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Optical Pulse Propagation in Photonic Bandgap Fiber Bragg Grating

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Abstract:

In this work we demonstrate and investigate the optical pulse propagation in a photonic band gap Fiber Bragg Grating (FBG). The light propagates in opposite direction in FBG is explained and discussed by a Coupled Mode Theory (CMT). The photonic band gap (stop band gap) is created by fabricate, a Bragg Grating in optical fiber. The results show the pulse spectrum falls entirely within the stop band gap, the entire pulse is reflected by the grating, while when the pulse spectrum is outside the stop band the pulses will transmitte through the grating. The group velocity (V_G) becomes zero at the edges of the stop band and group velocity dispersion β_2 is anomalous on the shorter side of the stop band gap whereas β_2 for uniform fiber becomes anomalous for wavelengths lower than the zero dispersion.

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انتشار النبضة الضوئية في فجوة الطاقة الفوتونية لمحزز براك للألياف البصرية

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الخلاصة:

في هذا العمل تم توضيح و فحص انتشار النبضة الضوئية في فجوة الطاقة لمحزز براك للألياف البصرية. وضح و نوقش انتشار الضوء في الاتجاه المعاكس لمحزز براك للألياف البصرية باستعمال نظرية نمط الأزواج CMT. فجوة الطاقة الضوئية تنشا بوساطة تصنيع محزز براك في الليف البصري. أوضحت النتائج، إذا كان طيف النبضة يقع داخل فجوة الطاقة الضوئية، فأن النبضة الضوئية ستنعكس بوساطة المحزز. بينما إذا كان طيف النبضة يقع خارج فجوة الطاقة الضوئية، فأن النبضة الضوئية ستنفذ خلال المحزز. تصبح سرعة المجموعة V_G صفراً عند حافات فجوة الطاقة وتشتت سرعة المجموعة β_2 يكون شاذ عند الجانب الأصغر لفجوة الطاقة الضوئية, في حين β_2 للألياف الاعتيادية يكون شاذ عند الأطوال الموجية الأقصر من التشتت الصفري.

Introduction:

FBG is a device that creates a periodic perturbation in the refraction index of the fiber core, reflecting only the specific wavelength corresponding to that period [1].

FBGs are attractive for their applications in the field of optical communication systems and optical fiber sensors [2]. In FBGs, two counter-propagating modes (the incident electrical field and the reflected) interact for the design Bragg wavelength of the grating. The range of wavelengths bandwidth reflected depends on the length and strength of the grating. This bandwidth is designed as the photonic band-gap zone where no forward propagation occurs [3]. In this paper, we report the characteristic of the optical pulse propagation in photonic bandgap FBG, which is explaining the values of V_G and β_2 of the FBG.

Theoretical Work

FBGs are achieved by exposing optical fiber to a pattern of ultraviolet intensity (varying along the fiber/grating length) the ultraviolet light cause's variations in the fiber refractive index that can be modeled by [4]:

$$n(z) = n_{eff} + \Delta n(z)\cos\left[\frac{2\pi}{\Lambda}z\right] ----(1)$$

where neff is the effective refractive index, Δn the amplitude of the induced refractive index perturbation (typically 10-5 to 10-3), z distance along the fiber grating longitudinal axis , Λ grating period. Two apodization profiles are considered: uniform and raised-cosine as shown in figure 1. In the uniform grating the maximum refractive index variation is follows:

$$\Delta n(z) = \Delta n(0) ----(2).$$

For the raised-cosine profile, the amplitude of the modulation slowly rise from the beginning of the grating, they achieve a maximum value in the middle of the grating and then decreases until the end, according to:

$$\Delta n(z) = \Delta n_{eff}\left\{\frac{1}{2} + \frac{1}{2}\cos\left[2\pi\frac{z - l/2}{l}\right]\right\} ---(3).$$

Where l is the grating length.

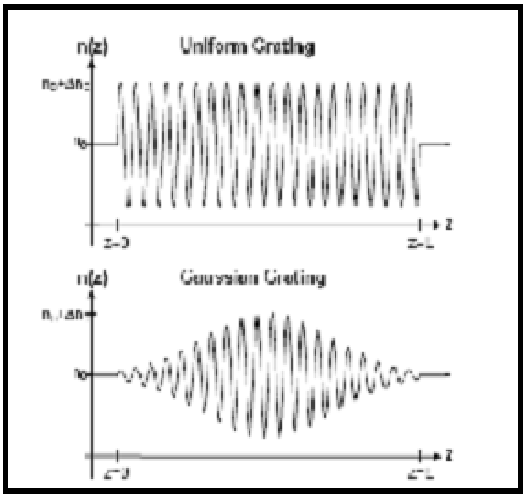

Fig.1 Apodization profiles of the gratings.

To describe pulse propagation in FBG we use coupled mode equation. The CMT is a commonly used for treating interaction between confined modes of optical fibers that are mediated by refractive index perturbation [5].

let A(z) the amplitude of the forward-propagating wave and B(z) the amplitude of the backward propagating wave, the electrical field distribution E(z)in the fiber may be represented by:

$$E(z) = A(z)\exp(-i\beta z) + B(z)\exp(i\beta z) ----(4)$$

A(z)and B(z) will also satisfy the mode coupling equations:

$$\begin{aligned} \frac{dA}{dz} &= -i\kappa B\exp(2i\delta z) \\ \frac{dB}{dz} &= i\kappa A\exp(-2i\delta z) \end{aligned} \quad ----- (5).$$

where κ is a coupling coefficient and δ is the detuning parameter and equal to $\beta - \pi/\Lambda$ where β wave number. Solving equation (4) for the vicinity of the peak, we then have two equations:

$$\begin{matrix} A(z) & \exp(-i\delta z) \\ B(z) & \exp(i\delta z) \end{matrix} = M \begin{matrix} A(0) \\ B(0) \end{matrix} ------(6)$$

$$M = \begin{matrix} \cosh(qz) - i\frac{\delta}{\gamma}\sinh(qz) & -i\frac{\kappa}{q}\sinh(qz) \\ i\frac{\kappa}{q}\sinh(qz) & \cosh(qz) + i\frac{\delta}{\gamma}\sinh(qz) \end{matrix} -(7)$$

where γ nonlinear parameter, q obey the dispersion relation [1] and equal to $q = \sqrt{\kappa^2 - \delta^2}$.

The reflectance R of a fiber grating with a length of (l) can be obtained by substituting z=l and B(l)=0 in equation (5) and (6) as:

$$R = \frac{\kappa^2 \sinh^2(ql)}{\delta^2 \sinh^2(ql) + q^2\cosh^2(ql)} -----(8)$$

At the Bragg grating center wavelength there is no wave vector detuning δ=0; therefore expression for the reflectivity becomes [6]:

$$R_{Max} = \tanh^2(\kappa l) ---(9)$$

Experimental work

One of the most effective methods for inscribing Bragg gratings is photosensitive fiber is the phase mask technique. This method employs a diffractive optical element (phase mask) to spatial modulate the UV writing beam. In this work as shown in figure 2, a phase mask was used with periodicity 1070 nm supplied by Lasiris Company. The illuminated FBG was a single mode photosensitive Boron-Germanium co-doped optical fiber (fiber core PS 1250/1500, 0.14 NA, and 1159 nm cut-off wavelength) by KrF (248 nm wavelength), the reflected wavelength is 1547.848 nm.

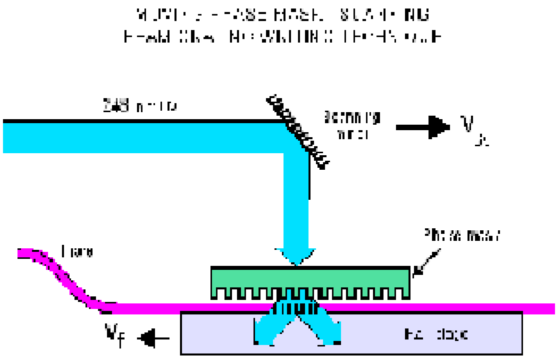

Figure 2: FBG fabrication by Phase Mask Technique

The FBG experimental setup contains UV laser (Eximer KrF laser) Ge-doped optical fiber, exposure length is 19 mm. Instantaneously using Anritsu MS9701 Optical Spectrum Analyzer (OSA) which monitors the light intensity transmitted and reflected through the fiber under exposure. The light source that has been used is a broad band Fermiocs SLD (Super Luminescent Light Diode) the KrF laser is switched off when the OSA indicating the desired value of reflectivity at the Bragg wavelength.

Results and Discussion

Figure 3 shows the reflectance spectrum for FBG with λB=1547.8nm, κ=1.575 cm-1, l=1.9 cm and R=0,989 was fabricated by KrF laser (284 nm) with phase mask [7].

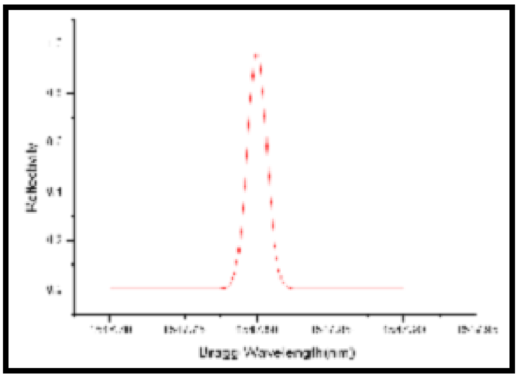

Fig.3 Reflection spectrum of a Bragg grating as a function of wavelength.

If the frequency detuning δ of the incident light falls in the range $-\kappa$ <δ< κ , q becomes purely imaginary. Most of the incident field is reflected in that case since the grating dose not support a propagating wave. The range $|\delta| \le \kappa$ is referred to as the photonic band gap it is called stop band. Since light stops transmitting through the grating when its frequency falls within the photonic band gap. The group velocity of the pulse inside the grating (VG) is given by:

$$V_G = \pm v_g \sqrt{1 - \kappa^2 / \delta^2} ----(10).$$

where v_g group velocity of the pulse outside the grating, the choice of ± signs depends on whether the pulse is moving in the forward or the backward direction. The variation of VG with detuning is shown in figure 4. One can seen from this figure, far from the band edges $|\delta| \le \kappa$ optical pulse is unaffected by the grating and travels at the group velocity expected in the absence of the grating, as $|\delta|$ .Approaches κ, the group velocity decreases and becomes zero at the edges of the stop band where $|\delta| = \kappa$.

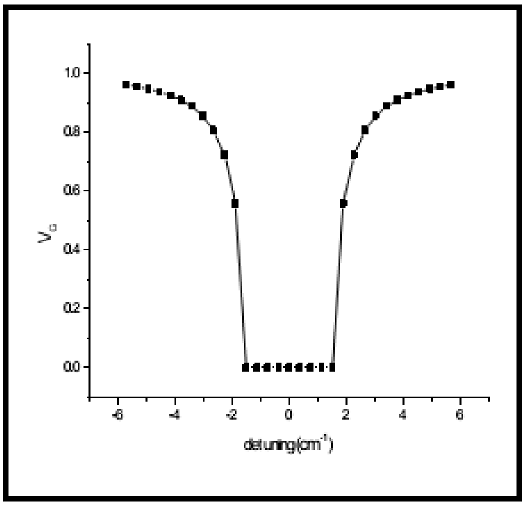

Fig.4: Group Velocity inside the Grating.

The velocity of light is constant and independent of the wavelength in vacuum, whereas in materials it may vary with wavelength of light. This phenomenon is commonly referred to as dispersion; the dispersion of optical components is due to a change in index of refraction of material used to build them with wavelength.

The values of second order dispersion β_2^g for the FBG are calculated from the following equation [8]:

$$\beta_2^g = -\frac{\sin(\delta)\,\kappa^2/v_g^2}{(\delta^2-\kappa^2)^{3/2}} --- (11).$$

Figure (5) shows the grating-induced GVD plotted as a function of δ for FBG with λB=1547.8 nm, l=1.9 cm and detuning (-5<δ<5) cm-1.

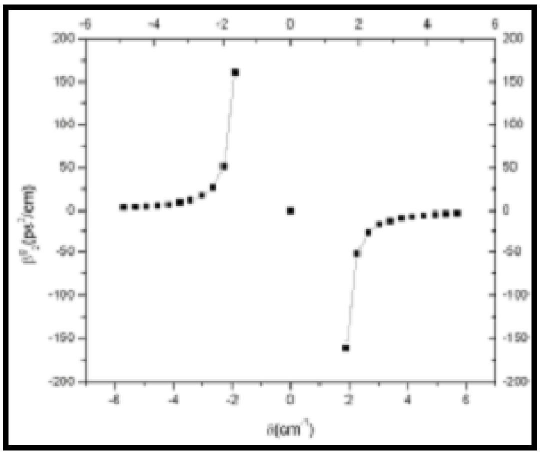

Fig.5: Grating-Induced GVD Plotted as a Function of δ.

The β_2^g depends on the sign of δ, the GVD is anomalous on the upper branch of the dispersion curve, where δ is positive and the carrier frequency exceeds the Bragg frequency. In contrast, GVD become normal on the lower branch of the dispersion curve, where δ is negative and the carrier frequency is smaller than the Bragg frequency. Therefore, β_2^g change sign on the two sides of the stop band gap centered at the Bragg wavelength whose location is easily controlled and can be in any region of the optical spectrum. So β_2^g is anomalous on the shorter side of the stop band gap whereas β_2 for uniform fiber becomes anomalous for wavelengths lower than the zero dispersion.

Conclusions

Frequencies inside the photonic band gap can not propagate through the grating. This corresponds to the region of high reflectivity. While frequencies outside the gap can propagate, but at velocities that can be substantially less than the speed of light in the uniform medium. The reduced group velocity can be explained in terms of multiple reflections at the grating. The group velocity υ_g vanishes at the band edge and asymptotically approaches (c/n~) far from the Bragg resonance. The range of wavelengths over which this occurs is roughly equal to the band width of the grating. Group velocity dispersion β_2 becomes normal when δ is negative. While β_2 is anomalous on the shorter side of the stop band gap (δ is positive) whereas β_2 for uniform fiber becomes anomalous for wavelengths lower than the zero dispersion.

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