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Abstract. Here, the concentration of TNT was detected by using evanescent absorption method, U-shaped plastic optical fiber was used as sensor head and light transmit element. A high brightness blue light-emitting diode with spectrum centered at 470 nm was used as excitation source. The relationship between the transmitted light power of U-shaped sensor head and TNT concentration was linearly and the linear coefficient was 0.944. The system showed excellent reversibility when the sensor tested by alternately cycling between 0 and 25 mg/100 ml TNT solution in five cycles. The stability of the sensor head in 25 mg/100 ml TNT solution was also tested within two hours. The proposed sensor is a cost-effective alternative to traditional TNT sensors and provides a platform for other optically based sensors. [DOI: 10.1117/1.OE.51.5.054403]

Subject terms: TNT; sensor; plastic optical fiber; evanescent.

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1 Introduction

Detection of nitro aromatic explosives (such as TNT) is of critical importance in countering terrorism, locating buried landmines, and providing useful information for environmental protection efforts. Various methods such as terahertz spectroscopy,[1] Raman spectroscopy,[2] molecularly imprinted polymers (MIP)[3] and fluorescence quenching[4–6] have been used for this purpose. These techniques are highly selective, but some of them are expensive and others are difficult to be fielded in a small, low-power package. Thus, because of considerable and distinct advantages of optical fiber sensors over the conventional sensors like immunity to electromagnetic noise, small size, remote and distributed sensing etc.,[7] which make them more advantageous in real field applications. Concentration measurement using evanescent field absorption fiber sensors has been performed in gaseous or liquid phases.[8,9] The advantage of evanescence absorption optical fiber sensor is inexpensive, simple and ideal candidates for in-line remote detection in dangerous locations and industrial process control.

The aim of this paper is to realize an optical fiber TNT sensor based on evanescence absorption. Such fiber sensors rely on weak interactions between the surrounding environment and the external "evanescent" field associated with bound modes of electromagnetic radiation propagating through an optical fiber.[10] In this article, plastic optical fiber (POF) was used as sensor head, POF has an aperture much larger than silica fiber used in optical communications, making it easier to couple with the source and to connect with each other, and is suitable for delivering both the exciting light and fluorescence with high coupling efficiency; in addition, POF shows advantages of low cost and high mechanical stability.

2 Experiments and Discussions

2.1 *Principles of the Sensor System*

Considering a multimode optical fiber whose cladding has been replaced locally by an absorbing fluid, the transmitted power through this fiber is given by:[9]

$$P = P_0 \exp(-\gamma L), \tag{1}$$

where γ is the evanescent absorption coefficient, L is the length of sensing region (unclad portion) and P_0 is the input power.

The evanescent absorption coefficient γ is given by:[9]

$$\gamma = \frac{\alpha \lambda n_2 \cos^2\theta}{2\pi\rho(n_1^2 - n_2^2)\sin\theta\sqrt{\sin^2\theta - \sin^2\theta_c}}, \tag{2}$$

where α is absorption coefficient and n_2 the refractive index of the surrounding medium, θ is the ray angle with the normal to the core-cladding interface, θ_c is the critical angle of the sensing region, λ is the wavelength of the launched light into the fiber, n_1 is the refractive index of the fiber core, and ρ is the radius of the fiber core. From Eqs. (1) and (2), we can see that when the refractive index of the surrounding medium is changed the transmitted power through the fiber will be changed. Based on this theory, we can detect the concentration of the TNT solution by measuring the output power of the optical fiber sensor head.

2.2 *Fabrication of the Sensor Heads*

The major problem with an evanescent-wave absorption sensor based on straight and uniform sensor head is the interaction length. As the evanescent tail has only a small fraction of power, a longer portion of fiber is needed to have an effective interaction of light with the analyte, and hence a detectable change at the output. Bending the fiber transfers

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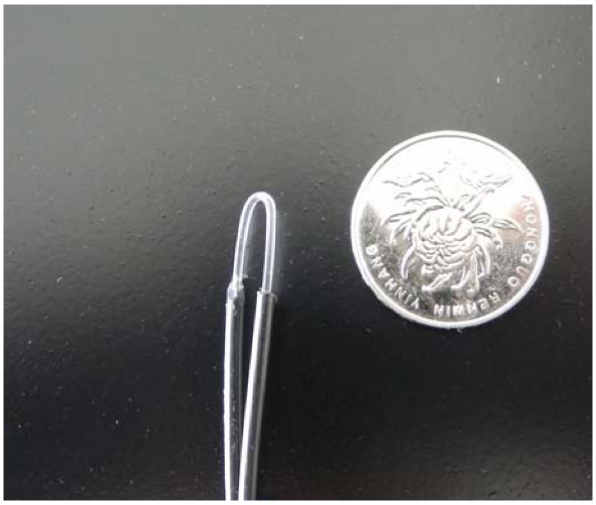

Fig. 1 The photo of U-shaped sensor head.

power from the guided modes to the leaky modes, providing more power to interact with the analyte in the sensing region. This results in a very high sensitivity with a very small interaction length.[7] Owing to this fact, our TNT sensor was constructed using a bent U-shaped fiber sensor head.

Plastic optic fiber made of polymethylmethacrylate (PMMA) with core diameter 1 mm was used to be the substrate of TNT sensor head, which plays also as a passage of light. Four centimeter long jacket of the POF was stripped off, and then the stripped portion was bent into U-shape (the bending radius of the U-shaped sensor head is about 0.5 cm), a TNT sensor head was then finished. Figure 1 shows a photo of the U-shaped sensor head.

2.3 *Experimental Setup*

A high brightness blue light-emitting diode (LED) was used as excitation source with spectrum centered at 470 nm. The U-shaped plastic optical fiber sensor head was putted into a test chamber with different concentration of TNT. The light radiated from LED is end coupled into the optical fiber sensor head. A PIN photodiode was used to detect the transmitted light; the output signal of the PIN was feed into the data acquisition card (DAQ) of the computer. Figure 2 shows the schematic diagram of the experimental setup.

Solutions of TNT with different concentration were prepared by dissolving TNT in alcohol, and then diluted with water to yield concentrations ranging between 0 and 25 mg/100 ml. After measurement of a certain concentration of TNT, the test chamber was washed with distilled water for several times to remove the residual TNT solution.

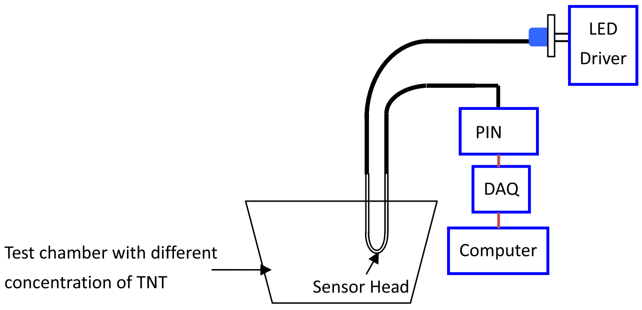

Fig. 2 Schematic diagram of experiment setup for detection of TNT.

2.4 *Experimental Results*

2.4.1 *Reversibility of the sensing system*

The procedures adopted for the examination of the reversibility of the sensing process are as follows: first, the test chamber was filled with distilled water, and the U-shaped fiber output light power was recorded. Second, 25 mg/100 ml of TNT solution was added, and the sensor output light power was recorded again. Third, after the measurement, the test chamber was washed with distilled water for several times. The whole process was repeated for several times. The results are shown in Fig. 3. With reference to the figure, it is clear that the response of the sensing system to TNT is fully reversible.

2.4.2 *Stability of the sensing system*

The procedures adopted for the examination of the stability of the sensing process are as follows: the test chamber was filled with 25 mg/100 ml TNT solution, the output light power of U-shaped plastic optical fiber was recorded every ten minutes within two hours. The results are shown in Fig. 4. It can be concluded that the output light power is between 0.0684 and 0.0729 V which may be caused by the fluctuation of the LED output light power external light disturbance etc.

2.4.3 *Sensing characteristic of the U-shaped sensor head*

Figure 5 shows the relationship between the U-shaped plastic optical fiber output light power and TNT concentration at room temperature. From this figure, it was found that the relationship between the output light power of U-shaped sensor head and TNT concentration was linearly and the linear coefficient was 0.944. We can calculate the sensitivity of the system by using the experiment data, the intensity difference between 0 and 5 mg/100 ml TNT is about 1 mV, the detectable fluorescence intensity difference of the system is 0.01 mV, from the above data we can calculate that the sensitivity of the sensing system is about 0.5 μg/ml.

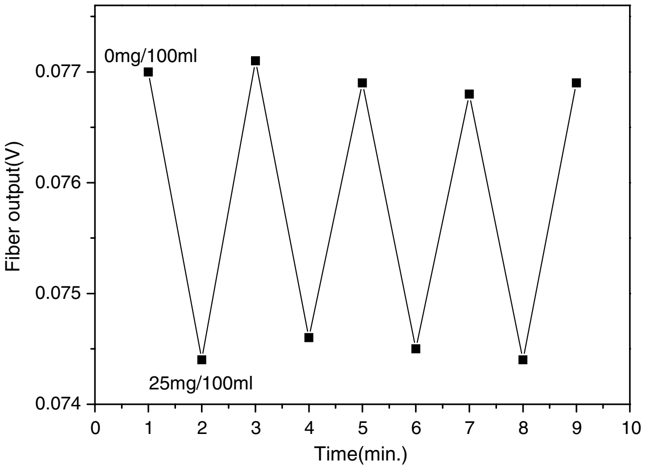

Fig. 3 Reversibility of U-shaped sensor head on switching between 25 and 0 mg/100 ml TNT.

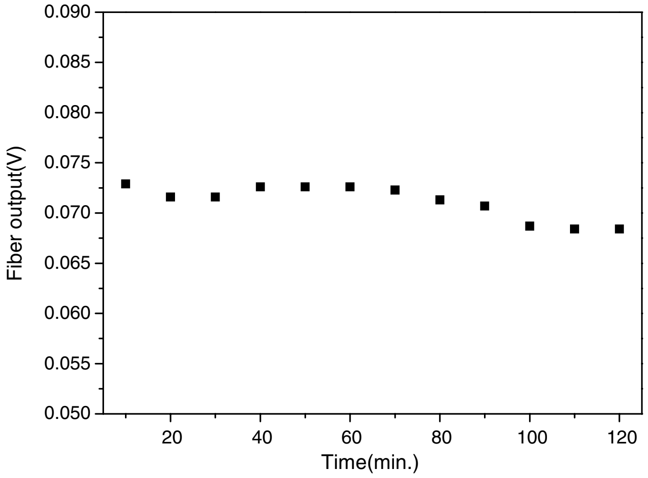

Fig. 4 Output light power of U-shaped plastic optical fiber sensor head within two hours in 25 mg/100 ml TNT solution.

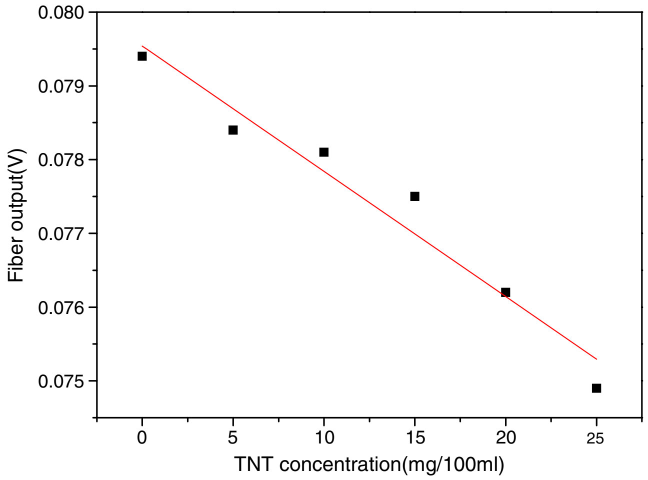

Fig. 5 Curve of TNT concentration and U-shaped sensor head output light intensity.

3 Conclusions

The sensing characteristics of U-shaped plastic optical fibers for TNT were studied in this paper. A high brightness blue LED with spectrum centered at 470 nm was used as excitation source. The system showed excellent reversibility when the sensor tested by alternately cycling between 0 and 25 mg/100 ml TNT solution in five cycles. The stability of the sensor head in 25 mg/100 ml TNT solution was also tested within two hours. The relationship between the output light power of U-shaped sensor head and TNT concentration was linearly and the linear coefficient was 0.944. The sensitivity of the sensing system is about 0.5 μg/ml. The stability of the sensing system can be improved by lowering the fluctuation of the output light power from LED. The proposed sensor is a cost-effective alternative to traditional TNT sensors and provides a platform for other optically based sensors.

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