A novel way to write fiber Bragg gratings with controllable wavelength and chirp using a phase mask

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Received August 15, 2002

A novel method for writing long fiber Bragg grating (FBG) with arbitrary multi-wavelength and chirp at the same place of a fiber by using a phase mask is presented. An experimental equation is derived for Bragg wavelength, and the Bragg wavelength is found to be a function of the distance between the fiber and the phase mask. The chirp of the overlapped FBG is decided by the angle between phase mask and fiber. A multi-wavelength FBG with 4, 8, 16 channels has been written by using a unique phase mask.

OCIS codes: 050.2770, 060.5060, 260.2030.

Because of the compatibility with fiber and the flexibility for achieving desired spectral characteristics, nowadays FBG has been extensively applied in many fields, such as grating dispersion compensator, erbium-doped fiber amplifier, semiconductor lasers with external Bragg grating reflector, band-rejection filters, optical switching[1−3]. However, for different applications, FBG with different refractive index modulation profiles and different Bragg wavelengths are required. Till now, the refractive index change that can be induced by UV light in photosensitive fiber core has not been completely understood, so further research on FBG are still needed. Writing FBG by phase mask is more promising than other methods, because it only demands lower source coherence and provides better repeatability.

The FBG with different wavelengths written at the same place of fiber by phase mask technology has now achieved more and more attentions, because of the potential applications in multi-channel dispersion compensation, multi-channel filters and multi-wavelength lasers. In this paper, we proposed a novel method to write long FBGs with arbitrary wavelength and desired chirp at the same place of fiber using one phase mask. The span between different gratings can also be designed by the method, The method can be used in FBG with various Bragg wavelength and arbitrary span between two neighbouring Bragg wavelengths when distance error is not considered, and UV light energy, diffraction and coherence have little impact on wavelength of written fiber grating by our experiments.

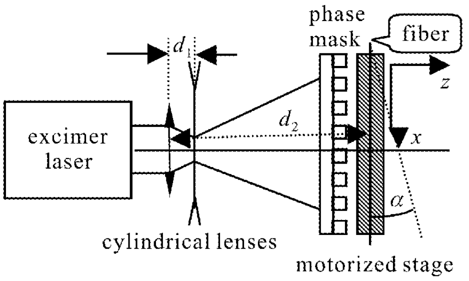

Fig. 1. Fabrication setup for chirped gratings at different wavelengths.

The experiment is shown in Fig. 1. The motorized stage can move along z axis; at the same time, it can also horizontally rotate around the center of the phase mask. The UV wavelength (λ) of the KrF excimer laser is 248 nm. The focal lengths of the convex and concave cylindrical lenses are f_1 and f_2, respectively. The distance between them is d_1, and the distance d_2 is counted from the convex lens to the mask. The parallel laser beam will be broadened through two cylindrical lenses[4,5], the amplification is

$$A=\left(\frac{f_1-f_2-d_1}{f_1 f_2}\right)d_2 \tag{1}$$

In the experiment, we can adjust d_1 and/or d_2 to change the width of excimer laser light beam to satisfy the desired grating's length and pre-adjust chirp. Theoretically the method can fabricate arbitrarily long FBG and the arbitrary span between two neighboring Bragg reflected wavelengths. The grating period written by phase mask is

$$\Lambda(x)=\frac{\Lambda_{\mathrm{pm}}}{2}\left[1-x\left(\frac{a}{f-d_2}\right)(1-\lambda^2/\Lambda_{\mathrm{pm}}^2)^{-1/2}\right] \tag{2}$$

where Λ is period of the core refractive index modulation namely Bragg period and Λ_{pm} is period of phase mask. α is the angle between fiber and phase mask. f is the assembled lenses focal length, $f=\frac{f_2 f_1}{f_2+f_1-d_1}$. The Bragg wavelength of FBG is

$$\lambda_{\mathrm{B}}=2n_{\mathrm{eff}}\Lambda, \tag{3}$$

where λ_{B} is Bragg wavelength, n_{eff} is effective index of FBG at corresponding Bragg wavelength. According to Eq. (3), we can change the Bragg wavelength of FBG by changing the phase mask period.

If photosensitive fiber and phase mask are parallel, or $\alpha=0$, we can write many uniform gratings with different center wavelength using the same uniform phase mask.

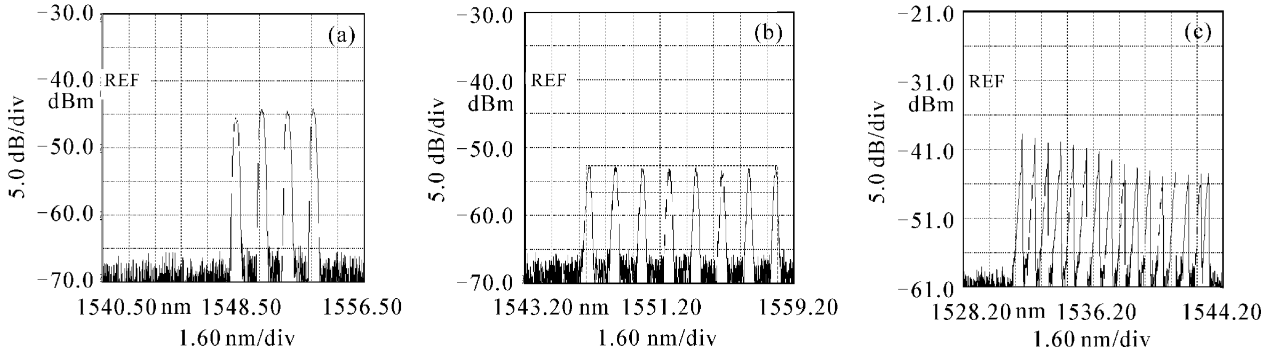

Fig. 2. Three experimental reflected spectra.

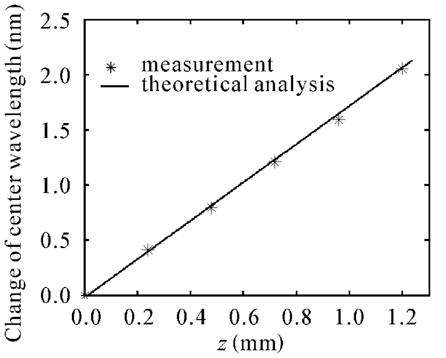

Fig. 3. Relation between displace z and change of center wavelength.

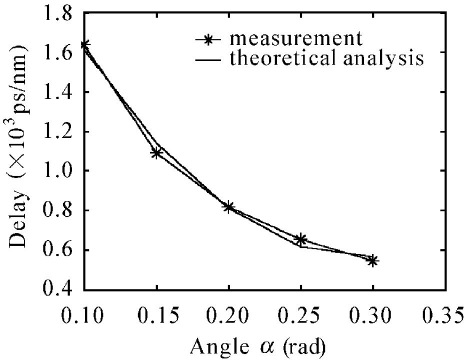

Fig. 4. Measured and theoretical curve of the delay when α is changed.

How to write chirped FBGs? Noticed in Fig. 1, if $\alpha \neq 0$, according to Eq. (2), the written FBG has chirped. The chirp is decided by α and distance d_2 from the convex lens to the phase mask.

The fiber used in the experiment was standard Corning single mode fiber (SMF-28), which was hydrogen loaded for four weeks at room temperature at 130 atm. For a directly written grating in the hydrogen loaded fiber, the 3-dB bandwidth of reflected spectrum was 0.244 – 0.148 nm, as shown in Fig. 2. Using a uniform phase mask (in Figs. 2(a) and (b), Λ_{pm} = 1067 nm and; and in Fig. (c), Λ_{pm} = 1057.3 nm) at the same place of the fiber, we wrote multi-wavelength fiber gratings (a) and (b) spaced at 1.6 nm, and grating (c) 0.8 nm. The exposure power per pulse was 120 mJ and the repetition rate was 15 Hz. α is 0.12 rad. The distance between fiber and phase mask is z and the change of Bragg wavelength with z for the FBG with 125 mm in length, $f_1 = 275.3$ mm and $f_2 = -25.25$ mm is illustrated in Fig. 3. As we can see, the reflected Bragg wavelength increased linearly with the increasing of distance z. We find the relation between z and λ_B is

$$\lambda_B = 3.054z + C, \tag{4}$$

where C is constant which is determined by period of phase mask and effective index of photosensitive fiber (n_{eff}). In Fig. 3, the symbols * illustrate experimental results and the straight line represents theoretical curve. It shows that the different wavelengths can be written with the same phase mask. The reflected spectra of FBG with four, eight, sixteen wavelengths are shown in Fig. 2. The relation between delay and angle is shown in Fig. 4. The dispersion analyzer is EG&G CD400. It shows that the angle α can control chirp of FBG, so it is easy to write different chirped FBG.

How to write multiwavelength FBG at the same place of fiber? When the reflectivity of a reflected peak is enough, the stage is moved to next place to write next reflected peak. If several reflected peak are wanted, repeatedly it can write multi-wavelength FBG at the same place of fiber. Multi-wavelength can be written at the same place, or overlapped and normally the characteristic of FBG begin to become worse when the reflected peaks beyond 8. Our experiment indicated that the range of z is less than 10 mm, otherwise the characteristic of FBG will become worse and the chirped angle α is less than 0.5 rad for high quality FBG.

We chose 1.6 nm as the even space between neighboring reflected wavelengths. It satisfied the ITU-T standard, because the neighboring wavelength difference of 1.6 nm was put forward by ITU-T. Our FBG can compensate dispersion of eight-channel wavelengths in WDM system at the same time. Later experiments in our institute conform that the dispersion compensation is perfect[6]. A multi-wavelength laser has also been made using the FBG[5]. We can also easily write FBG with arbitrary wavelength space and precisely control the reflectivity of different wavelengths. As the reflected wavelength to be written is sensitive to the distance z, the distance should be controlled precisely.

Using a uniform phase mask we have found a new way to write long chirped FBG with arbitrary wavelength and wavelength span. The multi-wavelength FBG with 16 channels has been written at the same place using single phase mask. Such multi-channel FBGs have found many applications in WDM systems.

This work was supported by Northern Jiaotong University Pandeng Fund. T. Ning's e-mail address is ntigang@163.com.

References

1. T. Erdogan, J. Lightwave Technol. **15,** 1277 (1997).
2. S. Kim, S. Kim, J. Kwon, and B. Lee, IEEE Photon. Technol. Lett. **13,** 839 (2001).
3. C. R. Giles, J. Lightwave Technol. **15,** 1391 (1997).
4. J. D. Prohaska, E. Snitzer, S. Rishton, and V. Boegli, Electron. Lett. **29,** 1614 (1993).
5. I. Riant, J. Gourhant, F. Bruyère, S. Gurib, J. da Loura, and P. Sansonetti, in *ECOC'98* 1998.
6. T. Ning, S. Jian, L. Pei, Z. H. Xie, F. P. Yan, T. J. Li, Z. Tong, H. Wei, and M. G. Wang, Acta Optica Sinica (in Chinese) **22,** 839 (2002).