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An investigation on the techniques for inscribing Bragg grating structures

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This article describes the various techniques used in fabricating standard and complex Bragg grating structures in optical fibers. The objective here is to review a detailed outlook on the technology for writing fiber Bragg gratings. The fiber Bragg grating represents a periodic variation of the refractive index of the fiber core along the length of the fiber. Writing a fiber grating optically in the core of an optical fiber requires irradiating the core with a periodic interference pattern. Depending on the fabrication technique employed, Bragg gratings may be labeled as internally or externally written. Far more useful, Bragg gratings are inscribed using external techniques such as the interferometric, point-by-point and phase mask which overcome the fundamental limitation of internally written gratings. Although, these processes were initially considered difficult due to the requirements of submicron resolution and thus stability, today they are well controlled and the inscription of Bragg gratings using these techniques is considered routine. One of these methods (phase mask) has been used to fabricate the fiber Bragg gratings for optical sensing such as temperature and strain. The main aim of this article is to compare these methods and the selection of the optimal method for the fabrication of required fiber Bragg grating.

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Keywords: Fiber Bragg grating, Fabrication techniques, Phase mask method, Optical sensing

1. Introduction

While the use of wavelength selective filters and grating related structures in semiconductor devices and thin film waveguides has been adopted for many years, the fabrication of periodic structures in optical fibers for practical use is still a relatively recent phenomenon, made possible by the discovery of photosensitivity in optical fibers by Hill et al. [1] at the Communication Research Center in Ottawa, Canada, in 1978. Most of methods intended to fabrication of fiber gratings are used to exposure of the fiber to the UV laser light. Several methods have been proposed to tune the Bragg wavelength of fiber gratings during UV exposure. Interferometric techniques [2-4], such as the two-mirror interferometer originally proposed by Meltz et al [2] or the classical Lloyd configuration [3],are often used to write short gratings with lengths usually less than 1 cm [2-4]. Longer gratings can be obtained by concatenation of these small gratings. Controlled motion of the optical fiber, usually obtained by interferometric sensing is then required to achieve precise positioning of the grating elements [5]. When using phase mask scanning techniques [6-7], tuning of the Bragg wavelength can be achieved over a limited range [8-12], typically less than 10 nm. Methods that have been proposed to control the Bragg wavelength include tilting the fiber [8], rotating the scanning mirror [9], stretching the fiber [10], varying the curvature of the writing wavefront [11] or moving the fiber relative to the phase mask [12]. Consequently, a variety of different methods to produce fiber Bragg gratings have been developed.

2. Fabrication techniques

Fabrication techniques can be grouped into two basic approaches; internally inscribed Bragg gratings and externally inscribed Bragg gratings;

2.1. Internally inscribed Bragg gratings

Writing a fiber grating optically in the core of an optical fiber requires irradiating the core with a periodic interference pattern. Historically, this was achieved by interfering light that propagated in a forward direction along an optical fiber with light that was reflected from the fiber end and propagated in a backward direction. This method for forming fiber gratings is known as the internal writing technique, and the gratings were referred to as *Hill gratings*. Internally inscribed Bragg gratings were first demonstrated in 1978 by Hill and his co-workers [1, 13] in a simple experimental setup as shown in Fig. 1. An argon ion laser was used as the source, oscillating on a single longitudinal mode at 514.5 nm (or 488 nm) exposing the photosensitive fiber by coupling light its core. Isolation of the argon ion laser from the back-reflected beam was necessary to avoid instability furthermore the pump laser and the fiber were placed in a tube for thermal isolation. The incident laser light interfered with the Fresnel reflection (approximately 4% from the cleaved end of the fiber) to initially form a weak standing wave intensity pattern within the core of the fiber. The high-intensity points alter the index of refraction in the photosensitive fiber permanently. Thus, a refractive index perturbation having the same spatial periodicity as the interference pattern is formed. These types of gratings normally have a long length (tens centimeters) in order to achieve useful reflectivity values due to the small index of refraction changes.

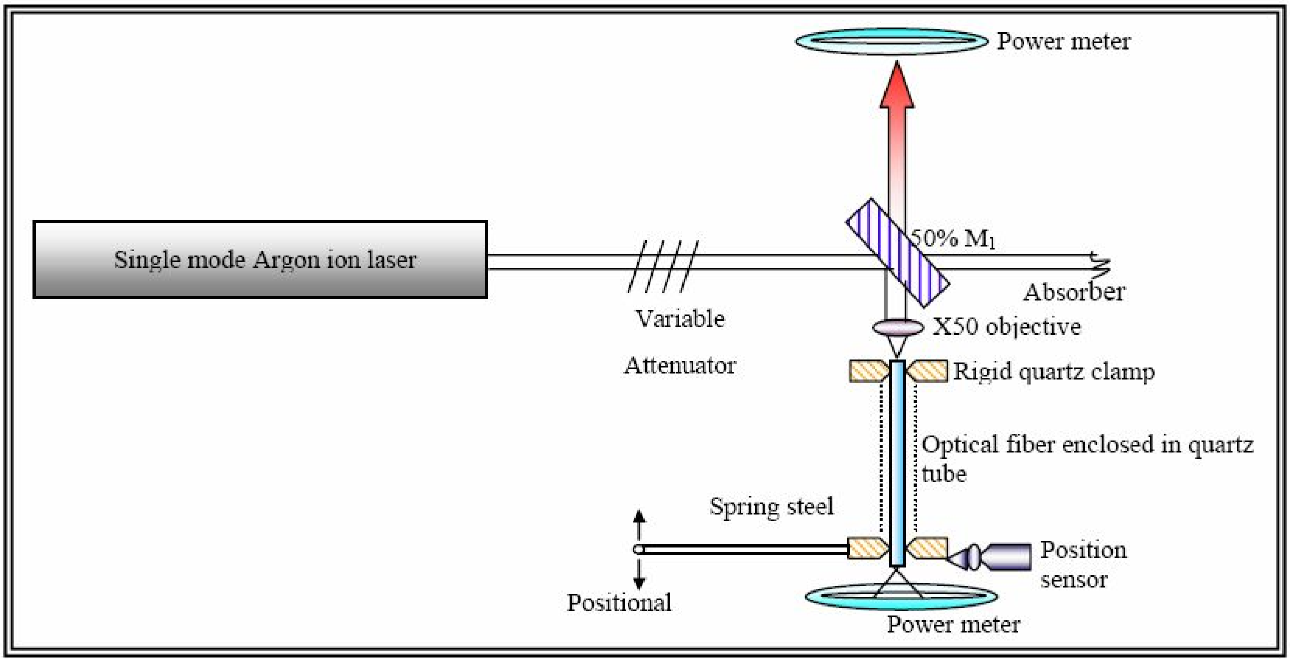

Fig. 1. A typical apparatus used for generating self-induced Bragg gratings.

2.2. Externally inscribed Bragg gratings

The externally inscribed Bragg gratings, which is an interferometric writing approach for inscribing Bragg gratings in photosensitive fibers, was first demonstrated by Meltz and coworkers [14]. In that experiment, an incident UV light beam was splitted into two beams that were subsequently recombined to form an interference pattern that side-exposed a photosensitive fiber, including a permanent refractive index modulation in the core. The externally inscribed Bragg grating is further divided into three main categories; interferometric, point by point and phase mask techniques.

2.2.1 Interferometric techniques

Interferometric technique exists in several various manifestations. Fabrication of fiber Bragg gratings in optical fiber using interferometric techniques has been demonstrated many researchers since 1989. A combination of interferometres setup with a phase mask is also reported such as;

(i) Amplitude-splitting interferometric
(ii) Wavefront-splitting interferometric
(iii) Sagnac interferometric phase mask technique
(iv) Noncontact interferometric phase mask technique
(v) Talbot interferometric phase mask technique
(iv) Transverse holographic interferometric technique

(i) Amplitude-splitting interferometers

The amplitude-splitting interferometer is the most versatile technique for fabricating Bragg grating. An amplitude-splitting interferometer was used by Meltz et al [14] to fabricate fiber a Bragg grating, the experimental arrangement is shown in Fig. 2. An excimer-pumped dye laser operating at a wavelength in the range of 486-500 nm was frequency doubled using a non-linear crystal. This provided a UV source in the 244 nm band with adequate coherence length. The UV laser light is splitted into two beams of equal intensity that were recombined to produce an interference pattern, normal to the fiber axis. A pair of cylindrical lenses focused the light onto the fiber and the resulting focal line was approximately 4 mm long by 124 μm wide. The interfering beams are normally focused to a fine line matching the fiber core using a cylindrical lens placed outside the interferometer. This results in higher intensities at the core of the fiber, thereby improving the grating inscription. Amplitude-splitting technique is based on the interferometer which splits the incoming laser beam into two beams and then recombines them to form an interference pattern. The interference pattern induces a refractive index modulation in the fiber core with the same spatial periodicity as the interference pattern [15].

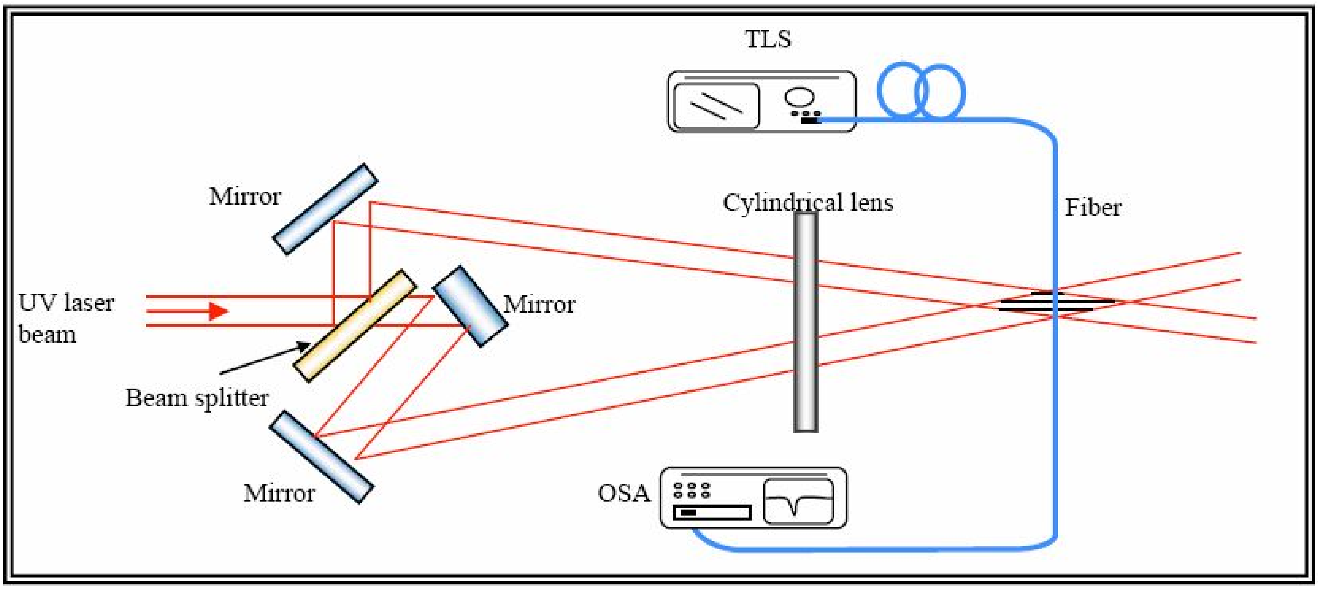

Fig. 2. Amplitude-splitting interferometer.

Obtaining of very high refractive index changes is depended on the high contrast and stability of the interference pattern. The spatial period Λ is related with the writing wavelength on the basis of equation:

$$\Lambda = \lambda_{UV} / 2 \sin(\theta / 2) \qquad (2.1)$$

Given the Bragg condition, the Bragg wavelength can be represented as

$$\lambda_B = \lambda_{UV} n_{eff} / \sin(\theta) \qquad (2.2)$$

One can easily see that the Bragg wavelength can be varied either by changing λ_{UV} and / or θ. Where λ_{UV} is the wavelength of the basic laser beam, θ is the intersecting angle between two writings beams; Λ is spatial period of grating. By changing the intersecting angle θ between the two writing beams, having a wavelength equal to λ_{UV}, it is possible to write Bragg grating for almost any wavelength [16].

(ii) Wavefront-splitting interferometer

Wavefront-splitting interferometers are not as popular as amplitude splitting interferometers for grating fabrication but, however, they offer some useful advantages.

This technique exists in several different manifestations, but here we describe only two types as follows;

(a) Wavefront-splitting by prism interferometer
(b) Wavefront-splitting by Lloyds interferometer

(a) Wavefront-splitting by Lloyd's interferometer

The experimental set up for fabricating gratings with Lloyd interferometer is shown in Figure 3. This interferometer consists of a dielectric mirror, which directs half of the UV beam to a fiber that is perpendicular to the mirror. The overlap of the direct and deviated portions of UV beam creates interference fringes normal to the fiber axis. A cylindrical lens is usually placed in front of the system to focus the fringe pattern along the core of the fiber. Since half of the incident beam is reflected, interference fringes appear in a region of length equal to half the width of the beam. Secondly, half the beam is folded onto the other half, interference occurs, but the fringes may not be of high quality. In the Lloyd arrangement, the folding action of the mirror limits what is possible. It requires a source with a coherence length equal to at least the path difference introduced by the fold in the beam. Ideally the coherence and intensity profile should be constant across the writing beam, otherwise, the fringe pattern and thus the inscribed grating will not be uniform. Furthermore diffraction effects at the edge of the dielectric mirror may also cause problems with the fringe pattern.

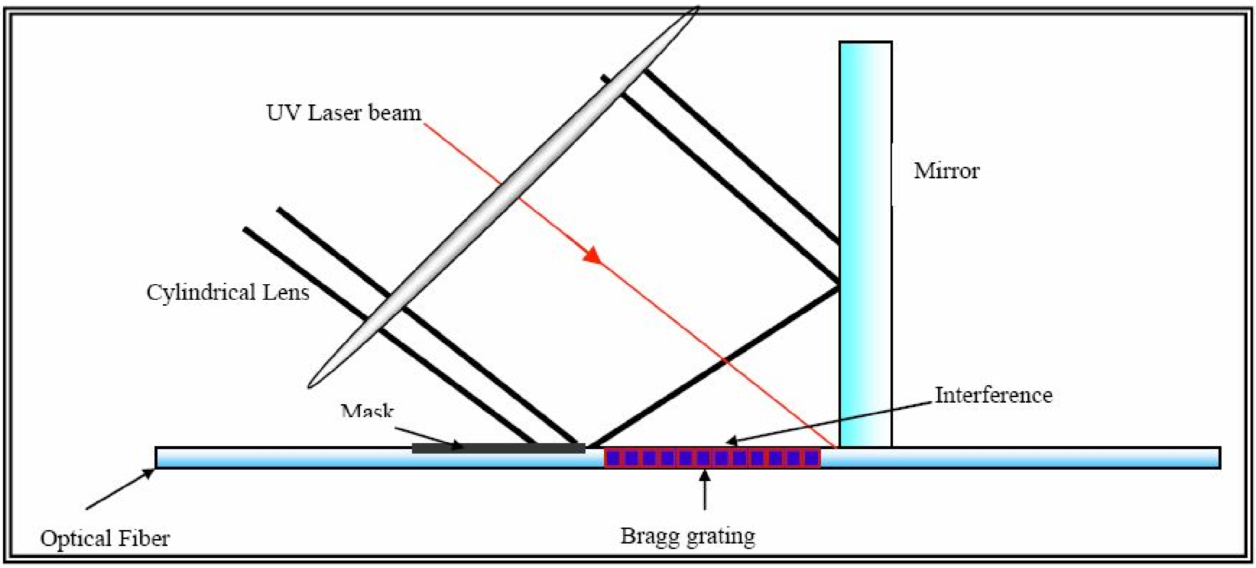

Fig. 3. A schematic of the Lloyd wavefront-splitting interferometer.

(b) Wavefront-splitting by prism interferometer

A schematic of the prism interferometer is shown in Fig. 4. The prism is made from high homogeneity, ultraviolet-grade, and fused silica allowing for good transmission characteristics. In this setup the UV beam is spatially bisected by the prism edge and half the beam is spatially reversed by total internal reflection from the prism face. The two beam halves are then recombined at the output face of the prism, giving a fringe pattern parallel to the photosensitive fiber core. A cylindrical lens placed just before the setup helps in forming the interference pattern on a line along the fiber core. The interferometer is intrinsically stable as the path difference is generated within the prism and remains unaffected by vibrations.

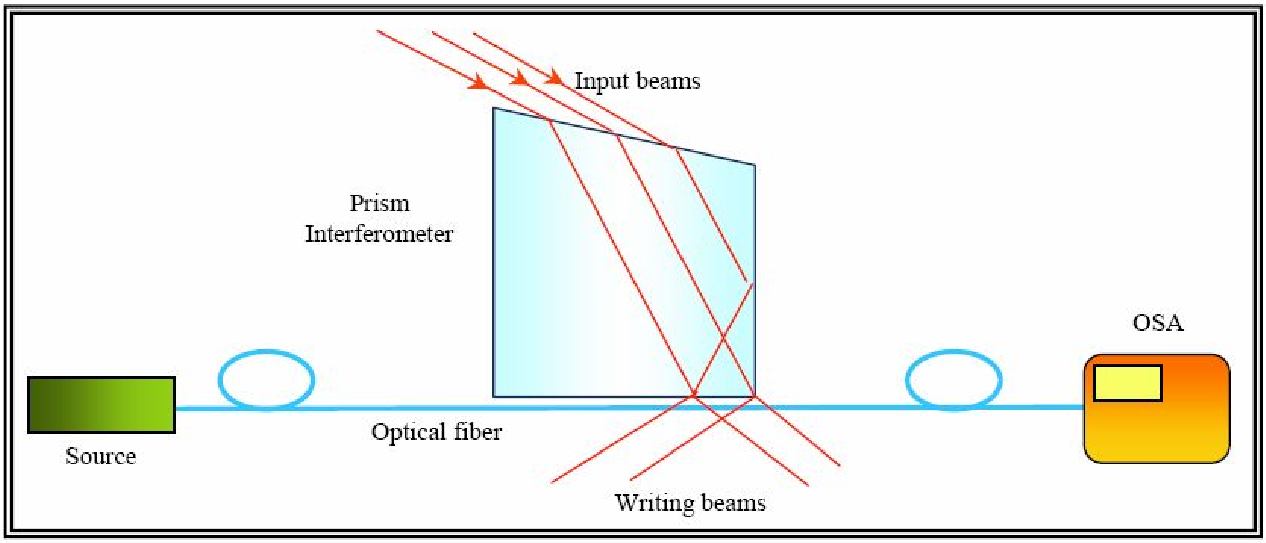

Fig. 4. A schematic of the prism wavefront-splitting interferometer.

(iii) Sagnac interferometric phase mask technique

The Sagnac-type interferometer, originally proposed by Ouellette and Krug [17] combines the flexibility of interferometric technique, by allowing tuning of the Bragg wavelength over a wide range, and the advantage of phase mask scanning techniques in producing good quality longer gratings. It has some similarities to a folded version of the Talbot interferometer proposed by Kahsyap [18]. The Sagnac interferometer used to write BGA is presented in Fig. 5. In this method, the phase mask diffracts the light in the +1 and – 1 order thereby producing two counter-propagating beams in the interferometer. The optical fiber is placed slightly above the phase-mask and a small out-of-plane tilt is introduced to the two mirrors to recombine the UV beams at the optical fiber position. Since both diffracted beams interact with the two mirrors, this interferometer is immune to some vibration modes of the mirrors and a stable interferometer can easily be realized.

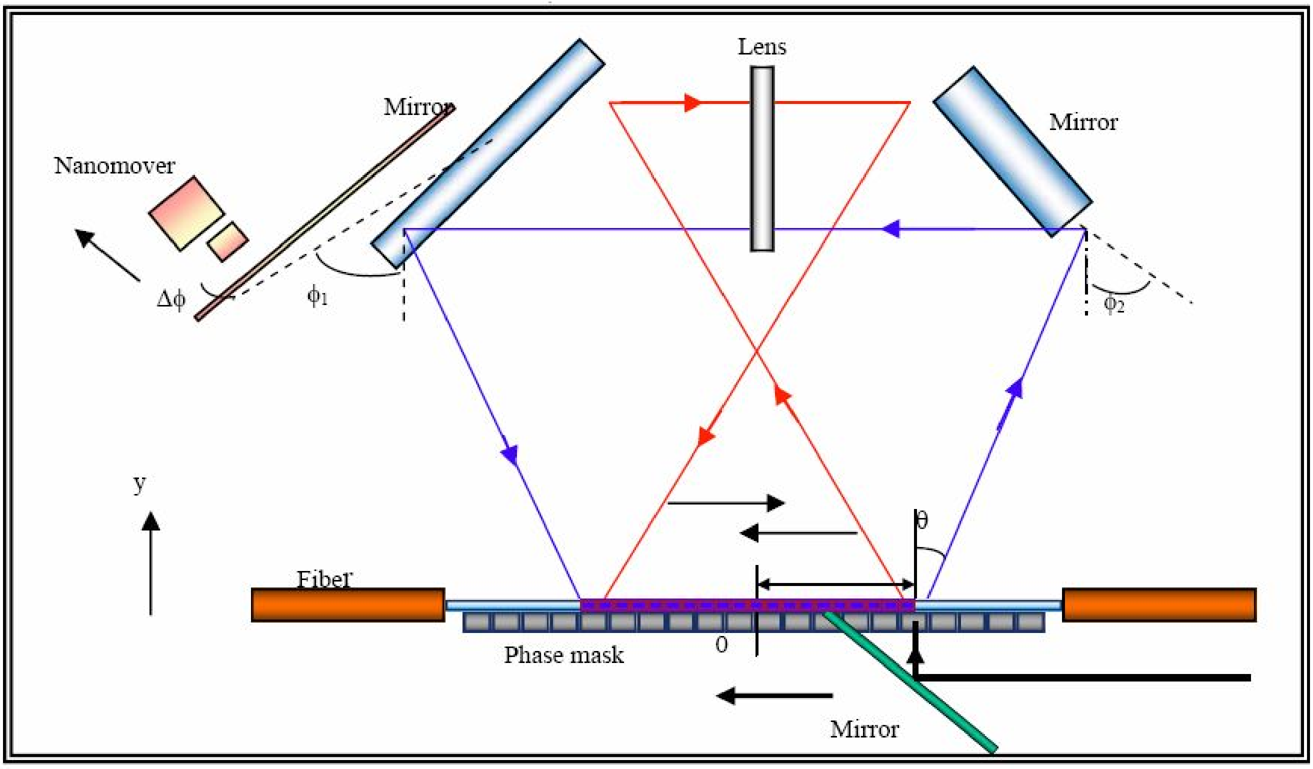

Fig. 5. Sagnac interferometric phase mask technique.

Any UV light diffracted to higher orders or remaining in the zero order is eliminated by this configuration. A cylindrical lens is introduced between the mirrors to focus the light along the optical fiber axis. When scanning of the phase mask is performed, the exposed region of the fiber moves in opposite direction to the translation of the UV beam. As in other interferometric methods, variation of the angle between the two interfering beams results in a modification of the photo-induced grating period. In this case, the Bragg wavelength, changes according to

$$\lambda_B = \lambda_{uv}\, n_{eff} / \sin(\pi - 2\Phi_1 - 2\Phi_2 - \theta) \qquad (2.3)$$

where n_{eff} is the effective index of the guided mode, λ_{uv} is the writing wavelength, Φ_1 and Φ_2 the mirror angles. When simultaneously moving both mirrors ($\Phi_1 = \Phi_2 = \Phi$), the Bragg wavelength tuning is

$$\Delta\lambda_B / \lambda_B = 4\cot(\pi - 4\Phi - \theta)\,\Delta\Phi \qquad (2.4)$$

when $\Phi_1 = \Phi_2 = (\pi/4) - (\theta/2)$ the interference occurs directly above the phase-mask and the Bragg wavelength is given by the usual expression $\lambda_B = n_{eff}\Lambda_{pm}$, where Λ_{pm} is the phase-mask period. With a typical phase mask period of $\Lambda_{pm} \approx 1070$ nm, the angular sensitivity of λ_B is typically $\delta\lambda_B / \delta\Phi \approx 460$ nm / deg.

(iv) Noncontact interferometric phase mask technique

The Interferometric phase mask technique is based on a UV transmitting silica rectangular prism [19]. In this method, shown in Fig. 6 an incident UV beam is diffracted into −1, 0, and +1 orders by a relief grating typically generated on a silica plate by electron beam exposure and plasma etching. The two first diffraction orders undergo total internal reflection at the glass-air interface of a rectangular prism and interfere at the location of the fiber placed directly behind the mask. This technique is wavelength specific, since the period of the resulting two-beam interference pattern is uniquely determined by the diffraction angle of −1 and +1 orders and thus the properties of the phase mask. Obviously, different phase masks are required for the fabrication of gratings at different Bragg wavelengths.

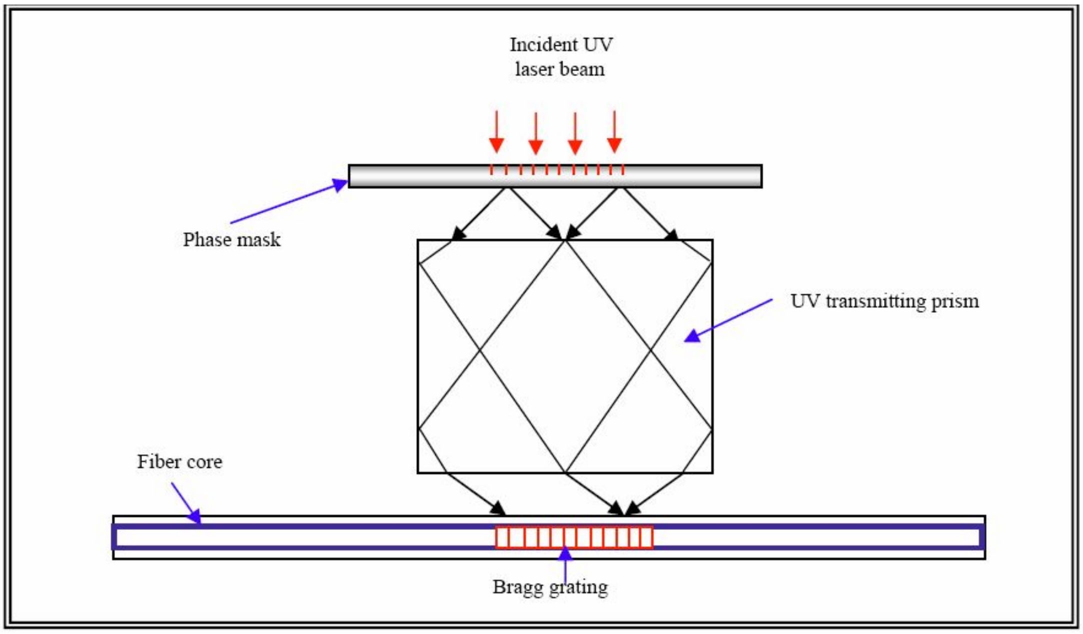

Fig. 6. Noncontact interferometric phase mask technique.

(v) Talbot interferometric phase mask technique

Talbot interferometric phase mask technique is very useful noncontact technique [20] and its experimental arrangement is shown in Fig. 7. This interferometer consists of two plane parallel mirrors and a diffractive element (a phase mask) with its surface aligned perpendicular to the mirrors. The illumination is arranged so as to recombine the first – order beams (or other orders such as the plus first and zero orders) to form the UV interference pattern.

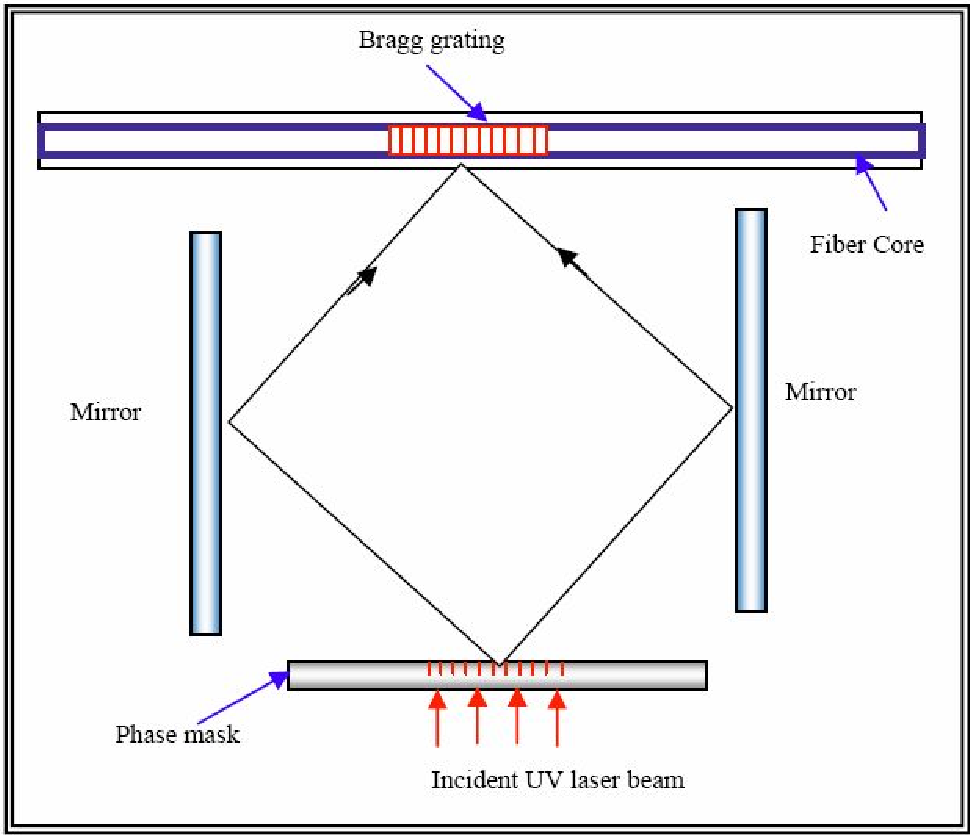

Fig. 7. Schematic diagram of the Talbot interferometer.

(vi) Transverse holographic interferometric technique

Currently, the most promising compromise to facilitate grating fabrication while still preserving the strength of the optical fiber is to combine the writing process with the fiber-drawing process. Askins et al. [21] have demonstrated an automated process whereby Bragg gratings are formed in newly drawn fiber from a drawing tower by means of the transverse holographic interferometric technique, as can be seen in Figure 8. Here a computer is used to control the positions of the various optical components, allowing automated control over the writing process, and facilitating the formation of gratings at different wavelengths. The dark arrows indicate computer-controlled adjustments in angle and translation used to write gratings with different Bragg wavelengths. The entire fiber is then coated with a uniform buffer jacket to protect the fiber.

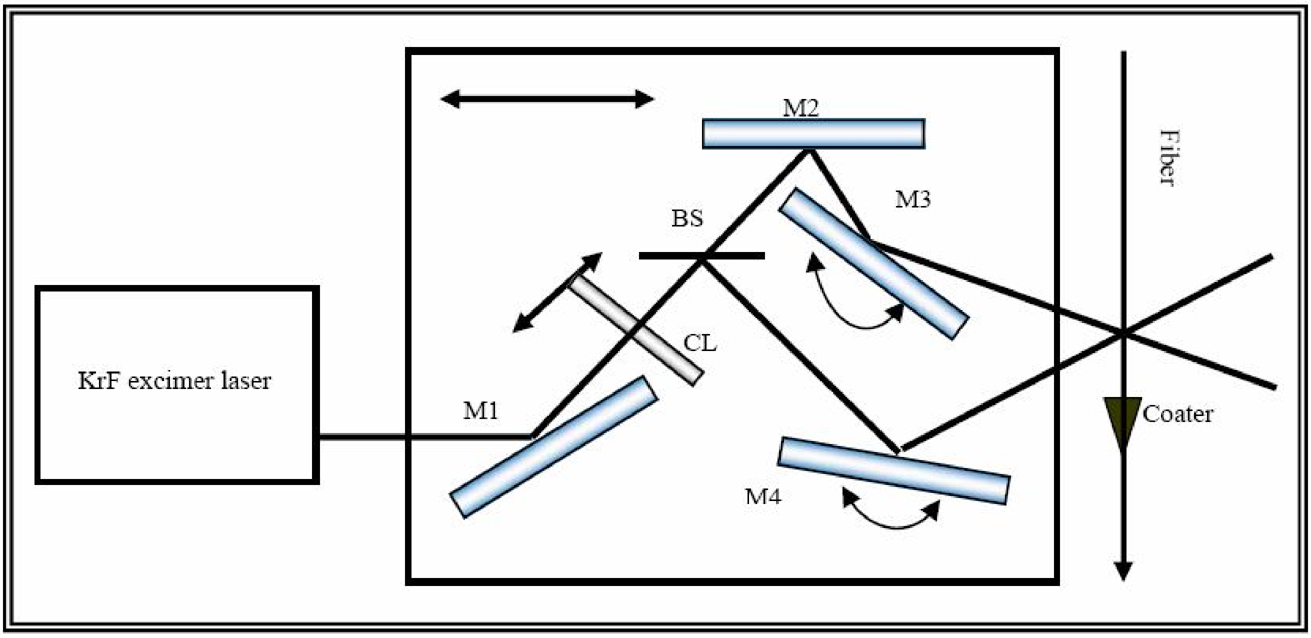

Fig. 8. Schematic of the interferometer to write gratings during fiber draw.

2.2.2 The point by point technique

As the name implies, this technique involves forming a change in the refractive index in the core of a fiber incrementally along its length. Each grating plane is produced individually by focusing a single pulse from an excimer laser, as first pioneered by Bernand Malo and Colleagues at the Communication Research Center, Ottawa [22], produces each grating plane 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, as shown in Fig. 9, and the refractive index of the core in the irradiated fiber section increases locally. The fiber is then translated through a distance Λ 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 very stable and precise submicron translational system. The main attraction of the point-by-point technique lies in its flexibility to alter the Bragg grating parameters. Because the grating structure is built up a point at a time, variation in the grating length, grating pitch and spectral response can easily be incorporated. This technique allows for the fabrication of spatial mode converters and polarization mode converters or rocking filters that have grating periods, Λ ranging from tens of micrometers to tens of millimeters. Because the UV 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. Nevertheless, it is tedious and requires a relatively long process time. Furthermore, thermal effects and small variations in the fiber's strain can produce errors in the grating spacing. Typically the grating period required for a first order reflection 1550 nm is approximately 530 nm. It is because of the tight focusing required to fabricate Bragg gratings; they have yet to be demonstrated using this technique. Malo et. al., [22] has been able to fabricate Bragg gratings that reflect light in the second and third order and that have a grating pitch of approximately 1 μm and 1.5μm, respectively.

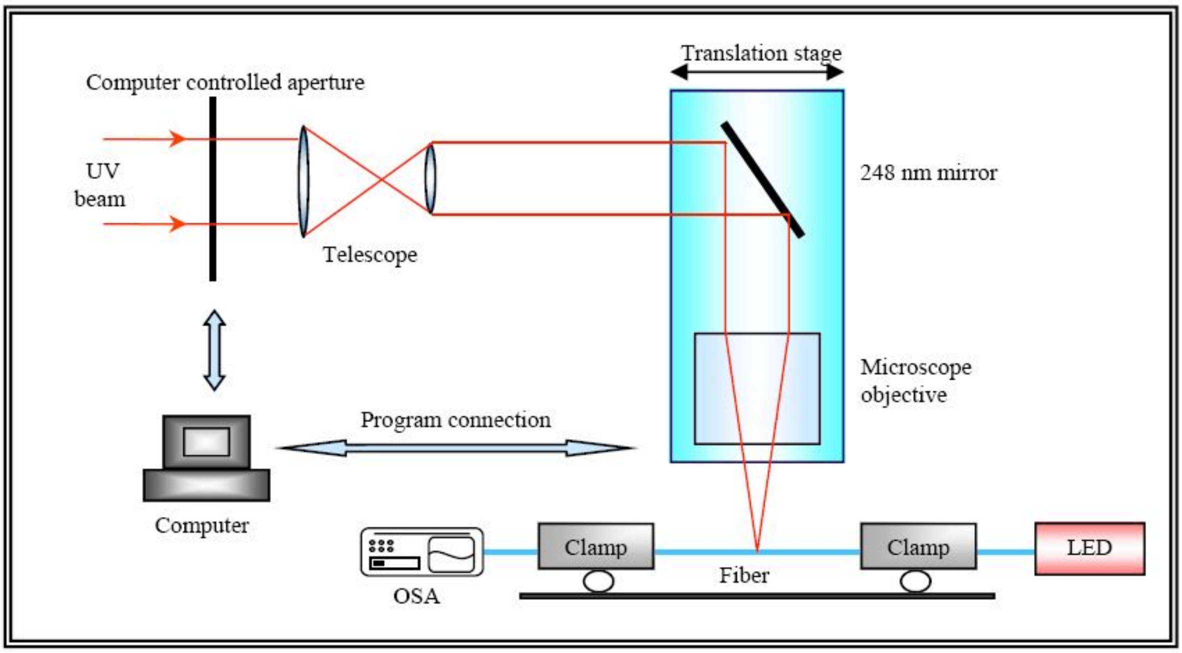

Fig. 9. A schematic setup for writing Bragg gratings using point-by-point technique.

2.2.3 The phase mask technique

One of the most effective methods for inscribing Bragg gratings in photosensitive fiber is the phase masks technique. This method employs a diffractive optical element to spatially modulate the UV writing beam. Generally, phase masks may be formed either holographically or by electron beam lithography. One of the advantages of the electron beam lithography over the holographic technique is that complicated patterns can be written into the mask's structure such as quadratic chirps and patterns. The phase mask technique (electron beam lithography) for writing fiber gratings has the advantages over the traditional holographic method because of its simpler writing setup and more reproducible characteristics. Specifically, the utilization of phase mask relaxes the strict requirement on the coherence of a UV light source. On the other hand, to photo induce an index change in the fiber core, light absorption must somehow occur. Alkins measured the absorption spectrum in a standard germanium doped monomode telecommunication fiber to the wavelength as short as 200 nm [23]. The results show that a light source in the UV spectral region 228 to 253 nm is most effective in photoinducing refractive index changes in such optical fibers. Therefore, we used an excimer laser with wavelength 248 nm as light source, and applied the phase mask technique for writing fiber gratings. Fig. 10 shows that the UV radiation at normal incidence to the phase mask and diffracted radiation is split into m = 0 and ± 1 order.

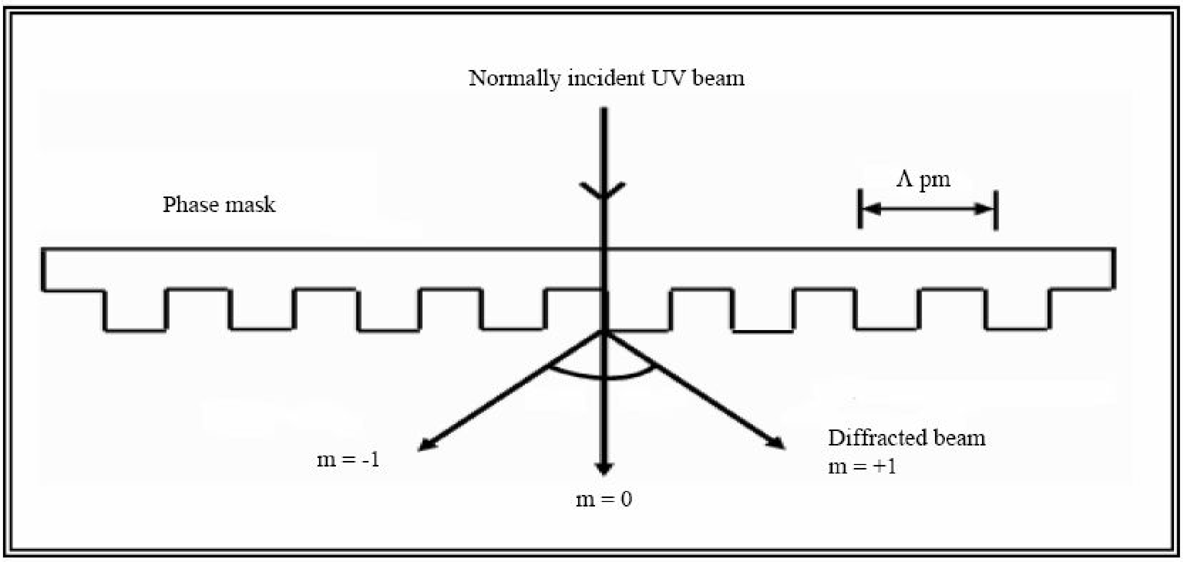

Fig. 10. Schematic of the UV radiation at normal incidence of a phase masks.

The interference pattern at the fiber of two beams of order ± 1 brought together has a period of the grating Λ_g related to the diffraction angle θm / 2 by

$$\Lambda_g = \lambda_{uv} / 2 \sin(\theta m / 2) = \Lambda_{pm} / 2 \qquad (2.5)$$

where Λ_{pm} is the period of the phase mask, Λ_g is the period of the fringes and λ_{uv} is the UV wavelength. The period of the grating etched in the mask is determined by the required Bragg wavelength λ_B for the grating in the fiber, yielding

$$\Lambda_g = N \lambda_B / 2 n_{eff} = \Lambda_{pm} / 2 \qquad (2.6)$$

where N > 1 is an integer indicating the grating period and n_{eff} is effective core index of fiber. The Bragg conditions are $\lambda_B = 2n_{eff}\Lambda_g$. The method employs a diffractive optical phase mask to spatially modulate the UV writing beam shown as Fig. 11, which may be formed holographically or by electron-beam lithography. The patterns can be written into the electron beams fabricated masks. The phase mask grating has a one-dimension surface-relief structure fabricated in high quality fused silica flat transparent to the UV writing beam.

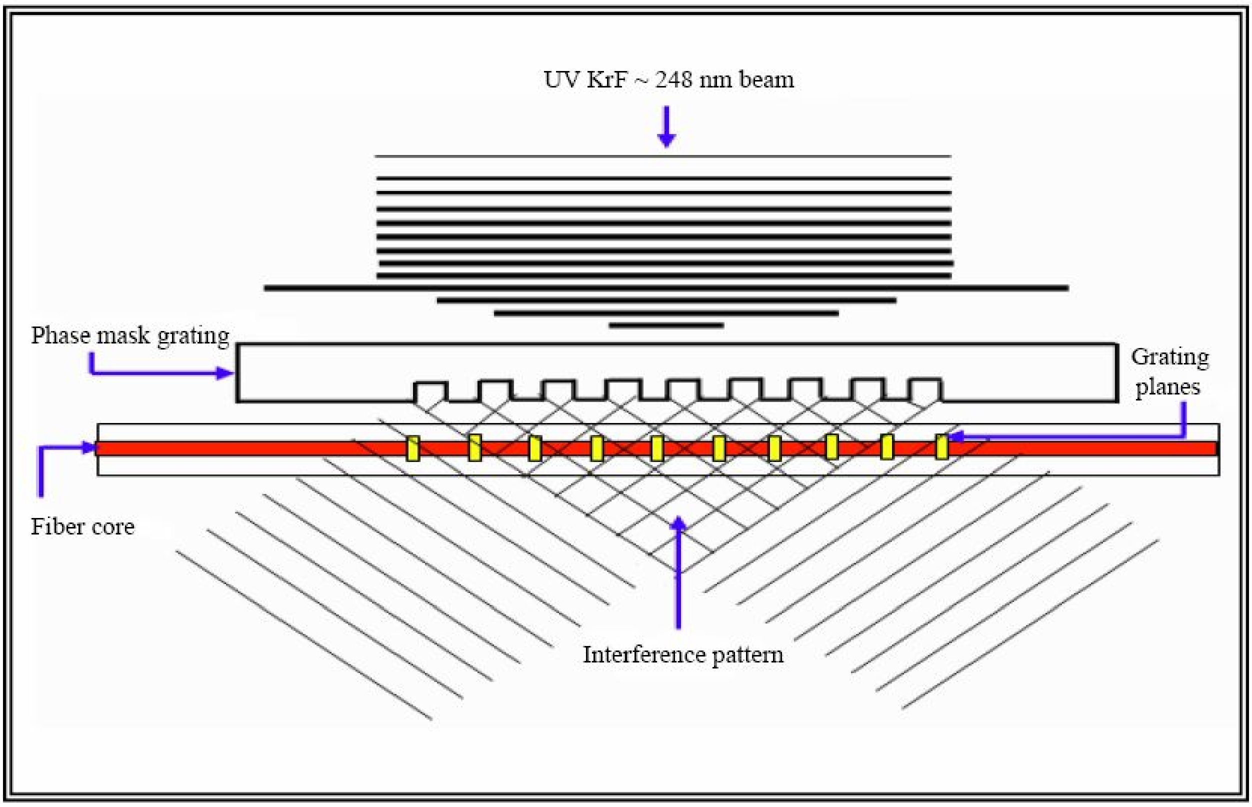

Fig. 11. The interference pattern photoimprints a refractive-index modulation in the core of a photosensitive optical fiber.

The phase mask method employs an optical phase mask, which is essentially a diffraction grating with grooves having a depth so that light traveling straight through a groove is one-half wavelength out of phase from light traveling straight through a ridge. This provides for strong suppression of the 0^{th} order diffraction less than a 5% percent of the transmitted power, so that a higher percentage of the incident light is concentrated in the +1 and – 1 diffractive order, each containing, typically, more than 37% of the transmitted power. In a region just after the phase mask, the +1 and -1 diffraction orders overlap due to the spatial extent of the laser beam. In this overlapping region, the two beams create an interference pattern so that if an optical fiber is placed in the overlapping region, an fiber Bragg grating can be written [6, 24]. The period of the fringes is one half that of the mask. The interference pattern photoimprints a refractive index modulation i.e. Bragg grating in the core of the photosensitive fiber which is placed directly behind the phase masks [6]. A cylindrical lens is used to focus the fringe pattern along the fiber core. The phase mask greatly reduces the complexity of the fiber grating fabrication system. Since the fiber is usually placed directly behind the phase mask in the near field of the diffracting UV beams, sensivity to mechanical vibrations and, therefore, stability problems are minimized. The fabrication of fiber Bragg grating using phase mask technique is demonstrated here. The experiment setup for inscribing Bragg grating with a phase mask is shown in Fig. 12. A KrF excimer laser was used as the UV source for inscribing Bragg grating with a phase mask. The loading of the mask and fiber was performed outside of the exposure unit, which was usually more convenient. The photosensitive fiber was positioned by removing the two round magnetic clamps and placing the fiber in the "V"–grooves on either side of the jig. Replacing the magnets clamps the fiber in place. The entire length of the fiber (from one end of the v-grooves to the other) should be stripped of its coating; otherwise the fiber was not sited properly at the correct separation. The photosensitive fiber was also attached to a mount that allowed its separation from the phase mask to be adjusted. Once the mask had been aligned in its holder, it did not need to be aligned again. Subsequent exposures can be made by simply changing the fibers in the v-grooves. The aperture was inserted before the phase mask to limit the length of the grating to be written. The excimer laser (248 nm) was operated at 100 mJ with a repetition rate of 10 Hz. to expose an 8 mm-long Bragg grating for duration of 90 min. The beam was directed into the phase mask and focused with a plane-cylindrical lens (f = 200 mm) onto the fiber. The dimension of the phase mask used in this experiment is 25 mm x 3 mm and the period of phase mask grating corrugation is 1060.81 nm. The zero-order-diffracted beam was suppressed below 3% and each of the plus and minus first-order diffracted beams contained 37% of the transmitted light. Using this phase mask, Bragg gratings inscribed in fiber (single mode fiber type I having a diameter 125 µm effective core index (n_{eff}) = 1.447 and fiber core is silica germanium boron). The duration of UV exposure was kept constant throughout the experiment. In this experiment, a broadband light source was launched into the fiber core traveled to the optical spectrum analyzer for a detected Bragg wavelength.

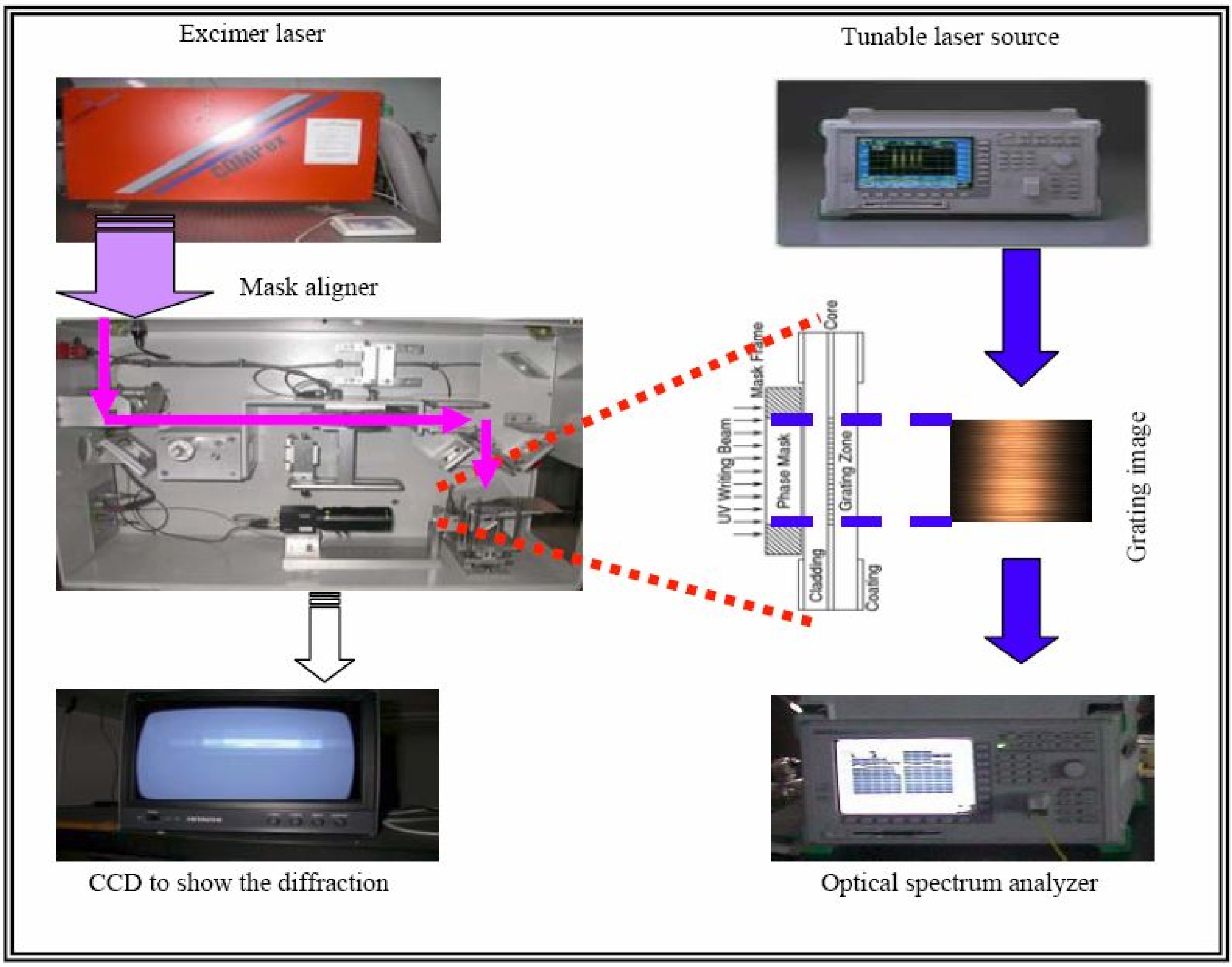

Fig. 12. The experiment setup for writing Bragg grating with a phase mask.

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 grating. However, placing the fiber in contact with the fine grating corrugations is not desirable due to possible damage to the phase mask. Othonos and Lee [8] demonstrated the importance of spatial coherence of UV sources used in writing Bragg gratings, employing the phase mask technique. Low temporal coherence does not affect the writing capability due to the geometry of the problem. 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.

(i) Modified phase mask

The modified phase mask method was developed to combine the stability of the phase mask method with the ability to write grating at different wavelengths [25]. As shown in Figure 13, this method employs a phase mask to split the beams into +1 and – 1 orders in a method similar to the phase mask method, but rather than place the fiber in the interference region after the phase mask, the +1 and – 1 orders of the light are sent onto two mirrors, then focused through a cylindrical lens onto the fiber [25, 20]. Rotation of the mirrors allow different wavelength to be inscribed, and the 0^{th} order light that comes through the phase mask can be blocked. Both beams experience the same path length and the same number of reflections so that coherence requirements are less for the modified phase mask method than the holographic method.

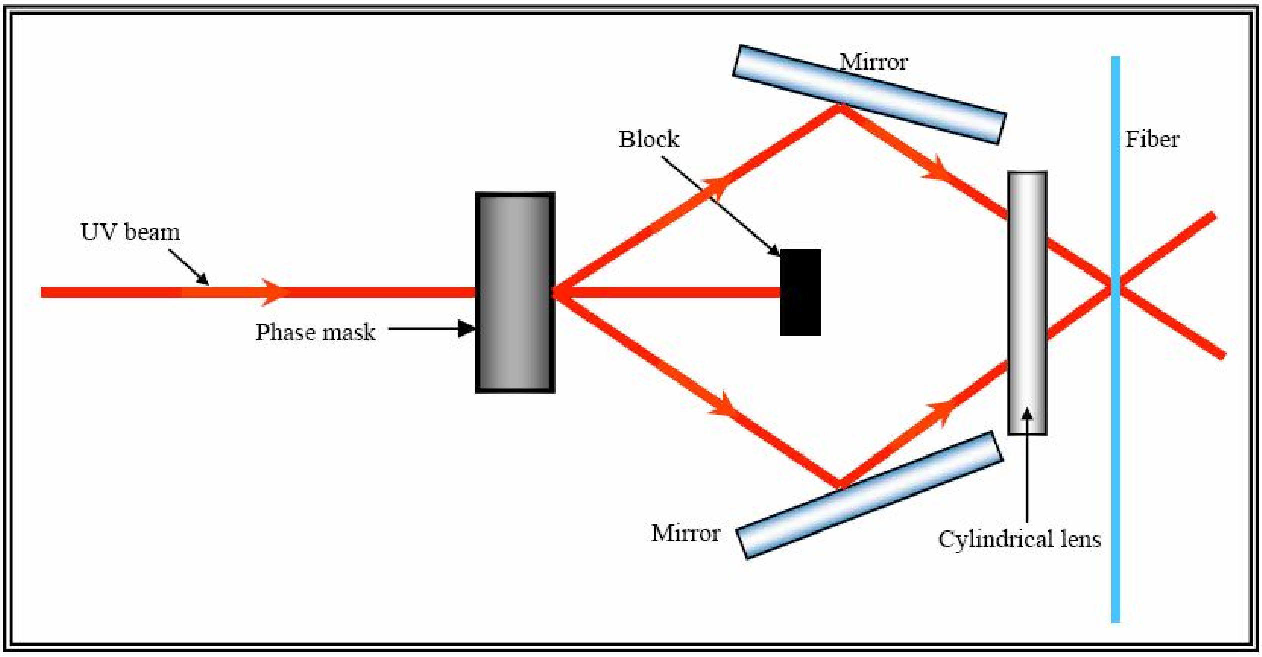

Fig. 13. A schematic setup of a modified phase mask technique.

3. Special fabrication processing of gratings

There are several techniques used in inscribing special Bragg grating structures. These techniques such as, the fabrication of fiber grating using a single excimer laser pulse, the inscription of gratings during fiber drawing, the writing of long and complex fiber Bragg gratings, some of the techniques for inscribing chirped gratings, phase-shifted gratings and apodized gratings can be included.

4. Discussion

All of the techniques described above have some merits and demerits altogether. In internally inscribed Bragg grating due to small index of refraction change induced, useful reflectivity may only be achieved for gratings having a long length (a few tens of centimeters). In externally inscribed Bragg grating, amplitude splitting interferometer technique offers a good flexibility to produce Bragg gratings at any wavelength desired. This is accomplished by changing the intersecting angle between the UV beams. This method also offers complete flexibility for producing grating of various lengths, which allows the fabrication of wavelength narrowed or broadened gratings. The main disadvantage of this approach is a susceptibility to mechanical vibrations. Submicron displacement in the position of mirrors, beam splitter, or other optical mounts in the interferometer during UV irradiation cause the fringe pattern to drift, washing out the grating from the fiber. Furthermore, because the laser light travels long optical path lengths, air currents, which affect the refractive index locally, can become problematic, degrading 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 and excellent wavelength and output power stability. However, in case of wavefront-splitting interferometer only one optical component is required, which greatly reduces its sensitivity to mechanical vibrations. In addition, the short distance for which the UV beams are separated reduces the wavefront distortion induced by air currents and temperature differences between the two interfering beams. Furthermore, this assembly can be easily rotated to vary the angle of intersection of the two beams for wavelength tuning. One disadvantage of wavefront-splitting interferometer system is the limitation on the grating length, which is restricted to half of the beam width. Another disadvantage is the range of Bragg wavelength tunability, which is restricted by the physical arrangement of the interferometers. As the intersection angle increases, the difference between beam path lengths increases; therefore, the beam coherence length limits the Bragg wavelength tunability. Wavefront-splitting interferometry is rarely used, although it has the advantage of using only a single bulk optic component, while amplitude-splitting interferometry requires manly lenses and mirrors. The main disadvantage to this technique is that it is difficult to vary the Bragg wavelength of the grating over a large range. Another externally inscribed Bragg grating technique is point-by-point. The main advantages of the point-by-point technique lie in its flexibility to alter the Bragg grating parameters. Because the grating structure is built up a point at a time, variations in the grating length, pitch and spectral response can easily be incorporated. Chirped gratings can be accurately produced simply by increasing the amount of fiber translation each time the fiber is irradiated. Long period (transmission) gratings can also be fabricated using this technique. While this process appears desirable due to the completely control over the modulation of each individual grating plane, the requirements of a completely stable submicron translation stage and the long time (Writing times of over 8 hours have been reported with this type of interferometer) required to produce each grating have made this system impractical for mass production. In addition, it is difficult to fabricate long length gratings due to thermal effects and small variations in the fiber strain which can affect the spacing of each grating plane.

Use of phase mask to write fiber Bragg grating has now become commonplace. The most used externally writing fiber Bragg grating method is the phase mask technique, because it is the steadiest and the most effective fabrication technique. 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 grating. The phase mask method is relatively easy to align and is the most stable of the transverse grating writing methods. This method of fabricating in-fiber Bragg gratings is flexible, simple to use, results in reduced mechanical sensitivity of the grating writing apparatus and is functional even with low spatial and temporal coherence laser sources. Unfortunately, each phase mask can only write optical fiber gratings at one wavelength, which depends only on the ruling spacing of the phase mask. Writing fiber Bragg Gratings at different wavelength require another phase mask at a high cost but this problem has been removed to some extent in modified phase mask technique.

Unfortunately all of the aforementioned Bragg grating fabrication techniques all shares a common problem. In every case it is necessary to mechanically strip the optical fiber of its protective buffer coating prior to irradiation with UV light. The disadvantage here is two fold. While the external coating (usually a polyacrelate) does not typically provide the fiber with a substantial increase in tensile strength, it does protect the silica cladding region from developing cracks and scratches while can weaken the fiber. To matters worse, the initial process of mechanically stripping the coating often induces these mechanical defects. For many sensing applications fiber strength can be a major issue, notably where a sensor may be subject to regions of high strain. In theses cases it is vital that the fiber be handled delicately during the grating fabrication stage. One possibility is to recoat optical fibers with a buffer region immediately following the writing process; however the vicinity of the grating will still have endured the initial stripping process, perhaps damaging it permanently. This issue becomes somewhat more crucial issue in the context of multiple sensor systems. Serial multiplexing requires the formation of Bragg gratings at more than one location along the length of an optical fiber. Careful handling is possible when fabricating 2,3, or even 10 gratings in a single fiber, however it becomes evident that if serially multiplexed FBG sensor arrays requiring tens or even hundreds of grating are to be constructed new fabrication techniques must be developed.

The advantages of forming gratings during the fiber draw process are threefold. Firstly, it is possible to produce grating at a much greater rate than was previously possible. No time is required to strip and prepare the fiber, so the production rate is limited only by the firing time of the laser, and an ultimate fiber draw speed of several meters per second. Askins et al. reported the fabrication of more than 450 fiber grating during a period of one hour. Secondly, no handling of the fiber is necessary as fiber passes automatically from the draw tower to the interferometer to the coating process. The integrity of the fiber surface is preserved without introducing any cracks or scratches during handling which may weaken the fiber. Thirdly, the automation of the writing process allows for the systematic variance in Bragg wavelength of each grating such as discretely incrementing the center wavelength of each grating, which may be used for wavelength division multiplexing.

5. Conclusions

From the above described fiber Bragg grating fabrication techniques, it is concluded that every fabrication technique has some advantages and disadvantages altogether. However, it is reported that phase mask technique is the most effective and widely used technique for the fabrication of fiber Bragg gratings. This technique is inherently stable method for reproducing fiber Bragg grating, relatively easy to align and function even with low spatial and temporal coherence laser sources. So using this technique, fiber Bragg grating has been fabricated during this study for optical sensing such as temperature and strain sensors. No doubt, the advantages of forming gratings during the fiber draw process are threefold; producing grating at a much greater rate, no handling of the fiber is necessary as fiber passes automatically from the draw tower to the interferometer to the coating process and the automation of the writing process allows for the systematic variance in Bragg wavelength of each grating.

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