A high-performance raman spectrometer

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A novel Raman spectrometer incorporates a high spectral brightness laser and a high-resolution axial spectrograph that minimizes image aberration.

Figure 1 shows the i-Raman spectrometer, an instrument designed to overcome the high instrumentation cost usually associated with Raman spectroscopy. Targeting the best possible balance between performance and cost for analytical Raman applications, it features a compact design, a user-friendly interface, and the two following key technology advancements.

1. Improved laser technology
For Raman spectroscopy applications, high spectral brightness (defined as laser power divided by its spectral linewidth) is a highly desirable property of the excitation laser. The recently developed CLEANLAZE technology is based on a high-power broad-stripe laser diode with its output spectrum narrowed and stabilized using a novel external cavity technology. Unlike conventional external cavity lasers, which require a long cavity, the wavelength selective element—i.e., a volume Bragg grating—is directly integrated onto the laser diode. As a result, the laser is both ultracompact in footprint (4×4×3mm) and stable to environmental change. The use of a broad-stripe laser diode guarantees the low cost of the entire module and can also provide much higher output power (up to 1.5W) than its distributed feedback or Bragg reflector counterparts. The new technology allows a spectral linewidth of 0.8cm⁻¹ (i.e., 0.05nm) at 785nm, which implies a two-orders-of-magnitude enhancement in spectral brightness over standard broad-stripe laser diodes.

2. Novel axial spectrograph technology
A conventional Czerny-Turner spectrograph suffers from large image aberration on the detector plane due to its off-axis optical system. This aberration broadens the image of the entrance slit by up to tens of microns, which lowers spectral resolution. The image aberration is even more severe at longer wavelengths, causing a loss of spectral features. The i-Raman spectrometer features a novel spectrograph design using a folded axial optical system that greatly improves the image quality on the detector plane. This enhances both the spectral resolution and sensitivity of the spectrograph, especially for Raman signals with longer wavelengths or larger frequency shifts. In addition, the spectrograph features an f number (f/#) of f/2.2. This corresponds to a light-collection angle several times larger than that of a Czerny-Turner spectrograph, which typically operates at f/#s greater than f/4. Thus the throughput of the spectrograph, that is, its sensitivity, is also improved. This improvement in spectral quality is clearly seen in Figure 2, which compares the Raman spectra of a mineral spirit sample measured by f/4 and f/2.2 spectrographs. Figure 2(a) shows the spectrum obtained from the f/4

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Figure 2. Shown are Raman spectra of an odorless mineral spirit sample measured by an f/4 Czerny-Turner spectrograph (a) and by an f/2.2 axial spectrograph (b). The insets show the calculated image aberration of the spectrograph on the detector plane.

Czerny-Turner spectrograph with an integration time of 50. The calculated image aberration of the entrance slit on the detector plane is also shown as inset, where rays of different wavelengths are color-coded. The large image aberration at longer wavelengths (red rays) causes degradation in spectral resolution and sensitivity as well as loss of spectral features. In contrast, the spectrum obtained from the f/2.2 axial spectrograph, shown in Figure 2(b), achieves much better spectral resolution and sensitivity due to its improved image quality. For example, the image size of the entrance slit at around $3000\text{cm}^{-1}$ is reduced from 300 to 30$\mu$m, which increases signal intensity by a factor of 4.5. The high throughput of the axial spectrograph also helps to reduce the integration time from 50 to 35s. Thus, overall sensitivity is improved by a factor of 6 for those Raman signals with larger frequency shifts. The spectral coverage of the axial spectrograph ranges from 750 to 1050nm (or 175 to 3100cm$^{-1}$ Raman shift) when used with a CLEANLAZE laser at 785nm excitation.

Other features of the $i$-Raman spectrometer include a TE cooled 2048-pixel CCD array, an integrated fiber optic probe, and a USB 1.1/2.0 computer interface.

The instrument has been successfully used for a variety of industrial applications, including gemstone identification, hazardous material detection, pharmaceutical analysis, and dental resin cure monitoring. The results will be published elsewhere.

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