A phase mask fiber grating and sensing applications

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Abstract

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This paper presents an investigation of a fabricated fiber grating device characteristics and its applications, using a phase mask writing technique. The use of a most common UV phase laser (KrF eximer laser), with high intensity light source was focussed to the phase mask for writing on a fiber optic sample. The device (i.e. grating) characteristic especially, in sensing application, was investigated. The possibility of using such device for temperature and strain sensors is discussed.

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บทคัดย่อ

สืบตระกูล สุชาติ [1] และ ปรีชา ยุพาพิน [2]
การสร้างเกรตติงในเส้นใยแก้วนำแสงด้วยเฟสมาร์กและการประยุกต์ใช้ทางด้านการตรวจรู้
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ในงานวิจัยนี้แสดงการสร้างเกรตติงในเส้นใยแก้วนำแสงและคุณลักษณะของเกรตติงในเส้นใยแก้วนำแสงที่ได้
โดยวิธีการสร้างเกรตติงในเส้นใยแก้วนำแสงนี้จะใช้เทคนิคเฟสมาร์ก ซึ่งเป็นเทคนิคการสร้างเส้นใยแก้วนำแสงโดย
ใช้เลเซอร์ชนิดแสงอัลตราไวโอเลต (UV, KrF Eximer laser) ที่มีความเข้มของลำแสงสูงเป็นแหล่งกำเนิดแสงแล้ว
ฉายผ่านตัวเฟสมาร์ก เพื่อใช้ในการเขียนลงบนเส้นใยแก้วนำแสงทำให้ได้เกรตติงในเส้นใยแก้วนำแสง โดยที่
คุณลักษณะของเกรตติงในเส้นใยแก้วนำแสงที่ได้จากการสร้างนี้สามารถนำไปใช้ประยุกต์ใช้เป็นอุปกรณ์การตรวจรู้ได้
ซึ่งในการทดลองได้มีการประยุกต์ใช้เป็นอุปกรณ์ในการตรวจรู้ทางด้านอุณหภูมิและอุปกรณ์ในการตรวจรู้ทางด้าน
ความเค้น (strain) โดยใช้เส้นใยแก้วนำแสงชนิดแบรกเกรตติงนี้

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Fiber Bragg grating (FBG) has been of great interest in communications such as tunable filter, in wavelength division multiplexing/demutiplexing (WDM/D), and as fiber sensors such as temperature sensor, vibration sensor, pressure sensor (Kashyap, 1999, Zhang, *et al.*, 2001, Othons and Kalli, 1999, Grattan and Meggitt, 2000) and strain sensitivity (Frazao, 2002). One of the techniques commonly used to inscribe Bragg grating in the core of optical fibers uses a phase mask to spatially modulate and diffract the UV beam to form an interference pattern. The interference pattern induces a refractive index modulation i.e. Bragg grating in the core of the photosensitive fiber which is placed directly behind the phase masks (Hill, *et al.*, 1993). The phase mask technique is a method of writing Bragg gratings because of its simplicity and reduced mechanical sensitivity. The most common UV source used to fabricate Bragg grating with a phase is KrF excimer laser. These 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 low reflectivity Bragg gratings.

Clearly, the separation of the fiber from the phase mask is a critical parameter in producing quality gratings and relatively easy to fabricate. The advantages offered by optical fiber include low loss transmission, immunity to electromagnetic interference, lightweight, and electrical isolation.

In this paper, we report and demonstrate the importance of the coherence light source in the UV laser used write Bragg grating in a core of fiber optic with the phase mask technique. In addition, the use of such a device for temperature sensors and strain sensors is discussed. In accordance with the strain effect and applied temperature on an optical fiber Bragg grating this corresponds to change in the grating spacing which shift in the Bragg wavelength. In this experiment can be using an application in the telecommunication and fiber optic sensors such as high temperature sensor, fire alarm sensor, vibration sensor, and pressure sensor.

Operating Principle
1. 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 to spatially modulate the UV writing beam. Generally, phase masks may be formed either holographically or by electron

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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.

Figure 1 shows that the UV radiation at normal incidence, the diffracted radiation is split into m = 0 and ± 1 order. 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 $\theta_m/2$ by

$$\Lambda_g = \frac{\lambda_{uv}}{2\sin(\theta_m/2)} = \frac{\Lambda_{pm}}{2} \qquad (1)$$

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_{Bragg} for the grating in the fiber, yielding

$$\Lambda_g = \frac{N\lambda_{Bragg}}{2n_{eff}} = \frac{\Lambda_{pm}}{2} \qquad (2)$$

where $N \geq 1$ is an integer indicating the grating period and n_{eff} is effective core index of fiber. The

Bragg conditions are $\lambda_{Bragg} = 2n_{eff}\Lambda_g$. The method employs a diffractive optical phase mask to spatially modulate the UV writing beam shown as Figure 2, 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.

The profile of the periodic gratings is chosen such that when the UV beam is incident on the phase mask, the zero-order-diffracted beam is suppressed to less than a few percent 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. A near-field fringe pattern is produced by the interference of the plus and minus first-order diffracted beams. The period of the fringes is one-half that of the mask. The interference pattern photoimprints 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 is 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
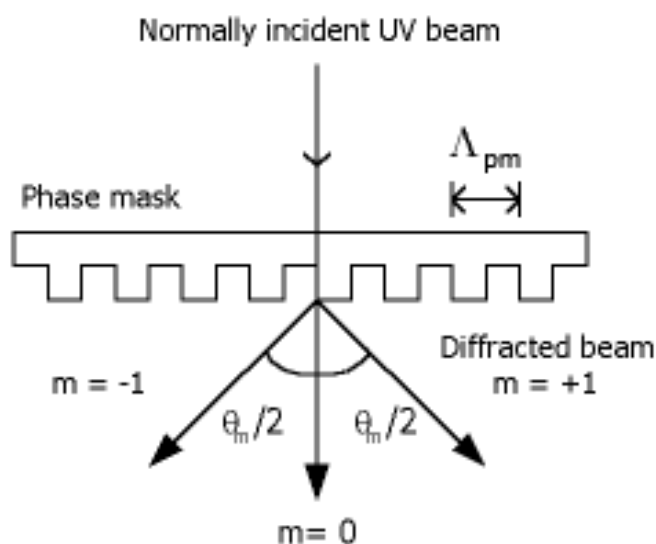

Figure 1. Schematic of the UV radiation at normal incidence of a phase masks.
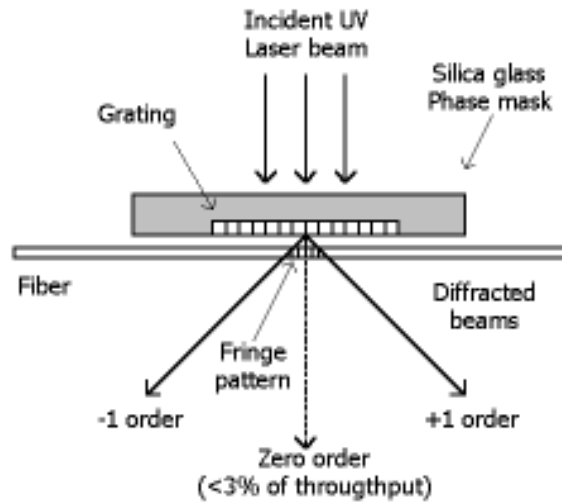
Figure 2. A schematic of a phase mask utilized in inscribing fiber Bragg grating.

using only one optical element provides a robust and an inherently stable method for reproducing fiber Bragg grating. 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. Low temporal coherence does not affect the writing capability due to the geometry of the problem.

2. Temperature and strain sensitivity of Bragg grating

The Bragg grating resonance, which is the center wavelength of light back reflected from a Bragg grating depends on the effective index of refraction of the core and the periodicity of the grating. The effective index of refraction, as well as the periodic spacing between the grating planes, will be affected by changes in strain and temperature. The shift in the Bragg grating center wavelength due to strain and temperature changes is given by

$$\Delta \lambda_{Bragg} = 2 \left(\Lambda \frac{\partial n}{\partial l} + n \frac{\partial \Lambda}{\partial l} \right) \Delta l + 2 \left(\Lambda \frac{\partial n}{\partial T} + n \frac{\partial \Lambda}{\partial T} \right) \Delta T \tag{3}$$

where T is temperature and l is length of strain effect. The first term in (3) represents the strain

effect on an optical fiber. This corresponds to a change in the grating spacing and the strain optic induced change in the refractive index. The above strain effect term may be expressed as

$$\Delta \lambda_{Bragg} = \lambda_{Bragg} (1 - p_e) \, \varepsilon_z \tag{4}$$

where p_e is an effective strain-optic constant defined as

$$p_e = \frac{n^2}{2} [p_{12} - \nu(p_{11} + p_{12})] \tag{5}$$

where p_{11} and p_{12} are components of the strain optic tensor, n is the index of the core, and ν is the Poisson's ratio. For a typical optical fiber $p_{11} = 0.113$, $p_{12} = 0.252$, $\nu = 0.16$ and $n = 1.482$.

The second term in (3) represents the temperature effect on an optical fiber. A shift in the Bragg wavelength due to thermal expansion changes the grating spacing and changes the index of refraction. This fractional wavelength shift for temperature change ΔT can be written as

$$\Delta \lambda_{Bragg} = \lambda_{Bragg} (\alpha - \zeta) \, \Delta T \tag{6}$$

where $\alpha = (1/\Lambda)(\partial \Lambda / \partial T)$ is the thermal expansion coefficient for the fiber ($\approx 0.55 \times 10^{-6}$ for silica). The
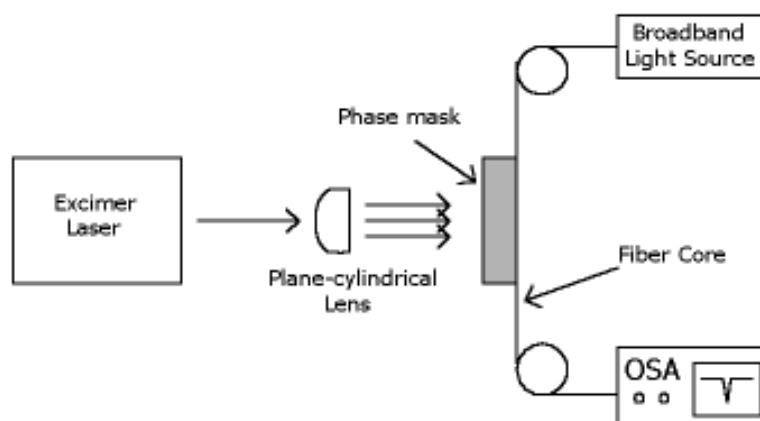
Figure 3. The experiment setup for inscribing Bragg grating with a phase mask.

quantity $\zeta = (1/n)(\partial n/\partial T)$ represents the thermo-optic coefficient and it is approximately equal to $8.6 \times 10^{-6}/°C$ for the germanium-doped silica core fiber.

Experiment

The experiment setup for inscribing Bragg grating with a phase mask is shown in Figure 3. A KrF excimer laser was using as the UV source for inscribing Bragg grating with a phase mask. The photosensitive fiber was attached on to a mount that allowed its separation from the phase mask to be adjusted. The excimer laser (248 nm) was operating at 10 mJ with a repetition rate of 200 Hz. 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, the period of the grating corrugation is 1060 nm. The zero-order-diffracted beam was suppressed below 3% and each of the plus and minus first-order diffracted beams contained 35% of the transmitted light. Using this phase mask, Bragg gratings inscribed in fibers (single mode fiber type I having a diameter 125 μm effective core index (n_{eff}) = 1.4474 and fiber core is silica germanium boron) and duration of UV exposure 60 s were kept constant throughout the experiment. In this experiment, using a broadband light source launch

into the fiber core traveled to the optical spectrum analyzer for a detected the Bragg wavelength.

The experimental set up for temperature sensitivity of fiber Bragg grating system is shown in Figure 4 (a), using the broadband light source launched into the fiber Bragg grating pass of the oven traveled on to be detected the Bragg wavelength (λ_{Bragg}) by the optical spectrum analyzer (OSA), at the oven controlled temperature and varied temperature from 25, 35, 45 to 205°C, which fiber Bragg grating.

The experimental setup for the strain sensitivity of fiber Bragg grating system is shown in Figure 4 (b). We used the broadband light source launched into fiber Bragg grating traveled to the detector and the detected by optical spectrum analyzer with Bragg wavelength. When the fiber Bragg grating have fixed distance 40 cm between point A and point B. At point B was a fixed with a micrometer for strain the fiber Bragg grating by varied a distance at the micrometer for micro strain ($\mu\varepsilon$) from 0, 200 $\mu\varepsilon$, 400 $\mu\varepsilon$ to 1800 $\mu\varepsilon$.

Results

The result for inscribing Bragg grating with a phase mask technique is show in Figure 5. The transmission spectrum of Bragg grating and the percent reflectivity of Bragg grating from writing using the phase mask technique.
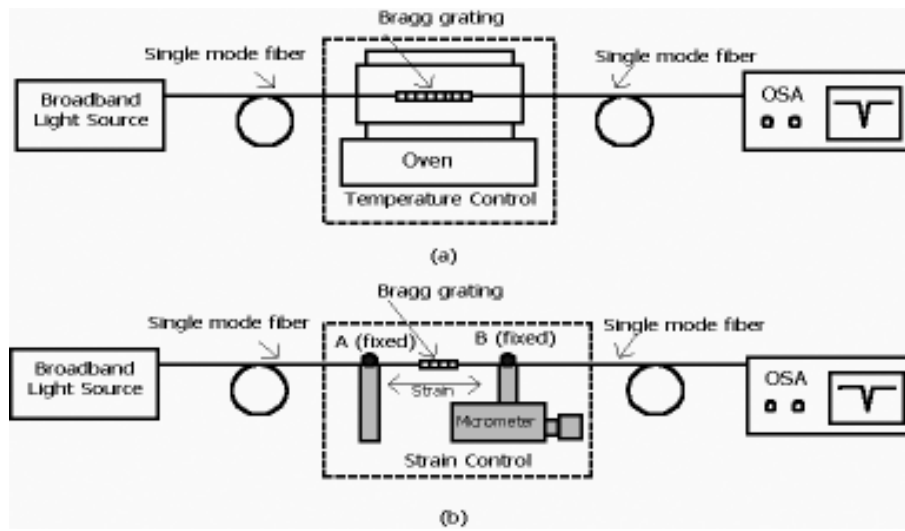
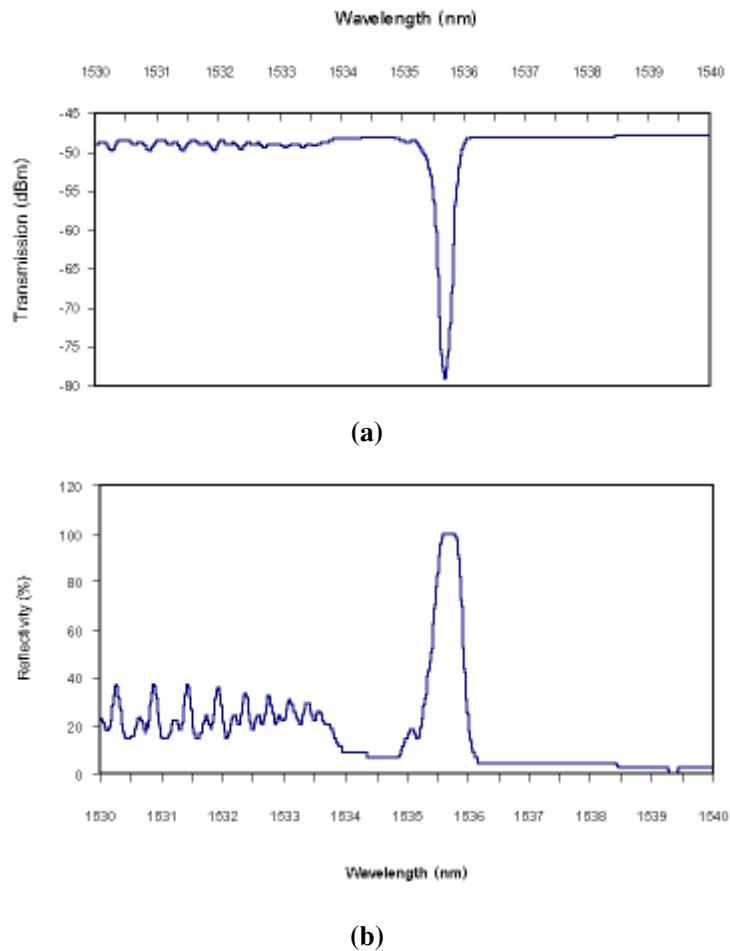**Figure 4. The experiment setup used: (a) temperature sensitivity and (b) strain sensitivity**

Figure 5. Graph of Bragg grating characteristics: (a) Transmission (b) Reflectivity (%)
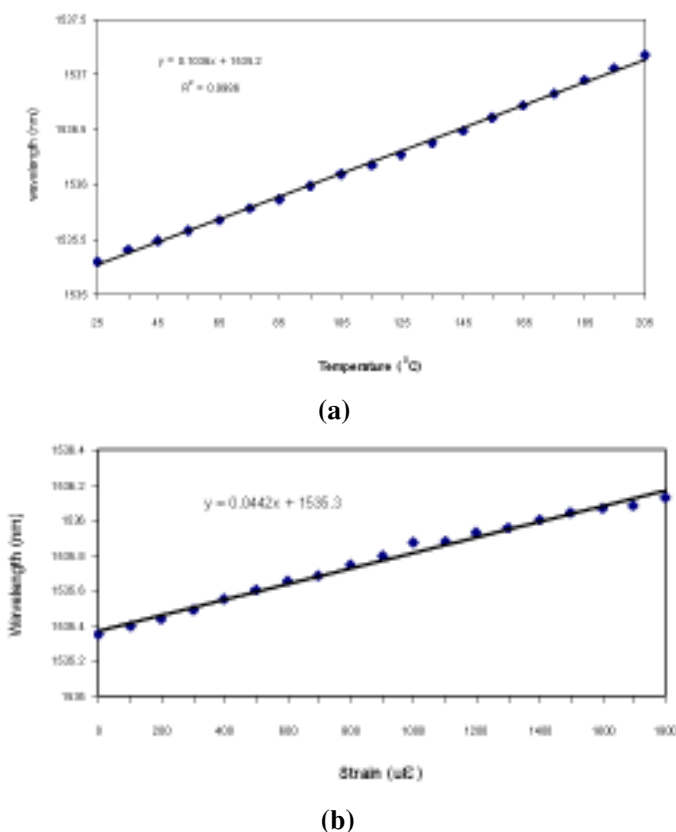
(a)

(b)

**Figure 6. Graph of Bragg grating wavelength as (a) a function of temperature change,
(b) a function of applied strain.**

Figure 6 (a), shows the effect of temperature while the applied is used temperature from 25ºC to 205ºC, Bragg grating wavelength as a function of temperature change for a 1535.44 nm grating. The grating spacing and changes of the index of refraction change the wavelength. Figure 6 (b), shows the result under variable strain from 0 µε to 1800 µε at constant temperature 25ºC, have a shift in the Bragg grating wavelength as a function of applied strain for a 1535.44 nm grating. From these results it can be observed that the wavelength of Bragg grating increases with both temperature and strain.

The good linear relationship between temperature and Bragg wavelength has shown the potential of using for a device sensing applications, railway track, bridge, building and earthquake monitoring, the strain or temperature measurement can used for the required monitor.

Discussion and Conclusions

The use of UV laser source for fiber Bragg grating by phase mask writing has been demonstrated. One of the techniques commonly used to inscribe Bragg grating in the core of optical fibers uses a phase mask to spatially modulate and diffract the UV beam to form an interference pattern. The interference pattern induces a refractive index modulation in the core of the photosensitive fiber, which is a placed directly behind the phase mask. The phase mask technique is relatively easy of fabricate, and makes the core grating an ideal candidate for use in telecommunication and sensing applications such as temperature sensing and strain sensing. Result of transmission spectrum and reflectivity of light in fiber Bragg grating have been relationship with Bragg wavelength. When resulted, of the strain effect and apply temperature

on an optical fiber Bragg grating. This is corresponds to change in the grating spacing and the refractive index of fiber. Therefore, it shifted in the Bragg wavelength. In this resulted, can be using an application, in the telecommunication and fiber optic sensors as high temperature sensor, fire alarm sensor, vibration sensor, and pressure sensor. The fiber grating for communication may be implement in the system for signal filtering, gain flatness, optical memory etc., The other increase of the communication capacity and performance.

Acknowledgments

References

Frazao, O., Romero, R., Rego, G., Marques, P.V.S., Salgado, H.M. and Santos, J.L. 2002. Sampled Fiber Bragg Grating Sensor for Simultaneous Strain and Temperature Measurement, Electronics Letters. Vol.38, No.14, pp.693-695.

Grattan, K.T.V. and Meggitt, B.T., 2000. Optical Fiber Sensor Technology: Advanced application Bragg Grating and distributed sensor, Kluwer Academic Publishers, London.

Hill, K.O. and *et al*. 1993. Bragg Grating Fabricated in Monomode Photosensitive Optical Fiber by UV Exposure Thorough a Phask Mask, Applied Physics Letters, Vol.62,1993, pp.1035-1037.

Kashyap, R. 1999. Fiber Bragg Grating, Academic Press, London.

Othons, A. and Kalli, K. 1999. Fiber Bragg Grating: Fundamentals and applications in telecommunication and sensing, Artech House, Inc.

Zhang, Y., Feng, D., Liu, Z., Guo, Z., Dong, X., Chiang, K.S. and Chu, C.B. 2001. High-Sensivity Pressure Sensor Using a Shielded Polymerfoated Fiber Bragg Grating, IEEE Photonics Technology Letters, Vol.15, No.6, June 2001, pp.618-619.