Sodium chloride concentration sensor based on long period fiber grating with dual resonant peak

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Abstract. The long period fiber grating (LPFG) with dual resonant peak was fabricated by exposing the core of a photosensitive optical fiber to an ultraviolet beam. The responses of this LPFG to sodium chloride aqueous solutions were investigated. Experimental results showed that, when the concentration of sodium chloride increased gradually from 0% to 26%, the left resonant peak gradually shifted from 1369.35 nm to 1345.17 nm, and the right resonant peak gradually shifted from 1599.68 nm to 1633.45 nm. The right resonant peak is much more sensitive to sodium chloride solution than the left resonant peak. Moreover, there was a good linear relationship between the resonant wavelength and the concentration of sodium chloride. For the left peak and the right peak, the linear equations are \( Y = -0.91X + 1369.32 \) and \( Y = 1.29X + 1598.81 \), respectively. Compared with the conventional LPFG, this LPFG with dual resonant peak possesses a higher sensitivity for sodium chloride concentration detection.

1. Introduction

Long period fiber gratings (LPFGs) are a class of gratings that typically have a period on the level of hundreds of micrometers, which can couple light from a guided core mode to forward propagating cladding modes of different orders, resulting in a series of distinct attenuation bands at specific wavelength. Because LPFGs can perceive the change of refractive index, they have been used to detect many materials such as ethylene glycol concentration [1], sugar concentration [2], dimethylsulfoxide [3], sodium chloride [4] and so on.

However, the conventional LPFGs are only sensitive to refractive indices approaching that of the cladding [5], so that they have very poor discrimination to different concentrations of sodium chloride solution.

In the paper, the LPFG with dual resonant peak was fabricated by ultraviolet (UV) irradiation. And it was further used to measure sodium chloride solution with different concentrations. The experimental results show that the LPFG with dual resonant peak has higher sensitivity to sodium chloride solutions.

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2. Results and discussion

2.1. Fabrication of the LPFG
The silica single-mode optical fiber (Corning SMF-28), which was purchased from Corning Incorporated Company, USA, has a core diameter of 8.25 μm and a cladding diameter of 125 μm in order to fabricate a LPFG. Prior to fabricating the LPFG, the fiber was hydrogen-loaded for more than a month at room temperature and 100 atm, which increased the photosensitivity of the fiber. Then, the grating was generated by exposing the fiber to an UV KrF excimer laser (Lumonics PM886) with a wavelength of 248 nm through an amplitude mask. In order to fabricate the LPFG with dual resonant peak, the UV laser pulse energy was set to 300 mJ, and each single exposure time was adjusted to 60 s. Subsequently, the LPFG was annealed for 10 h at 80 °C for stabilization.

2.2. Response of LPFG to sodium chloride solution
The transmission spectra of the LPFG with dual resonant peak in the sodium chloride aqueous solution with different concentrations were displayed in figure 1. As shown in figure 1, when the concentration of sodium chloride gradually increased from 0% to 26%, the two resonant peaks move to the opposite direction, respectively. The left resonant peak located at 1369.35 nm gradually shifted towards shorter wavelength, while the right resonant peak at 1599.68 nm gradually shifted towards longer wavelength. With the increase of sodium chloride concentration, the distance between the two resonant peaks gradually becomes larger.

As can be seen from figure 1, over the range of 0% to 26% sodium chloride solution, the left resonant peak shifted from 1369.35 nm to 1345.17 nm, generating a blue shift of 24.18 nm. Nevertheless, the right resonant peak moves from 1599.68 nm to 1633.45 nm, having a red shift of 33.77 nm. In the shift distance, the right resonant peak is 9.59 nm more than the left resonant peak. Therefore, the right resonant peak is more sensitive to the sodium chloride solutions than the left resonant peak.

In general, the conventional LPFGs only has higher sensitivity to the environmental media whose refractive index approaching that of the grating cladding [4,6] and show a very poor sensitive to environmental media with a refractive index of less than 1.400. Since the refractive index of 26% of
sodium chloride aqueous solution is 1.3743 at 15 °C, the conventional LPFGs have very lower sensitivity to different concentrations of sodium chloride solution.

Compared with the conventional LPFGs, the LPFG with the dual resonant peak exhibits higher sensitivity to sodium chloride solutions. In previous literature [4], the resonant wavelength of the LPFG described by R. Falciai has only less than 2 nm of shift in the different sodium chloride solutions. For the left resonant peak and the right resonant peak of this LPFG, the shifted resonant wavelength is about 12 times and 17 times that of the conventional LPFG in the literature [4], respectively.

In order to in comparison with the variation difference between the left resonant peak and the right resonant peak of this LPFG in the sodium chloride solutions, the refractive index sensitivity of the dual resonant peak in the sodium chloride solutions was further calculated. In the range of 0% to 26% sodium chloride solution, the refractive index sensitivity of the right resonance peak is 825.67 nm/RIU, while that of the left resonance peak is 591.19 nm/RIU. Therefore, the refractive index sensitivity of the right resonance peak is about 1.4 times that of the left resonance peak, that is, the right resonance peak is more sensitive to sodium chloride solutions than the left resonance peak.

3. Conclusions
The LPFG with dual resonance peaks was fabricated by exposing the fiber to an UV KrF excimer laser. Then it was used to measure the concentration of sodium chloride in aqueous solution. The results displayed that, with the increase of sodium chloride concentration, the left resonant peak is gradually blue-shifted, while the right resonant peak is gradually red-shifted. In the range of 0-26% sodium chloride solution, there is a good linear relationship between wavelength and sodium chloride concentration. For the left resonance peak and the right resonance peak, the linear equations between wavelength and the concentration of sodium chloride are $Y=-0.91X + 1369.32$ and $Y=1.29X + 1598.81$, respectively. Moreover, the right resonance peak is more sensitive to the sodium chloride solutions than the left resonance peak. Compared with the usual LPFG, the sensitivity of the
LPFG with dual resonance peak to sodium chloride solutions is increased by an order of magnitude. The LPFG with dual resonance peak has broad application prospects in many fields, such as the detection of seawater salinity, monitoring of ion concentration in the process of industrial fermentation, and so forth.

**Acknowledgments**

This work was supported by National Natural Science Foundation of China (No. 61340032, 61535010, 31500858), Key Research Development Program of Shandong Province (No. 2016ZDJS07A20, 2017GSF221014), the Foundation for Outstanding Young Scientist in Shandong Province (ZR2016CB42), Youth Fund of Shandong Academy of Sciences (2015QN009, 2017QN0010).

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