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A wavelength selective application for an optical fiber surface plasmon resonance sensor

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ABSTRACT

In this paper, a wavelength selective optical fiber surface plasmon resonance sensor, which provides a flexible detection capability, has been experimentally investigated. The light reflected from the sensor tip in response to flowing water and ethanol are monitored at several single wavelengths. The reflected light transient modulated by flowing solvent has an exponential form, which the change in magnitude and response time are dependent on the monitoring wavelength. Optimal wavelength best suited for measurement was determined by investigating the dynamic response curve. Rather than wavelength and angular interrogation methods commonly used in SPR measurement, this single wavelength monitoring scheme is a low-cost, flexible and reliable method.

1. Introduction

Surface plasmon resonance (SPR) sensing technique has been widely used in physical, chemical, and biochemical fields during the past two decades owing to its fast and precise advantages [1–3]. Surface plasmons are the coherent oscillations of conduction electrons at a metal–dielectric interface. Prism is usually employed to excite surface plasmons in the Kretschmann configuration. However, this prism-based SPR technique has a number of shortcomings, such as large size and high cost, which makes it unsuitable for miniaturized applications and remote sensing. Fortunately, these shortcomings can be overcome by replacing the prism with an optical-fiber [4–7]. The light transmitted in the optical-fiber experiencing a total internal reflection could also excite the surface plasmon at the metal–dielectric interface. Several types of configurations for optical-fiber SPR sensors have been reported. In 1993, Jorgenson and his colleagues first designed a new SPR model using optic fiber which a white-light source was used for wavelength interrogation [8]. Ronot-Trioli et al. employed a monochromatic-light source to excite a multimode fiber SPR sensor by angular interrogation technique [9]. In order to enhance the sensitivity, a number of studies have been carried out to investigate the parameters that influence the performance of optical fiber SPR sensors, including the metal film thickness [10], exposed length of core [11], geometries of fiber [12–14], metallic nanostructure [15,16] and so on.

No matter what strategies for sensitivity enhancement have been employed, the principle for surface plasmon resonance sensing explicitly depends on the incident angle and wavelength. Wavelength interrogation and angular interrogation methods are commonly used to extract the information from SPR spectrum [17,18]. Any change in refractive index near the metal–dielectric interface leads to a change in the output signal either with incident angle or wavelength. Due to the commercialization of SPR sensors, a lot of interest has been paid to the engineering aspects of practical configurations. Inexpensive, simple, robust and a long life are the primary requirements. Texas Instruments launched a commercial bench-top SPR sensor system designed with a mono-color light-emitting diode (LED) as the optical source and plastic prism for surface plasmon resonance coupling [19]. Ho reported a SPR sensor application by replacing a halogen lamp with a white light-emitting diode, which simplified the system design without too much compromising measurement accuracy [1].

To address the simplicity, flexibility and cost issue, we present an optical fiber surface plasmon resonance sensing system coupled with a mono-color light-emitting diode and a photodetector. The ease of direct measurement at single wavelengths improves the robust and economic features of SPR sensors. This configuration has been demonstrated to measure static and dynamic state of ethanol–water mixtures with varying constituent concentration. Several single-wavelength monitoring light perturbed by flowing ethanol–water mixtures are disclosed to analyze the

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corresponding relationship between transient of light and mixtures. The optimal single wavelength suited for measurement in terms of light change in magnitude and response time has been determined for further application. The introduction of this scheme will probably improve the optical-fiber SPR sensor for future practical application with the features of high flexible and efficient measurement.

2. Method

2.1. Materials

Ethanol (99.7%) was purchased from Chongqing Chemical Group (China) and used without any further purification. Milli-Q grade water was used in all the preparations. Multimode plastic clad silica (PCS) optical-fiber of 0.37 numerical aperture (NA) and 600 μm core diameter was purchased from Thorlabs. Gold (Au) wire (99.99%) was purchased from a local supplier. All procedures were conducted at room temperature unless specified otherwise.

2.2. Preparation of sensing probe

The optical fiber SPR probe was fabricated on the multimode plastic optical-fiber. The jacket and the cladding of 5 mm in length were removed mechanically from one end of the fiber. The unclad portion of the fiber was first cleaned with dilute nitric acid and then rinsed 4–5 times with de-ionized water and acetone. Cleaned unclad portion of the fiber was coated with a thin film of 50 nm thickness of gold. As the sensor is reflected type, this end face of fiber was used as a mirror. The thickness of gold layer was measured by quartz crystal monitor inbuilt in the thermal evaporation machine. The thickness of the depositing film on the fiber core can be controlled in real time. The evaporation of gold was performed at 5×10^{-6} mbars.

2.3. Apparatus

The experimental setup of SPR-based fiber optic sensor is shown in Fig. 1. The fiber optic probe was fixed in a small flow cell to enable the delivery and removal of aqueous solution around the sensing surface. The solvent was injected into the flow cell by a dual rate syringe pump (KDS Gemini 88, KDS Scientific). The refractive indices of all the samples were measured using an Abbe refractometer. Unpolarized light from a tungsten halogen lamp (HL-2000-HP, Ocean Optics) was coupled to the fiber-optic SPR probe though a 2 × 1 fiber coupler. The reflected spectrum was captured by a fiber optic spectrometer (HR4000, Ocean Optics), which was connected to the other side of the coupler as shown in Fig. 1a. In order to select the single wavelength light, a white light LED (MWWHF1, Thorlabs) and several single wavelength filters were used to replace the tungsten halogen lamp. A photodetector (PDA100A, Thorlabs) and a data acquisition PCI board (PCI-1706UL, Advantech) were connected to the output channel of the coupler as shown in Fig. 1b. The spectral information were recorded and analyzed by a program written in C++ and Matlab.

3. Experimental results and discussions

The spectra of SPR-based fiber optic sensor under the influence of different refractive index ethanol–water mixtures are shown in Fig. 2a. The SPR curve shifted toward higher wavelength side with the increasing ethanol concentration. Once the ethanol concentration approached 80%, the spectrum was slightly blue shifted by continuous increase of ethanol percentage, which is attributable to the hydrogen bonding effect [11,20]. In order to better understanding the relationship between the wavelength location and the SPR spectra in the following analysis, the spectra presented in Fig. 2a are classified as three zones. The spectral region located below 636 nm, which is the resonance wavelength produced by 0% ethanol in mixtures, is zone *A*. The spectral region located higher than 678 nm, which is the resonance wavelength produced by 80% ethanol in mixtures, is zone *C*. The wavelength region located between 633 and 678 nm is zone *B*.

The resonance wavelength shifted by the changes in refractive index of ethanol–water mixtures is shown in Fig. 2b. This response is able to be regarded as a non-linear function defined as

$$\lambda_{res} = 5156n^2 - 12552n + 8206.9 \quad (1)$$

where n is the refractive index of bulk solution, λ_{res} is the resonance wavelength of fiber optic sensor. The refractive index

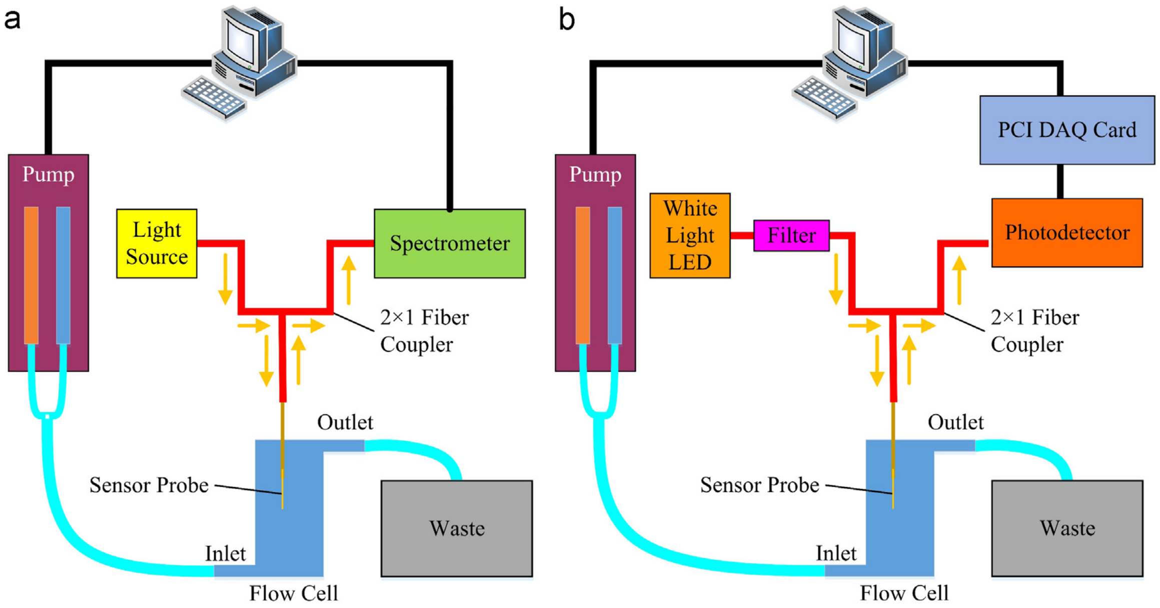

Fig. 1. Experimental setup for characterization of the optical-fiber SPR sensor. Spectral information collected by (a) a spectrometer and (b) a photodetector.