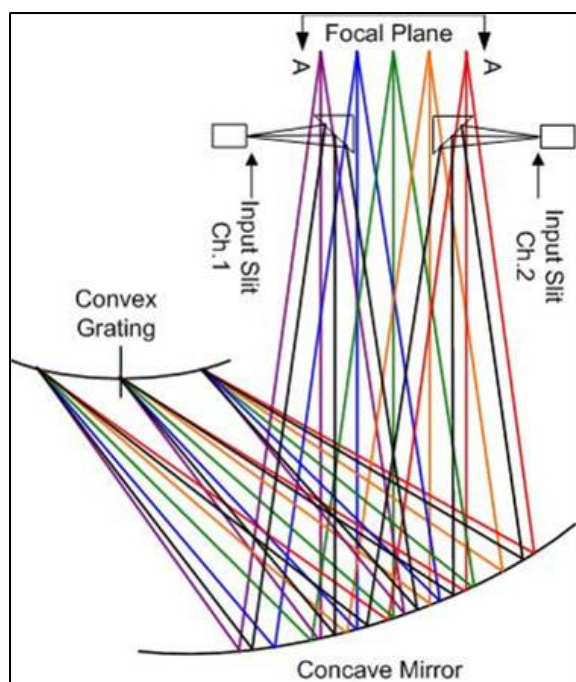


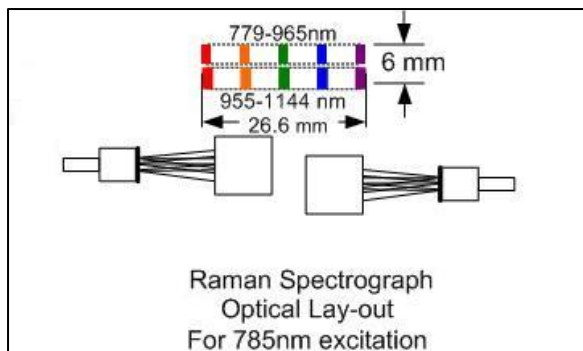
## Raman Spectrometer Monitors Multiple Reaction Sites With Doubled Dispersion

*Compact f/2.4 design efficiently handles large numbers of optical fibers at the entrance aperture and provides high spectral resolution as required for life sciences and process monitoring applications.*

Raman spectroscopy has risen to the top of a short list of technologies for identifying substances with high specificity. As a result, Raman spectrometers with high-spectral resolution, high-spatial resolution, high throughput, and small footprints are in high demand. Utilizing holographic diffraction gratings technology, Headwall Photonics has developed an imaging spectrometer that satisfies these performance demands through a retro-reflective concentric design utilizing the optimized properties of an advanced highly efficient convex grating (see Figure 1).



**Figure 1.** *Raman Explorer's unique concentric optical design enables multiple high resolution spectra on one array detector.*



Headwall Photonics' Raman Explorer is an imaging spectrometer that is optimized to detect Raman signals that are shifted up to  $4000\text{ cm}^{-1}$  by a 785-nm laser. A multi-channel, multi-spectrum imaging spectrometer with improved photometric and spectral resolution accuracy has several unique features, including the ability to place “dual spectra” onto the detector plane by using two separate entrance apertures. Each entrance aperture is located at a separate off-axis position and offset from one another in the spectral domain. This configuration allows each input aperture to direct its radiation at a unique input angle of incidence to the grating.

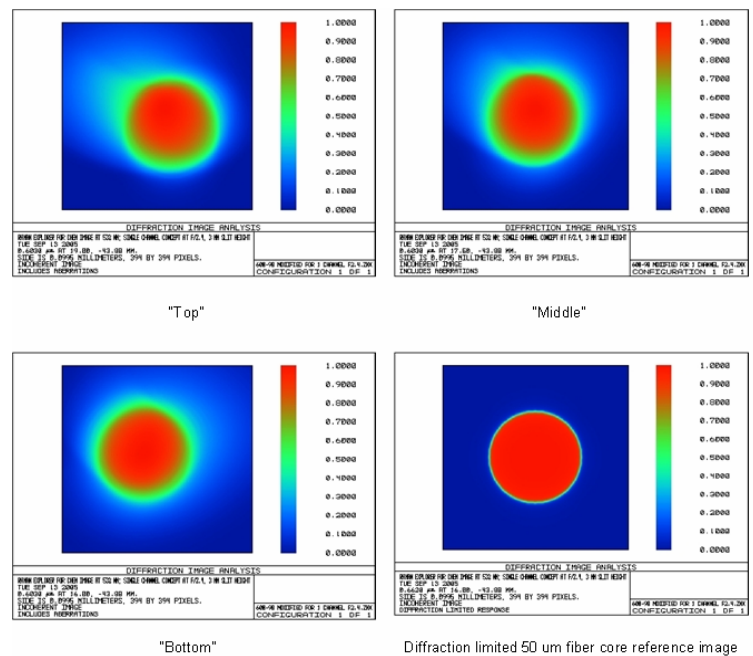
Both inputs are then dispersed and re-imaged as two separate wavelength ranges on the detector, one directly above the other.

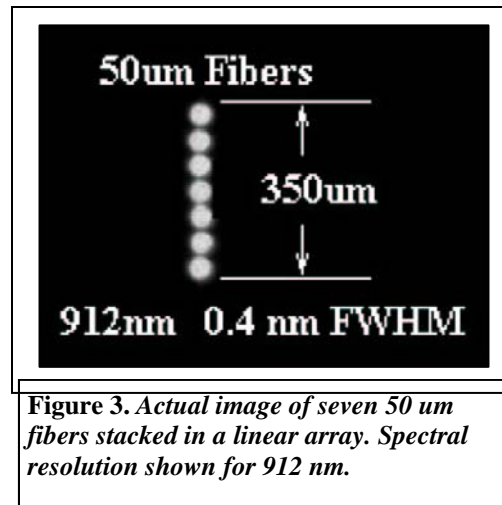
Spatial resolution in a spectrometer design refers to the instruments ability to faithfully reproduce an image positioned at the entrance aperture, or front focal plane, onto a multi-element detector array, or back focal plane. High-spatial resolution is important for an application that requires collecting a signal with a bundle of fibers because the fibers have to be aligned in a linear array at the entrance aperture to maintain spectral resolution. Many spectrometers are capable of reproducing a one-point image, such as a single optical fiber onto a detector array, but they are unable to discriminate features or fibers stacked above or below a single point because of astigmatism and aberrations. This results in an unacceptable compromise of both spatial and spectral resolution performance.

Ray trace images (see Figure 2) represent the re-imaged back focal plane spot size of a 50- $\mu\text{m}$  diameter fiber positioned at the top, middle and bottom of a 3-mm tall entrance aperture in a Raman Explorer spectrometer module designed for 532-nm laser excitation; a diffraction limited image of the fiber core is provided for a reference. In this case, the re-imaged spot energy is well contained at near the diffraction limited space, allowing the Raman Explorer spectrometer to accurately reproduce tall spatial images at the back focal plane for each input aperture.

As demonstrated by these ray trace diagrams, this optical design is well suited to process large stacks of linearly aligned fiber arrays. The system's spatial-imaging performance also can process several discreet fiber bundles within each entrance aperture. For example, a process requires monitoring at five separate locations along the process line. The Raman Explorer can collect the signal from each process monitoring location by using “six-around-one” 50- $\mu\text{m}$  circular fiber bundles. At the opposite end, the five fiber bundles are co-located in a single ferrule, with each bundle forming its own 300- $\mu\text{m}$  long linear array (see Figure 3). Each seven fiber array is physically separated by a small distance to avoid crosstalk. The ferrule then connects to the entrance aperture of the spectrometer and, when illuminated, the dispersion from each of the five linear arrays within that entrance aperture is spectrally re-imaged across the detector.

**Figure 2. This 3-mm tall ray trace shows the spatial imaging performance of a 785-nm excitation Raman Explorer configuration at 603 nm, using a 50- $\mu\text{m}$  fiber core diameter.**





**Figure 3. Actual image of seven 50 um fibers stacked in a linear array. Spectral resolution shown for 912 nm.**

By separately binning each of the five dispersed regions on the array detector, the spectra from each process location can be reviewed separately as if being monitored by its own spectrometer, greatly reducing the cost of the overall system.

Headwall Photonics has improved the system's optical efficiency by combining an optimized holographic grating design with an f/2.4 platform. The f/2.4 optical speed compliments the NA 0.22 of optical fiber, thereby utilizing the majority of the input signal. This optical speed provides many more times the efficiency of typical f/4-f/6 systems. The holographic grating design used for Raman Explorer is highly optimized to place the entire dispersed signal within one diffracted order. Grating efficiencies of greater than 70 percent are common. Combined with holographic gratings, these spectrometers provide superior stray light rejection of less than  $10^{-5}$ . Raman Explorer is relatively compact at 7 x 7 x 10 in., and weighs 12 lbs. The ability to spectrally image large apertures is of particular interest to those involved in multiple site industrial process monitoring, and optical fiber imaging endoscopy.

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