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Application Note: Broadband vs. Single Wavelength Monitoring

The historical method of calling an end of a layer in optical coating was to monitor a wavelength and when a condition was met calling the end of the layer. In the earliest days this method was done using the human eye of a trained observer. In some cases this is still done today but with the most limited of success. The next advent in coating control came with the advent of the ability to measure automatically the intensity of light in transmission or reflection mode by wavelength.

Either single wavelengths acquired by filters or via monochromator illuminate a photodetector. Wikipedia defines a monochromator as "A monochromator is an optical device that transmits a mechanically selectable narrow band of wavelengths of light or other radiation chosen from a wider range of wavelengths available at the input. The name is from the Greek roots mono-, "single", and chroma, "color", and the Latin suffix -ator, denoting an agent." The selection of the wavelength monitored is done by a controlled and calibrated mechanical movement. Once this single wavelength or narrow band of wavelengths is selected and measured, the trend of light intensity can be used to determine the end of a coating layer.

Early end point algorithms were based on the ability of an observing person watching a strip chart recorder or monitor, deciding when a turning point from or direction change occurred. Although subjective this did work well for simple coating structures.

Follow on technologies in the software applied to optical monitoring held to the same paradigm associated with the traditional observation of a single wavelength of optical information. Many examples of this method still exist where a single wavelength is monitored and end point decisions are based on the observation of that single wavelength. Oddly we as an industry do our final quality control using a spectral measurement of the finished sample expecting it and rightly so to give us a more perfect evaluation than the observation of a single wavelength sample. Because of this, some of the more expensive single wavelength monitors may take a time consuming scan of all wavelengths at the end of the coating layer to prove that the final result was what was expected. Much has been written to date on the ability of films design software to use this after layer scan data to re-optimize the design, the important caveat is that it is based on broadband spectral information rather than a single wavelength sample.

The broadband monitor captures instantly an entire spectrum of optical information in the wavelength range under observation. Each wavelength can be used simultaneously to call the end of the active layer. This means that more data goes into the end point calculation in the broadband method. But the single wavelength method still exists and has much historical support.

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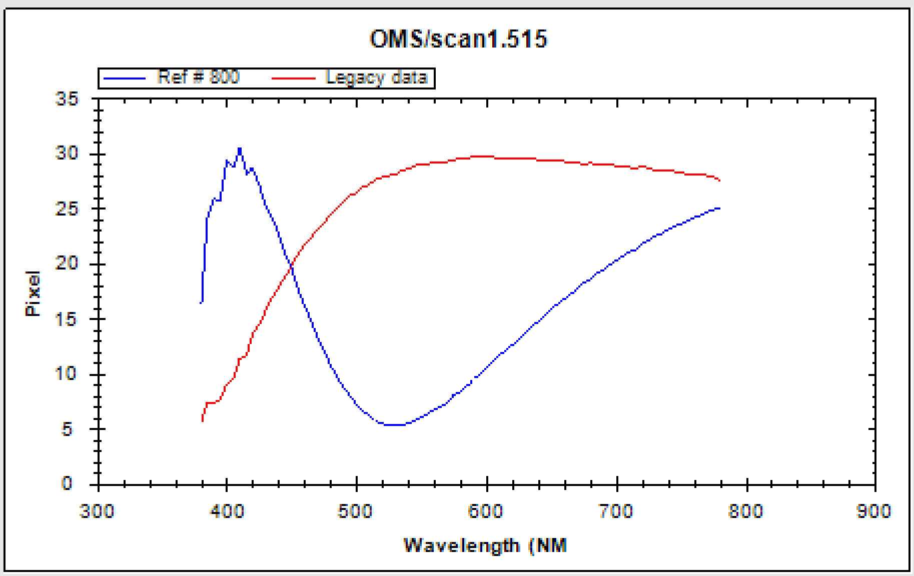
As discussed in a previous application note the NVision optical monitor supports this method with good success. There is one problem with this technology; the measurement of only one wavelength limits the potential precision as we are typically waiting until a condition has been exceeded such as a quarter wave minima or maxima. In most cases the end point is called at some time after the actual meeting of the end point criteria condition. This requires the process engineer to design the algorithm to compensate for the delay in the decision.

Much has been discussed over the past years as to the use of a spectral fit from a broadband optical monitor and the advantage provided by a spectral match of a target spectrum. Accuracy is enhanced because a real product spectrum is used in the decision of the actual layer end.



The blue trace is the reference spectrum to be matched. The red spectrum is the current spectrum from the acquisition of the NVision Optical Monitor. This device acquires the data using a spectrometer making measurements about every 100 milliseconds. More is discussed in other application notes on how to setup the system for highest repeatability. The acquisition time is basically a function of the measurement period (integration time of the detector array) and the number of samples averaged in each measurement. The reference scan is then compared to the current scan and a goodness of fit algorithm processes the two scans to find the scan that best meets the match to the reference spectrum.

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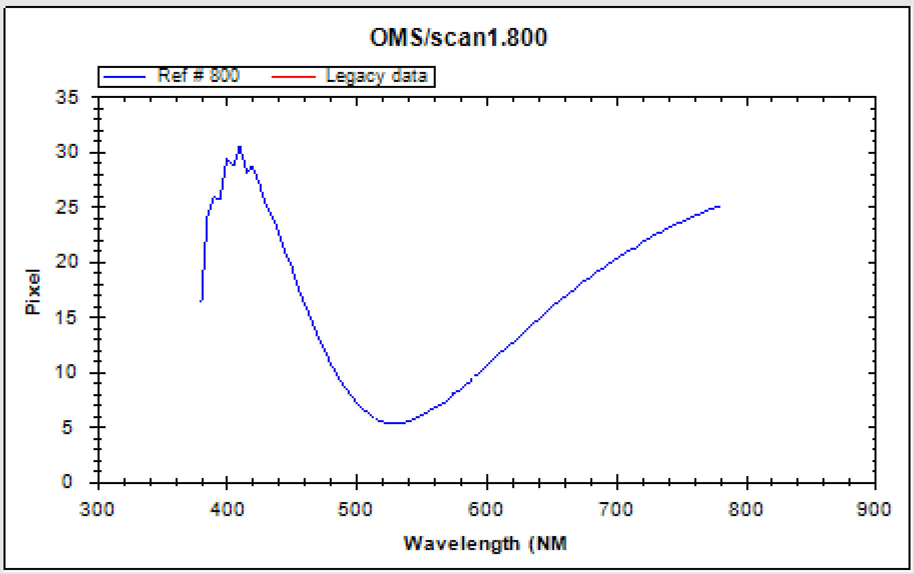
The question is what is a good fit? Some have suggested that a good fit is when each pixel is within a certain percentage of the required amplitude of the reference. This hard coding of goodness number then limits the robust nature of the potential algorithm. If only one pixel is just outside the limit then the algorithm fails and the system continues to deposit without stopping while looking for a match which will never occur.



This is not a problem with a match as seen above. The sample and reference coincide as a perfect match. Unfortunately in the real deposition world nothing is ever perfect as seen in the sample below. More often than not the deposition of optical thin films is fraught with issues that cause the deposition to be slightly different than the design. Notice that the spectra in the sample below no longer coincide. The adaptive algorithm still finds the “best” match allowing for the differences and the real world variation. When two samples match identically it is easy to call an end but when they are never an exact match then the algorithm must find the best of the choices. This takes some thinking on the computers part. An algorithm that does not have the ability to adjust on its own will be subject to failure.

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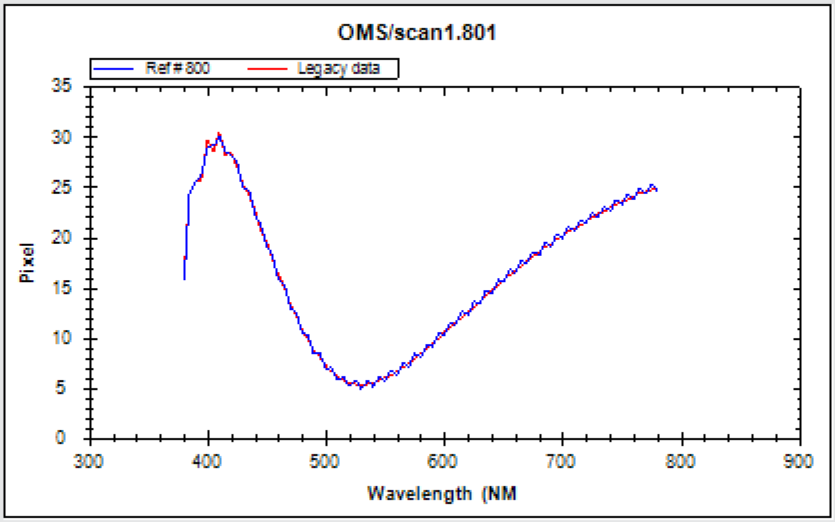
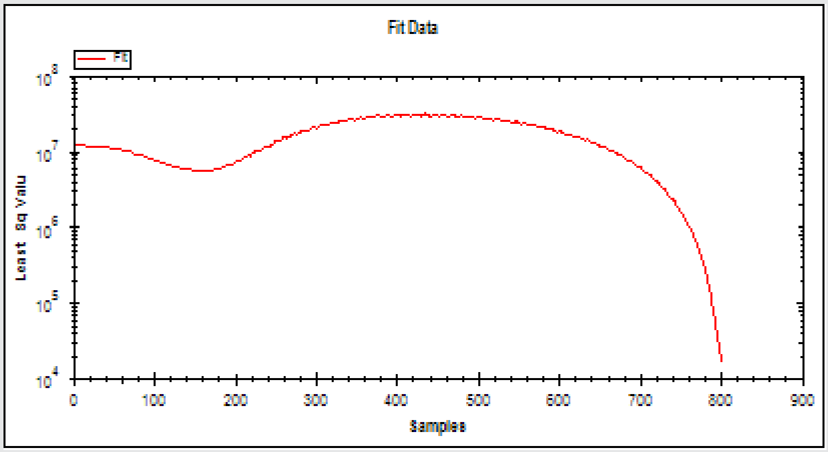
In a situation as described a single wavelength instrument would deliver an endpoint to the layer that would be offset by the optical error of the specific wavelength. This could be in the case below as much as several percent of the desired layer cut.



A spectral match can be determined by an evaluation of the lowest or best possible match. The following graphic describes the fit for the above match.



This graphic as mentioned describes the plunging goodness value as it draws close to the best fit.

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In every case the probability of the actual being perfect is so low that the fit threshold must be somewhere above zero. Therefore two fit algorithms monitor the goodness of fit. The first method monitors the fit for a basic goodness threshold. At this point the system will start looking for the best case condition that occurs after the threshold is met. This algorithm then looks for the lowest perceived difference between the reference and the measurement spectra. This will always be one measurement late because it will be looking for the slope to change to the positive. One measurement should be about 100ms plus some time for the coating system to shut down the deposition process.

The second algorithm will simultaneously be looking for a more refined threshold event to occur based on the input from the recipe. After the basic goodness threshold has been met the system also looks for the refined threshold. If this is met the coating fit is considered to be met and the coating system is commanded to stop deposition.

Given two different match criteria the worst case fit would be one scan past the best fit and the best case would be the best fit or an exact match. The system can also provide a best fit qualifying number to be tested for validity.

This validation value can be tested and then a decision can be made to evaluate the coating recipe for change. At the present time an interface has been designed to Essential Macleod for the creation of the reference spectra and for the export of the finished layer for optimization of the recipe.

The potential for more accurate and complex end points using the spectral match method has been discussed in many publications but is now finally available in a production instrument.

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