Holographic polymer Bragg gratings for dense wavelength division multiplexing at 1550nm

Weibiao Wang, Mai Xu, Yuxue Xia, Ming Chen, Jingqiu Liang, Shaojie Ma
Changchun Institute of Optics, Fine Mechanism and Physics,
Chinese Academy of Sciences, Changchun 130033, China
Tel: 86-431-6176339; Email: jincc@public.cc.jl.cn

Abstract
Bragg grating has lots of use in many optical field. Especially, in dense wavelength division multiplexing system and optical filters, and so on. Holographic Bragg grating with 1800 line/mm is fabricated in this experiment. Performances of holographic Bragg gratings are measured in our lab. Results show that this holographic Bragg grating can resolve 0.26nm fine line spectrum. Diffraction efficiency of Bragg grating can get 76% in 1.55\(\mu\)m wavelength. Results also show that this kind of holographic Bragg grating may use in DWDM device and can produce fine narrow width spectra.

Key words: Bragg grating; holographic; Photopolymer.

1, Introduction
Dense wavelength division multiplexing (DWDM) systems require the control of narrowly spaced bands within the silica fiber transmission windows. DWDM device have narrow spectral line width, and low loss. The dielectric thin-film reflection stacks, array waveguide gratings (AWGs)[1], and fiber Bragg gratings (FBGs)[2] are the primary form of narrow band used in optical communication systems at present time. Although these devices are important for modern fiber optical systems, other approaches of implementing DWDM devices are also seek to provide more design options and to reduce manufacturing costs. In this paper, we have developed a kind of DWDM device for this purpose and optical filters.

2, Grating principle
The design of grating is based on Bragg diffraction theory and grating theory. Generally, a grating designed according to formula as:

\[2n\Lambda \sin \theta = m\lambda...........................................................(1)\]

\(\Lambda\) is period of grating, \(\lambda\) is light wavelength, and \(\theta\) is incident angle. \(n\) is refractive index of grating material. \(m\) is diffraction orders.

For \(m=1\) order, Bragg grating is meet formula:

\[2n\Lambda \sin \theta = \lambda...................................................(2)\]

to write and recurrence of Bragg grating must satisfy principle of Bragg diffraction formula (1) and refraction law (3)
\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \] 

\( n_1 \) is refractive index of incident light medium, \( n_2 \) is refractive index of refraction light medium, \( \theta_1 \) is incident angle, \( \theta_2 \) is refraction angle

3. **Photopolymer**

The basic composition of photopolymer material has been described earlier\([3~8]\) contained acrylamide as monomer, triethanolamine as a donor-activator and aqueous soluble matrix based on polyvinyl alcohol. Photopolymer material used in our experiment is fabricated by professor Heling Zhang, who works in The Normal University of the Capital in Beijing. This kind of photopolymer is sensitive to red light—red sensitive photopolymer(RSP). Red sensitive photopolymer material compose by follow materials:

- acrylamide monomer: 2~8%
- gelatin or polymer fundus material: 5~10%
- photo cross linking reagent: 1~4%
- photo initiator: 0.5~3%
- complex photosensitive dye: 0.1~0.3%
- sensitizing agent: 0.1~1%
- stabilizer: 1~3%
- other assistants: 0.1~5%

Every component in dispensation is weight percent. Distilled water is used as solvent. Every component dispense in order and stirring. All process handle and finish at constant temperature and under safe light.

RSP have many better performances as follow:

1. It is sensitive to red, and suitable for He-Ne laser(632.8nm) and Kr ions laser holographic experiments. Its minimal exposure may get 1.2mJ/cm².
2. It could be used in daylight lamp.
3. It has high diffraction efficiency that larger than 80%.
4. It has high resolution, and could get 4000line/mm.
5. Light noise is very small. Especially there is little white fog phenomenon on gelatin plate. Surface of gelatin plate is clean.
6. Performance of gelatin plate is stable.

Absorption spectrum of RSP is shown in fig1:

![Absorption Spectrum of RSP](image)

**Fig.1 absorption spectrum of RSP.**
RSP refractive index is 1.5938 (after exposure) and 1.5026 (before exposure) determined by experiment.

The relation of grating efficiency (\(\eta\)) with exposure energy shows as fig 2.

![Grating efficiency vs. exposure energy](image)

**Fig. 2, Grating efficiency vs. exposure energy**

**Treatment of RSP after exposure**

Here, the wet treatment is used after RSP exposure. Temperature is 18~25°C, the process is:

1. Exposure gelatin plate dip in F5 solution for 10 sec.
2. Wash in water for 30 sec.
3. Dehydration in 40% isopropyl alcohol for 1 min.
4. Dehydration in 60% isopropyl alcohol for 1 min.
5. Dehydration in 80% isopropyl alcohol for 15 sec.
6. Dehydration in 100% isopropyl alcohol till emerge clear and light red image.
7. Blow by hot wind and then blow by cool wind.

**3. Experiment and Results**

**3.1 Grating fabrication**

Holographic photopolymer gelatin plate composes by RSP and bipolycarbonate substrate. RSP is coated on bipolycarbonate substrate by spin method. Its thickness is determined by spin speed. In our experiment, RSP thickness is 12 \(\mu\)m.

Experimental sketch of grating fabrication is shown in fig 3[9], RSP holographic gelatin plate is placed under a reflect mirror. A beam of He-Ne 632.8nm laser enlarged by lens incident to gelatin plate with angle \(\theta\) and at sametime there are half laser beam reflect to gelatin plate with angle \(\theta\) by a mirror, then these two half laser beams interfere on gelatin plate surface. Angle between two beams of laser decide by formula (2). Bragg grating write to RSP holographic gelatin plate through 632.8nm He-Ne laser. If grating is 1800line/mm, grating period \(\Lambda = 1/1800(\text{mm}) = 0.5556\mu\text{m}\). According to formula (2), angle \(\theta = 34^\circ 43'\) (\(n=1\) in air).

Two beams of He-Ne 632.8nm interference laser with angle \(2\theta\) incident to RSP gelatin plate surface and produce interference fringe to make RSP expose. Exposure parts of RSP happen chemical reaction to change its refractive index.
Fig.3, experimental sketch of grating fabrication

In this experiment, RSP holographic gelatin plate is exposed at 3.5mW/cm² for 3 ~ 4 seconds. After exposure, holographic gelatin plate were treated as described in section 2.

After treatment, fabrication of grating has finished. Photograph of gratings is shown in fig 4:

3.2 Grating recurrence

Grating is recurrence using light about 1.55μm wavelength: Bragg grating recurrence also meet formula (1), for m=1 order, its Bragg angle θₜ is given as follow formula:

\[ \sin \thetaₜ = \frac{λ₂}{2nₑ} \sin \theta \] ..............................(4) \n
\( λ₁ \) is write into wavelength (632.8nm, He-Ne laser), \( λ₂ \) is reconstruction wavelength. if \( λ₂=1.55μm \), according to (4), \( nₑ=1.58380 \), and \( φ=61° 4′ 33″ \), is about 61°.

Bragg grating accurate reconstruction at 1547.37nm, the measurement of Bragg angle 1
order Bragg diffraction can be measured accurately by using goniometer. Its angle accuracy is 1 min.

All experimental instrument sketch of grating reconstruction is shown as fig5. A beam of 1547.37nm wavelength laser incident upon grating and its angle scale is decided by read its value of angle degree, then rotate grating and measure 0 and 1 order diffraction angle.

Fig.5. Experimental instrument sketch of grating performances measurement.

All experiment process need to take pains because of invisible of 1547.37nm light. Incident laser spectrum is shows in fig 6.

Fig.6, spectrum of 1.55 μm laser
For grating reconstruction in air, refraction law (3) must be considered. Bragg angle of grating reconstruction is limited due to large refraction index difference (refraction index of substrate is 1.5). In air, Bragg angle of RSP grating must be smaller than 42°, it means that grating period must be larger than 0.81µm, i.e that about 1200 line/mm. For 1800 line/mm RSP grating, its minimal Bragg angle is about 61°. But it does not satisfy refraction law (3) in air, or incident light will all reflect on grating surface.

To measure the Bragg angle of 1800 line/mm RSP grating, two prisms (45°-90°-45°) are employed. Grating is placed between two prisms, as show in Fig 7(b). Prism is fabrication by polymer material bipolycarbonate with refractive index 1.50, as shown in fig 7(a):

(a) bipolycarbonate prisms (a) and grating between two prisms(b)

(b)
Fig. 8. Bragg angle measure instrument sketch of grating (a) and local sketch of light incident upon grating (b).

In fact, incident angle in air is not same with that in grating due to refractive index differences. It obey refraction law. So $\theta_b$ is not real Bragg angle of grating, as shown in fig.8(b). Considering small angle difference between prism ($n_p=1.5$) and RSP grating, real Bragg angle $\theta_{b1}$ of grating is about equal to incident angle $\theta_b$. Enlarging sketch of light in grating show in fig.8(b).

Laser incident from air with angle $\theta_0$ upon prism, as shown in Fig.8(a), one prism refract it into grating, another prism refract Bragg diffraction light into air again. Bragg angle $\theta_b$ can be calculated according to refraction law (3) by measuring incident angle $\theta_0$.

$$\sin \theta_s = n, \sin \theta_t = n, \sin(\theta_s - 45^\circ)$$

$$\theta_s = \arcsin(\frac{\sin \theta_t}{n}) + 45^\circ$$

Measurement and calculation results show in table 1:

<table>
<thead>
<tr>
<th>$\theta_0$ (degree)</th>
<th>$\theta_b$ (degree)</th>
<th>$\lambda_b$ (nm)</th>
<th>$\Delta \lambda$ (nm)</th>
<th>$P$ (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24°11’</td>
<td>60.85°</td>
<td>1546.61</td>
<td>1546.91</td>
<td>0.3</td>
</tr>
<tr>
<td>24°13’</td>
<td>60.90°</td>
<td>1547.34</td>
<td>0.15</td>
<td>8</td>
</tr>
<tr>
<td>24°15’</td>
<td>60.92°</td>
<td>1547.66</td>
<td>0.28</td>
<td>12</td>
</tr>
<tr>
<td>24°16’</td>
<td>60.92°</td>
<td>1547.66</td>
<td>0.32</td>
<td>8</td>
</tr>
<tr>
<td>24°18’</td>
<td>60.92°</td>
<td>1547.66</td>
<td>0.32</td>
<td>8</td>
</tr>
</tbody>
</table>

From table 1, we may find out that $\Delta \lambda$ is not same for every adjacent $\lambda$. It may has relation with many factors such as experiment method, change of grating period, goniometer accuracy, drift of laser wavelength, photodetector size, and so on. In our experiment, mean resolving accuracy of grating is 0.26nm.

0 order diffraction light energy is about 3.8dB, Input laser energy is 50dB, from table 1, grating efficiency is
about 76% for 1.55 μm. It illustrate that RSP and polymer prism exist some absorption losses.

If employing high accuracy photogeniometer that can measure 1 second angle, and improving experimental method, the results will more accurate.

4. Conclusion

High-performances holographic RSP gratings is designed according to Bragg diffraction principle and fabricated in holographic RSP.

RSP is coated on one polymer substrate and is sensitive to 632.8nm laser. Holographic Bragg grating is formed in RSP by controlling exposure conditions and treatment conditions. Our holographic Bragg grating is 1800line/mm. It realizes grating reconstruction by using about 1.55μm wavelength laser and get 0.26nm resolution. If employing photogeniometer with fine angle resolution, it may resolve and divide more fine structure of spectrum. Another, this kind of grating device is all polymer materials, so it has low costs.

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References: