Optics & Laser Technology 32 (2000) 307–310

Optics & Laser Technology

www.elsevier.com/locate/optlastec

Apodised fiber Bragg gratings fabricated with a uniform phase mask using Gaussian beam laser

Chingchung Yang [*,1], Yinchieh Lai [1]

Institute of Electro-Optical Engineering, National Chiao-Tung University, Hsinchu, Taiwan, ROC

Received 3 April 2000; received in revised form 29 June 2000; accepted 20 July 2000

Abstract

A new exposure scheme for fabricating apodised fiber Bragg gratings by the use of a uniform phase mask and a Gaussian beam laser is demonstrated. Average refractive index is kept nearly constant along the grating to derive a side lobe suppression of 20 dB in the shorter wavelength. This scheme allows the writing of truly apodized fiber Bragg gratings. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Fiber Bragg grating; Raised Gaussian apodisation; Side lobe

1. Introduction

Fiber Bragg gratings (FBGs) are well recognized as key components in DWDM systems because of their low insertion loss and high-wavelength selectivity. For passive devices in DWDM communication systems, sharp, well-defined filter amplitude responses are one of the critical characteristics [1]. For a typical FBG, the narrowness of the bandwidth is usually imposed by the side lobes on the spectral response [2]. A uniform FBG yields highly undesirable side lobes due to Fabry–Perot resonance at the sharp boundaries of the grating. A well-discussed method to reduce these side lobes is to apodize the grating coupling strength along the grating by gradually tapering the index modulation amplitude to zero at the two edges [3]. This helps to reduce the side lobes in the higher wavelength, but it still leads to resonance that occurs in the shorter wavelength. In this situation, the Bragg wavelength at either end of the grating is smaller than that at the center of the grating, and thus leads to some side lobes in the lower wavelength. To further suppress these side lobes, it is necessary to keep the average refractive index constant along the grating. Several approaches have been reported in the literature [4–6]. Pan et al. [4] used an apodised phase mask with variable diffraction efficiency to fabricate their steep skirt FBGs. Mola et al. [5] demonstrated a double-exposure method by using shadow masks to control the index variation along the fiber, while Singh and Zippin [6] have fabricated apodised fiber gratings by the use of a uniform phase mask and a single illumination process.

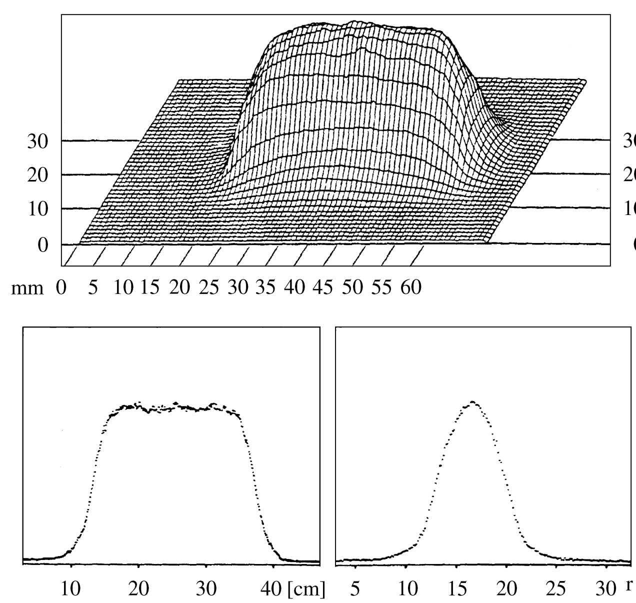

Fig. 1. 3D profile of a raw excimer laser beam, and cross-sections.

* Corresponding author. Tel.: +886-03-5917605.
E-mail address: ycjong@itri.org.tw (C. Yang).
[1] Also with Industrial Technology Research Institute(ITRI), Hsinchu, Taiwan, ROC.

PII: S0030-3992(00)00069-4

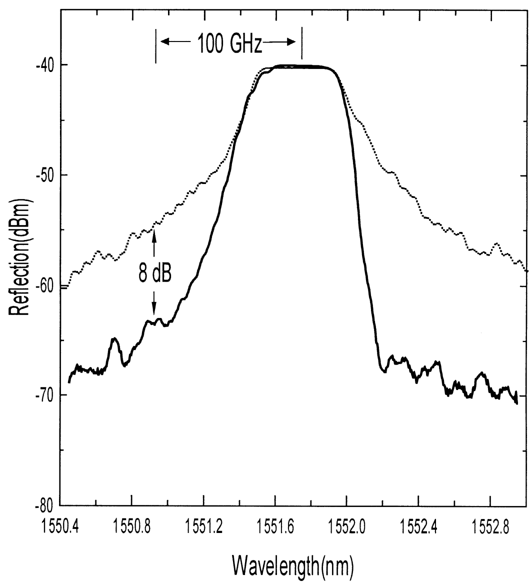

Fig. 2. Reflection spectrum (in solid line) of a Gaussian apodized fiber Bragg grating fabricated by a Gaussian beam. The reflection spectrum of the FBG formed by a plane wave is plotted in dots for comparison.

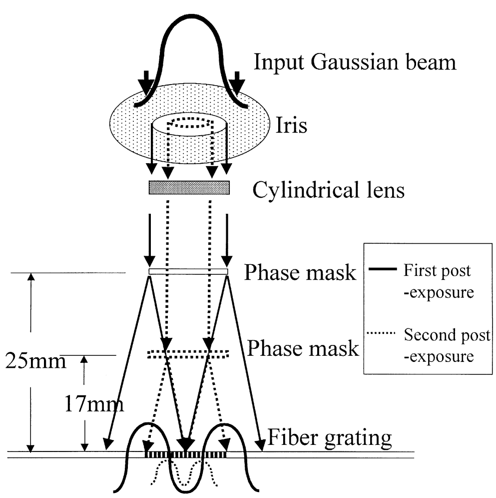

Fig. 3. Schematic diagram for fabricating raised Gaussian apodised fiber Bragg gratings by multiple exposure. For convenience, the scale in the diagram is not proportional.

In this work, we propose and demonstrate a new method for fabricating apodised FBGs without using any intensity mask. FBGs with a uniform pitch are first photoimprinted by a UV beam with a Gaussian spatial profile using the standard phase mask approach. However, the average local refractive indices of the imprinted gratings are corrected to remain nearly constant along the whole length of the grating. We achieve this requirement by using a multiple-exposure process without requiring any intensity mask. Side lobes have been significantly reduced to meet the requirements of DWDM communication systems.

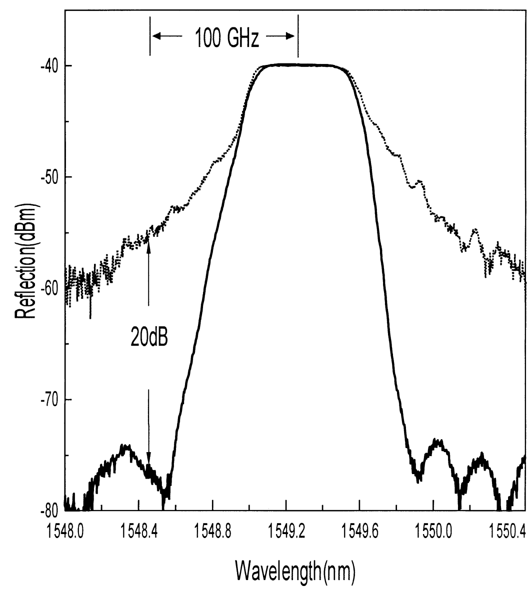

Fig. 4. Reflection spectrum (in solid line) of a raised Gaussian apodised grating fabricated by the set-up shown in Fig. 3. Also the reflection spectrum of the FBG formed by a plane wave is plotted in dots for comparison.

2. Experimental setup and results

The basic concept of our scheme is to utilize the ± 1 order diffraction beams produced by the phase mask to raise the average refractive index at both sides of the FBG. In our experiment, a Lamda Physik Compex 205 excimer laser is used for the fabrication of FBGs. The beam profile of the laser in the vertical direction is nearly a plane wave within a 15 mm region at the beam center, while in the horizontal direction, the distribution is nearly Gaussian. This is shown in Fig. 1. At first, we expose the plane wave on the mask to fabricate a FBG with a maximum reflectivity of 99.5%, and then we use the Gaussian beam to perform the same process. An iris is set in front of the laser beam to control the exposure length. The photosensitive fibers used in this experiment are from Fibercore and are with a numerical aperture of 0.12. The exposure length is set to be 12 mm. The reflection spectra of the fiber gratings fabricated by these two beams are shown in Fig. 2, where we could see that the FBG formed by a Gaussian beam has a sharper spectral response. But it still leads to some side lobes in shorter wavelength as we mentioned above. The 3 dB bandwidth of the grating fabricated by the Gaussian beam is about 0.6 nm and the side lobes at lower wavelength, 100 GHz from the center wavelength is -8 dB smaller compared to that fabricated by a plane wave. This proves that an apodised FBG could provide a better reflection spectrum.

To further suppress the residual side lobes in the shorter wavelength, we use the ± 1 order diffracted Gaussian beams coming from the phase mask for achieving a constant average refractive index as shown in Fig. 3. This is a

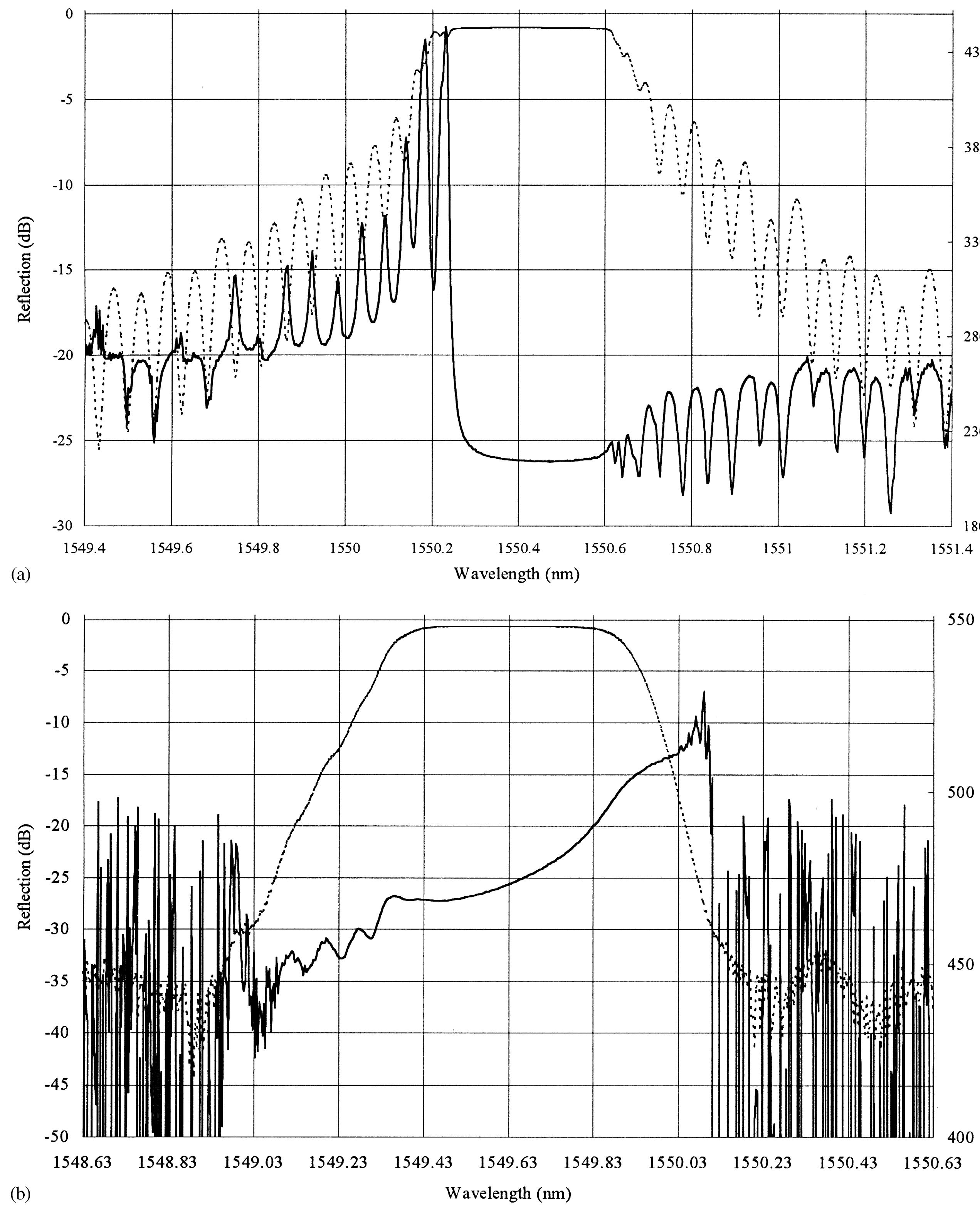

Fig. 5. Group delay time of two fiber Bragg gratings. (a) without apodisation, and (b) with raised Gaussian apodisation. The reflection spectrum is plotted in dots, while the group delay time is plotted in solid line.

multiple-exposure scheme. In this method, we use the Gaussian beam to fabricate a 99.5% grating for 3000 laser shots, and then pull the phase mask away from the fiber by a distance of 25 mm and perform the second exposure (4500 shots), with the iris adjusted to the width of 12 mm. After that, we push the mask toward the fiber by a distance of 17 mm, adjust the iris to the width of 6 mm, and then perform the third exposure (3000 shots). The spectrum of a typical FBG fabricated in this way is shown in Fig. 4. We find that the side lobes in the lower wavelength 100 GHz from the center wavelength is suppressed by −20 dB as shown in Fig. 4.

We also sketch the group delay diagram of these gratings with an optical network analyzer provided by Advantest Q7750; the result is shown in Fig. 5, where we could see that the phase response becomes worse when the side mode of the reflection spectrum is reduced. There exists trade-off between the amplitude response and phase response. Various efforts have been reported in the recent years to both acquire sharp reflection spectrum and linear-phase response [7, 8].

3. Conclusions

A plane wave or a pure Gaussian beam is found to fabricate FBGs with higher side lobes in this experiment. In order to fabricate a raised Gaussian apodised FBG that has a constant average index variation, we have developed a multiple-exposure scheme that can achieve this purpose without requiring the use of intensity masks. Our methods provide a flexible process for fabricating the FBG. Side lobe suppression of 20 dB is demonstrated in our experiment. Higher suppression ratio could be achieved by more post-exposures. The performance of FBGs made by this method is suitable to meet the requirements of DWDM communication systems.

References

[1] Carballar A, Miguel AM, Azaña J. Fiber grating filter for WDM systems: an improved design. IEEE Photonics Technol Lett 1999;11(6):694–6.
[2] Cortès P-Y, Ouellette F, LaRochelle S. Intrinsic apodisation of Bragg gratings written using UV-pulse interferometry. Electron Lett 1998;34(4):396–7.
[3] Matsuhara M, Hill KO. Optical-waveguide band-rejection filters design. Appl Opt 1974;13(12):2886–8.
[4] Pan JJ, Shi Y. Steep skirt fibre Bragg grating fabrication using a new apodised phase mask. Electron Lett 1997;33(22):1895–6.
[5] Malo B, Thériault S, Johnson DC, Bilodeau F, Albert J, Hill KO. Apodised in-fibre Bragg grating reflectors photoimprinted using a phase mask. Electron Lett 1995;31(3):223–5.
[6] Singh H, Zippin M. Apodized fiber Bragg gratings for DWDM applications using uniform phase mask. ECOC'98, Madrid, Spain, September 1998. p. 189–90.
[7] Ibsen M, Feced R, Petropoulos P, Zervas MN. 99.9% reflectivity dispersion-less square-filter fiber Bragg gratings for high speed DWDM networks. OFC 2000, Baltimore, USA, March 2000; PD21.
[8] Feced R, Zervas MN, Muriel MA. An efficient inverse scattering algorithm for the design of nonuniform fiber Bragg gratings. IEEE J Quantum Electron 1999;35(8):1105–15.