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Light Coupling Between a Singlemode-Multimode-Singlemode (SMS) Fiber Structure and a Long Period Fiber Gating

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Light Coupling Between a Singlemode-Multimode-Singlemode (SMS) Fiber Structure and a Long Period Fiber Grating

Qiang Wu, Yuliya Semenova, Youqiao Ma, Pengfei Wang, Tuan Guo, *Member, IEEE, Member, OSA*, Long Jin, and Gerald Farrell

***Abstract*—We propose a novel optical coupling technique based on evanescent field coupling between a singlemode- multimode-singlemode (SMS) fiber structure and a long period fiber grating (LPFG). By parallel placement of the two fiber sections in close proximity to each other, the excited multi-cladding modes from the SMS fiber section can be selectively coupled to the guided mode in the LPFG, and vice versa. A theoretical analysis based for such a structure is undertaken and the simulated results are verified by experiments demonstrating a maximum coupling efficiency of up to 1.66% (which could be improved to 27.5% in theory) over a broadband resonance (42 nm with a 3 dB bandwidth).**

***Index Terms*—Long period grating, optical coupler, optical switch, SMS fiber structure.**

I. Introduction

LIGHT coupling between two parallel long period fiber gratings (LPFG) written in single mode fibers or an LPFG and a tilted fiber Bragg grating (FBG) have been widely investigated recently [1]–[5]. The principle underlying the coupling technique is based on the fact that either an LPFG or a tilted FBG can couple light from the guided core mode to a cladding mode and inversely couple light from a cladding mode to the guided core mode. When two LPFGs or an LPFG and a tilted FBG are placed close to each other in parallel, the reciprocal power interaction that occurs between the fibers takes place due to the evanescent field coupling between the cladding modes excited by either the LPFG or tilted FBG. Couplers based on the above technique can be used as band pass filters or optical add-drop multiplexers in optical communication systems [5].

Compared to an LPFG or tilted FBG, a singlemode- multimode-singlemode (SMS) fiber structure has the advantages of low cost and ease of fabrication [6]–[14]. The principle of an SMS fiber structure is that multimode interference takes place within the multimode fiber (MMF) section when light is injected from the singlemode fiber (SMF) into the MMF. At the other end of the MMF the light is coupled to the output singlemode fiber (SMF), both core and cladding modes will be excited and will propagate within the output SMF. Our previous investigation has proved that the cladding modes can be reflected by an FBG and re-coupled to guided core mode if the FBG is located close to the SMS fiber structure [15]. In a fashion similar to two parallel LPFGs, the cladding modes excited by the MMF in the output SMF can also be coupled to another SMF if that SMF is placed close to and in parallel to the output SMF of the SMS. If one of cladding modes coincides with the resonance condition of the LPFG, then it will be coupled to a guided core mode. In this paper we propose using an SMS-LPFG configuration to construct a novel optical coupler to achieve broadband coupling, which also has the advantage of a relatively low cost and simple fabrication technique. A theoretical analysis based on the proposed configuration is provided supported by experimental verification.

II. Theoretical Background

The proposed coupling configuration between an SMS fiber structure and an LPFG is shown in Fig. 1.

In Fig. 1, the SMS fiber structure consists of a short section of MMF spliced between two SMFs at both ends (SMF1 and SMF2) and LPFG imprinted in SMF 3, positioned in parallel. When light is injected from SMF1 into MMF, multiple modes will be excited and transmitted within the MMF. For the multiple modes injected from MMF into SMF2, a portion of the light is coupled to the guided core mode while the remaining light is coupled to cladding modes in SMF2. If an LPFG is placed close (that is a small value of d in Fig. 1) and in parallel to the SMS fiber structure, the cladding modes will be coupled from SMF 2 to SMF 3 and some selected cladding modes in SMF 3 will then be coupled to the guided core mode in SMF 3 via the LPFG. The coupling regions are Sections 1 and 2 as shown in Fig. 1.

Assuming the amplitudes of the core and cladding modes within the SMF are $A(\mathrm{z})$ and $B(\mathrm{z})$ respectively and the field profile within the MMF is $\Psi_{\mathrm{m}}(\mathrm{r})$ which is mth eigenmode of the MMF, the field after a propagation distance L_1 within the MMF can be written as:

$$A1(r, L_1) = \sum_{m=1}^{M} b_m \Psi_m(r) \exp(j\beta_m L_1) \tag{1}$$

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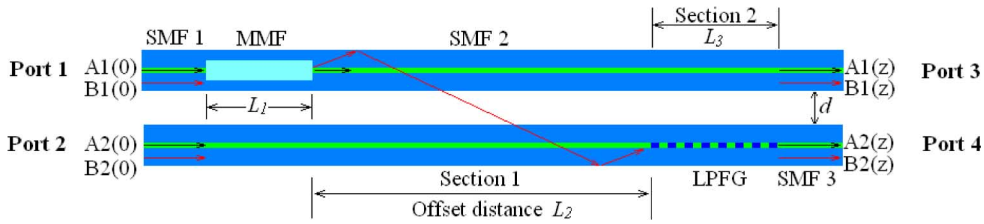

Fig. 1. Coupling configuration between an SMS fiber structure and an LPFG.

where β_m is the propagation constant of the mth eigenmode within the MMF and b_m is the excitation coefficient for each mode which can be expressed as:

$$b_m = \frac{\int_0^\infty A1(r,0)\Psi_m(r) r\, dr}{\int_0^\infty \Psi_m(r)\Psi_m(r) r\, dr} \tag{2}$$

where $A1(r,0)$ is the eigenmode of the SMF. At the interface between the MMF and the output SMF 2, the light will be coupled to both core and cladding modes within SMF 2 which can be expressed as:

$$b'_n = \frac{\int_0^\infty A1(r,L_1)\Phi_n(r) r\, dr}{\int_0^\infty \Phi_n(r)\Phi_n(r) r\, dr} \tag{3}$$

where $\Phi_n(\mathrm{r})$ is nth mode within SMF 2 ($\mathrm{n} = 1$ represents the core mode and $\mathrm{n} > 1$ represents cladding modes). The field of the cladding modes at a position L_1 within the SMF2 can be written as:

$$B1_n(r, L_1) = b'_n \Phi_n(r). \tag{4}$$

It is noted that in the above equations, the mode fields are normalised as

$$\int_0^\infty A1(r,0)A1(r,0) r\, dr = \int_0^\infty \Psi_m(r)\Psi_m(r) r\, dr = \int_0^\infty \Phi_n(r)\Phi_n(r) r\, dr = 1.$$

Over the length of coupling Section 1, the evanescent field coupling coefficient C between the two parallel fibers can be approximately expressed as [16]:

$$C = \frac{\sqrt{2\Delta}}{a_0}\frac{U^2}{V^3}\frac{K_0[W(2 + d/a_0)]}{K_1^2(W)} \tag{5}$$

where a_0 is the radius of the fiber cladding and d (shown in Fig. 1) is the separation between the two parallel fibers, K_0 and K_1 are the modified Bessel functions, $\Delta = (n_c^2 - n_s^2)/(2n_c^2)$ is the relative refractive index difference between the cladding (n_c) and surrounding medium (n_s). $U = (2\pi a_0)/(\lambda)\sqrt{n_c^2 - N_n^2}$, $V = (2\pi a_0)/(\lambda)\sqrt{n_c^2 - n_s^2}$ and $W = (2\pi a_0)/(\lambda)\sqrt{N_n^2 - n_s^2}$ are the normalized parameters and N_n is the effective refractive index of the nth cladding mode. Assuming the two parallel fibers are identical, then there is no mismatch between the propagation constants of the two fibers and hence the amplitudes of the nth cladding modes $B1_n$ and $B2_n$ at position $L_1 + L_2$ can be expressed as [17]:

$$B1_n(r, L_1 + L_2) = B1_n(r, L_1)\cos(CL_2) \tag{6}$$
$$B2_n(r, L_1 + L_2) = -jB1_n(r, L_1)\sin(CL_2). \tag{7}$$

The coupling over the length of Section 2 has been given by Chiang as follows [16]:

$$\begin{bmatrix} A2(L_1+L_2+L_3) \\ B2_n(L_1+L_2+L_3) \\ B1_n(L_1+L_2+L_3) \end{bmatrix} = T \begin{bmatrix} A2(L_1+L_2) \\ B2_n(L_1+L_2) \\ B1_n(L_1+L_2) \end{bmatrix} \tag{8}$$

where, see (9) at the bottom of the page, where $\kappa = \delta n \pi I/\lambda$ is the coupling coefficient of the LPFG (δn is the index modulation and I is the spatial overlapping of LP_{01} and the nth cladding mode) and $\gamma_1, \gamma_2, \gamma_3, \xi_1, \xi_2, \xi_3$ are the three roots of (10) and (11)

$$\gamma = \xi + \delta \tag{10}$$
$$\xi^3 + \delta\xi^2 - (\kappa^2 + C^2)\xi - \delta C^2 = 0 \tag{11}$$

$$T = \begin{bmatrix} -\frac{\kappa}{\gamma_1}\exp(j\gamma_1 L_3) & -\frac{\kappa}{\gamma_2}\exp(j\gamma_2 L_3) & -\frac{\kappa}{\gamma_3}\exp(j\gamma_3 L_3) \\ \exp(j\xi_1 L_3) & \exp(j\xi_3 L_3) & \exp(j\xi_3 L_3) \\ -\frac{C}{\xi_1}\exp(j\xi_1 L_3) & -\frac{C}{\xi_2}\exp(j\xi_2 L_3) & -\frac{C}{\xi_3}\exp(j\xi_3 L_3) \end{bmatrix} \begin{bmatrix} -\frac{\kappa}{\gamma_1} & -\frac{\kappa}{\gamma_2} & -\frac{\kappa}{\gamma_3} \\ 1 & 1 & 1 \\ -\frac{C}{\xi_1} & -\frac{C}{\xi_2} & -\frac{C}{\xi_3} \end{bmatrix}^{-1} \tag{9}$$

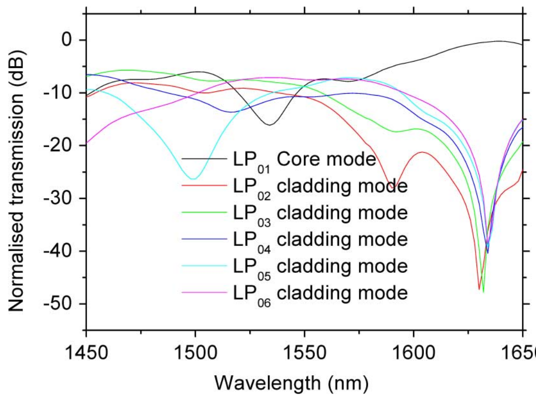

Fig. 2. Simulated transmission spectra for LP_{01-06} modes within SMF 2 in the SMS structure.

where $\delta = \beta - (\pi)/(\Lambda)$ is the detuning from the resonant wavelength and Λ is the period of the LPFG.

The above equations can all be numerically solved and hence the light coupling from port 1 to port 4 can thus be calculated.

III. Numerical Simulations

Unlike a structure consisting of two parallel LPFGs, there are multiple cladding modes excited by the SMS fiber structure in our proposed coupling technique. A study was firstly carried out to investigate the spectral response of different cladding modes excited by the SMS fiber structure. Fig. 2 shows examples of the simulated transmission spectra for the guided core mode and some cladding modes within SMF 2. In this simulation example, the MMF has core and cladding diameters of 50.8 and 125 μm and refractive indices of 1.4446 and 1.4271 respectively and the length of the MMF section is 10 mm. The SMF has core and cladding diameters of 8.3 and 125 μm and refractive indices of 1.4495 and 1.444 respectively and the surrounding media is assumed to be air.

Fig. 2 shows that the guided core mode has a minimum loss of 0.2 dB at a wavelength of 1640 nm, corresponding to the self-imaging condition for this particular SMS fiber structure [7], [8]. The cladding modes each have different spectral responses vs. wavelength, for example, for the LP_{03} mode there is minimum loss of 5.6 dB at a wavelength of 1470 nm. It should be noted that the positions of wavelengths with minimum loss for different modes can be adjusted by selecting different lengths of the MMF section. Of all the cladding modes shown in Fig. 2 the LP_{06} mode has the flattest response in the wavelength range from 1500 to 1600 nm and has a minimum loss of 7.1 dB.

We firstly investigated in simulation the coupling between an SMS fiber structure and an LPFG assuming that an LPFG has a resonance wavelength which corresponds to the LP $_{06}$ cladding mode. Fig. 3 shows the spectral response for coupling from Port 1 to Port 4 at different surrounding refractive indexes and length L_2 of Section 1. In this simulation, the fiber parameters are the same as those above and the LPFG has a period of 390 μm and length of 15.6 mm (40 periods), and it is also assumed that the two fibers are in perfect contact $(d = 0)$.

Fig. 3(a) shows that when the light is injected from port 1, the light is coupled to port 4 but as the surrounding refractive index increases from 1.0 to 1.44, the coupling efficiency increases from -33.87 to -8.85 dB when $L_2 = 20$ mm. The influence of the surrounding refractive index on the coupling efficiency is shown in Fig. 3(b).

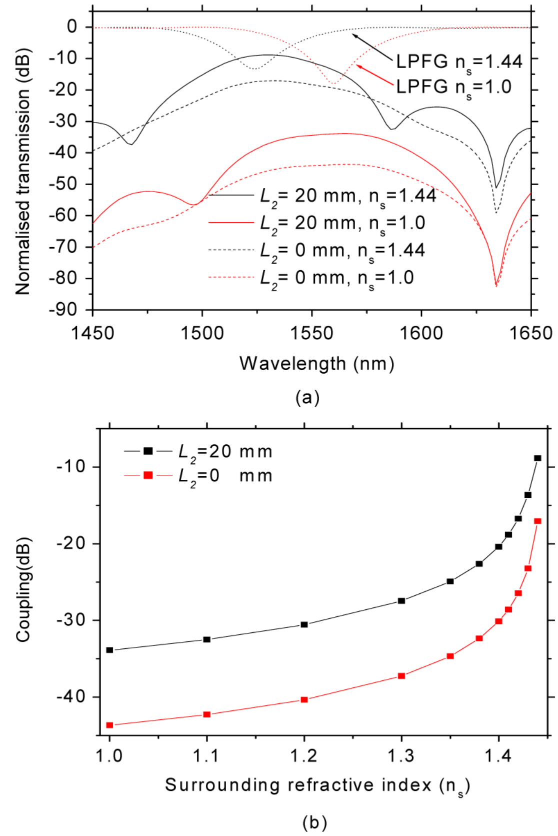

Fig. 3. Simulated (a) output spectra from port 1 to 4 for different L_2 values and surrounding refractive index and (b) coupling efficiency vs. surrounding refractive index at different L_2.

Fig. 3(b) shows that as the surrounding refractive index increases from 1.0 to 1.44 (the value close to the cladding refractive index), the coupling efficiency increases significantly in both cases when $L_2 = 0$ and 20 mm; the closer the value of surrounding refractive index approaches that of the cladding refractive index of the fiber, the steeper the change in the coupling efficiency. Also for the higher value of L_2, the coupling efficiency is significantly higher.

The above investigations are based on the assumption that the contact between two parallel fibers is ideal $(d = 0)$. However in practice it is very difficult to consistently achieve such an ideal contact between two fibers. The spectral responses at different separation distances d and surrounding refractive indexes for $L_2 = 20$ mm are shown in Fig. 4(a) and the relationship between the coupling efficiency and fiber separation d is shown in Fig. 4(b).

Fig. 4(a) shows that at lower values of the surrounding refractive index n_s, the influence of a change of 1 μm in the separation d is significant: the coupling efficiency decreases by 36.3 dB at $n_s = 1.0$ and by 19.5 dB at $n_s = 1.33$ respectively; as the surrounding refractive index n_s gets closer to the cladding refractive index of the fiber, the influence of separation d is much smaller with a decrease in the coupling efficiency

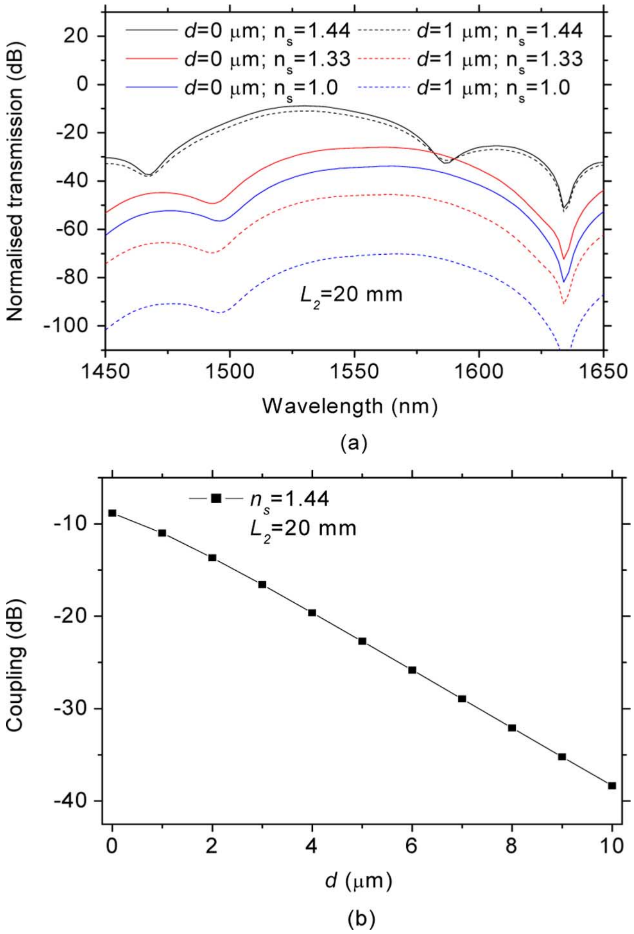

Fig. 4. Simulated (a) output spectra from port 1 to 4 at different separation d and surrounding refractive index and (b) coupling efficiency vs. fiber separation d at $n_s = 1.44$.

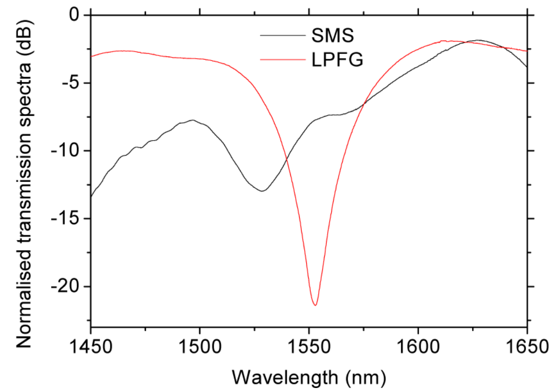

Fig. 5. Measured normalised spectral responses of the SMS fiber structure and LPFG.

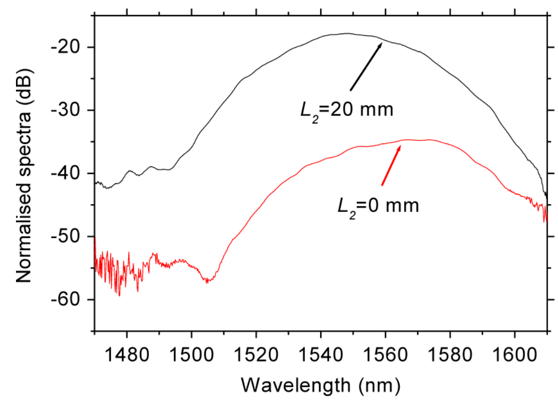

Fig. 6. Measured spectral response by injecting light from port 1 to 4 with L_2 of 0 and 20 mm.

of only 2.14 dB at $n_s = 1.44$. However Fig. 4(b) shows that even with a larger surrounding refractive index of 1.44, which is very close to the value of 1.444 of the cladding refractive index, larger values of the fiber separation d will nevertheless have a significant influence on the coupling efficiency which decreases linearly from -8.85 to -38.35 dB as fiber separation d increases from 0 to 10 μm.

IV. Experimental Verification

Experiments to investigate the coupling between an SMS fiber structure and an LPFG were carried out. A simple SMS fiber structure was fabricated by fusion splicing with an MMF length of 10 mm. The SMF used is conventional SMF28 made by Corning and the MMF has a core diameter of 50$\pm$1 μm. Both fibers have step index profiles. The LPFG is written in the fiber by a CO_2 laser with a grating period of 390 μm and the grating length of 15.6 mm. The separate normalised transmission spectra for the SMS fiber structure and LPFG are shown in Fig. 5.

Fig. 5 shows that the fabricated SMS fiber structure has a similar spectral response to that simulated for the LP_{01} core mode shown in Fig. 2 and the LPFG used has a resonant wavelength at 1552 nm. In order to achieve coupling between the SMS fiber structure and LPFG, they were physically arranged in close contact in free space over a contact region with a length of 10 cm. The fibers are pre-strained, aligned parallel with each other and secured by two V-grooves at either end of the 10 cm contact region. Since CO_2 laser illumination introduced a strong asymmetric index distribution which pulls the field of the cladding mode towards the exposed side of the LPFG, the side of the fiber exposed during fabrication is positioned to face the SMS fiber structure to achieve maximum coupling efficiency [5]. The measured spectral responses of the coupling between SMS fiber structure and LPFG are shown in Fig. 6.

Fig. 6 shows that the coupling efficiency with $L_2 = 20$ mm is much higher than that with $L_2 = 0$ mm and the maximum coupling efficiency is 1.66% (circa -17.8 dB). In the case of $L_2 = 20$ mm, the 3 dB bandwidth of the coupled light is 42 nm and the side lobe suppression ratio, defined as the ratio of the peak coupling efficiency to the side lobe coupling efficiency, is 24 dB. This result indicates that the proposed coupling technique offers potential applications in broadband filters, signal taps and optical add-drop multiplexers (OADMs) in coarse wavelength division multiplexed (CWDM) optical communication systems.

We also investigated experimentally the symmetrical transmission characteristics of the coupling technique. For light injected into port 4 and detected at port 1, the coupling has a very similar spectral response to the case above when injecting light from port 1 to port 4, which indicates that the coupling has symmetrical transmission characteristics. Finally the light injected from port 2 to port 3 was also investigated and our experimental result shows that there is no output power at port 3. This is because in this case a cladding mode only is excited in the LPFG and transmitted downstream, and while this cladding mode is coupled from SMF 3 to SMF 2, when light is transmitted through the LPFG, the coupled cladding mode will not transit through the MMF and therefore will not be re-coupled to the guided core mode in SMF 2. The coupled cladding mode in SMF 2 will therefore dissipate due to absorption by contamination at the cladding-air interface and the unstripped polymer coating of the SMF.

It is noted that due to the limitations of the equipment used in our experiments, it is very difficult to consistently achieve physically perfect contact $(d = 0)$ between the SMS fiber structure and LPFG. Since the fibers separation has significant influence on the coupling efficiency as shown in Fig. 5(b), the maximum coupling efficiency achieved in our experiments is 1.66% (circa -17.8 dB). The coupling efficiency can be optimized by ensuring that the mechanical support scheme for the structure provides for consistent close fiber-to-fiber contact across the length of the overall structure and also that contamination of both the fiber surfaces and of the RI matching liquid is minimised. In theory the maximum coupling efficiency could be 19.5% (circa -7.1 dB) for LP_{06} mode and this value could be as high as 27.5% (circa -5.6 dB) for the LP_{03} mode as shown in Fig. 2. By optimizing the parameters of the MMF such as core diameter, length and refractive index of core and cladding, we believe the coupling efficiency could be further improved.

V. Conclusion

In conclusion, a novel coupling technique based on the evanescent field coupling between an SMS fiber structure and an LPFG was proposed and theoretically analyzed. Experiments based on the proposed technique were carried out which agree well with the theoretical analysis. Experimentally we have achieved a maximum coupling efficiency of 1.66% which theoretically can be improved to 27.5% or even higher. In our proposed configuration the SMS fiber structure can excite multiple cladding modes and LPFG can act as a mode selector. By optimising the parameters of the MMF such as core diameter and length, the spectra of the excited cladding modes can be effectively tailored, and hence the final coupled spectra can be shaped. Since there are multiple cladding modes excited by the SMS fiber structure, it is feasible to extend this structure to eight ports by using three different LPFGs with different resonant cladding modes such as LP_{04}, LP_{05} and LP_{06} to achieve a different spectral response at different output ports. It is noted that the transmission spectrum of an SMS fiber structure is dependent on the length of the MMF section. For the SMS fiber structure used in our experiments, experimental results show that every 100 micron variation in the MMF length will introduce a wavelength shift of approximately 25 nm in the transmission spectrum. However the current technique used to set the MMF length prior to cleaving can easily achieve better than one micron accuracy, allowing for the fabrication of SMS fiber structures with a high degree of reproducibility.

References

[1] M. J. Kim, Y. M. Jung, B. H. Kim, W. T. Han, and B. H. Lee, "Ultra-wide bandpass filter based on long-period fiber gratings and the evanescent field coupling between two fibers," *Opt. Expr.*, vol. 15, no. 17, pp. 10855–10862, 2007.

[2] P. K. Lam, A. J. Stevenson, and J. D. Love, "Bandpass spectra of evanescent couplers with long period gratings," *Electron. Lett.*, vol. 36, pp. 967–969, 2000.

[3] Q. Liu, K. S. Chiang, and Y. Q. Liu, "Analysis of six-port optical fiber couplers based on three parallel long-period fiber gratings," *J. Lightw. Technol.*, vol. 26, no. 17–20, pp. 3277–3286, 2008.

[4] Y. Q. Liu, Q. Liu, and K. S. Chiang, "Optical coupling between a long-period fiber grating and a parallel tilted fiber Bragg grating," *Opt. Lett.*, vol. 34, no. 11, pp. 1726–1728, 2009.

[5] Y. Q. Liu, K. S. Chiang, Y. J. Rao, Z. L. Ran, and T. Zhu, "Light coupling between two parallel CO_2-laser written long-period fiber gratings," *Opt. Expr.*, vol. 15, no. 26, pp. 17645–17651, 2007.

[6] Q. Wu, Y. Semenova, P. Wang, and G. Farrell, "High sensitivity SMS fiber structure based refractometer—Analysis and experiment," *Opt. Expr.*, vol. 19, no. 9, pp. 7937–7944, 2011.

[7] L. B. Soldano and E. C. M. Pennings, "Optical multi-mode interference devices based on self-imaging: Principles and applications," *J. Lightw. Technol.*, vol. 13, no. 4, pp. 615–627, 1995.

[8] W. S. Mohammed, A. Mehta, and E. G. Johnson, "Wavelength tunable fiber lens based on multimode interference," *J. Lightw. Technol.*, vol. 22, no. 2, pp. 469–477, 2004.

[9] Y. Gong, T. Zhao, Y. J. Rao, and Y. Wu, "All-fiber curvature sensor based on multimode interference," *IEEE Photon. Tech. Lett.*, vol. 23, no. 11, pp. 679–681, 2011.

[10] Y. O. Yilmaz, A. Mehta, W. S. Mohammed, and E. G. Johnson, "Fiber-optic beam shaper based on multimode interference," *Opt. Lett.*, vol. 32, no. 21, pp. 3170–3172, 2007.

[11] S. M. Tripathi *et al.*, "Strain and temperature sensing characteristics of single-mode-multimode-single-mode structures," *J. Lightw. Technol.*, vol. 27, no. 13, pp. 2348–2356, 2009.

[12] Q. Wu, Y. Semenova, A. M. Hatta, P. Wang, and G. Farrell, "Bent SMS fiber structure for temperature measurement," *Electron. Lett.*, vol. 46, no. 16, pp. 1129–1130, 2010.

[13] E. Li, "Temperature compensation of multimode interference-based fiber devices," *Opt. Lett.*, vol. 32, p. 2064, 2007.

[14] B. Dong, D. P. Zhou, L. Wei, W. K. Liu, and J. W. Y. Lit, "Temperature- and phase-independent lateral force sensor based on a core-offset multi-mode fiber interferometer," *Opt. Expr.*, vol. 16, no. 23, pp. 19291–19296, 2008.

[15] Q. Wu, Y. Semenova, B. B. Yan, Y. Q. Ma, P. Wang, C. X. Yu, and G. Farrell, "Fiber refractometer based on a fiber Bragg grating and single-mode-multimode-single-mode fiber structure," *Opt. Lett.*, vol. 36, no. 12, pp. 2197–2199, 2011.

[16] K. S. Chiang, F. Y. M. Chan, and M. N. Ng, "Analysis of two parallel long-period fiber gratings," *IEEE J. Lightw. Technol.*, vol. 22, no. 5, pp. 1358–1366, 2004.

[17] H. Kogelnik and R. V. Schmidt, "Switched directional couplers with alternating $\Delta\beta$," *IEEE J. Quant. Electron.*, vol. QE-12, no. 7, pp. 396–401, 1976.

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