Journal of the Optical Society of Korea, Vol. 10, No. 2, June 2006, pp. 63-66

Investigation of Resonant Wavelength Separation in Microband-induced Fiber Gratings

Kyung Rak Sohn* and Joon Hwan Shim

Division of Radio and Information Communication Engineering, Korea Maritime University, Busan 606-792, KOREA

Kwang Taek Kim

Department of Optoelectronics Engineering, Homan University, Gwangju 506-714, KOREA

(Received April 7, 2006 : revised May 9, 2006)

In microband-induced fiber gratings, polarization properties and birefringence are investigated as a function of an applied line force. With the transmission curves associated with the maximum and minimum resonant wavelengths, the polarization-dependent behaviors are analyzed. By increasing the transverse line force, the resonance wavelength for an incident light polarized to the same direction of the force is blue-shifted as much as 0.69 nm/(N/cm) while that for the other polarization is insensitive. Using the resonant wavelength separation corresponding to the force variation, the transverse effective index change or modal birefringence variation is obtained. The ratio of modal birefringence versus applied line force is $\Delta B/\Delta f_x = \sim 8.38\times 10^{-7}$.

OCIS codes : 050.2770, 060.2310, 060.2340, 060.2400

I. INTRODUCTION

Optical fiber gratings are becoming important in optical communication and sensing systems. Many fiber grating components such as optical filters, sensing elements, and so on have been researched and developed [1-3]. Here, polarization effects play a key role in the operation of the optical devices. Fiber bragg gratings have a narrow reflection spectrum and long-period fiber gratings (LPGs) show a rather broad transmission spectrum without appreciable reflection. Photo-induced gratings are fabricated by exposure of an UV laser beam onto the single side of an optical fiber and cause asymmetric index variation of the core [4]. The asymmetry gives the geometric birefringence in the core mode. This type of LPG is based on the core-only birefringence. The difference of the effective indices for the LP_{01} core-guided mode over two polarizations induces the polarization dependence loss (PDL) of the gratings.

Another type of LPGs is created by using microband gratings. Many different fabrication methods such as a periodic pressure, electric arc, cladding etching, and electrical heating have been widely studied [5]. Compared to the photo-induced LPG, it is easily implemented to form the gratings. The gratings are also reconfigurable. This feature allows tunable gain equalizers in fiber amplifiers, band-rejection filters, and sensing heads of in-line fiber sensor systems. A drawback of such gratings is that they are inherently polarization-dependent because of asymmetric microband perturbation. Several researchers have studied the polarization-dependent loss (PDL) and birefringence in LPFs [6-8]. But, in mechanically-induced miacroband fiber gratings (MFG), the transverse refractive index changes with respect to an applied transverse force have not been reported.

In this study, we measured the spectral responses as a function of a line force to investigate polarization dependence for two orthogonal states of polarizations (SOPs). From the fact that the wavelength separation between maximum and minimum resonant wavelengths has a linear relationship, modal birefringence in terms of an applied pressure is indirectly calculated.

II. THEORY

In an LPG, the LP_{01} core mode is strongly coupled to the copropagating LP_{0m} cladding modes. A periodic index modulation with grating pitch of several hundred micrometers, therefore, imposes the phase matching condition that couples light effectively between two modes at a resonance wavelength of mth-order. For an ideal LPG with an azimuthally symmetric index change, the phase matching condition is well known as [7]

$$\lambda_m = (n_{co}^{01} - n_{cl}^{0m})\Lambda = (\Delta n)\Lambda, \qquad (1)$$

where λ_m is the resonant wavelength, Λ is the grating period, and n_{co}^{01} and n_{cl}^{0m} are effective indices of the LP_{01} core and LP_{0m} cladding mode, respectively. If a grating formation is not symmetricy, birefringence is caused in the fiber and the resonant wavelengths are dependent on the SOP of the incident light.

When a transverse pressure is applied to a SMF, a compressive strain in the direction of the applied force and a tensile strain in the direction of the orthogonal transverse direction are developed in the fiber. It is known that the magnitude of both strains remains within 96% of the axial value in the region around the axis which is surrounded by the circle of diameter d/10 [9]. d is the fiber diameter. In MFG, we can consider that the effective index variation of the LP_{0m} cladding-guided mode is much smaller than that of the LP_{01} core-guided mode, since the radius of cladding is much larger than that of the core. If the effective index variation of the cladding region caused by the transverse pressure is negligible, we have the resonant wavelength separation between the minimum and the maximum resonant wavelengths, λ_{SOP_x} and λ_{SOP_y}, given by

$$\Delta\lambda_m = \lambda_{SOP_x} - \lambda_{SOP_y} = \Lambda(n_{co}^{01,\max} - n_{co}^{01,\min}) = \Lambda\cdot B \qquad (2)$$

where $\Delta\lambda_m$, $n_{co}^{01,\min}$, $n_{co}^{01,\max}$, and B represent the largest resonant wavelength separation for a mth-order resonance peak, the minimum and the maximum effective indices of the LP_{01} core mode, and modal birefringence of the gratings, respectively. It means that the resonant wavelength is a function of the SOP of the incident light. The $n_{co}^{01,\max} - n_{co}^{01,\min}$ term in Eq. (2) represents the modal birefringence, B, in the fiber core. If B is dependent on the applied transverse force, a transverse refractive index variation of the fiber core in MFG can be obtained.

III. EXPERIMENT AND RESULTS

The gratings used for this experiment are made by a periodic array of a metal wire with a 250 µm diameter as shown in Fig. 1. The wires are arrayed on the metal plate at equal intervals of 570 µm and glued on their edges with an adhesive. To keep the grating equally spaced, the grating plate is fabricated on the grooves of the corrugated fixture with a 570-µm period. The total length of grating is about 4.5 cm. The SOP of the incident light into the gratings is adjusted to the two polarization states, SOP_x and SOP_y, using a fiber polarizer (FP).

Since the PDL in a MFG originates from the birefringence presented in the grating structure, the transmission characteristics of a MFG is dependent on all SOPs. Fig. 2 shows the transmission spectra and indirect measure of PDL when the transverse line force of 6.8 N/cm is applied. The wavelength separation between the minimum and the maximum resonant wavelengths is ~4 nm and modal birefringence is to be 7.15×10^{-6}. Compared to the previously reported modal birefringence in a photo-induced LPG and a CO_2-laser-induced LPG [7], the larger modal birefringence is occurred in the MFG. The wavelength-dependent PDL is characterized by the difference between the transmission curves associated with maximum and minimum resonant wavelengths so that the resonant wavelength separation serves as an indirect measure of PDL. Here, the wavelength-dependent PDL is represented as $SOP_x - SOP_y$ in Fig. 2. The maximum PDL is calculated to be 7.5 dB.

Next, the spectral response for SOP_x and SOP_y are measured as a function of the line force per unit length

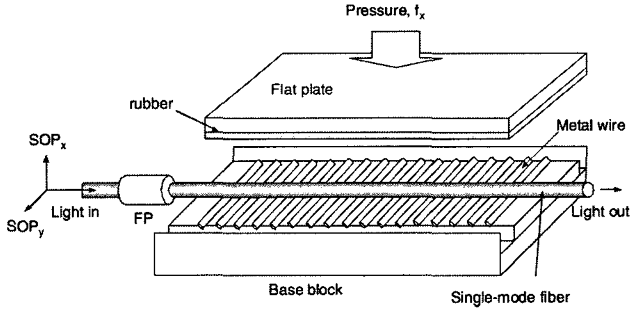


FIG. 1. Schematic of experimental setup with periodically arrayed metal wire block for creating the microband gratings. (FP: fiber polarizer)

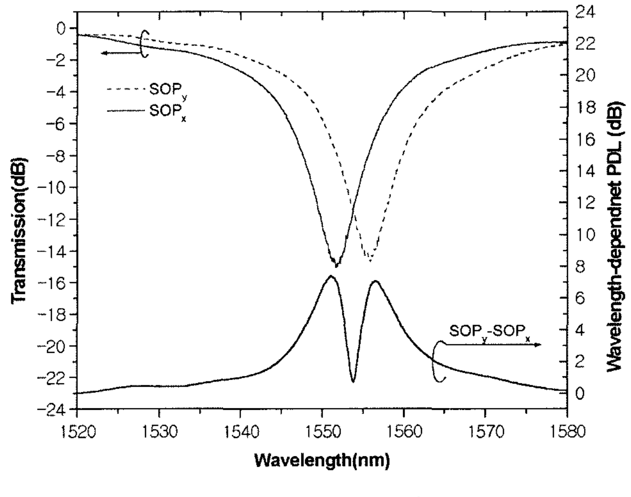


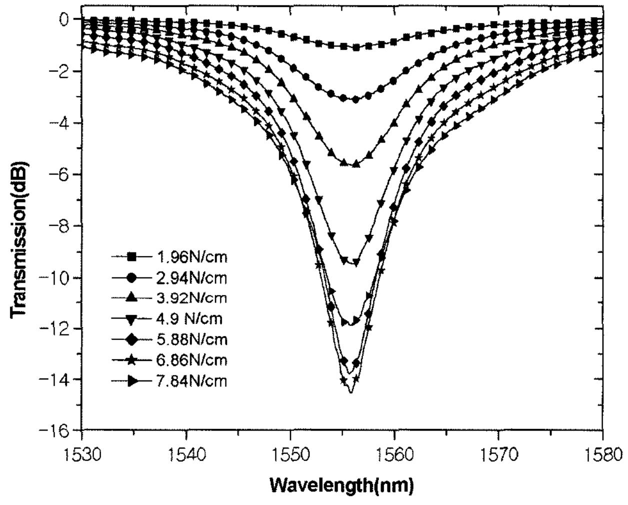
FIG. 2. Transmission spectrum for two orthogonal polarizations and wavelength-dependnent PDL calculated by SOP_x and SOP_y (f_x=6.8 N/cm).

applied to the SMF. As shown in Fig. 3, when two SOPs are launched to the gratings, the resonant peaks are more attenuated by increasing the applied pressure. We note that the center wavelength for SOP_y is insensitive to external pressure change as can be shown in Fig. 3 (a). But, in case of SOP_x polarized in the direction of the transverse force, the resonant wavelength is a function of the line force as depicted in Fig. 3 (b). Thus we can calculate the modal birefringence variation or transverse effective index change in MFG.

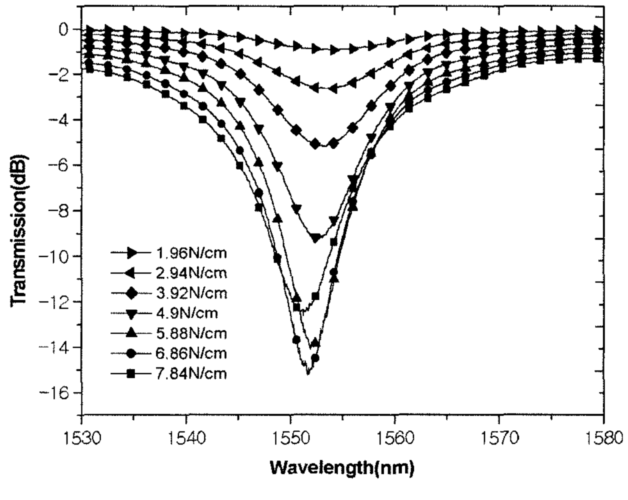
Fig. 4 (a) shows the attenuation peak variation versus the applied line force. For two SOPs, the fitting curves are similar to each other and thus the power coupling between a guided core mode and a corresponding cladding mode is insensitive to the polarization states. If the force increases beyond a certain point, the depth of greatest attenuation peak begins to turn upward. This is explained, over certain ranges of grating length and coupling constant, by the sin^2 transmission of LPFG's [10]. The resonant wavelength separation as a function of a line force is shown in Fig. 4 (b). When higher force is applied, the separation increases because the center wavelength for SOP_x linearly shifts to shorter wavelength. By using Eq. (2), the relationship between microband-induced effective index variation, or modal birefringence of the grating, and transverse force variation is $\frac{\Delta B}{\Delta f_x}=8.38\times10^{-7}$. Thus the transverse refractive index change of MFG is linearly controlled by the pressure on a grooved plate or a distributed wire block.

IV. CONCLUSION

We have investigated polarization dependence and

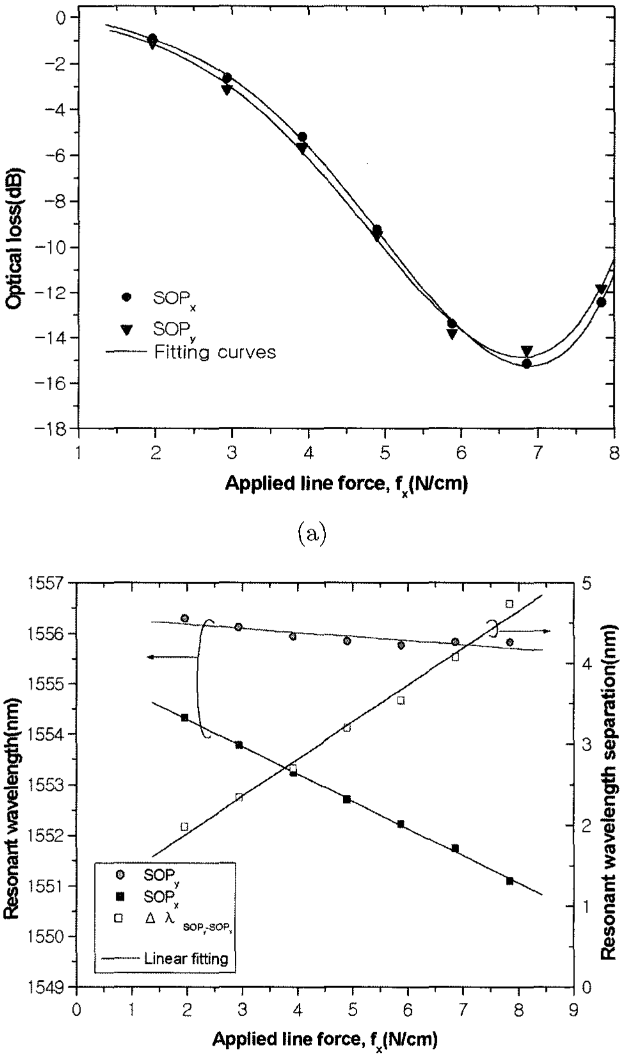


(a) for SOP_y



(b) for SOP_x

FIG. 3. Transmission spectra as a function of an applied line force.



(b)

FIG. 4. (a) Attenuation peak variation and (b) resonant wavelength separation as a function of an applied line force.

modal birefringence for MFGs formed by periodically arrayed metal wires. The spectral responses of the two polarization states are different according to the external asymmetric force. For SOP in direction of the transverse force, the resonant wavelength shifts to longer or shorter wavelength as much as 0.69 nm/(N/cm), whereas for SOP_y the center wavelength is rarely affected by the force. Using the fact that the resonant wavelength separation is linearly related to the applied line force, transverse effective index variation is achieved. This modal birefringence is not suitable to the optical communication devices but it can be applied to the optical measurement components such as a sensor in a smart structure.

*Corresponding author : krsohn@bada.hhu.ac.kr

REFERENCES

[1] J. K. Bae, S. H. Kim, J. H. Kim, J. Bae, S. S. Lee, and J-M. Jeong, "Spectral shape tunable band-rejection filter using a long period fiber grating with divided coil heaters," *IEEE Photon. Technol. Lett.*, vol. 15, pp. 407-409, 2003.

[2] J-R Lee and Hiroshi Tsuda, "Fiber optic liquid leak detection technique with an ultrasonic actuator and a fiber bragg grating," *Opt. Lett.*, vol. 30, pp. 3293-3295, 2005.

[3] K. R. Sohn and K. T. Kim, "Thermo-optically tunable band-rejection filters using mechanically formed long-period fiber gratings," *Opt. Lett.*, vol. 30, pp. 2688-2690, 2005.

[4] S. T. Oh, W. T. Han, U. C. Paek, and Y. Chung, "Reduction of birefringence and polarization-dependent loss of long-period fiber gratings fabricated with a KrF excimer laser," *Opt. Express*, vol. 11, pp. 3087-3092, 2003.

[5] O. V. Ivanov, "Wavelength shift and split of cladding mode resonances in microband long-period fiber gratings under torsion," *Opt. Comm.*, 232, pp. 159-166, 2004.

[6] B. H. Lee, J. Cheong, and U-C. Paek, "Spectral polarization-dependent loss of cascaded long-period fiber gratings," *Opt. Lett.*, vol. 27, pp. 1096-1098, 2002.

[7] B. L. Bachim and T. K. Gaylord, "Polarization-dependent loss and birefringence in long-period fiber gratings," *Appl. Opt.*, vol. 42, pp. 6816-6823, 2003.

[8] J. Y. Cho, J. H. Lim, and K. S. Lee, "Optical fiber twist sensor with two orthogonally oriented mechanically induced long-period grating sensors," *IEEE Photon. Technol. Lett.*, vol. 17, pp. 453-455, 2005.

[9] A. M. Smith, "Single-mode fiber pressure sensitivity," *Electron. Lett.*, vol. 16, pp. 773-774, 1980.

[10] S. Savin, M. J. F. Digonnet, G. S. Kino, and H. J. Show, "Tunable mechanically induced long-period fiber gratings," *Opt. Lett.*, vol. 25, pp. 710-712, 2000.