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Reflectance spectroscopy for investigating diamond inclusions and kimberlite indicator minerals

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Introduction

Inclusions in diamonds can provide valuable information on their source and formation conditions. Definitive analysis often requires destructive testing which can negatively affect their integrity and availability for subsequent analysis. Because of diamond's wide wavelength range of transparency, analysis of inclusions is possible using optical techniques, such as reflectance/transmission spectroscopy (optical spectroscopy: OS). Kimberlite indicator minerals (KIMs) can also be analyzed using non-destructive reflectance/transmission spectroscopy.

Optical Spectroscopy

OS is robust for non-destructive characterization of minerals. OS instruments can be deployed in the field or laboratory using relatively low-cost and ruggedized instruments. We are investigating OS over the 350-2500 nm wavelength range for analysis of diamond inclusions and KIMs.

In comparison to elemental determination techniques, such as electron microprobe analysis (EMPA), OS offers some additional advantages and complementary information, including:

- Acquisition of quantitative data with little or no sample preparation
- Low-cost instrumentation
- Rapid data acquisition
- Determination of oxidation state of transition-series elements

Methods

We have investigated a number of set-ups to acquire reflectance spectra of inclusion-bearing diamonds and KIMs that can be quantitatively analyzed to derive compositionally meaningful compositional data. The most robust system consists of a bifurcated bundle of 100 micron diameter optical fibers that direct incident broadband light onto the sample (normal to the sample) and collects the reflected light in the same configuration (normal to the sample). This configuration has been extensively tested on a wide variety of KIMs ranging from opaque (e.g., magnetite) to transparent (e.g., forsterite).

Results

Our investigation of OS of single diamonds has shown that absorption features in their spectra can be related to plausible inclusion minerals. The set-up involves placing a diamond on a reflectance plate or in a small (few mm diameter) well drilled into a reflective material, such as aluminum and using a bifurcated multiple optical fibre probe to direct incident light onto the sample and collected the reflected/refracted/transmitted light.

For KIMs, we use the same set-up as above. We have investigated garnets, chrome diopside, olivine, chromite, ilmenite, and magnetite, for single grains ranging from ~200 microns to 1 mm in size. The resulting spectra show absorption features that can be related to various compositional properties of each mineral. Useful spectral data is obtained for single grains as well as grains mounted in epoxy and polished for EMPA analysis.

The compositional information that can be provided includes quantitative or semi-quantitative elemental abundances, albeit generally of lower precision than EMPA analysis. However, the optical spectra can exhibit absorption features attributable to transition series elements of different oxidation states, such as Fe, Mn, Cr, and Ti. This is in contrast to EMPA, which provides elemental abundances from which oxidation states must generally be inferred from stoichiometry. In the case of iron, the presence of Fe^{3+} can be detected for abundances on the order of tens of ppm (Figure 1).

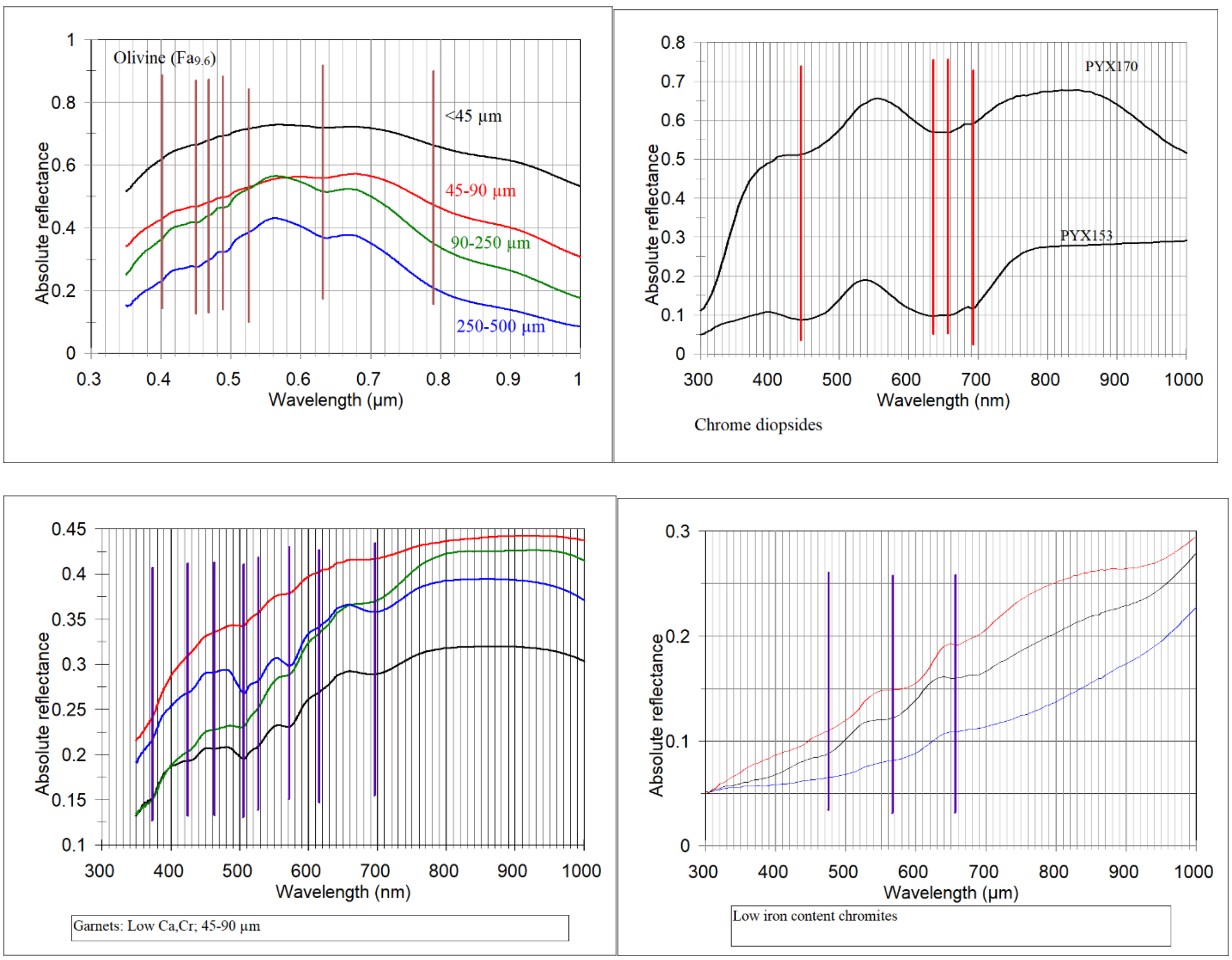

Figure 1. Reflectance spectra of selected KIM minerals: fine-grained powders (all <90 µm). Upper left: low-iron olivine with a range of grain sizes. Upper right: chrome diopsides. Lower left: Low Ca/Cr-garnets. Lower right: Chromites. Vertical line sindicate aborption bands that are related to presence of transition series elements whose wavelength positions are controlled by their oxidation state.

The spectroscopic data indicate that the most diagnostic absorption features occur in the 350-1000 nanometre region, which is accessible using off-the-shelf, easy-to-use, low-cost (few thousand dollar) silicon CCD detectors that can acquire near real time data.

Our results suggest that optical spectroscopy is useful for non-destructive interrogation of diamond inclusions (Figure 2). For KIMs, optical spectroscopy is complementary to EMPA analysis, and can be applied to KIMs prepared for EMPA analysis, and is also non-destructive. It can be applied to KIM analysis before or after samples are prepared for EMPA analysis.

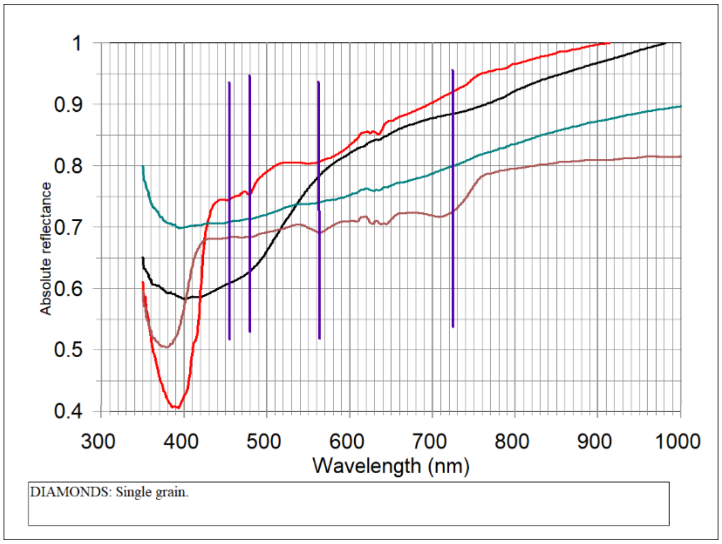

Figure 2. Reflectance spectra of individual diamonds. Vertical lines indicate wavelength positions of potentially diagnostic absorption bands.

We have partnered with Aurora College, NWT, Canada to bring this technology to the educational and commercial diamond exploration sector.

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