Focussing Optics for a Raman Fiber Optic Probe. Part I: Measurement Volume

In a previous note[1], the optical advantages of a focussed fiber optic probe for Raman spectroscopy were discussed. The RamanProbe™ has a final focussing lens which determines the laser spot size and collection volume of Raman scattering from the sample. When selecting the lens focal length, both the required distance from the probe and the desired measurement volume should be considered, as well as optical characteristics of the sample.

Focal Length and Numerical Aperture

The RamanProbe™ uses a single lens to both focus the laser and collect the Raman scattering from the sample. Lenses with different focal lengths (or working distances) can be selected. As a first approximation, the lens serves to change the size of both the excitation and collection focus spots on the sample, and also determines the numerical aperture of the collection optics. The most efficient Raman signal collection will take place with the largest collection angle or highest numerical aperture. This occurs with the shortest focal length collection lens available. One disadvantage of using a short focal length lens is that the laser power density at the sample is higher because the same power is focussed into a smaller volume. This situation may not be desirable when measuring colored samples that can absorb the laser light, causing photodegradation. Another potential drawback is that the probe must be positioned closer to the sample, which may not be physically possible. For example, the lens may not be able to focus through a thick-walled glass bottle, resulting in the measurement of the container rather than of the sample. Providing there are no physical disadvantages to the sampling arrangement, the shortest focal length lens should be used to obtain the highest Raman signal.

Measurement Volume

Experimentally, the choice of lens changes the sample volume that is analyzed with the probe because both the excitation and collection optical pathways must be considered simultaneously. In the standard RamanProbe design, the collection fiber is at least double the size of the excitation fiber, which results in higher overall signal collection. The asymmetric fiber design elongates the focal spot along the optical axis, or increases the depth of field of the probe. In free space, the sampling volume is a distorted cylinder, shown in Figure 1. The longer the lens focal length, the larger the resulting sample volume, particularly along the optical axis.

The depth of field can be measured by observing the Raman signal as a function of distance to a reflecting sample. Figure 2 shows the signal variations with distance for two probes with 5.0 mm and 7.5 mm focal length lenses. A

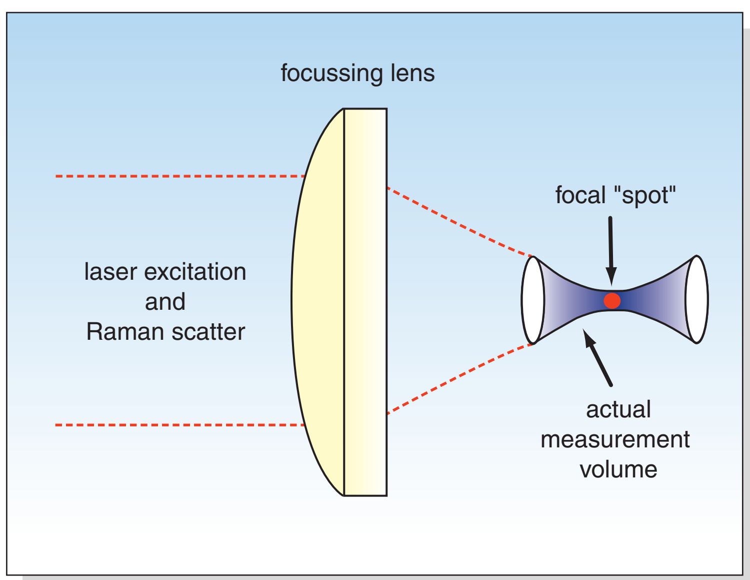

Figure 1. Measurement volume for the RamanProbe with assymetric fiber design. The volume becomes more elongated with a longer focal length lens.

[1]Technical Note #13, InPhotonics, Inc., 1999.

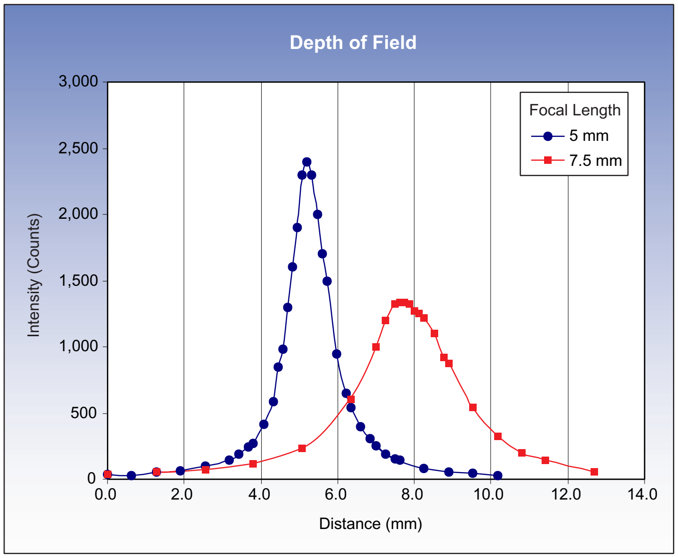

Figure 2. RamanProbe signal as a function of distance from reflective sample (silicon wafer). Note: Two separate probes were used for this test so intensities should not be compared.

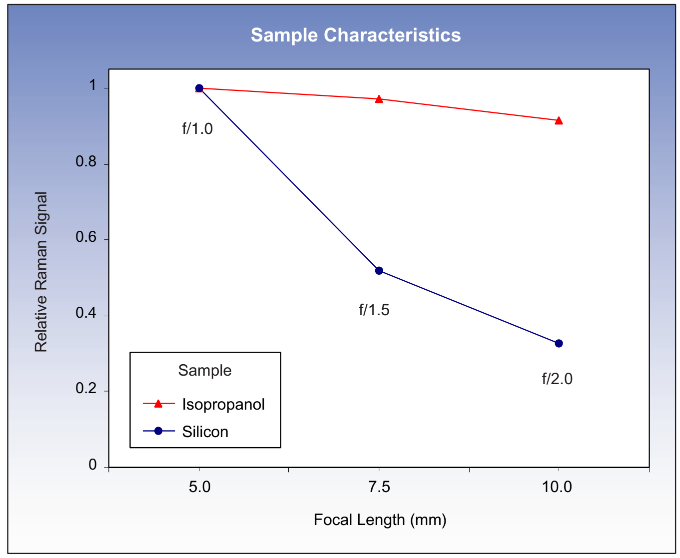

Figure 3. Relative Raman signal as a function of focal length for a transparent and reflective sample. Measurements were made by exchanging the front lens on a single probe.

long depth of field is advantageous for routine sampling since the distance requirement between the probe and sample is forgiving. An alternative, confocal arrangement, is more suitable for precise depth analysis, as in the case of thin film measurements.

Sample Properties

Optical characteristics of the sample will affect the measurement volume as well.[2] A highly reflective sample will not transmit the laser light past the surface. A transparent material will allow the laser to penetrate quite deeply and will benefit greatly from the long depth of field of the RamanProbe. A diffusing or scattering material will spread the excitation beam in all three dimensions, resulting in a larger measurement spot in the plane perpendicular to the incident beam.

The final analysis of sampling volume is achieved by combining the optical effects of the sample with the measurement volume determined by the lens.

When measuring transparent samples, such as clear liquids, the long depth of field matches the laser penetration into the sample, making the choice of focussing lens less important. The opposite is true with reflective materials, where the measurement volume is reduced to a cross-section of the distorted cylinder shown in Figure 1. As the focal length is increased, the cross-section is further reduced in size due to the elongation of the cylinder, resulting in lower Raman signal collection. These effects are shown experimentally in Figure 3, where the Raman signals of optically-different materials were measured using a probe and three focal length lenses. The transparent liquid shows less than 10% signal drop with progressively increasing focal length, while the reflective solid experiences a 50% drop. The effect on opaque liquids and powdered samples will fall between these two extreme cases.

Summary

Focal length, or working distance, is important when specifying a Raman fiber optic probe. In general, the shortest focal length will provide the best signal collection. Light sensitive samples may require a longer focal length to reduce laser power density. Physical restrictions, such as thick packaging materials, may also warrant a longer working distance. The RamanProbe has an elongated measurement volume due to the collection fiber being at least double the size of the excitation fiber. For transparent samples, a longer focal length lens has minimal effect on the signal collection. This is not the case with reflective samples, where a longer focal length lens results in considerably lower signal.

[2]B. Schrader, A. Hoffman, R. Podschadlowski and A. Simon, "7th International Conference on Fourier Transform Spectroscopy", Proc. SPIE Vol. 1145, p. 372, 1989.

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