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Study on sensing characteristics of LPFG

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Abstract

Based on the three-clad model of coated long-period fiber grating, the transmission spectrum of lateral PFC is simulated by means of Matlab and Origin. It is found that the LPFG varies with the resonant wavelength. The results show that the sensitivity of the sensor to copper sulfate solution is up to 465.57nm/RIU

Keywords

Refractive index; Sensitivity; LPFG.

1. Introduction

Fiber Bragg grating (FBG) is a kind of passive filter, which has been widely concerned since its appearance in 1978[1,2]. According to the period length of fiber grating, it can be divided into Fiber Bragg grating and long period fiber grating.

LPFG was first prepared by Vengsarker et[3]. with a period of about microns. Because of its simple structure and full compatibility with optical fiber, LPFG can be designed in many ways. For example, LPFG can be cascaded with other sensing structures to realize multi-parameter sensing, and LPFG can be coated with film, LPFG can enhance the detection sensitivity, realize ion recognition or enlarge the detection range, and in recent years, LPFG has been used in tilted fiber grating, and has high sensitivity in refractive index, temperature and strain[5].

2. Theoretical model and sensing characteristics of coated LPFGSection Headings

The sensor structure coated with a thin film on the cladding of long-period fiber grating is regarded as a three-cladding LPFG model. The thin film layer and the external environment medium are regarded as the second cladding layer and the third cladding layer respectively, and their structures are shown in Fig. 1

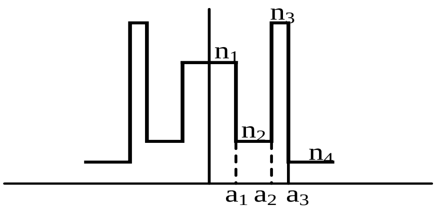

Fig. 1 Three-layer model map

n_1, n_2, n_3 and n_4 are the relative refractive index of core, cladding, coating and external environment respectively, a_1 is the radius of core, a_2 is the radius of cladding, a_3 is the radius of coating, so the thickness of coating $h = a_3 - a_2$, and the refractive index satisfies $n_3 > n_1 > n_2$. From the above coupling theory, it can be concluded that LPFG satisfies the following phase conditions:

$$\lambda_{res} = (n_{eff}^{co} - n_{eff}^{cl})\Lambda$$

The effective index of n_{eff}^{co} core is, that of n_{eff}^{cl} cladding mode is, and that of Λ is grating period. When the external environment changes, such as temperature, strain, environmental refractive index and so on, due to the thermal expansion effect and the elastic-optic effect, the grating period, length and the refractive index of the fiber core and cladding will change, these changes will change the mode coupling of the LPFG, which will lead to the change of the transmission spectrum of the grating. From the formula, it can be seen that the change of the resonant wavelength and the loss peak will be the final manifestation, which is the sensing characteristic of the long period fiber grating, the sensor with various functions can be made by using this characteristic.

3. Simulation results

Using Matlab and Comsol to analyze the data, the basic transmission spectrum parameters are set as: $n_1 = 1.4681$ fiber core refractive index, $n_2 = 1.4628$, cladding refractive index, fiber core radius $a_1 = 4.15\ \mu m$, $a_2 = 62.5\ \mu m$ at the same time the film material refractive index is set to $n_4 = 1.5$, fiber grating refractive index slowly change envelope value $\sigma(z) = 5\times10^{-5}$, the fiber grating has a period of $\Lambda = 500\ \mu m$, an incident wavelength of $\lambda = 1300$ nm and a film thickness of $h = 100$ nm. The resonance wavelength versus the ambient refractive index, as shown in figure 2:

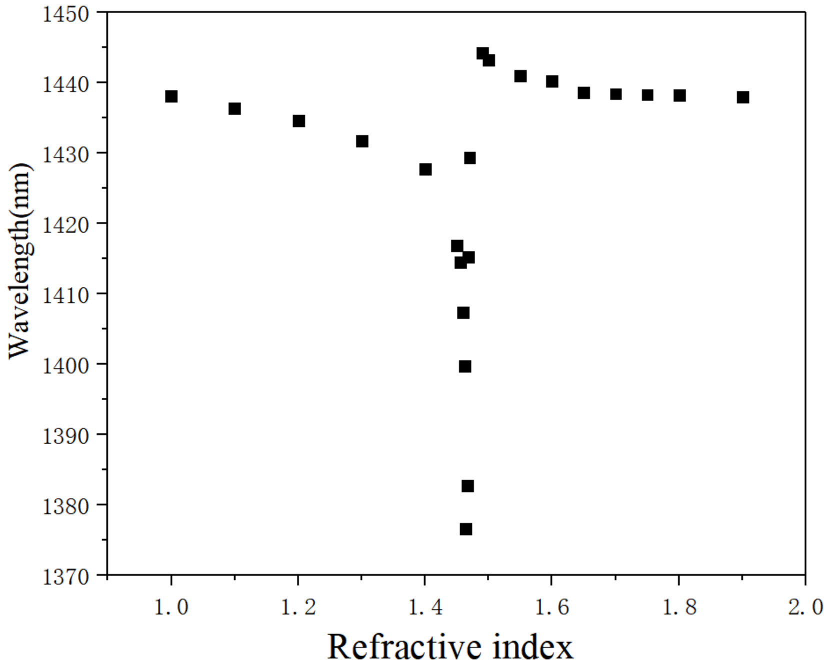

Fig. 2 Refractive index response curve

It can be seen from the figure that the resonant wavelength changes accordingly with the change of ambient refractive index. When the refractive index of the cladding is greater than that of the external environment, $n_2 > n_4$, the resonant wavelength shifts blue with the increase of n_4, and the phenomenon of wavelength drift becomes more obvious with the increase of n_4. At $n_2 = n_4$, the resonant wavelength of LPFG reaches the maximum. When $n_2 < n_4$, the resonant wavelength of LPFG jumps. In a small refractive index range, the resonant peak wavelength redshifts with the increase of n_4. After reaching the peak, with the continuous increase of n_4, the resonant wavelength begins to move to the short wave direction, and with the continuous increase of n_4, the drift phenomenon gradually slows down, but the central wavelength of the

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resonant peak after drift is always greater than the initial wavelength. Therefore, in theory, the refractive index can be detected with coated LPFG, which provides a basis for subsequent experiments.

4. Experimental analysis

The long-period fiber grating used in this section is made of high-frequency CO2 laser pulse writing device, as shown in Figure 3. Firstly, a single-mode optical fiber is stripped of about 50 mm coating layer with stripping pliers, and the surface of the optical fiber is cleaned with alcohol to avoid large errors caused by the residual coating layer; Secondly, place the cleaned optical fiber directly under the CO2 laser, and fix the optical fiber to be written with the 3D optical platform and optical fiber fixing frame; In order to avoid the deformation of the optical fiber caused by the release of laser energy during the writing process, a weight of about 30g is hung at one end of the optical fiber to keep the optical fiber in a natural straight state; Finally, the two ends of the optical fiber are connected to the light source and spectrometer respectively by using the optical fiber fusion machine to build a complete circuit. In the writing process, the spectrometer is used to monitor the output spectrum in real time to find the best parameters and prepare for the follow-up research.

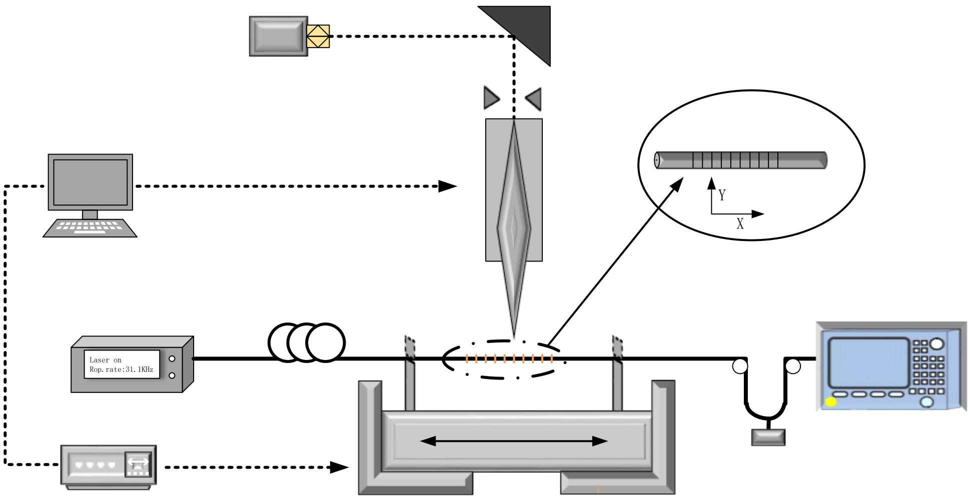

Fig. 3 Preparation of LPFG

The influence of writing parameters on the resonant wavelength of LPFG is analyzed. The intensity can be changed when the parameters of fixed period are unchanged. The transmission spectrum of long-period fiber grating is shown in Fig. 4:

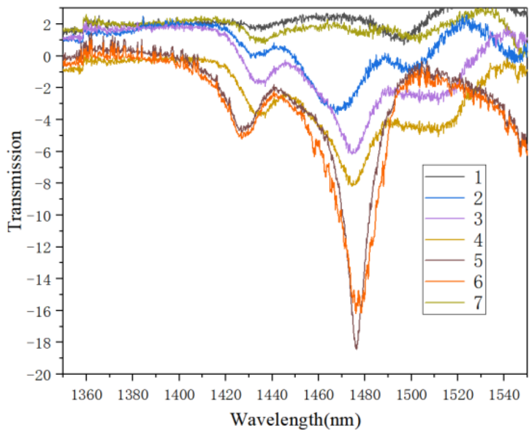

Fig. 4 Effect of different intensities on the waveform of LPFG

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It can be seen from the figure that the resonant peak amplitude of fiber Bragg grating increases first and then decreases with the increase of intensity, and the waveform becomes shallow, which is also known as over coupling phenomenon. Therefore, it can be concluded that when the writing cycle and the number of cycles remain unchanged, the coupling coefficient of the fiber Bragg grating has a certain relationship with the intensity, and the irregular drift of the resonant center wavelength is caused by the power fluctuation of the CO2 laser marking machine caused by the external environment, the deformation of the fiber during writing or the poor cleaning of the writing area.

Next, the fiber Bragg grating is coated to make it have the ability to identify aluminum ions, and the corresponding sensing experiment of aluminum ion concentration is carried out by using the coated fiber Bragg grating. The schematic diagram of the experimental structure is shown in Figure 5. It is composed of ultra continuous broadband light source, fiber holder, coated fiber Bragg grating and spectrometer. In the measurement process, a heavy object is hung at one end of the fiber to ensure that the fiber Bragg grating is under the same stress conditions during measurement and writing, reduce the error of the experiment, and the liquid to be measured is placed in the groove.

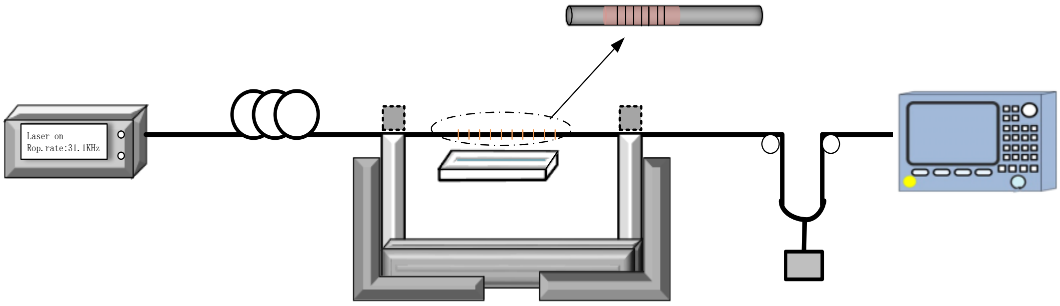

Figure 5 LPFG concentration sensing

The above sensor experimental device was tested and verified. Under the same external environment, only the refractive index of copper sulfate solution was changed. The three groups of solutions with refractive index 1.331, 1.338 and 1.352 were dripped into the reaction pool one by one, and the corresponding waveform changes were recorded. The results are shown in Figure 6. To facilitate the observation of waveform changes, three sets of solution transmission spectrograms are now arranged in a three-dimensional chart.

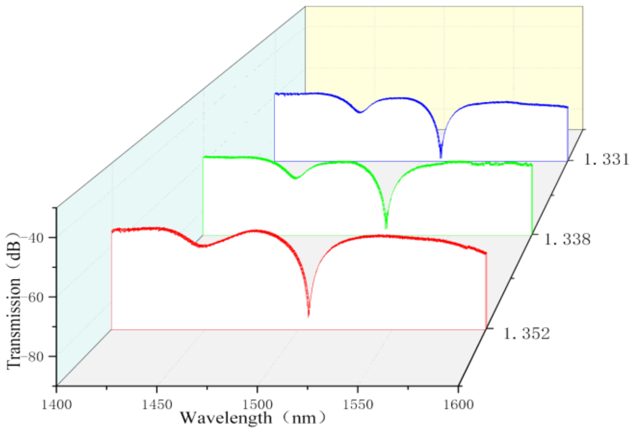

Fig.6 index of refraction

It is known that the concentration of Al^{3+} ions in solution has a linear relationship with the refractive index of the solution. With the increase of the concentration of Al^{3+} ions in the solution, the refractive index of the solution also increases. As shown in Figure 6, the center wavelength of the resonance peak of the FBG shifts blue, so the refractive index of the liquid to be measured can be theoretically deduced from the analysis of the wavelength drift. To further

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study the refractive index sensing characteristics of the sensor, the concentration of the measured area is subdivided and the number of test groups is increased. The test results are shown in Figure 7:

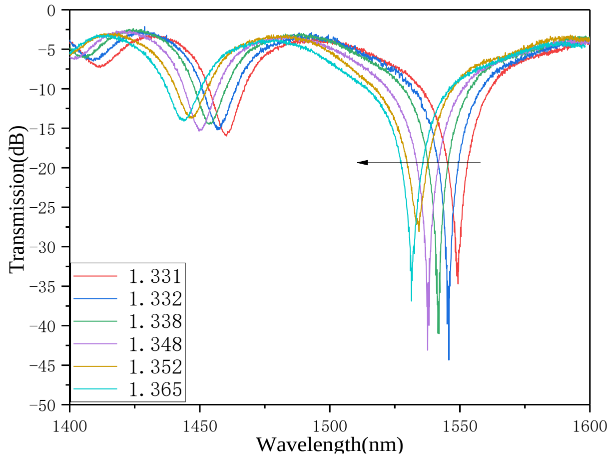

Fig.7 transmission spectrogram

As the refractive index of the solution increases, the center wavelength of the resonance peak of the FBG shifts blue as a whole. The wavelength point at the left edge of the resonance peak and the fixed loss of -20 dB is selected as the analysis object. The measured refractive index range of the solution is 1.331~1.365. The curve of the observed point wavelength changing with the refractive index of the solution is shown in Figure 4.10. The overall blue shift of the wavelength is 15.82946 nm. Linear fitting of the shift of the wavelength at the edge of the resonance peak with the change of refractive index is made, and the goodness of fit is only 96%, so the refractive index sensitivity can reach 465.27 nm/RIU.

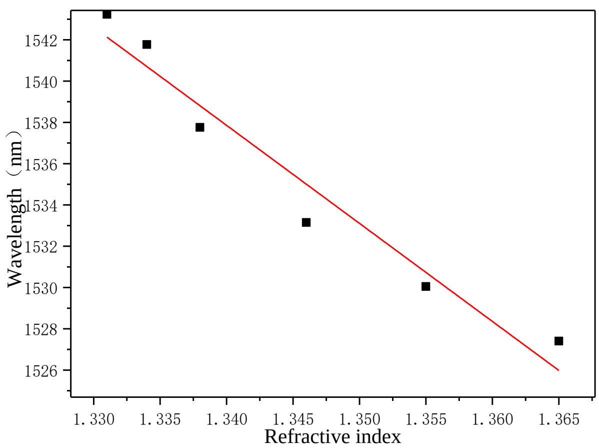

Figure.8 curve fitting

5. Summary

It is concluded from the above experiments that the structure can detect the concentration of aluminium ions by sensor, and the lower goodness of fit is mainly due to the waveform drift not only caused by the change of refractive index in the external environment. As the concentration and refractive index increase, the chelation reaction of aluminum ions becomes more complete. Precipitates produced by chelating reaction exist in the layer of the FBG, which changes the original refractive index of the layer. It can be seen from the formula that the change of the refractive index of the layer and the refractive index of the environment will cause the change of effective refractive index of the cladding mode, leading to the shift of the resonance wavelength. When the concentration exceeds a certain range, the chelation reaction of the ions

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to be measured in the film has been completed completely. At this time, the wavelength shift is mainly caused by environmental changes.

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