

Advantages of Infinity-Corrected Optics in FT-IR Microspectroscopy

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Key Words

- FT-IR
- Infinity-Correction
- Microscope Objective
- Micro-Spectroscopy

Introduction

The ability to quickly analyze microscopic samples has brought infrared microscopy to the top of the list of preferred analytical techniques. The implementation of technologies such as dual aperturing, automated sample mapping, and advanced microscopy software has enabled analysts to achieve high spatial resolution, high sensitivity, and experimental automation. However, all FT-IR microscopes suffer, to varying degrees, a loss of image quality, reduced energy throughput, and reduced sensitivity – all inherent in the use of real-world optical configurations. The recent implementation of infinity-correction within FT-IR microscope designs offer vast improvements over traditional designs by effectively minimizing real-world optical shortcomings.

Background and Implementation

Infinity-correction of optical components is a technology that has recently seen tremendous popularity in the world of visible microscopes. The term infinity-correction refers to the collimation of both the infrared and visible light beams in the microscope. Light rays from a distant object, or “at infinity”, enter the eye (or any detector of finite size) parallel to one another. An infinity-corrected objective or condenser is optimized for such a collimated beam of energy. The image of the aperture comes to focus at the focal length of the objective. The recent implementation of infinity correction in infrared/visible microscope instruments has allowed infrared microspectroscopy to advance to new levels of visual and infrared precision. The collimation of the beam contributes to significantly improved visual image and spectral data quality, increased signal to noise, and the relative insensitivity to components placed in the beam path, as compared to microscopes without infinity correction.

All lenses and lens systems, including reflective or catoptric lenses, are subject to degradations in image quality. Many of these problems are physically unavoidable, and largely due to the real-world fact that the rays of light in an optical system do not only travel paraxially close to the optical axis. Therefore, focal points and image locations are not just a function of a lens or mirror system, but of where and how a beam of light enters the system. Spherical aberrations, comatic aberrations, and field curvature are some of the monochromatic problems associated with real world optics. The results are light rays that focus at different points in the focal plane or at different focal planes, and are manifest as unclear, blurred, or distorted sample images, or as an inhomogeneity of focus across the field of view.

Spherical aberration occurs when the light gathered at the outer edges of the secondary mirror comes to focus closer to (or further from) the objective than the light that is reflected closer to the optical axis. This affects object points on the optical axis, making it impossible to obtain a perfectly sharp focus. This is of primary concern as it greatly affects the center of the viewing or sampling region. It also is the predominant problem with the catoptric objectives used for infrared energy collection. Coma, or comatic aberration, prevents points on an object a distance away from the optical axis from focusing to points, again related to varying speeds of focus by the objective with increasing distance from the axis. The effect is more dramatic for rays entering the objective obliquely, and it is found that coma can be eliminated entirely for a lens with one conjugate point at infinity (a collimated beam). Spherical aberration is a more persistent problem, but can be minimized by this same beam collimation. Figure 1 shows spherical aberration in Schwarzschild-type objectives, both for a focused beam and a collimated beam.

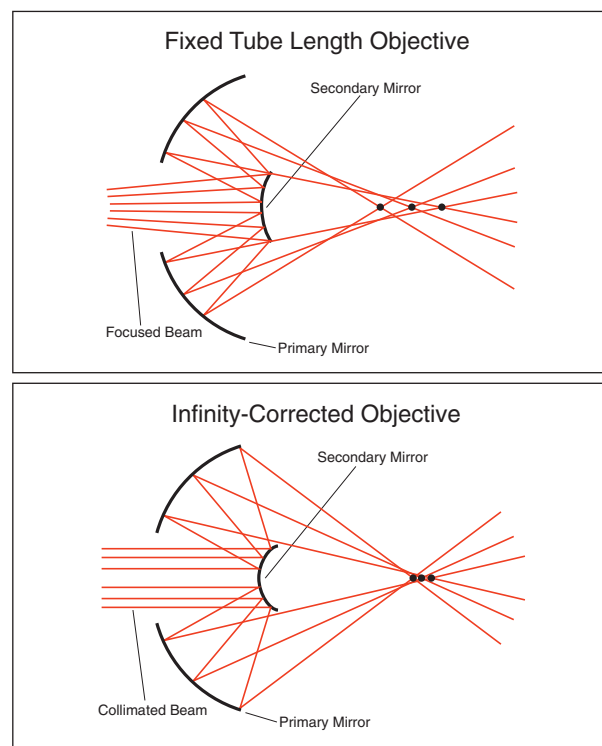
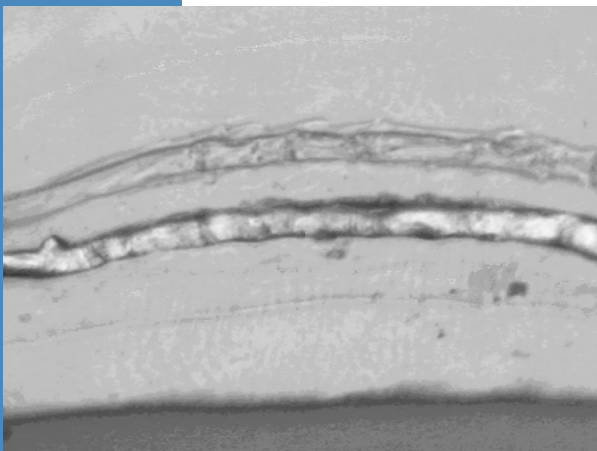
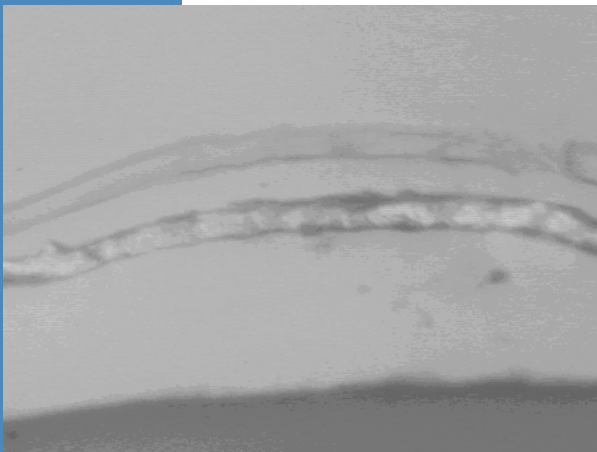


Figure 1: Spherical aberration. Light rays from the outer limbs of the secondary (larger) mirror come to focus at different planes than light from the inner part of the mirror. Collimation of the beam minimizes these differences.

While these effects are more obvious in the visible part of the spectrum, they also occur in the infrared and will degrade spectral quality and precision. Radiant energy that comes to focus at a point offset from the sample plane, or at the wrong point in the sample plane will result in infrared interaction with sample areas outside the area of interest. This produces spectral data with a reduced signal to noise ratio and exhibiting unwanted spectral features due to surrounding sample regions.

It is found that by placing one of the conjugate points of an objective at infinity, these aberrations are indeed minimized. Figure 2 shows a cross section of a can revealing coatings on both surfaces of a metallic layer. The sample is viewed through two research level FT-IR microscopes, one with infinity optics and the other without. The difference in image quality is impressive. Sharper focus, greater uniformity of focus across the field of view, improved contrast, and greater color clarity are obvious in the infinity-corrected system. Just as the eye detects significant improvement in visible wavelength "data", the detector sees a sharper, more accurate infrared absorption "image" of the sample.

Figure 2: Differences in imaging quality due to infinity correction. The image on the bottom is a cross section of a coated can imaged through a research-level FT-IR microscope with infinity optics. On top, the same section imaged through a research-level FT-IR microscope without infinity-correction. Notice the distinction between layers in the infinity-corrected system. Both samples are viewed with catoptric infrared objectives.



Another reality of optics is the inability to grind and polish a perfect powered mirror. Aspherical mirrors are particularly difficult, and are essential to traditional FT-IR microscope designs. When placed in a complex optical system, the fluctuations and aberrations due to small flaws are magnified by long beam paths and additional optical components. An infinity-corrected system will reduce or eliminate many of the aberrations, because spherical mirrors, which can be precisely ground and polished, can be used in place of aspherical mirrors. In general, a collimated beam travels more efficiently over distances than does a focused beam, resulting in increased energy throughput and a higher signal to noise ratio than that of comparable systems with an uncollimated beam.

In addition to the improvements in infrared and visible imaging, an infrared microscope with infinity optics offers benefits related to instrument versatility. Collimation of the beam allows plane mirrors to redirect the radiant energy to and from the objective and condenser. With a conjugate point at infinity, the objective and condenser positions can be freely varied relative to the other powered mirrors in the system, relaxing design constraints without loss of optical quality. More significantly, collimated energy is relatively insensitive to additional optical elements in its path. This insensitivity allows beam-modifying elements such as polarizers, for both visible and infrared energy, to be inserted anywhere into the collimated beam without a

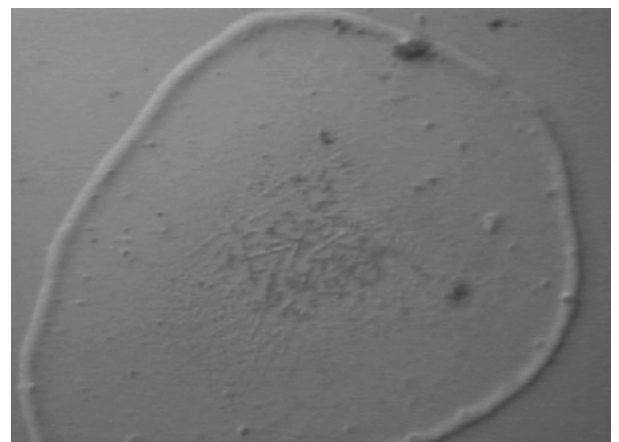
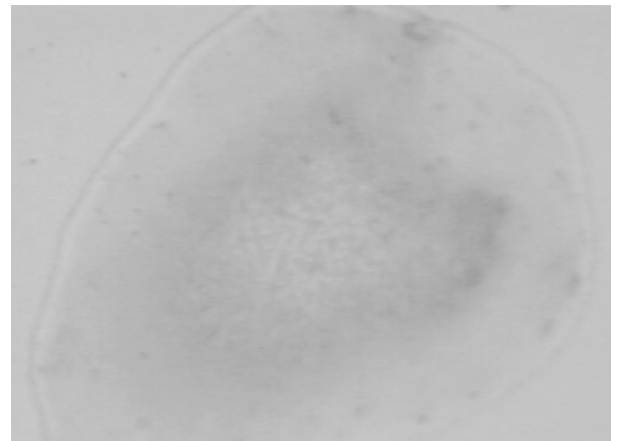


Figure 3: A human cheek cell. This sample presents a challenge due to its transparency. Both images as seen through an infinity-corrected scope and with an infrared objective; the image on the bottom is viewed through DIC prisms inserted into the collimated beam.

loss of image quality or sensitivity. The use of visible polarizers and Differential Interference Contrast (DIC) elements can greatly enhance visual quality, particularly in transparent or low contrast samples. Details that are normally difficult to see are sometimes emphasized by altering the polarization of the illumination. Infrared polarization is desired for grazing angle sampling as it greatly increases signal to noise. Polarization also allows crystalline orientation studies. DIC optics provide another beam-modifying option for enhanced viewing of samples by utilizing differences in optical pathlengths throughout a sample. Figure 3 shows the superior image enhancement of DIC used in an infinity-corrected system. It is duly noted that polarizing optics are available and useful with microscopes that are not infinity-corrected. However, these are placed in focused beams (though not necessarily at field stop positions), reducing the efficiency of the polarization and introducing extra light loss.

In addition to the ability to add polarization, a dichroic beamsplitter may be used to separate infrared radiant energy from the visible. This allows simultaneous infrared measurement and sample viewing of the entire field of view, while maintaining high precision as shown in Figure 4. Again, this technology is available without infinity-correction, but can introduce new problems as with any element added to a focused beam path.

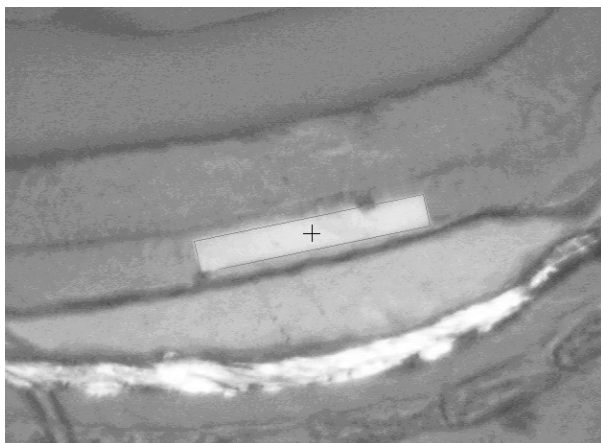


Figure 4: Simultaneous full-field sample viewing and masked data collection. Infrared data is being collected only from the illuminated aperture area in the center of the field of view.

The ultimate performance test of any microscope is considered by many to be spatial resolution. The wavelength-dependent ability to resolve separate objects, and to know and reduce the uncertainty in a measurement is determined largely by the numerical aperture of the objective, which is an angular measure of its light-gathering ability. Fortunately, infinity-corrected catoptric objectives have been developed to maintain a high numerical aperture, allowing an FT-IR microscope system to take advantage of the benefits of beam collimation without sacrificing spatial resolution.

An infrared microscope with infinity optics can be used with commercially available infinity-corrected refractive objectives for the visible inspection of samples. However, the glass lenses in these objectives preclude their use in FT-IR data collection. Standard FT-IR reflective optics have traditionally given poor visible images. The visual quality of the new catoptric objectives is a vast improvement over traditional infrared objectives.

Conclusion

The recent introduction of infinity-correction to instrumentation used for infrared microspectroscopy offers significant improvements and advantages over traditional designs. Dramatic improvements are seen in visible image quality, and infrared sampling precision is increased. The infinity-corrected system is relatively insensitive to optical components inserted into the collimated beam. This allows facilitation of and improvements in design, as well as very effective use of polarization and other enhancement techniques.

References

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