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Effects of structure parameters on the sensor performance of photonic crystal fiber

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ABSTRACT

A simple and compact sensor based on a photonic crystal fiber (PCF) for the in-situ detection of fluorescence signals with high sensitivity is demonstrated. Several different kinds of PCF probes are studied. The effect of PCF parameters on sensitivity and the guiding mechanisms are analyzed, and the performance of PCF probes is experimentally evaluated by measuring the fluorescence signal of Cy3 dye. In addition, the detection sensitivity of the hollow-core PCF probe and the flat-tippedmulti-mode fiber probe is compared. The experimental results show that the hollow-core PCF probe provides a greater than five-fold increase in detection sensitivity compared with direct measurements by a flat-tipped-multi-mode fiber probe, which shows its potential for wide applications to in-situ detection in the medical, forensic, biological, geological, and environmental fields with high sensitivity.

1. Introduction

Photonic crystal fibers (PCF) have recently been widely studied for their special structure and unique properties [1–3]. According to the guiding mechanisms, PCFs are usually categorized into two types: index-guiding and photonic bandgap-guiding. For both types of PCF, specific fiber properties can easily be varied by changing such parameters as hole size, arrangement, spacing, and shape. Several important subclasses of PCFs already exist. Different kinds of PCF can be changed by filling the air holes with different materials. Such changes can bring new applications, especially within biosensing [4, 5]. PCFs may offer unprecedented sensitivity because the material being sensed can be inserted into the fiber holes and can undergo long-range interaction with confined (guided) light. In this paper, we build an all-fiber PCF biosensor to study the different types of PCF probe for fluorescence signal detection. The experimental results show that fluorescence signals measured by a photonic bandgap fiber are stronger than those measured by other fiber probes. We also demonstrate that the photonic bandgap fiber is suitable for the in-situ detection of biomedical, chemical, and environmental samples using very small volumes and with high sensitivity.

2. Experimental

The schematic of all-fiber photonic crystal fiber biosensor is shown in Fig.1. The excitation light from a 532 nm pulse diode laser with pigtail was directly launched into the single-mode fiber of the single-multi-mode fiber coupler, which reduced the optical components and no longer required optical alignment. The power of the excitation laser used in the system was 5 mW. Thereafter, the excitation light from the laser was coupled to a photonic crystal fiber probe through the homemade fiber connector. The fluorescence signal excited from the sample was subsequently detected by photodiodes through lock-in detection. The lock-in amplifier system effectively acted as a narrow band-pass filter, which removed much of the unwanted noise while allowing the signal which was to be measured to pass through. A bandpass filter at 572 nm was employed at the detector part to block the fundamental excitation light that was elastically scattered back from the sample surface.

3. Results and discussion

We experimentally studied a PCF biosensor system based on fluorescence detection and demonstrated the detection of the fluorescence signals of different types of PCF probes. To determine the sensitivity of the probes for hollow core photonic crystal fibers further, the response of the probes to Cy3 dye of various

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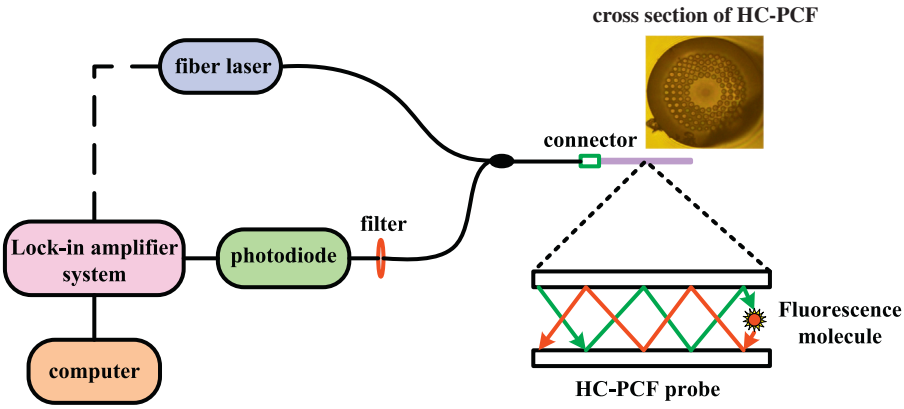

Fig. 1. Fiber biosensor system based on the fabricated PCF probe.

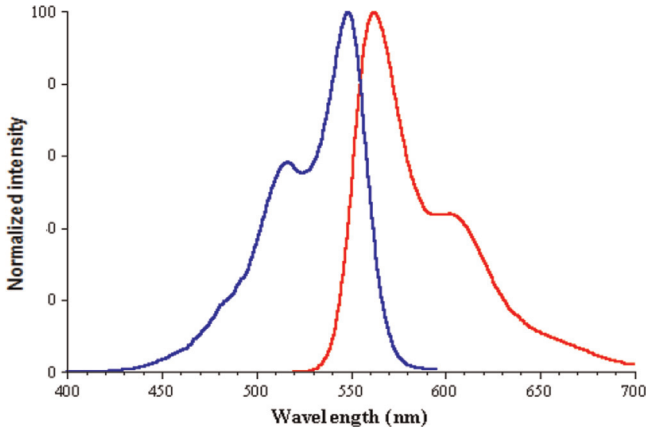

Fig. 2. Normalized absorption and fluorescence spectra of Cy3 solution.

concentrations was tested. Fig.2 shows the normalized absorption and fluorescence spectra of Cy3 solution. The PCF probes required only 2 μL of sample in our experiments, and the detection time was 2–3 min. We designed a negative pressure device using a disposable syringe, such that the sample solution could be sucked into the PCF probes via the application of the negative pressure at one fiber end.

3.1. *Fluorescence signals detection of several types of PCF probes*

To confirm the performance of various types of PCF probes, five PCF types: hollow-core bandgap, grapefruit, large mode field, high nonlinear, and endlessly single mode, were investigated. The response of the probes to Cy3 dye was tested. Fig. 3 shows the scanning electron microscopy image of the cross section of the PCFs used in this paper.

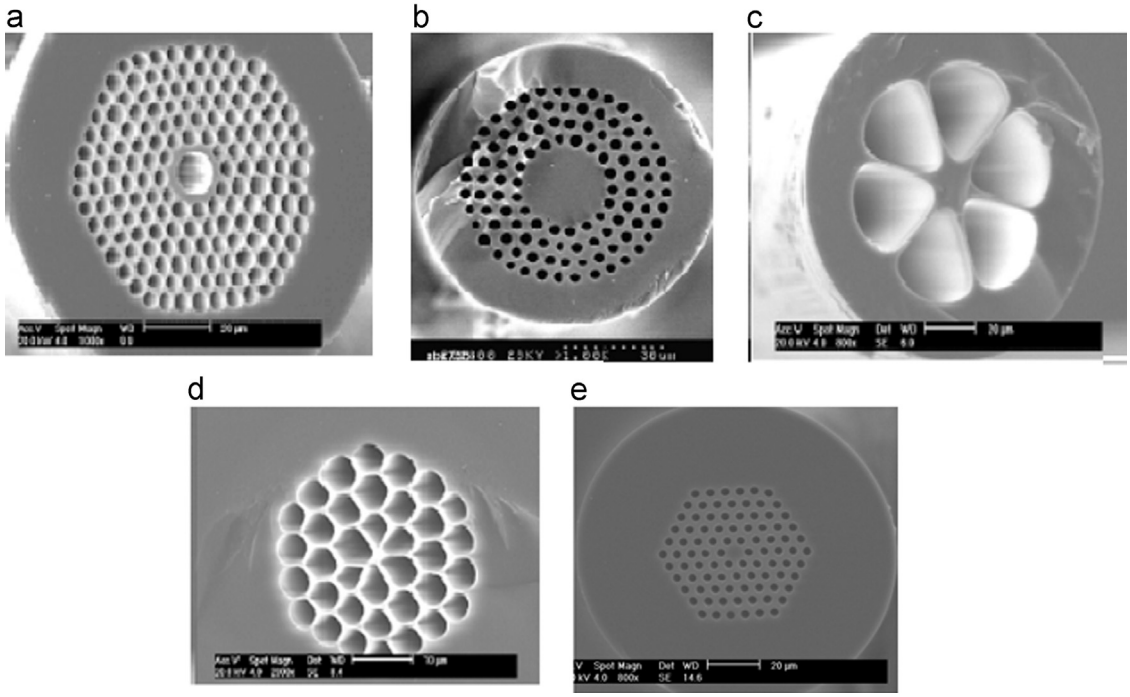

Fig. 3. Cross-section views of the PCFs of different structures. (a) Hollow-core (Λ=5.4 μm, d_{clad}=7.5 μm, and d_{core}=22.4 μm), (b) large mode field (Λ=10.6 μm, d_{clad}=8.1 μm, and d_{core}=34.4 μm), (c) grapefruit (Λ=12 μm, d_{clad}=34.6 μm, and d_{core}=35.3 μm), (d) high nonlinear (Λ=2.9 μm, d_{clad}=2.7 μm, and d_{core}=2.5 μm), and (e) endlessly single mode (Λ=5.4 μm, d_{clad}=4.3 μm, and d_{core}=8.3 μm), where Λ is the pitch, d_{clad} is diameter of the cladding holes, and d_{core} is diameter of the core.