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Fabrication of arbitrarily apodized fiber Bragg gratings with narrow bandwidth

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Abstract: A double-exposure fabrication method without any intensity shadow mask to fabricate arbitrarily apodized fiber Bragg gratings (FBGs) with narrow bandwidth is demonstrated by controlling the total ultra violet (UV) irradiation along the grating by varying the speed of a translation stage. The UV source used is a stable continuous intracavity frequency-doubled argon-ion laser. The parameters (such as length, apodization profile, average index change) of FBGs can be easily changed with this method. The total UV irradiation is kept constant in the double-exposure process because of the precise control of the exposure time, which ensures that the apodized FBG's bandwidth can be extremely narrow. The full width at half maximum (FWHM) bandwidth of the 2-cm-long apodized FBG fabricated by this method is 0.15 nm with a maximum reflectivity of more than 95%.

Key words: fiber Bragg grating; apodization; double exposure

Since the first observation of in-core fiber grating by Hill et al. in 1978[1], fiber Bragg gratings (FBGs) formed by ultraviolet irradiation[2] have developed into a critical component for many applications in fiber optic communication and sensor systems[3-5] due to their flexibility in easily achieving desired spectral characteristics, all-fiber geometry, low insertion loss, high return loss or extinction, and potentially low cost. In order to reduce the sidelobes of uniform FBGs, one may anodize the grating's coupling strength along the grating by gradually tapering the refractive index modulation amplitude to zero at both ends of the grating. In this way, a distributed Fabry-Perot interferometer is formed by the two sides of the grating, which causes resonant structure on the blue side of the spectrum although sidelobes on the red side are greatly reduced[6]. To further suppress these sidelobes on the blue side, it is necessary to keep the average refractive index constant along the grating. Either a phase mask with variable diffraction efficiency[7] or a specially designed intensity shadow mask[8] is usually used. However, one mask only corresponds to one apodization profile.

In this work, we demonstrate a novel double-exposure method for fabricating arbitrarily apodized FBGs with narrow bandwidths. Different apodization profile FBGs with arbitrary lengths can be obtained without any intensity shadow mask by using a stable continuous intracavity frequency-doubled argon-ion laser and varying the UV irradiation along the grating by controlling the speed of a translation stage.

1 Experimental Results and Discussion

The scheme of the experimental setup is the same as the one for the fabrication of the uniform FBG, which is shown in Fig. 1. The UV source is 244 nm laser radiation with a beam diameter of 0.9 mm, and a maximum output power of 100 mW generated by a continuous intracavity frequency-doubled argon-ion laser (Innova 300C FreD from Coherent). The UV laser beam is focused onto the radiation mode suppression photosensitive fiber (with acrylate coating removed, PS-RMS-50 from INO) through a fused silica cylindrical lens with 10-cm focal length and a uniform phase mask. The phase mask is fixed together with the fiber onto a translation stage which can be aligned relative to the laser beam. The specially designed phase mask with grating period of 1 070.59 nm employed in the experiments is optimized for 244-nm illumination (from StockerYale). The UV exposure is controlled by changing the speed of the programmable translation stage (M-521DD from Physik Instrumente) with a resolution of 0.1 μm, a maximum speed of 100 mm/s and a travel range of 200 mm. The Bragg grating transmission during inscription is monitored by a lightwave measurement system with a resolution of 1 pm (8164A from Agilent).

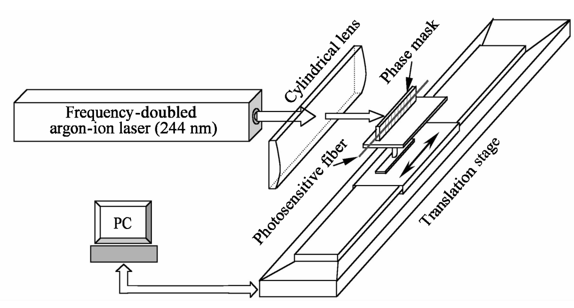

Fig. 1 Scheme of the experimental setup

During the first step of exposure, the inscription process is the same as that of a uniform FBG. The only difference is that we gradually taper the refractive index modulation amplitude to zero at both ends of the grating by increasing the scanning speed of the translation stage accordingly. During the second step of exposure, the uniform phase mask is taken away, and the fiber is directly irradiated by the UV laser to keep the same total exposure along the grating by programming the speed of the translation stage. For example, in order to fabricate a Gaussian-apodization FBG, the speed of the translation stage for the first exposure can be described by

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$$u_1(z) = \frac{u_{\min}}{\exp(-(z-z_c)^2/z_0^2)} \tag{1}$$

where $u_{\min}$ is the minimum scanning speed at the first step, and z_c is the center position of the grating. z_0 determines the Gaussian-apodization profile of the grating, because the UV exposure is proportional to the irradiation time and is thus inversely proportional to the scanning speed of the translation stage. Here, the photoinduced refractive index change is also presumed to be proportional to the UV exposure for simplicity, which is reasonable when the photosensitive fiber is not over-exposed.

During the second step of exposure, the speed of the translation stage can be expressed as

$$u_2(z) = \frac{u_{\min}u_{\max}}{u_{\min} + u_{\max} - u_{\min}u_{\max}/u_1(z)} \tag{2}$$

where $u_{\max}$ is the maximum scanning speed at the second step. Therefore, the total exposure R_{ex} is a constant along the grating as follows:

$$R_{ex}(z) \propto \frac{1}{u_1} + \frac{1}{u_2} = \frac{1}{u_{\min}} + \frac{1}{u_{\max}} = C \tag{3}$$

The parameters $u_{\min}$, $u_{\max}$, z_c and z_0 can be arbitrarily chosen according to the coupling strength, the fringe visibility of the index change, the length and the Gaussian-apodization profile of the grating. Fig. 2 shows the scanning speed and the normalized exposure of the two steps for the fabrication of the grating with the Gaussian-apodization profile, where $u_{\min} = 30$ μm/s, $u_{\max} = 1\ 520$ μm/s, $z_c = 10$ mm and $z_0 = 5$ mm.

In the apodized FBG fabrication with the double-exposure method, precisely controlling the total UV exposure along the grating is one of the most important issues to achieve a narrow bandwidth[9-10]. Pulse lasers are usually used in many reported FBG fabrication systems, such as ArF or KrF excimer lasers or self mode-locked Ti: sapphire femtosecond lasers. However, the energy of every shot always fluctuates considerably for pulse lasers, which may cause large errors when counting the shot number. It is much easier to precisely control the UV irradiation by changing the exposure time of a stable CW laser than by counting the shot number of a pulse laser.

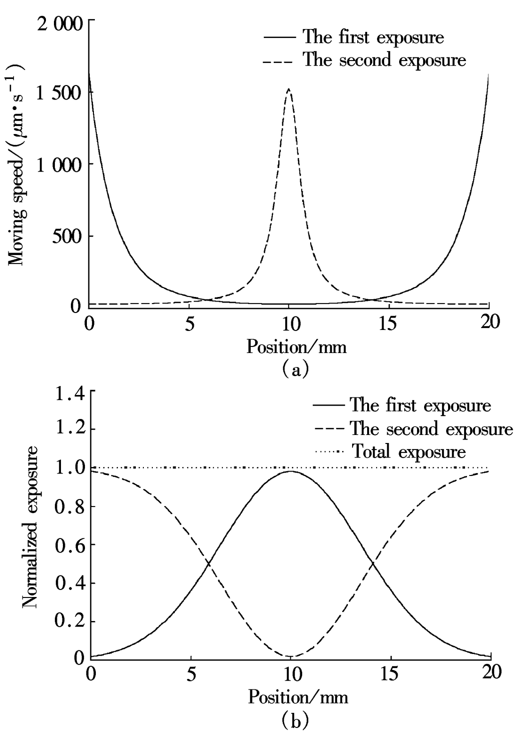

Fig. 2 Exposure intensity for the fabrication of the Gaussian-apodization FBG. (a) The speeds in the first and the second exposure; (b) The normalized UV exposure under the scanning speeds of (a)

Fig. 3 shows the schematic illustration of the refractive index modulation, transmission and reflection spectra of the Gaussian-apodization FBG after the first exposure with the scanning speed shown in Fig. 2. The average index change of the FBG also satisfies a Gaussian function as shown in Fig. 3(a). For the Gaussian-apodization FBG, the local Bragg wavelength at two sides is a little smaller than that at the center of the grating because the Bragg wavelength of a uniform FBG is proportional to its efficient refractive index[11]. Therefore, the fine structure of the distributed resonance on the blue side of the spectrum occurs, which can be obviously seen in Fig. 3(b). The FWHM bandwidth of the main reflection peak is around 0.16 nm.

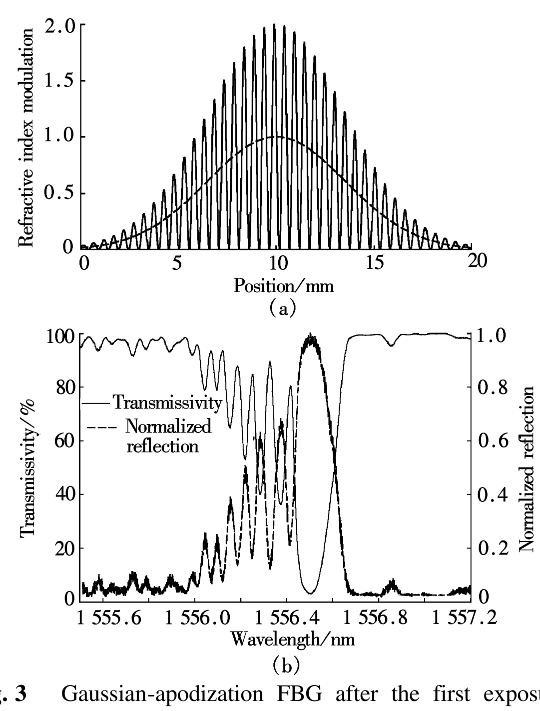

Fig. 3 Gaussian-apodization FBG after the first exposure with the uniform phase mask. (a) Schematic illustration of the refractive index modulation; (b) Transmission and reflection spectra

Fig. 4 describes the Gaussian-apodization FBG with constant average index change after the second exposure compensation. One can see that the distributed resonance is almost completely suppressed. The FWHM bandwidth and the 10% bandwidth of the 2-cm-long apodized FBG are around 0.15 nm and 0.20 nm, respectively, with a maximum reflectivity of more than 95%. This FWHM bandwidth of 0.15 nm is a little smaller than that (0.16 nm) of the main reflection peak of the FBG shown in Fig. 3, which means that the average index change remains almost unchanged along the whole grating.

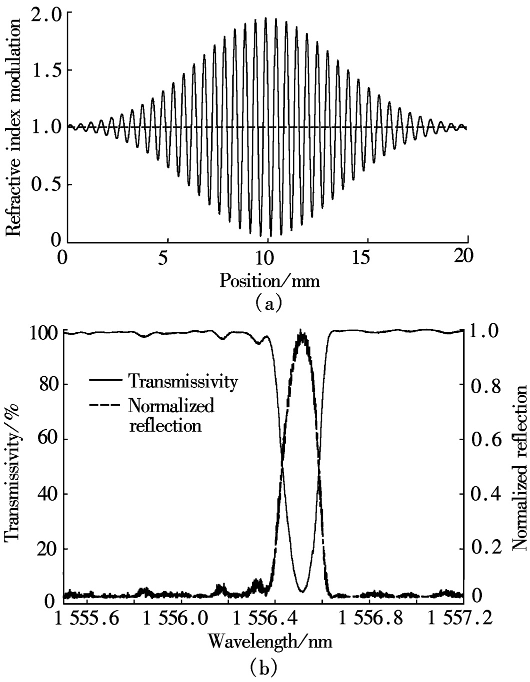

Fig. 4 Gaussian-apodization FBG with constant average index change after the second exposure without the uniform phase mask. (a) Schematic illustration of the refractive index modulation; (b) Transmission and reflection spectra

2 Conclusion

Arbitrarily apodized FBGs with narrow bandwidths can be obtained without any intensity shadow mask by precisely controlling the exposure time through a programmable translation stage. A 2-cm-long apodized FBG is fabricated by this method. Its FWHM bandwidth reaches 0. 15 nm with a maximum reflectivity of more than 95%. Based upon the technique, apodized FBGs with much narrower bandwidths can be easily obtained by increasing the grating lengths.

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任意变迹的窄带宽光纤布拉格光栅的制备

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摘要:通过控制平台移动速度来控制紫外曝光量和 2 次曝光的方法实现任意变迹光纤布拉格光栅的制备. 该方法采用连续氩离子激光作为紫外光源,不需要光强掩模板,通过对移动平台速度的编程控制可以获得任意的光栅结构参数,如长度、变迹包络、平均折射率改变量等. 在 2 次曝光过程中,由于对 2 次紫外曝光量的精确控制,整个光栅的总平均折射率变化保持不变,从而避免了由此引起的啁啾而可以获得无旁瓣窄带宽的反射光栅. 采用该方法制备了一根 2 cm 长的高斯变迹光栅,其反射带宽达到了 0. 15 nm,反射率约为 95%.

关键词:光纤布拉格光栅;变迹;2 次曝光

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