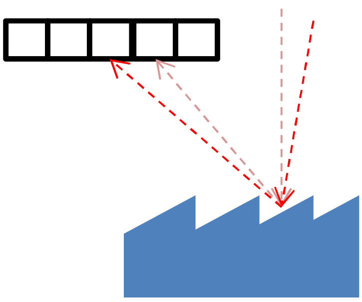
It’s all about throughput

One of the key parameters of any spectrometer based instrument is its sensitivity. However this is often confused with the net transmission of the spectrometer, or how efficiently a photon that enters the spectrometer is converted into a recorded count on the final device. However this parameter takes no account of how well the complete instrument gathers photons in the first place. Which is in turn proportional to the size of the receiving aperture, but this aperture is typically restricted by the spectrometer or other light separation device being used.

In any spectrometer or interferometer the amount of light that can be gathered is a function of the bandwidth of the instrument and the instrument design (including factors such as optical arrangement physical size etc). This is illustrated below by this simple reflective grating spectrometer design as light enters at different angles so it falls on a different pixel confusing the device.



This is often referred to as the instrument throughput and is the product of the receiver area and the FOV of the instrument. In Czerny Turner and similar instruments this parameter can easily be calculated from the slit width and the instrument F number. The lower the resolution of the spectrometer the higher this combination will be.

Michelson and Fabry perot interferometers are a viable alternative to diffraction grating based spectrometer the primary advantage of these type of systems is that typically have 100 times greater throughput making them ideal for integrating into large aperture instruments when high resolution measurement are required.

The IS instrument spectrometer offers the same throughput advantage as a Michelson or Fabry Perot Interferometer while providing the spectral characteristics suitable for a Raman spectrometer. This allows the device to be coupled with a larger aperture telescope and hence detect fainter signals dramatically improving the sensitivity of the complete instrument. This in turn allows stand off Raman measurements to be made or couple the instrument to a larger core optical fibre.

To illustrate this advantage lets consider the design of a Raman spectrometer, designed for stand off measurements using a laser with a 1 mrad divergence and a 1mm spot.

The signal to noise of the instrument and hence sensitivity is directly proportional to the amount of light gathered by the instrument. The amount of light gathered is given by

$$S = \frac{E\alpha_b k A_T T^2}{\pi R^2}$$

Where E is the laser energy α_b is the raman scattering net cross section, k is the instrument constant, A_T is the telescope aperture T is the transmission through the atmosphere and R is the distance to the target. Therefore using identical lasers at a fixed distance the total amount of light gathered is a function of the instrument constant and the telescope aperture. The telescope aperture is limited by the etendue or throughput that can be achieved by the spectrometer.

Therefore using a leading Czenry turner instrument a slit width of 50 µm with a f1:4 lens provides a 6 cm^{-1} resolution. Given the laser divergence of 1 mm the longest focal length receiver that can be used is 25 mm and given the f number limitation gives maximum diameter receiver that can be used of 6.25 mm.

With the IS instruments baseline Raman spectrometer configuration uses a 1 mm diameter optical fibre which defines the etendue with a Na of 0.22 providing a 4 cm^{-1} resolution. Therefore the maximum focal length that can be used is 500 mm which allows a 110 mm diameter lens to be used. This results in well over 100 increase in the total amount of light that is collected by the instrument improving the final observed signal to noise by a factor of **17 !!**

This fact clearly illustrates the advantages provided by the IS – Instruments spectrometer in particular the flexibility it provides as a OEM system for low light measurement.