Changing Inscribed Bragg Wavelengths with Biprism in Phase Mask Technique

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Abstract: A rotatable biprism is introduced in phase mask technique to change the inscribed Bragg of grating. In this system, the gratings are inscribed by the UV interference fringes of 248 nm derived from a rotatable biprism, where the phase mask is used as a beam splitter, and the biprism is rotated to change the intersection angle of two beams. For initializing the reference quantity of Bragg wavelength, the vertex angles of the biprism are determined by the ± 1 diffraction angle of phase mask and the refract index of the biprism. Because the change of grating period caused by the asymmetrical rotation of two beams is limited to 5×10^{-4} nm at a tunability of the Bragg wavelength of ~100 nm, the tilt of grating caused by the rotation of the biprism can be ignorable. As the shift of Bragg wavelength is 1 nm, the maximum rotation angle of the prism is ~1 degree, and the minimum rotation angle is ~3 min. By contrasting with the rotation angle ~23 s/nm of the mirror in Talbot interferometer, the rotation precision of the prisms is decreased by two or three orders of magnitude in this phase mask interferometer.

Key words: Phase mask interferometer; Biprism; Interference fringe; Fiber Bragg grating; Bragg wavelength
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0 Introduction

Since the fiber was placed directly behind a phase mask by K. O. Hill et al. [1], this method has been used widely for writing fiber Bragg grating. In this scheme, the grating period of phase mask corresponds to an identical inscribed Bragg wavelength. Thus, many methods for changing the inscribed Bragg wavelength are developed [2-6]. One of the most effective methods is the Talbot interferometer technique, which employs one phase mask and two UV-reflected mirrors to spatially modulate the UV writing beam[5-6]. However, the rotation angles of two mirrors are ~23 s/nm in Talbot interferometer.

Thus, this paper offers a tunable phase mask interferometer, where a phase mask is used as a beam splitter, and a biprism is rotated to change the inscribed Bragg wavelengths of gratings.

1 The operational principle of phase mask with a biprism

The phase mask interferometer consists of a phase mask and a rotatable biprism, where the fibers can be placed in near or far field interfering fringes, as shown in Fig. 1. Where a screen is placed in the zero-order block, the residual zero-order light is avoided from the far field interfering fringes.

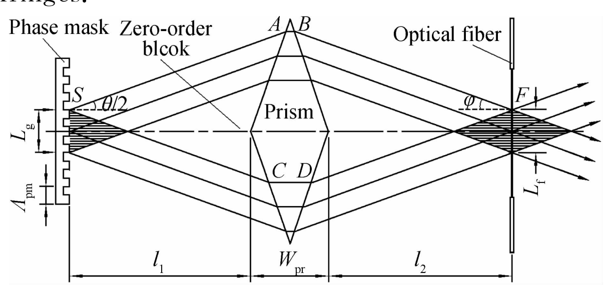

Fig. 1 Schematic diagram of the phase mask interferometer consisted of a phase mask and a biprism

With the period Λ_{pm} of phase mask, the incident light and the diffracted light satisfy the general diffractive equation

$$\Lambda_{pm}=\frac{\lambda_{uv}}{\sin(\theta/2)} \quad (1)$$

where $\theta/2$ is the ± 1 order diffracted angle, λ_{uv} is the wavelength of incident light. In this where $\theta/2$ is the ± 1 order diffracted angle, λ_{uv} is the wavelength of incident light. In this interferometer, the ± 1 order diffracted UV beams refracted twice by a biprism are interfered in fiber. Here, the period of the grating is given by the mutual angle of two interfering beams[7]

$$\Lambda=\lambda_{uv}/2\sin\varphi \quad (2)$$

As shown in Fig. 2, after the diffractive beam

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is incident to one of the equiangular planes of biprism at the angle of $\phi = \alpha/2 + \theta/2$, the beams are refracted at the angle of $\alpha/2$

$$\sin(\phi) = n_s \sin(\alpha/2) \tag{3}$$

where, n_s is the refractive index of UV-transmitted biprism with the vertex angle of α.

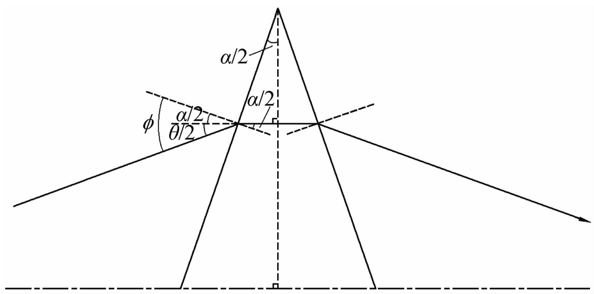

Fig. 2 Vertex angle of the biprism is determined by the ±1 diffraction angle $\theta/2$ derived from the phase mask and the refract index n_s of the biprism

Plugging $\phi = \alpha/2 + \theta/2$ into Eq. (3), the vertex angle of biprism is expressed as

$$\alpha = 2\arctan\left[\frac{\sin(\theta/2)}{n_s - \cos(\theta/2)}\right] \tag{4}$$

Then, the once refracted beams in biprism are projected to the other equiangular planes at the angle of $\alpha/2$. Refracted from these planes again, the beams transmit at the angle of ϕ from the biprism. Finally, the refracted beams are interfered in the fiber at the half angle of $\varphi = \theta/2$. In Fig. 1, the phase mask is not only used as a beam splitter, but also initializes the reference quantity of Bragg wavelength. When the vertex angles of biprism are satisfied the condition of Eq. (4), the period of grating is equal to the half period of phase mask

$$\Lambda = \frac{\lambda_{uv}}{2\sin(\theta/2)} = \frac{\Lambda_{pm}}{2} \tag{5}$$

In this scheme, the optical paths of two interfering beams are symmetrical, and make this interferometer suitable for use with low-spatial-coherence sources. In noncontact writing scheme, the fiber is placed in the far field interfering fringes, where the overlaps of the two interfering beams forms a diamond fringe with the maximum length of $L_f = L_g$. In Fig. 1, the maximum optical path difference δL_{SF} is the difference between the ±1 order diffractive light beams derived from the point S, and intersected at the point F, i. e.

$$\delta L_{SF} = (L_{SC} + n_s L_{CD} + L_{DF}) - (L_{SA} + n_s L_{AB} + L_{BF}) \tag{6}$$

where, L_{SA}, L_{AB}, L_{BF}, L_{SC}, L_{CD}, and L_{DF} are the lengths of SA, AB, BF, SC, CD, and DF. According to the geometry of optical path in Fig. 1, Eq. (6) can be formulated to

$$\delta L_{SF} = 2L_g\left[n_s \tan(\alpha/2) - \frac{\sin(\alpha/2)}{\cos\phi}\right] \tag{7}$$

To satisfy the coherence condition, the maximum optical path difference is less than the temporal coherence length

$$\delta L_{SF} < L_{tc} \tag{8}$$

where, L_{tc} is the temporal coherence length of the laser source in two beam interferometer.

The biprism is at halfway between the phase mask and the fiber, in Fig. 1. The distances l_1 and l_2 between the biprism to the phase mask and the biprism to the fiber can be expressed as

$$\begin{cases} l_1 = \left(\dfrac{W_{pr}}{2}\cot\dfrac{\alpha}{2} - \dfrac{L_g}{2}\right)\cot\dfrac{\theta}{2} - \dfrac{W_{pr}}{2} \\ l_2 = \left(\dfrac{W_{pr}}{2}\cot\dfrac{\alpha}{2} - \dfrac{L_g}{2}\right)\cot(\varphi) - \dfrac{W_{pr}}{2} \end{cases} \tag{9}$$

where, W_{pr} is the width of biprism. Due to the zero-order block, the width W_{pr} is satisfied to

$$W_{pr}\cot(\alpha/2) > 3L_g \tag{10}$$

2 Changing inscribed Bragg wavelength by rotating biprism

In this scheme, the rotation of biprism plays a critical role for changing the inscribed Bragg wavelength. The broken and solid lines indicate the optical paths before and after rotating the biprism at the angle of δ respectively, as shown in Fig. 3.

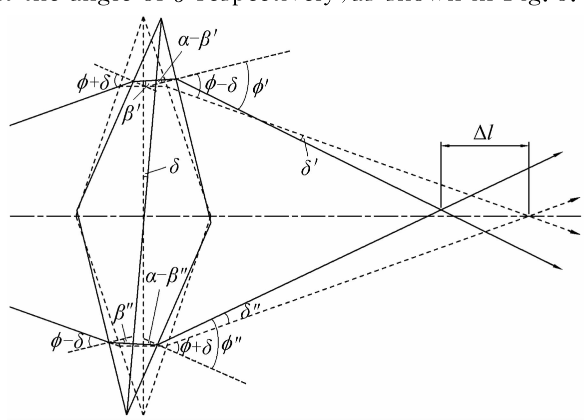

Fig. 3 Optical paths vary before and after rotating the biprism at the angle of δ

In Fig. 3, the ±1 order diffractive beams derived from the phase mask are incident to the equiangular planes of biprism at the angle of . As the biprism is rotated at the angle of , the incident angles are to $\phi + \delta$ and $\phi - \delta$. According to the refractive law, the refractive angles β' and β'' are formulated by:

$$\begin{cases} \beta' = \arcsin\left[\dfrac{\sin(\phi + \delta)}{n_s}\right] \\ \beta'' = \arcsin\left[\dfrac{\sin(\phi - \delta)}{n_s}\right] \end{cases} \tag{11}$$

where, n_s is the refractive index of the UV-transmitting biprism. Then, the once refracted beams in the biprism are incident to the other equiangular planes at the angles of $\alpha - \beta'$ and $\alpha - \beta''$. Finally, the beams are refracted from these planes at the angles of ϕ' and ϕ'' again

$$\begin{cases}\phi'=\arcsin\left[n_s\sin\left(\alpha-\beta'\right)\right]\\ \phi''=\arcsin\left[n_s\sin\left(\alpha-\beta''\right)\right]\end{cases} \tag{12}$$

i. e., the written angle changes δ' and δ'' are given by

$$\begin{cases}\delta'=\phi'-(\phi-\delta)\\ \delta''=\phi''-(\phi+\delta)\end{cases} \tag{13}$$

Thus, instead of φ in Eq. (2), the period of the fiber Bragg grating can be rewritten to:

$$\Lambda=\frac{\lambda_{uv}}{2\sin\left[\theta/2+(\delta'+\delta'')/2\right]} \tag{14}$$

Given the Bragg condition, the Bragg resonance wavelength can be represented in terms of the UV writing wavelength and the half angle $\varphi=\theta/2+(\delta'+\delta'')/2$ between interesting UV beams as:

$$\lambda_B=2n_{eff}\Lambda=\frac{n_{eff}\lambda_{uv}}{\sin\left[\theta/2+(\delta'+\delta'')/2\right]} \tag{15}$$

where, n_{eff} is the effective core index of fiber.

For photo-writing in the diamond bridge of interfering fringes, the fiber is moved with the maximum interfering length. Provided ignoring the position changes of refracted pots, the points of intersection between two beams and centre line are moved to:

$$\begin{cases}l_2'=\left(\frac{W_{pr}}{2}\right)\cot\left(\frac{\theta}{2}+\delta'\right)-\frac{W_{pr}}{2}\\ l_2''=\left(\frac{W_{pr}}{2}\cot\frac{\alpha}{2}-\frac{L_g}{2}\right)\cot\left(\frac{\theta}{2}+\delta''\right)-\frac{W_{pr}}{2}\end{cases} \tag{16}$$

Thus, the interference fringe of two beams is shifted:

$$\Delta l=\frac{l_2'-l_2+l_2''-l_2}{2}=\frac{1}{4}\left(W_{pr}\cos\frac{\alpha}{2}-L_g\right)\times\left[\cot\left(\frac{\theta}{2}+\delta'\right)+\cot\left(\frac{\theta}{2}+\delta''\right)-2\cot\frac{\theta}{2}\right] \tag{17}$$

In this phase mask system, the grating period of phase mask is $\Lambda_{pm}=1\ 084$ nm, the wavelength of UV is $\lambda_{uv}=248$ nm. By Eq. (1), the diffractive angle of ±1 order diffraction light is $\theta/2=13.225°$. Because the refractive index of deep ultraviolet fused silica prism is $n_s=1.55$ at the 248 nm wavelength[8], the vertex angular of prism is $\alpha=43.289°$ by Eq. (4), and the incident angle is $\phi=\alpha/2+\theta/2=34.870°$ in Fig. 2.

The coherence length of typical excimer laser is about fraction of one mm, even though the EX10BM laser (GAM LASER, Inc., USA) offers temporal coherence length of $L_{tc}=5$ mm. To satisfy the coherence condition Eq. (8), the maximum optical path different is $\delta L_{SF}=5$ mm. According to Eq. (7), the effect length of phase mask is limited to $L_g\leqslant15$ mm.

In this writing system, the rotation angles of two beams are different when the biprism is rotated. This angle difference $\delta'-\delta''$ between two beams causes the tilt of grating in Fig. 4.

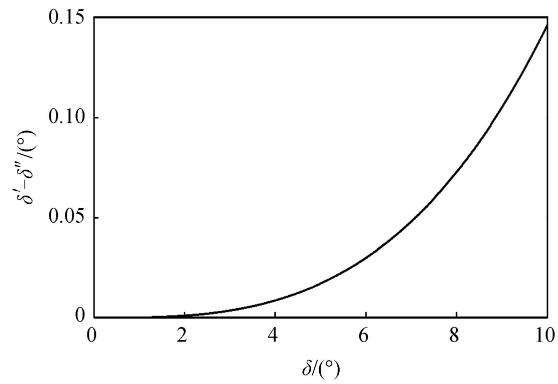

Fig. 4 The angle difference is followed with the rotation of the biprism

In Fig. 4, the angle difference is $\delta'-\delta''<0.15$ degree at the rotation of $\delta=0\sim10$ degree by Eq. (13). The grating period along the fiber axis determines the resonant wavelengths[9]:

$$\Lambda=\Lambda_g/\cos\left(\delta'/2-\delta''/2\right) \tag{18}$$

where, Λ_g is the original grating period defined by Eq. (5). The maximum variation of grating period is $\Lambda-\Lambda_g<5\times10^{-4}$ nm, which is lower than the wavelength accuracy of 0.2 nm. Thus, the tilt of grating caused by the rotation of the biprism can be ignorable.

In the core of optical fiber, the effective refractive index is $n_{eff}=1.46$. Fig. 5 shows the curve of the Bragg wavelength λ_B as a function of the rotation of prism by Eq. (15).

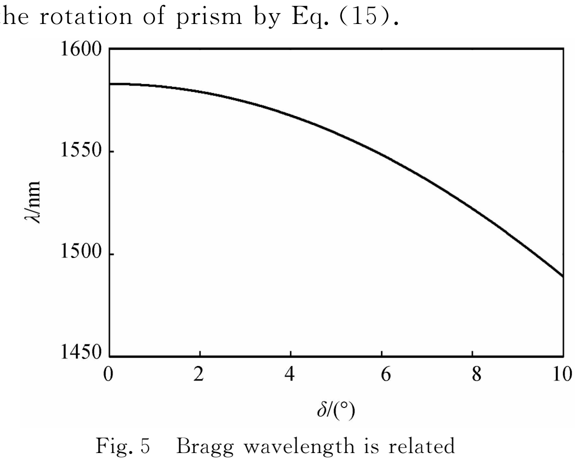

Fig. 5 Bragg wavelength is related to the rotation angles of biprism

In Fig. 5, as the angle of prism is rotated at the angle of $0\sim10$ deg, the Bragg wavelength is $1\ 582.7\sim1\ 489.0$ nm. As the shift of Bragg wavelength is 1 nm, the maximum rotation angle of the prism in this interferometer is $\sim1°$, and the minimum is ~3 min. By contrasting with the rotation angle ~23 s/nm of the mirror in Talbot interferometer[5-6], the rotation precision of the prism is decreased by two or three orders of magnitude in this phase mask.

To satisfy the size of the zero-order block by

Eq. (10) and the mechanical setup, the width of biprism is $W_{pr}=45$ mm. As a result of Eq. (9), the distance between the prism and the phase mask is $l_1=187$ mm, and the distance between the prism and the fiber is $l_2=187$ mm. By Eq. (17), the shift $\Delta l=0\sim-7.7$ mm of the maximum fringes is followed with the rotation of biprism in Fig. 6.

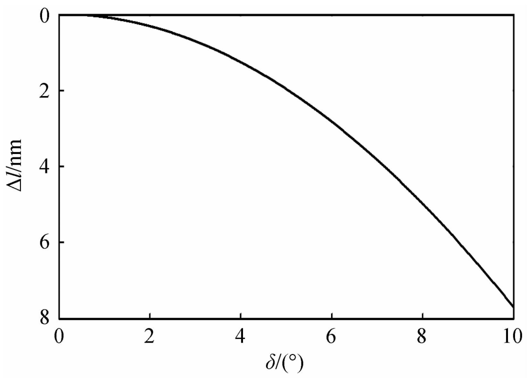

Fig. 6　Displacement Δl of the maximum interfering fringes is related to the rotation angles δ of biprism.

3　Conclusion

The fiber Bragg grating is written by the 248 nm UV interference fringes derived from the biprism, where the phase mask is used as a beam splitter of ±1 order diffraction light. The variation of inscribed Bragg wavelength is depended on the mutual angle between two writing beams, which are changed by rotating the biprism. At the same time, the fiber is moved with the diamond bridge of the interfering fringes. It is noteworthy that the rotation precision of a biprism in the phase mask interferometer is lower two or three orders of magnitude than two mirrors in Talbot interferometer.

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双棱镜改变写入 Bragg 波长的相位掩模技术

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摘　要：将一种可旋转的双棱镜引入到相位掩模技术中以改变光栅的写入 Bragg 波长．在该系统中，光纤光栅是由来自可旋转双棱镜所形成的波长为 248 nm 的紫外干涉条纹写入的，其中，相位掩模被用作 1 级衍射光的分束器，通过双棱镜的旋转可改变两写入光束的交叉角．为了初始化 Bragg 波长的参考值，双光栅的顶角由相位掩模的 1 级衍射角和双棱镜的折射率确定．因为在～100 nm 范围内两光束的非对称旋转对光栅周期的改变是 5×10^{-4} nm，双棱镜引入的光栅的闪耀可忽略．当 Bragg 波长的移位为 1 nm 时，棱镜最大的旋转角为～1 degree，最小的旋转角是～2.4 min．与 Talbot 干涉仪中平面镜的旋转角～23 s/nm 相比，该相位干涉仪中棱镜的旋转精度降低了 2～3 个数量级．

关键词：相位干涉仪；双棱镜；干涉条纹；光纤 Bragg 光栅；Bragg 波长

LI Chuan　was born in 1971. In 2002, he obtained his Ph. D. degree in optical engineering from Tianjin University. In 2001, he was awarded WANG DAHENG Optical Prize of the Chinese Optical Society. Since 2004, he has been a professor of Kunming University of Science and Technology, and his current research interests focus on fiber optic sensor technologies and applications.