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Characterization of Fiber Bragg Grating for Sensor Applications

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Abstract: In this paper, the fiber Bragg grating (FBG) is optimized for sensor applications. The size of the FBG sensor is very important for structural health monitoring applications. Therefore, the core diameter and grating length of FBG are selected for the optimization. The FBG response includes three important characteristics like reflectivity, full width at half maximum, and side lobe power. For sensor applications, reflectivity should be high and FWHM and side lobe power should be low. A GratingMOD tool from Synopsis is used for the simulation study of FBG. This tool uses coupled mode theory and a transfer matrix method for the characterization of FBG. The core diameter and grating length are optimized to 5 µm and 2.5 mm respectively. The optimized FBG offers reflectivity, 0.9945 a.u., full width at half maximum, 0.848 nm, and side lobe power, 0.3393 a.u.

Keywords: Fiber Bragg grating; Core diameter; Grating length; Reflectivity; Full width at half maximum; Side lobe power

I. INTRODUCTION

Fiber Bragg grating (FBG) sensors are based on wavelength modulation of light. FBG sensors offer high sensitivity, high-speed measurements, multiplexed measurements, remote sensing, immunity to electromagnetic interference, and corrosion resistance. The FBG sensor is used for both transmission of data and the sensing of various parameters. Therefore, the real-time monitoring of sensing parameters is possible. Along the length of the optical fiber, several FBGs can be written inside the core of the optical fiber. Therefore, FBG sensors have been used to monitor the structural health of buildings, bridges, railway tracks, etc [1]. The coupled mode theory and transfer matrix method are used for the characterization of FBG [2]. The performance of the FBG sensor depends on various parameters. The FBGs are characterized based on different parameters like the refractive index of the core, the refractive index of cladding, the refractive index modulation depth, and the length of grating [3-4]. Different grating shapes are investigated to increase the sensitivity of FBG [5-6].

For structural health monitoring applications, the size of FBG becomes a critical parameter. Therefore, the characterization of FBG based on core diameter and grating length needs to be done. In this paper, the core diameter and grating length of FBG are optimized for structural health monitoring applications.

II. THEORY

In FBG, the refractive index profile of the core of the optical fiber is modulated as shown in Fig. 1. The grating planes are formed inside the core of the optical fiber. If a broadband light is transmitted through optical fiber then part of the light gets reflected from each grating plane. The reflected light from each grating plane combines to form one reflected beam of light. Therefore, FBG acts as a wavelength selective filter. The wavelength of reflected light is called Bragg wavelength.

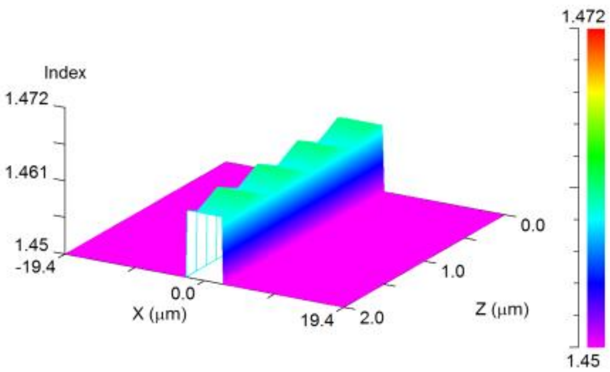

Fig. 1 Fiber Bragg Grating

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According to the Bragg condition, the Bragg wavelength is given by

$$\lambda_B = 2n_{eff}\Lambda \qquad (1)$$

Where λ_B is the reflected or Bragg wavelength, n_{eff} is the effective refractive index of the core of the optical fiber and Λ is a grating period. The distance between two adjacent grating planes inside the core of the optical fiber is known as the grating period.

A fiber Bragg grating is a wavelength modulation based sensor. The effective refractive index (n_{eff}) and grating period (Λ) change according to the change in sensing parameters like temperature, strain, and pressure. Accordingly, there is a shift in Bragg wavelength. The sensing parameter can be measured by monitoring the shift in Bragg wavelength.

The reflected power spectrum of FBG is shown in Fig. 2. The reflected power spectrum of FBG includes three important characteristics like reflectivity (R), full width at half maximum (FWHM), and side lobe power (SLP).

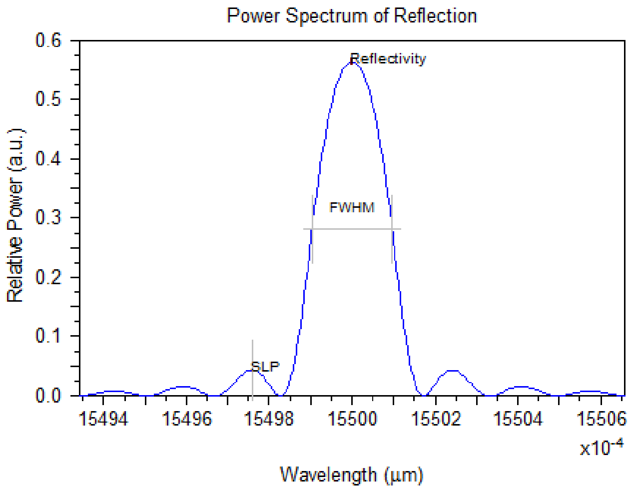

Fig. 2 Reflected power spectrum of Fiber Bragg Grating

In the reflected power spectrum, the power of the main lobe is called reflectivity. The power of the main lobe should be high. The FWHM is called the bandwidth of the channel. The accuracy of the FBG sensor depends on FWHM. To accommodate more FBG sensors in a single optical fiber FWHM should be low. The crosstalk between FBG sensors becomes less if FWHM is low. The FBG having low FWHM helps to provide a high sensitivity of FBG sensor. In the reflected power spectrum, power of the side lobe should be low. This parameter is considered noise. If the power of the side lobe is high then the detection of the main lobe is difficult. For sensor applications, reflectivity should be high and FWHM and SLP should be low.

The FBGs are embedded inside the structures to monitor structural health. The size of FBG becomes a critical parameter for structural health monitoring applications. Therefore, the effect of core diameter and grating length of FBG on its reflected power spectrum needs to study.

III. RESULTS AND DISCUSSION

The GratingMOD tool is used for the characterization of FBG. The GratingMOD tool is based on the transfer matrix method and coupled mode theory. The following parameters are kept constant for the FBG design.

- Profile type: Step index, single mode
- Bragg wavelength: 1.55 μm
- Grating period: 0.5 μm
- Cladding index: 1.45
- Core index: 1.46
- Modulation depth: 0.001
- Grating profile: Sinusoidal
- Apodization type: Uniform

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The core diameter and grating length are critical parameters for structural health monitoring applications. Therefore, these parameters are considered variables for the FBG design.

- Core diameter (a): 2 µm to 8 µm
- Grating length (L): 0.5 mm to 20 mm

The dependence of reflectivity on core diameter and grating length is shown in Table I and Fig. 3. As the core diameter increases grating strength of FBG increases. Therefore, the reflectivity of the reflected power spectrum increases. The number of grating planes inside the core of optical fiber increases when the grating length increases. The broadband transmitted light gets reflected from each grating plane and adds to a particular wavelength. Therefore, the reflectivity increases as the grating length increases.

TABLE I DEPENDENCE OF REFLECTIVITY

L (mm)	a = 2µm R (a.u.)	a = 3µm R (a.u.)	a = 4µm R (a.u.)	a = 5µm R (a.u.)	a = 6µm R (a.u)	a = 7µm R (a.u)	a = 8µm R (a.u)
0.5	0.0226	0.0772	0.2022	0.3341	0.4184	0.4709	0.5043
1	0.0866	0.2662	0.5597	0.7510	0.8319	0.8706	0.8914
2	0.2935	0.6642	0.9203	0.9797	0.9915	0.9952	0.9967
2.5	0.4098	0.7940	0.9690	0.9945	0.9981	0.9991	0.9994
5	0.8247	0.9868	0.9997	0.9999	0.9999	1	1
10	0.9907	0.9999	1	1	1	1	1
20	0.9999	1	1	1	1	1	1

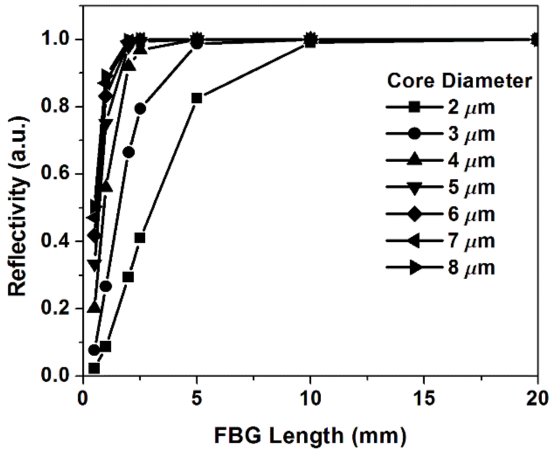

Fig. 3 Dependence of Reflectivity on core diameter and grating length

The dependence of FWHM on core diameter and grating length is shown in Table II and Fig. 4. The FWHM decreases with increasing the grating length. But the FWHM is increased with increasing the core diameter of optical fiber.

TABLE II DEPENDENCE OF FWHM

L (mm)	a = 2µm FWHM (nm)	a = 3µm FWHM (nm)	a = 4µm FWHM (nm)	a = 5µm FWHM (nm)	a = 6µm FWHM (nm)	a = 7µm FWHM (nm)	a = 8µm FWHM (nm)
0.5	1.48	1.50	1.584	1.683	1.758	1.811	1.848
1	0.758	0.817	0.960	1.123	1.233	1.306	1.354
2	0.415	0.520	0.721	0.898	1.006	1.075	1.121
2.5	0.352	0.472	0.676	0.848	0.955	1.024	1.069
5	0.246	0.382	0.575	0.747	0.856	0.925	0.971
10	0.200	0.330	0.527	0.704	0.820	0.946	1.039
20	0.174	0.309	0.528	0.733	0.837	0.960	0.975

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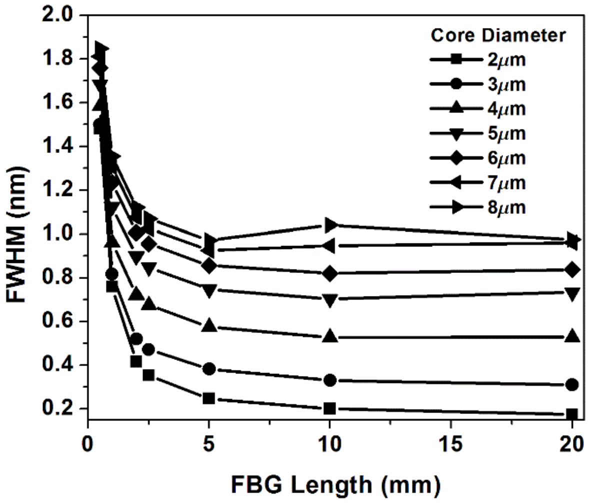

Fig. 4 Dependence of FWHM on core diameter and grating length

The dependence of SLP on core diameter and grating length is shown in Table III and Fig. 5. The SLP increases with increasing the grating length and core diameter.

TABLE III DEPENDENCE OF SIDE LOBE POWER

L (mm)	a = 2µm SLP (a.u.)	a = 3µm SLP (a.u.)	a = 4µm SLP (a.u.)	a = 5µm SLP (a.u.)	a = 6µm SLP (a.u.)	a = 7µm SLP (a.u.)	a = 8µm SLP (a.u.)
0.5	0.0010	0.0038	0.01098	0.020169	0.027272	0.032387	0.035966
1	0.0043	0.0151	0.0424	0.075921	0.100671	0.117935	0.129573
2	0.0170	0.0580	0.1504	0.247109	0.309428	0.348337	0.372557
2.5	0.0264	0.0877	0.2166	0.339351	0.411019	0.454545	0.481885
5	0.0979	0.2778	0.5250	0.67125	0.734748	0.768368	0.788169
10	0.3026	0.6061	0.8088	0.873573	0.915978	1	1
20	0.6324	0.8602	1	1	1	1	1

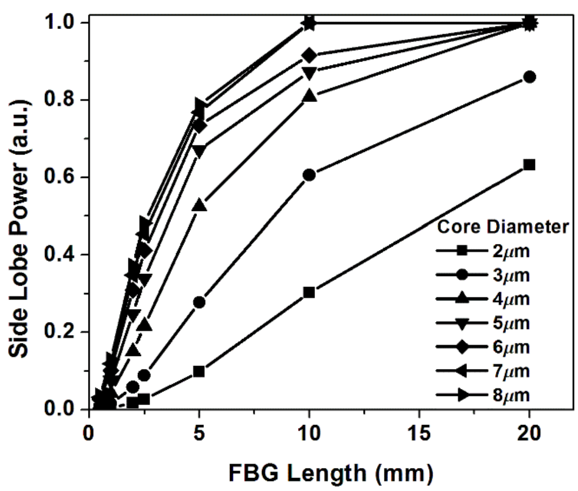

Fig. 5 Dependence of Side lobe power on core diameter and grating length

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The reflected power spectrum decides how many FBG sensors can be embedded in a single optical fiber, remote sensing ability, accuracy, sensitivity, etc. The reflectivity, FWHM, and SLP increase with increasing the core diameter of FBG. The reflectivity and SLP increase with increasing the grating length. The FWHM decreases with increasing the grating length.

For structural health monitoring applications, small-size FBGs are desired. Considering the requirements of structural health monitoring applications and the reflected power spectrum of FBG, the core diameter and grating length are optimized to 5 µm and 2.5 mm respectively.

IV. CONCLUSION

The characterization of FBG is done using the GratingMOD tool. The core diameter and grating length of FBG are selected for optimization because of structural health monitoring applications.

The core diameter, 5 µm, and grating length, 2.5 mm of FBG are optimized by analyzing the reflected power spectrum of FBG. The optimized FBG offers reflectivity, 0.9945 a.u. , FWHM, 0.848 nm and SLP, 0.3393 a.u.

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