Observation of mode-coupling in few mode fiber Bragg gratings

K. S. Lim,[1,*] M. M. Ali, [1] C.C. Loo, [1] W.Y. Chong[1] and H. Ahmad[1]

Photonics Research Centre, Department of Physics, Faculty of Science,
University of Malaya,
Kuala Lumpur, Malaysia
Corresponding author: kslim@um.edu.my

***Abstract* - Eight Bragg wavelengths are observed in the reflection spectra of a 4-mode optical fiber Bragg grating. The additional wavelengths are the results of coupling between two different transverse modes in the grating structure.**

I. INTRODUCTION

After the successful employment of Time Division Multiplexing (TDM) and Wavelength Division Multiplexing (WDM) technologies in the optical communication network, Space Division Multiplexing (SDM) based on few mode fibers (FMF) has emerged as a new promising technology for the achievement of higher transmission capacity. Hence, there is an increasing interest in the study of FMF and other associated device fabricated from FMF, for instance Few Mode Fiber Bragg Gratings (FM-FBG). Unlike SMF, FMF is capable of supporting more than one transverse mode in the fiber core, in which each mode can be employed as a transmission channel [1]. The inscription of Bragg grating structure in the few mode fibers enables the generation of more than one Bragg wavelength in the reflection spectrum [2].

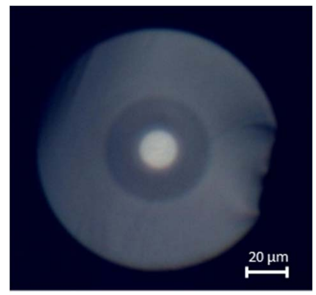
In this work, we investigate the relationship between the Bragg wavelengths and transverse modes of a FM-FBG. Core-offset technique is used to enhance the intensity distribution to the higher order modes in the fiber so that the Bragg wavelengths can be located. Simulation is performed and the result is compared with the experimental data. From the comparison, the Bragg wavelengths of a single transverse modes and coupled transverse modes are identified.

II. THEORY

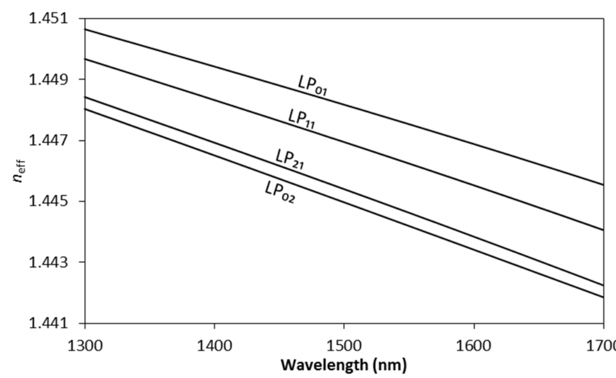
The relationship between each Bragg wavelength (λ_μ) with the corresponding mode effective index (n_μ) is given by

$$\lambda_\mu = 2n_\mu(\lambda_\mu)\Lambda \tag{1}$$

where Λ is the grating period and the subscript μ represents the order of the transverse mode. Figure 1(a) shows the microscope image of a cleaved step index few mode fiber (OFS). The fiber has a core diameter of ~19.5µm and NA of 0.2. The simulated effective indices for LP_{01}, LP_{11}, LP_{21} ane LP_{02} modes in the step index few mode fiber are given in Fig. 1(b) [3].



(a)



(b)

Fig. 1 (a) Optical microscope image (magnification factor of 4) of the cross section of a step index few mode fiber (OFS). (b) The simulated effective indices of LP_{01}, LP_{11}, LP_{21} ane LP_{02} modes in functions of wavelength

Due to the periodic change of refractive index along the fiber, the coupling between two transverse modes is introduced. As a result, new Bragg wavelengths are excited. The relationship between the excited Bragg wavelength and the two corresponding coupled trasnverse modes is given by [4]

$$\lambda_{\mu,\nu} = [n_\mu(\lambda_{\mu,\nu}) + n_\nu(\lambda_{\mu,\nu})]\Lambda \tag{2}$$

where μ and ν represent the order of two different transverse modes ($\mu, \nu \in \{ 01, 11, 21, 02\} \mid \mu \neq \nu$) and Λ is the grating period. Since the excited Bragg wavelength $\lambda_{\mu,\nu}$ is positioned exactly at the middle between between λ_μ and λ_ν, (2) can be rewritten as

$$\lambda_{\mu,\nu} = (\lambda_\mu + \lambda_\nu)/2 \tag{3}$$

978-1-4799-2767-8/50 $31.00 © 5250 IEEE

DOI 10.1109/SUM.2014.102

In this investigation, a 2cm long grating is inscribed in the few mode fiber. To ease the identification of Bragg wavelengths with their corresponding transverse modes, uniform grating structure is employed to produce narrow Bragg reflection bandwidth. For better visibility of the Bragg wavelengths, core-offset technique [5] is used to attain good reflected power from every Bragg wavelength particularly for those which correspond to the higher order modes.

III. RESULT AND DISCUSSION

Figure 2(a) illustrates the curve of $f(\lambda) = 2n_\mu(\lambda)\Lambda$ for every mode, calculated based on the simulated result in Fig. 1(b). The Bragg wavelength for each transverse mode can be theoretically estimated from the position of the intersection between the two functions, $f(\lambda) = 2n_\mu(\lambda)\Lambda$ and $g(\lambda) = \lambda$. Good agreement is found between the theoretical estimation in Fig. 2(a) and the corresponding Bragg wavelengths in Fig. 2(b), as indicated by the vertical dotted lines. The remaining Bragg wavelengths in the spectra can be attributed to the result of coupling between two different transverse modes. Similar theoretical estimation is performed based on the functions of $f(\lambda) = [n_\mu(\lambda)+ n_v(\lambda)]\Lambda$ and $g(\lambda) = \lambda$ (see Fig. 2(c)) and the four remaining Bragg wavelengths are found to be in correspondence with the mode combinations of (LP_{01}, LP_{11}), (LP_{01}, LP_{02}), (LP_{11}, LP_{21}) and (LP_{11}, LP_{02}).

Unfortunately, there is no clear signature of Bragg wavelengths for the mode combinations of (LP_{01}, LP_{21}) and (LP_{21}, LP_{02}). It is believed that the mode overlapping

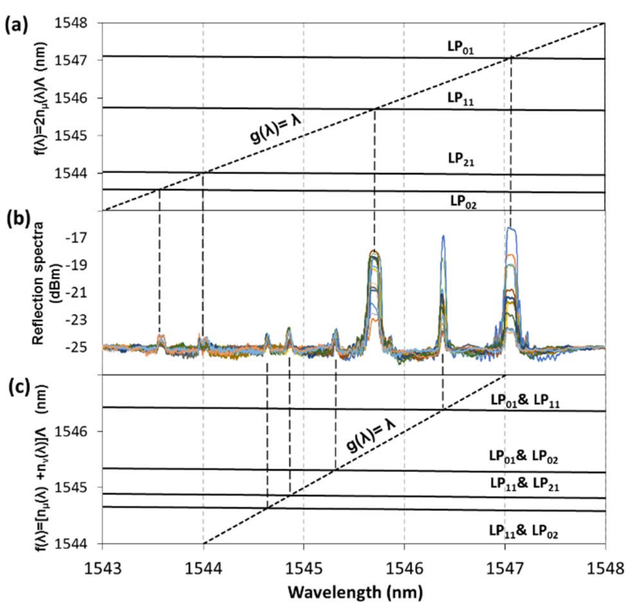


Figure 2. Theoretical estimation of the Bragg wavelengths (a) calculated curves of $f(\lambda) = 2n_\mu(\lambda)\Lambda$, (b) reflection spectra of the few mode fiber Bragg grating and (c) calculated curves of $f(\lambda) =[n_\mu(\lambda)+ n_v(\lambda)]\Lambda$.

factor / coupling coefficient between two modes is responsible for the Bragg wavelength reflectivitiy. More investigation is required to acquire better understanding and control of the coupled mode excitation in few mode fiber Bragg gratings.

IV. SUMMARY

A uniform grating structure has been inscribed in a four mode fiber. Eight reflection wavelengths have been observed. Four of them corespond to the transverse mode of LP_{01}, LP_{11}, LP_{21} ane LP_{02} while the remaining four can be attributed to coupling of mode combinations (LP_{01}, LP_{11}), (LP_{01}, LP_{02}), (LP_{11}, LP_{21}) and (LP_{11}, LP_{02}). The simulation results have provided the convenience of mode identification and Bragg wavelengths estimation. The potential applications of FM-FBG include mode conversion, mode filtering and mode multiplexing & demultiplexing.

ACKNOWLEDGMENT

We would like to acknowledge UMRG Grant (RP019-2012C), (RU002/2013) and IPPP Grant (PG029-2013A) for funding this work.

REFERENCES

[1] L. Fang, H. Jia, “Coupling analyses of LP0m modes with optical fiber gratings in multimode fiber and their application in mode-division multiplexing transmission,” Optics Communications, Vol. 322, 2014, pp.118-122.

[2] T. Mizunami, T. V. Djambova, T. Niiho, and S. Gupta, "Bragg Gratings in Multimode and Few-Mode Optical Fibers," J. Lightwave Technol. Vol. 18, 2000, pp.230-.

[3] A. Ghatak, and K. Thyagarajan, “*Introduction to fibre optics*,” chapter 8, Cambridge University Press, UK, 1998.

[4] R. Kashyap, “*Fiber Bragg Gratings*,” chapter 4, Academic Press, USA,1999.

[5] X. Feng, H. Y. Tam, W. H. Chung, P.K.A. Wai, “Multiwavelength fiber lasers based on multimode fiber Bragg gratings using offset launch technique,” Optics Communications, Vol 263, 2006, pp. 295-299.