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An Analysis of Fiber Bragg Gratings in Optical Fibers by using Amplitude-Splitting Interferometer

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ABSTRACT

In this paper, A Fiber Bragg Grating is a periodic or a periodic perturbation of the effective absorption coefficient and or the effective refractive index of an optical waveguide. Inscribing Bragg gratings in optical fibers is a formidable task. The requirement of a submicron periodic pattern makes the stability a severe constraint on the techniques able to write Bragg gratings in optical fibers. In an amplitude splitting interferometer, the UV writing laser light is split into two equal intensity beams and are later recombined after traversing through two different optical paths. This forms an interference pattern at the core of a photosensitive fiber.

Keywords: FGB, Optical, Wavelength, Fiber, Fabrication, Amplitude, Interferometer, Power, Meter.

1. Introduction

A Fiber Bragg Grating is a periodic or a periodic perturbation of the effective absorption coefficient and or the effective refractive index of an optical waveguide. In the periodic structure of the FBG the coupling of energy between different co-propagating and counter-propagating modes of the fiber takes place. The mode coupling phenomenon is a strong function of wavelength. A Bragg Grating can reflect a predetermined narrow or broad range of wavelengths of light incident on the grating, while passing all other wavelengths of the light. The capability to photo-imprint gratings in optical fibers requires that the glass be photosensitive. By irradiating the fiber with an intensive pattern that has a periodic or a periodic distribution, a corresponding index perturbation is permanently induced in the core of the waveguide. The result is an index grating that is photo-imprinted in the optical waveguide. As a result, the Bragg Grating becomes a very selective spatial reflector in the core of the fiber.

There are several distinct types of Fiber Bragg Grating structures such as the common Bragg reflector, the blazed Bragg grating, and the chirped Bragg grating. These Fiber Bragg Gratings are distinguished either by their grating pitch spacing between grating planes or tilt angle between grating planes and fiber axis. The most common Fiber Bragg Grating is the Bragg reflector, which has a constant pitch [1]. The blazed grating has phase fronts tilted with respect to the fiber axis, that is, the angle between the grating planes and the fiber axis is less than 90°. The chirped grating has a periodic pitch, that is, a monotonic increase in the spacing between grating planes.

2. Externally Written Bragg Gratings in Optical Fibers

Inscribing Bragg gratings in optical fibers is a formidable task. The requirement of a submicron periodic pattern makes the stability a severe constraint on the techniques able to write Bragg gratings in optical fibers. To date, there are only a few externally written fabrication techniques, namely, the interferometric technique, the phase mask technique, and the point-by-point technique.

2.1 Interferometric Fabrication Technique

The interferometric fabrication technique, the first external writing technique of forming Bragg gratings in photosensitive fibers, utilized an interferometer that split the incoming UV light into two beams and then recombined them to form an interference pattern. The fringe pattern was used to expose a photosensitive fiber, inducing a refractive index modulation in the core. Bragg gratings in optical fibers have been fabricated using both amplitude splitting and wave-front-splitting interferometers.

2.1.1. Amplitude-Splitting Interferometer

In an amplitude splitting interferometer, the UV writing laser light is split into two equal intensity beams and are later recombined after traversing through two different optical paths. This forms an interference pattern at the core of a photosensitive fiber. Cylindrical lenses are normally placed in the interferometer to focus the interfering beams to a fine line matching the fiber core. The Bragg grating period, L, which is identical to the period of the interference fringe pattern, depends on both the irradiation wavelength **λ*w*** and the half-angle between the intersecting UV beams.

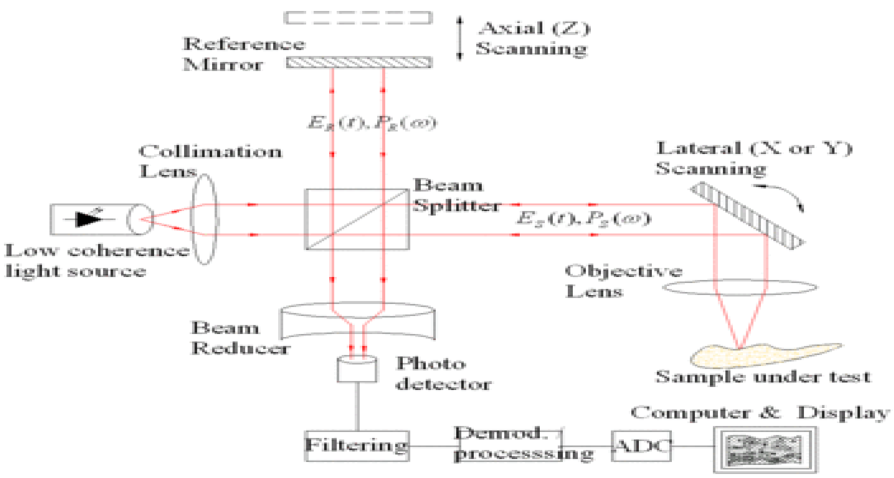

Figure 1: Amplitude-splitting interferometer

The period of the grating is given by:

$$\Lambda = \frac{\lambda\omega}{2\sin\varphi} \quad \ldots\ldots\ldots\ldots\ldots..1.1$$

Where λ*w*, is the UV wavelength and φ is the half-angle between the intersection UV beams. Although the interference pattern is formed in glass within the core of the optical fiber, its period is the same as it would be if the beams were interfering in air. This is a result of the refraction of the beams coupled with the shortening of the wavelength as they enter the glass [2]. The Bragg condition $\lambda_B=2n\Lambda$ states that the Bragg resonance wavelength, λ*B*, in the core of the fiber is twice the product of the effective core index, *n*, and the period of the grating. Hence, a Bragg grating resonance wavelength can be represented in terms of the UV writing wavelength and the half-angle between intersecting UV beams as:

$$\lambda_B=\frac{n\lambda\omega}{2\sin\varphi} \quad \ldots\ldots\ldots\ldots\ldots\ldots..1.2$$

Thus the Bragg grating wavelength can be varied either by changing λw and/or φ . The choice of λw is limited to the UV photosensitivity region of the fiber, however, there is no restriction set on the choice of the angle φ.

The most important advantage offered by the amplitude splitting interferometric fabrication technique is the ability to inscribe Bragg gratings at any wavelength. This is accomplished by simply changing the intersecting angle between the UV beams. This method also offers complete flexibility for producing gratings of various lengths, which allows the fabrication of wavelength narrowed or broadened gratings. Furthermore, unique grating geometries, such as linearly chirped gratings, can be produced by using curved reflecting surfaces in the beam delivery path.

The main disadvantage of the amplitude-splitting interferometric technique is its susceptibility to mechanical vibrations [3]. Displacements as small as sub-microns in the position of mirrors, beam splitter, or mounts in the interferometer can cause the fringe pattern to drift, washing out the grating.

Furthermore, due to long separate optical path lengths involved in the interferometers, air currents, which affect the refractive index locally, may cause a problem in the formation of a stable fringe pattern. In addition to the above shortcomings, quality gratings can only be produced with a laser source that has good spatial and temporal coherence with excellent output power stability.

2.1.2 Wave-Front-Splitting Interferometers

Wave-front splitting interferometers are not as popular as the amplitude splitting interferometers for grating fabrication. However, they have some useful advantages over the amplitude splitting interferometers. Two such wave-front-splitting interferometers that have been used to fabricate Bragg gratings in optical fibers are the prism interferometer and the Lloyds interferometer.

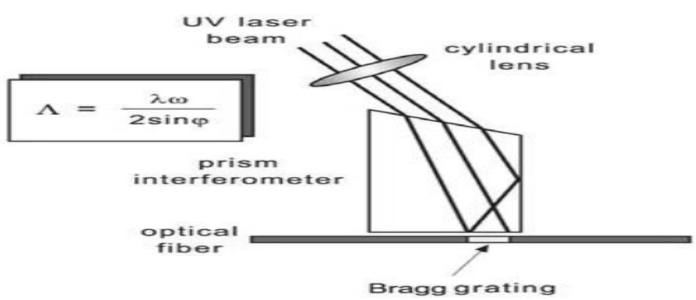

Figure 2: Wave-front-splitting interferometer

A schematic of the prism interferometer used in fabricating Bragg grating is shown in Figure 2. The prism is made from high homogeneity ultraviolet-grade fused silica allowing for good transmission characteristics. In this setup, the UV beam is expanded laterally by refraction at the input face of the prism. The expanded beam is spatially bisected by the prism edge, and half of the beam is spatially reversed by total internal reflection from the prism face. The two half beams are then recombined at the output face of the prism, giving a fringe pattern parallel to the photosensitive fiber core [4]. A cylindrical lens placed just before the setup helps in forming the interference pattern on a line along the fiber core. The experimental setup for fabricating gratings with the Lloyd interferometer is shown in Figure 3.

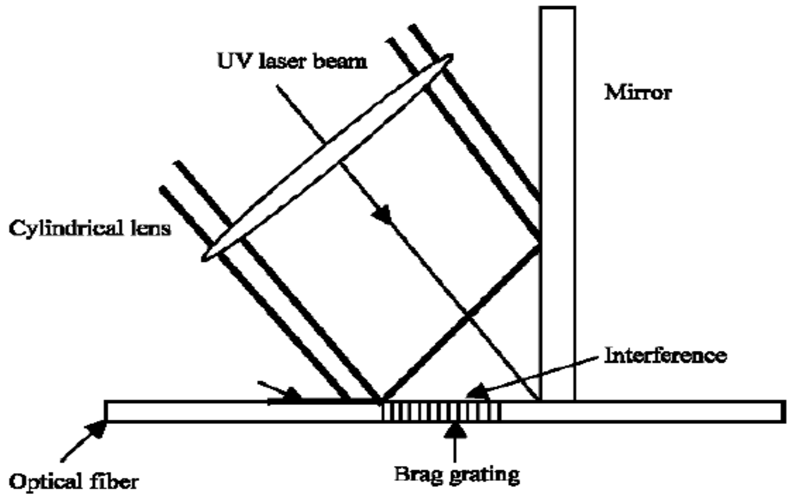

Figure 3: Experimental setup for Lloyd interferometer

This interferometer consists of a dielectric mirror, which directs half of the UV beam to a fiber that is perpendicular to the mirror. The UV beam is centered at the intersection of the mirror surface and fiber. The overlap of the direct and deviated portions of UV beam creates interference fringes normal to the fiber axis. As in the case of the previous interferometers, a cylindrical lens is usually placed in front of the system to focus the fringe pattern along the core of the fiber. A key advantage of the wave-front-splitting interferometers is that only one optical component is used. This greatly reduces the sensitivity to mechanical vibrations. In addition, the short distance where the UV beams are separated reduces the wave-front distortion induced by air currents and temperature differences between the two interfering beams. Furthermore, this assembly can be rotated easily to vary the angle of intersection of the two beams for wavelength tuning. One disadvantage of this system is the limitation on the grating length, which is restricted to half of the beam width [5]. Another disadvantage is the range of Bragg wavelength tune ability, which is restricted by the physical arrangement of the interferometers. That is, as the intersection angle increases, the difference between beam path lengths increases. Therefore, the beam coherence length limits the Bragg wavelength tune ability.

Laser sources used for inscribing Bragg gratings via the above interferometric techniques must have good temporal and spatial coherence. The spatial coherence requirements can be relaxed in the case of the amplitude-split interferometer by simply making sure that the total numbers of reflections are the same in both arms. This is especially critical in the case where a laser with low spatial coherence, like an excimer laser, is used as the source of UV light. The temporal coherence has to be at least the length of the grating in order for the interfering beams to have a good contrast ratio, thus, resulting in good quality Bragg gratings. The above coherence requirement together with the UV wavelength range needed forced researchers to initially use very complicated laser systems. One such system consisted of an excimer pumped tunable dye laser, operating in the range of 480– 500 nm. The output from the dye laser was focused on a nonlinear crystal to double the frequency of the fundamental light.

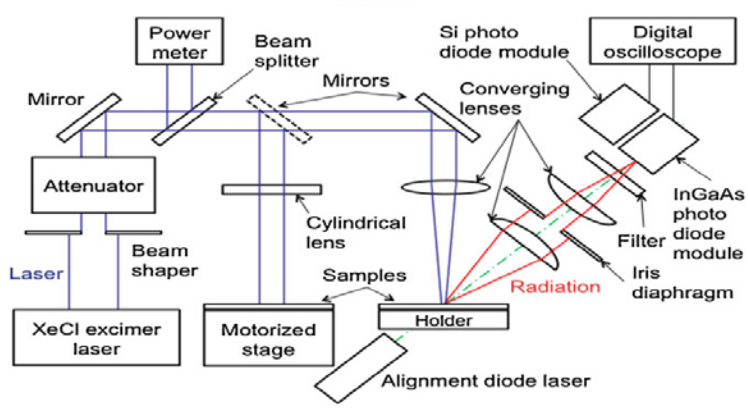

Figure 4: Experimental System for Excimer Laser

Typically, this arrangement provided 10–20 ns pulses depending on the excimer pump laser and of power 3–5 mJ with excellent temporal and spatial coherence. An alternative to this elaborate and often troublesome setup was a specially designed excimer laser that had a long temporal coherence length [5]. These spectrally narrow line width excimer lasers could operate for extended periods of time on the same gas mixture with little changes in their characteristics. Commercially available narrow line width excimer systems were complicated oscillator amplifier configurations, which made them extremely costly. Othonos and Lee developed a low-cost simple technique where existing KrF excimer lasers may be retrofitted with a spectral narrowing system for inscribing Bragg gratings in a side written interferometric configuration. In that work, a commercially available KrF excimer laser Lumonics Ex-600 was modified to produce a spectrally narrow laser beam as shown in Figure 5 with a line width of approximately 4x10-12 m.

This system was used to successfully inscribe Bragg gratings in photosensitive optical fibers. An alternative to the above system was the intracavity frequency-double argon ion laser that uses beta-barium borate.

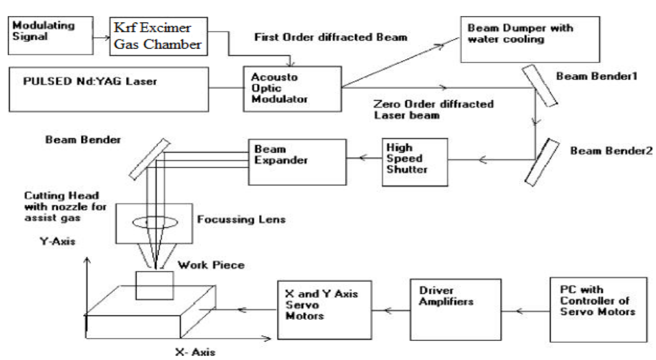

Figure 5: KrF Excimer Laser

This system efficiently converted high-power visible laser wavelengths into deep ultraviolet 244 and 248 nm. The characteristics of these lasers include unmatched spatial coherence, narrow line width and excellent beam pointing stability, which make such systems very successful in inscribing Bragg gratings in optical fibers.

2.1.3. Phase Mask Technique

One of the most effective methods for inscribing Bragg gratings in photosensitive fiber is the phase-mask technique. This method employs a diffractive optical element phase mask to spatially modulate the UV writing beam. Phase masks may be formed holo-graphically or by electron-beam lithography.

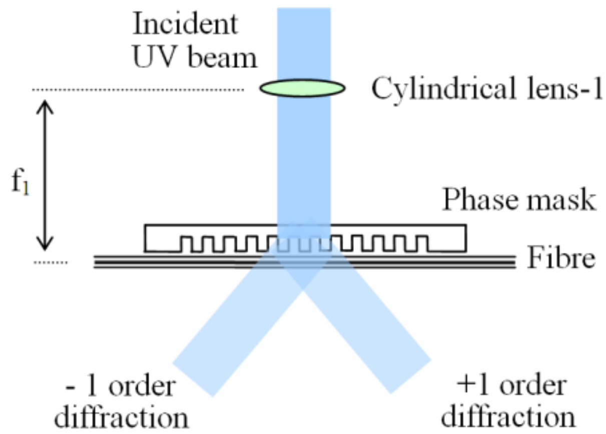

Figure 6: Phase Mask Technique

Holo-graphically induced phase masks have no stitch error, which is normally present in the electron-beam phase masks. However, complicated patterns can be written into the electron beams fabricated masks quadratic chirps, Moire patterns, etc. The phase-mask grating has a one-dimension surface-relief structure fabricated in a high-quality fused silica flat transparent to the UV writing beam. The profile of the periodic gratings is chosen such that when an UV beam is incident on the phase mask, the zero-order diffracted beam is suppressed to less than a few percent typically, less than 5% of the transmitted power. In addition, the diffracted plus and minus first orders are maximized; each containing, typically, more than 35% of the transmitted power [6].

A near-field fringe pattern is produced by the interference of the plus and minus first-order diffracted beams. Experimental setup is of an excimer pump dye laser with a frequency doubled BBO crystal for generating UV light at 245 nm for inscribing Bragg gratings in an interferometer minus first-order diffracted beams. The period of the fringes is one-half that of the mask. The interference pattern photo imprints a refractive-index modulation in the core of a photosensitive optical fiber placed in contact with or in close proximity immediately behind the phase mask. A cylindrical lens may be used to focus the fringe pattern along the fiber core.

The phase mask greatly reduces the complexity of the fiber grating fabrication system. The simplicity of using only one optical element provides a robust and an inherently stable method for reproducing Fiber Bragg Gratings. Since the fiber is usually placed directly behind the phase mask in the near field of the diffracting UV beams, sensitivity to mechanical vibrations and, therefore, stability problems are minimized. Low temporal coherence does not affect the writing capability as opposed to the interferometric technique due to the geometry of the problem. KrF excimer lasers are the most common UV sources used to fabricate Bragg gratings with a phase mask.

The UV laser sources, typically, have low spatial and temporal coherence. The low spatial coherence requires the fiber to be placed in near contact to the grating corrugations on the phase mask in order to induce maximum modulation in the index of refraction. The further the fiber is placed from the phase mask, the lower the induced index modulation, resulting in lower reflectivity Bragg gratings. Clearly, the separation of the fiber from the phase mask is a critical parameter in producing quality gratings [7]. However, placing the fiber in contact with the fine grating corrugations is not desirable due to possible damage to the phase mask. Improving the spatial coherence of the UV writing beam not only improves the strength and quality of the gratings inscribed by the phase-mask technique, it also relaxes the requirement that the fiber has to be in contact with the phase mask.

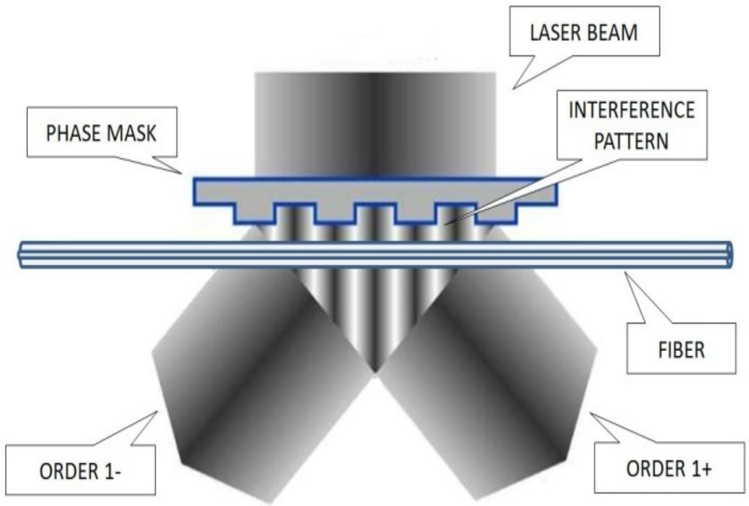

Figure 7: Schematic for Phase Mask Technique

To understand the significance of spatial coherence in the fabrication of Bragg grating using the phase-mask technique, it is helpful to consider a simple schematic diagram. Consider the fiber core to be at a distance h from the phase mask. The transmitted plus and minus first orders that interfere to form the fringe pattern on the fiber emanate from different parts of the mask separated by distance d. Since the distance of the fiber from the phase mask is identical for the two interfering beams, the requirement for temporal coherence is not critical for the formation of a high contrast fringe pattern.

On the other hand, as the distance ***h*** increases, the separation d between the two interfering beams emerging from the mask increases. In this case, the requirement for good spatial coherence is critical for the formation of a high contrast fringe pattern. As the distance ***h*** extends beyond the spatial coherence of the incident UV beam, the interference fringe contrast will deteriorate, eventually resulting in no interference at all. The spatial coherence uses a KrF laser irradiated phase mask to form gratings in polyimide film [8]. One of the advantages of not having to position the fiber against the phase mask is the freedom to be able to angle the fiber relative to the mask forming blazed gratings. Placing one end of the exposed fiber section against the mask and the other end at some distance from the mask, it is possible to change the induced Bragg grating center wavelength. From simple geometry, one can derive a general expression for the tunability of the Bragg grating center wavelength, given by:

$$\lambda B = 2n\,\Lambda\sqrt{1+\left(\frac{r}{l}\right)2} \qquad \text{……………………..1.3}$$

Where **Λ** is the period of the fiber grating, ***r*** is the distance from one end of the exposed fiber section to the phase mask, and ***l*** is the length of the phase grating. For a fixed phase mask period changing *r* will result in blazed gratings with changing center Bragg wavelength.

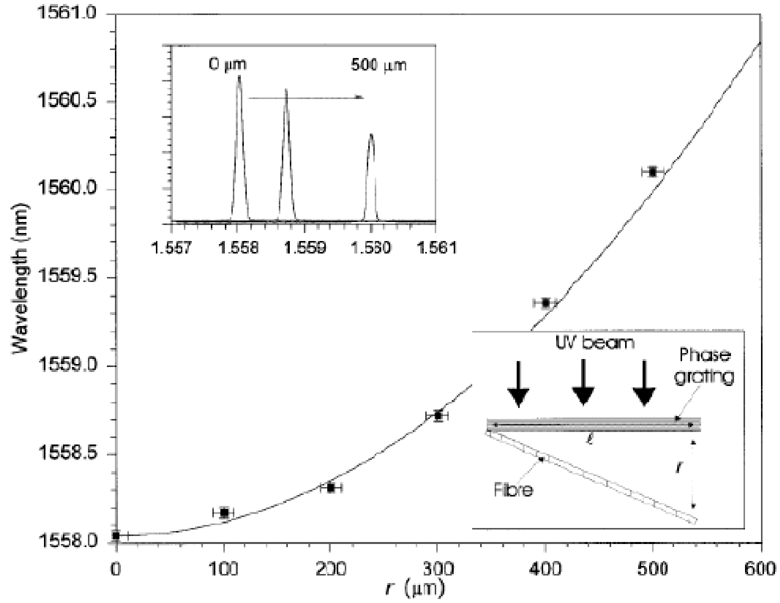

Figure 8: Theoretical curve for the tunability of the inscribed Bragg grating

Figure 8 shows the theoretical curve for the tunability of the inscribed Bragg grating as a function of distance *r*. The experimental values for the peak reflectivity of the Bragg gratings are also shown for different *r* values.

2.1.4. Point-By-Point Fabrication of Bragg Gratings

The point-by-point technique for fabricating Bragg gratings is accomplished by inducing a change in the index of refraction a step at a time along the core of the fiber. Each grating plane is produced separately by a focused single pulse from an excimer laser. A single pulse of UV light from an excimer laser passes through a mask containing a slit. A focusing lens images the slit onto the core of the optical fiber from the side, and the refractive index of the core in the irradiated fiber section increases locally. The fiber is then translated through a distance L corresponding to the grating pitch in a direction parallel to the fiber axis and the process is repeated to form the grating structure in the fiber core. Essential to the point-by-point fabrication technique is a very stable and precise submicron translational system.

The main advantage of the point-by-point writing technique lies in its flexibility to alter the Bragg grating parameters as the grating structure is built up a point at a time. Variations in grating length, grating pitch, and spectrum are possible. Experimental result of tuning a Bragg grating by tilting the writing fiber response can easily be incorporated. Chirped gratings can be produced accurately simply by increasing the amount of fiber translation each time the fiber is irradiated [9]. The point-by-point method allows for the fabrication of spatial-mode converters and polarization-mode converters or rocking filters that have grating periods, L, ranging from tens of micrometers to tens of millimeters. Because the UV pulse energy can be varied between points of induced index change, the refractive-index profile of the grating can be tailored to provide any desired spectral response.

One disadvantage of the point-by-point technique is that it is a tedious process. Because it is a step-by-step procedure, this method requires a relatively long process time. Errors in the grating spacing due to thermal effects and/or small variations in the fibers strain can occur. This limits the gratings to a very short length. Typically, the grating period required for first-order reflection at 1550 nm is approximately 530 nm. Because of the submicron translation and tight focusing required, first-order 1550 nm Bragg gratings have yet to be demonstrated using the point-by-point technique.

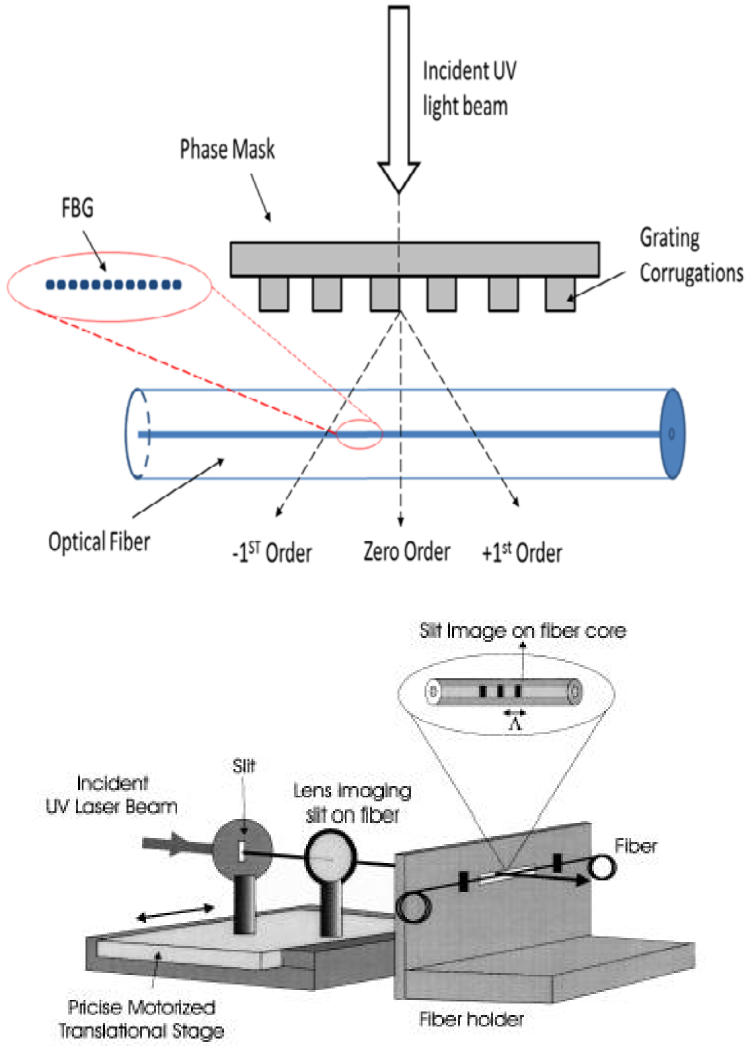

Figure 9: Point-by-Point Technique

3. Mask Image Projection

In addition to the above well-known techniques for fabricating Fiber Bragg Gratings, high-resolution mask projection has been demonstrated as a means of inscribing Bragg gratings in optical fiber using excimer laser pulses. The mass projection system consists of an excimer laser source generating an UV beam, which is incident on a transmission mask. In these experiments, the transmission mask consisted of a series of UV opaque line spaces [10]. The transmitted beam was imaged onto the fiber core by a multi-component fused silica high-resolution system having a demagnification of 10:1. Using this technique, gratings with periods of 1, 2, 3, 4, and 6 μm have been written in single-mode Ge doped fiber using mask-imaging techniques. Because of the simplicity of the source and setup, the recording of coarse period gratings by mask-imaging exposures, in some cases, may be more flexible than other techniques. Complicated grating structures like blazed, chirped, etc. can be readily fabricated with this method by implementing a simple change of mask.

4. Types of Fiber Bragg Gratings

There are several distinct types of Fiber Bragg Grating structures such as the common Bragg reflector, the blazed Bragg grating, and the chirped Bragg grating. These Fiber Bragg Gratings are distinguished either by their grating pitch, spacing between grating planes or tilt angle between grating planes and fiber axis. The most common Fiber Bragg Grating is the Bragg reflector, which has a constant pitch. The blazed grating has phase fronts tilted with respect to the fiber axis, that is, the angle between the grating planes and the fiber axis is less than 90°. The chirped grating has an a periodic pitch, that is, a monotonic increase in the spacing between grating planes.

4.1. Common Bragg Reflector

The common Bragg reflector was the first intra core fiber grating inscribed using the self-induced writing method. Depending on the parameters such as grating length and magnitude of induced index change, the Bragg reflector can function as a narrow-band transmission or reflection filter or a broadband mirror. In combination with other Bragg reflectors, these devices can be arranged to function as band pass filters. Bragg reflectors are considered as excellent strain and temperature sensing devices because the measurements are wavelength encoded. This eliminates the problems of amplitude or intensity fluctuations that exist in many other types of fiber sensors. Since each Bragg reflector can be designated with its own wavelength-encoded signature, a series of these gratings can be written on the same fiber, each having a distinct Bragg resonance signal [11]. This configuration can be used for wavelength division multiplexing or quasi distributed sensing. These gratings have also been demonstrated to be very useful components in tunable fiber or semiconductor lasers. It serves as one or both ends of the laser cavity, depending on the laser configuration, and it tunes the laser wavelength by varying the Bragg resonance feedback signal. Continuously tunable single-mode erbium fiber laser was made using these gratings. In this laser system, two Bragg reflectors were used in a Fabry–Perot configuration. Continuous tunability, without mode hopping, was achieved when both the gratings and enclosed fiber were stretched uniformly. Bragg grating fiber lasers can also be used as sensors where the Bragg reflector serves the dual purpose of tuning element and sensor. A series of Bragg reflectors having distinct wavelength-encoded signatures can be multiplexed in a fiber laser sensor configuration for multipoint sensing.

4.2. Blazed Bragg Gratings

Tilting or blazing the Bragg grating planes at angles to the fiber axis will result in light that is otherwise guided in the fiber, to be coupled out of the fiber core into loosely bound guided cladding modes or into radiation modes outside the fiber. The tilt of the grating planes and strength of the index modulation determines the coupling efficiency and bandwidth of the light that is tapped out. The criterion to satisfy the Bragg condition of a blazed grating is similar to that of the Bragg reflector that was analyzed earlier. Erbium-doped fiber amplifiers that use these gratings are now an integral part of long-haul high-bit-rate communication systems and are finding applications in areas of wide bandwidth amplification. Another interesting application of blazed gratings is in mode conversion [12]. Mode converters are fabricated by inducing a periodic refractive-index perturbation along the fiber length with a periodicity that bridges the momentum mismatch between the modes to allow phase-matched coupling between the selected modes. Different grating periods are used for mode conversion at different wavelengths.

4.3. Chirped Bragg Grating

A chirped Bragg grating is a grating that has a monotonically varying grating period. This can be realized by axially varying either the period of the grating L or the index of refraction of the core or both. Chirped gratings have been written in optical fibers using various methods. A double exposure technique has been used in forming a 1.5 cm long chirped grating. The effective mode index of the waveguide was modulated linearly over the grating length with radiation from an excimer laser and then the same length was re-exposed with a phase mask to produce a linearly chirped grating. A chirp of 0.4 nm was demonstrated at 1549 nm. The delay induced by the gratings was shown to be approximately 120 p_s over the entire bandwidth of the grating.

A highly repeatable and simple technique for producing chirped gratings is based on the phase mask where the linear chirp is approximated by a step chirp. In this technique, a cascade of several gratings with increasing period is used to simulate a long chirped grating. The chirped structure is initially inscribed on the phase mask and then the mask is used to fabricate the chirped Bragg gratings in the photosensitive fiber. Clearly, this is a highly repeatable and controllable technique for producing any type of chirped Bragg structure in fiber.

For forward propagating light, longer wavelengths travel further into the grating before being reflected. With the introduction of an erbium-doped amplifier in long-haul high-bit-rate communication systems, the main limitation in transmitting over such distance is the pulse broadening caused by chromatic dispersion. Dispersion induced pulse broadening can be eliminated by an element having a dispersion of opposite sign and equal magnitude to that of the optical fiber link. In a chirped grating, the resonant frequency is a linear function of the axial position along the grating so that different frequencies, present in the pulse, are reflected at different points and, thus, acquire different delay times [13]. Chirped gratings, therefore, can be used as dispersion compensators to compress temporally broadened pulses.

In telecommunication systems, residual pump light emitted from an optical fiber amplifier can cause major problems. The performance of a receiver can be adversely affected by the residual pump power emitted from a preamplifier because it can cause excess noise and receiver saturation. The fiber amplifier performance can be improved by reflecting back the unabsorbed pump light at the amplifier output. Broadband chirped Fiber Bragg Grating can be used for pump rejection and recycling of unabsorbed pump light from an erbium-doped fiber amplifier.

4.5. Bragg Gratings and Novel Bragg Gratings

In an experiment carried out to study the relationship between pulse energy and grating strength, a series of single pulse gratings were produced with an UV excimer laser beam. The UV beam was focused to an area of approximately 1530.3 mm^2 at the fiber. The peak-to-peak index modulation of each grating was estimated from its reflection spectrum using coupled-mode theory. It is apparent that there is a sharp threshold at pulse energy of 30 mJ, above which the induced index modulation increases dramatically. Doubling the pulse energy from 20 to 40 mJ results in an increase in the photo induced index modulation by almost three orders of magnitude. Below the threshold point, the index modulation seems to grow linearly with energy density, whereas above the index modulation it appears to saturate. The gratings formed with a low index of refraction modulation were labeled as type I and those formed with a high index of refraction modulation were called type II. There is a critical level of absorbed energy, which triggers off a highly nonlinear mechanism, initiating dramatic changes in the optical fiber.

Examination of a type grating with an optical microscope revealed a damaged track at the core-cladding interface. This damage track appears only in type gratings, which suggests that it may be responsible for the large index change. The fact that this damage is localized on one side of the core suggests that most of the UV light has been absorbed, most likely never reaching the other side. A characteristic of type Bragg gratings is that they have a very high reflectivity and large bandwidth [14]. The irregularities in the spectra are a sign of grating non uniformity, which is because of the non uniformities in the intensity profile of the excimer laser writing beam. In addition, type gratings transmit wavelengths longer than the Bragg center wavelengths but strongly couple shorter wavelengths into the cladding, permitting the gratings to act as effective wavelength selective taps. Results of stability tests have shown type II gratings to be extremely stable at elevated temperatures. At 800 °C over a period of 24hrs, no degradation in grating reflectivity was evident. At 900 °C, the grating reflectivity decays quite slowly until a permanent component appears. At 1000 °C, most of the grating disappears after 4 hrs.

The mechanism behind high-reflectivity type II single-pulse gratings differs from the usual type I mechanism. The superior temperature stability of gratings make them useful for sensing applications in hostile environments. One of the most attractive features of gratings is that highly reflective gratings can be formed in just a few nanoseconds i.e. duration of a single excimer pulse. This is of great practical importance for large-scale mass production of strong gratings during the fiber drawing process before application of the protective polymer coating. One distinct advantage of producing Fiber Bragg Gratings during the draw process is that in-line fabrication avoids potential contact with the pristine outer surface of the glass. Whereas, off-line fabrication requires a section of the fiber to be stripped off its UV absorbing polymer coating, in order for the grating to be exposed. This drastically weakens the fiber at the site of the grating due to surface contamination, even if the fiber is subsequently recoated.

Superimposed multiple Bragg gratings basically perform a comb function, this device is ideally suited for multiplexing and de multiplexing signals. This device is that it does not require much space because all the gratings are written at the same location of the fiber. This lends itself to optical integrated technology, where the issue of size is always a concern, and can also be used for material detection where the multiple Bragg lines can be designed to match the signature frequencies of a given material [15]. Another interesting observation is that the center wavelength of the existing Bragg gratings shifted to longer wavelengths each time a new grating was inscribed due to a change of the effective index of refraction. Superstructure Bragg grating is referred to a grating fiber structure fabricated with a modulated exposure over the length of the gratings. One such approach was to translate the UV writing beam along a fiber and phase-mask assembly while the intensity of the beam was modulated. An excimer pumped dye laser was used with a frequency doubler to produce 2.0 mJ at 240 nm. Hydrogenated, single-mode, boron co doped fiber was placed in near contact with a phase mask, and the ultraviolet light was focused through the phase mask into the fiber core by a cylindrical lens, exposing a length of approximately 1 mm. To fabricate a 40 mm long superstructure, the excimer laser was periodically triggered at intervals of 15 s to produce bursts of 150 shots at a repetition rate of 10 Hz, while the ultraviolet beam was translated at a constant velocity of 0.19 mm/s along the mask. The resulting period of the grating envelope was approximately 5.65 mm, forming seven periods of the superstructure. These superstructure gratings can be used as comb filters for signal processing, and for increasing the tunability of the fiber laser grating reflector.

Bragg gratings generally act as narrow-band reflection filters centered at the Bragg wavelength because of the stop band associated with a one-dimensional periodic medium. Many applications, such as channel selection in a multichannel communication system, would benefit if the fiber grating could be designed as a narrow-band transmission filter. Although techniques based on Michelson and Fabry–Perot interferometers have been developed for this purpose, their use requires multiple gratings and may introduce additional losses. A technique commonly used in distributed feedback semiconductor lasers can be used to tailor the transmission spectrum to suit specific requirements [16]. The technique consists of the introduction of phase shift across the fiber grating whose location and magnitude can be adjusted to design a specific transmission spectrum. One of the most obvious applications includes production of very narrowband transmission and reflection filters. Moreover, multiple phase shifts can be introduced to produce other devices such comb filters. They can also be used to obtain single-mode operation of DFB fiber lasers.

5. Properties of Bragg Gratings

In its simplest form, a Fiber Bragg Grating consists of a periodic modulation of the index of refraction in the core of a single-mode optical fiber. These types of uniform fiber gratings, where the phase fronts are perpendicular to the fiber longitudinal axis and the grating planes are of a constant period, are considered the fundamental building blocks for most Bragg grating structures.

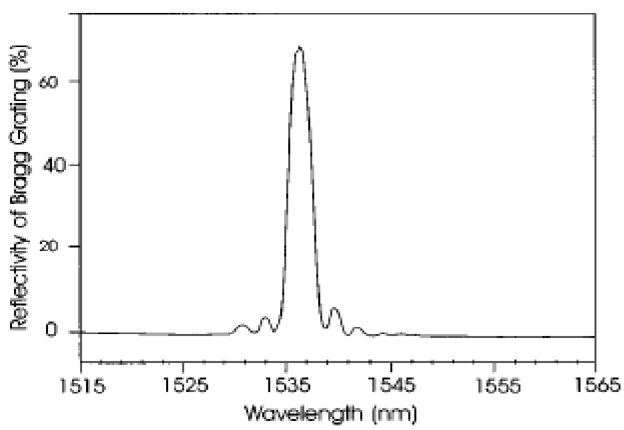

Figure 10: Spectral Response of FBG.

Light guided along the core of an optical fiber will be scattered by each grating plane. If the Bragg condition is not satisfied, the reflected light from each of the subsequent planes becomes progressively out of phase and will eventually cancel out. Where the Bragg condition is satisfied, the contributions of reflected light from each grating plane add constructively in the backward direction to form a back-reflected peak with a center wavelength defined by the grating parameters. The Bragg grating condition is simply the requirement that satisfies both energy and momentum conservation. Energy conservation requires that the frequency of the incident radiation and the reflected radiation is the same. Momentum conservation requires that the incident wave vector, **k*i*** , plus the grating wave vector, **K**, equal the wave vector of the scattered radiation **k*f*** , this is simply stated as:

ki+K = kf …………………..1.4

Where the grating wave vector, **K**, has a direction normal to the grating planes and it has a magnitude 2 p/L, L is the grating spacing.

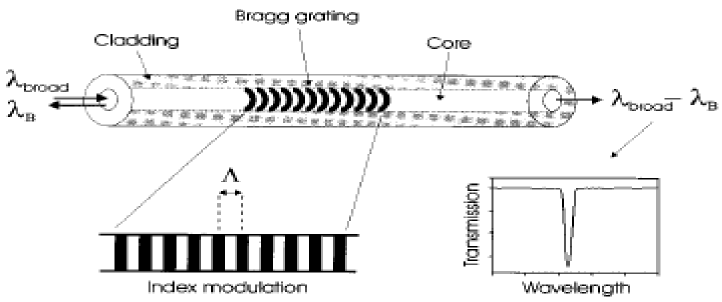

Figure 11: Transmission Spectra of FBG

The diffracted wave vector is equal in magnitude but opposite in direction to the incident wave vector. Hence, the momentum conservation condition becomes.

$$2\frac{(2\pi n)}{(\lambda B)} = \frac{2\pi}{\Lambda}$$ …………….1.5

Which simplifies to the first-order Bragg Condition?

$$\lambda B = 2n\Lambda$$ ………………1.6

Where the Bragg grating wavelength, λB, is the free-space-center wavelength of the input light that will be back reflected from the Bragg grating, and n is the effective refractive index of the fiber core at the free-space-center-wavelength. Software tools are available for simulating fiber bragg gratings.

6. Conclusion

There are several distinct types of Fiber Bragg Grating structures such as the common Bragg reflector, the blazed Bragg grating, and the chirped Bragg grating. These Fiber Bragg Gratings are distinguished either by their grating pitch spacing between grating planes or tilt angle between grating planes and fiber axis. In addition to the above well-known techniques for fabricating Fiber Bragg Gratings, high-resolution mask projection has been demonstrated as a means of inscribing Bragg gratings in optical fiber using excimer laser pulses.

7. References

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