

Fast Raman Hyperspectral scanning of mining core samples

A White Paper



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INTRODUCTION

Long wave infrared (LWIR) spectroscopy is of great interest to spectral geologists. This is because minerals such as quartz, k-feldspar, pyroxene, hornblende, anorthite, calcite, and dolomite are only identifiable in the LWIR range, not in the short-wave infrared (SWIR) range. However, Raman

spectroscopy is complementary to LWIR spectroscopy, providing fingerprint spectra of these minerals and an alternative identification method. But Raman spectroscopy also provides several additional benefits on the instrument side. Unlike LWIR spectrometers, Raman spectrometers do not have to manage large thermal backgrounds with cooled housings. They also provide a higher spectral resolution, and are a more cost-effective solution, compared to IR cameras.

In this whitepaper, we demonstrate a Raman hyperspectral instrument for mineral mapping at a standoff distance of 250mm from a conveyor belt moving core samples at a speed of 25mm/s. To achieve the desired spatial resolution, integration times of the order of 20ms are realized. The Raman hyperspectral instrument is composed of an $f/1.95$ VPH grating spectrograph, a relay lens to form a slit image at 250mm, a 1024 x 1024 EMCCD camera, and a 1.5W 532nm laser focused to a line coaxial to the optical axis of the spectrometer. The design is based on a push-broom scanning observation concept providing hyperspectral imagery over 256 spatial channels, at a spatial resolution of 0.25 mm and on a swath of 64mm. The achieved spectral resolution is better than 6 cm^{-1} over a wavenumber range of 100-2000 nm^{-1} . The SensIR spectrograph at $f/1.95$ provides more than four-times the photon collection compared to an $f/2$ spectrograph, translating to significantly faster scans.

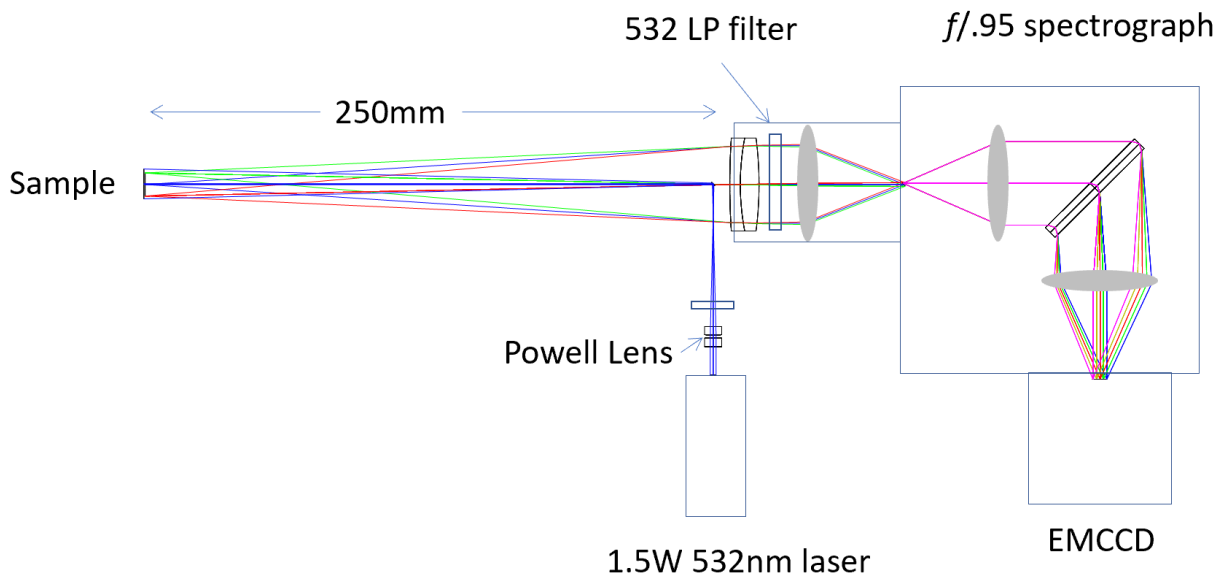


Fig 1. Optical schematic of the Raman scanner

EXPERIMENTAL SETUP

The setup uses a high throughput spectrograph at $f/1.95$ built by SensIR with a 1024 x 1024 Ixon EMCCD camera from Andor Instruments. The slit is reimaged to the sample using an $f/1.95$ relay with a 532nm longpass filter to reject the laser. The sample area on the sample at 250mm away from the spectrometer is 64mm by 0.25mm, which provides 256 spatial channels of spatial resolution. The spectral resolution is better than 6 cm^{-1} over a wavenumber range of 100-2000 nm^{-1} .

The 532nm laser is folded into the optical path on axis to provide depth of field and accommodate rocks with varying heights. The laser is a 1.5W 532nm single mode output focused to a line using a cylindrical lens and Powell lens to form uniform illumination on the sample. A narrow 532nm bandpass laser is used to clean up any fluorescence produced by the laser optics and the out of band emission from the laser.

Core samples measuring 75mm in diameter were halved and the flat part was analyzed. The core samples were analyzed earlier and contain large amounts of albite and moderate amounts of dolomite, pyrite, quartz, and white mica.

The core samples were scanned over roughly a four-inch scan where 500 frames were captured. The integration time at each scan is 20ms and the scan speed was 25mm/s.



RESULTS & DISCUSSION

Strong Quartz Spectra

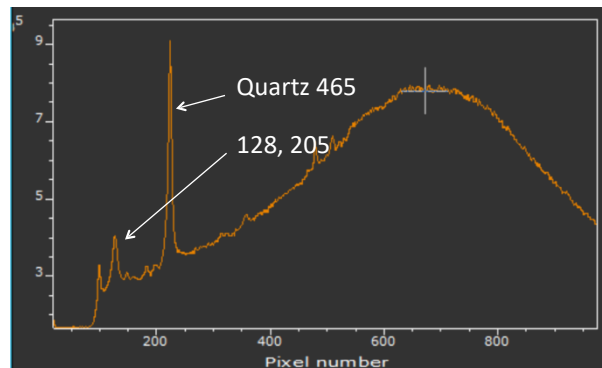
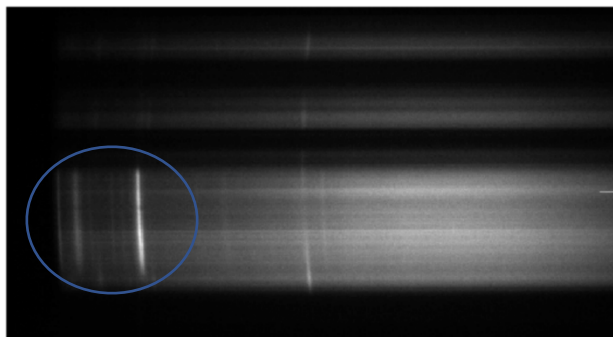


Fig 2. Single frame showing Quartz Raman spectra in lower left in image.

In the sample shown in Figure 2, strong spectra are observed for quartz with a prominent peak at 465 cm^{-1} , and two lower peaks at 128, and 205 cm^{-1} . More Raman lines are seen here as well, but they are in a fluorescence background. We chose 532nm as the excitation wavelength, due to the availability of a high-power single mode laser and the higher Raman cross section achieved using this shorter wavelength. The fluorescence background can also be separated using Principal Component Analysis (PCA), as detailed on page six.

Identifying Albite, Dolomite, and Quartz

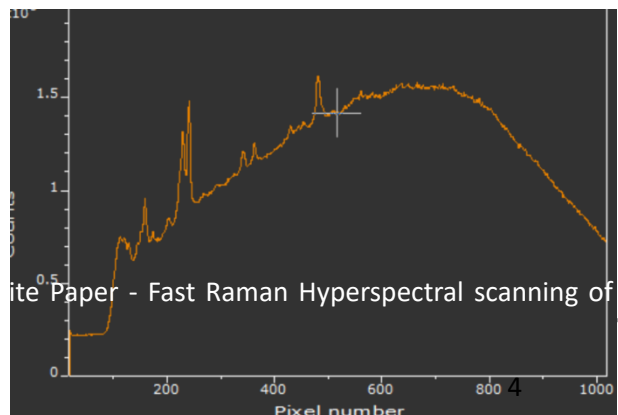
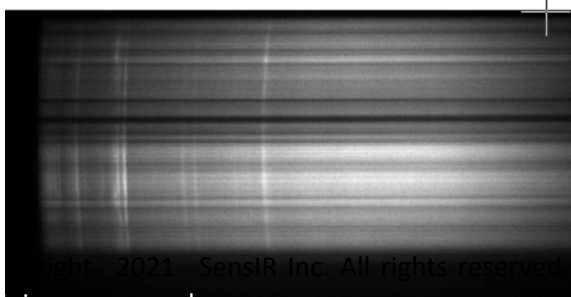


Fig 3. Single frame showing multiple Raman spectra of albite, dolomite, and quartz

We could identify albite quite easily across this entire sample, as shown in Figure 3. The dolomite spectra are also apparent as well as a lower amount of quartz overlapping on one of the albite peaks. Figure 4 reveals more details about these mineral spectra in this frame.

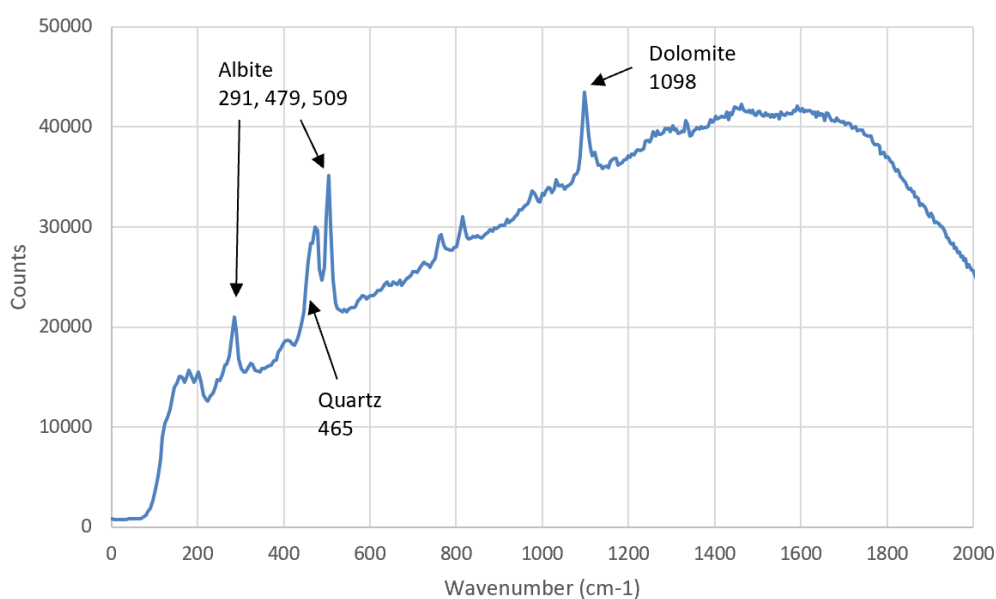


Fig 4. Raman spectral peaks associated with albite, dolomite, and quartz

The strong peak for dolomite is at 1098cm-1, while albite has two primary peaks at 479cm-1 and 509cm-1 and a smaller peak at 291cm-1. The small quartz peak at 465cm-1 is seen right next to the 479cm-1 albite peak and cannot be resolved by this spectral plot.

Principal Component Analysis (PCA)

To fully examine the PCA components, the image sequences were imported into a hyperspectral image analysis software package called IDCube from HSpeQ in St. Louis, MO. The first component vectors revealed mostly fluorescence but, by the 8th to 15th component, we could clearly see Raman peaks for albite, dolomite, and quartz. Figure 5 shows the spectra of component 11 with primary peaks for albite and dolomite. Figure 6 shows the distribution of albite and dolomite on the sample is a gray scale map.

Fig 5. PCA component 11 shows peaks of albite and dolomite

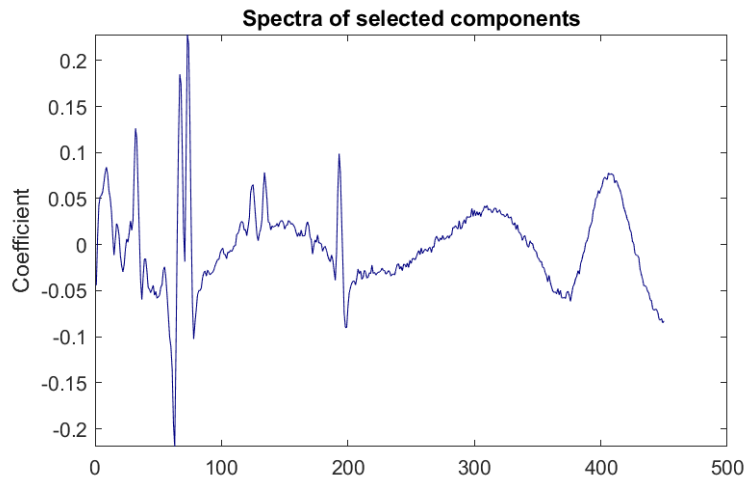
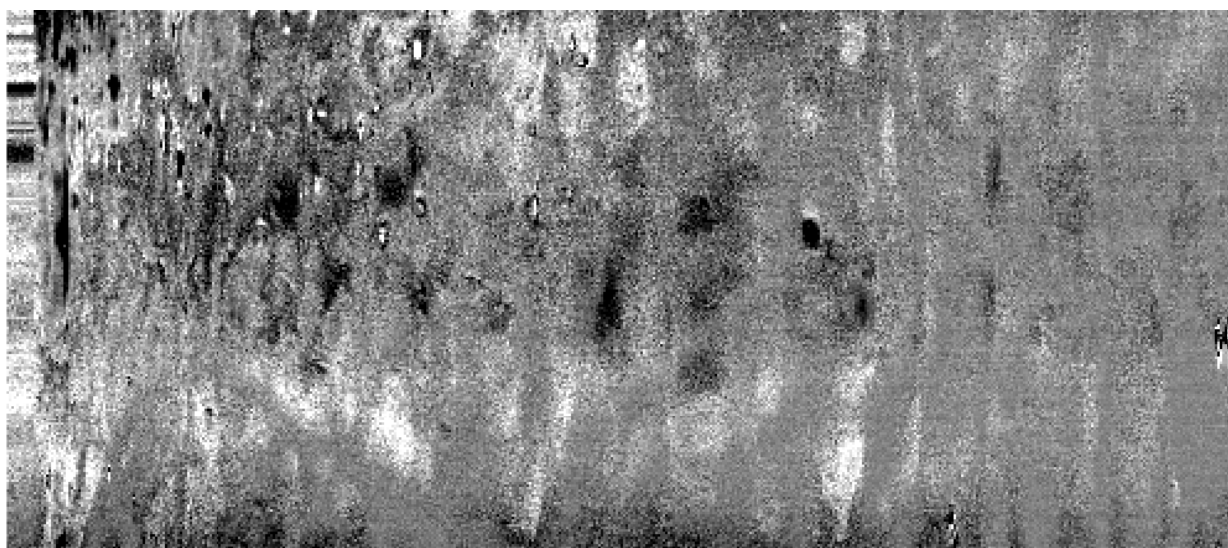


Fig 6. PCA component 11 shows the distribution of albite and dolomite in the sample. The gray scale uses white at high concentration and black at low concentration



SUMMARY

It is feasible to use fast Raman hyperspectral scanning in mineral analysis with integration times of the order of tens of milliseconds at a standoff distance of 250mm. A very high throughput spectrograph is required though. There is a four-fold difference between an $f/2$ and $f/.95$ spectrograph for photon collection. In other words, your integration times or laser power density is four-times greater using traditional IR imaging techniques to achieve the same signal and results, when realized with a Raman spectrometer.

The Raman features in these samples were very apparent in the spectral scans, even in the presence of a strong fluorescent background. Using PCA, this fluorescence background can be separated, revealing very apparent mineral spectral signatures in higher components.

To conclude, fast Raman hyperspectral scanning can be used in many applications that currently rely on LWIR or FTIR instruments due to the complimentary nature of the Raman spectra to LWIR spectra.