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It is now well known that Raman spectra of carbons can differentiate materials with varying properties and histories. While a Raman microscope can be quite useful under some circumstances, a simple macro measurement may be adequate for characterizing a material. In addition, performing a macro measurement eliminates all issues of microscopic measurements not capturing the materials' properties.

The spectra shown in Figure 1 were captured from a variety of materials in our collection. The samples were excited by the 785 nm diode laser on the MacroRAM and spectra were collected using a touch probe, as shown in Figure 2. The materials' identities were taken at face value from the package in which they had been stored.

The spectra were ordered from top to bottom in decreasing graphitic character.

Each spectrum shows the usual bands of  $sp^2$  carbon. The G band at about  $1575\text{ cm}^{-1}$  is the band that always appears in graphitic materials. The D band that appears between  $1310$  and  $1400\text{ cm}^{-1}$ , depending on the excitation wavelength, is a mode of motion that is forbidden in crystalline graphite, but becomes allowed by defects and the double resonance<sup>1,2</sup>. In addition, a band close in value to twice the D band Raman shift appears near  $2700\text{ cm}^{-1}$ . In highly crystalline materials this band is quite intense and may have several components; in addition, there may be a band at twice the G band Raman shift.

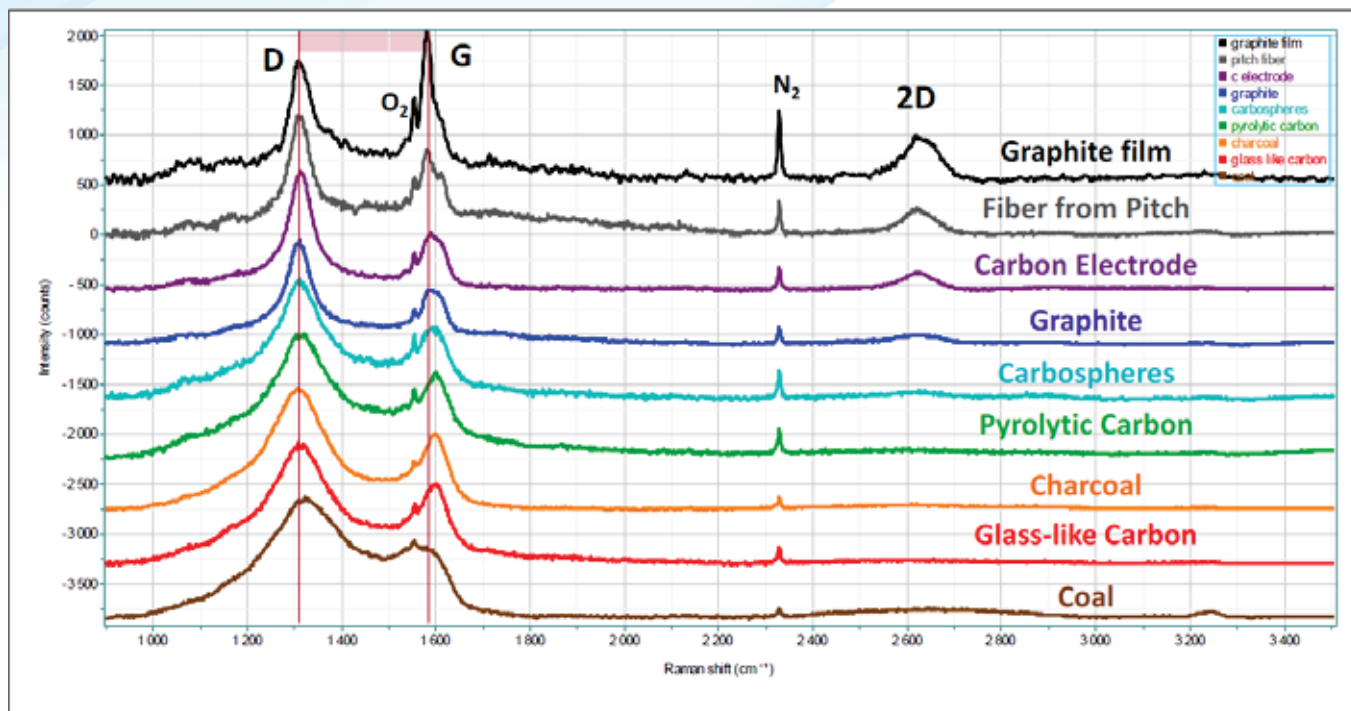


Figure 1: Example Macro-Raman spectra for different types of carbons, shown in order of decreasing graphitic character from top to bottom.



Figure 2: Sample measurement configuration; touch probe connected to the MacroRAM for easy and fast data collection.

The ratio of the D to G bands is commonly used to characterize carbon for industrial applications. But because of the double resonance in these materials, the spectra are highly dependent on the excitation wavelength<sup>1</sup>. In addition, the bands' central Raman shift, band width, and relative intensity (peak height or integrated intensity) vary with the ordering of the carbon lattice. The properties that affect

these spectra include the size of the aromatic  $sp^2$  clusters, their stacking, H content, and the  $sp^3$  bonding between the clusters. The interpretation of the carbon spectral results is complicated<sup>2,3,4,5</sup> but inspection of references 3-5 indicates how the H content and temperature treatment affect the Raman spectra. References 1-3 include theoretical material describing these spectra.

Having said that, if one only wants to qualify materials during manufacture, this can be done after acquiring spectra with varying sample histories and chemical/physical properties of relevance to the final product. Then the application of standard software for spectral classification of product qualities will enable deciding if a product is acceptable.

### References

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