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Short Note

Dependence of Fiber Bragg Grating Characteristics on its Length

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A fiber Bragg grating (FBG) is normally made with a length of 10 to 30 mm. Depending on the application, however, a short length may be desired, especially in sensor applications for local detection. Under the most common fabrication conditions using the phase mask method, we have fabricated FBGs with lengths ranging from 0.35 to 15 mm using different excimer laser irradiation times. Although 0.35-mm-long FBGs can be made with laser exposure times exceeding 1 h, the practical minimum FBG length appears to be around 3 mm with exposure times in the range of 3 to 5 min. [DOI: 10.1143/JJAP.43.4234]

KEYWORDS: fiber Bragg grating, optical fiber, KrF eximer laser, phase mask, refractive index

Owing to the excellent characteristics of fiber Bragg grating (FBG), particularly its sharp spectral response, the FBG is widely used for many applications in devices which need accurate wavelength control such as wavelength-selecting devices in dense wavelength division multiplexing (WDM) optical telecommunication, resonators of fiber lasers and many types of optical sensors. For sensor applications,[1)] the spatial resolution of parameters to be detected such as strain, load, vibration, and temperature depends on how the FBG is embedded in the structures. The parameter being detected will be averaged over the length of the mounting element containing the FBG. To increase the spatial resolution of the parameters, the element must be made with its length as short as possible. Therefore, the first question that arises is how much the FBG itself can be shortened. The FBGs originally developed for optical telecommunication applications are normally made with typical lengths of 10 to 30 mm. The purposes of the present study are to determine the dependence of FBG characteristics on the FBG length and to find how much the FBG can be shortened from these typical values under the constraints of typical fabrication conditions.

The optical signal size reflected from the FBG, that is, the transmission minimum, depends on the type of application, but it is quite common that the transmission minimum should be less than -10 dB. We have studied experimentally how the transmission minimum depends on the FBG length under the most commonly adopted fabrication conditions by exposing a single-mode fiber to an excimer laser using the phase mask method. Our result shows that the FBG length is inversely proportional to the exposure time of excimer laser irradiation for a given transmission minimum. Although the FBG with a length as short as 0.35 mm can be made with an exposure time longer than 1 h, 3 mm appears to be a practical minimum FBG length, when exposure to the laser irradiation in the range of 3 to 5 min is considered.

Under the commonly adopted fabrication conditions, we fabricated FBGs of different lengths. The optical fiber we used was a standard single-mode fiber (Corning SMF-28). Prior to the fabrication, the fiber was loaded with hydrogen gas by maintaining it under a high hydrogen gas pressure of 100 atm for approximately 10 days. After the hydrogen loading, we kept the fiber in a -70°C freezer for approximately 5 days before using it. After removing the fiber-coating resin and placing the bare fiber underneath the phase mask, we irradiated the bare fiber using a KrF excimer laser (Lambda Physik COMPex-102) from the other side of the phase mask. The energy density of the laser radiation is 420 mJ/cm^2 per pulse at the plane of the fiber,[2)] and the laser was run at a repetition rate of 20 Hz. These conditions are very typical for FBG fabrication commonly adopted in industry. To obtain FBGs of different lengths, we placed an optical stop before the phase mask and changed the opening width of the stop from 0.35 mm to 15 mm which results in different FBG lengths. The growth of the FBG during the pulse-to-pulse irradiation of the excimer laser has been monitored *in situ* by injecting wideband light from an amplified spontaneous emission (ASE) light source (Thorlabs ASE-7701-AP) into the optical fiber and detecting the transmitted light through the FBG from the other end using an optical spectrum analyzer (Advantest Q8384).

Transmission spectra are shown in Fig. 1 for 3 min irradiation of the laser with different FBG lengths of 0.35, 1, 3, 5, 10 and 15 mm. Sharp spectra with deep transmission minimums were observed for the FBGs with lengths greater than 3 mm, but for the 0.35- and 1-mm-long FBGs, the transmission minimums were about 1 dB or below.

The growth of the FBG was monitored *in situ* up to 100 min. Results are shown in the log-log plot in Fig. 2,

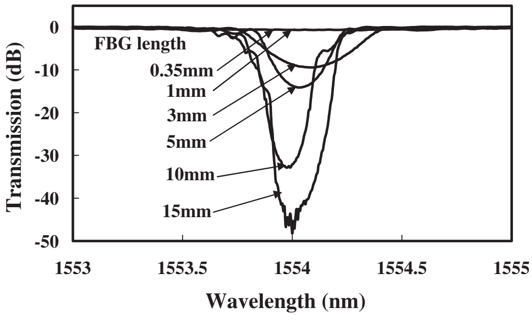

Fig. 1. Transmission spectra of FBGs with different lengths. The FBGs are all made with 3 min exposure to the excimer laser.

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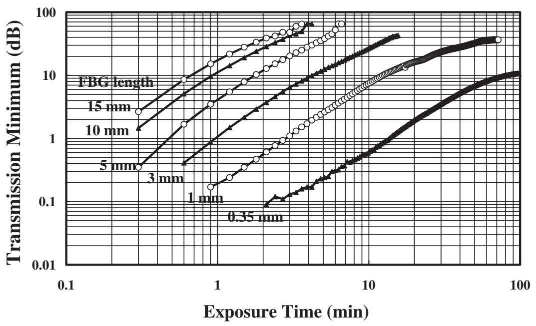

Fig. 2. Transmission minimums of FBGs with different lengths against exposure time to the excimer laser.

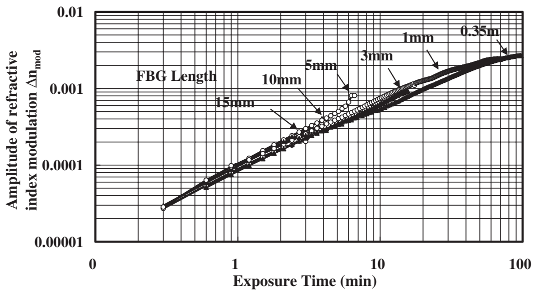

Fig. 3. Amplitude of refractive index modulation for FBGs of different lengths.

where the transmission minimum is plotted against the laser exposure time for the FBGs with lengths of 0.35, 1, 3, 5, 10 and 15 mm. All the cases show a linear increase when the exposure time is short and deviate from linearity slightly when the time is long.

The amplitude of the refractive index modulation Δn_{mod} of the FBG is expected to be the same locally for the same exposure time within the FBG even when its length is varied. Using the two well-known FBG formulas[3] below, Δn_{mod} can be calculated as

$$\lambda_{\mathrm{B}} = 2 n_{\mathrm{eff}} \Lambda \tag{1}$$

$$1 - T = \tanh^2\left(\frac{\Delta n_{\mathrm{mod}}}{n_{\mathrm{eff}}} \frac{\pi L}{2\Lambda}\right), \tag{2}$$

where λ_{B} is the Bragg wavelength, n_{eff} the effective refractive index of the fundamental mode LP_{01}, Λ the grating pitch, L the FBG length and T the transmission. The amplitude of the refractive index modulation Δn_{mod}, thus calculated for the data in Fig. 2, is shown in Fig. 3. The values for FBGs of different lengths are approximately the same as expected.

Laser exposure times for a fixed transmission minimum are plotted for the data set in Fig. 2 against the FBG length in Fig. 4 for 5, 10, 20 and 30 dB transmission minimums. The exposure time is approximately inversely proportional to the FBG length. The transmission minimum differs for different FBG applications, but normally, the values less than -10 dB are required. This minimum can be obtained with the 3-mm-long FBG by 4 min laser irradiation, but when the 1-mm-long FBG is used, laser irradiation takes 12 min, which is 3 times longer than that with the 3-mm-long FBG.

Based on our observations, under the standard FBG fabrication conditions, the exposure time of the FBG to excimer laser irradiation for a given transmission minimum is inversely proportional to the length of the FBG. The transmission minimum of 10 dB commonly required for FBG applications is obtained with approximately 4 min exposure to the laser for the 3-mm-long FBG. This is the shortest FBG for most practical applications under the standard fabrication conditions.

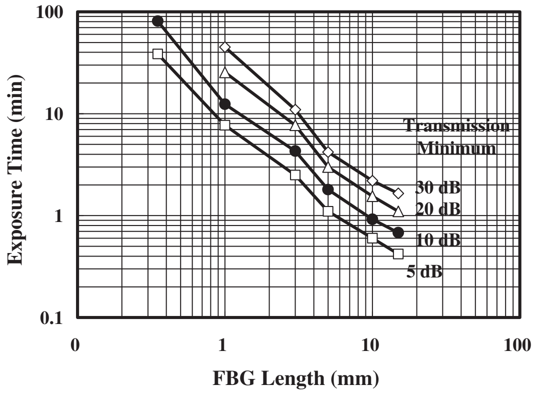

Fig. 4. Exposure time to the excimer laser and FBG lengths for different transmission minimums.

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