How to Configure a Microspectrometer

By: Greg Neece

How many pixels do you need to measure your spectrum? For many spectrometer customers the typical answer has been as many pixels as the manufacturer will sell. Is this the correct answer? As you may expect, the answer is sometimes yes and sometimes no. There are several factors to consider in order to properly specify the spectrometer best suited for use in a given application.

Optical resolution is frequently one of the driving factors in configuring a spectrometer and falls into the “yes” category with respect to demanding more pixels. The pixel number in combination with the slit and grating options will determine the final optical resolution. Often dispersion, or wavelength range divided by the number of pixels, is used when discussing resolution. Full width-half maximum (FWHM), or the width of a peak at half of its maximum intensity is a better way of determining resolution (see Figure 1). By using FWHM the actual optical performance of one spectrometer design can be compared directly to another. This avoids such pitfalls as, for instance, having a grating that does not use all of the available pixels; or, in another case, having an optical design that does not produce a sharp image of the slit onto the detector array. Cross Czerny-Turner designs can exhibit this latter problem due to the sharp angles of reflection and inherent system magnification required.

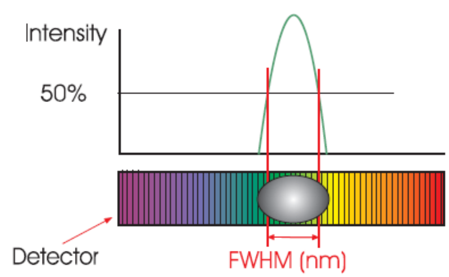

Figure 1 Full Width Half Maximum

Sensitivity is another factor to consider in specifying your microspectrometer. Sensitivity is completely independent of the number of pixels in linear arrays typically found in today’s microspectrometers. The exception to this rule is the use of a 2-D array in a vertically binned arrangement or horizontal binning of a linear array. In the case of vertical binning, the vertical line of pixels is used, or in a crude sense added up, to be one larger pixel. So, when considering the sensitivity requirements of a given application it is much more important to look at the response curves of the detectors offered. A few example detector sensitivity curves are given in Figure 2. If the application is in the visible range, several different brands of CCD’s (regardless of the number of pixels) may be employed. However, as one moves to the NIR range where CCD sensitivity is declining, perhaps a different array with better NIR response would be a better choice.

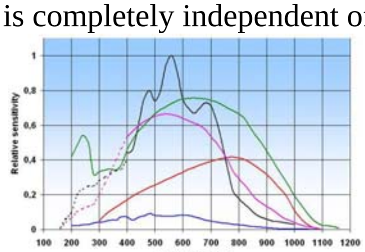

Figure 2 Detector Sensitivity Curves

Signal to noise performance may also be a part of the decision matrix. In typical CCDs, higher sensitivity leads to decreasing signal to noise performance. To a certain extent this can be overcome by the use of spectra averaging. Averaging multiple spectra for a single output increases the signal to noise performance by the square root of the number of averages, e.g., averaging 100 spectra improves signal to noise by a factor of 10. Still some applications require superior performance with respect to signal to noise. For this, customers should look to the signal to noise performance published for each optical bench and detector combination utilized in a spectrometer platform. It is important to note that the published signal to noise performance figures should be data measured through the entire spectrometer system since it is the overall system performance that matters most. A good detector with respect to signal to noise is not much use if employed in a poorly performing system. A good method of comparing signal to noise performance among detectors and manufacturers is to calculate the mean and standard deviation per pixel for 100 scans. Signal to noise is then the mean divided by the standard deviation. This calculation should be done with the signal near the saturation limit of the detector with an appropriate smoothing setting (if any is required).

Grating selection can be the trickiest option to specify. There are typically two factors discussed with respect to gratings, wavelength range and optical resolution. Wavelength range can be limited by the detector chosen or the grating or both. Optical resolution is driven by not only the grating but the slit and detector (number of and size of pixels) as well. There is also a third factor to consider. The grating can have an impact on the system's sensitivity. This is because different gratings will have differing points where they are most efficient. It is sometimes valuable to look at grating efficiency curves when system optimization is important. Figure 3 contains some examples of typical gratings with 600 lines/mm and various points of maximum efficiency from the UV to the NIR. This is where the fun begins and if you find yourself confused, you will not be alone…call your supplier. There are trade offs here that can lead to dual or multi-detector systems for microspectrometers that are able to support this capability.

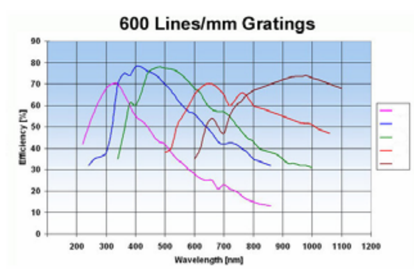

Figure 3 Grating Efficiency Curves

Did I mention the slit? Microspectrometers typically have a choice of slit sizes that will be installed in the fiber optic entrance (see Figure 4). Most typically, microspectrometers have permanent, fixed slits. Generally speaking there are two considerations to keep in mind. The smaller the slit, the better the system resolution will be, and the larger the slit, the more light will be allowed to enter the optical bench. In essence it is a trade off between resolution and sensitivity (signal strength would be more accurate).

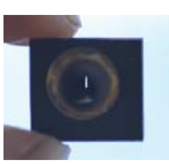

Figure 4 Slit Example

Luckily, determining the remaining options for your spectrometer can be fairly straightforward. For instance, for UV performance below 360 nm, a coating must be applied to standard CCDs. Other detectors, e.g., back-thinned CCDs or CMOS will not require this option. In order to avoid second order effects some version of a second order coated optic or long pass filter can be included. Other options may be application specific such as non-linearity or irradiance calibrations if you are making radiometric measurements.

So, now that the basics have been outlined, how about a simple and practical example? Suppose a system is needed to measure fluorescence of a liquid sample. For simplicity let's assume the sample will be presented in a standard cuvette. Now, what should we consider with respect to the spectrometer? First of all we should consider both the wavelength range and optical resolution required. Many basic fluorescence measurements have an excitation in the UV range with a response in the visible. If we want to see both the excitation and response we should choose a broadband instrument covering 200-1100 nm. If we want to exclude the excitation and see only the response we can choose a more narrow range instrument, e.g., 360-1100 nm or 500-1100 nm. All of these configurations can be done with either a 300 line/mm or 600 line/mm grating.

Experience tells us that fluorescence response is typically weak and presents a fairly large FWHM (broad peak). Considering these factors we should choose a sensitive detector, most likely a CCD array, and use a relatively large slit…perhaps 200 microns. The large slit will allow more light into the spectrometer but, of course, the larger slit will reduce system resolution. The resolution impact may be OK since fluorescence response is typically broad. Looking back at the previous grating selection (300 or 600 lines/mm) we can see that the optical resolution will be either 8 nm or 4 nm in a typical microspectrometer. Likely this is more than sufficient for fluorescence.

Beyond the spectrometer, we need to consider light source and sampling options which are numerous for fiber optic spectrometers, but this goes beyond the scope of this article. As is evident in the example, by following a few simple steps one can configure a micro-spectrometer to the application at hand. Most importantly, don't hesitate to ask the supplier of the instrument for recommendations and explanations. Your supplier should be able to confirm your assumptions and make productive, cost effective recommendations in determining the final configuration of your microspectrometer that will be most suited to your application.

About the Author:
Greg Neece is President of Avantes North America. He has a MS Degree in Management and a BS degree in Mechanical Engineering. Greg has worked in leadership roles in Aerospace, Industrial Manufacturing, Industrial Automation, and Photonics.