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Miniature refractive index fiber sensor based on silica micro-tube and Au micro-sphere

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ABSTRACT

We demonstrated the refractive index sensing characteristics of a miniature fiber sensor composited by silica-hollow-tube (SHT) and Au-micro-sphere (AmS). The high sensitivity is obtained due to the evanescent field effect existing in the SHT with the inner diameter of ~2.3 μm and the surface plasmon resonance effect excited on the surface of AmS with the diameter of ~2 μm. Experimental results indicate that this sensor can continuously measure the glucose concentration in range of 0–60% with a good linearity. The high detection sensitivity up to 8.33 μmol/L (47.33 mW/RIU) enables its ability in determining the glucose concentration in either blood or body fluids. Furthermore, the tiny structure is promise to be integrated into the microchip or other injectable structures, and monitor the glucose concentration in real-time.

1. Introduction

In recent years, the evanescent field and surface plasmon resonance (SPR) effect based microscale or nanoscale optical fiber sensors have been widely studied for measuring the refractive index (RI), velocity, pressure, strain, gas concentration and liquid concentration. The advantages of small size, light weight, high sensitivity and electromagnetic independence [1–5] have been widely concerned in the fields of biological, chemical and environmental monitoring [6–8]. The performance of RI sensors have been improved significantly by introducing different functional materials, such as metal nano-particles, semiconductor nano-wires or other functional materials [9,10]. Although some metal (Fe_3O_4, Cu, Pt, PdCu, etc.) nano-particles modified heterostructures have been demonstrated to determine the glucose concentration in recent years [11–14], the response time of these electrochemical sensors was too long and hard to reduce further [15]. The optical glucose sensors based on RI measurement have gained a wide interest because of their fast response time, opening the possibility of real-time monitoring [16,17]. The tilted fiber grating has been demonstrated as the glucose sensor with a sensitivity of 0.298 nm/(mg/ml) [18]; the SPR based RI glucose sensor has been proved with a high sensitivity of 6613 nm/RIU [19]. The micro/nanofibers are the promising candidate for the implanted glucose sensor due to their light weight, small scale and excellent sensing performance [20].

This paper presents a composite fiber structure contained a silica micro-tube (SHT) and Au micro-sphere (AmS) for determining the glucose concentration. Here, the evanescent field effect and SPR effect are introduced to improve its sensitivity. SPR effect can be excited on the surface of AmS to increase the intensity of the evanescent field effect in the SHT and enhance the detection sensitivity.

2. Experimental setup and sensor structure

This paper presents a method for measuring the concentration of glucose solution with high sensitivity. The experimental schematic is shown in Fig. 1(a), the 400–900 nm light source is launched into the sensor element. This sensor probe consists of the AmS with a diameter of ~2 μm, and the SHT with an internal diameter of ~2.3 μm, in which the polymethylmethacrylate (PMMA) is filled to fix the AmS. The micrographs of the SHT-AmS fiber structure are shown in Fig. 1(b) and (c). The composited fiber sensor was fabricated by the method reported in our previous works [21,22]. The wide laser beam is focused into the SHT through

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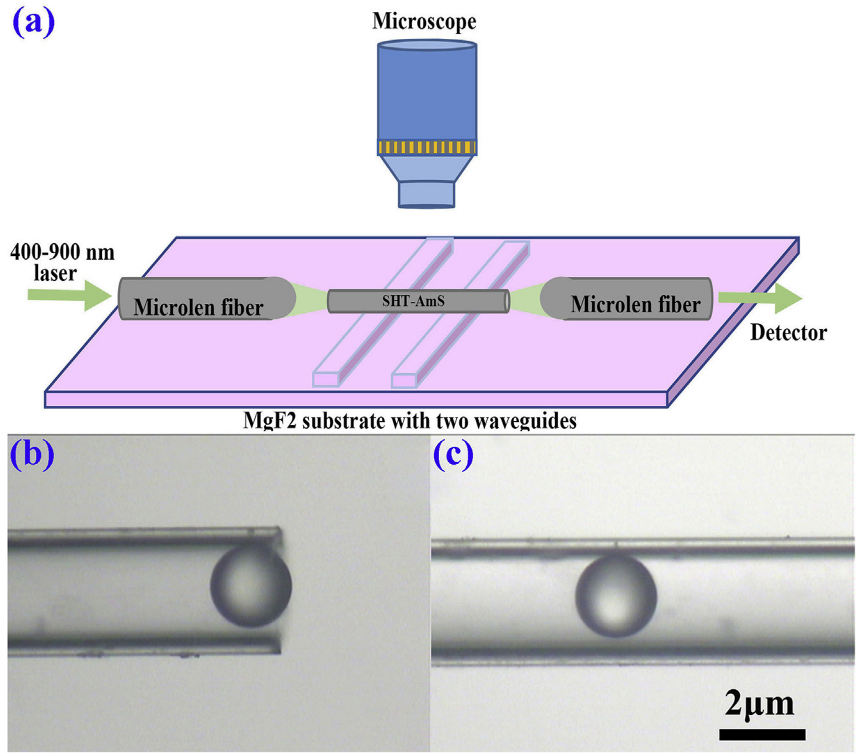

Fig. 1. (a) Schematic diagram of SHT-AmS composite fiber sensor; (b) and (c) are micrographs of SHT filled with AmS.

a microlen fiber, which was prepared from normal single mode fiber by high temperature melting technique using fiber splicer. Then, the evanescent field is aroused in the sub-wavelength SHT. Meanwhile, the incident light effects on the AmS surface and excites the resonance between the free electronics and incident photons, known as SPR effect, which will further strengthen the EF intensity. Another microlen fiber was used to collect the transmission light from the sensing probe and transfer it to the optoelectronic detector as well as the visible light spectrograph. The above-mentioned fibers and sensing probe were placed on a piece of MgF_2 substrate with a pair of narrow waveguides to support the sensing probe and reduce the light loss due to the low refractive index (~1.37) of MgF_2 crystal. The analyst was injected through the microchannel (~20 μm wide) between the two waveguides. The sensing properties will be analyzed by studying the relationship between the spectral signals and different concentrations of glucose solution from 0% to 60%.

3. Sensor properties analysis and discussion

The transmission spectra of the SHT-AmS composite fiber sensor for pure water and glucose concentration of 5% are shown in Fig. 2. It can be concluded that the transmitted light intensity changes significantly. The peak intensity of transmitted light for 5% glucose solution is about 0.5 mW higher than that of water. The enhancement of the light intensity can be contributed to the increasing of the RI around the sensing element due to the higher liquid concentration (RI), which resulted more light was confined within the sensing element. The intensity enhancement can also be observed through the far field scattering spot of the transmitted light, as indicated by the Insets. In addition, the resonant splitting modes are observed in the transmission spectra due to the introduction of the whispering gallery modes when the light is launched on the AmS surface.

The sensing properties of the SHT-AmS composite fiber sensor for different concentrations of glucose solution from 0% to 30% (0% refers to the pure water) was studied by analyzing the variation trend of the sensor's transmission spectra, are shown in Fig. 3. The peak intensity of transmission spectrum increases with the glucose concentration. In addition to the main transmission peak P_0, another peak P_{01} appears for a higher glucose concentration, whose intensity becomes significant when the glucose concentration becomes higher than 10%. Since the changes of the transmission peak P_{01} is not sufficient to reveal the sensing performance for the glucose concentration from 0% to 30%, the main transmission peak

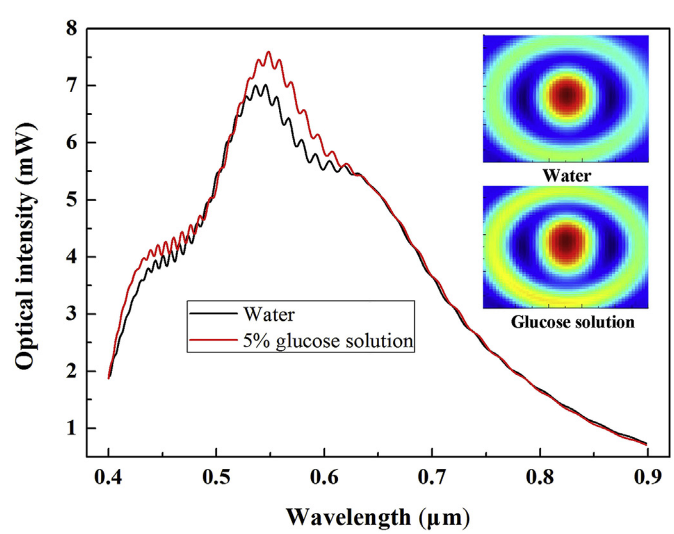

Fig. 2. Transmittance spectra of pure water and glucose solution (5%). Inserts show the far-field scattering spots for above two cases.