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How Renishaw's inVia Raman system provides high spectral resolution from a 250 mm focal length spectrometer

The pitfalls of combining standard components

Traditionally, Raman systems have been developed by combining standard off-the-shelf components; microscope, spectrometer, and detector.

These components are normally designed in isolation, with very different design criteria, and cannot be coupled together efficiently. The outcome of this design approach is a system that is severely compromised in performance.

A fresh start

In contrast, Renishaw's micro-Raman system is of revolutionary—not evolutionary—design.

Renishaw, a world-leader in high precision measurement, entered the Raman market over 12 years ago. Renishaw's scientists and engineers were briefed to develop a system that would collect and analyse the Raman scattered light from a 1 µm laser spot as efficiently as possible. To achieve this, they designed a Raman microscope system starting from first principles, paying particular attention to the efficient matching of the various components of the system.

Resolution

The resolution of a spectrograph is its ability to separate adjacent peaks.

It is often measured by analysing the Raman spectrum of a compound with close Raman bands, such as CCl_4, or by measuring the width of a very narrow atomic emission band, from a material like neon. These measurements are detailed in Technology Note SPD/TN/079 "Renishaw's Raman microscopes – Obtaining high spectral resolution".

The resolution of a spectrograph is affected by many factors, such as:

- diffraction grating groove density
- grating diffraction angle (include angle – the angle between incident and diffracted light)
- grating diffraction order
- spectometer slit width
- detector pixel size
- system magnification
- focal length
- aberrations, such as astigmatism
- cross-talk between detector pixels

The following sections briefly review some of the key design decisions that resulted in Renishaw's Raman microscope offering both high efficiency and high resolution in the same instrument.

Mirror-based spectrometers – a compromise

Most general-purpose spectrometers are unsuited to Raman spectroscopy as they use off-axis mirror designs that suffer from poor focusing because of astigmatism. This is especially bad for short focal lengths.

The poor imaging spreads the precious Raman scattered light over unnecessarily large areas of the detector, reducing signal-to-noise levels and making the spectrometer far less sensitive. This lower sensitivity is not a problem for the techniques for which these spectrometers were designed—such as atomic emission and fluorescence spectroscopies—where light levels are many orders of magnitude higher than those produced by Raman scattering.

The poor imaging also limits the resolution (measured in wavenumber), making it significantly worse than the dispersion (wavenumber per detector pixel). The only way these systems can try to achieve high resolution is to use longer focal lengths to reduce the amount of aberration.

inVia Reflex Raman microscope

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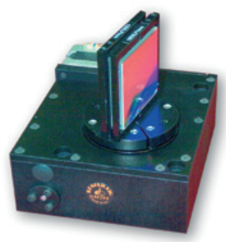

Renishaw's precision diffraction grating stage enables you to switch rapidly and easily between gratings, so you can tailor spectral range and resolution to match your particular analysis requirements

However, longer focal length systems must use a wider entrance slit to accept all the light from the microscope and maintain optical efficiency. This is because the longer focal length in the spectrometer prevents it from accepting as wide a cone of light as before. The cone has to be narrowed by increasing the focal length of the lens before the entrance slit; this produces a correspondingly larger magnified image of the sample's laser spot.

Unfortunately, the larger entrance slit is imaged to a larger area on the detector and this limits resolution. The slit can be narrowed to regain resolution, but only at the expense of optical efficiency, sensitivity, and performance. These systems can offer resolution or sensitivity, but not both.

Renishaw's lens-based design

Renishaw's design uses an on-axis lens-based imaging spectrometer; this ensures light is sharply focused onto the detector.

The 1 µm laser spot on the sample is imaged onto a relatively narrow spectrometer entrance slit (adjustable, but typically 12 µm to 15 µm), which is in turn imaged onto the minimum number of pixels on the detector. This enables an optically-efficient short focal length spectrometer to be used without sacrificing resolution.

Dispersion and resolution vary with wavelength, but are typically 1 cm^{-1}, decreasing to 0.5 cm^{-1} for certain gratings and wavelengths. This is illustrated in Figures 1 and 2.

Figure 2 shows that the spectral dispersion and spectral resolution of the inVia microscope are sufficiently high that the bands of the cooled CCl_4 are clearly resolved. Those of the room temperature CCl_4 are thermally broadened, illustrating that in most cases the instrument resolution exceeds the natural linewidth of a Raman peak.

Additional examples are given in Technology Note SPD/TN/079 "Renishaw's Raman microscopes – Obtaining high spectral resolution".

All factors affecting resolution—such as detector pixel size, grating groove density, slit width—are matched to the target resolution. Modifying the design to boost a single factor is detrimental, since the resolution is not improved and optical efficiency is necessarily degraded.

This carefully balanced design is key to Renishaw's success in demonstrating that high spectral resolution can be achieved from a 250 mm focal length spectrograph. High resolution does not imply long focal length as long as the system design is good.

Whilst some people argue "never mind the efficiency, look at the focal length", Renishaw's Spectroscopy Products Division believes differently, and has the Raman system to prove it.

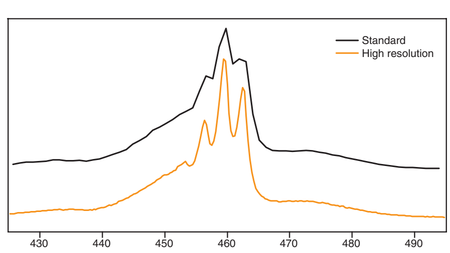

Figure 1
Spectra of CCl_4 taken with standard and high resolution inVia Raman microscopes (spectra offset for clarity)

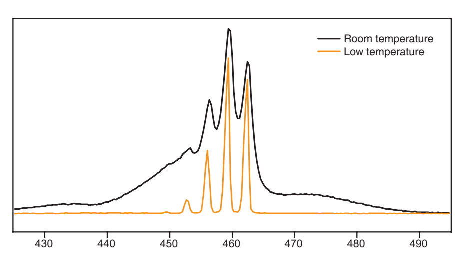

Figure 2
Spectra of room temperature and cooled CCl_4 taken with a high resolution inVia Raman microscope