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Sensitivity enhancement of FBG sensor for portlandite monitoring

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ABSTRACT

In this paper, a cladding etched fiber Bragg grating (FBG) sensor is proposed to monitor chemicals ($Ca(OH)_2$ and $Mg(OH)_2$) which produces in civil structures. Further, to enhance the sensitivity, an indium tin oxide is coated on cladding etched FBG sensor. It is observed that the indium tin oxide coated sensor is highly sensitive in terms of chemical detection and inducing wavelength shift of 12 nm and 10 nm with $Ca(OH)_2$ and $Mg(OH)_2$ respectively. On the other hand, cladding etched FBG sensor produces a wavelength shift of 8 nm and 6 nm for $Ca(OH)_2$ and $Mg(OH)_2$ respectively.

1. Introduction

Concrete is the most important artificial material used to build civil structures such as bridges, buildings, dams, tunnels etc. [1]. There are some factors that affect its properties and these factors are natural hazards, physical, chemical and biological events. Due to these factors deformations in the concrete structures are formed like cracking, corrosion, moisture and spalling [2]. Portlandite is oxide mineral that naturally occurs from calcium hydroxide ($Ca(OH)_2$) and calcium analogue of brucite ($Mg(OH)_2$). Portlandite creates a problem in concrete in terms of corrosion and spalling, so it is essential to monitor it continuously. So, it is necessary to monitor the structures continuously as lack of immediate and preventive treatments can lead to expensive repairs. Continuous Structure Health Monitoring (SHM) techniques can possibly detect the deformations at early stages so that appropriate remedial action can be taken. Currently, use of fiber optic sensors is the best technique to monitor the health of civil structures along with its various advantages such as high speed, large sensitivity, easy installation, exact measurement, light in weight, small size, passive, low attenuation, immunity to electromagnetic interference (EMI), wide bandwidth, environmental ruggedness etc. [1,2]. Uva et al. [3] used the optical fiber sensor for real-time structural monitoring and implemented it on the bridge which was recently built in the city of Bari, Italy. Regnault et al. [4] experimentally observed and quantified the reactivity of portlandite with supercritical CO_2.

Till now, various researches have been worked on portlandite carbonation with CO_2 enriched water or at higher pressure [5–8]. Unfortunately, the investigations were not based on the real-time monitoring. Moreover, the sensitivity of the proposed sensors was less. These limitations can be overcome with real-time monitoring of chemicals in concrete structures that are responsible for Portlandite using an optical sensor having high sensitivity. In this work, we have proposed a highly sensitive FBG based sensor which can sense the in real time scenario.

Introduction and motivation of an optical sensors for chemical detection is present in Section 1. The Section 2 discuss the design of optical refractive index sensor and Section 3 focuses on the results and discussion of proposed sensors, which shows the outcomes for different concentration level of chemicals to detect the portlandite. Finally, conclusion is made in Section 4.

2. Design of optical refractive index sensor

Fig. 1 shows the schematic representation design of optical refractive index sensor based on FBG. The proposed design is divided into five different steps. In first step optical fiber is proposed with an 8.2 μm and 125 μm diameter of cladding with a refractive index of 1.449 and 1.444, respectively. In the second step standard grating type, also known as uniform fiber Bragg gratings (UFBG) are introduced in the core with a constant period (grating pitch (Λ) of 535 nm). For this fiber, the phase fronts are perpendicular to the length of an optical fiber. When light is transmitted through the proposed fiber, with the help of Fresnel principle, Bragg wavelength is reflected back through the gratings and remaining light transmitted to an optical spectrum analyzer for determination of different physical and chemical measurands.

Wherein third step, cladding etched FBG; etched the cladding (61.2 μm thickness removed, radius remained cladding is 0.3 μm) almost to the fiber core. After the third step, chemical sensing techniques are divided into two parts, one is to measure these chemicals with cladding etched FBG sensor and then analyze it with an optical spectrum analyzer.

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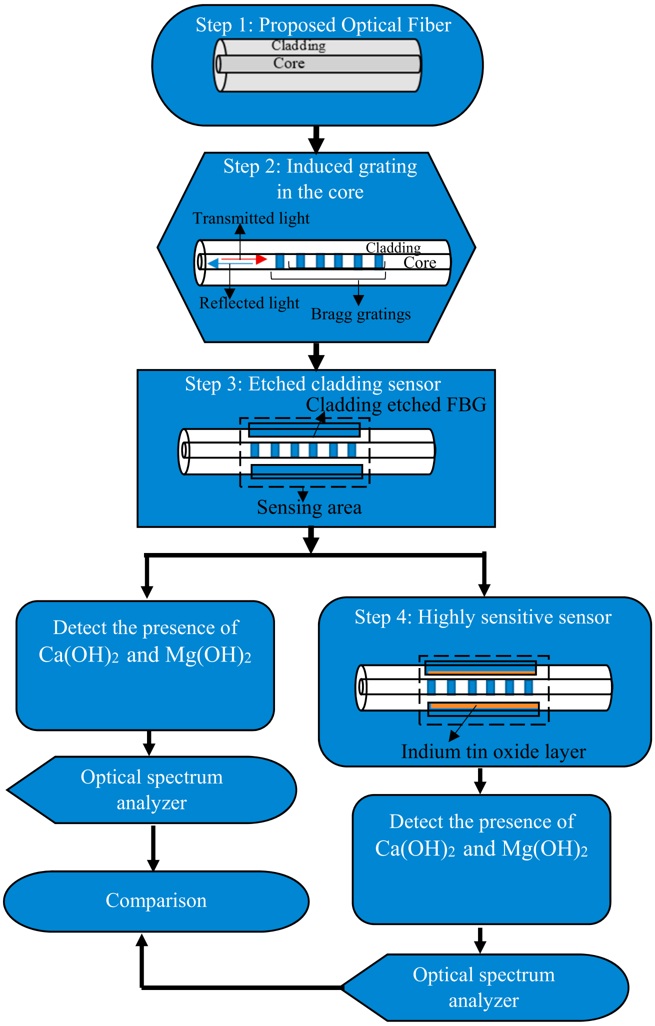

Fig. 1. Design of optical refractive index sensor based on FBG.

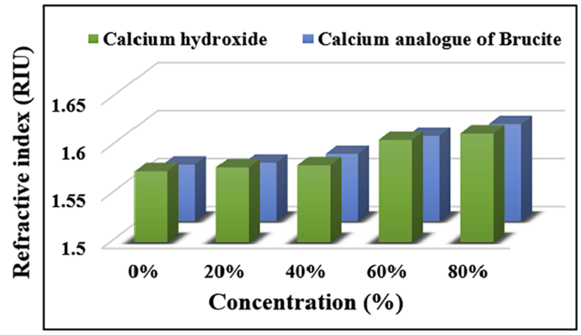

Fig. 3. Refractive indices variation at different concentrations of $Ca(OH)_2$ and $Mg(OH)_2$ [].

The second technique has first improved the sensitivity of the proposed sensor (cladding etched FBG) with a coating of ITO layer (step 4) (highly sensitive sensor) then observe the presence of measurand chemicals with the help of optical spectrum analyzer. After these steps, the results are compared at the end. Refractive index profiles of proposed sensors are shown in Fig. 2(a) and (c). Fig. 2(a) shows the refractive index profile of cladding etched FBG sensor wherein green color shows the cladding area and red color represents the core with gratings. Fig. 2(c) shows the refractive index profile of ITO coated sensor wherein green color shows the cladding area, orange color represents the core with gratings and red color represents the coated layer with ITO. Light propagation through the proposed design is shown in Fig. 2(b) and (d), from the pattern it is clearly seen that light travels symmetrically along the core.

3. Refractive indices and spectrum analysis

Fig. 3 describes the refractive indices value for both $Ca(OH)_2$ and $Mg(OH)_2$ as a function of different chemical concentration levels, which are used for further analysis. By placing the sensors under different concentration levels of chemical solutions, we obtain the changes in resonance wavelength shift which is reported in Figs. 4–9. Figs. 4 (a–c) and 5(a–c) shows the transmitted field pattern for cladding etched FBG sensor and for the highly sensitive sensor, respectively, in the presence

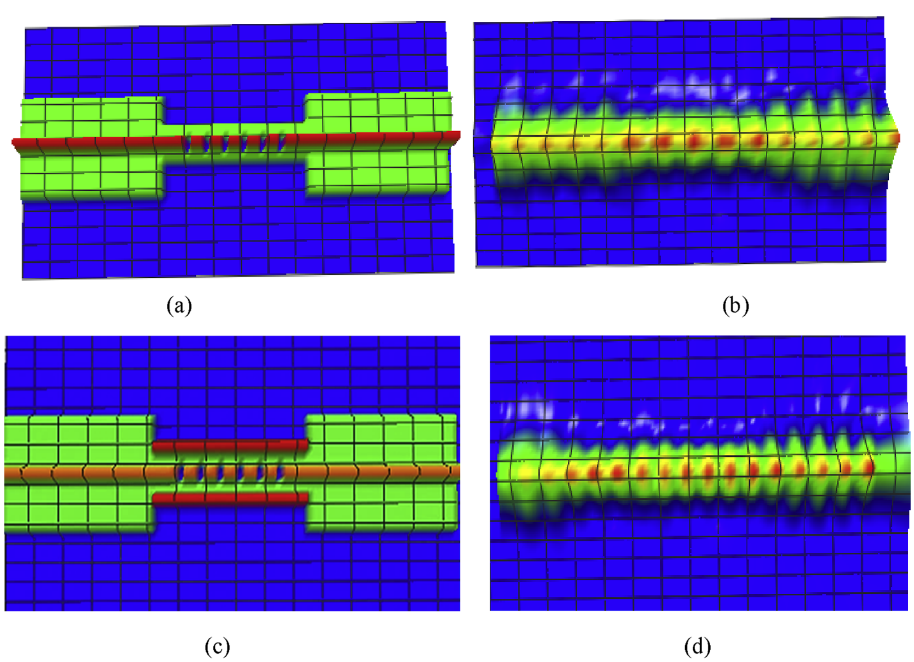

Fig. 2. (a) Refractive index profile of cladding etched sensor, (b) light propagating through the cladding etched FBG sensor, (c) refractive index profile of ITO coated sensor, (d) light propagating through ITO coated sensor.