Humidity Sensor Based on Fiber Grating Coated with Graphene Oxide

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Abstract. Graphene oxide (GO) is a new two-dimensional carbon nano-material with large specific surface area and outstanding hydrophilicity. Its refractive index varies significantly with humidity, which can be used to improve the sensitivity of optical fiber humidity sensor. A kind of fiber Bragg grating (FBG) humidity sensor based on GO is proposed and experimentally demonstrated. GO is uniformly coated on the FBG surface by deposition. When the ambient humidity changes, the GO film adsorbs or releases water molecules and its refractive index changes. Thus the effective refractive index of FBG changes and the transmission wavelength also changes. The experimental results show that the sensor has a linear response of 2.53 pm/% RH in the range of 20%-70% RH, so it has the advantages of high sensitivity and simple structure.

1. Introduction
Relative humidity (RH) is one of the most important physical quantities in the field of physics. Numerous applications such as chemical processing, air conditioning, agriculture, food storage, and civil engineering require humidity sensing. Optical fiber humidity sensor is different from traditional mechanical or electrical humidity sensor. Fiber humidity sensor using optical fibers as carriers instead of complex mechanical structures, does not depend on semiconductor materials. So it has the advantages of compact size, immunity to electromagnetic interference and high sensitivity [1]. In recent years, researchers have developed a variety of optical fiber humidity sensors. Fizeau interferometer humidity sensor is constructed by the micro-cavity at the end of single mode optical fiber (SMF). The sensitivity of the sensor is 0.0545nm/% RH [2]. Many types of humidity sensors based on in-fibre gratings have been reported [3]. Fiber Bragg grating (FBG) sensors have been topic of sizable research efforts in recent years. A FBG is a permanent, periodically index-changing structure written into the core of an optical fiber. FBGs are attractive sensing elements because they exhibit a response that is reversible, accurate, and stable over long time periods, which can be used for absolute measurements. An intrinsic relative humidity (RH) sensor that uses polyimide-recoated FBGs is presented by Pascal Kronenberg and Pramod K. Rastogi [4]. It has already been shown that the response behavior of a polyimide-recoated FBG is a linear superposition of RH and temperature (T) effects[5].

Recently, research on various types of graphene oxide (GO)-based optical sensors has been reported [6, 7], especially in humidity sensing [8]. GO is a very attractive material for refractive index and humidity sensing due to its unique two-dimensional structure, which results in faster response times and improved sensitivity over alternative materials. Response of a GO-coated long period
grating-based sensor to changes in relative humidity and external refractive index was reported by Kasun P. W. Dissanayake et al.[9]. Based on the above research, it can be seen that it is meaningful to study FBG humidity sensor based on GO.

In this paper, a kind of FBG humidity sensor based on GO is proposed and experimentally demonstrated. The transmission spectrum of the sensor is changed by using self-made half-opened chamber to change the ambient humidity of the sensor. The experimental results show that there is a good linear correlation between the humidity and wavelength drift with a humidity sensitivity of 2.53 pm/% RH and a linear correlation coefficient of 0.9984. The sensor has the advantages of high sensitivity, simple fabrication and easy encapsulation. So it has potential value for humidity measurement.

2. Fabrication of the FBG humidity sensor and Principle

GO humidity sensitive film is deposited on the surface of FBG uniformly. Firstly, GO solution with a mass concentration of 2 mg/mL and a diameter of more than 500 nm is dripped onto the surface of FBG. Laser with a central wavelength of 1046 nm and a power of 50 mW is inserted into the FBG and placed for one hour. In the process of coating, part of the light energy of the laser in the FBG is converted into heat energy, which causes local temperature rise. And the solubility of GO sheet decreases, and then it deposits on the surface of FBG. The optical micrograph of FBG without GO and FBG coated with GO film is shown in figure 1 (a) and (b). The distribution of GO layer on the surface of FBG can be reflected directly from figure 1 (b). It is beneficial to select the larger sheet diameter (greater than 500 nm) to improve the hygroscopicity of GO films. It can be seen that some GO sheets are stacked under hydrogen bond during the static process. Because of the larger sheet diameter, the stacking part has less influence on the humidity sensitivity of the films.

![Figure 1](image1.png)

According to the Bragg condition of FBG, its propagation equation can be expressed as

\[ \lambda_B = 2n_{eff} \Lambda \]

Here \( \lambda_B \) is the wavelength of the reflection/transmission peak of the FBG, \( n_{eff} \) is the effective refractive index of optical fibers and \( \Lambda \) is the grating period constant. The change of ambient humidity around the sensing area will cause the change of \( n_{eff} \) or \( \Lambda \). Thus the reflection or transmission spectrum of the FBG is changed. The change of humidity can be detected by detecting the change of reflection or transmission spectrum of the FBG.

3. Experiment results and discussions

The experimental setup is shown in figure 2. The broadband amplified spontaneous emission (ASE) spectrum from an erbium-doped fiber amplifier (EDFA) with the wavelength range of about 100 nm is utilized as the broadband light source. The output spectrum of the proposed structure is measured by YOKOGAWA AQ6317C optical spectrum analyzer (OSA) with 0.02 nm resolution. The sensor head, that is the FBG coated with GO layer, is mounted and fixed within the half-opened chamber. The humidity level in the chamber is controlled by inputting humid air released from humidifier through the inlet and monitored by a calibrated commercially available hygrometer under the sensor head.
Increasing the ratio of humid air will increase the RH value and vice versa. In this experiment, the RH value is tuned into a range from 20-70%.

The ASE spectrum of EDFA and the transmission spectrum of FBG without GO coated at room humidity are shown in figure 3. The central wavelength of FBG transmission spectrum is 1550.0750 nm. The 3 dB bandwidth and the side-mode suppression ratios of the spectrum are less than 0.05 nm and more than 35 dB.

The ASE spectrum of EDFA and the transmission spectrum of FBG without GO coating at room humidity are shown in figure 3. The central wavelength of FBG transmission spectrum is 1550.0750 nm. The 3 dB bandwidth and the side-mode suppression ratios of the spectrum are less than 0.05 nm and more than 35 dB.

The measurement spectra of FBG humidity sensor under different RH conditions are shown in figure 4 (a). In order to show more clearly the variation of the central wavelength of the transmission spectra with RH, the zoom-in of the part spectra from 1549.6 nm to 1550.6 nm are shown as figure 4 (b). In the experiment, the RH changes from 20% to 70%, and the transmission spectrum of the grating coated with GO is recorded with interval of 10% RH. Lines of different colors represent different humidity. The sensitivity of experimental data is higher near ambient humidity. In low humidity (less than 20%) condition, the refractive index of the optical fiber surface changes slightly due to insufficient water molecule to permeate GO film, so the central wavelength of the transmission spectrum of the grating is almost unchanged. In high humidity (more than 70%) condition, adsorption of water molecules by GO films has tended to be saturated. Therefore, though the RH continues to rise, the refractive index of the film has hardly changed and the central wavelength of the transmission spectrum tends to be stable. It can be seen from figure 4 (b) when the humidity increases, the peak wavelength of FBG drifts toward long wavelength. And a good linear correlation between the humidity and wavelength drift is observed with a humidity sensitivity of 2.53 pm/% RH and a linear correlation coefficient of 0.9984 as shown in figure 5. The relationship between them is expressed as: 

\[ y = 2.533x - 47.47 \]
Figure 4. (a) Transmission spectra of FBG coated with GO at different relative humidity levels (b) The zoom-in of the part spectra from 1549.6 nm to 1550.6 nm

Figure 5. The relationship between relative humidity and peak wavelength shift of FBG

4. Conclusion
A novel fiber optic humidity sensor applying the GO coated on FBG as the humidity sensitive film was proposed. GO humidity sensitive film is deposited on the surface of FBG uniformly. The change of ambient humidity around the sensing area will cause the change of the central wavelength of the transmission spectrum of FBG. The broadband ASE spectrum from an EDFA with the wavelength range of about 100 nm is utilized as the broadband light source and the transmission spectrum of FBG is detected by YOKOGAWA AQ6317C OSA. The experimental results show that there is a good linear correlation between the humidity and wavelength drift with a humidity sensitivity of 2.53 pm/% RH and a linear correlation coefficient of 0.9984. So based on the promising results obtained, GO has been proved to be a very attractive sensing material for optical fibre sensors. The on-going work shows considerable promise to increase the device sensitivity by varying the RI of the GO solution, and also by experimenting with the effects of different coating thickness.

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