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HF-based clad etching of fibre Bragg grating and its utilization in concentration sensing of laser dye in dye–ethanol solution

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Abstract. This paper presents a fiber Bragg grating (FBG) based sensor to study the concentration of laser dye in dye–ethanol solution. The FBG used in this experiment is indigenously developed using 255 nm UV radiations from copper vapour laser. The cladding of the FBG was partially removed using HF-based etching to make FBG sensitive to changes in the surrounding refractive index. The experimental results on the shift of the Bragg peak wavelength with HF etching and different dye concentration in ethanol are presented. The Bragg wavelength shifted from 1534.670 nm to 1534.225 nm in 30 min and from this point to 1533.97 in the next 2 min. The clad-etched Bragg peak shifted almost linearly from 1534.056 nm to 1534.162 nm as surrounding dye concentration in ethanol changes from 0 mM to 1.5 mM. It was observed that sensitivity depends on the concentration of the solution and found to be 70 pm/mM.

Keywords. Fibre; fibre Bragg grating; chemical sensor.

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1. Introduction

Various fibre-optic sensors have been proposed for physical, chemical and biological parameters in industrial processes and medical treatments [1,2]. It is well known that the fibre-optic sensors have numerous advantages over conventional sensors: immunity to electromagnetic interference, high sensitivity, fast response, remote sensing [3,4]. In the textile industry, colour matching assessment is required in textile dyeing processes. In this case, if the colour produced is different from the colour specified in the dyeing recipe, the manufactured goods have to be reworked or rejected [5]. Conventional methods for colour determination employ colorimeters or spectrophotometers to estimate the colour from the dyed materials [6]. It has been shown that FBG can also be used as chemical sensor by removing partially cladding region around the grating to make the FBG

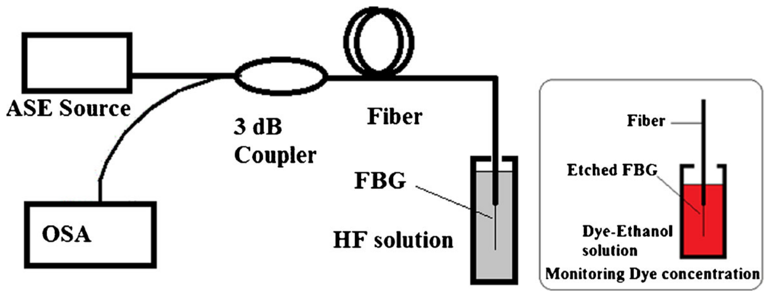

Figure 1. Set-up for FBG clad etching/dye concentration monitoring.

sensitive to changes in the surrounding refractive index [7,8]. Due to the etching of the cladding region, the effective refractive index of the fibre core is significantly affected by the refractive index of the external medium [9]. This results in the change of Bragg peak wavelength due to the changes in the surrounding chemical [10]. Monitoring of the concentration of a dye Rh 6G in ethanol solution, based on HF-based etched fibre Bragg grating (FBG) is presented in this paper. The temperature of the dye solution was maintained at 25°C in order to avoid wavelength shifts due to variation in temperature [10].

2. Experimental arrangement

The UV beam (255 nm) was generated from the second harmonic of the copper vapour laser (CVL). The CVL beam (510 nm) was focussed into the BBO crystal by a cylindrical lens of focal length 6 cm. The second harmonic and fundamental beams were re-collimated by another cylindrical lens and then separated by a quartz prism. The output power of 400–500 mW was obtained. The UV beam was magnified to around 10 mm using telescopic combination of lenses. This UV beam was focussed by a cylindrical lens (focal length = 50 mm) on the fibre core through a phase mask (period $\sim$ 1060 nm) [11]. The FBG of different reflectivity was written by controlling the exposure time. The experimental set-up for HF-based etching process and the dye concentration is shown in figure 1. It comprises a broadband ASE source (1525–1600 nm) as the light source, a directional 3 dB coupler to collect the reflected spectrum from the sensor head and an optical spectrum analyser (OSA).

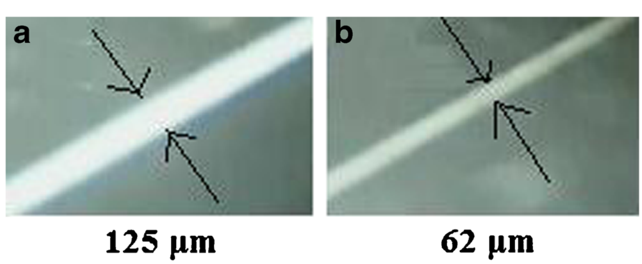

Figure 2. Microscopic view of FBG cladding (**a**) before etching and (**b**) after etching.

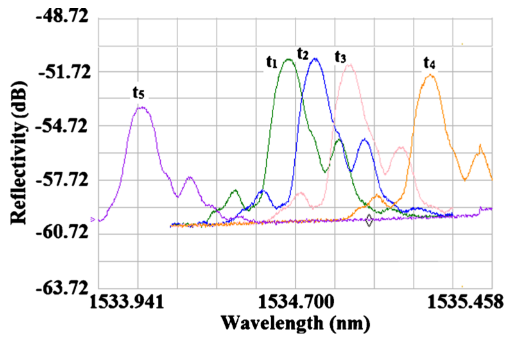

Figure 3. OSA traces showing shift in Bragg wavelength with etching time ($t_1 < t_2 < t_3 < t_4 < t_5$).

3. Results and discussion

3.1 *Etching of cladding using HF solution*

The exposed region where the gratings are formed is etched with 40% HF. Room temperature was maintained at 25°C. As the optical fibre without coating layer is immersed in an etching liquid, the cladding is etched gradually and the cladding radius decreases. Figure 2 shows the microscopic view of the FBG cladding (a) before and (b) after etching. Due to HF etching of around 30 min, the FBG cladding diameter reduced from 125 μm to 62 μm. The change in the Bragg wavelength associated with the chemical etching is given by [12]

$$\delta\lambda_B = 2\Lambda\eta_{po}(n_{cl} - n_{sur}) , \tag{1}$$

where Λ is the grating period, η_{po} is the fraction of the total power of the unperturbed mode that flows in the etched region, n_{cl} is the refractive index of the cladding and n_{sur} is the refractive index of the surrounding medium. During etching the Bragg wavelength of

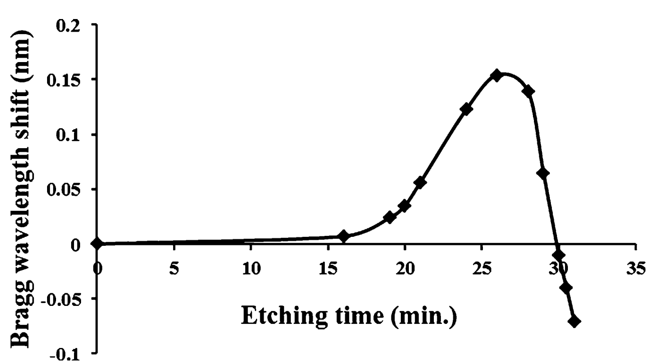

Figure 4. Change in Bragg wavelength as a function of etching time.

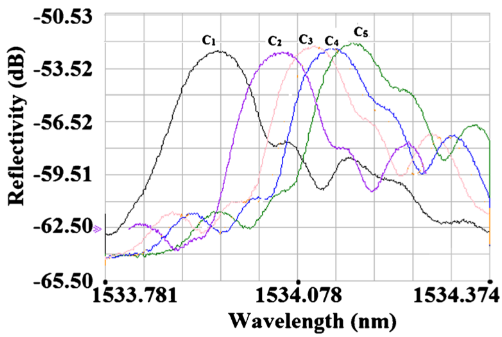

Figure 5. OSA traces showing change in Bragg wavelength for different dye concentrations (C_1 – Air, C_2 – 0.0 mM, C_3 – 0.5 mM, C_4 – 1.0 mM, C_5 – 1.5 mM).

the grating was monitored as a function of time. Figure 3 shows the variation of Bragg peak wavelength (traces) with etching time. The Bragg wavelength was shifted from 1534.670 nm to 1534.225 nm in 30 min and from this point to 1533.97 in the next 2 min. Wavelength shift with respect to the initial Bragg wavelength measured during etching is shown in figure 4. It is clear that Bragg wavelength increases slowly with etching time but after 30 min it decreased rapidly. This is the point where the clad is removed almost 50% of the initial clad diameter.

3.2 *Dye concentration monitoring using etched FBG*

Figure 5 shows the reflection spectra of FBG for different concentrations of the dye solution. Figure 6 shows the change in the Bragg wavelength for different dye concentrations. The Bragg wavelength changes from 1533.96 nm to 1534.056 nm as the surrounding medium is changed from air to ethanol. The wavelength further changes from 1534.056 nm to 1534.162 nm as the surrounding dye concentration in ethanol changes from 0.0 mM to 1.5 mM. The sensitivity of the chemical sensor comes to around 70 pm/mM. It is also clear from figure 6 that there is a good linear relationship between the dye concentration in ethanol and the Bragg wavelength shift.

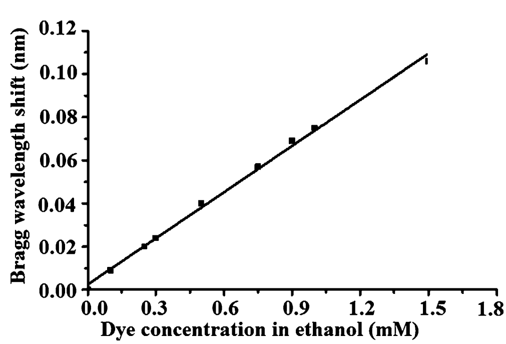

Figure 6. Change in Bragg wavelength as a function of dye concentration.

4. Conclusions

A FBG-based sensor to study the concentration of laser dye in dye–ethanol solution is presented. The cladding of the FBG was partially removed using HF-based etching to make FBG sensitive to changes in the surrounding refractive index. The experimental results on the shift of the Bragg peak wavelength with HF etching and different dye concentrations in ethanol are presented. The Bragg wavelength shifted from 1534.670 nm to 1534.225 nm in 30 min and from this point to 1533.97 within 2 min. The Bragg peak shifts from 1534.056 nm to 1534.162 nm as the surrounding dye concentration in ethanol changes from 0 mM to 1.5 mM. The sensitivity of the chemical sensor is 70 pm/mM. The sensitivity of the sensor can be further enhanced by increasing the resolution of the reading equipment and precisely etching the FBG to lower cladding diameter. The etched FBG can also be utilized in a variety of sensing applications.

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