Letter to the Editor

GROWTH CHARACTERISTICS OF FIBER BRAGG GRATINGS FABRICATED IN HIGH GERMANIA BORON CO-DOPED FIBER

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Abstract: This paper reports and provides an explanation for the growth characteristics of fibre Bragg gratings (FBGs) fabricated in high germania boron co-doped optical fiber by using a continuous wave (CW) doubled frequency Argon ion laser as an UV light source. The grating reflectivity and Bragg wavelength shift as a function of exposure time are measured. The index modulation time is observed to have a good fit to a power law of the form $\Delta n = Ct^b$ (t is the time, C and b are constants), whereas the exponent b of 0.3 is obtained for the FBGs. The UV laser light also causes a shift of the resonant wavelength with fabrication time. The fastest wavelength shift is shown to be 0.53 nm after 524 seconds exposure.

Keywords: *Fiber Bragg grating, Argon ion laser, Phase mask method, Growth characteristics.*

1. INTRODUCTION

Fiber Bragg gratings have a wide range of applications in optical communication, in optical sensors or in laser areas [1-2]. They are commonly fabricated in germanosilicate fiber by exposure to pulsed or CW UV light in the wavelength band of 240 to 260 nm. The existence of a germanium defect absorption band near 240 nm suggests that index changes caused by UV light result from one-photon absorption by germanium-related defect [3]. One of the techniques commonly used to inscribe Bragg gratings in the core of optical fibers utilizes a phase mask to spatially modulate and diffract the UV beam to form an interference pattern. The interference pattern induces a refractive index modulation in the core of the photosensitive fiber which is placed directly behind the phase mask. The phase mask technique is gaining recognition interferometric and point by point writing due to its simplicity and reduced mechanical sensitivity. In this paper, the growth characteristic of FBG’s inscribed with a 244 nm CW frequency doubled Argon ion laser in high germania boron co-doped optical fiber is investigated.

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2. EXPERIMENT AND DISCUSSION

In the experiments, FBG's with a Bragg wavelength of 1553.3 nm were written in high germania boron co-doped optical fiber by the contact printing method. The fiber was exposed to a 244 nm CW UV laser with a ex-shutter power of 80 mW through a phase mask. A broadband light source from a fiber amplifier and an optical spectrum analyzer (OSA) were used to monitor transmission spectra of FBG's during UV inscription. The growths of the reflectivity of the FBGs with time are plotted in Fig. 1. It can be seen that the reflectivity grew rapidly during the first few minutes before slowly reaching the maximum value.

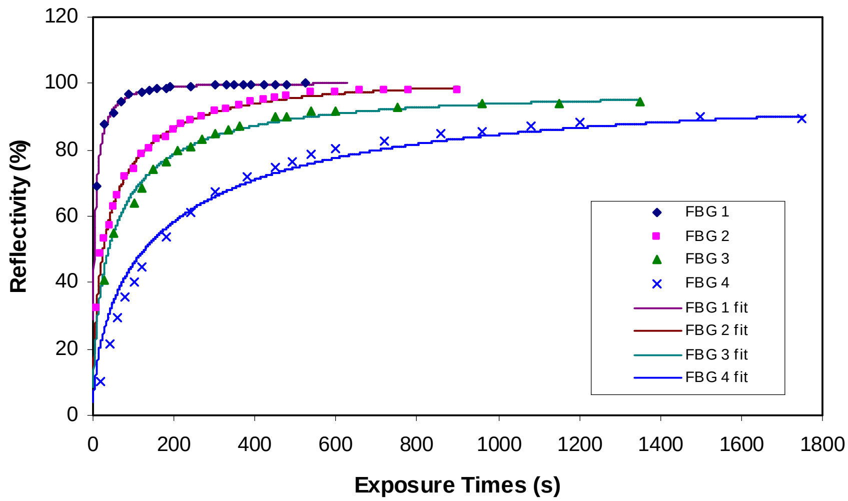

Fig. 1: The FBGs reflectivity as a function of exposure time. The reflectivity growth with time is fit using equation (2) , which is explained in the text.

The growth in reflectivity is explained in terms of an effect called "photosensitivity" which enables an index grating to be written. The photosensitivity of the optical fiber is due to a defect formation inside the Ge-doped core of silica fiber [4]. The presence of Ge atoms leads to formation of oxygen-deficient bonds (such as Si-Ge, Si-Si, and Ge-Ge), which acts as defects in the silica matrix. The most common defect is the so-called GeE' defect. It forms a defect band with an energy gap of about 5 eV (energy required to break the bond). Single photon absorption of 244 nm radiation from a frequency doubled Argon ion laser breaks this defect bonds, and the released electrons are trapped at hole-defect sites to form color centers such as Ge(1) and Ge(2). Resulting changes in the absorption spectrum are accompanied by a corresponding index change through the Kramers-Kronig relation [5]. Since index changes occur only in the regions of fiber core where the UV light is absorbed, a periodic intensity pattern is transformed into an index grating.

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Gilbert *et. al.* [3] explained a simple model of grating growth arising from the depletion of a homogeneously broadened defect population by one-photon absorption. That model predicts an exponential growth of the index to a maximum value corresponding to the complete depletion of the defects. The dependence of Δn on the time and intensity is given by

$$\Delta n = \Delta n_{max} \left[1-\exp(-AIt)\right] \tag{1}$$

where Δn_{max} is the index change that would be produced if the defect population were fully depleted, t is the UV exposure time, I is the intensity of the UV light, $A = \sigma/h\upsilon$, and σ is absorption cross section and $h\upsilon$ is the energy of a 244 nm photon. This equation assumes that the grating is in the early stages of growth. For exposure times long enough to saturate the index change, however, the reflectance is expected to reach a maximum and then decrease to zero as the defects in the low intensity regions are depleted. However, it is observed that the dependence of index modulation on time and intensity does not agree with the predictions of the model.
The reflectivity R of the fabricated FBG is given by [4]

$$R = \tanh^2 \left[(\eta \pi L \Delta n)/\lambda\right], \tag{2}$$

where η is the fraction of the single mode intensity contained in the core, L is the grating length and λ is the Bragg wavelength. The solid curves in Fig. 1 are obtained by fitting Δn to a power law of the form $\Delta n = Ct^b$, and inserting this dependence into Eq. 2. The fit given by the power law is very good, whereas the exponent b is evaluated as 0.3 for the FBGs. The power law dependence of Δn is produced by an inhomogeneous broadening of the defect population.
Although the phase mask limits the wavelength that can be reflected in the fiber, however, there are effects of the UV laser light that causes a shift of the resonance wavelength with fabrication time. Fig. 2 shows the change of Bragg reflection wavelength with fabrication time, which increases in tandem with Bragg reflection strength for the fabricated FBGs. The FBG 1 shows the fastest wavelength shift. Its wavelength is shifted roughly by 0.53 nm after 524 seconds exposure. We assume that the shift is mainly due to a variation of the core index of the optical fiber averaged over the irradiated region that arise from the un-modulated component of the UV induced index change. Another mechanism that could explain a grating wavelength shift is the possibility of residual curvature of the UV laser wavefront impinging on the phase mask which causes a slight increase of the grating period from one edge of the grating to the other. This causes the grating wavelength to shift as the grating grows with line. Because the intensity and the visibility of the interference pattern decrease when the interference order increases [6], a possible saturation and/or threshold of the writing may lead not only to an asymmetry and to a broadening of the spectral shape but also to a positive shift in the resonance wavelength of the grating as the fabrication time is increased.

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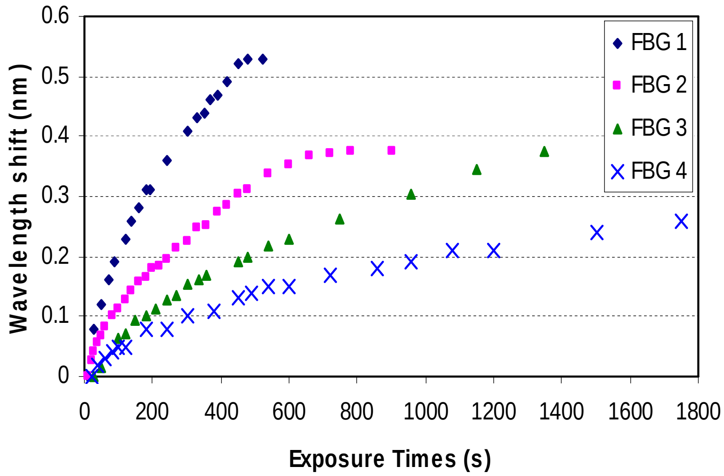

Fig. 2: Bragg wavelength shift with time. There are many factors influencing the wavelength shift and therefore was not fit with theoretical calculation.

3. CONCLUSIONS

This work has shown that high reflectivity FBG can be produced with the frequency doubled Argon ion laser that is considerably less expensive than the pulsed UV systems. An exponent b of 0.3 for the dependence of index modulation on time ($\Delta n = Ct^b$) is obtained and the index modulation is produced by an inhomogeneous broadening of the defect population. The positive shift in Bragg resonant wavelength is observed as the fabrication time is increased.

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