Analysis of Bicomponent Fibers Using Confocal Raman Mapping

ABSTRACT

Raman microscopy is an analytical tool which nondestructively provides chemical information on samples, often without the need for any preparation. Bicomponent fibers, those composed of at least two polymer types, were examined using Confocal Raman mapping to determine chemical composition and cross-sectional shape. Cross-sections were prepared for the bicomponent fibers of known composition and compared to the Raman results. Confocal Raman mapping provided chemical compositions and indications of cross-sectional shape for bicomponent fibers without any sample preparation. For an accurate shape determination and/or comparison, however, preparation of a cross-section is still recommended.

INTRODUCTION

Raman spectroscopy, a long recognized technique in research, is an instrumental technique forensic chemists may use to characterize a number of types of evidentiary materials. These materials include, but are not limited to, inks, drugs, paints, explosives, minerals, and cosmetics. Researchers have also applied Raman spectroscopy to a variety of types of textile fibers. Raman has been found to distinguish chemical compositions of generic fiber classes (1,2,3,4), including vegetable fibers (2,4,5), and sometimes can distinguish sub-generic classes of fibers (2,3,4). Pigmented and dyed synthetic fibers (6,7,8), dyed cotton (7,8,9), and wool fibers (8) have also been examined. For colored fibers, Raman has provided information on the colorant, often in addition to the generic fiber class, without any required extraction from the fiber.

Raman spectroscopy is useful for forensic analysis because it requires limited sample preparation and is typically nondestructive. Sample preparation of fibers simply requires placing them on a Raman–inactive substrate. The coupling of a Raman instrument with a microscope permits focusing and analyzing samples with extremely small diameters. The sample must be at least the size of the focal spot, which can vary between one to five microns, depending on the objective power and laser wavelength (8,10).

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Mapping is also possible with Raman spectroscopy to include area mapping (x– and y–axes) and confocal mapping (x– and z–axes, depth profiling). Confocal Raman Microscopy involves the collection of Raman scattering from thin slices taken along the vertical (z) axis, producing a spectral cross-section of the sample. Confocal microscopes have the ability to capture sharp optical sections making it possible to build three-dimensional renditions of a specimen. For fiber samples, this means coupling chemical composition data with optical cross-sectioning. This application is particularly suited for bicomponent fibers, or fibers which are composed of two chemically and/or physically different polymers.

Most commercially available bicomponent fibers have a sheath/core, side–by–side, or eccentric sheath/core configuration (11). The market, however, has expanded in more recent years to include a variety of other configurations, such as pie wedge, sea/islands, and tipped trilobal arrangements (12). When submitted for forensic analysis, bicomponent fibers may be difficult to recognize. The more obvious indicators include differences in color, delustrant concentration, or birefringence between the polymer types (13). If these indicators are not present, other commonly used instrumental techniques may not be able to assist in this determination (13). Furthermore, characterization of each component’s chemical composition may be difficult as well.

Traditionally, bicomponent fibers have been analyzed using Fourier Transform Infrared Spectroscopy (FTIR). Sample preparation is required for FTIR analysis of fiber samples involving component isolation or sample flattening. If the spatial configuration is known, spectra can be collected for each component. As previously mentioned, bicomponent fibers may not be recognized as such or their configuration may not be revealed prior to FTIR analysis. This lack of information may lead to an incomplete characterization or worse yet a misidentification of the fiber evidence as well as a loss of evidentiary value recognition. Bicomponent fibers have inherently stronger evidential value due to their rareness in society and casework. (13)

For the purpose of this study, Confocal Raman mapping was employed to identify fiber chemical composition(s) of bicomponent fibers and to determine how the components were arranged. As Confocal Raman mapping produces an image of a vertical section of the fiber, width measurements and cross-sectional shapes were also compared from this image to manually prepared cross-sections.

MATERIALS AND METHODS

Fiber Samples

The sample set consisted of seven fiber samples. One sample, previously acquired from a fiber manufacturer, was available within the forensic laboratory. Five samples were obtained by contacting fiber manufacturers specifically requesting bicomponent fibers with sheath/core configurations. The final sample was obtained and analyzed by Thermo Fisher Scientific. The
bicomponent fiber samples include Nylons, Olefins, and Polyesters. All samples are listed in Table 1.

The fiber samples used for this study were of indefinite length. For ease of handling, long sections were used and secured to a potassium bromide block that was placed upon a microscope slide. The fiber was taped on each end, ensuring straight portions from which data could easily be collected. Potassium bromide was used as the sampling substrate because it does not produce a Raman signal. As the x, z-map is not length dependent, much shorter fiber lengths can be used for examination.

<table>
<thead>
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<th>Sample Number</th>
<th>Composition (identified by source)</th>
<th>Helpful Information</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Nylon 6/Nylon 6,6</td>
<td></td>
<td>Thermo Fisher Scientific</td>
</tr>
<tr>
<td>2</td>
<td>PE/PP</td>
<td>PE: Polyethylene; PP: Polypropylene</td>
<td>Fiber Manufacturer</td>
</tr>
<tr>
<td>3</td>
<td>PE/PP</td>
<td>Found to be PE/PET during analysis</td>
<td>Previously obtained – Fiber Manufacturer</td>
</tr>
<tr>
<td>4</td>
<td>PP/PP</td>
<td></td>
<td>Fiber Manufacturer</td>
</tr>
<tr>
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<td>Hytrel/Hytrel</td>
<td>Hytrel: Thermoplastic polyester elastomer</td>
<td>Fiber Manufacturer</td>
</tr>
<tr>
<td>6</td>
<td>PETG/PET</td>
<td>PETG: Glycol–modified polyethylene terephthalate (polyester); PET: Polyethylene terephthalate (polyester)</td>
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</tr>
<tr>
<td>7</td>
<td>PBT/PET</td>
<td>PBT: Polybutylene terephthalate (polyester); PET: Polyethylene terephthalate (polyester)</td>
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</table>

Table 1: List of Bicomponent Fiber Samples

**Raman Spectroscopy**

Raman spectra, in the range 3389–50cm⁻¹ of Raman shift, were collected using a dispersive Thermo Fisher Scientific DXR Raman Microscope. Spectra were collected using two lasers, with excitation wavelengths of 532nm and 780nm, and their respective optical filters and diffraction gratings. The 532nm laser has a 10mW maximum power while the 780nm laser has a 14mW maximum power at the sample. The 532nm laser provided superior data with greater abundance; therefore only data obtained with this laser will be presented. The microscope is equipped with two objectives, 10x and 50x, with the 50x used due to the small fiber size, smaller focal spot size and increased signal strength. A motorized stage was used for the mapping experiments.
Confocal depth profile mapping along the fiber width was used to accomplish cross-sectional analysis. Mapping experiments were collected using Thermo Fisher Scientific's OMNIC Atlas software package. One to two micron step sizes were used resulting in mapping measurement times in the range of three and one half to five hours. The parameters, which affect the measurement time, varied and were based on the size of the fiber, the time requirement, and signal abundance. While step sizes of less than one micron may provide a more accurate chemical map and better component resolution, step size is a function of the motorized stage capability.

Components were determined using a combination of methods. The components were often determined manually by comparing spectral peaks which were present in one component and not in another. Once these peaks were located, the components could be differentiated and identified using spectral libraries, either generated internally or commercially available (i.e. Thermo Scientific High Resolution Polymer Library). Occasionally, it was more useful to use the Multivariate Curve Resolution (MCR) option in the Omnic Software package. MCR analyzed the data and attempted to produce spectra that represented the user defined number of pure components. MCR software also provided spatial distributions of each component.

Width measurements were made using the Confocal Raman maps. The ruler tool, available in the Atlas software, allowed a user defined line to be measured. Ten measurements were collected for each component of samples 2, 3, 6, and 7 and then respectively averaged.

*Confirmation Techniques*

Cross-sections were manually prepared for comparison to the resulting Confocal Raman mapping cross-sectional shape. Fibers were inserted into micropipettes. Norland Optical Adhesive 60 was allowed to fill the pipette via capillary action. The filled pipettes were cured under UV light to harden the adhesive and then cross-sections cut using a razor blade.

These cross-sections were mounted on a microscope slide and the sheath and core component widths were measured using an Olympus BX40 Compound Microscope (400x). Multiple measurements were taken using the calibrated eyepiece reticule. When appropriate, a width range was necessary to fully represent the variability observed.

When needed, a Thermo Nicolet 6700 FTIR with Continuum Microscope attachment was used to confirm a fiber component. This was accomplished using a microcompression cell with diamond windows. Spectra were collected from $4000\text{cm}^{-1}$ to $650\text{cm}^{-1}$.
RESULTS AND DISCUSSION

Nylons

In the data provided by Thermo Fisher Scientific, sample 1 appears to have a sheath/core bicomponent configuration with a Nylon 6 sheath. Figure 1 shows a correlation image based on the distribution of Nylon 6 within sample 1. The areas colored red indicate a better correlation, or better match, to the spectrum of Nylon 6 and the blue the lowest correlation to the spectrum of Nylon 6. Figure 2 shows a comparison of the Raman spectrum from the sample’s sheath with a corresponding library spectrum of Nylon 6, drawing attention to the doublet which is present ~1300 cm\(^{-1}\) in Nylon 6.

![Correlation image](image1)

Figure 1: Correlation image of the sheath component based on the distribution of Nylon 6 within sample 1 (Red = better match to the spectrum of Nylon 6; Blue = lowest correlation to the spectrum of Nylon 6.)

![Raman spectrum](image2)

Figure 2: Raman spectrum of the sheath component of sample 1 (top spectrum) versus a corresponding library spectrum of Nylon 6 (bottom spectrum)
The fiber core appears to be Nylon 6,6. Figures 3 and 4 show the correlation image for this component and the comparison of the Raman spectrum from the sample with a library spectrum of Nylon 6,6. Where a doublet appears for Nylon 6, a single peak is present for Nylon 6,6. Although the sheath and core material are very similar polyamide materials, there are clear spectral characteristics which allow for their differentiation.

**Figure 3:** Correlation image of the core component based on the distribution of Nylon 6,6 within sample 1 (Red = better match to the spectrum of Nylon 6,6; Blue = lowest correlation to the spectrum of Nylon 6,6.)

**Figure 4:** Raman spectrum of the core component of sample 1 (top spectrum) versus a corresponding library spectrum of Nylon 6,6 (bottom spectrum)

A third component, Titanium Dioxide (TiO₂), was detected in this cross-sectional analysis. Titanium dioxide may be added during the manufacturing process of synthetic fibers as delustrant to reduce sheen or luster. Of interest, two different structural forms of TiO₂ were detected within this fiber sample: Anatase and Rutile. The two forms of TiO₂ differ in number of
peaks as well as peak shift locations. The spatial distribution of the Rutile and Anatase forms are shown in Figure 5. Both forms were confirmed by comparison to known library spectra, Figures 6 and 7.

Figure 5: Correlation images showing the distribution of TiO$_2$ Rutile Form (Left) and TiO$_2$ Anatase Form (Right) in the sample 1 cross-section

Figure 6: Raman spectrum from sample 1 core (top spectrum) versus a corresponding library spectrum of Rutile TiO$_2$ (bottom spectrum) The extra peaks above 1000 cm$^{-1}$ in the top spectrum are due to the polymer matrix of the fiber.
Figure 7: Raman spectrum from sample 1 core (top spectrum) versus a corresponding library spectrum of Anatase TiO$_2$ (bottom spectrum). The extra peaks above 1000 cm$^{-1}$ in the top spectrum are due to the polymer matrix of the fiber.

Polyethylenes and Polypropylenes

Sample 2 was identified as having a sheath/core configuration, based upon manual component analysis, with a PE sheath and a PP core. The chemical images in Figures 8 and 9 illustrate the relative arrangement of each component. The Raman spectrum originating from the component is included as well as the corresponding library spectrum.

Figure 8: Chemical image of sample 2’s sheath component (using 1129 cm$^{-1}$ shift) as well as the Raman spectrum of this component (red) versus the corresponding library PE spectrum (blue)
Both chemical images and correlation images allow for a sample to be visualized in terms of how the chemical components are distributed spatially within the sample. However, chemical images differ from correlation images. While a correlation map looks for a specific reference spectrum within the sample data, a chemical image is a color representation of a specific wavenumber shift. When the particular peak or wavenumber shift is selected, the intensity of the wavenumber shift is indicated by a color gradient. Red indicates the areas in the sample in which the selected wavenumber shift is most intense; blue indicates the areas in the sample in which the selected wavenumber shift is least intense. By manually identifying peaks that are present in only one sample component, separate chemical images can be created that depict the sheath and core.

The sample 2 components are very similar, both being olefins by generic class, however, differing by subgeneric class. The Raman spectra may be easily differentiated. The relative arrangement of the components can be compared with the manually prepared, more symmetrical appearing, cross-section in Figure 10.

**Figure 9:** Chemical image of sample 2’s core component (using 808 cm\(^{-1}\) shift) as well as the Raman spectrum of this component (red) versus the corresponding library PP spectrum (blue)

**Figure 10:** Image of manually prepared cross-section of sample 2
Sample 3, was found to also have a sheath/core configuration with a PE sheath and a PET core. Interestingly, the core was identified by the manufacturer as PP, not PET. The core material was analyzed on the FTIR to verify the identification of the core component. The FTIR results confirmed the Raman component identification as PET. Confocal Raman mapping correctly identified the sheath/core components and was able to graph their relative spatial configuration, Figures 11 and 12. Comparison of the Raman spatial distributions versus the manually prepared cross-sections in Figure 13 illustrates how important this practice can be.

**Figure 11:** Chemical image of sample 3’s sheath component (using 2846 cm⁻¹ shift) as well as the Raman spectrum of this component (red) versus the corresponding library PE spectrum (blue).

**Figure 12:** Chemical image of sample 3’s core component (using 858 cm⁻¹ shift) as well as the Raman spectrum of this component (red) versus the corresponding library PET spectrum (blue). The black arrow indicates a peak consistent with Anatase TiO₂.
While a general idea of cross-sectional shape can be obtained with Confocal Raman mapping, it is not able to provide the entire circumference of the cross-sectional shape. As illustrated by this sample, one cannot assume the fiber cross-sectional shape is symmetrical. The sheath is not evenly surrounding the core in this sample. Also, the manually prepared cross-section shows TiO$_2$ in the core, which is only indicated by a single peak $\sim$140 cm$^{-1}$ in the spectrum of the core component (see black arrow). This peak location indicates the presence of Anatase TiO$_2$ as opposed to Rutile.

Multiple components could not be identified within Sample 4. This sample was identified by the manufacturer as having a sheath/core configuration with both components consisting of PP, differing only in melt flows. Confocal Raman mapping was able to show only one PP component, as seen in Figure 14, however, indicated a different cross-sectional shape than had been identified by the manufacturer. The manually prepared cross-section illustrates the accurate bow-tie shape, which is also represented by Confocal Raman mapping. The only indication of differing components is provided in both the manually prepared and the optical cross-sections seen as a difference between the lobe sizes. Chemical lobe differentiation would not be expected by Raman or FTIR given the melt flow difference, but Raman was able to give an indication of the shape that FTIR could not have provided.
Polyesters

Similarly, sample 5 was also identified as containing a single component. This fiber was identified by the manufacturer as having a sheath/core configuration which differs only by grade of Hytrel. The manually prepared cross-section as seen in Figure 15 indicated the presence of two components and confirmed a sheath/core configuration. Initially, not expecting high-quality Raman results due to the black fiber color, the Raman surprisingly was able to identify the composition as polyester without any difficulty, Figure 16. Therefore, the guidance that Raman does not analyze dark or black materials well is sample specific and should not be taken as a rule of thumb. For this specific sample, the recognition of its bicomponent nature can be obtained visually due to the color difference between the colorless sheath and dark core. No peaks could be identified, manually or with the use of MCR, as possibly originating from the dye or pigment used to color the core. As expected, Raman was not able to differentiate the sheath and core components of sample 5 based on a material grade difference. Raman was also not able to distinguish the components based on peaks associated with the colorant; however, this could be due to a lack of a reference pigment library. Consistent with the Raman results, FTIR was able to identify the sheath and core components as polyester, but could not distinguish them from one another.

Figure 15: Image of manually prepared cross-section of sample 5

Figure 16: Chemical image of sample 5 (using 1607 cm$^{-1}$ shift), single component, as well as the Raman spectrum of this sample (red) versus the corresponding best match to library Polyester PBT spectrum (blue).
Samples 6 and 7, however, are each comprised of two different types of polyester. Confocal Raman mapping was able to differentiate the two polyester components as well as the third component located only in their cores, TiO$_2$. Sample 6’s PETG sheath and PET core could be distinguished from one another spectrally with the use of the 2850cm$^{-1}$ peak, which is present only in PETG. The relative spatial distribution of the core was visible with the help of peaks originating from TiO$_2$, which is present only in the PET core. PETG was the more difficult of the components to identify, mostly attributable to the limitations of the spectral searching library. PETG, glycol modified, and PET are very similar but small differences can be seen around 2850cm$^{-1}$ and 800cm$^{-1}$ in Figures 17 and 18. PET and PETG are structurally similar; however, PETG’s structure includes a non-aromatic, six carbon ring (14). Peaks around 2850cm$^{-1}$ and 800cm$^{-1}$ in the PETG spectrum are most likely attributable to the in-phase stretching of the ring and the ring’s methylene groups (15). The manually prepared cross-section of sample 6, as seen in Figure 19, corresponds with the Confocal Raman mapping results for component spatial distribution.

![Chemical image of sample 6’s sheath component (using 2853 cm$^{-1}$ shift) as well as the Raman spectrum of this component (red) versus the corresponding library PETG spectrum (blue). Black arrows indicate the differences between PETG and PET: peak at ~2850cm$^{-1}$ present in PETG and absent in PET, and doublet ~800cm$^{-1}$ present in PETG where single peak present in PET.](image-url)
Figure 18: Chemical image of sample 6’s core component (using 143 cm⁻¹ shift) as well as the Raman spectrum of this component (red) versus the corresponding library PET spectrum (blue). Black arrows indicate the differences between PETG and PET: peak at ~2850 cm⁻¹ present in PETG and absent in PET, and doublet ~800 cm⁻¹ present in PETG where single peak present in PET. Black box surrounds 4 peaks in the red core component spectrum indicating the presence of Anatase TiO₂.

Figure 19: Image of manually prepared cross-section of sample 6

Sample 7’s PBT sheath and PET core were distinguished from one another only with the help of MCR coupled with the RGB (red, green, blue) display. MCR will attempt to seek out the number of pure components present in the sample that is input by the user. Using the component information obtained, the RGB display will assign a red, green or blue color to each of the components the software identifies. The components, a maximum of 3, are presented individually as well as in a compilation, Figure 20. This particular way of displaying the data was the most useful for this sample given the similarity between the core and sheath chemical components. PBT and PET are very similar structurally, with PBT having four methylene groups where PET has only two. The additional methylene group vibrations may account for the slight peak shifts seen at ~1700 cm⁻¹, 1300 cm⁻¹, and 1100 cm⁻¹ which allow for their differentiation. Titanium dioxide, Anatase form, was also present in the core of sample 7 indicated by the presence of three minor peaks between 650–350 cm⁻¹ and a dominant peak ~140 cm⁻¹. Figure 21 compares Sample 7’s sheath component to corresponding PBT and PET library spectra. The PET library spectrum is shifted to the left of PBT and the sheath component at ~1700 cm⁻¹, 1300 cm⁻¹, and 1100 cm⁻¹ which is consistent with the spectra in the RGB display. The sheath was therefore identified as PBT. The core component of sample 7, seen in Figure 22, was identified as PET. Keeping in mind the very thin sheath seen in the manually prepared cross-sectional images in Figure 23 and the fact that PET is such a good Raman scatterer, it is not
It is surprising that there is influence from the PET core affecting the spectrum of the PBT sheath, as seen in the areas of ~2920–2960 cm\(^{-1}\) and ~826 cm\(^{-1}\).

Figure 20: RGB display of sample 7, with spectra and images of each component and their compilation image to the bottom right. Note the four peaks outlined with the black box in the blue spectrum indicating the Anatase form of TiO\(_2\). Illustrating components 1 (core) and 2 (sheath) are very similar with slight differences, the black arrows note peak shifts at ~1700 cm\(^{-1}\), 1300 cm\(^{-1}\), and 1100 cm\(^{-1}\) (red PET core is shifted to the left).
Figure 21: Comparing sample 7's sheath component (red Raman spectrum) to corresponding PBT (blue) and PET (purple) library spectra. Noted by black arrows, the PET library spectrum is shifted to the left at ~1700 cm⁻¹, 1300 cm⁻¹, and 1100 cm⁻¹ (consistent with RGB display). Also, correlation image of sample 7's sheath component based on the distribution of PBT (Red = better match to the spectrum of PBT; Blue = lowest correlation to the spectrum of PBT.).

Figure 22: Chemical image of sample 7's core component (using 857 cm⁻¹ shift) as well as the Raman spectrum of this component (red) versus the corresponding library PET spectrum (blue). Note only a weak indication is present ~150 cm⁻¹ of TiO₂ in the red spectrum.
Though the components could be identified and differentiated for both samples 6 and 7, the Confocal Raman maps are not equally useful. As can be seen in the manually prepared cross-section of samples 6 and 7 in Figures 19 and 23 respectively, sample 6 is symmetrical while sample 7 has a more sporadic sheath covering. For asymmetrical samples, the quality of the Confocal Raman map will most likely depend on the orientation of the fiber at the point of measurement, and may not provide an entirely accurate representation of the sheath/core configuration.

**Width Measurements**

Samples 2 and 6 are good examples for the potential of simultaneously measuring fiber diameter, identifying fiber composition, and determining cross-sectional shape with a single Confocal Raman map analysis. Both of these samples are symmetrical and the measurements taken manually are similar to those measured using the Altus software, see Table 2. With this additional possibility, Confocal Raman analysis can accomplish a number of tasks in one mapping analysis that would normally require multiple steps using various other pieces of instrumentation. The map experiment may be set up and allowed to run without any supervision, requiring minimal data interpretation once complete.

While measurements are possible, these would be approximate width measurements only. Their accuracy relies heavily on the beginning and ending of the software measuring tool, which is user defined, Figure 24. As can be seen in the component chemical images, where one component begins and ends is subjective. The color gradient from red to blue also makes the measurement points unclear. Width measurements can also be incorrectly interpreted in the case of non-symmetrical cross-sections. This can be seen with samples 3 and 7 in Table 2 where the sheath is not of a uniform width surrounding the core. Multiple Confocal Raman maps could be collected and these measurements averaged to get a better idea of the ranges that might be present. However, the addition of more map experiments will greatly increase the time required to obtain this information. It would be a better use of time to use other methods if multiple mapping experiments were required. Confocal Raman mapping may be best used as
an initial screening method supplemented with manually prepared cross-sections or other confirmatory techniques as needed.

The incomplete cross-sectional image provided by Confocal Raman mapping is also a limitation to this type of analysis. It is particularly problematic when the fibers are not symmetrical to achieve an accurate depiction of the cross-sectional shape and accurate width measurements. As can be seen in the Confocal Raman maps, one surface is sharp while the other is indistinct and hazy. What is displayed as the bottom surface in the Confocal Raman map is actually the uppermost surface of the fiber. The blurred surface is not a function of fiber width, as much thinner fibers were analyzed with the same results. Thermo Fisher Scientific proposes the indistinct surface may be due to the fiber acting as a lens, producing lensing effects.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Component Measured</th>
<th>Width Measurement using Raman (μm)</th>
<th>Width Measurement using Compound Microscope (μm)</th>
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<td>5</td>
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Table 2: Comparing Approximate Width Measurements of Fiber Sample Components

![Figure 24: Chemical image of sample 2’s core with the software measuring tool overlaid displaying the distance measured to the right. The measuring tool’s beginning and ending points are user defined.]

Distance: 20.19μm
CONCLUSIONS

Recognition of a bicomponent fiber can be difficult. Confocal Raman mapping can alert the examiner to the presence of a bicomponent fiber, as long as the components vary in sub-generic class. Simultaneously, Raman mapping can provide the chemical composition of each component and offer their relative spatial arrangements. Lengthy analysis times are required to obtain the map using small micron steps, but the analysis does not demand the examiner's time to monitor the collection. The Confocal x, z-map presents an image of the general cross-sectional shape of the fiber sample; however, due to a possible lensing effect, a complete image is often not available. Minimal sample preparation is required and presentation into the instrument is simple. For comparisons, accurate shape determinations, and/or accurate width measurements, preparation of a cross-section is still recommended as Confocal Raman mapping is limited to the general shape present.

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REFERENCES


