Design and Optimization of Sensing Layer for Terminal Reflective SPR Optical Fiber Hydrogen Sensor

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Design and Optimization of Sensing Layer for Terminal Reflective SPR Optical Fiber Hydrogen Sensor

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Abstract. Based on the principle of surface plasmon resonance(SPR), the terminal reflective optical fiber hydrogen sensor structure has been obtained. By simulating, gold is selected as plasma coating material. The performance of the sensor of has been further studied with different thickness of gold film and hydrogen sensitive film. This work can provide theory support for the design of optical fiber surface plasmon resonance hydrogen sensor.

1. Introduction

Compared with other hydrogen sensors, optical fiber hydrogen sensor has the advantages of miniaturization, corrosion resistance, anti-electromagnetic interference and low cost, and can be operated in the dangerous environment of potential explosion[1-2]. It is a more promising device for hydrogen leakage detection. Surface plasmon resonance technology has the advantages of high sensitivity, and optical fiber SPR technology provides a safe, reliable and highly sensitive sensor technology, which can be used for remote measurement of flammable or explosive hydrogen[3-5].

In order to design an optical fiber SPR hydrogen sensor with good performance and wide detection range, many researchers have researched on the selection of coating materials and the thickness of sensitive film[6-7]. We study the influence on optical fiber SPR curve causing by the layer type, the layer thickness and the fiber structure parameters, and design the terminal reflective optical fiber SPR hydrogen sensor based on wavelength modulation.

2. Principle

The optical fiber SPR hydrogen sensor is made by coating metal film on the bare fiber core, after part of the cladding has been removed. And then the hydrogen sensitive film (Pt/WO_3 composite film) is coated. When light travels through the core, evanescent waves are generated near the core layer and the metal film layer, and surface plasmon resonance occurs at the interface between the metal film layer and the hydrogen sensitive film layer through the metal film. The complex dielectric constant of hydrogen sensitive thin film will change when hydrogen and hydrogen sensitive thin film contact each other, which will cause the change of resonance angle, and then determine the change of hydrogen concentration.

The terminal reflective fiber optic hydrogen sensor is a three-layer mode system with metal layer , tungsten trioxide (WO_3) layer and platinum layer on the bare core surface, and then a thick high reflective film (silver layer) is coated on its terminal, the model is shown in Figure 1. When the sensor is placed in an environment containing hydrogen, hydrogen reacts with the WO_3 layer under the catalysis

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of platinum, blue tungsten bronze will generate. Thus, the dielectric constant and refractive index of tungsten trioxide layer are changed, and the angular spectrum of SPR curve will be different. The concentration of hydrogen is determined by the angular spectrum of SPR curve.

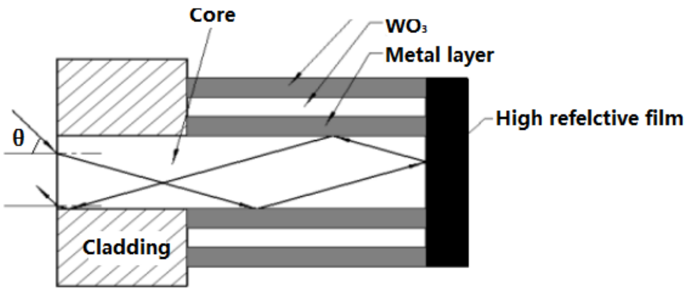

Figure 1. Terminal reflective structure

3. Design and optimization of sensing layer

The performance of the sensor mainly refers to the basic characteristic parameters of SPR angular spectrum curve for terminal reflective optical fiber SPR hydrogen sensor, including resonance angle, resonance peak half width and resonance depth. The resonance half-peak width is approximately the angular spectrum width at half of the sum of the maximum and minimum of the resonance peak, and the resonance depth is the difference between the two adjacent peaks and valleys.

3.1 Selection and optimization of metal layer

Because the complex dielectric constant of different metal films is different, the effect of different metal film layers on surface plasmon resonance angular spectrum will be very significant. Gold(Au) and silver(Ag) are very effective plasma coating materials. For optical fiber SPR hydrogen sensor, the selection of metal layer directly affects the sensitivity of the sensor. SPR angular spectrum of Ag and Au layers is simulated, as shown in Figure 2(the abscissa represents incident angle θ, and the longitudinal coordinate represents reflectivity R), in which the wavelength of incident light is 750nm, the thickness of hydrogen sensitive film is 100nm,the thickness of the film is 50nm (corresponding dielectric constant is -48+2i), and the thickness of the gold film is 50nm(corresponding dielectric constant is -13.736+0.979i). It can be seen that the metal film layer will affect the resonance angle, the half width of the resonance peak and the resonance depth. The more sharp the SPR angular spectrum curve, the greater the resonance depth and the higher the sensitivity of the sensor. Through the comparison of Figure 2, it can be seen that gold is better than silver, and gold is preferred in the design of metal layers for terminal reflective optical fiber SPR hydrogen sensor.

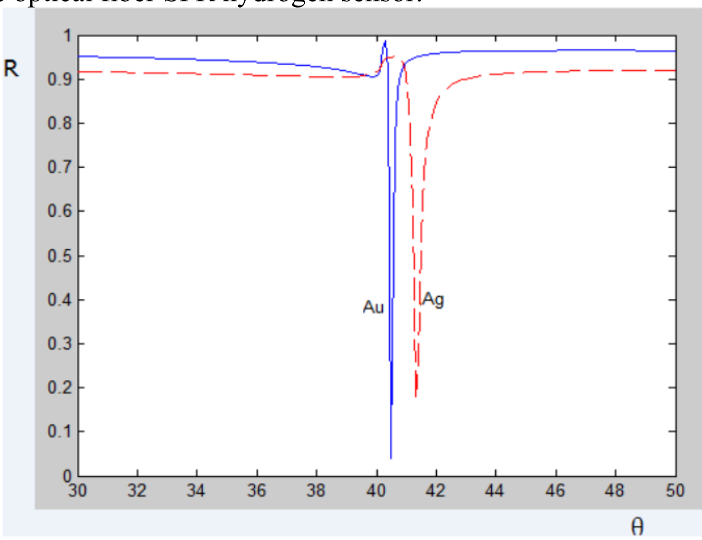

Figure 2. Angular Spectra of Reflectivity under Different Metal Films

Next the thickness of Au layer has been optimized. The SPR angle spectra are simulated under different Au film thickness(25nm, 35nm, 45nm and 55nm), as shown in Figure 3(abscissa coordinate represents incident angle **θ**, longitudinal coordinate represents reflectivity R).

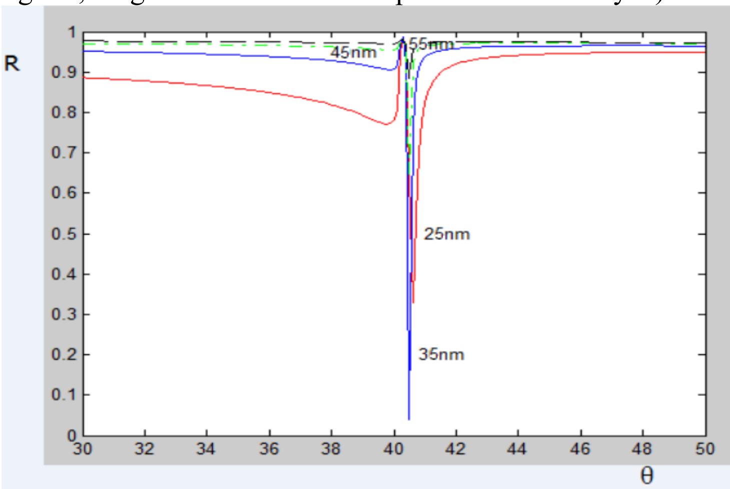

Figure 3. Angular Spectra of Reflectivity of Au Film with Different Thicknesses

Obviously, when the thickness of the silver film is 35nm, the reflectivity is the lowest, the resonance effect of the sensor is the most remarkable.

Table 1. Reflectivity, resonance angle and resonance depth of with different thickness Au film

Au film thickness	25nm	35nm	45nm	55nm
Reflectivity	0.3286	0.03964	0.6472	0.8853
Resonance angle	40.6	40.5	40.5	40.5
Resonance depth	0.6584	0.94736	0.3356	0.0945

From Figure 3 and Table 1, it can be concluded that the minimum reflectivity is 0.03964 and the maximum resonance depth is 0.94763 when the thickness of Au film is 35nm. Therefore, when making the optical fiber SPR hydrogen sensor, the thickness of Au film should be controlled at about 35nm, so that the terminal reflective optical fiber SPR hydrogen sensor can exhibit better sensitivity. It can also be concluded that although the minimum reflectivity and resonance depth of SPR angular spectrum are greatly affected by the thickness of Au films, the effect on resonance angle is not significant.

3.2 Optimization of Hydrogen Sensitive Thin Film Layer (Pt/WO_3)

The hydrogen-sensitive film designed in this paper is Pt/WO_3 composite hydrogen sensitive film, in which Pt is the main catalyst.

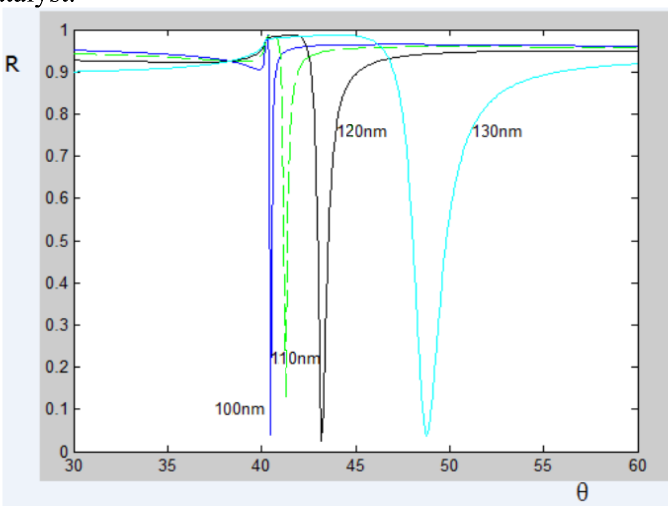

Figure 4. Angular Spectra of Reflectivity at Different Thicknesses of Pt/WO_3 Films

The SPR angular spectra of hydrogen sensitive thin films with different thickness (100nm, 110nm, 120nm and 130nm) are simulated, as shown in Figure 4. Detailed parameters are shown in Table 2.

Table 2. Reflectivity, resonance angle and resonance depth of with different thicknesses Pt/WO_3 films

Pt/WO_3 Film thickness	100nm	110nm	120nm	130nm
Reflectivity	0.03964	0.1308	0.03568	0.03662
Resonance angle	40.5	41.3	43.2	48.8
Resonance depth	0.94696	0.8571	0.95152	0.94718

When the thickness of Pt/WO_3 film is 100nm, the resonance angle does not change and the minimum reflection does not change too. Therefore, when making the optical fiber SPR hydrogen sensor, the thickness of Pt/WO_3 film should be controlled at about 100nm, so that the optical fiber SPR hydrogen sensor can have better sensitivity. Although different thickness of Pt/WO3 film has great influence on resonance angle, it has little effect on minimum reflection coefficient and resonance depth.

4. Conclusion

By selecting and optimizing the metal layer, it is concluded that 35nm Au film is suitable for the terminal reflective optical fiber SPR hydrogen sensor. The simulation results show that the terminal reflective optical fiber SPR hydrogen sensor has good performance when Pt/WO_3 thin film is about 100nm.

Acknowledgments

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