Design and Optimization of Multimode Fiber Sensor Based on Surface Plasmon Resonance

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***Abstract*—Using finite element method (FEM), a D-shaped multimode fiber sensor (MFS) based on surface plasmon resonance (SPR) was designed and optimized. Here the core radius of multimode fiber is 52.5µm. The simulations show that the resonant wavelengths of 45th~50th propagation modes and their wavelength redshifts due to the ambient refractive index change are all the same. Among the SPR spectrums for different modes, higher order mode will induce deeper notch and larger extinction ratio. By tracing the wavelength shift of the 45th mode, the MFS was optimized. The optimized MFS has 75µm residual fiber thickness and gold film coated on D-shaped multimode fiber. Its average sensitivity of 4989nm/RIU can be attained, which is much higher than 3150nm/RIU of the single mode fiber SPR sensor in the ref. [1].**

Keywords—Refractive index; multimode fiber sensor; surface plasmon resonance; sensitivity;

I. INTRODUCTION

In recent years, the optical fiber sensors have attracted considerable attention due to its high sensitivity and compact configuration [1-2]. Surface plasmons are charge density waves of free electrons which occur on a surface of a thin metal film interfacing with an adjacent dielectric and propagate along the interface [3-5]. In this paper, we mainly calculate the impact of different residual fiber thickness and the gold film thickness on the SPR sensor sensitivity to obtain the optimal performances.

II. SIMULATION MODEL

In simulation, the main design performances of the sensor included the length of the sensor L (10mm), the radius and refractive index of the core ($r_{core}=52.5\mu m$ and $n_{core}=1.4378$, respectively) and of the cladding ($r_{cladding}=62.5\mu m$ and $n_{cladding}=1.4457$, respectively), the residual fiber thickness d, the thickness of the gold d_{au}, and the refractive index of the environ ambient medium n_a. For dispersion of metal layer, we can obtain through the Drude model [6]. The maximum element size and the minimum element size of the mesh are 2.8µm and 0.1µm. And we determine the optimum performances according to the sensitivity and the FOM [7].

Fig. 1(c) illustrates the intensity of the electric field of the cross section [8]. Obviously, a sharp peak in the electric field is apparent near the gold film. Fig.1 (d) shows that the different fiber mode does not affect the location of the resonance wavelength but only affects the depth and the FWHM of the resonance peak.

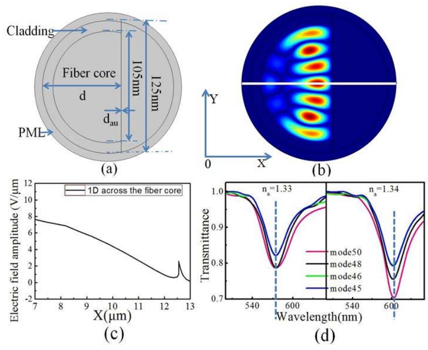

Fig.1 (a)Structure of a multimode fiber optic sensor based on SPR.(b)Full view of the electric field amplitude distribution, and electrical field amplitude 1D across the fiber core(c),and the identical resonance wavelength position of different fiber modes(d).

III. RESULTS AND DISCUSSIONS

A. The relation between the residual fiber thickness and the SPR sensor sensitivity.

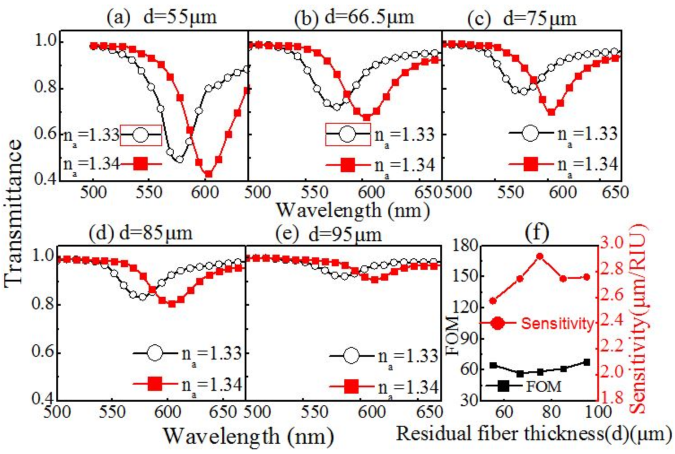

Fig.2 (a-e)Transmittance of the multimode fiber SPR sensor with different residual fiber thickness, with $d_{au}=50\ nm$, and resonance wavelength with variant d and SPR sensitivity when the refractive index of the ambient is changed from 1.33 to 1.34.(f)the FOM(n_a=1.33) and the sensitivity of the multimode fiber SPR sensor.

We depict the transmittance curves for all the five residual fiber thickness, i.e., 55, 66.5, 75, 85, and 95μm. We can find that the resonance depth decreases as the residual fiber thickness increases. And the highest sensitivity is 2920 nm/RIU when the residual fiber thickness is 75μm.

B. The relation between the gold film thickness and the SPR sensor sensitivity.

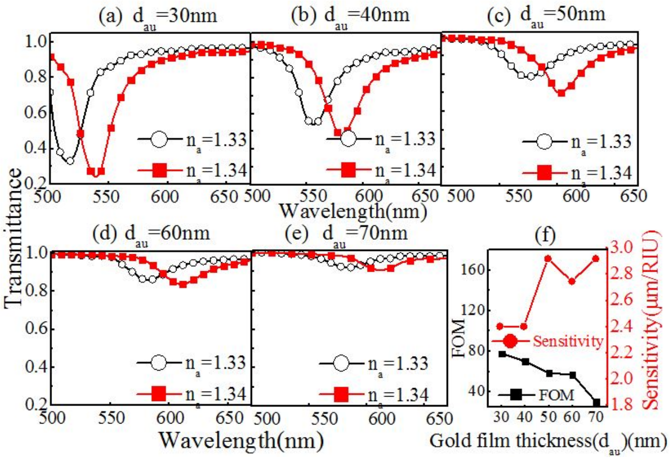

Fig.3 (a-e)Transmittance of the multimode fiber SPR sensor with different gold film thickness, with *d=75μm*, and resonance wavelength with variant d_{au} and SPR sensitivity when the refractive index of the ambient is changed from 1.33 to 1.34. (f)the FOM(n_a=1.33) and the sensitivity of the multimode fiber SPR sensor.

We analyze the transmittance curves of different gold film thickness (30, 40, 50, 60, and 70nm). Fig.3 shows that the resonant valley becomes shallower with the increase of gold film thickness, and the FWHM become wider. And the highest sensitivity is 2920 nm/RIU when the gold film thickness is 50nm and 70nm. However, the FOM of the 50nm is higher than 70nm. Therefore, to obtain the better performance, the selected thickness of gold film is 50nm.

C. Sensitivity under the optimal performance

Through the above analysis, we get the optimal performance for a multimode fiber SPR sensor, which the residual fiber thickness is 75μm and the gold film thickness is 50nm.

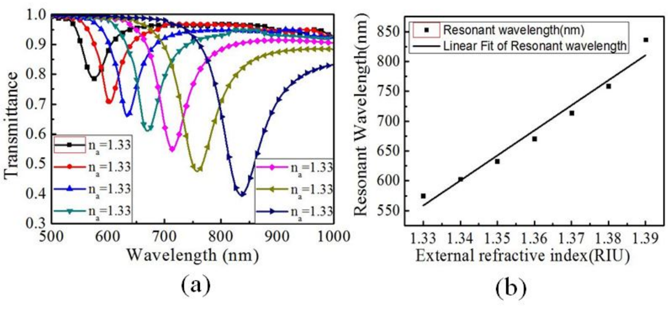

Fig.4 Simulation of transmittance of the sensor for different ambient refractive index(a), and(b) linear fitting lines of the fiftieth mode resonant wavelength versus ambient refractive index of 1.33-1.39

In the case of the optimal performances, we calculate the location of the resonance wavelength under different ambient refractive index and point out the linear fitting lines of the resonant wavelength versus ambient refractive index of 1.33-1.39. Fig.4 shows the resonance wavelength obviously moves toward longer wavelength as the refractive index of the ambient increases, and we have an average sensitivity of 4989nm/RIU, and have high linearity.

IV. CONCLUSIONS

Simulation results shows that the residual fiber thickness and the thickness of the gold film both have a great influence on the sensitivity of SPR fiber sensor. When the residual fiber thickness approaches 75μm and the gold film thickness is close to 50nm, this multimode fiber SPR sensor has ability to work in a large dynamic ambient range from 1.33 to 1.39 with high sensitivity of 4989nm/RIU and linearity.

V. ACKNOWLEDGMENT

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