Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 140 (2016) 72 – 76
Procedia Engineering
www.elsevier.com/locate/procedia

MRS Singapore – ICMAT Symposia Proceedings

8th International Conference on Materials for Advanced Technologies

Investigation of temperature sensitivity under the influence of coupling strength between a silica core and a satellite waveguide in a photonic crystal fiber with selective infiltration of glycerin

Kun Li[a,b,c,e], Jun Long Lim[a,b,e], Zhilin Xu[a,b,d], Dora Juan Juan Hu[a,*], Rebecca Yen-Ni Wong[a], Perry Ping Shum[b], Emily Jianzhong Hao[a], Yixin Wang[a], Qizhen Sun[d], Meng Jiang[c]

[a]*Photonic Technology Department, Institute for Infocomm Research, A*STAR, Singapore*
[b]*School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore*
[c]*College of Science, Donghua University, Shanghai, China*
[d]*School of Optical and Electronical Information, Huazhong University of Science and Technology, Wuhan, Hubei, China*
[e]*Both authors contributed equally in this work and should be regarded as joint first authors*

Abstract

In this report, we carry out simulation and experimental investigations of directional coupler structures with different separations between the glycerin selectively infiltrated channel and silica core of a large mode area Photonic Crystal Fiber (PCF). We assess their coupling characteristics and the corresponding temperature sensing capabilities. The temperature sensitivities of the glycerin selectively infiltrated channel adjacent to the silica core and two periods away from the silica core are −3.115 nm/°C and −2.332 nm/°C respectively. The glycerin selectively infiltrated channel three periods away from the silica core displays −107.8 pm/°C, an order of magnitude less temperature sensitive. The simulation results agree with the experimental results that there is a strong correlation between the coupling strength of the glycerin selectively infiltrated channel and the silica core, affecting its temperature response.

Selection and/or peer-review under responsibility of the scientific committee of Symposium 2015 ICMAT

* Corresponding author. Tel.: +65-6408-2097; fax: +65-6467-9019.
E-mail address: jjhu@i2r.a-star.edu.sg

Selection and/or peer-review under responsibility of the scientific committee of Symposium 2015 ICMAT
doi:10.1016/j.proeng.2015.08.1115

Keywords: Photonic crystal fiber; optical fiber sensor; selective infiltration; temperature; coupling strength;

1. Introduction

Optical fibers with periodically arranged air channels are commonly known as Photonic Crystal Fibers (PCFs), representing a versatile platform for material integration such as [1], gas [2], and liquid crystals [3] to build functional devices. Previous studies have infiltrated material in PCFs for various sensing applications such as electrical field [4], temperature [5] and hydrostatic pressure [6]. However, to the best of our knowledge, there has been no prior investigation concerning the influence of the coupling strength between the liquid filled waveguide and the silica core on its temperature sensitivity. In this work, the simulation and experimentation of directional coupler structures with different separations between the glycerin selectively infiltrated channel and the silica core of a large mode area Photonic Crystal Fiber (PCF), assessment of their coupling characteristics and the corresponding temperature sensing capabilities have been investigated. This work will provide insights into designing and optimizing PCF-based directional couplers for sensing purposes.

2. Fabrication

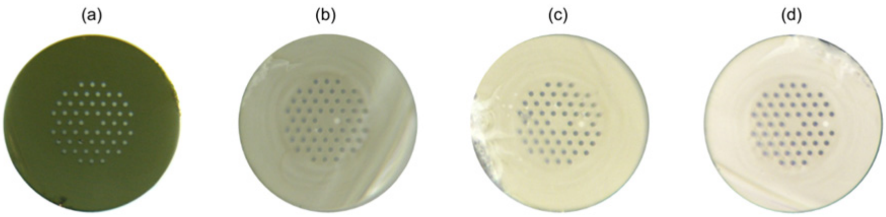

Fig. 1. Microscope images of (a) LMA-25 PCF and the fabricated samples (b) 1, (c) 2 and (d) 3.

The experiment uses LMA-25 PCF as shown in Fig. 1(a). It is a Large Mode Area (LMA) fiber (NKT Photonics) with an air hole diameter of 8.4µm, outer diameter of 268 µm and pitch of 16.35 µm. The solid silica core with periodic hexagon arrays of air hole guide light by the modified Total Internal Reflection (TIR) mechanism [7].

Tapered Single Mode Fibers (SMF), manipulated by micro-positioning stages [8], transfer tiny droplets of UV glue (Thorlabs NOA81) to the cleaved end of the LMA-25 to block its air holes. To investigate the coupling strength of a glycerin selectively infiltrated channel with the silica core, three samples with three air holes along the same axis remain unblocked. Only one air hole remains unblocked in each sample. The blocked samples are cured via exposure to UV light (Xenon RC-250B) for 30 seconds. Next, the cured ends of the samples are immersed into glycerin to allow the capillary force to infiltrate the single unblocked air hole in each of them. After infiltration, the unblocked ends of the samples are inspected under the microscope, as shown in Fig. 1(b-d). The white circular spot in each of the sample shows the glycerin selectively infiltrated channel and the black circular spots shows the un-infiltrated air holes.

Sample 1 has the glycerin selectively infiltrated channel adjacent to the silica core, sample 2 has the glycerin selectively infiltrated channel two periods away from the silica core, and sample 3 has the glycerin selectively infiltrated channel three periods away from the silica core. The lengths of sample 1, 2, and 3 are 8.5 cm, 9.5 cm and 10.5 cm respectively. After verifying the samples are infiltrated correctly, the UV blocked ends are cleaved and both sides of the samples are spliced to SMF pigtails using a fusion arc splicer. One end of the spliced sample connects to an amplified spontaneous emission source (1530 nm to 1600 nm) while the other end connects to an optical spectrum analyzer (Advantest Q8384). To test the temperature response, the samples are placed into a temperature controlled oven and subjected to different temperatures.

3. Results & Discussions

The measured transmission spectrums at different temperatures are shown in Fig. 2. Fig. 2(a) and 2(b) depict spectra of sample 1 and 2 are shifted to shorter wavelengths as temperature increases. Fig. 2(c) shows sample 3's spectrum without any obvious shift as temperature increases. This is due to the fact that the glycerin selectively infiltrated channel is too far away from the silica core, thus the glycerin selectively infiltrated channel modes have little coupling strength to the silica mode. It can be observed that sample 1 has a shorter Free Spectral Range (FSR) than sample 2; sample 2 has approximately the same FSR as sample 3; and sample 1 has many multi-peaks and dips indicating multiple liquid modes coupling occurring with the silica core mode.

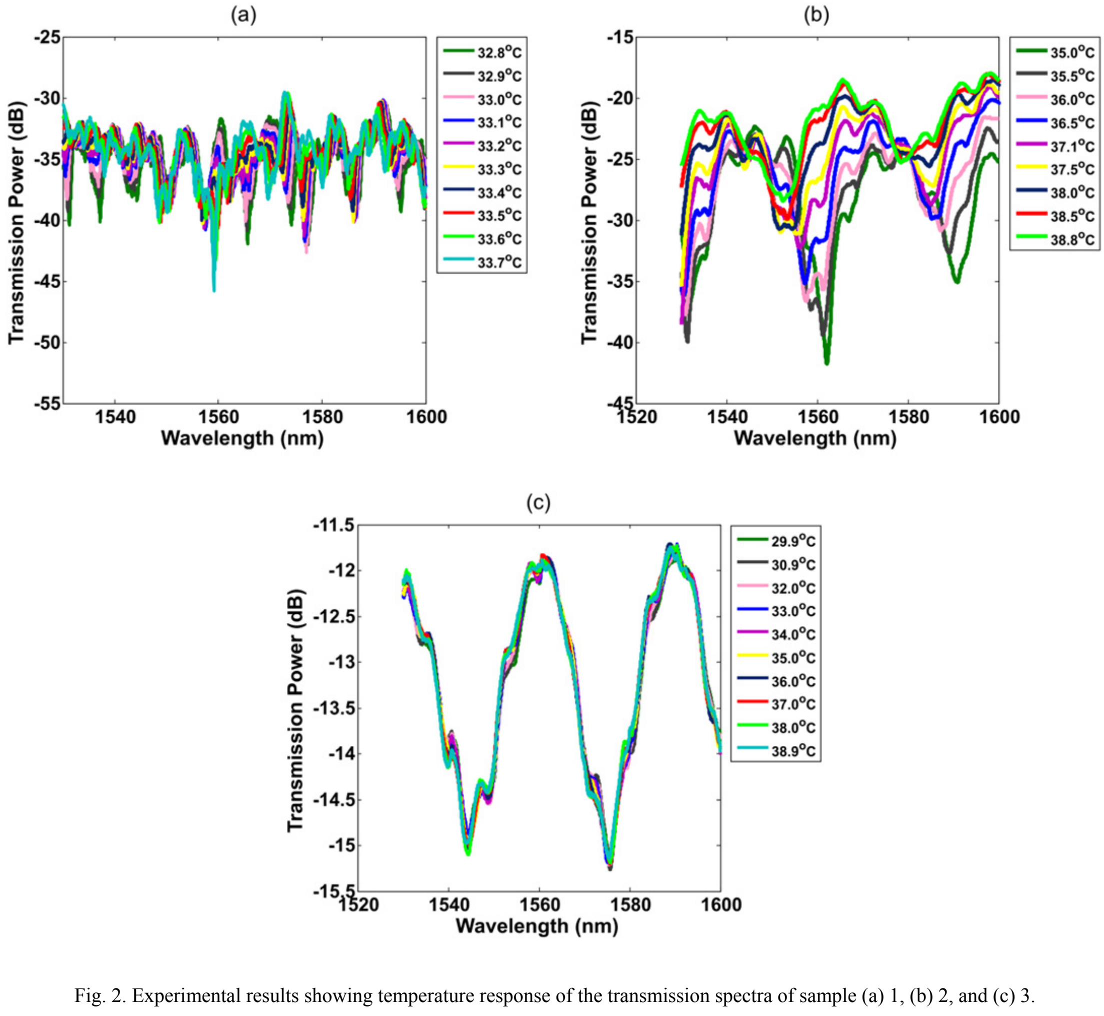

Fig. 2. Experimental results showing temperature response of the transmission spectra of sample (a) 1, (b) 2, and (c) 3.

The ~1586 nm dips in sample 1 and 2 are traced and plotted in Fig. 3 as a function of temperature. A linear fitting is applied to the experiment data as depicted by the straight lines. The corresponding temperature sensitivity of sample 1, 2, and 3 are −3.115 nm/°C, −2.332 nm/°C, and −107.8 pm/°C respectively.

From the temperature sensitivity results, we deduce that the separation distance between the glycerin selectively infiltrated channel and silica core does not have a linear relationship with the temperature sensitivity but more on the coupling modes involved. It can also be observed that sample 2, has FSR about three times larger than sample 1, providing a larger sensing range than Sample 1.

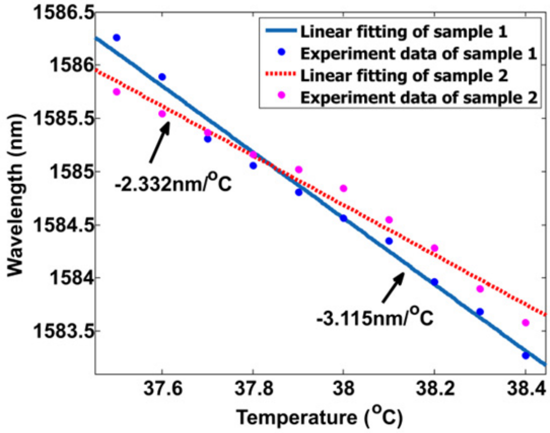

Fig. 3. Temperature sensitivities of sample 1 and 2 by tracking a dip. Linear line shows the fittings of the experimental data.

To validate the mode coupling mechanism, the commercially available FemSIM software (RSoft) simulates the samples' Refractive Index (RI) profiles and dispersion properties as shown in Fig. 2 and Fig 3 respectively. Fig. 4 shows the RI of silica, glycerin, and air which are 1.448 and 1.470, and 1.000 respectively.

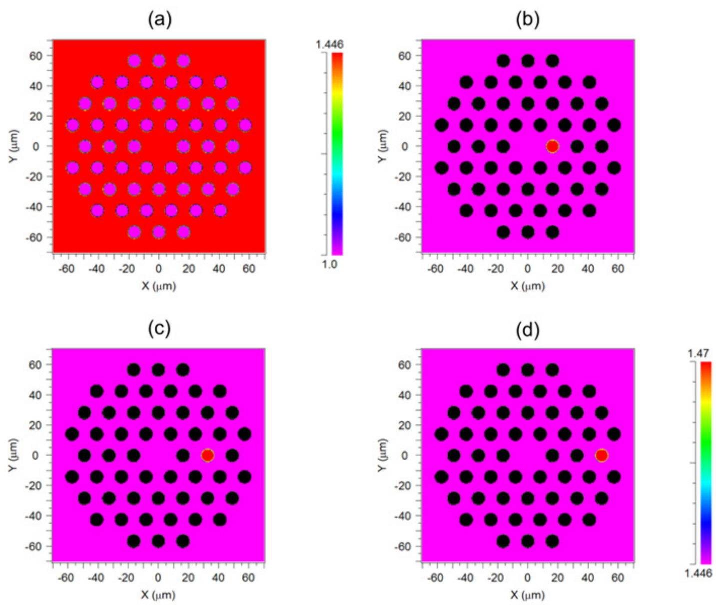

Fig. 4. Refractive index profile of the samples. (a) LMA25 structure without any liquid infiltration. Sample 1, 2, and 3 represent structures of liquid infiltrated into the air holes (b) adjacent to core, (c) two periods away from core and (d) three periods away from core. Colour bars show the Refractive Index (RI) value. The black circles in (b-d) are RI of 1.000.

Fig. 5 shows the calculated dispersion curves for both the silica core's fundamental mode and the glycerin selectively infiltrated channel 'liquid' waveguides LP_{02} mode. The core mode intersects the liquid mode where the phase matching condition is satisfied, resulting a resonance dip in the transmission spectrum. Glycerin displays a negative thermal-optic coefficient; in other words as temperature increases the RI of glycerin decreases. The phase matching intersections also shift to shorter wavelengths in the simulation, indicating a blue shift of resonance wavelength as temperature increases.

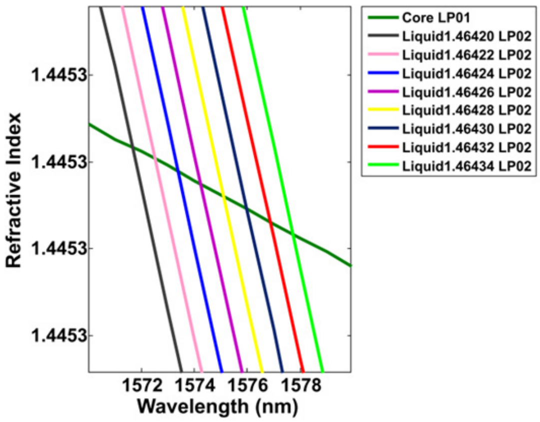

Fig. 5. Simulation results of phase matching between silica core mode and liquid core mode. LP represents linear polarized.

4. Conclusion

We investigate the temperature response of three different PCF coupler structures with the selective infiltration of a liquid at different positions in the holey cladding. The temperature sensitivities show their dependence on the coupling strength in the structures. This study will provide insights into designing and optimizing PCF-based directional couplers for sensing purposes.

Acknowledgements

This work is supported in part by the Agency for Science, Technology and Research (A*STAR), Singapore, and in part by the Postgraduate Internship from Nanyang Technological University, Singapore. K. Li acknowledges funding from Donghua University's Central Universities Fundamental Research Funds.

References

[1] M. Vieweg, T. Gissibl, S. Pricking, B. T. Kuhlmey, D. C. Ww, B. J. Eggleton, and H. Giessen, Ultrafast nonlinear optofluidics in selectively liquid-filled photonic crystal fibers, Optics Express, 18(24) (2010) 25232-25240.

[2] F. Benabid, F. Couny, J. C. Knight, T.A. Birks, and P. St J. Russell, Compact, stable and efficient all-fiber gas cells using hollow-core photonic crystal fibres, Nature 434 (2005) 488-491.

[3] D. J. J. Hu, P. P. Shum, J. L. Lim, Y. Cui, K. Milenko, Y. Wang, and T. Wolinski, A compact and temperature-sensitive directional coupler based on photonic crystal fiber filled with liquid crystal 6CHBT, IEEE Photonics Journal 4(5) (2012) 2010-2016.

[4] S. Mathews, G. Farrell, and Y. Semenova, Liquid crystal infiltrated photonic crystal fibers for electric field intensity measurements, Applied Optics 50(17) (2011) 2628-2635.

[5] Y. Wang, M. Yang, D. N. Wang, and C. R. Liao, Selectively infiltrated photonic crystal fiber with ultrahigh temperature sensitivity, IEEE Photonic Technology Letters 23(20) (2011) 1520-1522.

[6] P. Lesiak, T. R. Wolinski, J. Tul, and A. W. Domanski, All fiber optic modular sensing system for hydrostatic pressure measurements with a photonic liquid crystal fiber analyzer, in Proc. of SPIE 6608, Lightguides and Their Applications III, (2007) 66081K.

[7] J. C. Knight, Photonic crystal fibres, Nature 424 (2003) 847-851.

[8] D. J. J. Hu, J. L. Lim, Y. Cui, K. Milenko, Y. Wang, P. P. Shum, and T. Wolinski, Fabrication and characterization of a highly temperature sensitive device based on Nematic Liquid Crystal-filled photonic crystal fiber, IEEE Photonics Journal 4(5) (2012) 1248-1255.