

Product Note T31-10/17

BRAVO – Contactless Material Verification and Identification

The ability to perform a quick on-site material analysis without extensive effort, such as transporting the sample to an off-site reference laboratory involving costly tests, is an attractive option. Vibrational spectroscopy techniques like FT-IR or Raman, available in smart, portable, or even handheld instruments, which are designed for routine operation at maximum ease of use, can provide an in-field analysis with laboratory quality results. Most importantly, handheld Raman spectroscopy is gaining more and more widespread acceptance due to its capability to probe materials through transparent barriers such as packaging material. This approach has many advantages, such as reducing the risk for the accidental introduction of contaminants during incoming goods inspection. Likewise, the operator is protected from possible hazards from toxic substances, which is of special importance for the identification of unknown substances.

Obviously, using a handheld instrument, an analysis result is instantaneously available, which can yield very cost efficient material control processes with a 100% inspection rate. In cases where an identification is needed, such as at customs control, immediate results can be important in determining the appropriate response to an initially unknown substance. In both cases, analysis results can be reported according to Pharmaceutical standards of data integrity, e.g. (c)GMP and 21 CFR Part 11 regulations.



Advantages

- Supports Material Identification and Verification workflows
- DuoLaser™ excitation has a large spectral range accessible (300 – 3200 cm^{-1}) and provides highest sensitivity.
- Fluorescence mitigation SSE™ for maximum material suitability
- Unmatched wavenumber accuracy achieved of $\pm 1 \text{ cm}^{-1}$ in the fingerprint and $\pm 2 \text{ cm}^{-1}$ in the CH-stretching region [1].
- Reduced risk of material alteration or damage because of a low laser output power of $< 100 \text{ mW}$.
- Maximum user safety (Laser Class 1M)
- BRAVO can be remote controlled via WiFi or Ethernet [2].

Analysis through packaging material

By nature, a non-invasive analysis through barriers like packaging material is fascinating. To understand how this is facilitated one needs to reflect on the principles of Raman spectroscopy: The material to be analyzed is illuminated by laser light and the backscattered light, including the Raman signals, is analyzed within the instrument.

Following this principle, the requirements for the packaging material are obvious:

- The packaging needs to transmit the laser light in order to illuminate the material of interest.
- The backscattered light, which carries the material specific Raman information, again has to be transmitted through the packaging, to enable the analysis.

Consequently, to a first approximation, if it is possible to look by eye through a material, one can measure through. Any losses due to absorption and reflection of the incident and scattered light, will reduce the sensitivity.

Measurement through bottles

As a simple example consider the analysis of a chemical stored in an amber bottle, commonly used in laboratories and industry. Ideally, it would be desirable to conduct the Raman measurements through amber glass, but the absorption and its exponential increase as a function of the glass thickness, tremendously decrease the sensitivity for thicker bottles or ones being darker in color (higher absorption). Figure 1 shows the transmission as function of the wavelength, multiplied with the transmission at the corresponding excitation wavelength (to consider the transmission of the incident laser as well as scattered light), through the wall of a big 3L amber bottle (supplied from Carl Roth, Germany). This transmission value denoted as efficiency is a measure of signal losses towards transparent material. The red curve corresponds to 785 nm excitation, the black curve to 1064 nm excitation (most common lasers in handheld Raman instruments).

The corresponding wavelength range which includes the "fingerprint" information is marked by shaded areas.

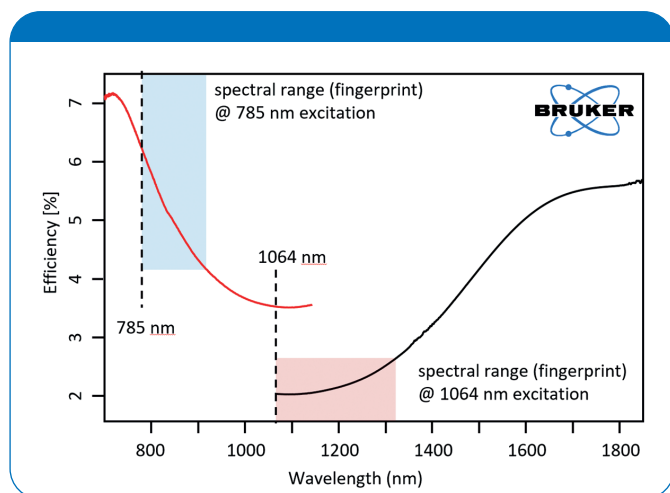


Figure 1: Efficiency towards 0% absorption losses, in measuring through a 3L amber bottle.

It is clear that on average 95% (785 nm) or even 98% (1064 nm) of the initial sensitivity is lost because of absorption by the amber glass. This directly translates to a tremendous increase in measurement time to achieve similar signal to noise levels compared to clear bottles.

For routine applications, such as incoming goods control requiring a high sample throughput and sensitivity towards contaminants, the above mentioned limitations for thicker/darker bottles are severe, whereas for identification of unknown substances, e.g. at customs, such possibilities may remain attractive.

It needs to be pointed out that absorption cannot be circumvented by any technical innovation, which means that for some packaging the sampling of materials is unavoidable. For example, spatially stand-off Raman spectroscopy (SORS) considers the Raman and fluorescence contribution by the packaging, but does not avoid absorption.

Clear packaging

This is certainly where Raman spectroscopy can demonstrate its strengths: The laser and Raman scattered light can pass through transparent materials nearly unchanged and hence, the capability to measure through barriers of a certain thickness is to a first approximation determined by the focus position of the laser. For handheld Raman instruments, the focus position is usually fixed, and is adapted using different measuring tips, which serve to align the sample at an optimal distance towards the focus. BRAVO's measurement tip for bags for example is designed to probe materials through packaging films. Raman signals detected by the spectrometer mainly originate from a volume around the focus position (depicted by a green circle in figure 2).

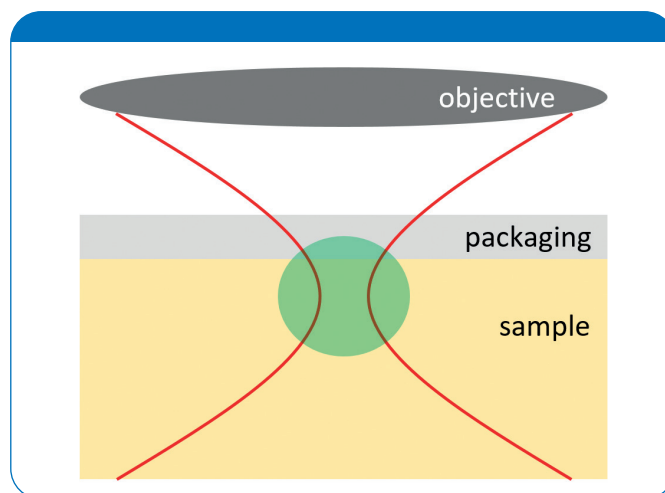


Figure 2: Focus position is optimized for packaging films. Signals from of a certain volume (here depicted by the green circle) around the focus position are mainly contributing to the Raman spectrum.

This volume should be aligned to a position to yield a maximum in signal intensity and to minimize the contribution of the signal from the packaging. For example in figure 2, the probed volume includes the sample as well as the packaging. In most cases the contribution of the film is negligible, as its signals in this configuration are very weak. But of course, in general one needs to consider the signal strength of the sample material with that of the packaging material. The upper spectrum in figure 3 represents a spectrum measured of talc in a heavy PE bag. Talc exhibits a fairly weak Raman signal and therefore a pronounced PE contribution is included in the spectrum above 1000 cm^{-1} .

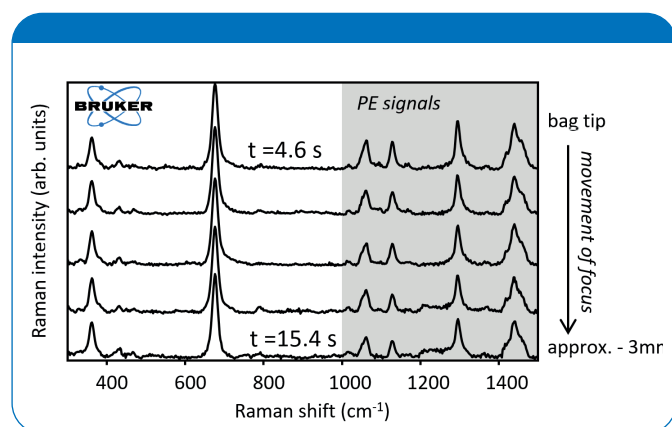


Figure 3: Raman spectra of talc in a PE bag as function of the focus position. Spectra are normalized to talc bands and displayed with an offset.

At first glance, it would seem obvious to move the focus deeper into the talc in order to avoid a contribution of the PE (see figure 2). But as shown in figure 3, moving the focus deeper into the material does not significantly reduce the PE signals towards talc. This is because next to the focus position, the absorption of the material needs to be considered. Of course, moving the focus deeper into the material reduces the PE contribution, but also the signal from talc is reduced, because the laser as well as the Raman light is absorbed within the sample material. This effect causes the measurement time to increase to yield the same signal intensity, which is indicated for two measurements in figure 3.

Therefore, it is only possible for transparent, non-absorbing samples, to move the focus to such an extent inside the sample, that packaging signals to a first approximation do not contribute at all. For samples like talc, BRAVO offers the possibility to setup material specific spectral ranges used for data evaluation in order to exclude packaging signals from the analysis. The invariance of the analysis result towards variances in packaging thickness is achieved for such materials (e.g. in an experiment stacking thin PE bags, the correlation coefficient is almost independent for 20 PE layers being stacked).

Thicker than a film?

As reviewed in the previous paragraph, for thicker packaging like bottles, the standard “bag tip” of BRAVO is not appropriate as it is optimized for films. Therefore, a tip with a variable focus position is available to move the probed volume further away from the surface of the sample tip and to consider barriers up to several millimeters of thickness.

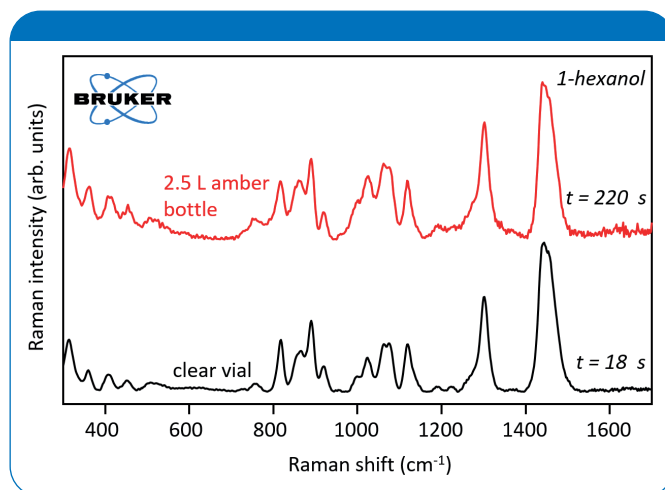


Figure 4: Measurement with BRAVO of 1-hexanol through a 2.5L amber bottle (red) and through a clear vial (black).

Figure 4 shows Raman spectra measured from 1-hexanol in a clear vial (black) and in a 2.5L amber bottle (red). The change of the focus position using the tip with variable focus position enabled the measurement through the bottle and the spectrum matches the one measured through a clear vial. But the absorbing nature of the amber glass (see figure 1) caused a tremendous increase in measurement time by a factor of 12 (given values correspond to the total time including electronics control of laser wavelengths for SSE™). This increase in measurement time to achieve an adequate signal to noise ratio makes larger amber bottles unsuitable for routine measurements using handheld Raman instruments.

For clear bottles, the absorption is certainly absent but it needs to be considered that Raman spectroscopy is susceptible to interference from stray light, especially that emitted from neon lamps. These are all factors to take into consideration using Raman spectroscopy for QC, where robustness is a key parameter. Certainly, a vial inserted into its dedicated measuring tip is the optimal measurement condition.

SSE™ and packaging

The fluorescence mitigation SSE™ applies in the same manner to packaging signals as for sample signals, and any fluorescence contribution from the packaging is considered by the algorithm [3]. For example, often glasses emit an intense fluorescence signal (see figure 5).

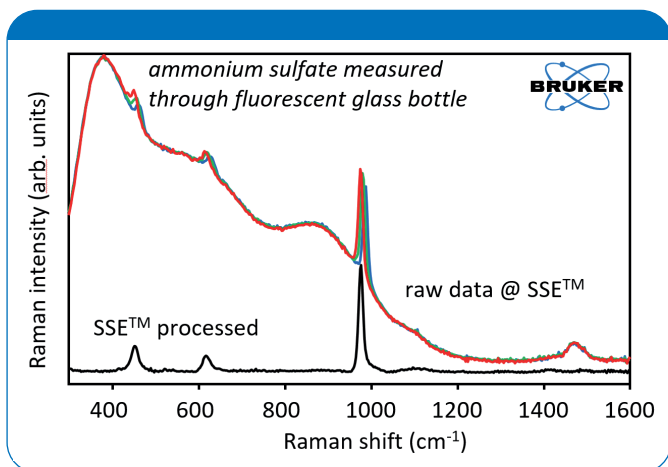


Figure 5: Raman spectra of ammonium sulfate in a fluorescent glass bottle before (red, green and blue) and after (black) SSE™ processing.

The raw data measured at sequentially shifted excitation (red, green and blue spectrum) includes the characteristic sample signals next to a non-linear fluorescence contribution. The SSE™ processing successfully extracts the Raman signal from the fluorescent background (black spectrum). This processing therefore enables the unambiguous identification of materials in the presence of intense fluorescence signals.

Raman spectroscopy is a powerful method enabling new options for material testing in routine analyses and for other applications, for which it is an integral requirement not to open packaging material and expose the sample to the surrounding environment. The BRAVO handheld Raman spectrometer offers unique solutions to address fluorescence contributions from the sample or the packaging material, while minimizing to exclude the Raman contribution from the packaging with a maximum flexibility in method setup.

References

- [1] Bruker Product Note T30 03/16, Accuracy is crucial: The starting point for a robust transfer of methods
- [2] Bruker Product Note R34 05/16, Advanced Data Acquisition and Evaluation in Handheld Raman Spectroscopy.
- [3] Bruker Product Note T29 12/15, Efficient mitigation of fluorescence in Raman spectroscopy using SSE™.