International Journal of Psychosocial Rehabilitation, Vol. 24, Issue 04, 2020
ISSN: 1475-7192

# Detection of Hazardous Chemical H2S using Multi Porous Core Photonic Crystal Fiber

[1]S. Mohamed Nizar, [2]B. Kesavaraman, [3]B. Elizabeth Caroline

***Abstract***

*The Photonic Crystal Fiber (PCF) is used as a chemical sensor to detect the hydrogen sulfide ($H_2S$) released from the industries. The cladding area in which the air gaps are arranged as in the shape called hexagon, and the micro porous air gaps are present in the inner core area. The required solution which has to be analyze is placed in the air gaps of the inner core area. In this proposed method the simulation of PCF is done with COMSOL Multiphysics software by using the full vectorial Finite Element Method (FEM) which provides relatively high sensitivity, high effective area and extremely low confinement loss. The proposed idea has been accomplished with relatively optimum level sensitivity at 2.5 µm and minimum confinement loss of 1.34918 E-09 dB/m at 5 µm pitch. This proposed structure will be elite commitment for recognizing the $H_2S$ gas precisely.*

***Keywords:*** *Confinement Loss (CL), Effective area, Gas detector, Multi Porous Core Photonic Crystal Fiber (MPCPCF) and Relative Sensitivity (RS).*

## I. INTRODUCTION

Hydrogen sulfide is a lackluster gas, which is well known for its rotten egg-like odor that is being its trademark. Hydrogen sulfide is an uncommonly perilous gas. It also reacts with protein content presents in the body circulatory system that may repress all cells to breath. As such, higher groupings of $H_2S$ can damage the lungs and prompts demise. It is released from the industries like

- Wastewater treatment industries
- Gas and Oil industries
- Paper and Pulp manufacturing industries

$H_2S$ produces various side effects to the humans at different ppm (parts per million) level. When its 0.13 ppm produce negligible discernible scent, 4.60 ppm produce effectively identified & moderate smell, 10 ppm produce starting eye rupture (irritation), 27 ppm produce Solid, disagreeable smell& however not heinous, 100 ppm produce

[1] Associate Professor, Department of Electronics & Communication Engineering, IFET College of Engineering, Villupuram, Tamil Nadu, India
[2] UG Final year Student, Department of Electronics & Communication Engineering, IFET College of Engineering, Villupuram, Tamil Nadu, India

[3] Associate Professor, Department of Electronics & Communication Engineering, IFET College of Engineering, Villupuram, Tamil Nadu, India

coughing, eye aggravation & loss of feeling of smell following 2 to 5 minutes, 200-300 ppm checked conjunctivitis (eye aggravation) and respiratory tract bothering after one hour of introduction, 500-700 ppm produce Loss of awareness, end (halting or delaying) of breath and 1000-2000 ppm produce Obviousness without a moment's delay, with early discontinuance of breath and passing in a couple minutes, Death may happen regardless of whether the individual is evacuated to natural air on the double.

In the ongoing years, the researches and development over the PCF is vast. Total internal reflection is the principle in which the light propagates through the Index guiding PCF. However the refractive index of the cladding is higher than the refractive index of the core in the Photonic band gap PCF. Where in PCF a few air gaps are presented in the center of the cladding and core area which stays all through the whole fiber. However, PCFs are being successfully utilized over various applications which includes tumor detection [1], chemical sensing applications [2], spectroscopy [3], image reconstruction [4], Change in parametric amplification of optical switching [5], detection of hazardous gases [6], biomedical applications [7] [8] and different kinds of chemical samples [9]. The MPCPCF is a sensor which contains air material and solid material together in core area using that we can sense the harmful gas.From the earlier development of PCF hexagonal type model had been proposed for chemical detecting by various kinds of structures, for example, octagonal [10], decagonal [11], circular, honeycomb [12] fiber was proposed by the analysts. Habib et al. suggested a decagonal PCF along with two kinds of circular and two kinds of elliptical openings inside the cladding structure [13].Liu et al. have suggested a modified interior cladding, combining elliptical tellurite core with hexagonal PCF comprising three kinds of gaps [14]. Ademgil has contemplated RS of specifically penetrate micro structured octagonal and hexagonal PCF [15].

Section 2 describes about the geometric structure of the MPCPCF sensor, section 3 describes about the simulation methodology, section 4 describes about the graph, results & discussion and at last section 5 describes about the conclusion and usage of the MPCPCF sensor.

## II. Proposed Sensor -- Geometry

The geometric cross sectional perspective of the implemented MPCPCF for sample chemical detector is depicted in Fig. 1. The air gaps that present the cladding area are arranged in the form of hexagon, and in the inner core area the circular shape air gaps are placed vertically in 3 columns whereas each single column consists of 9 air gaps. There are three additional sections of the vertical column air gaps are placed in both side of focal three segments and the line consists of 7, 5 and 3 air gaps individually. The division among two close air openings of similar fragment is implied by means of pitch ($\Lambda$) where the partition among two segments are $\Lambda = 5$ µm. The air gaps present in the cladding region has the diameter (d) = 5 µm. The center circular air gaps of the hexagon shape is considered as the core area, which is designed as MPCPCF. A boundary state of the perfectly matched layer is used in each PCF model to resist the propagation of the Electro Magnetic (EM) waves against the exterior layer.

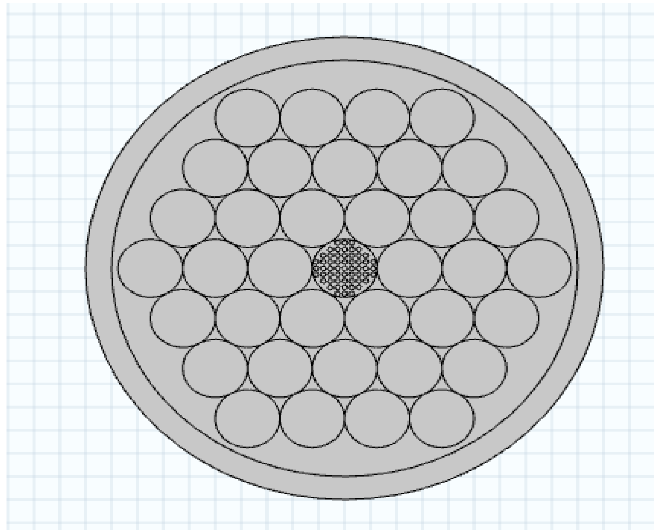

Fig. 1. Geometric structure for the proposed MPCPCF model.

The MPCPCF guiding properties are also subject to the background material of the designed structure and some of the normally utilized background materials are Silicon, Topas, Silica Aerogel, Zeonex, Teflon *etc*. In this proposed method, silicon is used in the core whose refractive index is 1.45. The material used in the cladding area is silica aerogel. It is the only material with low solid density, quit stronger enough and a good insulator with refractive index of 1.265.

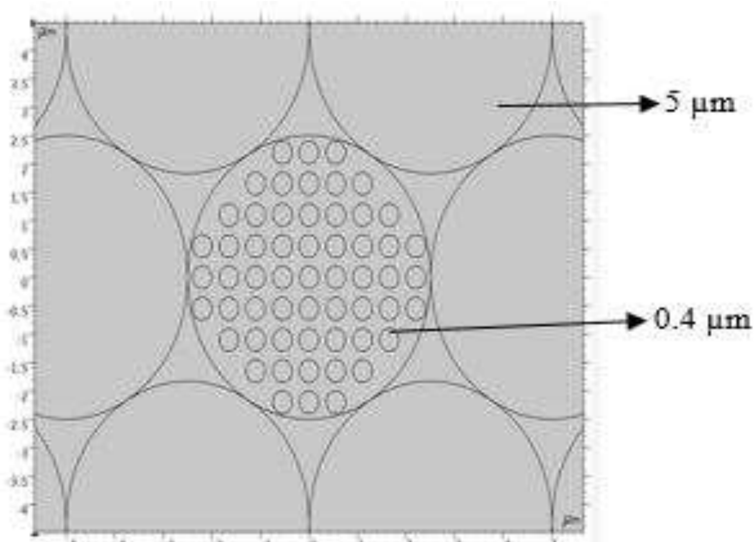


Fig. 2. Geometrical view the of core area for the proposed MPCPCF model.

The multi porous air gaps in the core is filled by the hydrogen sulfide ($H_2S$), whose refractive index is 1.3682. By utilizing experimentation method, i.e trial and error method the air gaps which are present in the core area is found to have a diameter ($d_1$) = 0.4 µm. Through which the better core is designed for the implemented method.

## III. Simulation Methodology

The FEM based Comsol V5.4 software which is utilized for the proposed MPCPCF. This software is utilized in various engineering and numerical material science, where scientific arrangements can't be acquired because of the material properties, convoluted geometries and loadings of the issues. It has been apparent that the viable refractive index diminishes with an expanding wavelength together in X and Y polarization directions and it is legitimate in light of the fact that with expanding wavelength for some particular recurrence the speed of the light in any kind of the medium may get increments, therefore the viable refractive index diminishes because the speed of the light in vacuum is always steady. From the software COMSOL Multiphysics, it is seen that the refractive index has been effective in both X and Y polarization directions by choosing a bolt surface mode.

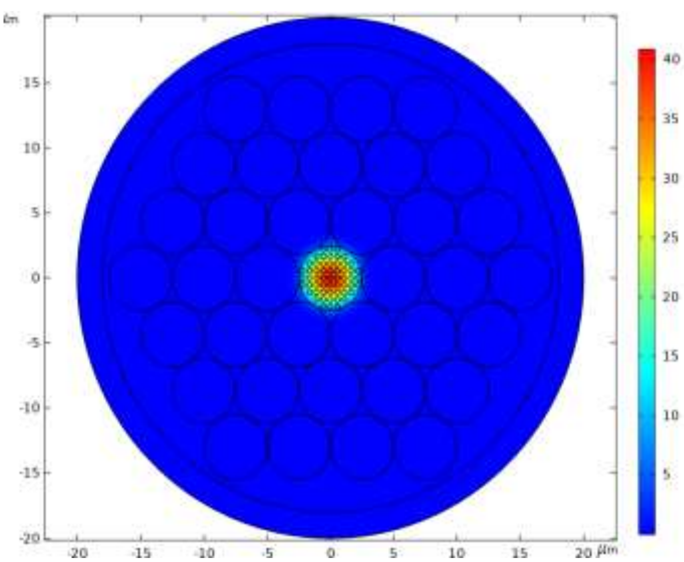

Fig. 3. Light is confined at the center core area.

Thus to determine the efficient transmission of the signal in the sensor fiber the light must be propagate through the core area of the MPCPCF. The accompanying figure shows that the firmly bound light signal into the core area of the fiber.

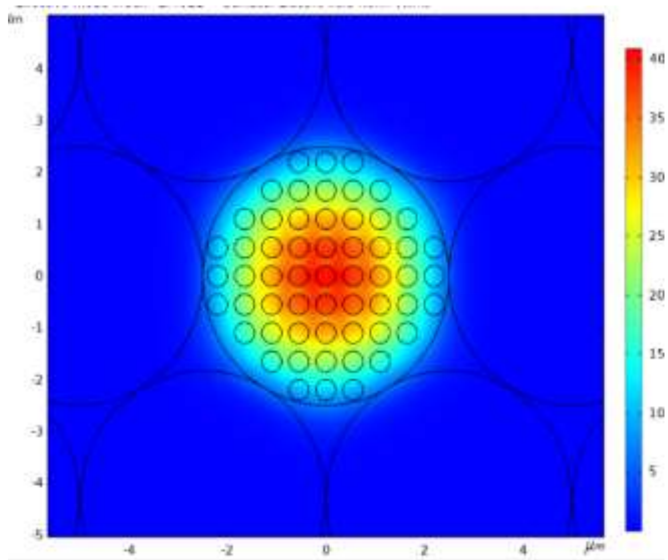

Fig. 4. Confinement of the light at the center of the sensor.

It is obvious from fig.4 the light source is tightly bound at the middle of the air gaps in the center core area of the MPCPCF model, it is clearly observed that CL will be less on this proposed MPCPCF model.

## IV. Result and Discussion

To analyze the proposed hazardous gas detection sensor, the RS of the MPCPCF ought to be computed. The RS exhibits the proportion of association of light with the respect to the chemical substance. The RS of various hazard detectors are effectively determined by purely utilizing the equation (1) [16] [17] [18],

$$r = \frac{n_r}{n_{eff}} \times p\% \qquad (1)$$

where $n_r$ describes the samples refractive index, r describes the RS, $n_{eff}$ describes the directed mode's viable refractive index and P describes the directed mode's power fraction.

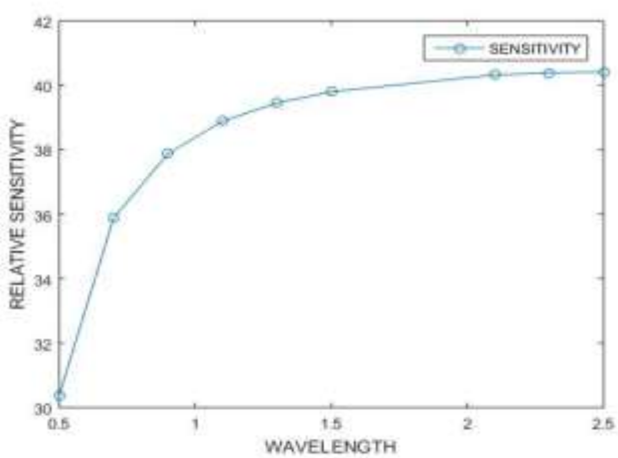


Fig.5. Relative sensitivity of $H_2S$ Vs wavelength

**Received: 03 Dec 2019 | Revised: 21 Jan 2020 | Accepted: 18 Feb 2020** 

From fig.5 it has been clearly shown that the RS of the implemented MPCPCF gradually raised to the value 40.41926% at 2.5 μm wavelength.

The measurement of complete light propagation in the core area is shown by power fraction (PF). Determining the PF from the equation (2).

$$P = \frac{\int_{sample} R_e(E_x H_y - E_y H_x)dxdy}{\int_{total} R_e(E_x H_y - E_y H_x)dxdy} \times 100 \qquad (2)$$

The magnetic field and transverse electric field of the directed light are determined by $H_x$, $H_y$ and $E_x$, $E_y$ respectively.

When the light goes via the optical waveguide, the light measurement may get varied at the particular point due to the trap of light by the air gaps in the cladding region. Which is called as CL. This kind of certainly misfortune effectively evaluate by just utilizing from the equation (3).

$$\alpha_{CL} = 8.686 \times \frac{2\pi f}{c} \mathrm{Im}(n_{eff}) \qquad (3)$$

where the light speed in free space is denoted by c, the operating signal frequency is denoted by f and the imaginary part of direct mode's viable refractive index is denoted by Im(neff).

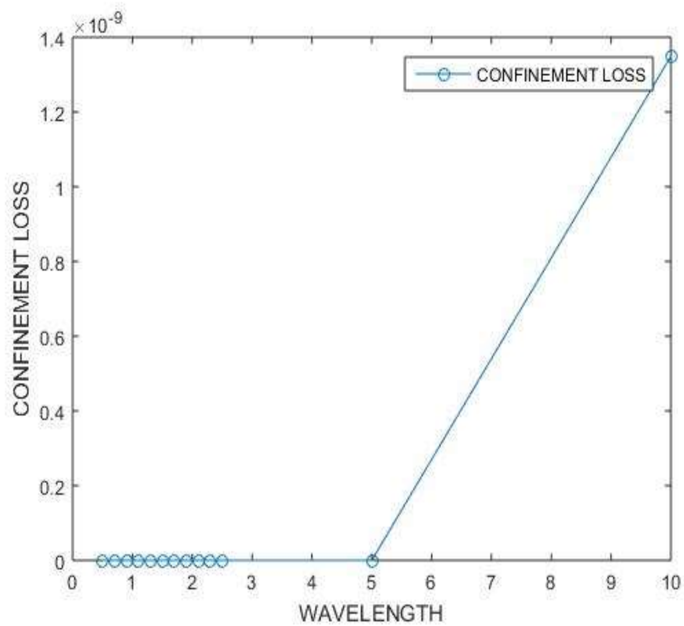


Fig. 6. Confinement loss of $H_2S$ Vs wavelength.

Thus the proposed MPCPCF has the CL zero for the wavelength from 0.5 μm to 8.5 μm and this model produce a small CL of 1.34918E-09 dB/m is obtained for the wavelength 9 as appeared in the fig.6.

The area which the propagation of the light gets confined in the center of the core area is known as effective area. The effective area may get varied while changing the wavelength of the implemented sensor. The effective area of the directed mode can be calculate from the equation (4).

$$A_{eff} = \frac{(\iint |E^2|dxdy)^2}{\iint |E^4|dxdy} \qquad (4)$$

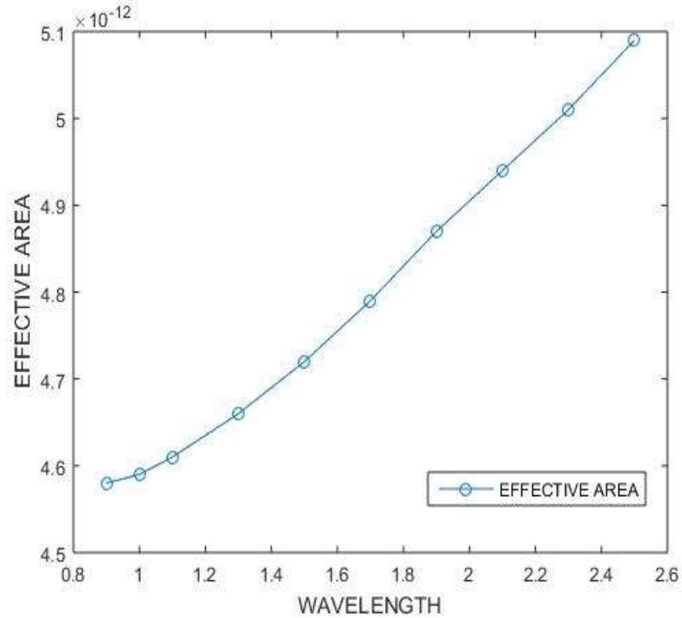


Fig. 7. Effective area of $H_2S$ Vs wavelength.

Thus the effective mode area for the proposed sensor is being increased from the wavelength 0.9 µm to 2.6 µm and it reaches the maximum value of 5.0859E-12 for the wavelength 2.6 µm which is also in increasing order as appeared in the fig.7.

**Table 1. Analysis parameters of the designed MPCPCF sensor.**

| **Lambda** | **neff** | **p** | **r** | **Aeff** |
|---|---|---|---|---|
| | | | | |
| 0.5 | 1.4181 | 31.471 | 30.3636 | 4.28E-12 |
| 0.7 | 1.4143 | 37.053 | 35.8452 | 4.45E-12 |
| 0.9 | 1.4113 | 39.072 | 37.8787 | 4.58E-12 |
| 1.1 | 1.4082 | 40.024 | 38.8871 | 4.61E-12 |
| 1.3 | 1.4048 | 40.511 | 39.4555 | 4.66E-12 |
| 1.5 | 1.4011 | 40.757 | 39.7999 | 4.72E-12 |

Received: 03 Dec 2019 | Revised: 21 Jan 2020 | Accepted: 18 Feb 2020 

| | | | | |
|---|---|---|---|---|
| 2.5 | 1.3775 | 40.694 | 40.4192 | 5.09E-12 |

This table shows the reading between Relative sensitivity, Power fraction and Effective area for various Lambda value given in the computation.

## V. Conclusion

The proposed and examined method of the $H_2S$ gas detector depends upon hexagonal shape arrangement of air gaps at the cladding area and MPCPCF arrangement of air gaps in the core area. The entire plan and recreation mode of the MPCPCF have been practiced by the software called COMSOL Multiphysics through utilizing FEM. In this proposed model the confinement of light arrived with optimum RS of 40.41926%, and a CL of 1.34918E-09 dB/m at 5 µm pitch. Thus the RS and the viable mode area are raised and the CL is decreased. So it is increasingly fundamental to recognize the nearness of $H_2S$ gas accurately. Which will be most widely used in the chimney and the valve of the $H_2S$ releasing industries. Where the accuracy of hazards of the chemical can be more precisely detect and protect it before mix into the atmosphere.

## References

[1] Y. Miura, A. Kamataki, M. Uzuki, T. Sasaki, J. Nishizawa, T. Sawai, Terahertz-wave spectroscopy for precise histopathological imaging of tumor and non-tumor lesions in paraffin sections, Tohoku J. Exp. Med. 223 (2011) 291–296.

[2] M. Walther, B.M. Fischer, A. Ortner, A. Bitzer, A. Thoman, H. Helm, Chemical sensing and imaging with pulsed terahertz radiation, Anal. Bioanal. Chem. 397 (3)(2010) 1009-1017.

[3] W. Withayachumnankul, et al., T-ray sensing and imaging, Proc. IEEE 95 (8) (2007) 1528–1558.

[4] Q. Guo, T. Chang, G. Geng, C. Jia, H. Cui, A high precision terahertz wave image reconstruction algorithm, Sensors 16 (2016) 1139.

[5] H. Pakarzadeh, M. Sharifian, Modelling of a variable optical switch based on the parametric amplification in a photonic crystal fibre, J. Mod. Opt. 65 (16) (2018) 1855–1859.

[6] S. Olyaee, A. Naraghi, Design and optimization of index-guiding photonic crystal fiber gas detector, Photonic Sens. 3 (2) (2013) 131–136.

[7] M.A. Habib, M.S. Anower, M.R. Hasan, Ultrahigh birefringence and extremely low loss slotted-core microstructure fiber in thz regime, Curr. Opt. Photon. 1 (6) (2017) 567–572.

[8] M.A. Habib, M.S. Anower, Low loss highly birefringent porous core fiber for single mode terahertz wave guidance, Curr. Opt. Photon. 2 (3) (2018) 215–220.

[9] J. Park, S. Lee, S. Kim, K. Oh, Enhancement of chemical sensing capability in a photonic crystal fiber with a hollow high index ring defect at the centre, Opt. Express 19 (3) (2011) 1921–1929.

[10] Ademgil, H. (2014) Highly Sensitive Octagonal Photonic Crystal Fiber Based Sensor. Optik: International Journal for Light and Electron Optics, 20, 6274-6278.

[11] Razzak, S.M.A., Namihira, Y., Begum, F., Kaijage, S., Kinjo, T., Nakahodo, J., Miyagi, K. and Zou, N. (2007) Decagonal Photonic Crystal Fibers with Ultra-Flattened Chromatic Dispersion and Low Confinement Loss. Optical Fiber Communication Conference/National Fiber Optic Engineers Conference (OFC/NFOEC), Anaheim, 25-29 March 2007, 1-6.

[12] Hou, Y., Fan, F., Jiang, Z.-W., Wang, X.-H. and Chang, S.-J. (2013) Highly Brief Ringent Polymer Terahertz Fiber with Honey Comb Cladding. Optik: International Journal for Light and Electron Optics, 124, 3095-3098. https://doi.org/10.1016/j.ijleo.2012.09.040

[13] M.S. Habib, E. Khandker, Highly birefringent photonic crystal fiber with ultraflattened negative dispersion over S+C+L+ U bands, Appl. Opt. 54 (2015) 2786–2789, https://doi.org/10.1364/AO.54.002786.

[14] M. Liu, A.L.C. Hongtao Yuan, Shum Ping, Shao Cong, Han Haonan, Simultaneous achievement of highly birefringent and nonlinear photonic crystal fibers with an elliptical tellurite core, Appl. Opt. 57 (2018) 6383–6387, https://doi.org/10.1364/ AO.57.006383.

[15] H. Ademgil, Highly sensitive octagonal photonic crystal fiber based sensor, Optik (Stuttg.) 125 (2014) 6274–6278, https://doi.org/10.1016/j.ijleo.2014.08.018.

[16] M.S. Islam, J. Sultana, K. Ahmed, M.R. Islam, A. Dinovister, B.W.H. Ng, D. Abbott, A novel approach for spectroscopic chemical identification using photonic crystal fiber in the terahertz regime, IEEE Sens. J. 18 (2) (2018) 575–582.

[17] Md. Ahasan Habiba, Md. Shamim Anowera , Lway Faisal Abdulrazakb , Md. Selim Rezac, Hollow core photonic crystal fiber for chemical identification in terahertz regime, Optical Fiber Technology 52 (2019) 101933.

[18] Md. Ranju Sardar, Mohammad Faisal, Methane Gas detector Based on Microstructured Highly Sensitive Hybrid Porous Core Photonic Crystal Fiber, Journal of Sensor Technology, 2019, 9, 12-26.