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The Study of Effects of Hydrogen Loading Time to the Fluctuation of FBG Wavelength

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***Abstract*—This paper studies effects of hydrogen loading time for four conditions, which control hydrogen loading pressure at 13 MPa to the fluctuation of FBG wavelength at final optical inspection process. Hydrogen loading technique is a major technique to enhance photosensitivity and refractive index of optic fiber. FBG reflective target at 9% of writing process leads to a small refractive index change and a small distribution of UV exposure time affect to the high stability of FBG wavelength. Therefore, the fluctuation of FBG wavelength at final optical inspection process was the a similar manner for four hydrogen loading times conditions.**

***Keywords:* Fiber Bragg Grating, Hydrogen loading, Photosensitivity, Refractive index, and Fiber optic.**

I. INTRODUCTION

Recently, optical communication technology has been developed to enable communication between people in globalization edge. One important device that is implemented to improve the performance of optical communication is Fiber Bragg Grating (FBG). The FBG is used in several applications such as in fiber laser, optical amplifiers, fiber sensing, and Dispersion compensator [1]. The FBG is periodically changed corresponding to the refractive index of fiber core through the ultraviolet radiation process. The ability to change the refractive index with radiation of the UV light is referred to photosensitivity.

Several studies have been made in terms of the UV photosensitivity, including, for example, the color center model and photoelastic model [2]. These theories are relatively complicated. One major technique to enhance photosensitivity in fiber core is a hydrogen loading technique.

The fiber in hydrogen loading process is soaked with hydrogen gas in the chamber at room temperature. Hydrogen molecule penetrates into fiber glass network and makes a physical reaction in fiber core. This reaction affects to refractive index of fiber core and photosensitivity increase.

Exposing UV radiation to hydrogen loading fiber lead to dissociation of molecule, resulting in the formation of Si-OH and Ge-OH bonds. Based on the formation of Si-OH and Ge-OH bonds, there is formation of Ge oxygen-deficient centers [2,3]. However, the FBG wavelength shifts to shorter wavelength during fabrication process caused by the diffusion of hydrogen [4]. Such an effect leads to the required wavelength at writing process, which needs to include the wavelength shift from hydrogen diffusion. Therefore, the wavelength shift is an important factor for FBG fabrication.

The wavelength shift quantity mainly depends on hydrogen concentration in a fiber core. According to gas diffusion equation (1) [5] , the factors that affect to hydrogen concentration at hydrogen loading process are hydrogen loading pressure, hydrogen loading temperature, and hydrogen loading time. Hydrogen loading temperature and hydrogen loading pressure are controlled from the chamber designs while hydrogen loading time is an important to productivity of production in term of fabrication.

In this paper, the effects of wavelength shift at different cases of hydrogen loading time will be studied in terms of wavelength fluctuation at final optical inspection process. In

the experiment processes, hydrogen loading time will be varied at 48, 72, 120, and 192 hours hydrogen loading pressure will be controlled at 13 MPa. under room temperature.

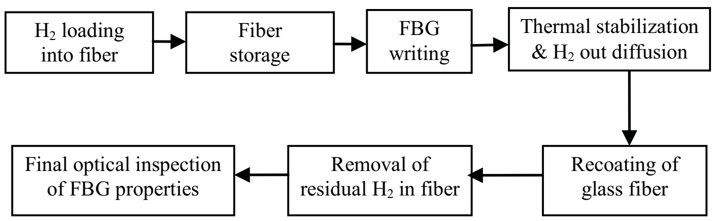

Fig.1 FBG fabrication processes flow

II. EXPERIMENTS

A. Hydrogen loading process, Hydrogen absorption loss at wavelength 1.24 µm.measurement and FBG fabrication

In this experiment, Hydrogen gas was loaded into a single-mode optical fiber (Corning HI1060) at 13 MPa and room temperature for 48, 72,120 and 192 hours measure hydrogen absorption loss which observes a minimum value at 1.24 µm.

The experiment starts with writing the grating on this study was performed using solid state laser at 266 nm and phase mask technique. Laser power was 0.398 watt. Laser power expose to fiber glass was 0.16 watt. The tension control was set at 150 gf. Reflectivity target for all test conditions were controlled at 9%. Figure 2 shows Optic configuration at writing process.

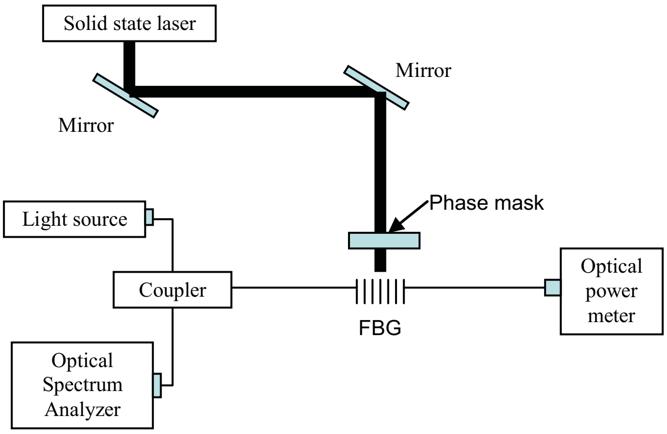

Fig.2 Optic configuration at writing process

Grating was subsequently proceeded into thermal stabilization process. This process was heat grating at high temperature. Then, grating was prevented from failures by coating UV resin at grating area, which is called a recoating process. All hydrogen of fiber length was removed by input fiber in the oven. Lastly, all important FBG parameter such as wavelength, reflectivity, and bandwidth were measured at final optical inspection process. All of these experiments were shown in Fig.1

III. RESULTS AND DISCUSSIONS

In this study, hydrogen concentrations in fiber core were evaluated by three methods, involving the hydrogen absorption loss at wavelength 1.24 µm, wavelength shift, and UV exposure time method. FBG wavelengths at final optical inspection process were reported in term of fluctuation.

A. Loss-increase spectrum due to molecular hydrogen at wavelength 1.24 µm.

Hydrogen absorption loss technique can be used for evaluating hydrogen concentration in fiber core due to the spectrum of loss increase of hydrogen molecule at 1.24 µm. [6].

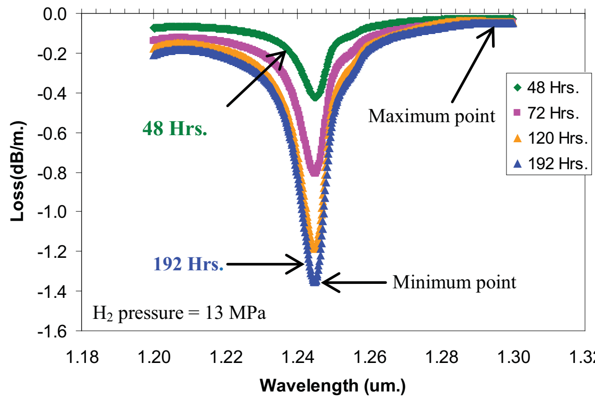

Fig.3 Hydrogen absorption loss peak at 1.24 µm. at hydrogen loading time 48, 72,120, and 192 hour

Figure 3 shows hydrogen absorption loss peak at 1.24 µm. at hydrogen loading time 48, 72, 120, and 192 hours. As seen in Fig. 3, there is a minimum value at 1.24 µm. due to molecular-hydrogen vibration and O-Si-O vibration in silica. Hydrogen absorption loss quantity was calculated from a different of loss at minimum point and loss from maximum point.

The result of hydrogen absorption loss shows that hydrogen loss increases when hydrogen loading time is long, indicating that the long hydrogen loading time affect to high concentration of hydrogen molecule in fiber core. However, hydrogen absorption loss quantity at hydrogen loading time 192 and 120 hours were not different when compare with the other hydrogen loading condition. This results reveals the quantity of hydrogen in fiber core of that both hydrogen loading time were not different.

B. FBG wavelength shift cause hydrogen out diffuse.

The wavelength was shifted during fabrication process due to hydrogen diffusion. Fabrication process, which affects to the shift on wavelength, is FBG thermal stabilization and removal residual hydrogen process.

Figure 4 shows the plots of H_2 loading time (Hr.) versus wavelength blue-shift (nm).

It can be seen in Fig. 4 that the solid points is referred the wavelength shift, which estimate from experimental data were obtained from the difference between FBG wavelength at writing process and FBG wavelength at final optical inspection process. The dash lines in this figure is calculated values obtained through equation (1)

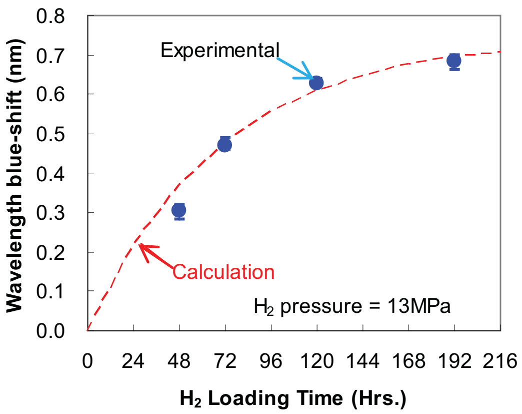

Fig.4 shows the plots of H_2 loading time (Hr.) versus wavelength blue-shift (nm). of target FBG reflectivity at 9 % at hydrogen loading time 48,72,120, and 192 hours.

Gas diffusion equation as follows;

$$C = C_{sat}\left[1 - \exp(-\lambda_i^2 D_H t / b^2)\right] \quad (1)$$

Where C is the hydrogen concentration at the fiber-core c enter, C_{sat} is the saturated value of C, λ is the i^{th} root, which depends on the zeroth order Bussel function, D_H is diffusivity of hydrogen into silica, t is hydrogen loading time, and b is the fiber radius [5]. Based on gas diffusion equation (1), hydrogen concentration is proportional to hydrogen loading time. Therefore, hydrogen loading time is long, which affects to the increase in FBG wavelength shift. However, wavelength shift of the last hydrogen loading condition was a few higher than hydrogen loading condition at 120 hours. This mean, The saturation of hydrogen gas diffusion at hydrogen loading pressure 13 MPa under room temperature is around 192 hours.

C. UV exposure time due to photosensivity effect.

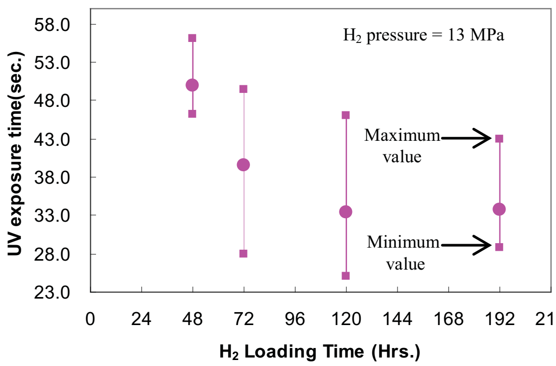

Fig.5 UV exposure time of target FBG reflectivity at 9 % at hydrogen loading time 48,72,120, and 192 hours.

Reflectivity target was controlled during writing process at 9%. Laser power radiates to fiber core is 0.16 watts. These two conditions were controlled for all writing test. Figure 5 shows the graph of UV exposure time at H_2 loading pressure at 13 MPa. The graph shows The UV exposure time was long when hydrogen loading time was short. The results can be described by photosensitivity effects. The radiation of UV to a fiber core leads to a dissociation of Si-O-Ge site, and therefore the hydrogen molecule can react to that site.

Based on such phenomena, there are formations of Si-OH and Ge-OH bonds, which can be called Ge oxygen-deficient centers. This formation affects to a refractive index change, and therefore hydrogen loading time is long, leading to high refractive index change. UV exposure time of hydrogen loading condition 120 and 192 hours was in a similar manner. This results reveals the hydrogen concentration of the last two loading condition was a similar.

The result of three methods, which use for evaluation the hydrogen concentration in fiber core were similar trend. Hydrogen loading time is proportional to hydrogen concentration in fiber core however hydrogen concentration in fiber core will be saturated at one value of hydrogen loading time.

D. Fluctuation of FBG wavelength shift, FBG wavelength at writing and final optical inspection process

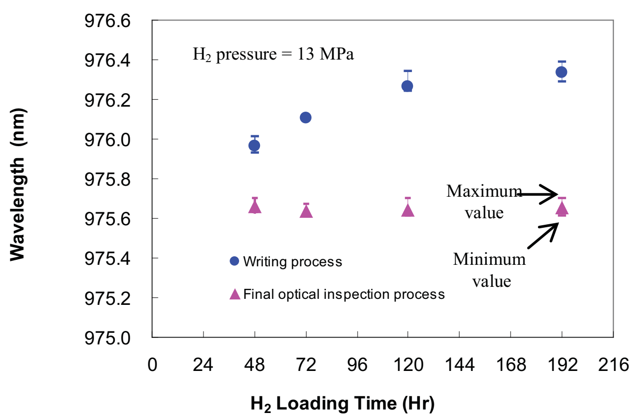

Fig.6 The average FBG wavelength at writing and final optical inspection processes of target FBG reflectivity at 9 % at hydrogen loading time 48,72,120, and 192 hours.

Figure 6 shows the average FBG wavelength at writing, which refer from the circle dot and final optical inspection process, which refer from the triangle dot. The result from Fig. 6 indicates that the FBG wavelength at writing process was long when hydrogen loading time was long. This result reveals the relationship of wavelength and refractive index as follow;

$$\lambda_{FBG} = 2 n_{eff} \Lambda_{FBG} \quad (2)$$

where λ_{FBG} is FBG wavelength, n_{eff} is effective index of refractive index of fiber core, and Λ_{FBG} is FBG pitch. $\Lambda_{\text{phase mask}}$ is a half of Λ_{FBG}. Hydrogen loading time is long, affect to high hydrogen concentration in fiber core.

Therefore, refractive index of fiber core high change from penetration of hydrogen molecule

In contrast, The FBG wavelength at final optical inspection process was in a similar manner in all hydrogen loading conditions, causing by hydrogen molecule diffusion from FBG, which leads to refractive index of fiber core reduction.

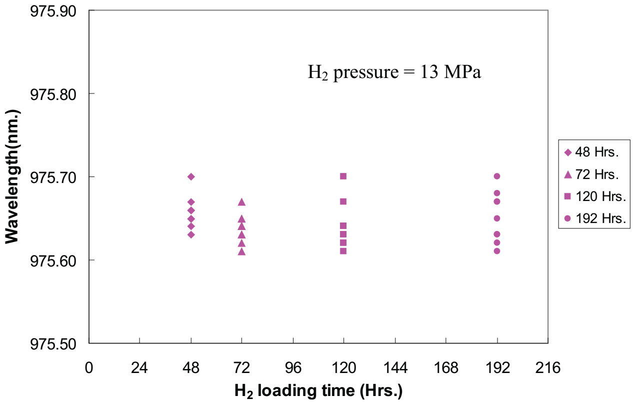

Fig.7 The average FBG wavelength at final optical inspection process of of target FBG reflectivity at 9 % at hydrogen loading time 48,72,120, and 192 hours.

The fluctuation of FBG wavelengths at final optical inspection processes was the a similar manner for four hydrogen loading times conditions as shown in Fig. 7 The two reasons to describe such result due to FBG reflectivity writing target at 9% and The few distribution of UV exposure time of four hydrogen loading conditions. The first reason due to FBG reflectivity writing target at 9%. This affects to a small changing of refractive index change. The refractive index change of FBG was shown in Fig. 8

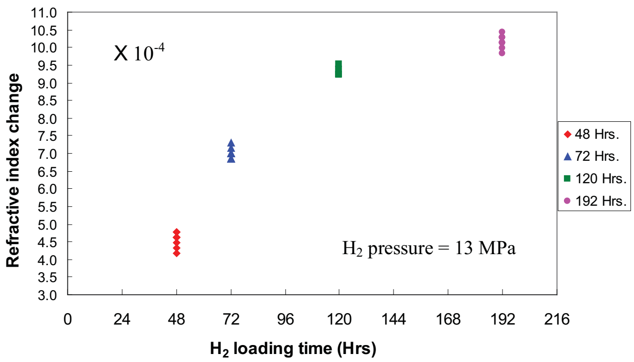

Fig. 8 The FBG refractive index change of target FBG reflectivity at 9 % at hydrogen loading time 48,72,120, and 192 hours.

The relation of FBG wavelength for both process and FBG wavelength shift as shown as follow;

$$\lambda_A = \lambda_B - \lambda_C \qquad (3)$$

$$2n_A\Lambda_{FBG} = 2n_B\Lambda_{FBG} - 2n_C\Lambda_{FBG} \qquad (4)$$

Where λ_A is FBG wavelength at final optical inspection process, λ_B is required FBG wavelength, λ_C is FBG wavelength shift from hydrogen diffusion, n_A is a refractive index change, n_B is a refractive index change after finished writing process, and n_C is a refractive index change due to hydrogen molecule. Refractive index change at final optical inspection process (n_A), which can calculate from equation (4). The result is shown in fig8. The result show, that FBG reflectivity at 9% of writing process requires a small change of refractive index. Refractive index was changed around 4.17×10^{-4} to 10.42×10^{-4} therefore FBG wavelength at final optical inspection process become a similar manner in all hydrogen loading conditions. The second reason that the small distribution of UV exposure time of four hydrogen loading conditions as shown in fig. 9

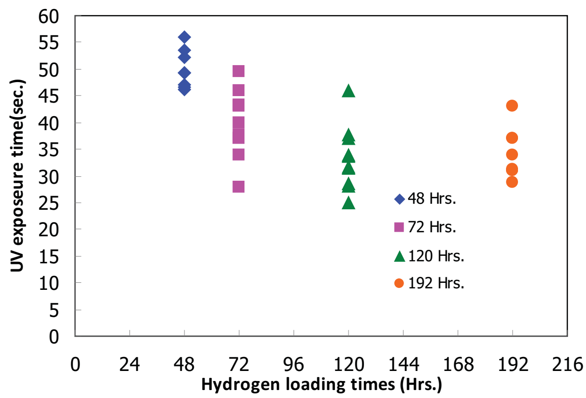

Fig. 9 The UV exposure time distribution UV exposure time of target FBG reflectivity at 9 % at hydrogen loading time 48,72,120, and 192 hours.

It can be seen in Fig. 9 that the distribution of UV exposure time was the similar manner for four hydrogen loading times conditions therefore FBG wavelength at writing process becomes stable. This phenomenon affect to small distribution of FBG wavelength at final optical process.

IV. CONCLUSIONS

The hydrogen adsorption loss, the FBG wavelength shift, and the UV exposure time technique can be used for evaluating hydrogen concentration in fiber core at four hydrogen loading time conditions. The hydrogen concentration in the fiber core increases when hydrogen loading time is long, which is corresponding to gas diffusion equation. The saturation of hydrogen gas diffusion at hydrogen loading pressure 13 MPa under room temperature is around 192 hours. The four conditions of hydrogen loading time at hydrogen loading pressure 13 MPa and room temperature has no significant impact on a fluctuation of

FBG wavelength 974-976 nm range at writing, and final optical inspection process due to a small of refractive index change at reflectivity 9 b% and the a small distribution of UV exposure time.

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