Highly Sensitive SPR Sensor Based on Two-Mode Fiber Coated with Indium Tin Oxide at Near-Infrared Wavelength

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***Abstract*—A surface plasmon resonance (SPR) sensor based on side polished two-mode fiber (TMF) coated with indium tin oxide (ITO) film is proposed. Benefitting from the adjustable complex refractive index of ITO, the sensor is applicable for refractive index sensing in the near-infrared (NIR) region. The characteristics of the sensor are numerically investigated with LP_{01} and LP_{11a} modes coupled to specific surface plasmon (SP) modes. The results show that ~5980 nm/RIU and ~6332 nm/RIU can be achieved for LP_{01} and LP_{11a} modes coupling, respectively, when the environmental refractive index varies between 1.33 and 1.34 RIU, which is higher than the sensitivity of single-mode fiber (SMF) and multimode fiber (MMF) based SPR sensors.**

Keywords—Fiber sensor; two-mode fiber; surface plasmon resonance; sensitivity; near infrared.

I. Introduction

Fiber optical SPR sensors have attracted intensive attention in recent years for their advantages of lightweight, compact, immune to electromagnetic interference, remote sensing capability [1]. Most of the prior SPR sensors operate at visible wavelengths, since the plasma frequencies of commonly used metal materials such as gold and silver are in the visible wavelength region. It is promising to develop SPR sensors in NIR region. This is because, firstly, a NIR wavelength is demanded by many applications such as security and medicine [2]; secondly, the evanescent field in NIR has larger penetration depth compared with that of visible wavelengths, given that the penetration depth is proportional to the operation wavelength. Therefore, SPR sensors in NIR window can provide higher sensitivity; thirdly, optical fibers have a much lower transmission loss in NIR window.

SPR sensors based on SMF have been reported with a typical sensitivity of ~3000 nm/RIU [3]. In order to improve the coupling efficiency between the light source and fiber, SPR sensors based on MMF were demonstrated, and a sensitivity of about 5000 nm/RIU was obtained [4]. However, a large number of modes existing in the MMF can inevitably simultaneously excite many plasmon modes, which thus limit the sensitivity of the sensors. The few-mode fiber (FMF), on the other hand, can improve the sensitivity of SPR sensors [5] by taking advantage of its optimal core size. Only several core modes are guided in the FMF, and consequently only several SP modes can be excited.

In this paper, we present a fiber SPR sensor based on a side-polished TMF, which is coated with ITO film. Taking advantage of the tunable characteristics of ITO, the sensor can operate in the NIR region. The impact of ITO film thickness and residual fiber thickness (RFT) on the sensing performance are also investigated.

II. Simulation Model

The scheme of the proposed D-shaped TMF SPR sensor is demonstrated in Fig. 1(a). The main design parameters are length of the sensor (1000μm), radiuses of the core and cladding (9.5 μm and 62.5 μm, respectively), refractive indices of core and cladding (1.449 and 1.444, respectively), RFT, ITO thickness d_{ITO}, and refractive index of the environment medium n_e.The polished fiber surface is coated with ITO film. The permitivity of ITO can be tuned by varing doping concentration, which can be described by the Drude-Lorentz model [6]. The carrier concentration of ITO is chosen to be 2.48×10^{21} cm^{-3} for shifting the sensor operation wavelength to NIR. Fig 1(b) shows the real and imaginary parts of the permittivity in the wavelength range from 1.0 μm to 2.0 μm.

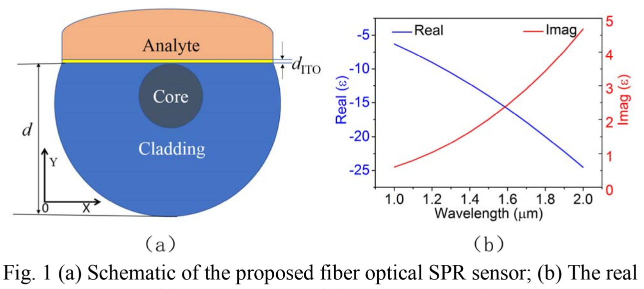
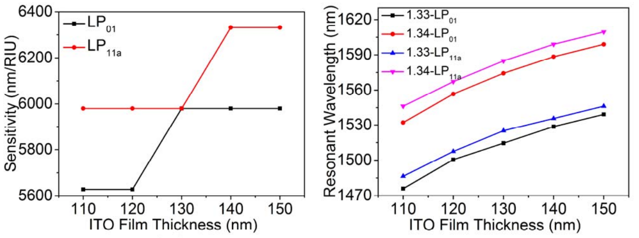


Fig. 1 (a) Schematic of the proposed fiber optical SPR sensor; (b) The real and imaginary parts of the ITO permittivity.

III. Results And Discussions

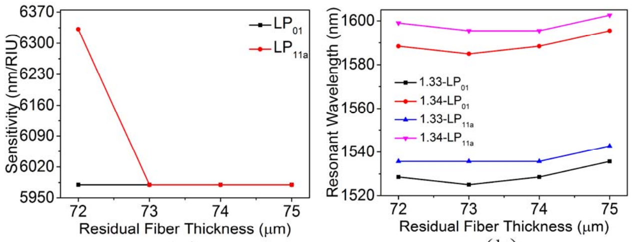
The surface plasmon resonances are stimulated with core modes LP_{01} and LP_{11a} coupled to the SP modes using

COMSOL Multiphysics. Firstly, we investigate the sensitivity dependence on ITO film thickness with n_e changed from 1.33 to 1.34 RIU and RFT fixed to 72 μm. As shown in Fig. 2(a), the sensitivity increased form 5628 nm/RIU to 5980 nm/RIU for the LP_{01} mode with the ITO film thickness varied from 110 nm to 150 nm. In comparison, the LP_{11a} mode has a higher sensitively, which increased from 5980 nm/RIU to 6332 nm/RIU in the same range of ITO film thickness. Fig 2(b) shows the dependence of resonant wavelength on ITO film thickness for LP_{01} and LP_{11a} modes. The resonant wavelengths increase with ITO film thickness in the thickness range from 110 nm to 150 nm. The resonant wavelengths shifted to longer wavelengths with n_e varied from 1.33 to 1.34 RIU. In addition, the resonant wavelengths of LP_{11a} mode located at longer wavelengths compared with that of the LP_{01} mode.



(a) (b)

Fig. 2 (a) Sensitivity variation with ITO film thickness for LP_{01} and LP_{11a} modes coupling; (b) Dependence of resonant wavelength on ITO film thickness for LP_{01} and LP_{11a} modes coupling.

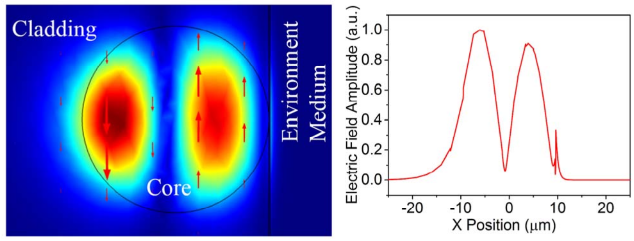


(a) (b)

Fig. 3 (a) Sensitivity variation with RFT for LP_{01} and LP_{11a} modes coupling; (b) Resonant wavelength variation with RFT for LP_{01} and LP_{11a} modes coupling.

Then we investigate the sensitivity dependence on RFT with n_e changed from 1.33 to 1.34 RIU and the ITO film thickness fixed to 140 nm. Figure 3(a) shows the variation of sensitivity with RFT from 72 μm to 75 μm. The sensitivity of LP_{01} mode is the same for different RFT. The sensitivity of LP_{11a} mode decreased from 6332 nm/RIU to 5980 nm/RIU when RFT increased from 72 μm to 73μm and then remained the same when RFT increased from 73 μm to 75 μm. The resonant wavelengths change with RFT slightly for LP_{01} and LP_{11a} modes coupling, as shown in Fig. 3(b).

In order to verify the surface plasmon resonances, we give the electric field distribution for $n_e = 1.34$, as shown in Fig. 4. Figure 4(a) illustrates the electric field intensity for coupling between the LP_{11a} mode and a SP mode at the resonant wavelength of 1600 nm, where the arrows specify the orientation of electric field. The corresponding 1D electrical field amplitude in the optical fiber is shown in Fig. 4(b). As shown in Fig. 4(b), at X = 9.5 μm, corresponding to the plane of the ITO film, a sharp peak in the electrical field amplitude is apparent, indicating the existing of surface plasmon resonance. Similar results are obtained for coupling between the LP_{01} mode and a SP mode.



(a) (b)

Fig. 4 (a) Electric field intensity for coupling between the LP_{11a} mode and a SP mode and (b) the corresponding electric field amplitude 1D across the fiber core.

IV. CONCLUSIONS

We have proposed and numerically investigated a SPR sensor based on side polished FMF coated with ITO film. This sensor can operate in the NIR region. The sensing performance of the sensor is investigated by changing the ITO film thickness and RFT. Coupling between the LP_{11a} mode and a SP mode can achieve a sensitivity of ~6332 nm/RIU, which is higher than the sensitivity of SMF and MMF based SPR sensors.

V. ACKNOWLEDGMENT

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