is a risk of noise being incorrectly identified as turning points, which leads to incorrect calculations of etch depth, rate and termination point. If it is too high, there is a significant delay between data at a turning point being collected and the turning point being identified, which can lead to inaccuracy in endpoint detection if the cut point is in this region. As a general rule the buffer size should be initially set to the size of one fifth of a quarter wave (buffer size = quarter wave time*sample rate/5), down to a minimum of 5 points. If the signal noise level is low (can be improved by reducing the filter frequency on the Endpoint params window) the buffer size can be reduced. This has the benefit of reducing the lag between turning point measurement and identification.

Why does the signal level decrease throughout the process?

A drop off in signal level during the process that is not predicted in the model can result in a loss of instrument performance. This is because clear interference fringes (ie good signal to noise) with good amplitude (ideally 1V peak to peak) are required for accurate turning point detection and therfore depth measurement. There are two common causes of rapid signal degradation during a process. The first is roughening of the wafer during the process. As the surface of the wafers becomes rough, more of the incident laser light is scatters and is not reflected back to the optical head. Consequently the measured signal instensity drops and noise becomes more significant. The effects of noise (i.e. flase turning point detection) can be removed by reducing the filter frequency in the Endpoint params window. However, if the signal to noise level becomes too small to reliably identify any fringes, then the problem must be solved by changing the process chemistry to improve the surface quality.

Roughening can be identified by looking at the camera image of the wafer. As the surface becomes rough, scattering more light, the illuminating light reflected back to the camera is also reduced and the wafer surface appears dark grey or black. Often certain materials in a wafer are more susceptible to roughening than the others and the drop off in signal occurs at an interface breakthrough and once through that layer, the surface condition may improve again. In this case a suitable hold off or multi step endpoint may be suitable to configure a reliable automatic endpoint.

The second cause is degradation of the chamber window. This may be caused by etching or more commonly coating the window. Coating often occurs when polymers are produced as a biproduct of the etch. The instrument will measure a drop in signal level or soemtimes act as a deposition monitor and detect a few very large period fringes as the material coats the glass, scattering or absorbing the laser light. Again this effect is visible on the cmera image, as a fading and eventually total disappearance of the mask pattern. If the process conditions cannot be altered then the window can be recessed from the plasma on an extension tube or possibly heated to reduce the rate at which coating occurs. Etching can roughen the viewport window, which scatters the laser light and prevents the camera viewing the mask pattern. This problem can be reduced by either recessing the viewport or replacing the standard window with sapphire or sapphire coated glass.

Endpoint termination questions

How do I run an endpoint process without allowing the endpoint computer to terminate the run?

If the etch tool has been configured to interface to the LEP400, it will receive a 'Cut' signal (defined in the digital IO configuration) upon an endpoint being detected, which will cease data acquistion and, via the electrical interface, terminate the etch process. However, the operator may wish to control the precise point of termination manually, using the endpoint detector as a guide only. To do this the 'accept' box on the Endpoint params window should be deselected. With this setup, the communications interface (SECS and Digital I/O) may be used to remotely load settings and initiate data acquisition, but the LEP400 hardware will not not output a 'Cut' signal that will terminate the process. When **Etch*Director*©** finds an endpoint, the usual marker will be displayed on the data, but data acquisition will continue until stopped manually or a timeout is reached.

Why does the endpoint detector not stop the etcher when an endpoint is found?

The etch tool should be configured to accept an 'Cut' output signal from the LEP400 in order to terminate the process. It should be checked that the hardware interface matches the Digital IO configuration set up in **Etch*Director*©**. It should be possible to perform 'dummy' runs, monitoring the physical output of the endpoint detector with a meter when **Etch*Director*©** finds an endpoint and manually joining connections to the tool to simulate a cut signal.

If the data acquisition does also not stop at the endpoint, this indicate the 'accept' box on the Endpoint params window has not been selected, which deactivates the 'Cut' output. Checking the box (on all active endpoint steps) reactivates the the Cut output. Finally, check the over etch time set. Though an endpoint marker will be displayed on the data trace when the set endpoint is found, the cut point does not occur until any set over etch is complete, i.e the entire process is finished.

What level of termination accuracy might I expect to achieve?

This is a very common question, but unfortunately there is no straight answer. There are, however, several factors that when considered can provide a guide to the expected accuracy and indeed a guide to however to improve the stopping accuracy.

The first set of considerations is how the endpoint detector monitors off the wafer. The instrument makes a local measurement, i.e. at the point upon which the laser is incident on the wafer. In addition, the etch process will probably not be uniform across the entire chamber and RIE lag will cause different size features to etch at different rates Therefore, the position of the laser psot should be carefully chosen and any ex-situ comparison measurement should be made at the same location. The second set of considerations is how the process data is handled by **Etch*Director*©**. In interferometry mode, the fundamental accuracy of the instrument is a quarterwave (the depth between turning points). However, termination accuracy greater than this should be achievable, by optimising the data acquisition rate and endpoint parameters.. The faster the sampling rate and the slower the etch rate, the smaller the depth etched between data points, so increasing the depth resolution. Also if the model or simplex mode are being used, the accuracy of all the physical parameters (thickness and refractive index) will affect the termination depth. For example if a refractive index of 1.9 is used instead of an actual value of 2, then at 670nm the calculated quarterwave depth is 88.2nm, as opposed to the actual value of 83.8nm (5% more). Consequently on an etch of 1um, **Etch*Director*©** would signal the endpoint when only 950nm has been etched.

Finally, changes that occur to the wafer after the endpoint is found should be considered. Any delay between the endpoint being detected and the etch ceasing will result in an over etch. For example, in a 2um/min process, every second of over etch results in a further 33nm of material being removed. The problem is most prevailent when the process is terminated manually upon endpoint detection, where this termination lag is liable to be more than when a 'cut' is delivered via electonic communications. In addition, the faster the etch rate, the greater the discrepancy between target and actual. If a wafer undergoes significant cooling or heating during the process, it will contract or expand accordingly (by an amount dependant on the thermal expansion coefficient for that material). This will change the physical starting thickness of the layer, which may cause the process data to start at a different position to the model. The termination depth will then be found at the process temperature, but when the wafer is removed from the chamber it will return to room temeperature resulting in a change in the physical final thickness.

In practice, many of these sources for error are repeatable from run to run and a tooling factor offset may be used to fine tune the endpoint. Previous work has shown that repeatable average accuracy of 5nm is achievable [D J Heason & A G Spencer, J.Phys.D: Appl. Phys. 36 (2003) 1543-1549)].

Communications questions

Why do digital I/O or SECS messages sent to the system have no effect on Etch*Director*© controls?

First check the commands are being received by the endpoint system by enabling and monitoring the logs on the Digital I/O and SECS clients. If no commands are registered then the hardware interface should be tested, details supplied in the installation manual. Comms commands received by the endpoint detector will not link to **Etch*Director*©** unless 'Remotes enabled' is true. This is shown by the indicator light below the control panel buttons. Therefore, either the 'enable remote' digital input must be assigned to an active port or a type 3 SECS command must be received first. Again, this can be confirmedby looking at the appropriate client window.

Why is the keyboard and mouse locked out?

The keyboard and mouse can be locked over the **Etch*Director*©** window panels and control panel by sending a type 2 SECS message to the electronics unit. If this case an explanatory message will be displayed if there is an attempt to use the keyboard and mouse in these regions. The reactivate local control, the appropriate type two message should be sent to the system (commonly in the form of an 'enable endpoint' button). Alternatively, the command simulator on the SECS client can be used. If the keyboard and mouse do not respond and no message is displayed on the screen when an attempt is made to use these controls, then this is evidence of a non-SECS related issue. Check the devices are plugged in and the 'keyboard lock' switch on the front of the electronics module is not active.

Why has the process context file not loaded?

To load a process context a type 4 SECS command containing the file name must be sent to the endpoint detector. A load error will occur if the called file name does not exist in the process context directory (C:\EtchDirectorWork\ProcessContext as default) or the file extension (.edc) is not included in the name.

Tutorials

This section contains examples of typical etches and how to set up the endpoint parameters obtain relaible performace from the LEP400. The endpoint runs can be broadly divided into two types:

Endpointing at a layer interface

During a process run, the most noticeable changes in signal level are likely to occur at the etch through between layers, due to the change in physical properties of the material being monitored. These distinct features can be identified by **Etch*Director***© operating in the Kink analysis mode. This provides more reliable endpointing than targeting a depth in this case, since it is independent of variations in layer thickness, which may occur from wafer to wafer. When setting up endpoint parameters for this mode of operation, it is advisable to optimise the values by reprocessing several data sets to take into account run to run process variations. If there is reasonable contrast between the layer, it may also be apparent on the wafer image display when the breakthrough occurs. The endpoint set up for serveral common process are discussed in the sections below.

Endpointing at the substrate
Endpointing on a selective material
Endpointing at an interface between absorbing materials
Endpointing at an interface between III-V materials
Endpointing at an interface between optically similar materials

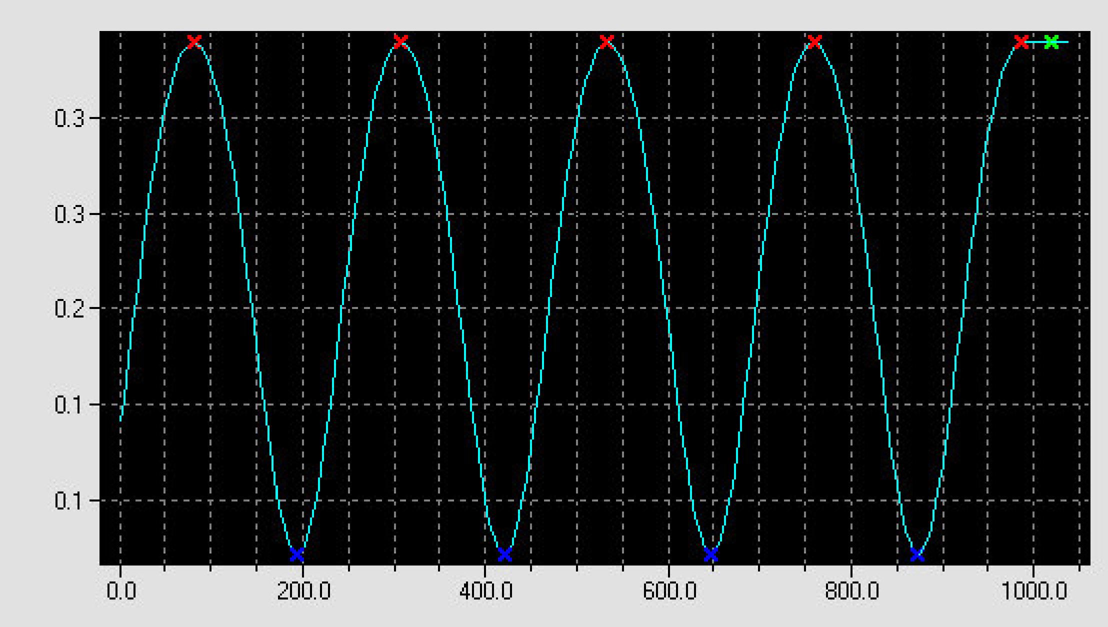
Endpointing within a layer

In addition to detecting film interfaces, the LEP400 can utilise interference effects to provide a real-time measurement of the etch depth within a layer. The simplex and model analysis modes enable endpoints to be detected in a film. However, there are certain requirements for intra-layer monitoring. The endpoint set up for several common types of endpoint are discussed in the sections below.

Etching a single layer
Multi-layer etches
Causes of differences between model and process data
Etching into the substrate
Endpointing on a remaining film thickness

Endpointing at the substrate

A popular endpoint requirement is to terminate on the wafer substrate. Typical examples include silicon dioxide or silicon nitride on bulk silicon or a metal. In most cases the subtrate material will be opaque to the probe wavelength and the rear surface will not be poilished. Consequently, once the bulk is exposed to the laser, a reflected signal is only obtained from one surface (the top of the substrate) and no additional interfaces. Therefore, no interference will occur and the measured signal level will remain approximately constant, i.e. you observe a flat line on the process chart. This is in clear contrast to the good fringes observed during the etch of the overlying dielectric. The trace below shows the signal variation during an etch of 1000nm of silicon dioxide down to a bulk silicon substrate, monitored at 670nm.



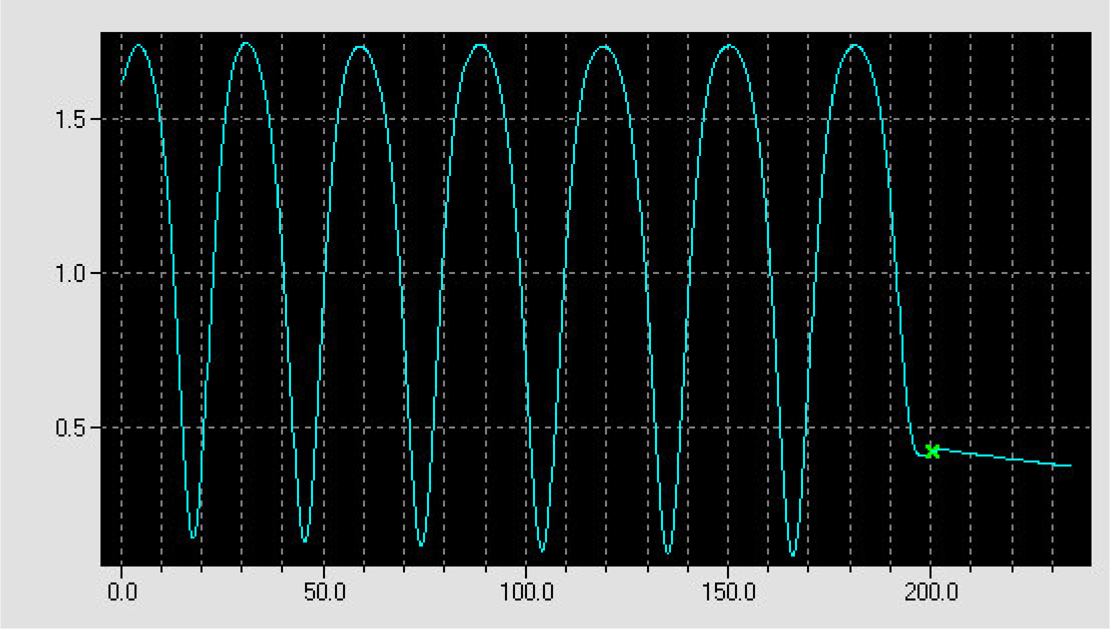
To endpoint on a flat line, the analysis mode should be set to kink, with the slope parameter (the signal gradient) as zero. The other parameters should be set up by loading a previously obtained trace and using the reprocessing function. The window size should be set sufficiently small that the endpoint will be detected quickly after the substrate is exposed, maximising accuracy. This value is typically between 10 and 40, but depend on the etch rate and sample rate applied. However, the window size should not be set so small that there is a danger of a flat line being detected at the turning points measured during the etch of the overlying film. In addition, the sensitivity can be reduced (say, to a few percent), so that signal shapes that are all but very close to the specified slope are rejected.

In this example, the overlying material is transparent at the probe wavelength, enabling interference fringes to be measured throughout the process. This allows the etch depth and rate to be calculated, if additional parameters are set (see Kink analysis mode).

Also see Etching into the substrate.

Endpointing on a selective material

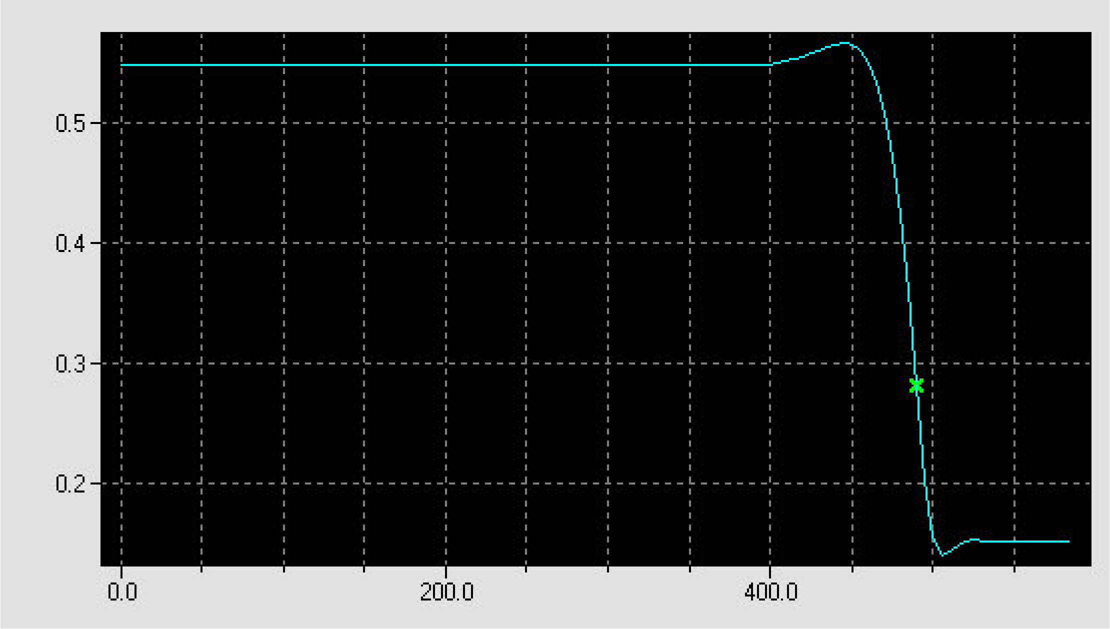
The 'flat line' type of endpoint, seen when terminating on the substrate, is also observed when etching down to a material with a much higher selectivity than the overlying film. When this material is exposed, the slower etch rate is reflected in a significant increase in the quaterwave time (time between turning points), so much so that the signal level will change very slowly, effectively creating a flat line over the window size required to endpoint. For example when monitoring a SOI (Silion on Insulator) process at 1500nm, rapid fringes are observed during the etch of the epitaxial silicon until the oxide is exposed and the etch rates slows by a factor of twenty or more.



The Kink mode parameters can then be set up as in the case of endpointing on the substrate. Also note on this type of etch that the shape of the interference fringes is much more assymetric. The high refractive index contrast between the silicon (~3.55) and oxide (~1.45) results in the maxima becoming flatter and the minima becoming more tapered. If the turning point detection is enabled, than some care should be taken to ensure the buffer size is set appropriately to fit both these different shaped extrema.

Endpointing at an interface between absorbing materials

When etching absorbing materials, like metals, no interference fringes are detected. Therefore, depth cannot be continuously monitored, but interfaces can be identified by 'step' changes in signal level. The example shown below is for titainium on litium niobate.



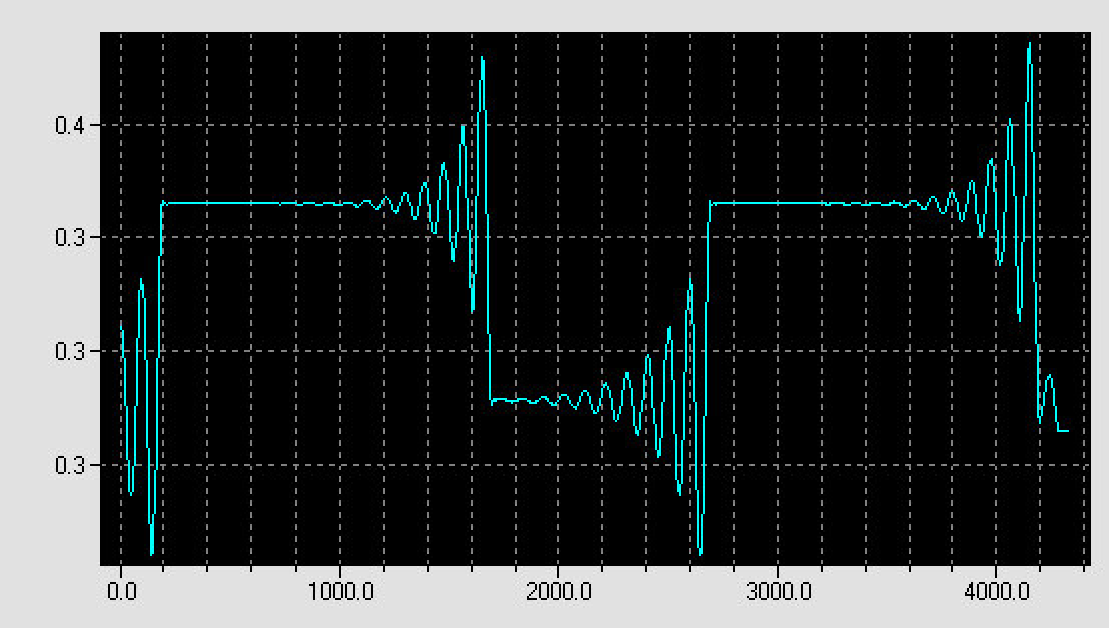
To endpoint on the underlying layer, it is possible to use 'flat line' detection, as used for endpointing at the substrate. However, a sufficiently large hold off (see General endpoint settings) must be set to avoid endpointing in the top layer. Using the hold off in this way relies on repeatable etch rates from run to run. A much more stable method is to use the kink analysis mode to detect the actual signal slope at the interface.

To do this the slope parameter should be set to a negative value if the signal level is decreasing (as above) or a positive value if the signal level is increasing. The actual magnitude of the value will depend on the contrast between the layers, hardware gain setting and etch rate, varying between typically 5 and 0.005. A suitable setting can be identified by reprocessing acquired process data using test values. The example above has a Kink slope parameter of -0.01.

The window size and sensitivity should be set to account for run to run variations. They can also be used to move the the endpoint to a position along the slope. However, the more precise the endpoint is to be positioned, the more reliant the system is on signal repeatability. When making adjustments to the window size, it mak be useful to display the data points, rather than line plot (set on Process all window).

Endpointing at an interface between III-V materials

When etching compound semiconductor materials (GaAs, InP, InGaAsP, etc), often distinct signal changes can be seen between different layers, below, even though the refractive index change may be relatively small (~10%), provided the layers are at least a quarter waver thick (λ/4n). As with the case of absorbing materials, the Kink analysis mode can be used to endpoint on these signal slopes.



The same procedure should be followed to set up the endpoint through reprocessing. In addition, there may be several signal level changes that are similar to one another, for example material films may be repeated in the structure. Here, the hold off may be used to avoid endpointing on the first of these features detected.

These types of materials may also be partially absorbing at the probe wavelength. Consequently, at the start of relatively thick layers, the amplitude may be small. If this results in the signal to noise ratio becoming very low, then the endpoint trace will become highly non-repeatable, which in turn reduces the depth targeting accuracy of the instrument operating in Model analysis mode. A technique to avoid these types of errors is to use a step approach. First use Kink mode to endpoint on the closest distinct signal feature before the required endpoint position. Then either apply an overetch to reach the required endpoint depth or activate a second endpoint step on the Endpoint params window, which will endpoint on a depth using either Simplex or Model analysis modes. However, it may be the case that the endpoint is not close to a kink feature or within a transparent material. In this situation it is more appropriate to use a probe wavelength to which the wafer material is transparent.

Endpointing at an interface between optically similar materials

Many wafer structures contain materials with significant differences in refractive index, so the interfaces are readily identifiable throughout the etch by distinct changes in signal level. However, sometimes it is required to endpoint at an interface where the materials have very similar optical properties (refractive index difference <1%), such as doped oxide on thermal oxide. In this situation there is no visible change discernable in the oscillatory reflected signal as the etch progresses through the interface. Therefore, in order to detect the endpoint, Intellevation have developed intensive curve-fitting routines. Please contact us for further details of this termination method.

Requirements for intra-layer monitoring

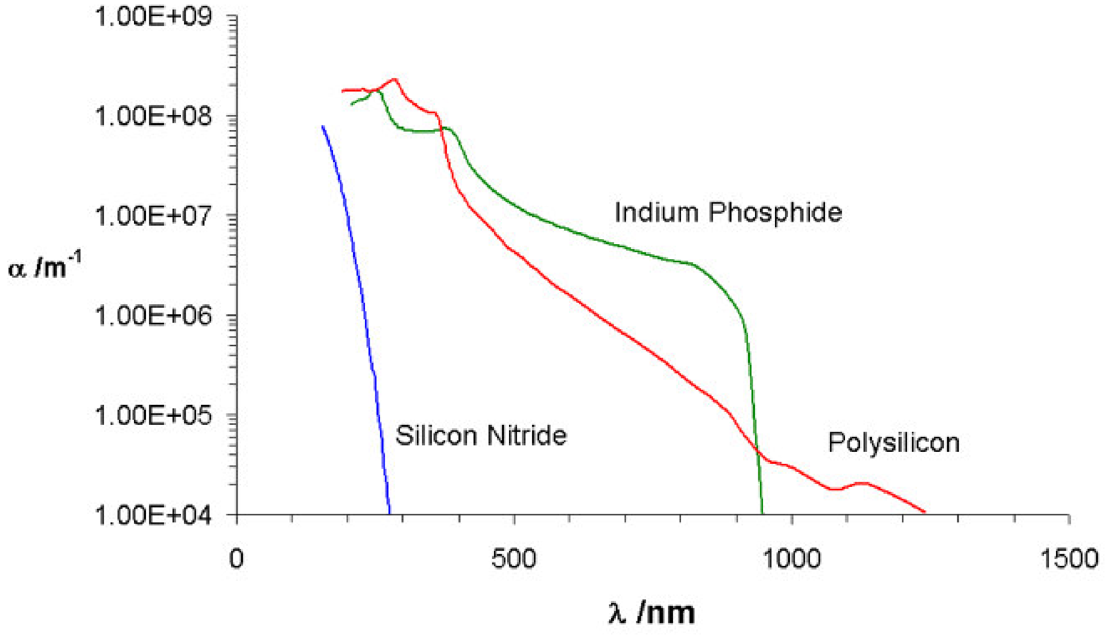
In order to monitor etch depth throughout a film layer interference of the probe laser beam must occur. This gives rise to a series of maxima and minima in the reflected signal intensity. By using known information about the wafer (material composition and optical properties), the etch depth can be calculated from the process data.

In order for interference to occur, the film on which the laser spot is positioned must be significantly transparent at the probe wavelength, so light is reflected from the lower interface of the film as well as the top surface. If the film is absorbing, the reflected intensity from the back of the film will be reduced, weakening the interference effect and consequently reducing the measured signal amplitude. This decrease in amplitude becomes more marked the thicker the layer is until, in a practical situation, it is indistinguishable from the background noise. Once the interference fringes cannot be clearly identified, no depth measurement can be make.

The absorbancy of a material is determined by the complex component of the refractive index or extinction coefficient, which can be found in the materials database. A value of zero means the materialis completely transparent and it is theoretically possible to detect interference when etching through films of any thickness provided the two surfaces remain flat and smooth. A non-zero value means the material is absorbing and the higher the number, the more absorbing it is. Using **Etch*Director***©, the wafer structure can be modelled to see if sufficiently clear fringes will be obtained throughout the etch, that reliable endpoints can be achieved.

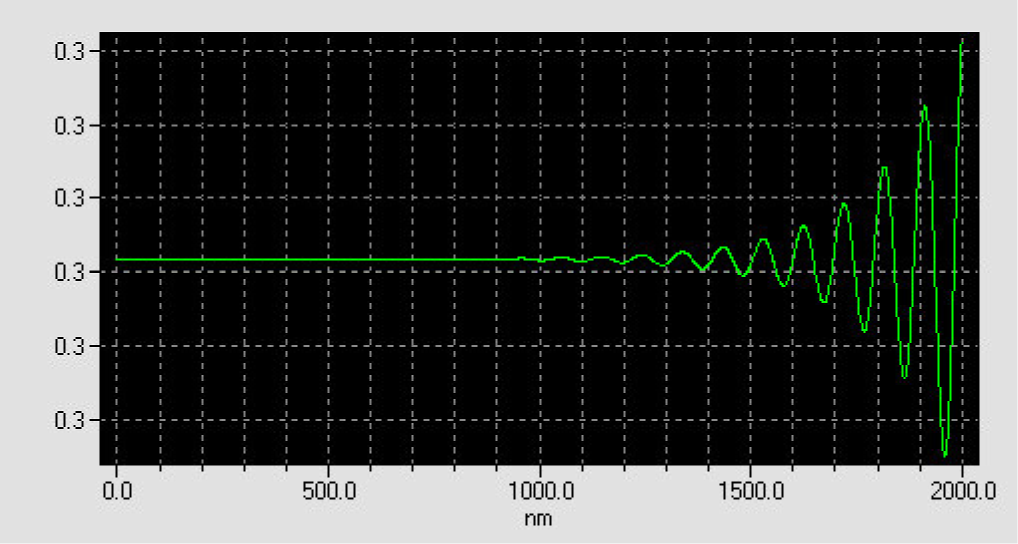
If the material being etched contains highly absorbing layers, automatic endpointing using a model becomes unreliable, since the fringes in the process data cannot be clearly matched to the model. There are two soultions for this problem if the endpoint is close to a distinguishable endpoint feature. The first is to use a model, but disable the automatic endpoint detection (un-check the 'accept' box on the Endpoint params window) and manually terminate the process by visual comparison with the etch data. Alternatively, the Kink analysis mode can be used to terminate on a distinguishable signal change before the endpoint and an overetch used to reach the required termination depth.

If the endpoint depth is on a thick layer of absorbing material where no interference fringes are detectable changing the probe wavelength may enable endpoint detection. As with refractive index, the extinction coefficient changes with wavelength. The graph below shows the absorption coefficient (proportional to the extinction coefficient) against wavelength for three commonly etched materials.

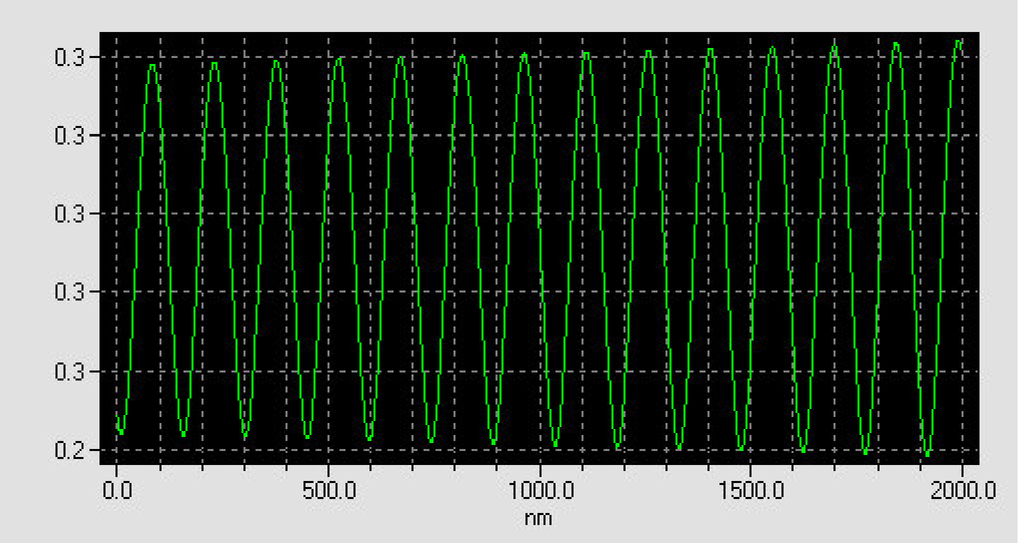


The standard 670nm laser is transparent to many materials, including silicon nitride, silicon dioxide, gallium nitride and thin layers of gallium arsenide. However, higher wavelengths are available for materials that are heavily absorbing in the visible, such as 980nm for indium phosphide (see below) and 1500nm for silicon.

Monitoring indium phosphide at 670nm:



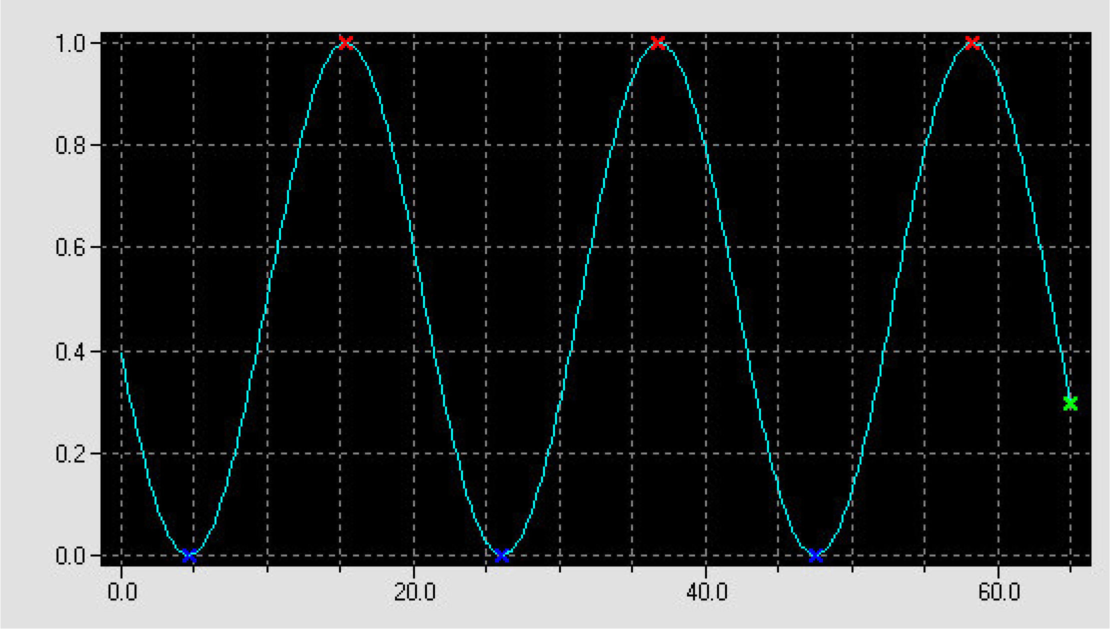
Monitoring indium phosphide at 980nm:



In addition to transparency, the surface condition of the material being processed also determines the quality of the interference signal measured. Roughening of the wafer surface increases scattering of incident laser light and reduces the reflected signal level intensity. As the degree of roughness increases, the signal amplitude and mean level decrease, until measurement is no longer possible. The onset of roughening is often made apparent by a sudden drop in signal level and the wafer surface appearing much darker (probably very close to black) on the camera display.

Etching a single layer

The most basic instance of an intra-layer endpoint is terminating within the top film of a wafer. To endpoint on a simple etch such as this there is no need to construct a model file, as the simplex analysis mode has been developed for this specific application. Only three specific parameters are required - probe wavelength, refractive index (found in the Materials database) and endpoint depth.

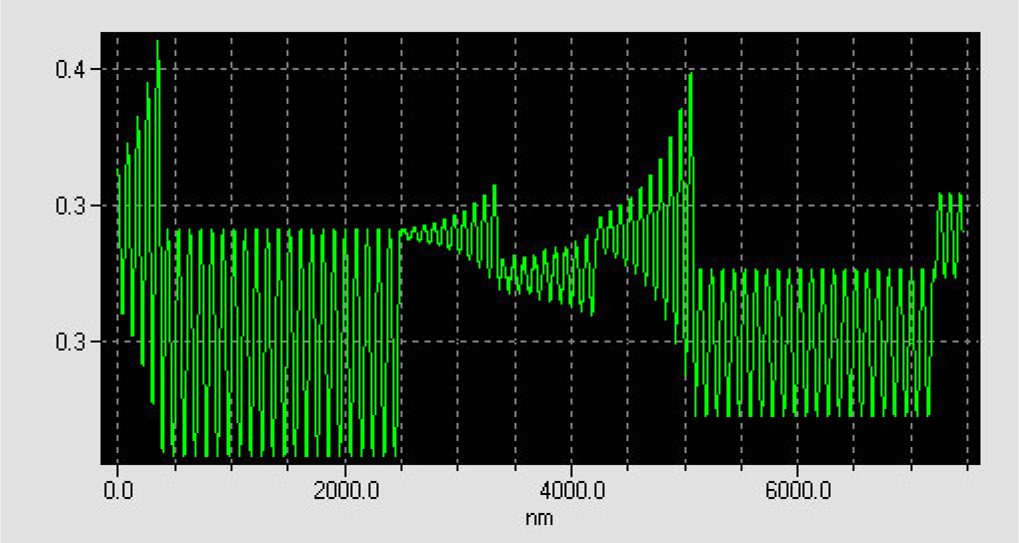


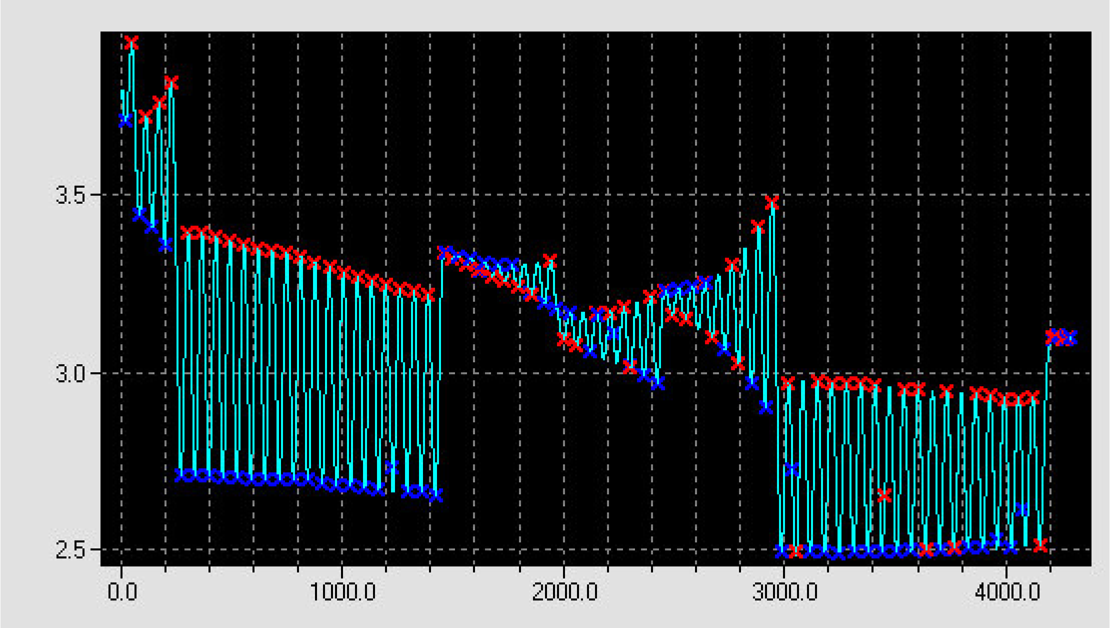
In simplex mode, the endpoint depth is not sensitive to variations in the starting thickness, as in the case of using a model. The model mode relies on the process trace starting in exactly the same position as the model for good accuracy, but in simplex mode the software will extrapolate back from the first turning point to calculate the depth from the start and thereby cope with variations in starting position.

Multi-layer etches

Where more than one layer is being etched, the model analysis mode is the most appropriate termination method to use. A model file can be generated from a structure, as described in this help file. This modelling feature enables the variation in the reflected signal intensity to be predicted in advance of the etch, removing the need for calibration runs to be carried out. This is particularly useful for wafers containing many separte layers, or repeats of layers.

The accuracy of the modelling software is shown below, where a model trace (top) and process data (bottom) are displayed for a quantum cascade laser etch containing more than 200 layers (courtesy of Sheffield University, UK).





However, the accuracy of the model is determined by the accuracy of the data used to compile it and several factors can cause differences between model and process traces.

Causes of differences between model and process data

If a model trace differs from the actual process data it is because of a difference in the specified physical parameters (wavelength, refractive index or physical thickness), the software data processing settings or a process effect. In situations where there is a gross difference between the actual and expected traces, the hardware set up of the equipment should be verified, with reference to the installation manual.

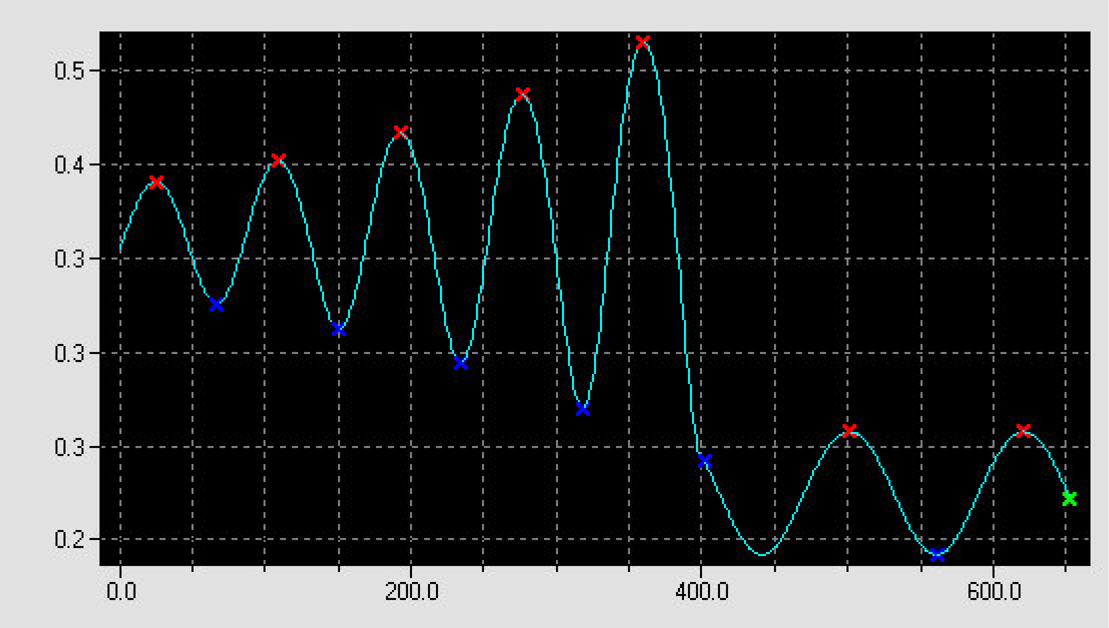
Physical parameters

The laser wavelength should be accurate to within one percent and so will only create significant error on deep etches (i.e. more than 100 quarter waves, typically of the order of 10um). However, if a tuneable laser is being used you should ensure it is set to the same wavelength specified in the structure or simplex mode parameter box.

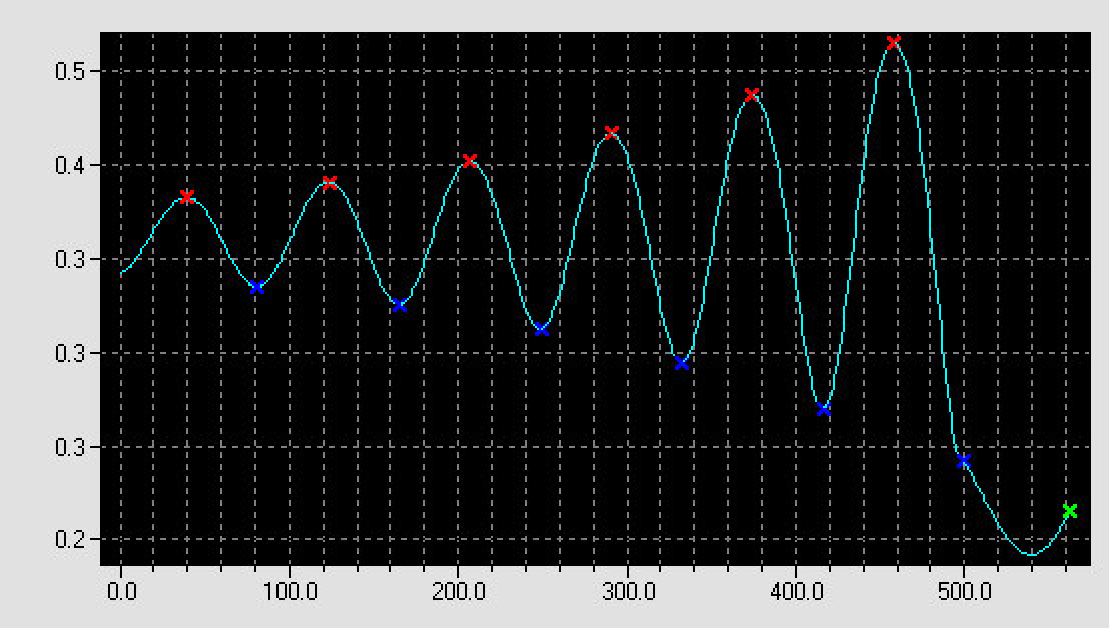
Likewise, if the refractive index is known accurately, errors will only occur over deep etches.

The layer thickness is the physical parameter most likely to vary from wafer to wafer and cause an offset in the endpoint depth. In a situation where the accuracy of the films is less than the accuracy of the required endpoint termination, a model cannot be used to reliably endpoint. However, depending on the process, the endpoint parameters may be adjusted to compensate for this variation and achieve the required termination accuracy.

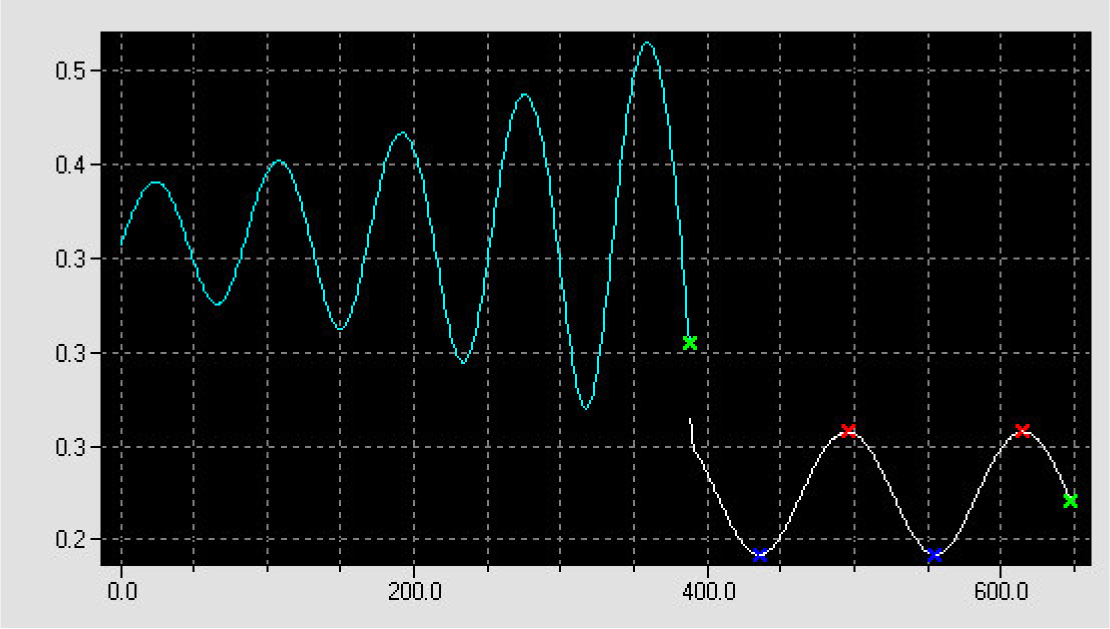
In the example below it is required to end point a short distance into the second layer (shown by smaller amplitude fringes). Using a model, the first run endpoints correctly.

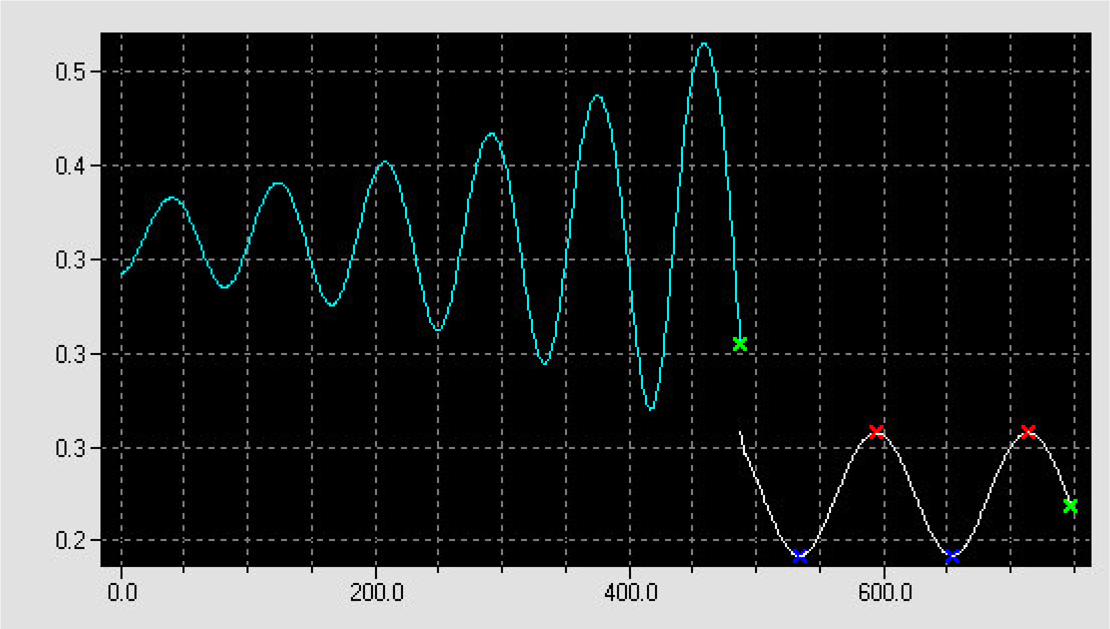


However, on a second run, the thickness of layer one is greater than specified in the model, so more fringes are measured as it is etched and the process is stopped too early in layer two.



To make the termination position insensitive to the thickness of the top layer, the run can be broken down into two endpoint steps. The first utilises the kink mode to identify the distinct signal drop at the interface between the two layers. This is endpoint will be independent of changes in the thickness of layer one. Then the second step uses the simplex analysis mode to endpoints on to a further fixed depth. This method enables repeatable termination positions to be obtained, even if the thickness of layer one varies.





Software data processing

If the software data processing parameters have been not been optimised, the filtered data may appear disimilar to the predicted model. To verify the data is being displayed in a representative form some basic checks should be made. First, reprocess the acquired trace with very little filtering applied (filter cutoff to 100Hz) to view the raw data. If the trace then appears similar to the model it is evidence that the data was acquired with an excessive level of filtering. Then reprocessing should be used to find a suitable setting. If the raw data does not appear close to the model trace, check the sample rate and buffer size are correctly set.

Process effects

Several process effects may occur that may cause the process trace to differ from that of the model.

- A requirement for intra-layer interferometry is that the surfaces remain smooth. Any drop off in measured signal level could be due to surface roughening.
- Check the wafer has actually etched to the required depth, for example using a calibrated profilometer at the spot position.
- Check there is no significant vibration of the optical head or wafer. If there is, it will be apparent by observing the camera image and can be investigated further by referring to the troubleshooting section in the installation manual.
- Ensure the laser spot is positioned on an open area and that there not over the mask or small mask features not clearly visible on the camera image.
- If the signal level amplitude is weak, check the hardware setup. Changing the wafer carrier may require the tilt or focus to be adjusted (see installation manual).
- If the period of the interference fringes cannot be explained by the expected rate and refractive index (i.e. the quarter wave time is significantly larger or smaller than expected) then thermal expansion may be occurring. If there is a temperature difference between the wafer and the surroundings, it will be heated or cooled in order to attain an equilibrium state, resulting in it expanding or contracting by a fraction determined by the coefficient of thermal expansion for the material. This will move the top surface of the wafer either in the the direction or against the direction of the etch and thus modify the measured quarter wave time. A test to see if thermal expansion is a prevalent effect is to continue monitoring after the process plasma has been extinguished. If there has been significant heating/cooling of the wafer, clear fringes of increasing period should be observed as wafer temperature returns to equilibrium with the surroundings. Thermal expansion has a greater effect where interference in the substrate can occur, since the increased starting thickness gives rise to a

greater physical change in wafer thickness than expansion in the thin overlying films. These effects can be reduced by improving the thermal contact of the wafer to the surroundings, enabling it to reach thermal equilibrium faster.

Etching into the substrate

Most wafers have a rough (non-polished) back surface. Consequently, when the bulk material is exposed, the laser beam probing the wafer is only reflected from one surface (the top) and no intference fringes are generated. The reflected signal intensity remains almost constant, so no depth measurement can be made. Therefore, to endpoint within the bulk material, the kink analysis mode can be used to detect the interface with substrate and an overetch applied to reach the termination depth.

Alternatively, positioning the laser spot over a suitable mask pattern (e.g. an array of narrow lines smaller than the spot diameter) will generate reflections from two surfaces (the top of the wafer and mask), enabling stepped level interferometry to occur during the etch. However, since the trenches are very narrow, laser light becomes easily scattered as the depth increases and the sides become angled and base rounded. Consequently, the detected signal intensity reduces and the depth measurable using this method is limited.

Should the rear surface of the wafer be polished AND the substrate is transparent to the probe wavelength interference fringes can be obtained from etching the bulk material enabling depth and rate measurements on a thru' wafer etch. For a straight forward bulk etch, it is most convenient to use the simplex analysis mode and a model can be created for more complicated structures containing a double polished substrate. Since the modelling software assumes a rough back surface of the substrate, the 'substrate' layer in the structure should be entered as a vacuum (RI = 1, Ext Coef = 1) and the actual substrate properties entered in the appropriate layer above this. However, due to the relative thickness of most substrates, the associated model file is likely to be large and difficult to use, which is why the simplex mode is the preferred method in this case.

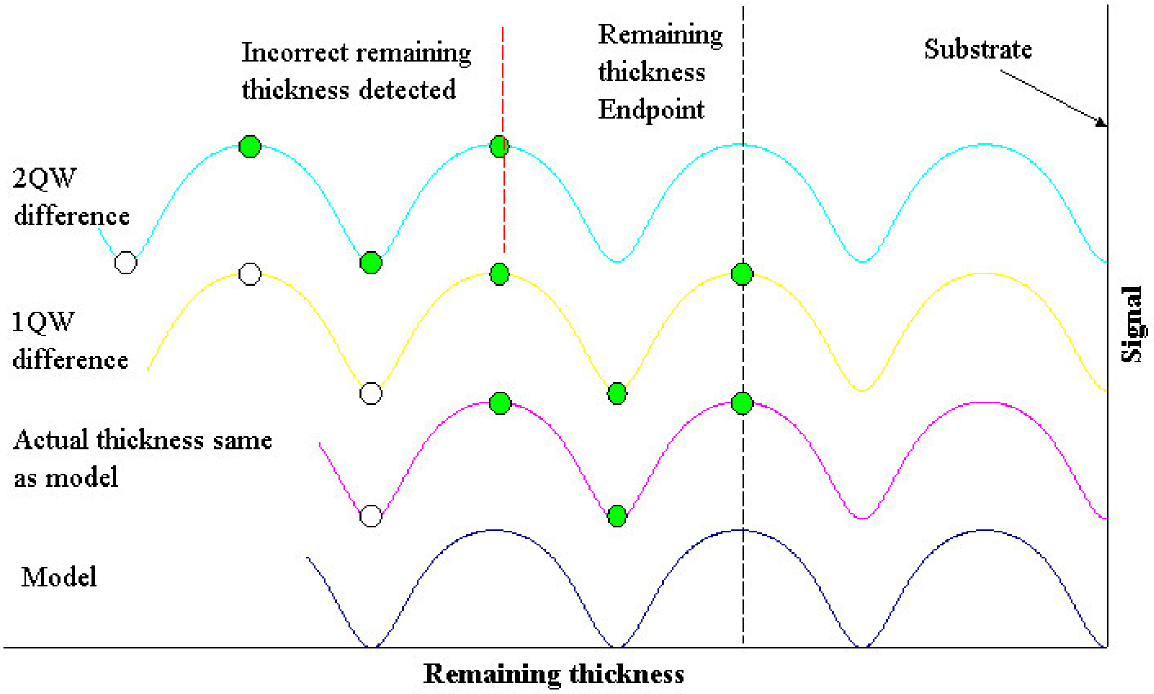
Endpointing on a remaining film thickness

The LEP400 monitors etch depth, however, since the model will always end in a turning point at the substrate, under certain circumstances a *remaining* thickness endpoint can also be found.

In the simplest case, where the starting thickness is accurately known, subtracting the value of the required remaining thickness yields the target endpoint depth. However, if the starting thickness is not well known then a remaining thickness endpoint is more difficult.

The model analysis mode relies on matching two subsequent turning points in the process data with those at the start of the model in order to 'lock on'. Therefore, if the thickness is a quarterwave thicker thicker than predicted in the model (i.e. the first turning point is of the opposite sense - maxima instead of minima or vice versa) then 'lock' on will still be achieved at the same point and the same remaining thickness found. This allows some tolerance in thickness in remaining thickness etches.

If the tolerance in starting thickness is such that the process trace begins in the second part quarterwave of the model or two or more part quarterwaves before the model starts, then the remaining thickness endpoint will be two whole quarterwaves out. In these circumstances, hardware modifications are available to obtain an in-situ starting thickness measurement enabling calculation of the correct model and target depth for each wafer before it is processed. For further information on this application, please contact Intellevation.



Contact details

If you have any comments or questions, Intellevation support can be reached using the contact details, below. If you have purchased the instrument through an OEM or local agent who has the service contract, they should be your first point of contact. In all correspondence, please quote the serial number on the electronics module and optical head, so your enquiry can be efficiently processed.

If you have a process related enquiry, it is often useful to send copies of the data files (process runs, endpoint params, model, structure, etc). In some cases an event may be demonstrated more clearly by taking a screen dump as it occurs. Press the 'print screen' keyboard button to copy an image of your monitor display to the clipboard. Then open a graphics package (such as Paint), select 'paste' to display the image, crop as required and save in a convenient graphics format. Large files can be compressed using Winzip (pre-installed on the machine) to assist with emailing.

Intellevation Ltd
5 Dalziel Road
Hillington Park
Glasgow
G52 4NN
United Kingdom

Tel: +44 (0)141 882 0058
Fax: +44 (0)141 882 9223
Email: enquiries@intellevation.co.uk
Web: http://www.intellevation.co.uk