Experimental Study of Fiber Bragg Grating for different Period by using Phase Mask Technique.

Nahlah Q. Mohammed (*)
Department of Physics, College of Education, Salahaddin University – Erbil, Kurdistan Region Iraq

ARTICLE INFO

Article History:
Received: 16/08/2017
Accepted: 8/11/2017
Published: 23/1/2018

Keywords:
Fiber Bragg Grating
Phase mask technique
Short period
Long period

*Corresponding Author:
Nahlah Q. Mohammed
nahlah.mohammed@su.edu.krd

1. INTRODUCTION
1.1 Fiber Bragg Grating (FBG)

In 1978, at the Canadian Communications Research Centre (CRC) in Ottawa, Ontario, Canada, (HILL et al. 1978) first demonstrated the formation of permanent grating structures in optical fiber by Hill et al. A fiber Bragg grating is an optical fiber in which the refractive index in the core is perturbed, forming a periodic or quasi-periodic index modulation profile. A schematic of the structure of a typical FBG is shown in figure 1.

Figure (1): The refractive index structure in a typical FBG.

When the grating has a uniform periodicity, the beam propagating in the core of the fiber is reflected by the grating when its wavelength fulfills the Bragg or resonant condition of the grating. The resonant wavelength is equal to the optical path length of the beam that takes a round trip between the adjacent grating elements, Bragg wavelength is given by (KAWASAKI et al. 1978)

\[ \lambda_B = 2 \Lambda \text{neff} \]

Where \( \lambda_B \) is the Bragg or resonant wavelength of the grating, \( \Lambda \) is the periodicity of the grating, and \( \text{neff} \) is the effective index of the core mode of the fiber. The physical property that is responsible for the index change in an optical fiber is called...
The photosensitivity phenomenon, which is a basis for the fabrication of fiber gratings, is commonly ascribed to two essential physical mechanisms. The creation of color centers and structural transformation photosensitivity of the optical fiber is due to defect formation inside the core of Ge-doped silica fibers. The fiber core is often doped with germanium to increase its refractive index and introduce an index step at the core-cladding interface; the relative change in refractive index can be controlled by material properties of the optical fiber, and by the dose of ultraviolet light exposure (YOUNIS et al. 2015).

The Ge concentration in the standard telecommunication fiber is typically (3-5 %) which gives as a result in relatively small index change (3.4×10⁻⁵) compared with concentration of doped fibers about 10%, 14%, and 20% gives as a high index change (0.001), however these dopants also tend to increase fiber losses. The presence of Ge atoms in the fiber core leads to the formation of oxygen deficient bands such as (Si-Ge, Si-Si, and Ge-Ge) bands, which act as defects in the silica matrix. It forms a defect band with an energy gap of about 5eV (energy required to break the bond). Single photon absorption of 244 nm and 193nm radiation from excimer lasers or two-photon absorption of 488 nm light from an argon-ion laser breaks these defects bonds. However, a 157 nm F₂ excimer lasers give highly efficient photosensitivity in Ge silica fibers (BASHIR et al. 2006).

Fiber Bragg grating divided into two categories:

a) Short period gratings: short period grating used as a reflection grating, where the refractive index periodicity is between 0.5 to 1 times the operating wavelength. Short period grating couple the forward propagating core mode to the backward propagating guided mode as shown in figure (2-a). The Bragg wavelength is given by equation (1).

\[ \lambda_B = (n_{\text{core,eff}} - n_{\text{cladding,eff}}) \Lambda \]  

b) Long period gratings: long period grating fabricated to be used as the transmission grating, the refractive index periodicity is 100 times the operating wavelength. Long period grating couple the forward propagating core mode (LP01) with the forward propagating cladding mode (LP₁₁), as shown in figure (2-b). The Bragg wavelength of the long period grating is given by (BASHIR et al. 2006).
1.2 Fabrication Technique of the (FBG)

Fiber grating can be made by using several different techniques, each having its own merits. There are four major techniques commonly used for fiber grating: the single-beam internal technique, the dual-beam holographic technique, the phase mask techniques, and the point by point fabrication techniques (HILL et al. 1997). The technique was used in this work is a phase mask technique.

a) Single-Beam Internal Technique.

A single beam obtained from an argon-ion laser operating in a single mode near 488 nm is launched into a germanium doped silica fiber. The light reflected from the near end of the fiber is then monitored. The reflectivity is initially about 4% as expected for a fiber-air interface. However, it gradually begins to increase with time and can exceed 90% after a few minutes when the Bragg grating is completely formed (HILL et al. 1997). The grating formation is initiated by the light reflected from the far end of the fiber and propagating in the backward direction (YOUNIS et al. 2015).

The periodicity of standing wave pattern is given by:

\[ \Lambda = \frac{\lambda}{2 \left( \tilde{n} \right)} \]  

Where \( \lambda \) is the laser wavelength and \( \left( \tilde{n} \right) \) is the mode index at that wavelength.

A disadvantage of the single-beam internal method is that the grating can be used only near the wavelength of the laser used to make it. Since Ge-doped silica fibers exhibit little photosensitivity at the wavelength longer than (0.5 μm) such gratings cannot be used in the 1300 nm to 1600 nm wavelength region that is important for optical communications (HILL et al. 1997).

b) Dual-Beam Holographic Technique.

In the dual-beam holographic, two optical beams are obtained from the same laser (operating in the ultraviolet region) and making an angle \( \theta \). These two beams are interfering at the exposed core of an optical fiber. A cylindrical lens is used to expand the beam along the fiber length, and the interference pattern creates an index grating. The most important feature of the holographic technique is that the grating period \( \Lambda \) can be varied over a wide range by simply adjusting the angle \( \theta \). The Bragg wavelength \( \lambda_B \) at which the grating will reflect light is related to \( \Lambda \) as in equation (1). Bragg gratings operating in the visible or infrared region can be fabricated by the dual-beam holographic method even when \( \lambda_{UV} \) is in the ultraviolet region. A disadvantage of the dual-beam holographic technique is that it requires an ultraviolet laser with excellent temporal and spatial coherence (HILL et al. 1997).

c) Phase Mask Technique

A more recent development, which greatly simplifies the requirements of the optical fiber grating fabrication setup, is the use of diffractive optical phase mask grating. The phase mask technique has largely superseded the holographic and interferometric methods for grating fabrication. A phase mask is a diffractive optical element made by etching grating patterns on fused silica substrates using standard photolithographic techniques (BASHIR et al. 2006). The optical fiber is placed almost in contact with the corrugations of the phase mask as shown in figure 4. Ultraviolet light incident normally to the phase mask passes through and is diffracted by the periodic corrugations, creating an interference pattern. The phase mask acts a master grating that is transferred to the fiber using a suitable
method. Photosensitivity of the fiber converts intensity variations into an index grating. The basic idea is to use a phase mask with periodicity related to the grating period. For normal incident, the grating period $\Lambda$ and the phase mask period $\Lambda_{pm}$ is related by:

$$\Lambda = \Lambda_{pm} / 2 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

The phase mask technique has the advantage of greatly simplifying the manufacturing process for Bragg grating, yet yielding gratings with high performance, furthermore a chief advantage of the phase mask method is that the demands on the temporal and spatial coherence of the ultraviolet beam are much less stringent because of the known interferometric nature of the technique. In fact, even a non-laser source, such as an ultraviolet lamp can be used. Relatively long fiber grating can be made using a phase mask technique, which is used as dispersion compensation. Whereas a disadvantage of a phase mask technique is limited tuning of the Bragg wavelength (HILL et al. 1997).

2. MATERIALS AND METHODS

To verify the designed and implemented optical communication link, a different measurement technique should be achieved. These measurements were essential points for the optical communication system designer, to choose fibers, materials and devices.

The experimental results of the practical measurements and calculations for short and long FBG fabrication calculations will be presented in this work.

The manufacture of the reflection and transmission FBG are made by using a phase masks technique. These phase mask consist of a polished piece of UV grade silica which has a diffraction grating etched into the surface. The pitch of the phase mask is twice the required pitch of the grating in the fiber.

Figure 4 shows the experimental setup for fabrication of the FBG. In these experiments, permanent optically induced change of the refractive index in the core of an optical fiber wave made. This was accomplished by Bragg grating which is produced a periodic refractive index change within the core from ultraviolet laser. This periodic structure is known as an internally

**d) Point-by-Point Technique**

This technique can be done by exposing a short section of width $x$ of the optical fiber to a single high energy pulse. The fiber is translated by distance $\Lambda-x$ before the next pulse arrives, resulting in the periodic index pattern such that only a fraction $x/\Lambda$ in each period has a higher refractive index. The method is referred to as point-by-point fabrication since a grating is fabricated period by period even though the period $\Lambda$ is typically below 1000 nm. The technique works by focusing the spot size of the ultraviolet beam so lightly that only a short section of width $x$ is exposed it. There are practical limitations of this technique first, only short fiber grating (<1cm) are typically produced because of the time-consuming nature of the point-by-point fabrication method. Second, it is hard to control the movement of the translation stage accurately enough to make this scheme practical for long grating. Third, it is not easy to focus the laser beam to a small spot size that is only a fraction of the grating period (HILL et al. 1997).
written Bragg grating.

The FBG experimental setup contains the ultraviolet laser, diffraction grating as a phase mask for short period grating and meshes as a phase mask for long period grating, the cylindrical lens, D-coupler (50% beam splitter), laser source operated at 1310 nm and 1550 nm, and two optical power meter.

The ultraviolet laser used for the fabrication of the short and long FBG is N\textsubscript{2} laser supplied from Molectron Corporation; this laser was operated at 30 tor pressure. A vacuum pump of at least (1000/min) capacity is recommended with a high throughput. Fresh N\textsubscript{2} gas is fed into the discharge channel from each end and evacuated from the center. This gas flow direction keep both windows clean and optimizes laser performance.

The N\textsubscript{2} laser 337 nm wave length has maximum average power is 450 mw, pulse duration (10 nsec.), energy pulse is (1.5 mJ) measured using Jules meter DJ-100, beam polarization is linear, beam divergence is (1 m.), spectral bandwidth (0.1nm). This laser is operated with (10 psec.) repetition rate. Output pulse laser from the N\textsubscript{2} laser is 2 cm length and 0.5 cm width, and was focused to 5 mm length which represented the exposure length (L) and 1mm width using a quartz cylindrical lens.

The pulse incident on the phase mask normally, to produce a short period FBG (1.6 \mu m) and (1.75 \mu m) mask periodicity. They are used for 1310 nm 1550 nm respectively, while (260 \mu m) and (308 \mu m) mask periodicity are used for long period FBG. Standard optical fiber was used to expose to UV laser, and a fiber is placed in contact with such grating and illuminated through the mask with N\textsubscript{2} laser, hence a photorefractive grating will be formed in the core of the fiber.

In order to test the single mode operation, determined the wave length and pulse line shape of our source. The laser source GaAs type PROMAX: PROLITE-90 working in two recommended wavelength \lambda for optical communication which (1330 and 1550 nm), typical spectral width is 2nm, the range of output power is (-5dB± 1dB), connected with an optical spectrum analyzer type PROMAX: PROLITE-60 : wavelength range (1250-1650nm) span;(10-100nm), optical resolution :0.15, accuracy:±0.5nm, was used to transmit the light at these wavelengths to the exposed optical fiber via the first line of the D- coupler and measured the power effect due to the time exposed . An optical power meter type PROLITE-23: PROMAX (InGaAs, wavelength:(850-1550)nm, measure range: -60 to +70 dBm, Resolution:0.01) is used for this purpose, whereas the power reflection due to the Bragg grating was measured from the second line of the D- coupler using a second power meter same type.

The choice of the optical fiber usually occurs according to the following characteristics: core size, core refractive index, optical fiber bandwidth, attenuation, and numerical aperture. The utilized single mode optical fiber cable is used with the length of about (103.2 km.) Prepare to this work, the fiber ends should be cut and clean precisely. In order to do the fiber connections, the single mode optical fiber was cleaned by Jacket Remover type: QMS-2e, JR-25, SOMOTOMO. This is a tool for removing the protective coating from a single mode fiber of cladding .The total fiber length long as 103 km after 14 splices. A splicing machine was used to connect the fiber to fiber and fiber to the 6FC connector. The type of the splicing unit is Optical Fiber Fusion Splice QMS-02e, SOMOTOMO. The Core to cladding radius of a single mode optical fiber used is (10/125\mu m), core refractive index is (1.48), numerical aperture is (0.11-0.140) \mu m, outside diameter (coating) is 245 \mu m, attenuation of a single mode fiber are 0.60 dB/km and 0.2 dB/km for a wavelength 1310 nm and 1550 nm respectively, and the bandwidth is 100 GHz. The splice loss is about 0.0001 dB which is measured using the splicing machine and connection loss of 0.1 dB for each connector.
The reflectivity of the optical FBG was determined by measuring the transmitted optical power through the grating and the power that was reflected to the detector.

3. RESULTS AND DISCUSSION

In order to test our laser transmitter line shape, wave lengthly, and mode of operation single frequency or multi frequency and type of the laser diode the spectrum analyzer is necessary. These measurements were carried on by the help of the experiment setting. The line shape of output laser is shown in figure 5 (a, b) for 1310 nm and 1550 nm wavelength respectively.

![Figure (5): The measurement setting of the FBG.](image)

3.1. Short Period results FBG

The optical properties of silica fiber are changing permanently due to the exposure fiber material to the intense radiation. In this work N2 laser operating in 337 nm wavelength to produce periodic change in refractive index of the fiber core is used. The refractive index change is due to the photosensitive effect. Fiber Bragg Grating was fabricated to operate at the regions 1310 nm and 1550 nm wavelength. For short period grating at a wavelength 1550 nm the effective refractive index ($n_{eff}$) of the core is 0.482, and the period of the phase mask used is 3.2 µm to produce grating periodicity in the core of about 1.6 µm. Using these values in equation (1), the Bragg wavelength ($\lambda_B$) is 1543.46 nm. Because of the Bragg grating effect in the optical fiber, the transmitted optical power in the core will be decreased, because of the energy that is associated to Bragg wavelength is reflected in opposite direction ($E_B$). The variations of the transmitted and reflected ($\lambda_B$) output optical power with exposure time of the core to N2 laser are shown in figures 6 and 7 respectively. While figure 8 shows the measurement setting.

![Figure (7): The Transmitted Optical Power with the exposure Time](image)

![Figure (8): The Reflected Optical Power with the exposure Time](image)

It can be seen from figures 7 and 8, the transmitted optical power decreases with increasing of the exposure time, whereas a reflected power is increased with the exposure time. After 15 min of the exposing the transmitted and reflected optical power becomes constant because of the photo induced index change is unvaried or unchanged (OTHONOS 1997).

For short period grating at a wavelength 1310 nm the effective refractive index ($n_{eff}$) of the core is 0.379, the period of the used phase mask is 3.5 µm, then the grating produced periodicity in the...
core of the fiber is 1.75 µm. Substituting the above values in equation (1), the Bragg wavelength ($\lambda_B$) in this condition is 1326.5 nm.

The variations of the transmitted and reflected optical power with core exposure time to the U.V laser are shown in figures 9 and 10 respectively.

![Figure (9): The Transmitted Optical Power with the exposure Time.](image)

![Figure (10): The Reflected Optical Power with the exposure Time.](image)

The incident optical pulses on a fiber grating depend strongly on the location of the pulse spectrum with respect to the stop band associated with the grating. If the pulse spectrum falls entirely within the stop band the entire pulse is reflected by the grating. On the other hand, if a part of the pulse spectrum is outside the stop band, that part will be transmitted through the grating. The shape of the reflected and transmitted pulses will be quite different than that of the incident pulse because of the splitting of the spectrum and dispersive properties of the fiber grating.

3.2 Long Period results FBG

Long period grating is fabricated by increasing the periodicity of the grating to 260 µm and 308µm for 1310 nm and 1550 nm respectively, whereas the difference of the core-cladding refractive index effect for standard optical fiber is 0.005. Substituting these values in equation (2), the Bragg wavelength ($\lambda_B$) are 1300 nm and 1540 nm.

The variation of the transmitted optical power with exposure time are shown in figures 11 and 12 for 1310 nm and 1550 nm, which decreases exponentially and the photosensitive effect is stopped when the photo induced index is unchanged.

![Figure (11): The Transmitted optical Power with the exposure time for 1310 nm wavelength.](image)

![Figure (12): The Transmitted optical Power with the exposure time for 1550 nm wavelength.](image)

The light guided along the core of a single mode fiber normally travels as a plane "inhomogeneous" wave perpendicular to the axis: this corresponds to the single mode of the propagation. Most of the power travels in the core with a small part corresponding to the evanescent wave that travels outside near the core in the cladding. This wave is perturbed by the constant index –grating plans perpendicular to the axis. The contributions of each reflection add constructively in the backward direction for wavelengths defined by the grating period. These results gives a good agreement with (OTHONOS A. 1997).

Finally, that photo mask technique is much low cost and simpler because there is no need for the laser to have a good coherence and there are no mirrors to align and that utilization of the ultraviolet laser offers fast technique to prepare or manufacture a Fiber Bragg Grating and that is agree with (SAJEEN et al. 2014)
The results of long period grating are more efficient than the short period fiber Bragg grating at the same exposure time for 1310 nm and 1550 nm wavelengths and are agree with (STEPHAN et al. 2005)

4. CONCLUSIONS

In conclusion, we have studied the Fiber Bragg Grating for different Period by using Phase Mask Technique. The value of Bragg wavelength is also studied and obtained to be: \{1326nm & 1543.46nm\} wavelengths at short period and \{1300nm & 1540nm\} wavelengths at long period. Therefore give a good agreement with the theoretical results.

Finally, we conclude that photo mask technique is much low cost and simpler because there is no need for the laser to have a good coherence and there are no mirrors to align and that utilization of the ultraviolet laser offers fast technique to prepare or manufacture a Fiber Bragg Grating. The Long period grating is more efficient than the short period fiber Bragg grating at the same exposure time for 1310 nm and 1550 nm wave lengths.

REFERENCES

HILL K. O., FUJII Y., JOHSON D. C. and KAWASAKI B. S. 1978, Photosensitivitiy in Optical fiberwaveguides; Application to reflection filter fabrication, Appl. Phys. Lett., Vol. 32, pp. 647-649.

KAWASAKI B. S., HILL K.O., D.C. JOHSON and FUJII Y.1978, Narrow-band Bragg reflectors in Optical fibers, Opt.Lett., Vol. 3, pp. 66-68.

YOUNIS M. SALIH, YUSOF MUNAJAT, A. ISMAIL, HAZRI BAKHTIAR. 2015, Response of FBG-Bonded Graphene Plate at different applied stress location, Journal of Technology., Vol. 78, pp.217-223.

KEIGO IZUKAG, BAHAA E. A. SALEH.2002, Elements of Photonics, Volume II For Fiber and integrated Optics, Wiley Inters Science, NewWork.

BASHIR A. T., JALIL A., ROSLY A.B. 2006, Fabrication of fiber grating by phase Mask and its sensing application, Journal of Optoelectronics and Advanced Materials., Vol.8: pp,1604-1609.

HILL, K. O. and MELTZ, G. 1997, Fiber Bragg grating technology fundamentals and overview. Light. Tech., Vol. 15, pp, 1263–1276.

OTHONOS A. 1997, Fiber Bragg gratings Review of scientific instruments. Vol. 68, pp, 4309

SAJEEN DEWRA, VIKAS and AMINTGROVER, 2015.
Mohammed, N. Q. /ZJPAS: 2017, 29(6): 10-17