O E L E T T E R S

New idea for a D-type optical fiber sensor based on Kretschmann's configuration

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Abstract. A new idea for a D-type optical fiber sensor based on Kretschmann's configuration is proposed. The sensing device is a D-type single mode fiber with a half-polished core, and a thin film layer of gold deposited on the flat side of the sensor. In order to achieve the best sensitivity of the D-type optical fiber sensor, we must choose suitable parameters, e.g., the thickness of the thin film layer of gold and the length of the sensor. We found that the experimental results are in good correspondence with theoretical results. The sensor's sensitivity can reach 2×10^{-4} refractive index unit (RIU) at least. Because the sensor has some merits, e.g., small size, less costly, smaller sample volume, easy measurement, and suitability for *in vivo* testing, etc., the D-type optical fiber sensor is valuable for chemical, biological, and biochemical sensing.

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1 Introduction

As is well known, the phenomenon of surface plasmon resonance (SPR) in thin metal films is highly sensitive to the optical and structural properties of the metal interface. In recent years there have been many sensors proposed using Kretschmann's configuration[1] where the index of refraction of the prism increases the wave vector of the incoming light and the phenomenon of the surface plasmons are excited at a certain angle for a specific wavelength. Owing to well-known advantages over the conventional sensors of Kretschmann's configuration, optical fiber sensors have attracted much attention in the past two decades. In 1993, Jorgenson et al. proposed an optical fiber for SPR sensing.[2] Afterward, optical fiber sensors with SPR have attracted considerable interest. Many researchers have proposed various configurations of optical fiber sensors including uncladded multimode fibers,[3] D-shaped fibers,[4] and single-mode taped fibers.[5] In spite of their configurations, the claddings of the fibers were removed and coated with a thin layer of metal.

Recently, Chiu et al. presented a paper[6] on a fiber optical liquid refractometer where the sensing device was a D-type single mode optical fiber with a half-polished core. In this letter we develop an alternative configuration for an optical fiber sensor (OFS) based on Kretschmann's SPR theory. The D-type OFS is still used as the sensing device, but a thin film layer of gold is deposited on the flat side of the sensor. The D-type OFS is different from the D-shaped[5] fiber sensor. The core of the D-type OFS was half-polished, but Sorin et al. proposed a D-shaped fiber sensor for which the cladding was only partially polished. However, the D-type OFS is a new type of fiber sensor. From the results of simulations, we find that the sensor has the best sensitivity only if we choose suitable parameters, e.g., the thickness of the thin film layer of gold and the length of the sensor.

2 Principle

The D-type OFS configuration is shown in Fig. 1(a). Figure 1(b) shows that a beam with P polarization (P-Pol.) is coupled in and out of the fiber using two objective lenses (L1,L2). The D-type OFS consists of a D-type fiber (D) with two transmission fiber sections. The sensing section is

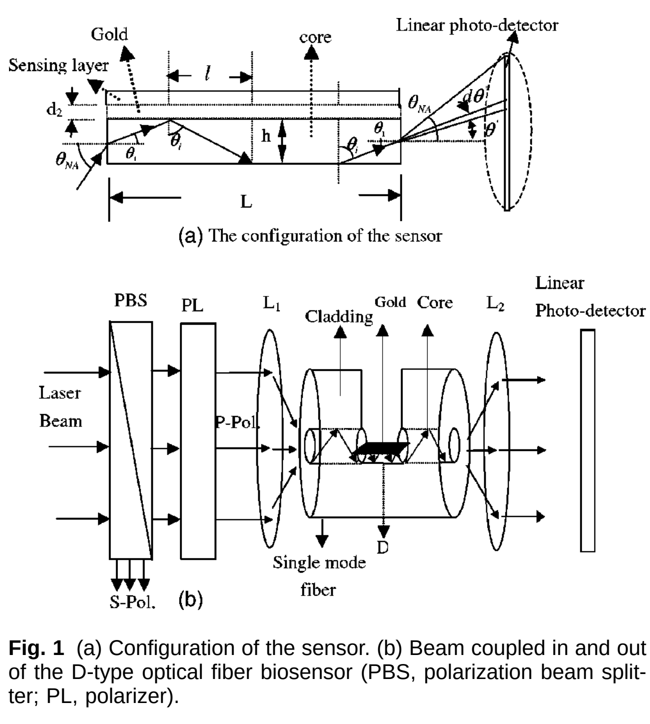

Fig. 1 (a) Configuration of the sensor. (b) Beam coupled in and out of the D-type optical fiber biosensor (PBS, polarization beam splitter; PL, polarizer).

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Table 1 Refractive indices for various alcohol concentrations.

Concentration (%)	0	10	20	30	40	50
Refractive index	1.3320	1.3365	1.3430	1.3485	1.3530	1.3570

polished as a D-type probe (D), and the core is coated with a thin film layer of gold. From Fig. 1(a), the number of attenuated total reflections (ATRs) is given using

$$m=\frac{L}{2h\times\tan\theta_i}. \tag{1}$$

The parameters of the D-type OFS are $n_1=1.47$, $L=4$ mm and $h=4\ \mu$m. As an example, for the special incident angle $\theta_i=86.45$ deg, the number m of ATRs was calculated to be about 31, by substituting the values of L, h, and θ_i into Eq. (1). Because the SPR phenomenon does not occur when the incident beam has an s-polarization (S-Pol.), a polarization beam splitter (PBS; the transmitted light from PBS is P-Pol. and the reflected light from PBS is S-Pol.) and a polarizer (PL, extinction ratio: $1/10^5$) were placed in front of the objective lens L1 to allow the p-polarization light (P-Pol.) to only pass through the D-type OFS. In order to match the scheme of the D-type OFS, we used the linear photodetector as the detector, which is orthogonal to the plane of the sensing surface as shown in Fig. 1(b). The normalized transmission power P_{trans} in the D-type OFS is[7,8]

$$P_{\text{trans}}=\frac{\int_{\theta i,\min}^{\pi/2}R_p^m(\theta)[n_1\sin\theta/(1-n_1^2\cos^2\theta)]\mathrm{d}\theta}{\int_{\theta i,\min}^{\pi/2}[n_1\sin\theta/(1-n_1^2\cos^2\theta)]\mathrm{d}\theta}, \tag{2}$$

where $R_p^m(\theta)$ is the intensity reflectance of the p-polarization light at some incident angle θ in the case of $m=L/(2h\times\tan\theta)$, $\theta_{i,\min}=86.1$ deg and n_1 is the index of refraction of the core.

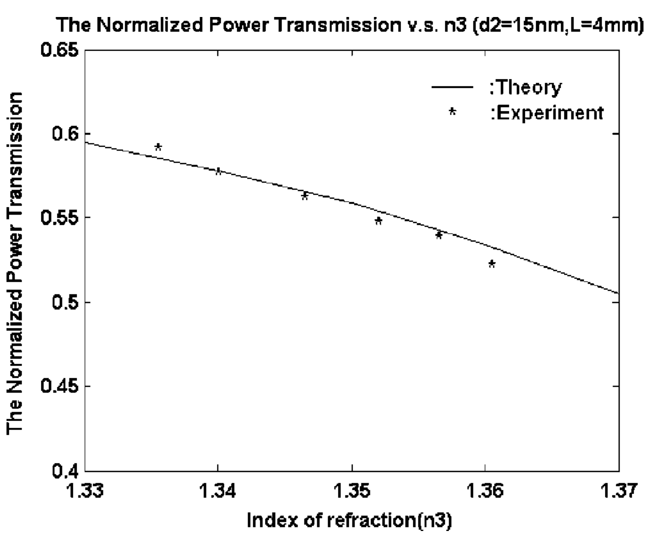

Fig. 2 Experimental and theoretical results for $d_2=15$ nm and $L=4$ mm.

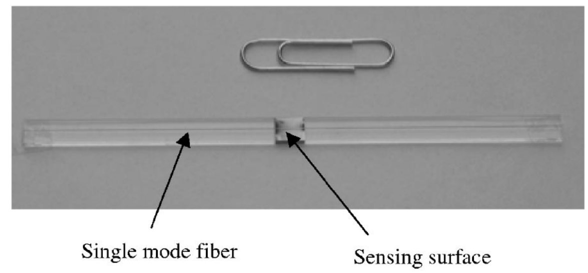

Fig. 3 Photograph of the D-type optical fiber sensor.

3 Simulation and Experimental Results

In order to demonstrate its feasibility, we measured the transmission powers for various alcohol concentrations. As listed in Table 1, the refractive indices n_3 of alcohol with variable concentrations are measured by an Abbe refractometer (Model 2WAJ, Milton Roy Co.). As shown in Fig. 2, these experimental and theoretical results are in good correspondence for $d_2=15$ nm and $L=4$ mm at a constant wavelength $\lambda=632.8$ nm.

4 Conclusion and Discussion

As shown in Fig. 3, we have designed a D-type OFS. The fiber sensor is designed as D-type configuration in order to increase the sensitivity of the sensor and coat the film easily. It does not reduce the feasibility of the sensor because the NA value of the single fiber is very low. From Fig. 2, the normalized transmission power P_{trans} can reach above 50% for $d_2=15$ nm and $L=4$ mm at a constant wavelength $\lambda=632.8$ nm. The sensitivity S could be defined as

$$S=\frac{\Delta P_{\text{trans}}}{\delta P_{\text{trans}}/\delta n_3} \tag{3}$$

where ΔP_{trans} is an estimation performed by considering the resolution of practical normalized transmitted power P_{trans} variation measurement ($\Delta P_{\text{trans}}\sim 0.1\%$) and $\delta P_{\text{trans}}/\delta n_3$ is the slope of P_{trans} variation versus the change in the refractive index n_3. Therefore, the sensitivity can be given as 2×10^{-4} refractive index unit (RIU) at least. Owing to the merits of the sensor, e.g., small size, less costly, smaller sample volume, easy measurement, and suitability for *in vivo* testing, etc., the D-type OFS is valuable for chemical, biological, and biochemical sensing.

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