A simple relative humidity sensor employing optical fiber coated with lithium chloride

Abstract: A simple optical fiber relative humidity sensor was fabricated using a lithium chloride film coated on the distal end of sensing fiber. The sensing element, lithium chloride film, are sensitive to moisture and thus the humidity of the atmosphere, thereby altering its refractive index and changing the reflected light intensity of the sensing end. By monitoring the change of reflected light intensity under different RH levels, the information about RH of the environment can be obtained. A difference of up to 0.64uW of the reflected optical power is observed when RH changes from 11 to 75%. The LiCl-based sensor has a sensitivity of about 0.01uW/%RH with a slope linearity of more than 99.8%. The results demonstrate that LiCl-based optical fiber sensors are both sensitive and efficient for economical and flexible, fast response, has the potential of remote on-line monitoring humidity.

Keywords: Optical fiber; Humidity sensor; Lithium chloride; Relative humidity

1. Introduction

It is important to monitor the relative humidity (RH) of surrounding air in many territories, such as industry [1,2], weather forecasting, air conditioning, and chemical processing[3,4], agriculture [5,6], pharmacy [7] etc. Compared to electronic humidity sensor, optical fiber humidity sensors have a few distinguished advantages such as small size, lightness, easy to integration, remote monitoring, the possibility of working on flammable environments and at higher temperature and pressure ranges, and, most important, immune to electromagnetic environments. The vast majority of fiber optic humidity sensors are related to employ optical fibers coated with moisture sensing material, which coating on the optical fiber induce light intensity variation in response to ambient humidity. In order to develop optical fiber humidity sensors with excellent performances to meet different humidity monitoring requirements, different humidity sensitive materials have been tested, such as semiconducting metal oxides [8-10], block polymers [11,12] and grapheme based composites [13–15] etc. Lithium chloride (LiCl), as a humidity sensitive material, has good adsorption and desorption water molecules features such as fast response and recover time, wide response range, good linearity of the working curve, making it a unique and probably the most suitable material both in structures and properties. In recent years, silicas [16,17], metal oxides [18,19] and organic polymers [20,21] have been developed to load LiCl for fabricating optical fiber humidity sensor. But the preparation of these complexes involves complex processes which are time-consuming and laborious.

In this paper, we propose a simple method for optical fiber humidity sensor based on LiCl material. The sensing probes are easily fabricated by attaching thin LiCl film on the fiber tip. The absorption and desorption of water molecule changes the reflected light intensity of the interface of the LiCl film, which can be exploited for humidity measurement. The proposed sensor based on the LiCl films was prepared and the characteristics were systematically discussed and analyzed.

2. Sensing principle

Fig. 1 shows the experimental setup of the proposed Fresnel reflection-based optical fiber sensors for relative humidity measurement. The measuring principle is based on a two-channel Fresnel reflection technique [22]. One of two channel fibers work as sensing head, another fiber work as a reference, which is exposed to the air environment, used to eliminate the influence of light source fluctuation. In addition, the undesirable effects or the errors coming from the different losses of fibers and couplers and environment temperature can be also decreased. In this paper, the reflection light from LiCl-coated fiber interface is used to measure the surrounding humidity. For the sensing head, the refractive index of the coated LiCl film changes with the relative humidity, and its Fresnel reflection intensity will change with the surrounding humidity synchronously.

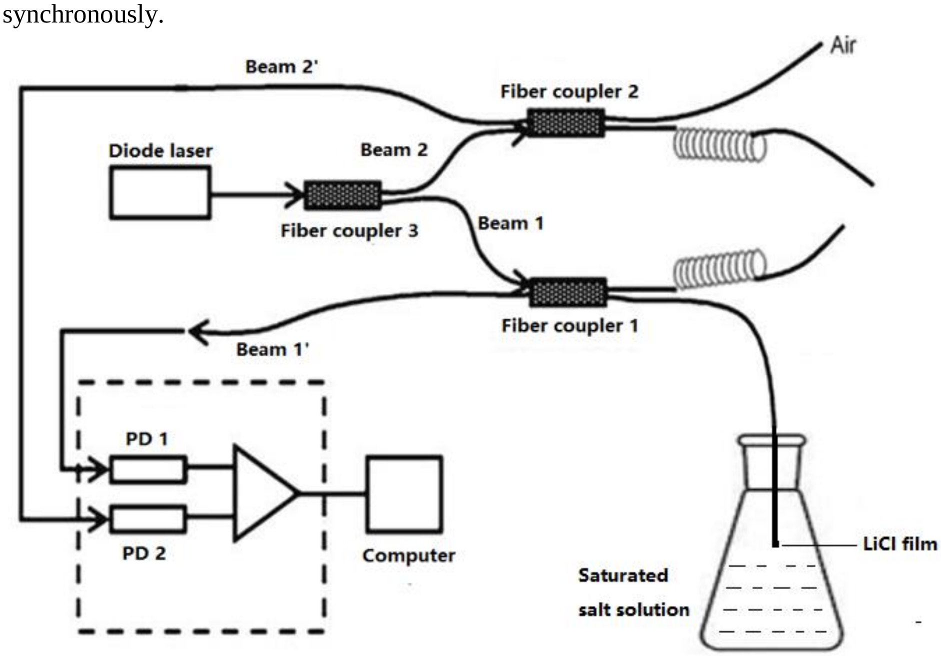

Fig. 1. Schematic diagram of measurement system.

The working principle of the fiber-optic refractive index sensor is introduced in literature [22].

The refractive index of air is 1.0003. The effective index nf of the fiber mode is 1.44961 at $\lambda = 1550$ nm.

3. Materials and methods

The distal end of the sensing fiber was first treated by deionized water and absolute ethyl alcohol in order to obtain the clean surface. The LiCl granules were mixed with deionized water to form a solution of a certain concentration (wt./wt.). Then the LiCl/water solutions were prepared for coating the sensing end as thin films through a immersion process of a solvent and subsequently the coated optical fiber was placed in an oven to be dried at 50^0C for 6 h.

To construct the sensing setup, a conical flask was used to contain saturated salt solutions, the prepared sensing region was put through a small hole into the sealed chamber, which contains an inlet to insert the sensing head. Interaction between the moisture and the LiCl film was monitored by recording the variation in output intensity of reflected light from the interface sensing film. The modulation of output intensity was displayed and recorded by the software (written by LabVIEW).

The RH atmospheres were produced by different saturated salt solutions in their equilibrium states including LiCl for 11%RH, $MgCl_2$ for 33% RH, $Mg(NO3)_2$ for 54% RH, KI for 69% RH, NaCl for 75% RH.

4. Results and discussion

In order to test the influence of LiCl solution concentration, humidity sensors based on different concentrations of LiCl solutions were fabricated. the performance of the three LiCl film obtained from 5%, 20%, 30% LiCl/water solution is compared, the results are shown in Fig. 2. It is clear from Fig. 2 that the curves show negative slope in presence of RH, the reflected light intensity of the interface decreases linearly with humidity. Overall, the sensor exhibited high linearity more than 98%. It is also found that the curve a shows the best sensitivity and linearity of 0.01uW% and 99.8% respectively, indicate that the sensor a has the high humidity sensitivity and good linearity in the RH range from 11% to 75%. In a conclusion, 5% LiCl solution is more suitable for the preparation of LiCl films. Therefore, the sensor based on the 5% LiCl solution is elected for the following measurement.

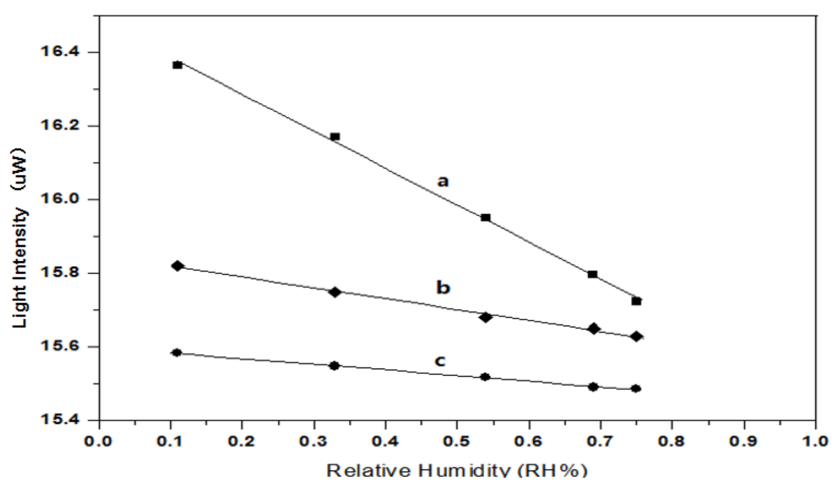

Fig.2. Output reflected light intensity against relative humidity for the LiCl humidity sensing film obtained from different LiCl concentration (a: 5% LiCl solution; b: 20% LiCl solution; c: 30% LiCl solution).

The response and recovery times are significant parameters for evaluating the performance of humidity sensors. The characteristic of the sensor based on the 5% LiCl solution is measured for 10 cycles with the RH changing from 11 to 75%. The humidity sensor was put in the atmosphere (11% RH) of the saturated LiCl solution until the reflected light intensity of the LiCl film interface became steady, then the sensing head was transferred to the atmosphere (75% RH) of the saturated NaCl solution. The continuous response and recovery curves between 11% and 75% RH are given in Fig. 3. The obtained sensors show good repeatability during continuous measurements. When the humidity was increased from 11 to 75%, the response time for our sensor was less than 5s, the RH was decreased from 75 to 11%, the recovery time was less than 7s. It can be obtained the response time is 5 s and the recovery time is less than 7s. The rapid response processes benefits from the successful coating and uniform distribution of LiCl. LiCl is extremely sensitive to changes in humidity, surface area is the main factor affecting the water molecules adsorption/desorption property of lithium chloride. During the process of adsorption/desorption, LiCl can contact with water molecules and ionize thoroughly. It is easy to reach a balance with the external environment. Therefore, the rapid response to the change of RH is contributed to the characteristic of the LiCl film.

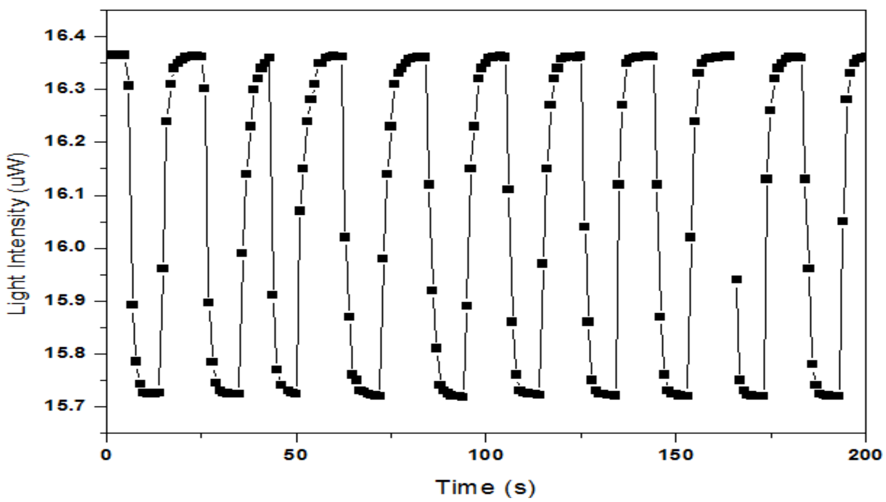

Fig.3. Continuous response and recovery curves of 5 wt% LiCl sensor between 11% and 75% RH.

To test the stability, the sensor based 5% LiCl solution was exposed in 11% RH and 75% RH atmosphere for 10 minutes. As shown in Fig. 4, there were almost no changes in the reflected light intensities, which shown a good stability of our sensors.

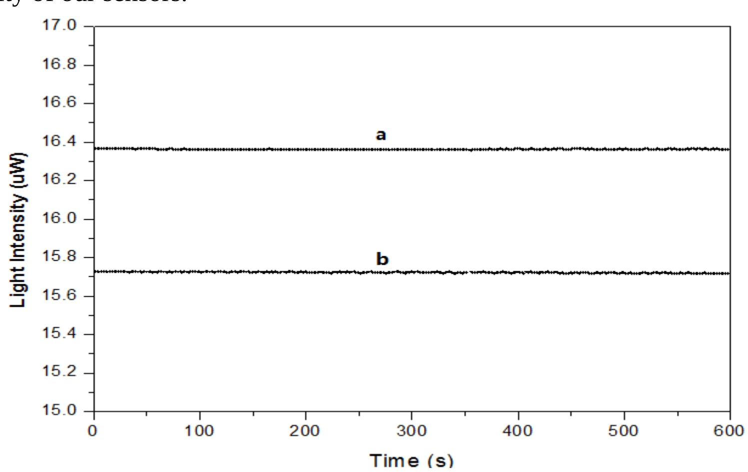

Fig.4. Stability of the sensor after exposing in 11% RH (a) and 75%RH (b) for 10 minutes (Sampling interval: 2s).

6. Conclusion

A fiber optic humidity sensor based LiCl film was proposed and demonstrated for RH sensing at room temperature. The LiCl humidity sensitive film was fabricated using a immersion method. The results indicate that the LiCl humidity sensor exhibits a sensitivity of 0.01uW/% and a slope linearity of 99.8%, shows good properties over a wide humidity range. In addition, this sensor also has the following advantages:

good reproducibility, easy to fabricate, low-cost, fast response, it could be used for remote on-line humidity monitoring.

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