Long Range Surface Plasmon Resonance Sensor Based on Side Polished Fiber with a Buffer Layer of Magnesium Fluoride

Kai Xia, Xinjie Feng, Mei Yang, Yunhan Luo*, Jieyuan Tang, Heyuan Guan, Huihui Lu, Jianhui Yu, Jun Zhang, Yongzhu Chen, Zhe Chen

Key Laboratory of Optoelectronic Information and Sensing Technologies of Guangdong Higher Education Institutes, Jinan University, Guangzhou 510632, China

Guangdong Province University Key Lab of Numerical Controlled Technology, Guangdong Polytechnic Normal University, Guangzhou 510635, People's Republic of China

Correspondence: e-mail:yunhanluo@163.com

Abstract- **In this paper, a theoretical analysis for surface plasmon resonance sensor with the buffer layer of magnesium fluoride has been carried out. The numerical treatment is based on side polished single mode fiber SPR sensor and Drude model of metals. Meanwhile, the comparison for conventional SPR sensor, symmetrical SPR sensor and long range SPR sensor has been performed. On the basis of all these studies, the optimal design of a fiber optical SPR sensor achieves the maximal figure of merit (FOM) of 103.66.**

Keywords—Surface Plasmon Resonance; Side Polished Fiber; Magnesium Fluoride; Figure of merit

I. INTRODUCTION

The SPR sensors based on side polished fiber structure have significant advantages, such as smaller size and longer transmission distance, over other types of SPR sensors [1]. A conventional SPR (CSPR) sensor is made of monolayer of gold film. In 1981, Sarid [2] proposed a structure consisting of a thin metal layer surrounded by two dielectric layers which have similar refractive index. This structure is called long range surface plasmon resonance (LRSPR). This structure has higher sensitivity, higher resolution and deeper penetration depth when compared with the CSPR sensor. The magnesium fluoride (MgF_2) can be used as a buffer layer because its refractive index is similar with the analyte on the sensing area [3].

II. PHYSICAL MODELS

The physical models of CSPR, symmetrical SPR (SSPR) sensor and LRSPR sensor based on side polished fiber with MgF_2 material substrate are showed in Figure 1 respectively. A conventional structure consists of fiber, gold film and sensing layer. LRSPR is built upon the conventional structure by adding a layer of MgF_2 between the fiber and the gold film. SSPR is built upon the LRSPR structure by adding a layer of MgF_2 between the gold film and the sensing layer. The side polished fiber is made from a single mode fiber. The diameters of the core and the cladding are 8 μm and 125 μm, respectively. The residual fiber thickness is 66.5 μm. The refractive index of the fiber core is 1.4457. The MgF_2 has a refractive index in the vicinity of 1.38. The thicknesses of the MgF_2 for the SSPR and LRPSR structure are 50 nm and 100 nm, respectively. The thickness of the gold film is 50 nm. The dispersion in the metal layer is given by the Drude model [4],

$$\varepsilon_m = 1 - \frac{\lambda^2 \lambda_c}{\lambda_p^2(\lambda_c + j\lambda)} \tag{1}$$

where λ_p and λ_c are 168.26nm and 893.42nm respectively. The refractive index is given with the following equation,

$$n_m + jk_m = \sqrt{\varepsilon_m} \tag{2}$$

n_m and k_m represent the real part and imaginary part of the metal refractive index. The transmittance can be given as:

$$T = \exp(-\frac{4\pi}{\lambda_0}\mathrm{Im}(n_{eff})L) \tag{3}$$

λ_0 , n_{eff} and L represent the incidence wavelength, the effective refractive index of the metal and polished length of the fiber, respectively. In the simulation, L is set to be 10 mm. The transmittance spectra of the SPR sensor can be calculated as a function of the incidence wavelength. Both Sensitivity (S) and full width at half maximum (FWHM) are the two key factors to evaluate the SPR sensor performance. FOM is defined by FOM=S/(FWHM). Therefore, when the transmission spectra with different refractive index are simulated, the FOM could be calculated according to its definition.

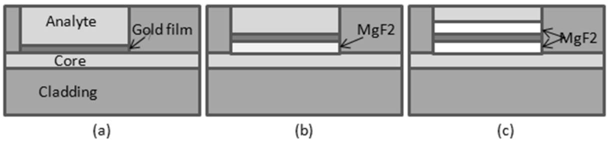

Fig.1. The physical models of CSPR (a), LRSPR (b) and SSPR (c).

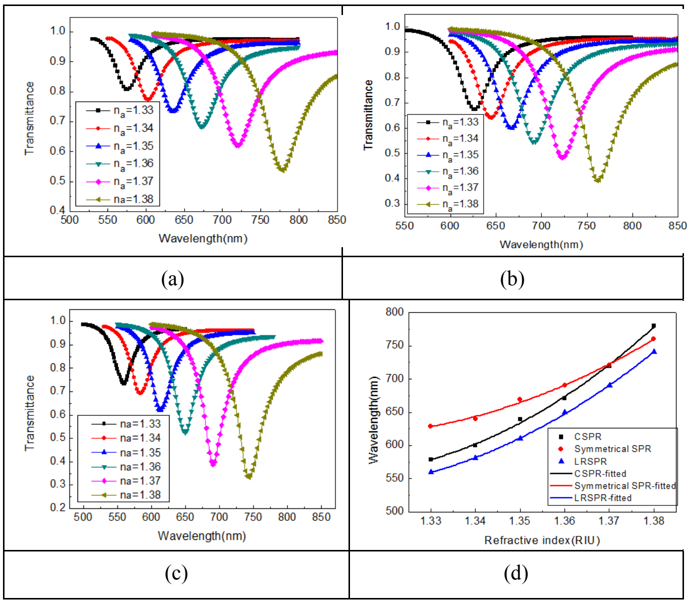

Fig.2. The resonance spectra for CSPR (a), SSPR (b) and LRSPR (c). The dependence of resonance wavelength on the refractive index (d).

TABLE I. The FWHM, average sensitivity and FOM for the CSPR, SSPR and LRSPR

Structure	CSPR	SSPR	LRSPR
FWHM(nm)	50	40	35
Average sensitivity(nm/RIU)	3987	2631	3628
FOM(RIU^{-1})	79.74	65.78	103.66

III. RESULTS AND DISCUSSIONS

Figure 2 shows the resonance spectra for the three SPR structures with analyte refractive index ranging from 1.33 RIU to 1.38 RIU with an increasement of 0.01 RIU. It can be seen that the resonant dip shifts towards longer wavelength as the analyte refractive index increases, which indicates that, for the same structure of the SPR sensor, the resonance condition is satisfied at different wavelengths for different analyte refractive index. Further, the FWHM of the LRSPR is the smallest and equals to 35 nm. The dependence of the wavelength on refractive index and the fitted lines are showed in figure 2 (d). The average sensitivity of the three types of SPR sensors can be figured out from this graph. The FWHM, average sensitivity and FOM for the CSPR, SSPR and LRSPR sensors are summarized in Table I. The maximum FOM of all these structures is 103.66, which is achieved in the structure of LRSPR. While the minimum FOM of all these sensors is 65.78 for the structure of SSPR.

IV. CONCLUSIONS

The FOM is a key factor to evaluate the performance of the SPR sensors, because it provides higher sensitivity and smaller FWHM. Comparing the performance of three kind of SPR structures, the best design of a fiber optic SPR sensor is the LRSPR, with the maximum FOM of 103.66, where the thickness of MgF_2 layer is 100 nm. This design is expected to play an important role in the field of optical fiber biosensor.

V. ACKNOWLEDGEMENTS

This work is supported by National Natural Science Foundation of China (Nos. 61177075, 61275046, 61361166006, 61475066, 61405075, 61505069, 61575084, and 61401176),

REFERENCES

[1] Leidberg B, Nylander C and Sundstrom I 1983 Surface plasmon resonance for gas detection and biosensing,[J] Sensors Actuators 4 299–304.

[2] SARID D. Long-range surface-plasma waves on very thin metal films [J].Physical Letters, 1981, 47(26):1972-1930.

[3] HOMOLA J. Suface plasmon resonance sensors for detection of chemical and biological species[J].Chemical Reviews, 2008, 108(2): 462.

[4] Anuj K.Sharma. On the perfomance of different bimetallic combinations in surface plasmon resonance based fiber optic sensors[J].J. Appl. Phys, 2007,101:09311.