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Direct remote Raman imaging using hollow fiber bundle

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1. Introduction

Remote sampling systems using a flexible optical fiber are necessary for various applications of the Raman spectroscopy in biomedicine. Recently the use of a hollow optical fiber as a Raman probe has been proposed [1]. Because the hollow optical fiber, which consists of a thin glass capillary tubing inner-coated with a silver film, generates no fiber background, the filter-free Raman probe with a single fiber can be realized.

In this report, a flexible fiber bundle based on a hollow optical fiber is developed for remote Raman spectral imaging. The fiber bundle is fabricated by coating silver film on the inner surface of a glass capillary bundle formed by the stack-and-draw technique. Raman spectral images of polymer samples are obtained by combining fabricated fiber bundle with a high-speed imaging system.

2. Design and fabrication

The fiber bundle has honeycomb structure, and is inner coated with a silver film as the reflection layer. Fig. 1 (left) shows the relationship between the element diameter, the number of elements and the theoretical HE_{11} mode loss. In this calculation the wavelength and the outer diameter of fiber bundle were assumed to be 785 nm and 1 mm, respectively. The upper limit of the number of elements which can be estimated by assuming 10 dB/m loss is about 600 pixels. If an objective lens of 10× is used, 3.5 μm spatial resolution over a field of view of 100 μm diameter is achieved, which allows cell observation.

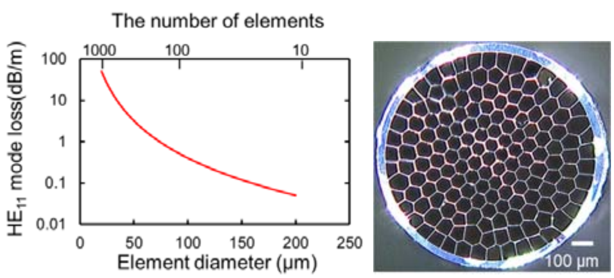

Figure 1. Calculated HE_{11} mode loss (*left*) of fiber bundles and a micrograph of a fabricated fiber bundle (*right*).

Hollow fiber bundles were fabricated by the stack-and-draw technique and the Ag plating technique. Fig. 1 (right) shows a micrograph of a fabricated hollow fiber bundle. The outer diameter of the fabricated fiber bundle was 1.1 mm. The average diameter of elements, the length and the air-filling ratio were 70 μm, 18 cm and 0.93, respectively. The loss at the excitation wavelength 785 nm of 12 dB was measured.

3. Measurement

To demonstrate the remote Raman imaging using fabricated hollow fiber bundle, we constructed a measurement system based on the direct imaging method well known as the high-speed imaging technique. A laser diode of 785 nm wavelength for excitation and a cooled CCD were used. The distal end of the fiber bundle is homogenously illuminated and the Raman image is obtained from a single exposure by passing the Raman light through a narrow-band filter onto the imaging CCD.

The mixture of polystyrene and PMMA beads was used as a target, and the Raman bands of 1015 cm^{-1} and 819 cm^{-1}, which are assigned to the vibration modes of polystyrene and PMMA, respectively, were selected by a tunable thin film filter. The result is shown in Fig. 2. Here, the total intensity of the excitation light was 93 mW and the measuring time was 8 s. It is confirmed that two kinds of polymer beads are indicated separately by different colors although it is difficult to distinguish by conventional microscope.

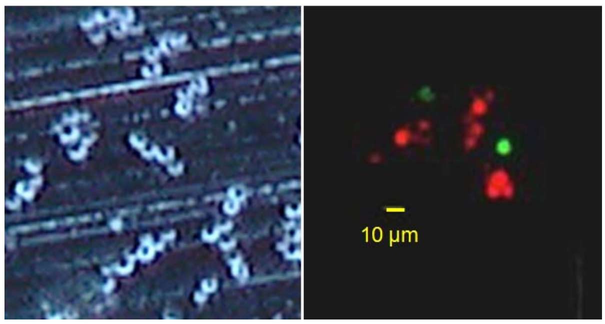

Figure. 2 Measured Raman image of polystyrene (red) and PMMA (green) beads.

4. Conclusions

The flexible fiber bundle based on a hollow optical fiber was fabricated by coating silver film on the inner surface of a glass capillary bundle. A Raman spectral image of polymer beads was obtained by combining fabricated hollow fiber bundle with the direct imaging system.

References

[1] Y. Komachi, et al., Opt. Lett., **30** (2005) 2942.

Appendix

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