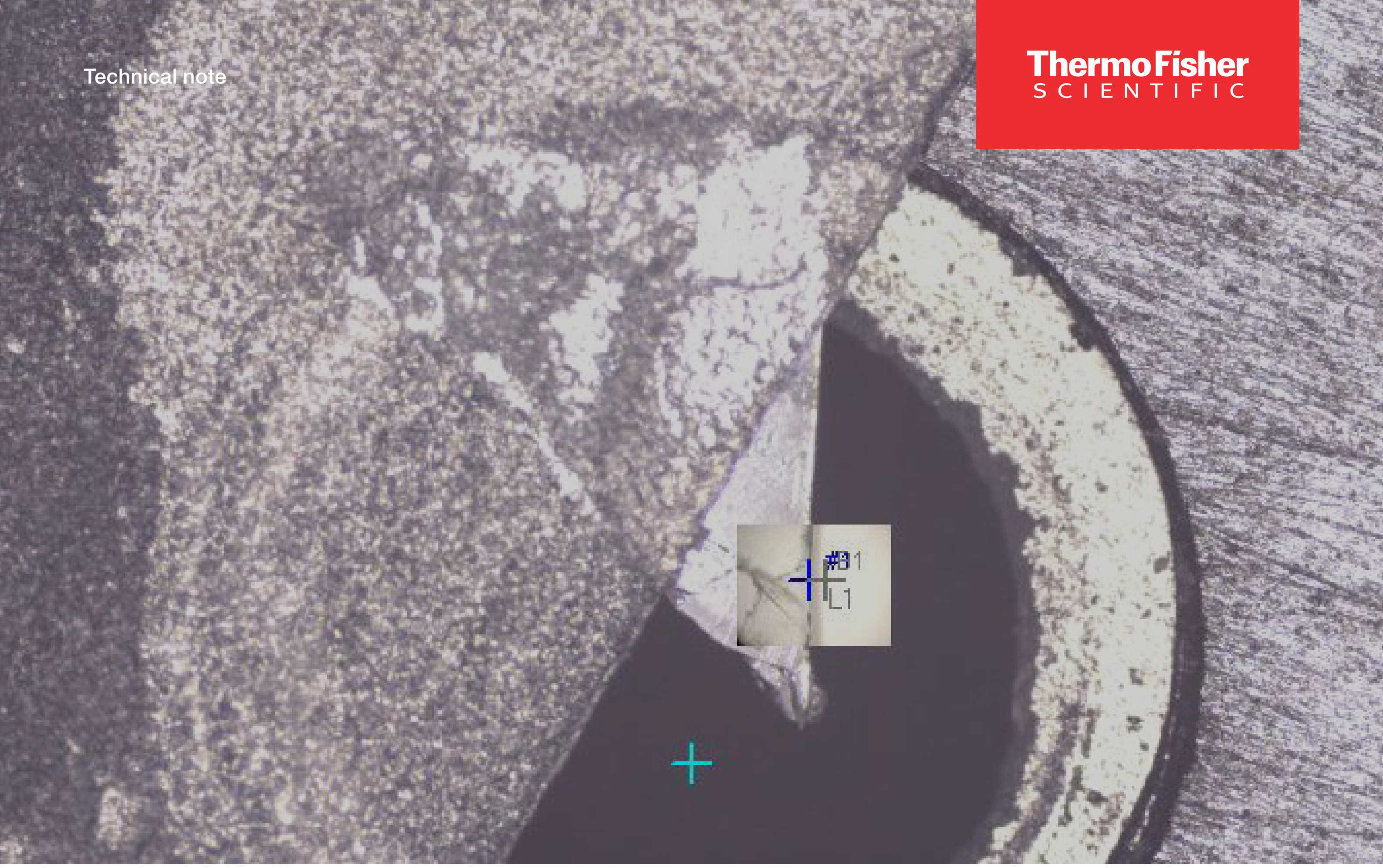
Technical note



Determining the Spatial Resolution of an FTIR Microscope

Introduction

Infrared microscopy involves the analysis of small samples, typically in the 10 to 100 µm range. On this scale, spatial resolution is often a significant consideration. The theoretical limit of the spatial resolution of infrared microscopy is imposed by the long wavelengths of the infrared light, but the attainable spatial resolution is determined by the optical design and infrared performance of the infrared microscope.

Achieving high spatial resolution requires balancing a variety of distinct elements in the optical design of infrared microscopes, including the collection optics (objectives and condensers), number of apertures (size and location), and even the mechanical stability of the microscope. These design issues affect one important factor that contributes to the spatial resolution: the diffraction of light. There are many potential sources of diffraction in the optical path of an infrared microscope. The design of the Cassegrainian optics is one of the factors that determines the degree to which diffraction effects the spatial resolution.[1]

The Thermo Scientific™ Nicolet™ RaptIR™ and RaptIR+ FTIR Microscopes utilize high numerical aperture (NA) Cassegrainian optics with an innovative design that avoids optical aberrations and reduces diffraction effects. This allows the RaptIR+ to achieve excellent spatial resolution without the need to use multiple apertures and thus avoid the loss of throughput (intensity) associated with additional apertures. The data presented here show that the RaptIR+ can provide 5 µm spatial resolution.

Nicolet RaptIR+ FTIR Microscope coupled with the Nicolet iS50 FTIR Spectrometer.

Experimental

The data were collected using a Nicolet RaptIR+ FTIR Microscope. The RaptIR+ was configured with a 4X optical objective, with a wide field of view to help easily locate the areas of interest, and with innovative 15X Cassegrainian optics (objective and condenser) for higher-magnification visible images and for collecting the infrared data. The RaptIR+ was attached to a Thermo Scientific™ Nicolet™ iS50™ FTIR Spectrometer. All measurements were collected as horizontal line maps with 1 µm steps and an aperture of 5 µm x 5µm.

Two different types of spatial resolution measurements were conducted. The first sample used was an Edmund Optics USAF 1951 optical target. The sample consisted of a dark USAF 1951 pattern deposited on a chrome-coated glass slide (2” x 2”). Data were collected in reflection mode using the chrome-coated glass as the background. USAF 1951 optical target group 6 elements 1-5 were used for collecting spatial resolution data. The second type of sample was a flat piece of topaz with a clean, straight edge. The sample was thin enough to use for transmission experiments. The topaz sample has a well-defined sharp O-H peak (3649 cm^{-1}). The data was collected as a knife-edge experiment where the transition from no sample peak to full intensity was used as a measure of the spatial resolution.

Results

The reflection measurements on the USAF 1951 target were conducted as line maps across the vertical lines of the first 5 elements of group 6. The thickness of the Element 5 lines (4.92 µm) is very close to the 5 µm goal for this investigation. The transition from the chrome-coated portions of the target to the dark lines resulted in a shift in the baseline intensity to lower reflection values. The data presented in Figure 1 shows plots of reflection values at 4000 cm^{-1} as the map transverses the lines in the patterns.

Two different metrics were calculated from this collection of data. The first was the full width at half maximum (FWHH) of the peaks associated with the dark lines. This provides a measure of the width of the lines. The second measurement was the contrast. The contrast is measured as the difference in reflection between the peaks and valleys associated with the dark lines. As the lines get thinner and more closely spaced, the contrast decreases. Contrast is required for resolving the lines from each other. The Rayleigh criteria for image contrast is 26.4%.

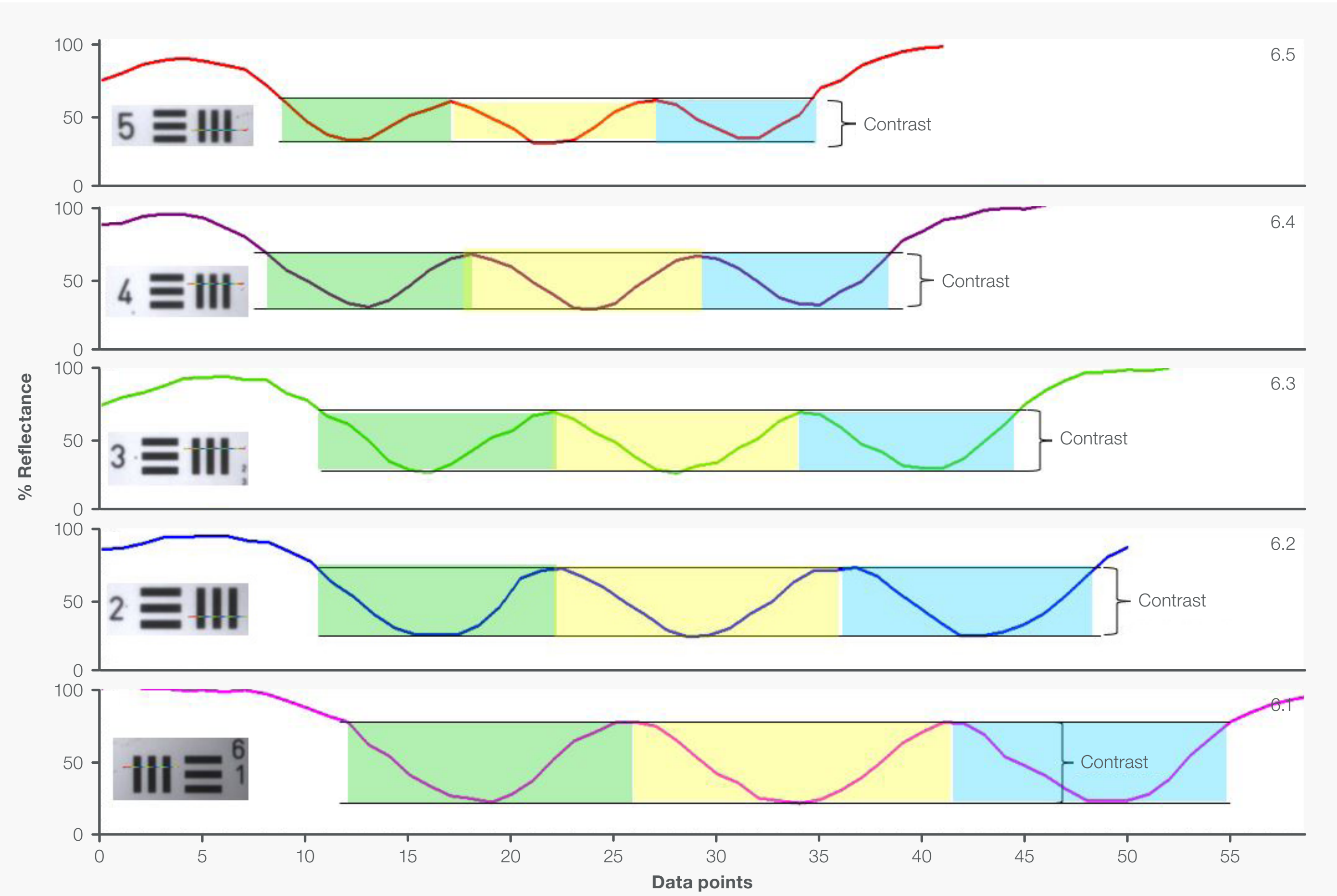


Figure 1. Plots of intensities (reflection) at 4000 cm^{-1} versus map steps across the USAF 1951 optical target - group 6 patterns (elements 1-5).

Table 1 shows a summary of the data from all 5 group 6 elements. The widths of the lines as measured from the FWHH values are close to the expected widths. The differences are certainly well within any errors associated with the experiment. The contrast values are all above the Rayleigh criteria for spatial resolution indicating that there is sufficient contrast to resolve the lines. This confirms that 5 µm spatial resolution is achievable with a RaptIR+.

The second spatial resolution test was a transmission knife-edge test. In this test, the data collection traversed the edge of the sample using 1 µm steps. The sharpness of the transition is a measure of the spatial resolution. A thin piece of topaz was used because it forms in thin sheets and can have straight, sharp, well-defined, edges (see video images in Figure 2). The topaz sample displayed a sharp O-H peak at 3649 cm^{-1} that was used for the measurement (Figure 3). Figure 4 shows a plot of the peak area of the O-H peak as a function of moving across the sample edge. The figure also includes the second derivative of the curve that was used to define the limits of the transition. The distance of the transition represents the spatial resolution. The second derivative limits occur at 13% and 88% of the full peak values. Based on those limits, the spatial resolution is calculated to be 5 µm. It should be noted, however, that this does not necessarily mean complete spectral isolation. If there were infrared active materials on both sides (such as a cross-section of a layered polymer), then on the 5-µm scale, there may still be some small residual contributions from the previous layer in the spectra of the new material. If more rigorous spectral isolation is required, then that will affect the transition limits and the spatial resolution values.

Group 6 Element	Actual line thickness (µm)	FWHH (µm)	Difference (µm)	Contrast (%)
6-1	7.81	8.1	-0.29	54
6-2	6.96	7.0	-0.04	47
6-3	6.20	6.4	-0.2	42
6-4	5.52	5.7	-0.18	36
6-5	4.92	5.0	-0.08	28

Table 1. Contrast and Full Width at Half Height (FWHH) results from the plots of the reflection intensity at 4000 cm^{-1}.

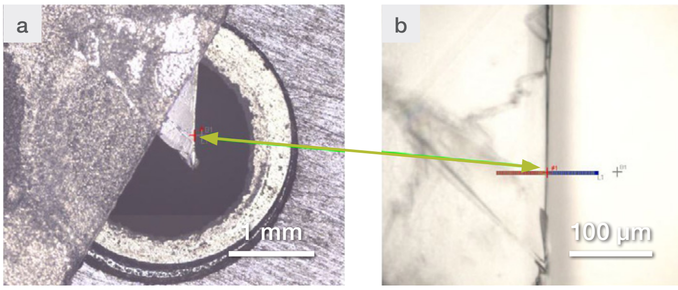


Figure 2. Visual images from the topaz sample. (a) Visual image collected with the 4X objective on the RaptIR, (b) Visual image collected with the 15X objective on the RaptIR.

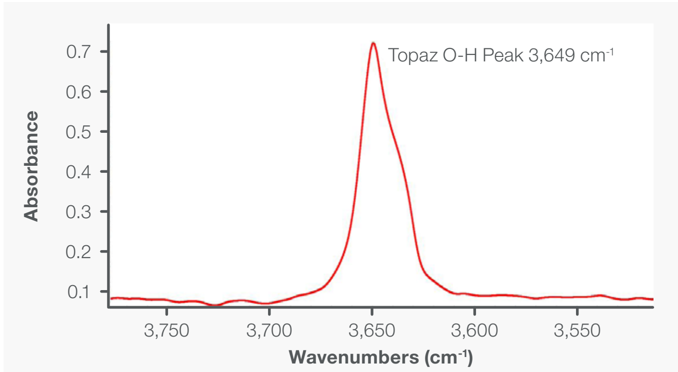


Figure 3. Oxygen-Hydrogen peak (3649 cm^{-1}) from the topaz sample.

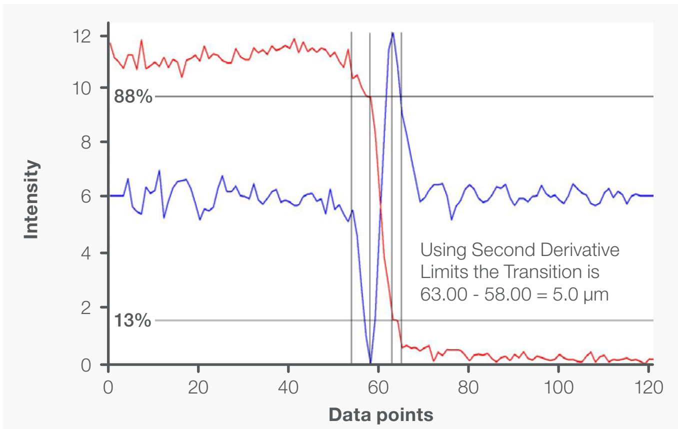


Figure 4. Transmission knife-edge measurements using the topaz sample. The plot of peak area (3649 cm^{-1} peak) as a function of map steps across the edge of the sample is in red and the second derivative of the curve is in blue.

Conclusion

The results presented here show that the RaptIR+ can achieve 5 µm spatial resolution. This was observed in both the reflection and transmission experiments. The Rayleigh criteria for the contrast in the reflection experiment and the second derivative limits of the transition in the topaz knife edge experiment both indicate that 5 µm spatial resolution is achievable. Given these results it is clear that the RaptIR microscopes provide good spatial resolution without requiring the use of multiple apertures and thus does not suffer the inevitable loss of throughput associated with an additional aperture.

References

1. Koichi Nishikida, Spatial Resolution in Infrared Microscopy and Imaging, *Application Note 50717 Thermo Electron Scientific Instrument Corporation* (2004).