Effect of Strain,Temperature and Apodization on Reflection Spectrum of Fiber Bragg Grating

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ABSTRACT *: This paper presents the effect of strain, temperature on Bragg wavelength of Fiber Bragg Grating.Effect on reflectivity of Fiber Bragg Grating is analyzed by Keeping constant grating length and increasing strain and temperature. The effect of Apodization functions on side lobe level and the reflectivity of the reflection spectrum are studied using coupled mode theory. Apodization function have the best performance in reducing side lobes, where side lobe oscillations are reduced. Simulation is carried out using Opti-grating software.*

KEYWORDS *-Apodization, Couple Mode Theory (CMT), Fiber Bragg Grating (FBG), Reflectivity.*

I. Introduction

Fiber Bragg grating (FBG) is a periodic modulation of the index of refraction along the length in the core of single mode optical fiber. [1] FBG is formed by exposing the core of the fiber to a periodic pattern of UV light which introduces permanent change in the refractive index of the core. [2] Germanium doped silica fibers are used for the fabrication of FBG because of its photosensitivity. Photosensitivity is the ability to change the refractive index of the core when it is exposed to UV light. For high reflectivity the level of Germanium doping must be higher.FBG can be used in strain and temperature sensing. [3]

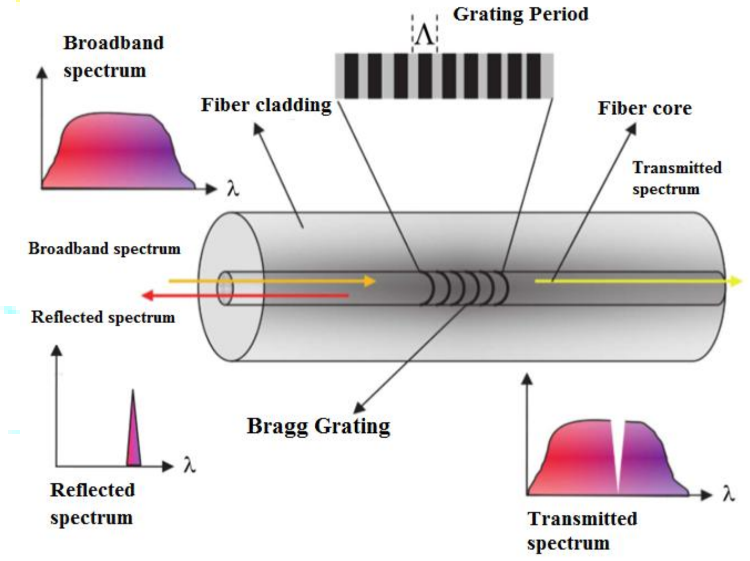


Fig.1 Fiber Bragg Grating [4]

Bragg gratings are analyzed based on the principle of Bragg reflection as shown in Fig.1. When light propagates through the fiber through periodically alternating regions of refractive index, part of light will be reflected back from each period to the input. Reflected light has a wavelength equals to Bragg wavelength so that light reflects back. [5] When reflected light combine coherently to one large reflection at a particular wavelength with the grating period approximately half the input light's wavelength. It is referred to as the Bragg condition, and the wavelength at which reflection occurs is called Bragg wavelength.The condition for higher reflectivity is Bragg condition which is given by,

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

Where λ_B is the central wavelength of FBG, wavelength that satisfies Bragg condition. n_{eff} is the effective refractive index, Λ is the grating period or pitch of the grating.[4]

1.1 Coupled Mode Theory (CMT)

Coupled mode theory is used to calculate the spectral response of Bragg gratings. For a single mode fiber, the simplified couple mode equations are given by, [6]

$$\frac{dR}{dz} = i\hat{\sigma}R(z) + ikS(z) \quad (2)$$

$$\frac{dS}{dz} = -i\hat{\sigma}S(z) - ik^*R(z) \quad (3)$$

Where, R and S are the transmitted and reflected fields respectively. $R(z)$ is the amplitude of forward and $S(z)$ is the amplitude of backward propagating mode. k , $\hat{\sigma}$ are ''ac'' & ''dc'' coupling coefficients respectively.

If the grating structure is uniform along z, then equation (2)&(3) can be coupled with constant coefficients. With appropriate boundary conditions the reflectivity is given by,

$$r = \frac{\sinh^2(\sqrt{k^2 - \hat{\sigma}^2}L)}{\cosh^2(\sqrt{k^2 - \hat{\sigma}^2}L) - \frac{\hat{\sigma}^2}{k^2}} \quad (4)$$

Where L is the length of the grating.

In this paper, the effect of strain and temperature on FBG reflectivity is analyzed in section 2. Section 3 presents the various Apodizationfunctions and its effect on Fiber Bragg Grating reflectivity. Results and analysis are presented in section 4.

II. Strain & Temperature distribution along FBG

Fiber Bragg grating reflection spectrum is based on the physical parameters such as grating length, grating period and refractive index. Grating period and refractive index changes due to externally applied strain and change in the temperature.The shift in Bragg wavelength due to applied longitudinal strain $\lambda_{B/S}$ is given by

$$\Delta\lambda_{B/S} = \lambda_B(1 - P_e)\varepsilon_z \quad (5)$$

Where λ_B is the Bragg wavelength, ε_z is the applied strain along the longitudinal axis and P_e is an effective strain optic constant defined as,

$$P_e = \frac{{n_{eff}}^2}{2}[P_{12} - \nu(P_{11} + P_{12})] \quad (6)$$

Where P_{11}, P_{12} are photo elastic coefficients, n_{eff} is the effective refractive index and ν is the Poisson's ratio.[7]
Due to variation of temperature, the length of the fiber changes and consequently the grating period changes. The Bragg wavelength then deviates from the original FBG wavelength. The deviation of the wavelength of reflected signal is measured and we can estimate the temperature. The shift in Bragg wavelength $\Delta\lambda_{B/T}$ as a result of temperature changes ΔT is described by

$$\Delta\lambda_{B/T} = \lambda_B(\alpha - \xi)\Delta T \tag{7}$$

$$\alpha = \frac{1}{\Lambda}(\frac{\partial\Lambda}{\partial T}) \tag{8}$$

$$\xi = \frac{1}{n_{eff}}(\frac{\partial n_{eff}}{\partial T}) \tag{9}$$

Where ΔT is the change in temperature, Λ is the grating period, α is the thermal expansion coefficient for the fiber and ξ is the thermo-optic coefficient. [2]

III. Apodized Fiber Bragg Grating

The spectral response of grating with uniform index modulation and length of the fiber has secondary maxima on the sides of main reflection peak which is undesirable and which may be suppressed by Apodization. It is a variation of modulation index over the grating length of the fiber.Apodization can be achieved by exposure to UV light to reduce the excursions towards both ends of the grating**.** [8]
Apodization functions rely on the principle that sum of the dc index change and the amplitude of the refractive index modulation should be kept constant throughout the grating. Several Apodization functions are,[9,10]

Gaussian:
$$f(z) = \exp\left[-4.\ln(2).\left(\frac{z-\frac{L}{2}}{\alpha\frac{L}{3}}\right)\right]; 0 \le z \le L, \alpha = 0.75,1,2,4 \tag{10}$$

Hamming:
$$f(z) = \frac{1 + H\cos\left(\frac{2\Pi\left(z-\frac{L}{2}\right)}{L}\right)}{1+H}; H = 0.9, 0 \le z \le L \tag{11}$$

Sine:
$$f(z) = \left[\sin\left(\frac{\Pi z}{L}\right)\right]; 0 \le z \le L \tag{12}$$

Where L is the grating length, z is the coordinate of propagation of light, α is the Apodization factor.

IV. Results and Analysis

The reflection spectrum of FBG with externally applied strain, temperature and different Apodization functions are obtained using Opti-grating.FBG parameters are listed in Table 1.

Table 1.Parameters of FBG

Parameters	Symbols	Values
Bragg wavelength	λ_B	1550 nm
Index modulation	Δn	0.0001
Grating period	Λ	533.81 nm
Effective refractive index	n_{eff}	1.47
Grating length (For strain and temperature)	L	10000 µm
Grating length (For Apodization functions)	L	40000 µm

4.1 Effect of strain on reflection spectrum

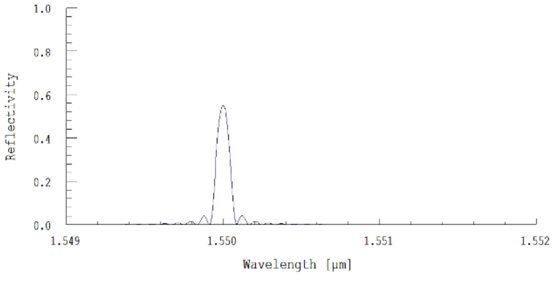
Effect of strain on the reflection spectrum is observed by varying the strain with grating length 10000 µm shown in Fig.2,3,4,5. In Fig.2 at Bragg wavelength, the reflectivity is 54.94%. With increase in strain by 10 µε, reflectivity remains same but there will be shift in the Bragg wavelength by 0.000012 nm. Similarly for 100µε and 150µε, the Bragg wavelength is shifted to 1.5501220, 1.5501820 nm respectively.

4.2 Effect of temperature on reflection spectrum

Effect of temperature on reflection spectrum is observed by varying the temperature with grating length 10000 µm shown in Fig.6, 7, 8, 9. In Fig.6 at Bragg wavelength the reflectivity is 54.94%. For 35C the Bragg wavelength is shifted to 1.5501400. Further increase in temperature shows the Bragg wavelength shift. For 45 & 55C Bragg wavelengthis at 1.5502720, 1.5504100 nm respectively.

4.3 Effect of Apodization on reflection spectrum

Effect of Apodization profiles on reflection spectrum is investigated using different Apodization functions with grating length 40000 µm. In Gaussian function, for Apodization factor α = 0.75, 1, 2, 4 the reflectivity is 83.13, 93.16, 99.19, 99.73% respectively shown in Fig.10, 11, 12, 13. For Apodization factor α =0.75 there are no side lobes present. As we increase the Apodization factor, we get maximum reflectivity but the sidelobe level increases. For Hamming and Sine functions the reflectivity is 93.04, 96.94 % respectively as shown in Fig.14, 15.



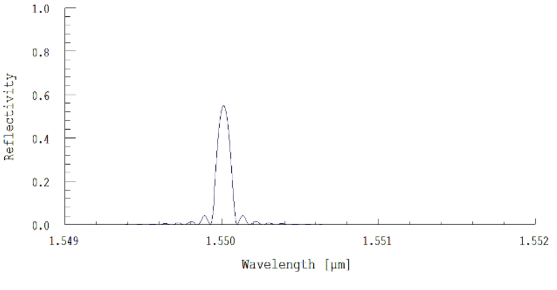


Fig.2 Reflection spectrum with uniform strainFig.3 Reflection spectrum with strain= 10µε

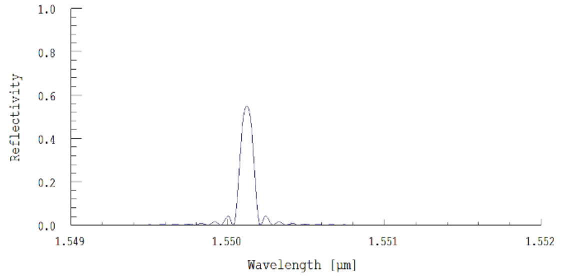


Fig.4 Reflection spectrum with strain= 100 με

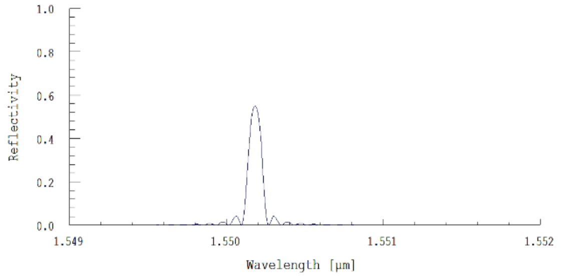


Fig.5 Reflection spectrum with strain= 150 με

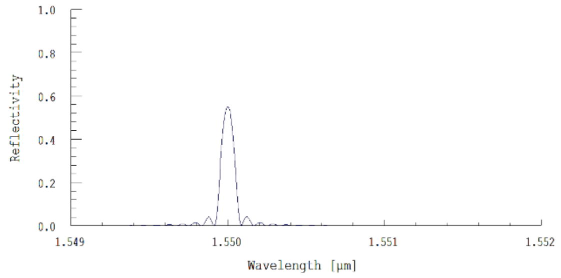


Fig.6 Reflection spectrum with temperature= 25C

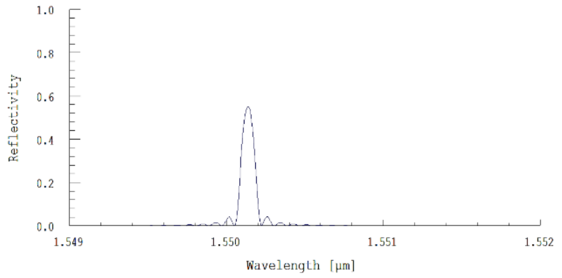


Fig.7 Reflection spectrum with temperature= 35C

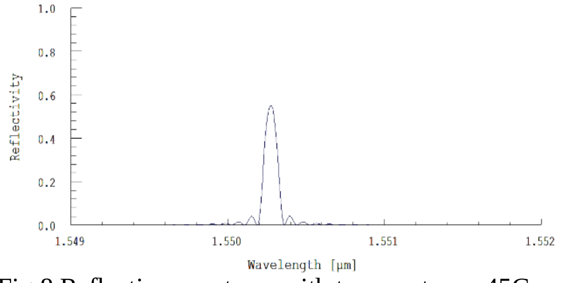


Fig.8 Reflection spectrum with temperature= 45C

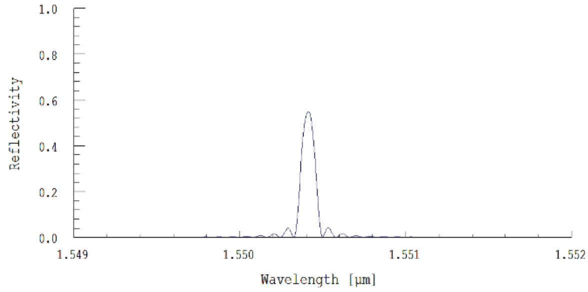


Fig.9 Reflection spectrum with temperature= 55C

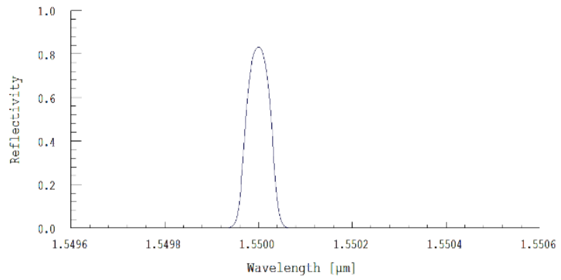


Fig.10 Gaussian Apodization with α = 0.75

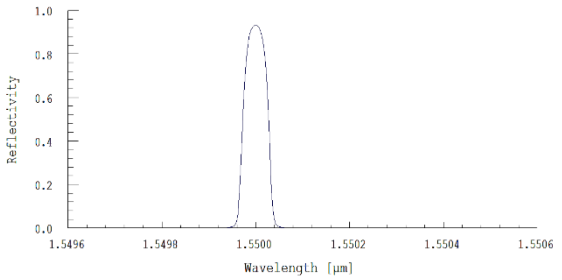


Fig.11Gaussian Apodization with α =1

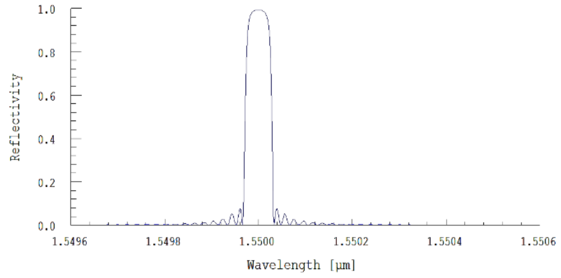


Fig.12 Gaussian Apodization with α =2

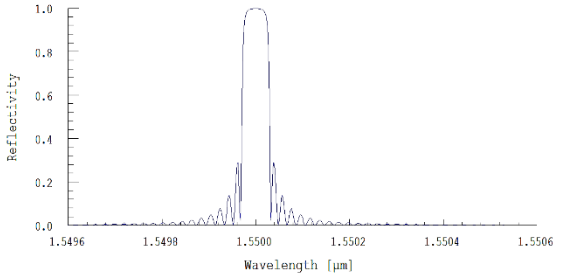
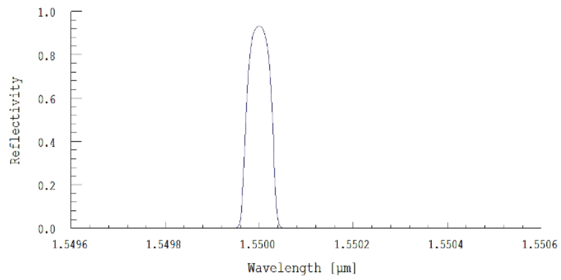


Fig.13 Gaussian Apodization with α =4



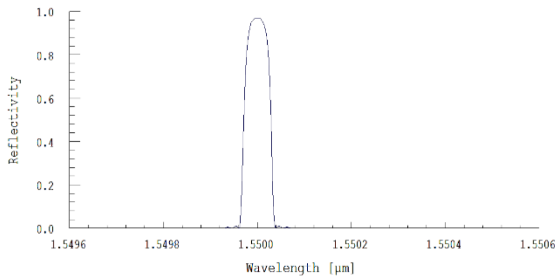


Fig.14 Hamming profileFig.15Sine profile

V. CONCLUSION

Strain and temperature change the grating period which results in the Bragg wavelength shift. When strain and temperature distribution changes, response of the grating device is changed. This Bragg wavelength shift can be used for sensing application. Different Apodization functions for maximum reflectivity is compared using constant grating length and index modulation. Apodization shows a trade-off between reflectivity and suppression of side lobes. Gaussian Apodization function has maximum value of reflectivity as compared to Hamming and Sine function when Apodization factor is greater than 2 in Gaussian function. Hamming profile is the best Apodization function for reducing the side lobe level which can be used in strain sensing.

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