Chapter 4

Effect of Kerr Nonlinearity on Transmittivity of FBG

In Chapter 2, we have studied the reflection characteristics of fiber Bragg grating under Kerr nonlinearity. It was found that the Kerr nonlinearity affects the reflected spectrum of the grating and also play a key role to support the optical bistability phenomena which play a vital role in all-optical memory elements. This Chapter deals with the study of transmission characteristics of fiber Bragg grating under nonlinear regime and explores the effect of Kerr nonlinearity on the optical wave transmitted through it.

The work presented in this Chapter is split into two parts: In the first part optical limiting phenomena in FBG is studied while in the second part multistable characteristics are investigated. In order to study the above nonlinear phenomenon, we have derived an expression for transmittivity of fiber Bragg grating in section 4.1 using solutions of nonlinear coupled mode equations as obtained in Chapter 2. The complete analysis is made considering the propagation of a CW laser beam at high input intensity. In section 4.2, we have reported the results of an analytical study of nonlinear transmission
characteristics of FBG at high excitation intensity. The fiber Bragg grating based optical limiter is demonstrated introducing the Kerr nonlinearity in the medium. The device performance is explored using the derived analytical solutions and numerical simulations. Section 4.3 of this chapter is devoted to the analysis of optical multistability in the fiber Bragg grating.

4.1 Theoretical Analysis of Fiber Bragg Grating in Transmission Mode

To study the transmission characteristics of fiber Bragg grating we have used nonlinear coupled mode equations (NLCMEs) 2.3 and 2.4 as

\[
i \frac{\partial A_f}{\partial z} + \delta A_f + \kappa A_s + \gamma \left( |A_f|^2 + 2|A_s|^2 \right) A_f = 0, \tag{4.1}
\]

and

\[
-i \frac{\partial A_s}{\partial z} + \delta A_s + \kappa A_f + \gamma \left( |A_s|^2 + 2|A_f|^2 \right) A_s = 0. \tag{4.2}
\]

Here, \( \delta \), \( \kappa \) and \( \gamma \) are detuning parameter, coupling coefficient and nonlinear parameter, respectively, and are defined as

\[
\delta = 2 \pi n_o \left( \frac{1}{\lambda} - \frac{1}{\lambda_s} \right), \quad \kappa = \frac{\pi n_g}{\lambda} \quad \text{and} \quad \gamma = \frac{2 \pi n_s^2}{\lambda s}.
\]

The solutions of above nonlinear coupled mode equations (NLCMEs) are obtained in Chapter 2 as

\[
A_f(z) = A_1 \exp(i S_1 z) + A_2 \exp(i S_2 z), \tag{4.3}
\]

and

\[
A_s(z) = B_1 \exp(i S_1 z) + B_2 \exp(i S_2 z) \tag{4.4}
\]

with

\[
S_1 = -\gamma I_o + \frac{\sqrt{\gamma^2 I_o^2 + 4 q_{ad}^2}}{2} \quad \text{and} \quad S_2 = -\gamma I_o - \frac{\sqrt{\gamma^2 I_o^2 + 4 q_{ad}^2}}{2}.
\]
Here, $I_0 = |A_f|^2 + |A_b|^2$ is the input intensity at Bragg wavelength $\lambda_B$. $q_{nl}$ is the nonlinear dispersion parameter in Kerr medium and is defined as

$$q_{nl}^2 = q^2 + \delta X + Y,$$

with $q = (\delta^2 - \kappa^2)^{1/2}$ being the linear dispersion parameter for the Bragg grating and the parameter $X$ and $Y$ are defined as

$$X = \gamma \left( I_0 + 2 |A_f|^2 \right) \quad \text{and} \quad Y = \gamma ^2 |A_f|^2 \left( I_0 + |A_f|^2 \right).$$

Equations (4.5) and (4.6) exhibit the intensity dependent modification in the dispersion parameter $q$. On substituting parameter $q_{nl}$ in equations (4.3) and (4.4), the fields of forward and backward propagating modes for the transmitted wave have been obtained in the same manner as described in Chapter 2 as

$$A_f(z) = A_1 \exp(i S_1 z + t_{eff} B_2 \exp(i S_2 z)) \quad (4.7)$$

and

$$A_b(z) = B_2 \exp(i S_2 z) + t_{eff} A_1 \exp(i S_1 z). \quad (4.8)$$

In the above equations, $t_{eff}$ is the effective transmission coefficient under nonlinear regime and on mathematical simplification, one finds

$$t_{eff} = -\frac{\kappa}{S_1 + \delta + \gamma \left( I_0 + |A_f|^2 \right)}. \quad (4.9)$$

The equation (4.7) and (4.8) gives the solution to the coupled mode equations in exponential form. The transmission coefficient of fiber Bragg grating under nonlinear Kerr regime can be calculated by using equations (4.7) and (4.8) with the appropriate boundary conditions as

$$A_b(z = 0) = 0 \quad \text{and} \quad A_f(z = L) = 1 \quad \text{for} \quad \delta \neq 0 \quad (4.10)$$
where $L$ is the length of the grating and $\delta$ is detuning parameter and taken $\lambda 
eq \lambda_g$. The above boundary condition implies that the amplitude of the transmitted wave at $z = L$ is unity (say). Figure 4.1 illustrates the field propagation in the FBG.

![Figure 4.1: Schematic of a FBG of length $L$ illuminated by electromagnetic field of amplitude $A(z)$.](image)

We defined the transmission coefficient ($t_{ng}$) of the FBG by the ratio of the amplitude of transmitted wave at $z = L$ to the amplitude of incident wave at $z = 0$ using equations (4.7) and (4.8) as

$$
t_{ng} = \frac{A_f(z = L)}{A_f(z = 0)} = \frac{A_1 \exp(iS_1 L) + t_{ef} B_2 \exp(iS_2 L)}{A_1 + t_{ef} B_2} \tag{4.11}
$$

If we use the boundary condition $A_b(L) = 0$ in equation (4.8),

$$
B_2 = -t_{ef} A_1 \exp(ikL) \tag{4.12}
$$

Using equation (4.9) and equation (4.12) in equation (4.11), we obtained the transmission coefficient in nonlinear Kerr regime as

$$
t_{ng} = \frac{A_f(z = L)}{A_f(z = 0)} = \frac{(k'^2 - k^2) \exp(iS_1 L)}{k'^2 - k^2 \exp(ikL)} \tag{4.13}
$$

with $k' = \left(\frac{k}{2} + \tau\right)$, $\tau = \delta + \gamma |A_f|^2$ and $k = \sqrt{\gamma^2 r_0^2 + 4q_n^2}$. 

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The above formalism yields the expression for the transmittivity $T_{\nu} = |r_{\nu}|^2$ in the FBG acting like a nonlinear optical material as

$$T_{\nu} = \frac{1}{1 + F' \sin^2(\Phi'/2)}$$  (4.14)

where $F' = 4k'^2/k^2/(k'^2 - k^2)^2$ is the effective finesse, $\Phi' = kL$ is the phase shift and $L$ is the length of the fiber Bragg grating. Equation (4.14) can be compared with the well known expression for the transmittivity in a standard nonlinear Fabry-Perot device [1] given by

$$r = \frac{1}{1 + F \sin^2(\Phi/2)}$$  (4.15)

where $F = 4R/(1 - R)^2$ is the finesse of the resonator, $R(T + R = 1)$ is the mirror reflectivity, $\Phi = 2\pi n_0 L (\lambda / 2)^{1}$ is the round trip phase shift, $\lambda$ is the wavelength of the radiation and $L$ is the length of the cavity. Thus the FBG can be considered to be equivalent to an optical resonator with mirror reflectivity $R = k'^2k^2$, transmissivity $T = 1 - R = k'^2 - k^2$ and the phase shift $\Phi = \Phi' = kL$.

We observe that the finesse of fiber Bragg grating cavity is intensity dependent and increases with increasing input intensity whereas finesse of nonlinear Fabry-Perot device is constant and depends on the ratio of mirror reflectivity and transmittivity.
4.2 Study of Optical Limiting in Kerr FBG

Optical power limiters (OPL) have tremendous potential as simple yet effective devices for controlling the optical power to protect the sensitive optical components from high-power laser radiation. Nowadays, optical fiber network technology demands the all-optical fiber based nonlinear devices to control the intensity of light in an efficient manner. In this aspect optical fiber limiters have received significant attention. Optical limiting (OL) is a nonlinear phenomenon in which the transmittance of the device decreases with increased incident light intensity. Optical limiters are one of the most important types of devices used to control the amplitude of high intensity optical pulses. These devices work due to intrinsic properties of the materials used for their fabrication. An ideal optical limiter has a linear transmittance at low input intensities, but above the threshold intensity its transmittance becomes constant. In modern optical communication system it is demonstrated that optical limiting not only controls the optical power but can also be used for pulse shaping, pulse smoothing pulse compression and sensor applications [1-3].

Optical limiting results from irradiance-dependent nonlinear optical properties of materials. The incoming intense light alters the refractive and absorptive properties of the materials resulting in a greatly reduced transmitted intensity and therefore it is important to determine the magnitude of the nonlinearity of materials to select suitable materials as optical limiting media. The ideal behaviour of such a device is shown in Figure 4.2.
After the pioneer work of Siegman in 1962 [4], OL is extensively investigated both theoretically and experimentally in a wide range of materials via different nonlinear optical mechanisms such as: (1) Reverse Saturable Absorption (RSA), which translates into increased optical absorption with increased incident optical intensity; (2) Nonlinear Refraction (due to molecular reorientation, electronic Kerr effect, excitation of free carriers, photorefraction, optically induced heating in the material); (3) Induced Scattering (optically induced heating or plasma generation in the medium); (4) Thermal Blooming; and (5) Multiphoton Absorption (Two Photon Absorption) [5-9].

Recently, optical signal processing using nonlinear periodic structures is the interest of the researchers for current photonic network technology. Nonlinear periodic structures work on the principle of nonlinear refractive index change and distributed Bragg reflection. These structures also offer many structural and material degrees of freedom for achieving desired optical signal processing functionality. From the available literature, one may find that nonlinear periodic
structures support optical switching, optical bistability, and solitonic propagation of pulses [10-16]. Herbert et al [17] for the first time experimentally observed optical power limiting in nonlinear periodic structures using a thermal nonlinearity in a dye-doped colloidal crystal. Brzozowski and Sargent [18-19] have analyzed broad-band optical limiting behavior in disordered nonlinear structures that are periodic on average. They have shown that highly disordered structures exhibit true optical limiting over a spectral range much greater than the limiting bandwidth of perfectly periodic nonlinear media. The same authors provided the solutions of coupled-mode equations for one-dimensional (1-D) periodic medium composed of layers with an identical linear refractive index and alternating opposite Kerr coefficients [20]. Pelinovsky et al [21-23] analyzed both theoretically and numerically the all-optical limiting in nonlinear periodic structure when the Kerr nonlinearity is compensated exactly across the alternating layers. Using the coupled mode theory, Sheriff et al [24] investigated numerically the optical limiting and intensity dependent diffraction in low-contrast nonlinear photonic crystals periodic in one, two and three dimensions. Dong and Hu [25] studied the propagation of coherent light through a passive optical power limiter consisting of two alternating layers with different linear and nonlinear refractive indices and obtained general formulas for the transmittance and the optical limiting output power.

The coupled mode theory developed in reference [19] yields the relationship between the incident and transmitted intensities for distributed feedback structure which consist of alternating layers of materials possessing opposite Kerr nonlinearities. The physical structure of such periodic devices seems to be complicated from fabrication point of view. Nowadays, optical signal processing operations demand a compact optical fiber based systems to maintain data rate speed and couple light in and out of optical fibers in efficient way. Fiber Bragg
Grating offers one possible solution for constructing inline optical devices to fulfil above requirements. Advantages of fiber Bragg grating over competing semiconductor material based distributed waveguide components include all-fiber geometry, low insertion loss, low absorption loss, low scattering loss, high return loss, and potentially low cost. Moreover, the most distinguishing feature of fiber Bragg grating is the flexibility they offer in achieving desired spectral characteristics. The lossless optical transmission at 1550 nm wavelength and other advantages of fiber Bragg grating have stimulated the present authors to examine analytically the occurrence of optical limiting in optical fiber Bragg gratings in place of the conceptualized distributed feedback systems introduced by several authors [17-25].

With this in mind, we have made our efforts to investigate analytically the occurrence of optical limiting action in an optical fiber Bragg gratings using the basic set of nonlinear coupled mode equations and derived the solutions for both forward and backward propagating field amplitudes. We have obtained an expression of transmittivity for a quasi CW laser beam in section 4.1 that gives physical insight of optical limiting and relate the response of the FBG as limiter to its physical parameters. The investigation is based on the nonlinear refraction mechanism which describes an intensity dependent refractive index modulation. To study the optical limiting, we have compared the limiting action for four different incident wavelengths. All the wavelengths are considered slightly above the Bragg wavelength. The results of our study show that the transmittance of the grating gradually increases as a ramp function and roll off after certain threshold intensity. If we further increase the incident intensity beyond the threshold intensity the transmittance of the grating become constant and FBG works as a perfect optical limiter.
On the basis of the theoretical formulations developed in the preceding section 4.1, Equation 4.14, we have demonstrated optical limiting behaviour of fiber Bragg grating in nonlinear Kerr regime by plotting the transmitted intensity $I_r = I_o \times T_{mg}$ as a function of input intensity $I_o$ in Figure 4.2. The response of the FBG limiter was investigated for four different incident wavelengths such as 1550.5 nm (doted curve), 1551 nm (dashed curve), 1551.5 nm (dashed-doted curve) and 1552 nm (solid curve) considering the reflectivity of the grating as 99% corresponding to value of $\kappa L = 3.65$. The incident wavelength used here are slightly greater than the Bragg wavelength of the Bragg grating. The tunable quasi-CW laser source in C-band (1535 - 1565 nm) can be selected as the light source [15, 26]. Looking to the potentiality of the chalcogenide glass as FBG materials [27-29] for optical limiting, we have made the numerical analysis of the occurrence of optical limiting in a chalcogenide glass with physical parameters as effective index $n_0 = 2.45$, change in grating index $n_g = 6 \times 10^{-4}$, nonlinear Kerr coefficient $n_2 = 2.7 \times 10^{-17}$ m²/W, length of the grating $L = 3$ mm and Bragg wavelength $\lambda_B = 1550$ nm.

Figure 4.3 illustrates distinctly the optical limiting actions of fiber Bragg grating as studied by varying the incident intensity upto 900 MW/cm². It is clear from this Figure that for very low excitation intensity the transmitted intensity increases with incident intensity as a ramp function. Once this input intensity exceeds certain limit, the transmitted intensity begins to roll off and become almost constant. Such nonlinear characteristics of the grating are the signature of the well known phenomenon known as optical limiting action and the system demonstrating this behaviour is called an optical limiter.
Figure 4.3: Optical limiting behavior of chalcogenide FBG with four detuning wavelengths 1550.5 nm (doted curve), 1551 nm (dashed curve), 1551.5 nm (dashed-doted curve) and 1552 nm (solid curve).

The physical mechanism behind the limiting action of the grating can be explained as follows: at low excitation intensity, the FBG is highly reflective for wavelengths falling in the range $-\kappa < \delta < \kappa$ and transmittive for $-\kappa > \delta > \kappa$. The detuning parameter $\delta$ represents the difference between the frequency of the applied signal and the Bragg frequency of the grating and $\kappa$ as the coupling coefficient. At high excitation intensity, detuning parameter $\delta$ as defined earlier becomes intensity dependent and lies in the range $-\kappa < \delta \left( 1 + \frac{X}{\delta} + \frac{Y}{\delta^2} \right)^{1/2} < \kappa$. The nonlinear dispersion parameter $q_{nl}$ becomes purely imaginary and most of the incident field will be reflected due to the fact that the grating will not support the propagating wave. If the frequencies of the illuminated beam are chosen outside of the stopband, the incident field will be transmitted and transmittance increases with increasing incident intensity. As the input intensity is increased further, the average refractive index of the structure increases with intensity.
which shifts the Bragg wavelength to a longer wavelength side and changes the width and depth of the photonic band gap [2, 30]. This average increase in refractive index due to the presence of Kerr nonlinearity also modulates the phase of reflected and transmitted waves. As a result, new frequency components are continuously generated in the nonlinear medium.

It is very important to note that the stable optical limiting can be achieved when the frequency of the incoming beam completely lies within the stopband, it means that the photonic band gap should widen with increasing excitation intensity rather than shifting of the stopband. In order to obtain true optical limiting Brzozowski and Sargent [19] have given a theoretical model to analyze the passive optical limiter in nonlinear distributed structure which consist of alternating layers of materials possessing opposite Kerr nonlinearities. This arrangement kept average refractive index constant with increasing intensity but the width of the stopband increased such that the Bragg frequency remained unchanged. In our analysis, we have chosen strong grating with $\kappa L \approx 3.65$. The width of photonic band gap of such grating increases with increasing intensity [30, 31]. As a result, most of the newly generated frequency components due to SPM are accommodated in the widened stop band. Hence, very small change in transmitted intensity with increasing intensity is observed after certain threshold input intensity. These observations lead one to infer that grating acts as a limiter in transmission regime. The value of threshold intensity at which grating starts behaving as a limiter called threshold limiting intensity $I_{Limiting}$ which has been obtained by plotting the derivative $dI_T/dI_0$ as a function of the input intensity in Fig. 4.4.
Fig. 4.4 manifests that for positive value of the derivative $\frac{dI_T}{dI_0}$, the corresponding transmitted intensity as plotted in Fig. 4.2 increases linearly with incident intensity. The region for which $\frac{dI_T}{dI_0}>0$ can be designated as the switching region of the limiter. For negative values of $\frac{dI_T}{dI_0}$, the transmitted intensity is fairly constant. Such region can be considered as the clamped region of the device. The value of input intensity at which $\frac{dI_T}{dI_0}$ becomes zero can be termed as the threshold limiting intensity. A close look at Figure 4.3 and 4.4 enables one to conclude that $\frac{dI_T}{dI_0}=0$ and $I_{\text{Limiting}}$ occur at the same value of the input intensity.
4.3 Study of Optical Multistability in Nonlinear FBG

Optical memories are optical bi(multi-)stable systems whose states can be switched all optically. Acting as a fundamental building block for digital optical signal processing, these systems have received considerable attention. Several types of optical memories have been demonstrated so far, in which thing is common that all these have optical storage elements with two states. Multistable optical logic building blocks are interesting for applications in optical communication systems, since they have potential to process a large number of wavelength channels in parallel. As described earlier in Chapter 2, optical bistability (OB) characterizes as an optical system which exhibits two possible output intensities for the same input intensity. Such bistable devices have extensive interesting applications such as optical transistor, differential amplifier, optical switch, optical limiters, optical clipper, optical discriminator and optical memory elements.

If the optical system exhibits many possible outputs for the same input intensity such system known as optical multistable and the phenomena is known as optical multistability. The multistable response of a nonlinear device or structure is shown in Figure 4.5. For the first time Smith et al [32] demonstrated that if a Fabry-Perot resonator contains an electro-optic element then multistability can be observed instead of bistability which has vital role in multilevel optical logic and many state optical memory operations. Later on Okada and Takizawa [33] examined theoretically and experimentally optical multistable characteristics in mirrorless electro-optic device. Miller et al [34] demonstrated optical bistability, multistability, differential gain, limiter and optical transistor in semiconductor InSb Fabry-Perot devices. Lee et al [35] experimentally realized hybrid optical multistability using a semiconductor light
emitting device, a photodiode and transistor, where they presented graphical solution as well as a stability analysis to explain the occurrence of optical multistability.

![Graphical representation of optical multistable response](image)

**Figure 4.5**: Optical multistable response of a nonlinear F-P interferometer. After Ref. (32).

The optical bistability and multistability of periodic media in the form of distributed feedback structure in integrated optics was first investigated by H. G. Winful et al. in 1979 using III-V semiconductor material [10]. Another theoretical demonstration of optical bistability and multistability in semiconductor periodic structure was reported by He and Cada [36], where they have calculated for the first time nonlinear reflectivity and obtained large OB in the vicinity of its stopband due to the optical resonance effect. Herbert and Malcuit [12] described first experimental observation of optical bistability and multistability in nonlinear periodic structure.

The multilevel optical logic operations based on multistability is important to reduce complexity of devices and interconnections since it increases the information capacity of each line and each storage element in an optical communication system as compared to the binary logic operations. The opportunities provided by fiber Bragg grating are of enormous importance for
further development of fiber optic communication systems [37]. The nonlinear nature of the grating allows dynamic tuning of the band gap, hence the study of optical bistability and multistability in FBG has been of considerable significance in recent days. Wabnitz [38] analyzed numerically the nonlinear propagation of counterpropagating pulses in a nonlinear fiber Bragg grating and discussed bistable switching of intense optical pulses. Broderick [14] presented theoretically and numerically all-optical switching characteristics in nonlinear fiber Bragg grating using cross phase modulation. Melloni et al [39] demonstrated experimentally all-optical switching phenomena in phase shifted FBG based on a cross phase modulation induced by an intense pump pulse on a low intensity probe. Ogusu and Kamizono [40] investigated the effect of the material response time on optical bistability in a nonlinear fiber Bragg grating and found that switch-on time depends on the material response time and the switch-off time is almost independent of it. Lee and Agrawal [15] considered both the uniform and phase shifted grating and compared their performance numerically as a nonlinear switch when optical pulses are sent to the grating. Recently, Yosia et al. [29] have observed double optical bistability in nonlinear n-phase shifted chalcogenide fiber Bragg grating (c-FBG) and suggested all optical transistor operation in such devices.

In the present work, we have studied the phenomena of optical multistability in transmission mode of fiber Bragg grating using coupled mode theory. It is observed that multistable features occur near the stopband when operating wavelength is chosen in the vicinity and inside the stopband and features are strongly dependent upon the applied input electric field intensity as well as on the wavelength of the incident light.
To study the optical multistability we have used the expression for the transmittivity $R_\infty \left( = |r_\infty|^2 \right)$ in the nonlinear Kerr regime which is obtained in Section 4.1.2 (Equation 4.14) as

$$T_\infty = \frac{1}{1 + F' \sin^2 (\Phi' / 2)} \tag{4.16}$$

where $F' = 4k'^2 \kappa^2 / (k'^2 - k^2)^2$ is the effective finesse, $\Phi' = kL$ is the phase shift and $L$ is the length of the fiber Bragg grating. All the physical parameters have same meaning described in preceding Section 4.1. We have plotted the transmitted intensity with input intensity in Figure 4.6. The tunable quasi-CW laser source in C-band (1535 – 1565 nm) is assumed as the light source [15, 26]. All the results presented here are for chalcogenide FBG having effective index $n_0 = 2.45$, change in grating index $n_g = 3 \times 10^{-4}$, nonlinear Kerr coefficient $n_2 = 2.7 \times 10^{-17}$ m$^2$/W. The length of the grating $L = 2$ cm and Bragg wavelength $\lambda_b = 1550$ nm were chosen [29]. We have considered the chalcogenide glass FBG because it reduces the required input intensity to observe nonlinear effects as compared to silica FBG due to high value of nonlinear Kerr coefficient $n_2$ in such glasses. The plot is given for four different values of incident wavelengths such as $\lambda = 1549.75$ nm (Fig. 4.6a), $\lambda = 1549.80$ nm (Fig. 4.6b), $\lambda = 1549.85$ nm (Fig. 4.6c) and $\lambda = 1549.90$ nm (Fig. 4.6d). All the incident wavelengths considered below the Bragg wavelength but are lying inside the stop band of the Bragg grating. At low intensity these wavelength are reflected by the grating as a result the transmission of the structure is low. As the intensity of the input beam is increased the average refractive index of the grating will increases and the stop band appear to shift towards higher wavelengths side resulting in an increase in the transmission of those wavelengths which were reflected by the grating at low intensity.
Figure 4.6: Transmitted vs. incident intensity for a nonlinear fiber Bragg grating for different values of detuning wavelengths.

It is observed from Fig. 4.6, that when the wavelength of the incident light is tuned deeper into the stop band (very near to the Bragg resonance, Fig. 4.5d) the transmitted intensity shows strong oscillatory behavior. The occurrence of oscillatory behavior can be explained as follows: It is well established that reflection spectrum of FBG shows the presence of multiple sidelobes with decreasing intensity located at each side of the stop band. These sidelobes
originate from the weak reflections occurring at the two grating ends where refractive index changes suddenly compared to its value outside the grating region due to which a Fabry-Perot cavity with its own wavelength dependent transmission is formed. As the input intensity increases the feedback path of the Fabry-Perot cavity increases. As a result the phase shift of the incident light increases due to self phase modulation. This causes the strong periodic sidelobes showing multistability in the transmission.

Our observations are consistent with the stability analysis of Sterke [41] who suggested that at high excitation intensity there are many regions where the high transmission states are predicted due to temporal fluctuations which become chaotic. He found that as the wavelength of the incident beam is tuned deeper and deeper into the stopgap, the system tends to become more and more unstable giving rise to many stable and unstable states at the output. Multistable behavior in nonlinear fiber Bragg grating can also be considered in terms of many gap solitons formation inside the stopband of the grating [42-45]. In 1998 Broderick et al. [46] has observed experimentally five gap soliton at a particular input intensity when the wavelength of the incident beam is tuned inside the photonic bandgap of fiber Bragg grating. They suggested that the bistable switching is associated with the formation of gap soliton inside the grating.
4.4 Conclusion

We have investigated the phenomenon of optical limiting and optical multistability in transmission mode of nonlinear fiber Bragg grating by incorporating Kerr effect in the coupled mode analysis. The expression for the intensity dependent transmittivity is obtained by solving nonlinear coupled mode equations analytically for quasi-CW laser beam. To study optical limiting, we have compared the limiting action of FBG for four different incident wavelengths. The results of our study show that for \((\pi n_g L / \lambda_p) \approx 3.65\), the transmittance of the grating gradually increases with input intensity as a ramp function and roll off after certain threshold intensity. If we further increase the incident intensity beyond the threshold intensity the transmittance of the grating become almost constant and FBG works as a perfect optical limiter. The study also demonstrates that FBG shows optical multistability when operating wavelengths are chosen slightly lower side of the stopband of fiber Bragg grating at suitable incident intensity. We believe that the present analytical study will be useful in future experimental work to explore optical limiting and multistability in nonlinear fiber Bragg grating and for the development of nonlinear optical components to be used in all-optical signal processing.

The work reported in this chapter is presented in two parts, the first one is related with multistable behavior of FBG. This work was published in *Journal of Optoelectronics and Advanced Materials – Rapid Communication*, 6, 25-28 (2012) and the later section described the optical limiting behavior which has been published in *Journal of Nonlinear Optical Physics and Materials*, 21, 1250017.1-1250017.10 (2012)
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