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Optimization of Fiber Bragg Grating Sensor for Enhanced Sensitivity and Accurate Measurement

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Abstract: ***Sensor technology is transforming more rapidly to fulfill the needs of modern healthcare standards. Conventional electronic sensors are used for monitoring various biological parameters. These conventional sensors are based on electrical detection mechanisms and have several limitations. Conventional electronic sensors are prone to noise and electromagnetic interference and give inaccurate measurements in noisy environment. The optical fiber-based sensors are more promising than the conventional sensors due to their many advantages. Fiber Bragg Grating sensors are one of the emerging optical fiber-based sensors. FBG sensors are more suitable in biomedical measurement due to their small size and lightweight. Also, FBG sensors offer higher sensitivity than electronic sensors due to their high immunity to electromagnetic interference. FBG reflects the specific wavelength from grating structure known as Bragg wavelength. The strength of reflected signal is known as reflectivity. The unwanted wavelengths reflected along the Bragg wavelength are known as side lobe levels which contribute to the noise. High reflectivity and low side lobe levels are desirable for accurate measurements. The design of FBG sensors is crucial to achieve the desired sensing performance. The grating parameters affect reflectivity and side lobe levels. In this work the effect of grating length on reflectivity and side lobe levels is investigated to determine optimum grating length. The optimized grating length is necessary to obtain desired reflectivity and side lobe levels for precise measurements.***
Keywords: Sensor Technology, Fiber Bragg Grating sensor; Grating length; Reflectivity; Side lobe levels.

I. INTRODUCTION

The sensors are integral part of many medical applications to provide patient centric services. The modern trends like Artificial intelligence, Machine leaning and IoT are changing paradigm in many applications. These technological trends can be most effectively used in medical application to give improved patient outcomes. The modern healthcare standards rely on smart disease detection, virtual care, intelligent monitoring, and data-driven decision-making. The optical fiber sensors can be most effectively with modern technological trends can fulfil needs of such a healthcare standard. The conventional sensors have limitations and not suitable in transformed healthcare standards. Optical fiber sensors offer many advantages over conventional electronic sensors. Optical fiber sensors are compact, small, lightweight, has better immunity to RF and electromagnetic interference, high sensitivity and multiplexing capability. The fiber Bragg Grating (FBG) sensor a type of optical fiber sensor is most promising for healthcare professionals. The FBG is optical fiber with core surrounded by cladding. The periodic variation of refractive index is introduced in the core is known as grating [1]. The length of fiber over which these gratings are introduced is known as grating length (L). The period of grating is represented as Λ, and the amplitude of periodic variation is known as modulation index (neff). The typical structure of FBG is shown in figure 1.

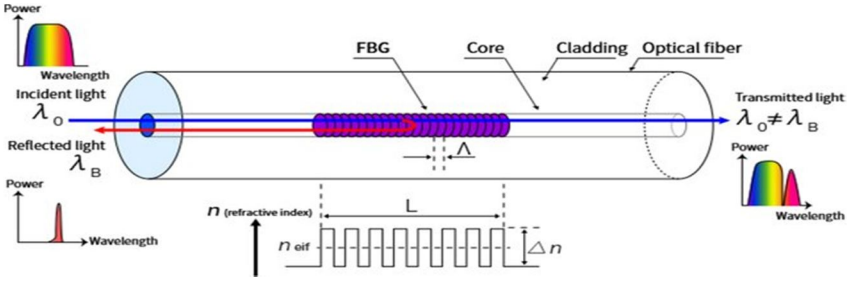

Figure 1: Fiber Bragg Grating Structure [2]

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The working of FBG is based on Bragg reflection. When the light is launched inside the FBG by optical source, it reflects the specific wavelength and transmits the other wavelengths. The reflected wavelength is known as Bragg wavelength and is given as,

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

The strength of the reflected wavelength depends on the grating length and modulation index. The ratio of back-reflected power to the input power is known as the reflectivity. The reflectivity of the FBG sensor can be determined as,

$$R = tanh^2(\kappa L) \quad (2)$$

Where k is the coupling coefficient and L is the Grating length.

The reflectivity varies directly with length [3]. Hence at longer grating lengths reflectivity increases but this also increases side lobe level and bandwidth. Reflectivity saturates at longer grating length. Also longer Grating length increases fabrication complexity Hence optimum length is required to get desired reflectivity, side lobe level and bandwidth. The sensitivity of the FBG sensor depends on the reflectivity and side lobe level. The precision in the measurement depends on the side lobe levels. The undesired wavelengths which are back reflected along with Bragg reflected wavelength treated as a noise. These undesired wavelengths are referred as side lobe levels (SLL). The careful optimization of design parameters gives high reflectivity and minimum SLL and minimum which is desired in medical applications.

II. FBG SIMULATION MODEL AND PARAMETERS

The simulation model of FBG sensor is developed by using OPTIGRATING simulation tool. The model consists of Uniform Bragg Grating as shown in figure 2. This model is used to understand the effect of grating length on the reflectivity and side lobe levels.

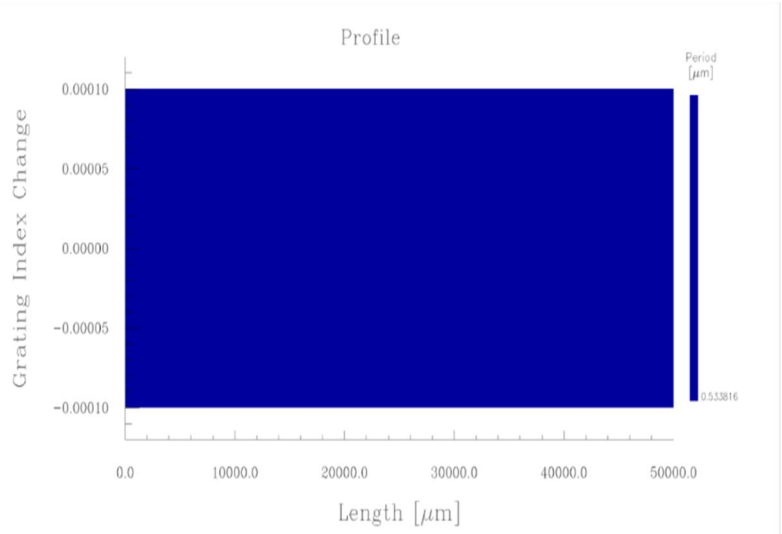

Figure 2: Uniform FBG Model

The following FBG dimensions are used to observe the effect of the grating length. The effect of Grating length is on FBG performance is observed at different Grating lengths.

Table 1: FBG Simulation Parameters

Sr. No.	Parameter	FBG Dimension
1	Grating Period	0.5338 µm
2	Modulation Index	0.0001
3	Core dimension	2 µm
4	Cladding dimension	20 µm
5	Wavelength	1550 nm

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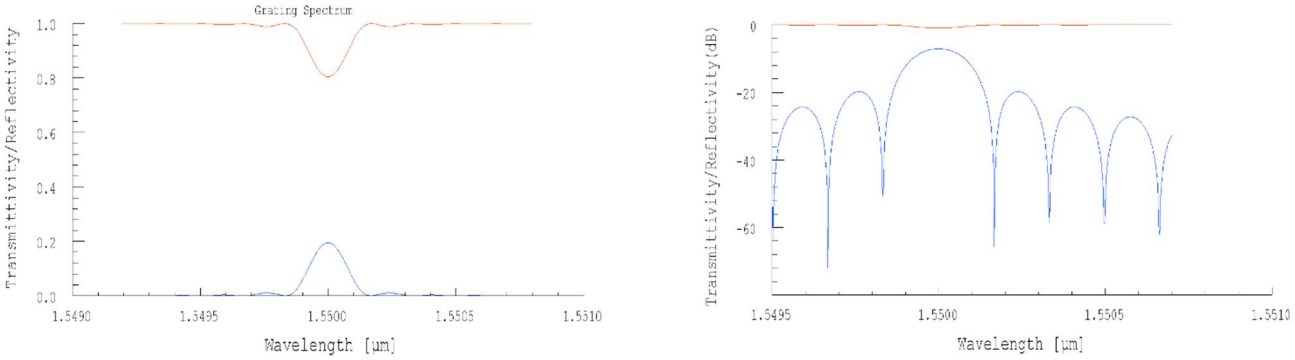
III. RESULT AND DISCUSSION

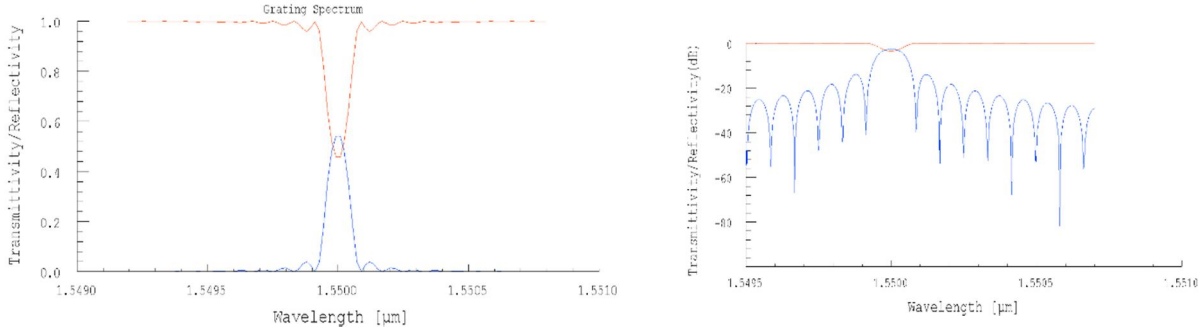
The grating lengths (L) of 5 mm, 10 mm and 50 mm are considered to show the variance of reflectivity and SLL on grating length. The peak reflectivity is observed at 1.55 µm.



3a: Grating Spectrum 3b: SLL Spectrum

Figure 3: Grating and SLL Spectrum of FBG at grating length of 5 mm

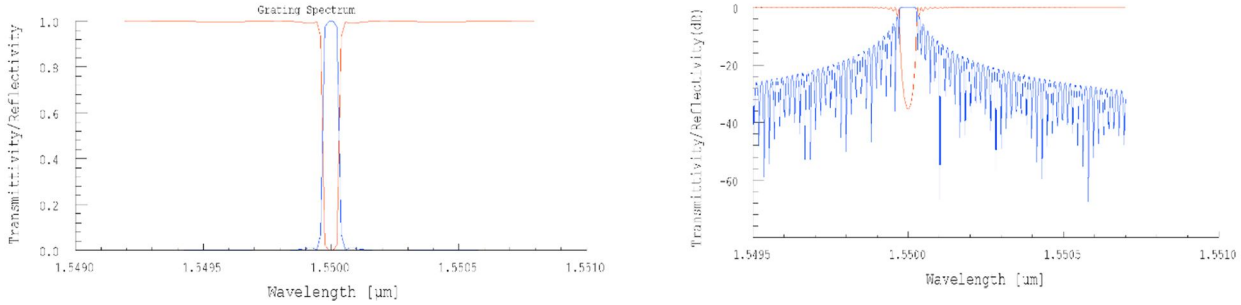
The low reflectivity and side lobe levels are noticed at grating length of 5 mm. The figure 3 shows the grating spectrum and SLL spectrum for grating length of 5 mm. Gratings length is increased to 10 mm and reflectivity and SLL are observed. The result shows that reflectivity as well as SLL increases with grating length. Figure 4 shows the grating spectrum and SLL spectrum for 10 mm grating length. Spectrum shows increased reflectivity as well as side lobe levels.



4a: Grating Spectrum 4b: SLL Spectrum

Figure 4: Grating and SLL Spectrum of FBG at grating length of 10 mm

Then Grating length is further increased to 50 mm and grating and SLL spectrums are obtained as shown in figure 5.



5a: Grating Spectrum 5b: SLL Spectrum

Figure 5: Grating and SLL Spectrum of FBG at grating length of 50 mm

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The further improvement in reflectivity is observed at grating length of 50 mm. The comparison of reflectivity at different grating length is shown in table below.

Table 2: FBG Reflectivity and SLL at different Grating Length

Sr. No.	Grating Length (mm)	Reflectivity	SLL
1	5	0.19488	0.00560
2	10	0.54097	0.45630
3	50	0.99956	0.66075

The result shows the lowest reflectivity of19.49 % at grating length of 5 mm. This is increased to 54% at grating length of 10 mm. The maximum reflectivity 99.95% is observed at 50 mm grating length. The side lobe levels are also increased with increasing length. The minimum SLL of 0.00560 is observed at grating length of 5 mm. The apodization techniques with parameter optimization can give further improvement in reflectivity [4] [5].

IV. CONCLUSION

FBG sensor is most promising in sensing applications due to their high sensitivity and high immunity to electromagnetic interference. FBG sensor design optimization is essential for desired performance in medical sensing application. The grating length, grating period and modulation index plays crucial role to obtain desired reflectivity and side lobe levels. In this work effect of grating length is shown on the reflectivity and side lobe levels. The obtained simulation results show that reflectivity and sidelobe levels increases with length. High reflectivity and low side lobe levels is desirable for precise sensing performance. Hence FBG sensor grating length should be optimum and carefully selected to obtain high reflectivity and low side lobe level. The apodization technique can be employed to reduce side lobe levels. Optimum grating length with apodization techniques can give high reflectivity and low sidelobe levels. This optimised FBG sensor will provide high sensitivity and accurate measurements in biomedical sensing applications.

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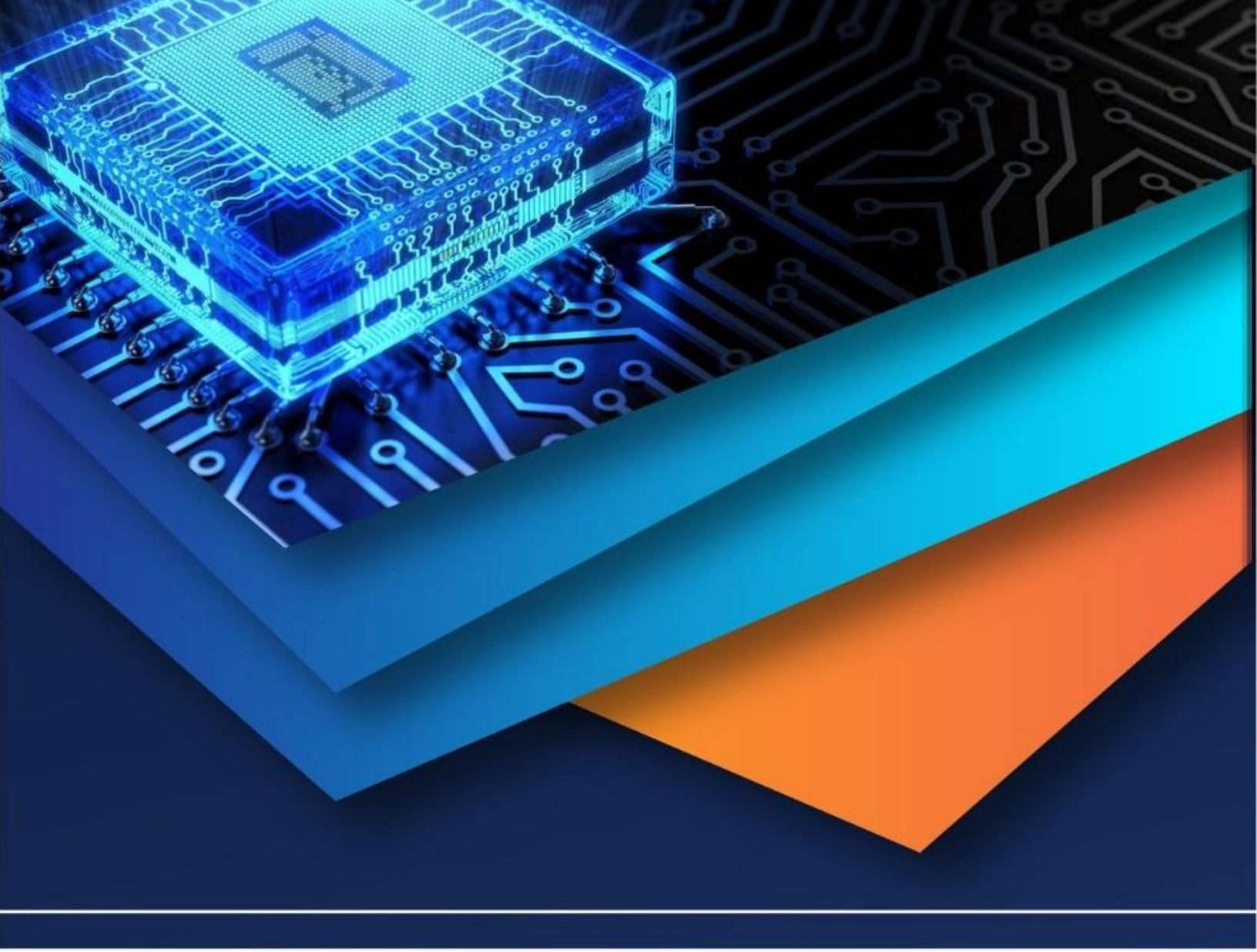

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