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Effect of irradiation time on refractive index and reflectivity during growth of fiber Bragg grating

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To measure the induced refractive index and reflectivity of fiber Bragg grating, various samples of FBGs with different experimental conditions were fabricated by phase mask technique using KrF excimer laser operating at 248nm. In this study, only two samples are reported here. These samples were written by varying the UV exposure time and at constant pulse energy of 70 mJ (sample I) and 30 mJ (sample II) respectively. The induced refractive index and reflectivity of two samples were monitored during the growth of fiber gratings at different value of UV exposure time. The maximum refractive index modulations for sample I & II are 5.109 x 10^{-5} and 1.77 x 10^{-4} respectively. The reflectivity for sample I is 69% at Bragg wavelength 1551.3nm and sample II is 54% at Bragg wavelength 1552.2nm. The increasing of reflectivity of fiber grating with more UV exposure time results the more microstructural changes occur within the lattice of the photosensitive core and the more the residual axial stress builds up within the cross section of the fiber. It means that the induced index of modulation was increased with the increasing of UV exposure time. It is also inferred that the reflectivity increases gradually with the rise of UV exposure time and then saturates.

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1. Introduction

The basic parameter controlling the behavior of the resulting fiber grating is the magnitude of an induced refractive index change in the fiber core after it has been irradiated [1]. The induced fiber core index of refractive change can be easily altered by changing the magnitude, direction and/or exposure time of the incident UV laser beam on the fiber core [2]. It is a well-known fact that UV exposure increases the refractive index of the glass, but the mechanism for the index change still not fully understood. Several causes for the index change have been proposed, including colour center formation, dipole, and stress-relief model [3]. The colour center model was suggested due to the observation of increased absorption in the deep UV region when glass was irradiated UV light. The Kramer-Kronig relationship is used to explain the index change, and is given by [4].

$$\Delta n_{eff}(\lambda) = \frac{1}{2\pi^2} P \int_0^{\infty} \frac{\Delta\alpha_{eff}(\lambda)}{1-(\lambda/\lambda')^2} d\lambda \tag{1}$$

Where P is the principal part of the integral, λ is the wavelength, and $\Delta\alpha(\lambda)$ is the effective change in the absorption coefficient of the defect, given by

$$\Delta\alpha_{eff}(\lambda) = \left(1/L \int_0^L \Delta\alpha(\lambda, z) dz\right) \tag{2}$$

where L is the sample thickness. This takes into account the fact that the bleaching beam is strongly attenuated as it passed through the sample, and the bleaching does not occur uniformly with increasing depth. $\Delta\alpha_{eff}(\lambda)$ may be modeled as a Gaussian distribution. Equation (1) may be used to calculate the index change that is induced by bleaching of the absorption bands. The boundaries are set to λ_1 and λ_2, the limits of the spectral range within which absorption changes take place and λ is the wavelength for which the refractive index is calculated.

Bragg gratings have periodic index structures in the core of the optical fiber. During irradiation, a refractive index modulation (index grating) is formed with the same grating period, Λ as the writing interference pattern [5]. A small amount of incident light is reflected at each periodic refractive index change. The entire reflected light waves are combined into one large reflection at a particular wavelength when the strongest mode coupling occurs. This is referred to as the Bragg condition, and the wavelength at which this reflection occurs is called the Bragg wavelength. Only those wavelengths that satisfy the Bragg condition are affected and strongly reflected. The reflectivity of the input light reaches a peak at the Bragg wavelength. The maximum reflectivity can be calculated by measuring the transmission dip T_d or the peak of the reflected signal R_p below the transmitted signal in dBs. The translation from the measured dip/peak to the reflectivity is

$$\Re = \left(1 - 10^{\frac{-T_d}{10}}\right) \quad \text{or} \quad \Re = \left(1 - 10^{\frac{-Rp}{10}}\right) \tag{3}$$

Where T_d is dip in the transmission spectra and R_p is the reflection peak below maximum transmission.

2. Materials and Methodology

The schematic experimental setup to monitor the growth of fiber grating is shown in Figure 1(a). The UV light that passes through the cylindrical lens was focused linearly onto the fiber core. With fabrication of each subsequent grating the time was recorded at the same point with stopwatch. An optical spectrum analyzer monitors the growth of the grating in terms of the center wavelength and its reflectivity. Light from the tunable laser source (TLS) is launched into the core at one end and is monitored with optical spectrum analyzer (OSA) at other end. The writing process was stopped when the desired characteristics of the grating were achieved. Obviously, grating's period is related to the mask's period directly. The period on FBG is the half of phase mask [6].

$$\Lambda_g = \frac{\lambda_{uv}}{2\sin\theta} = \frac{\Lambda_{pm}}{2} \tag{4}$$

Where Λ_g is the fiber Bragg grating period and θ is the diffraction angle of the ± 1^{st} order beams. Λ_{pm} is the phase mask period. In a region just after the phase mask, the +1 and -1 diffraction orders overlap due to the spatial extent of the laser beam as shown in Figure 1(b). In this overlapping region, the two beams create an interference pattern so that if an optical fiber is placed in the overlapping region, a fiber Bragg grating can be written.

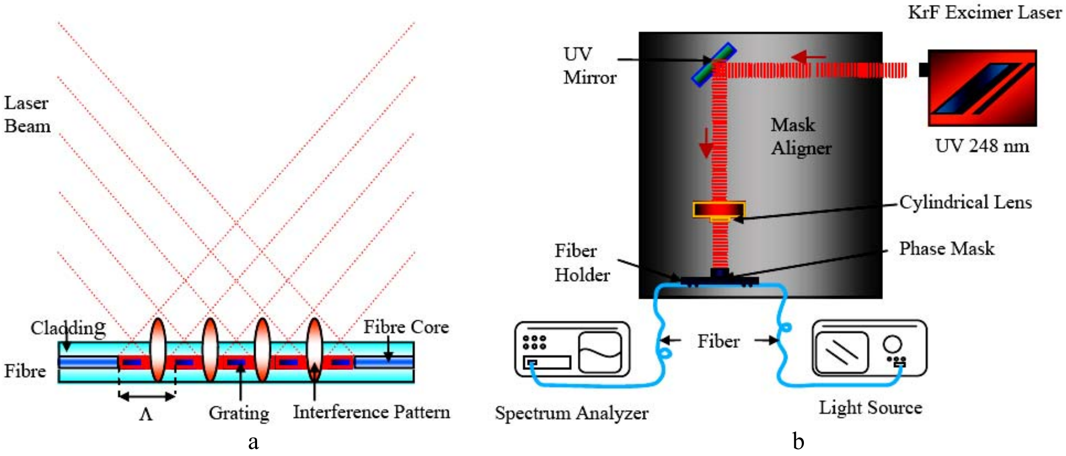
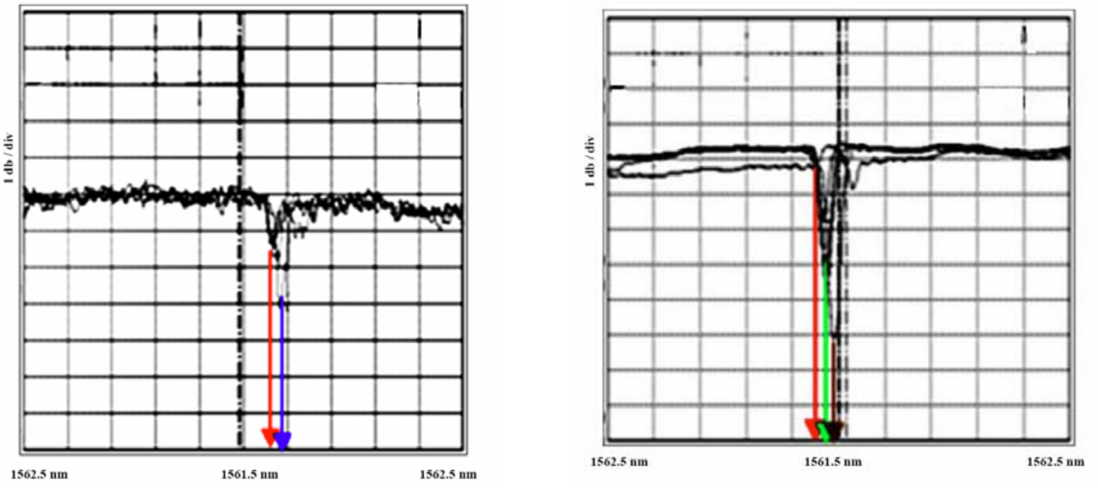


Fig. 1. (a) Monitoring the growth of FBG (b) Writing of FBG in an optical fiber .

3. Result and discussions

The results for inscribing fiber Bragg grating with a phase mask technique can be found in Figure 3. Perturbation of the grating results in a shift in the Bragg wavelength of the device which can be detected in either the reflected or transmitted spectra. The centre wavelength of the grating reflection was measured by an optical spectrum analyzer. Growth of these two FBGs was monitored during fabrication process by typical transmission curves.



(a) Sample I (b) Sample II

Fig. 3. Transmission curves during the growth process of two FBG's.

It can be observed that the dips of transmission curves (as indicated by red, green, blue and orange arrows) increases by increasing the UV exposure time. The increasing of dips of the transmission curves indicates the increase in the index modulation. The plots of sample I and II for UV exposure time against index modulation can be drawn and as shown in Fig. 4(a) and 4(b).

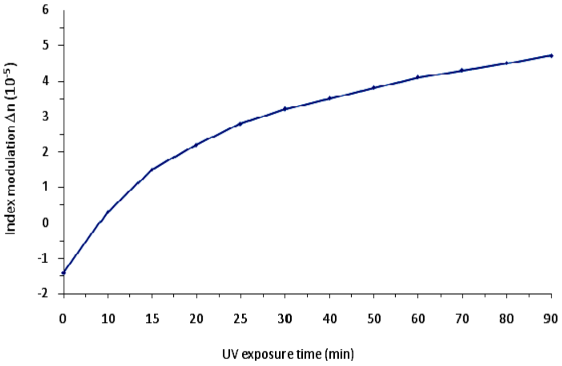


Fig. 4(a). Change of photoinduced refractive index of sample I as function of exposure time

It can be noted that index modulation is increased with increase of exposure time. Initially, it increased then it attained saturation. To photoinduce an index change in the fiber core, light absorption must somehow occur. In accordance with the phase matching condition, a variation in the local effective refractive index, Δn_{eff} will appear as a shift in the local Bragg wavelength, $\Delta\lambda_B$ such that:

$$\Delta n_{eff} = \frac{\Delta\lambda_B}{2\Lambda} \tag{5}$$

Alkins measured the absorption spectrum in a standard germanium doped monomode telecommunication fiber to the wavelength as short as 200nm. The results show that a light source in the UV spectral region 228 to 253nm is most effective photoinducing refractive index changes in such optical fibers. Therefore, we used an excimer laser with wavelength 248 nm as light source, and applied the phase mask technique for writing fiber grating

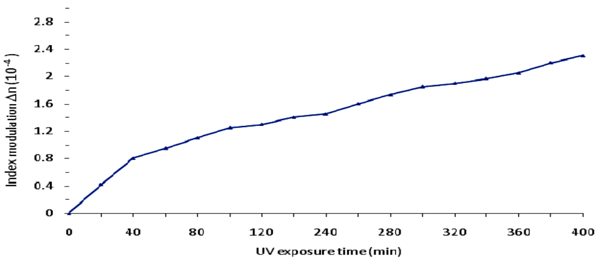


Fig. 4(b). Change of photoinduced refractive index of sample II as function of exposure time

The photosensitivity in germanium-doped optical fiber arises from germanium-oxygen defect centres (GODCs). Regular SiO_2 and GeO_2 have one oxygen atom between each Ge and Si atom. Sometimes a weaker bond is formed between Ge and Si atoms or between two Ge atoms that lacks the intermediate oxygen atom. This weaker bond requires 5.06eV of energy to break which lies within the UV range. UV light photoionizes some bleachable defects of the germanosilicate glass. Electrons released from these defects are free to move to other defect sites. The resultant refractive index change is linked simply to the photoinduced change in absorption through the Kramers–Kronig relationship. The changing of the index modulation follows by the Kramer-Kronig relationship [7]. The only consensus that has been reached is that the germanium oxygen vacancy defects or 'wrong bond', are responsible for the photoinduced refractive index change. Defects in optical fiber play an important role because of the transmission losses caused by the absorption bands associated with various defects. These defects are called colour centers on account of their strong absorptions, where there are due to rise of the refractive index change. The maximum refractive index modulations are ~ 5.109×10^{-5} and 1.77×10^{-4} for sample I and sample II, respectively. With the increase of reflectivity of a grating, the more microstructural changes occur within the lattice of the photosensitive core and the more the residual axial stress builds up within the cross section of the fiber. It means that the induced index of modulation was increased with the increasing of UV exposure time.

Reflectivity is another important characteristic of fiber Bragg grating. The amount of reflectivity is the extent to which the index modulation in the core changes. The reflectivity of fiber grating depends on the exposure time and pulse energy as well. The reflectivity depends upon the dip of transmission curve, as calculated by Equation (4). For sample I, initially the reflectivity is 25% for an exposure time of 10 minutes as shown in Figure 5(a). As the exposure time increases, there is a little increase in reflectivity and researches upto 54 % after an exposure time of 65min at constant pulse energy of 75mJ. The reflectivity after attaining a value of 54% is not further increased and becomes saturated. The reason behind it is the low pulse energy. The increase in reflectivity up to 90 % is possible with the increase of pulse energy and exposure time as well. The full wave half maximum for sample I is 0.138nm.

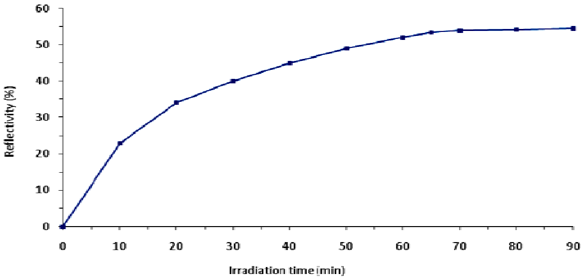


Fig. 5(a). Growth rate of sample I.

For sample II, this FBG was written at 30mJ pulse energy but the exposure time is larger. The reflectivity was 15% at 20 minutes exposure time. A higher percentage of reflectivity is obtained but for a higher value of exposure time as shown in Fig. 5(b). After 70 min, the reflectivity reaches to 60 % and it is clear from the graph that if we made the exposure time is doubled from 70 min to 140 min produces only a slight increase (about 10%) in the reflectivity. The reflectivity appears to be saturate at 60% for sample II. A further increase of 10% is obtained when the exposure time reached a value of 200 min. The full wave half maximum for sample II is 0.142 nm.

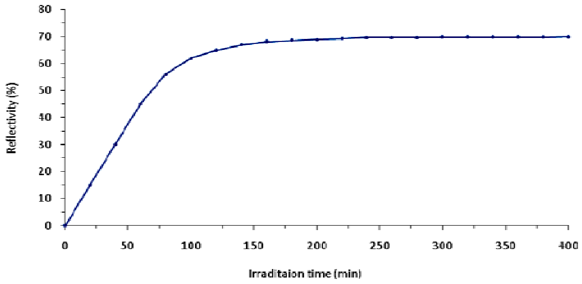


Fig. 5(b). Growth rate of sample II.

The other researchers like Atkin have reported the similar results as presented in this study [10]. They obtained ~55% reflectivity grating written in AT&T Accutether fiber (10 mol% germania) with a 240sec UV exposure time. Alkin inscribed this grating in a very small UV exposure time because he used high power laser beam of pulse energy. If the reflectivity is low then signal to noise ratio is high, it leads to poor reflected signal and vice versa.

Fig. 6, below describes the effect of UV exposure time on fiber grating reflectivity at constant pulse energy with different level such as 13 mJ, 28 mJ, 42 mJ, 56 mJ and 60 mJ respectively. In the writing of fiber Bragg grating, the peak reflectivity increased rapidly at the beginning and then attained saturation, as shown in Fig. 6 below.

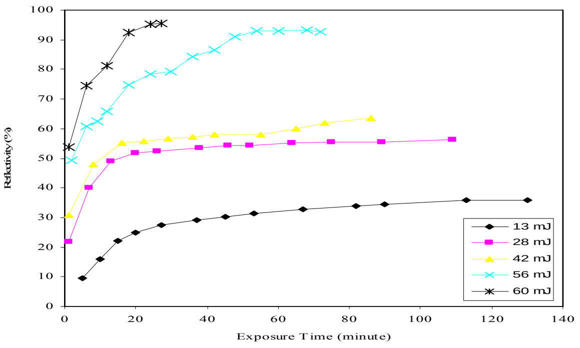


Fig. 6. Reflectivity versus exposure time at various pulse energy

From this graph, we also observe the relation between UV exposure time and pulse energy. There should be larger pulse energy is required to write the grating with high reflectivity in short UV exposure time. After a long time of UV exposure, the spectrum broadened and the grating became saturated. After this stage the peak reflectivity will not increase even by increasing the pulse energy.

4. Conclusion

To measure the index modulation and reflectivity of fiber Bragg gratings corresponding the UV exposure time, two samples of fiber grating were investigated. Based on the results, it is inferred that the induced index of modulation increases with the increasing of UV exposure time. It is also is concluded that reflectivity increases exponentially with the rise of UV exposure time at constant pulse energy and then reaches saturation.

Acknowledgements

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