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Simple pure apodization method for fiber Bragg gratings by sequential UV writing

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Abstract

A simple UV exposure method is proposed to achieve pure apodization for fiber Bragg gratings fabricated by sequential UV writing. Through the exposure phase and/or time control of multiple UV shots, the ac-index can be adjusted independently with the dc-index kept constant.

1 Introduction

Many pure apodization methods for realizing advanced fiber Bragg gratings (FBGs) have been developed in the literature during the past decade [1-3]. Here pure apodization means to keep the average refractive index to be constant through the entire grating length while the ac index modulation can change independently. Previous developed technologies include the double-ultraviolet exposure method, complex design of phase mask, moving-fiber scanning-beam dithering technique, phase mask method with polarization control, and two beam interference with polarization control. However, these methods may suffer from the introduction of additional uncertainties, requiring additional optical elements, limitation of grating length, or only being suitable in either phase mask or holographic approach. In this work, a simple and cost-effective FBG writing method is proposed to realize pure apodization for both the phase mask and holographic sequential UV writing schemes [2,4]. The UV dose exposed on the fiber to form every grating section is divided into two sequentially writing shots instead of one. In this way one gain the freedom to adjust the ac-index independently while keeping the dc index profile fixed. By precisely connecting grating sections with partial overlap, the desire grating profile can be matched while the dc index become constant through the whole grating length.

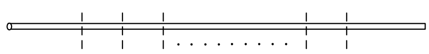
2 Theory and experiment

For long FBG fabrication by the sequential UV writing scheme, Gaussian-shaped writing beam is equally-spaced and partially-overlapped to sequentially imprint grating sections. The phases of the overlapped grating sections must be controlled precisely to form a long-length grating without phase errors. The average refractive index (n_{dc}) has to be constant along the fiber while the ac index modulation (n_{ac}) can be locally changed to form specific apodized profiles. In the proposed method we set the exposure location to be x_i, i = 1, 2….N, and let the UV dose to be $2I_0$ at every x_i. The total UV dose, $2I_0$, is divided into two shots, shot 1 and shot 2, with the beam amplitudes I_1 and I_2, respectively, and the phases of the two UV fringes are θ_1 and θ_2, respectively, as shown in Fig. 1(a) and Fig. 1(b). The index modulation amplitude and phase of every grating section are determined by the superposition of the two shot profiles, as shown in Eq. 1.

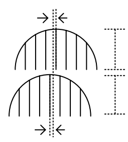
$$I(x) = I_1 e^{i(kx+\theta_1)} + I_2 e^{i(kx+\theta_2)} \quad \propto \quad n_{dc}(x) + n_{ac}(x) \quad (1)$$

$$I(x) = 2I_0 e^{ikx} \cos(\Delta\theta) \quad (2)$$

$$I(x) = 2I_0 e^{ikx} (m-1) \quad (3)$$



(a)



(b)

Fig. 1. (a)Illustration of UV sequential writing. (b)Illustration of intensities and phases of the two shots.

To achieve pure apodization, two exposure configurations can be used. In configuration 1, the total UV dose is $2I_0$, and the two shots have equal intensity I_0. The ac index modulation is adjusted by symmetrically changing the fringe phase of the two shots to be $\Delta\theta$ and $-\Delta\theta$, resulting in zero phase-shift at x_i due to amplitude adjustment. Equation 2 in the previous page shows the superposed UV fringe distribution, which amplitude can be determined by the factor $\cos(\Delta\theta)$. Table 1 shows some example conditions of the two shots in this configuration.

In configuration 2, the index modulation is achieved by setting θ_1 and θ_2 equal to 0 and π, respectively, and let the intensity $I_1 = mI_0$. The total UV dose is $2I_0$. Equation 3 in the previous page shows the superposed UV fringe amplitude distribution. The net phase shift at x_i is zero, and the final fringe amplitude is determined by the factor (m-1). Table 1 shows some example conditions of the two shots in this configuration.

	Configuration 1 $\theta_1 = -\theta_2 = \Delta\theta$ $I_1 = I_2 = I_0$	Configuration 2 $\theta_1 = 0$, $\theta_2 = \pi$ $I_1 = mI_0$, $I_1 + I_2 = 2I_0$
Normalized $n_{ac} = 1$	$\Delta\theta = 0$	m = 2
Normalized $n_{ac} = 0.5$	$\Delta\theta = \pi / 3$	m = 1.5
Normalized $n_{ac} = 0$	$\Delta\theta = \pi / 2$	m = 1

Table 1 The conditions of the two configurations.

The proposed methods have been experimentally tested by exposing photosensitive optical fibers to 244-nm UV radiation, which has a Gaussian fringe profile with its beam size $1/e^2$ about 6.5 mm. The UV dose for achieving maximum index modulation is divided into two shots, and sequentially exposes onto the fiber at the same location. To ensure linear index response, the fibers are performed with UV treatment in advance [4]. The grating index modulation envelopes are measured by side-diffraction method [4] and the transmission dips are measured by the optical spectrum analyzer. Figure 2(a) and 2(b) shows some measured grating index profiles. The index modulation profiles of the gratings are Gaussian-shaped, similar to the shape of UV writing profile. By using the measured Gaussian index envelopes in the transform matrix calculation to fit the transmission spectra, the curve between the normalized index modulation and phase shift $\Delta\theta$ is shown in Fig. 2(c), and the curve between the normalized index modulation and I_1/I_0 is shown in Fig. 2(d). The simulation curves are derived from Eq. 2 and Eq. 3. The experimental data in dots fit well with the theoretical predictions. These correlation results for index modulation can then be used in actually fabricating complex FBGs, which is in progress right now and further results will be reported during the conference.

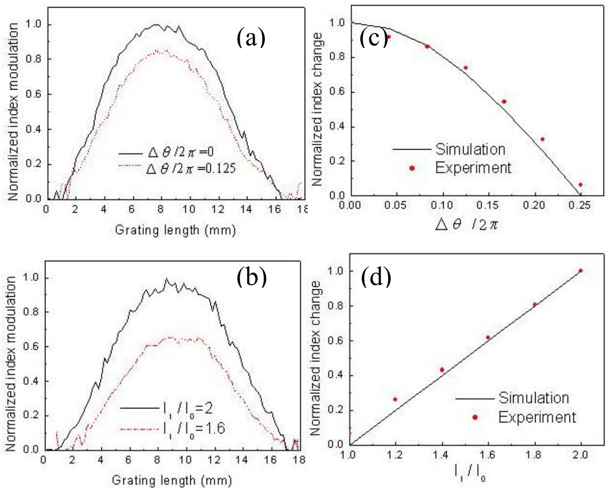


Fig. 2. (a)Index profiles of single grating section in configuration 1. (b)Index profiles in configuration 2. (c) Index modulation in configuration 1. (d) Index modulation in configuration 2.

In conclusion, a simple method for attaining pure apodization is proposed for FBG sequential UV writing. The UV dose at every exposed location is divided into two, and the ac index modulation is adjusted by controlling the superposed phase and amplitude of the two imprinted UV fringes. The average refractive index is kept constant due to the constant net UV flux per grating section, and the ac index modulation can be locally and independently changed in both configurations.

3 References

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