Improved Spatial Resolution For Reflection Mode Infrared Spectromicroscopy

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Abstract. Standard commercial infrared microscopes operating in reflection mode use a mirror to direct the reflected light from the sample to the detector. This mirror blocks about half of the incident light, however, and thus degrades the spatial resolution by reducing the numerical aperture of the objective. Here, we replace the mirror with a 50% beamsplitter to allow full illumination of the objective and retain a way to direct the reflected light to the detector. The improved spatial resolution is demonstrated using a microscope coupled to a synchrotron source.

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INTRODUCTION

Infrared microscopes are typically designed to be used with standard blackbody sources. Because these sources suffer from poor brightness, spatial resolution is controlled by geometrical apertures that are typically limited by signal-to-noise ratios to 20 µm or larger. In the mid-infrared, these aperture sizes are far from the diffraction limit. Consequently, most designers choose to maximize the throughput of the system rather than achieve the best possible spatial resolution at the diffraction limit. Synchrotron sources, which are 100-1000 times brighter than a typical blackbody source[1-8], have made diffraction-limited spatial resolutions possible. Here, we discuss a simple modification to commercial infrared microscopes that allows the user to take full advantage of the spatial resolution achievable by synchrotron infrared radiation.

Infrared microscopes operate in either transmission or reflection mode, with the choice primarily depending on the optical properties of the sample and/or the substrate. In transmission mode (Fig. 1a), an objective focuses the infrared radiation onto the sample and a second objective or condenser collects the transmitted radiation before directing it to the detector. In the standard reflection mode (Fig. 1b), light that is reflected off the sample is collected by the same objective that focuses the infrared light. The light is then directed to the detector by a “sluice” mirror, which is removed during transmission mode measurements. The mirror, however, blocks a portion of the incident light and effectively shadows half of the objective’s secondary mirror. Because the spot size for a diffraction-limited system is determined by the

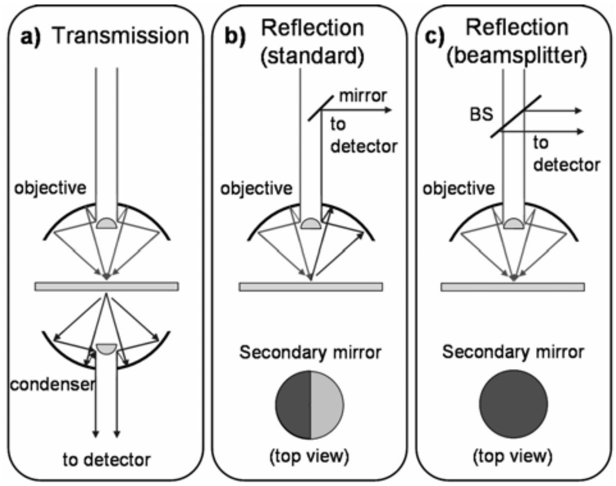

FIGURE 1. Schematic diagram of three different modes of infrared microscopy: a) transmission, b) reflection with the standard mirror design, and c) reflection with the beamsplitter design.

wavelength of light and the numerical aperture of the objective, this half-illumination degrades the spatial resolution of the microscope by creating an asymmetric focal spot. An alternative method of reflection that achieves the same resolution as in transmission mode replaces the “sluice” mirror with a beamsplitter (Fig. 1c). Although this design limits the throughput to 50% of the standard reflection mode, the maximal spatial resolution for the microscope is achieved because the secondary mirror is fully illuminated.

RESULTS

Measurements were performed at Beamline 1.4.3 at the Advanced Light Source (ALS). Synchrotron infrared radiation was directed through a Nicolet Magna 760 FTIR interferometer with a KBr beamsplitter and a Spectra Tech Nic-Plan IR microscope (32x objective, NA=0.65) before being detected by a mercury cadmium telluride (MCT-A) detector. Images were acquired with an automated microscope stage (Prior ProScan II) capable of step sizes as small as 0.1 μm. The microscope was modified to accommodate a 50:50 CaF_2 beamsplitter (ISP Optics) at the position of the “sluice” mirror. In this case, the CaF_2 beamsplitter limits the spectral range to wavelengths shorter than 10 μm, but another beamsplitter substrate (e.g. KBr) could be used to obtain spectra of the entire mid-infrared spectral region if necessary. The modifications we made to the microscope allow easy switching between the standard and beamsplitter reflection modes, so our users can choose.

To demonstrate the improved spatial resolution of the beamsplitter reflection mode, an 8 μm Ti dot on a Si substrate was imaged using both reflection modes (Fig. 2). At $\lambda = 2$ μm, the two images are nearly identical because the diffraction pattern for both modes of reflection is smaller than the test sample. At longer wavelengths, however, the standard reflection mode images are clearly distorted in one dimension and appear elliptical (oriented at approximately 45° because of the optical design of the microscope). The images from the beamsplitter reflection mode, on the other hand, remain symmetrical and relatively unchanged with increasing wavelength.

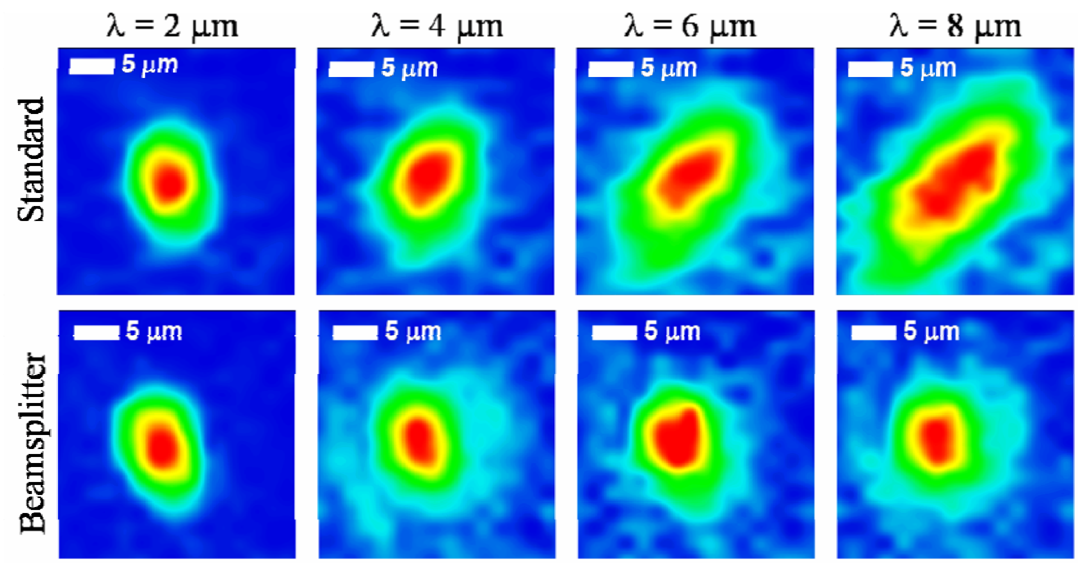

FIGURE 2.) Images of an 8 μm Ti dot on a Si substrate at different wavelengths for standard and beamsplitter reflection modes.

By illuminating the entire secondary mirror, the beamsplitter reflection mode achieves the same symmetric illumination and therefore the same diffraction-limited spatial resolution obtained in transmission mode. This improved spatial resolution over the standard reflection mode, however, comes at the expense of infrared light throughput. If the measurements are shot-noise limited, the factor of two reduction in throughput should reduce the signal-to-noise ratio by $\sqrt{2}$. In measurements at the ALS, we find the signal-to-noise ratio of the beamsplitter reflection mode to be only slightly worse than the standard reflection mode because shot-noise is usually not the limiting noise source. An rms noise value of <0.05% is routinely achieved on a 100% line on gold (128 scans, 4 cm^{-1} resolution) for the beamsplitter mode, allowing both good sensitivity and high spatial resolution for infrared measurements of small samples or regions of samples.

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