PRAMANA — journal of physics
© Indian Academy of Sciences
Vol. 82, No. 2
February 2014
pp. 255–258

Development of tilted fibre Bragg gratings using highly coherent 255 nm radiation

O PRAKASH*, J KUMAR, R MAHAKUD, U KUMBHKAR, S V NAKHE and S K DIXIT

R&D C-1 Block, Raja Ramanna Centre for Advanced Technology, Indore 452 013, India
*Corresponding author. E-mail: oprakash@rrcat.gov.in

DOI: 10.1007/s12043-013-0672-7; ***e*Publication:** 6 February 2014

Abstract. This paper reports the study on development of tilted fibre Bragg gratings using highly coherent 255 nm radiation, obtained from the second harmonic generation (SHG) of copper vapour laser (CVL). The transmission and reflection spectra of the tilted fibre Bragg gratings (TFBG) were studied for the tilt angles of 0° (normal FBG), 1°, 3° and 4° between the fibre axis and the interference fringe plane. It was observed that as the angle of fibre axis and phase mask increased, the main Bragg peak shifted towards the higher wavelength and transmission dip decreased. The transmission dip of the cladding mode first increased and then decreased after reaching a maximum with the increase in the tilt angle.

Keywords. Tilted fibre Bragg grating; second harmonic of copper vapour laser.

PACS Nos 42.79.Dj; 42.81.Pa; 42.65.Ky

1. Introduction

The tilted fibre Bragg grating is inscribed, when an angle between the grating plane and fibre cross-section is introduced [1–3] as shown in figure 1. In a tilted fibre Bragg grating (TFBG), with a tilt angle between the grating fringes and a normal angle to the fibre axis, a forward propagating LP_{01} core mode can couple to co-propagating or counterpropagating cladding modes [2]. The introduction of an angle causes the coupling efficiency between the guided modes to decrease and simultaneously increases the coupling between the guide modes and the cladding modes. The resonance wavelength corresponding to the coupling of the guided modes shifts to the long wavelength as the tilt angle is increased [3]. The central wavelength and the reflectivity of a TFBG are dependent on the angle. Due to the presence of tilt angle, the transmission spectra of TFBGs exposed in air consisted of multiple resonance peaks occurred due to coupling between part of the forward propagating core mode and counterpropagating cladding mode [3]. Since the cladding mode is affected by the refractive index of the surrounding medium, a TFBG is a very

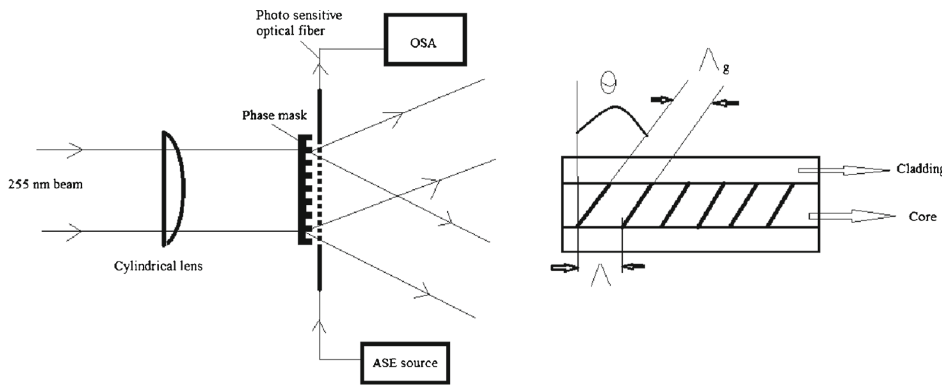

Figure 1. Experimental set-up for writing tilted fibre Bragg grating.

effective tool for many sensor applications such as monitoring humidity and refractive index of different liquids. The second harmonic of copper vapour laser is found to be a very efficient source for writing FBGs using phase mask as well as interferometers [4–7].

In this paper, we report the study on the development of tilted fibre Bragg gratings using highly coherent 255 nm radiation, obtained from the second harmonic generation (SHG) of copper vapour laser (CVL). The transmission and reflection spectra of the tilted fibre Bragg gratings (TFBG) were studied for the tilt angles up to 4°.

2. Experimental set-up

Figure 1 shows the experimental set-up for writing the tilted fibre Bragg grating. High spatial coherent UV beam (255 nm) was generated from the second harmonic generation of high beam quality copper vapour laser beam in β-BBO crystal [8]. The UV beam of about 10 mm diameter was allowed to fall on the phase mask as shown in figure 1. The phase mask tilt angle was varied by changing the angle between the fibre axis and the phase mask. The cylindrical lens placed before the phase mask, was also tilted simultaneously by same amount as the angle of phase mask. The fibre was kept about 0.5 mm after the phase mask. In order to increase the UV intensity at the fibre, it was kept slightly before the focal plane of the cylindrical lens. Online growth of the gratings was recorded using optical spectrum analyser (OSA) and a broadband ASE source.

3. Results and discussion

Figures 2a–2d show the transmission spectra of the tilted fibre Bragg gratings (TFBGs) for the tilt angle 0° (corresponds to FBG), 1°, 3° and 4° respectively. The Bragg peak wavelength was 1534.41 nm at 0° tilt angle. The transmission dip of the Bragg peak was about 10 dB. There was no cladding mode observed in this case as expected. For 1° tilt angle, central Bragg wavelength is shifted to 1534.74 nm. The cladding modes start appearing at the lower wavelength. However, the reflectivity of central Bragg peak was decreased to 8.0 dB as compared to 10 dB for 0° tilt angle. Also the peak was shifted towards the longer wavelength. At further higher tilt angle of 3°, the transmission dip

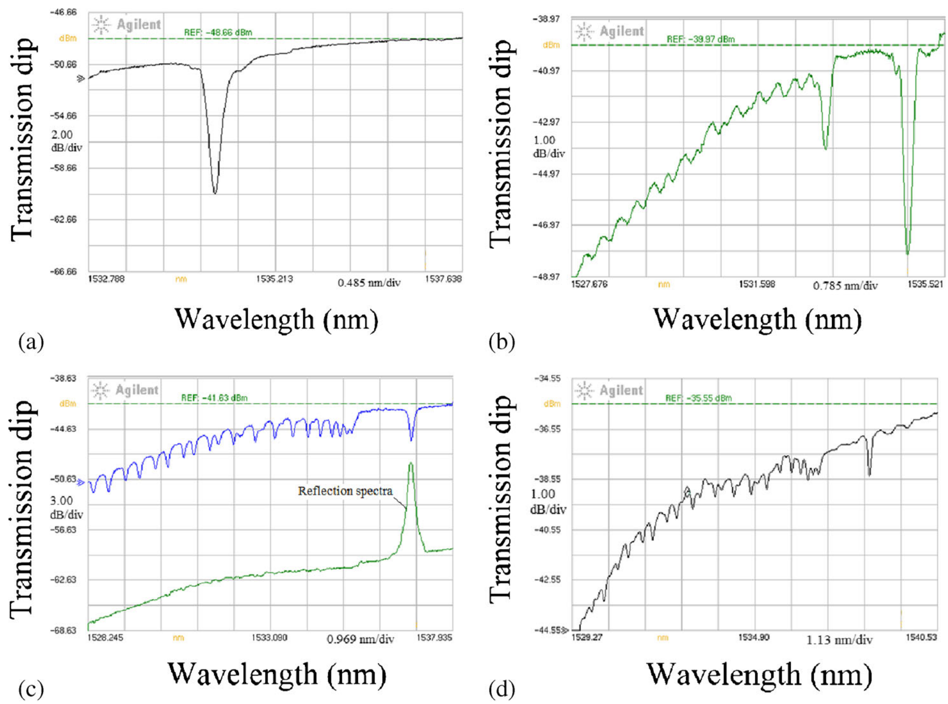

Figure 2. Transmission spectra for grating tilt angles: (**a**) 0°, (**b**) 1°, (**c**) 3° and (**d**) 4°.

of the Bragg peak (1536.77 nm) reduces to 4.5 dB. The cladding mode transmission dip increased to 1.5 dB. The cladding mode is the loss of the radiation, therefore the reflection spectrum does not show any reflection peak as shown in figure 2c (lower trace). At further higher angle of 4°, transmission dip reduces for both cladding mode and core mode to 0.5 dB and 1.5 dB, respectively. Again the Bragg peak was shifted towards the longer wavelength of 1538.46 nm.

The resonance condition satisfying the Bragg condition can be written as [3],

$$\lambda_{\mathrm{Bragg}} = (n_{\mathrm{eff.co}} + n_{\mathrm{eff.co}})\,\Lambda_{\mathrm{g}}, \tag{1}$$

where $n_{\mathrm{eff.co}}$ is the refractive index of the fibre core and Λ_{g} represents the grating period along the fibre axis. For the tilted grating, the resonance condition can be written as (taking grating period along the fibre axis into account)

$$\lambda_{\mathrm{Bragg}} = (n_{\mathrm{eff.co}} + n_{\mathrm{eff.co}})\,\frac{\Lambda_{\mathrm{g}}}{\cos\theta}, \tag{2}$$

where θ is the angle between grating fringe and the fibre cross-section. Due to the presence of tilt angle, the part of forward propagating mode will be coupled into counter-propagating cladding modes and the resonance wavelength of the cladding mode is given by

$$\lambda_{\mathrm{cl.i}} = (n_{\mathrm{eff.co}} + n_{\mathrm{eff.cl.i}})\,\frac{\Lambda_{\mathrm{g}}}{\cos\theta}, \tag{3}$$

where $n_{eff.cl.i}$ is the effective refractive index of the ith cladding mode.

From eq. (2), it is clear that as the angle between the grating fringe and fibre cross-section increases, the value of grating period increases too and thus the central Bragg peak shifts towards the side of the longer wavelength. For grating period (Λ) of 530 nm and the refractive index ($n_{eff.co}$) of effective core mode of 1.446, the theoretically calculated central Bragg peak wavelength were 1534.61 nm, 1534.87 nm, 1536.74 nm and 1538.36 nm for the tilt angle of 0°, 1°, 3° and 4° respectively. Theoretical calculated peak Bragg wavelength are in good agreement with the experimentally observed value. As the angle increased, the losses of the core mode increase and thus the transmission dip of the central Bragg peak reduced too.

4. Conclusions

In conclusion, the tilted fibre Bragg gratings are inscribed for the tilt angle of 0° (corresponding to normal FBG), 1°, 3° and 4° between the fibre axis and interference fringes using high coherence 255 nm UV beam obtained from the second harmonic generation of copper vapour laser. It was observed that as the angle of fibre axis normal and phase mask fringes increase, the main Bragg grating peak shifted towards the higher wavelength. The transmission dip decreased with an increase in the tilt angle. However, for cladding mode, the transmission dip first increases, reaches a maximum and then decreases as the tilt angle is increased.

Acknowledgements

Authors wish to acknowledge Shri Jagdish Kumar for the maintenance of copper vapour laser power supply.

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