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# Porous shaped photonic crystal fiber with strong confinement field in sensing applications: Design and analysis

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ABSTRACT

In this article, porous core porous cladding photonic crystal fiber (P-PCF) has been proposed for aqueous analytes sensing applications. Guiding properties of the proposed P-PCF has been numerically investigated by utilizing the full vectorial finite element method (FEM). The relative sensitivity and confinement loss are obtained by varying distinct geometrical parameters like the diameter of air holes, a pitch of the core and cladding region over a wider range of wavelength. The proposed P-PCF is organized with five rings air hole in the cladding and two rings air hole in a core territory which maximizes the relative sensitivity expressively and minimizes confinement loss depressively compare with the prior-PCF structures. After completing all investigations, it is also visualized that the relative sensitivity is increasing with the increment of the wavelength of communication band (O + E + S + C + L + U). Higher sensitivity is gained by using higher band for all applied liquids. Finally the investigating effects of different structural parameters of the proposed P-PCF are optimized which shows the sensitivity of 60.57%, 61.45% and 61.82%; the confinement loss of $8.71 \times 10^{-08}$ dB/m, $1.41 \times 10^{-10}$ dB/m and $6.51 \times 10^{-10}$ dB/m for Water (n = 1.33), Ethanol (n = 1.354) and Benzene (n = 1.366) respectively at 1.33 μm wavelength. The optimized P-PCF with higher sensitivity and lower confinement loss has high impact in the area of the chemical as well as gas sensing purposes.



## 1. Introduction

In recent years, photonic crystal fiber (PCF) reveals a novel era in the optical fiber technology that subdues the diverse restrictions of the conventional optical fiber because of its ability to confine light in the hollow cores with confinement characteristics which offers many opportunities for researchers and pioneers [1]. PCF technology offers better performance for both telecom and nonlinear devices applications [2]. The PCFs are primly divided into two parts based on the guiding properties of light. One is effective index guidance PCF which contains solid core with air holes in cladding and both areas are distributed in randomly or periodically. Air holes at the solid core have a higher effective refractive index than the cladding area in index guiding PCFs [3,4]. The hollow core photonic band gap fiber (PBGF) is another type of PCF, where the light passes through the core region via photonic band gap mechanism [5]. A sophisticated device is used to convert the light rays into electrical signals. It has ability to detect the changes and responses of the ambient conditions which can measure the intensity of electromagnetic waves which is known as optical sensor [6]. According to the unique geometrical structure, photonic crystal fiber exhibits its potentiality for sensing applications.

In chemical and biomedical applications the evanescent wave based PCF sensors are extended swiftly due to imploring features. To compare with conventional fibers, newly designed PCFs exhibit revolutionary achievement in dispersion [1], birefringence [7], guiding of light in air [8], and nonlinear effect enhancement [9–11] in the area of sensing applications. The popularity of PCF sensors are gradually augmented day by day due to its higher sensitivity and smaller size. The carve Fiber Bragg Grating's (FBG) shows nonlinear behavior on the temperature response which is caused by the high Refractive index sensitivity (RIS) in media. The FBG carve is also shown high nonlinear behavior thermo optic coefficients (TOC) such as Water, Ethanol, and other hydrocarbons. A vital role is played by the evanescent field of PCFs in gas sensing with different index materials [12–16], chemical [17] and bio sensing [18] sectors.

In addition, PCF also plays a momentous role in biomedical [19], industrial [20] and environmental [21] sensing applications. The sensing technique of the PCF is interrelated between light and the measured parameters. Sensing can be expressed as the mutual action between passing light and analysts are changed due to distinct intensity, wavelength,

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frequency, phase and polarization state of light etc. [22]. The guiding properties of PCFs change according to the different geometric parameters [23]. Due to obtain better guiding properties various geometric shape lattice structures such as hexagonal [24], octagonal [25], decagonal [26], elliptical core [27], spiral shape [28], hybrid and circular cladding [29] have been already proposed. In modern age, the guided mode of index guiding PCFs has mutual action with the evanescent wave which is also considered as transmission property of optical fiber. Comparing with the prior fiber-optic, PCF enhances performance in chemical sensing contrives like as D-shaped fibers [30] and tapered fibers [31] because those fibers has been introduced with extremely advantages.

Two major propagation characteristics of PCF based chemical sensors are relative sensitivity and confinement loss. A large number of papers has been published which focused on chemical sensing applications due to maximize the relative sensitivity level and minimize confinement loss at a sufficient level. In 2000, Lee and Asher [32] was proposed photonic crystal fiber as a chemical sensor which was used to sense $p^H$ level and Ionic Strength. In the article [33] an Octagonal PCF structure has been proposed where 3-layers cladding was consisted with circular air hole and shows sensitivity 23.05% and confinement loss $5.74 \times 10^{-6}$ dB/m respectively compare to a Hexagonal PCF structure with 3-layers cladding. But in 2016, Ahmed and Morshed [6] proposed a micro structured octagonal PCF as a chemical sensor where five layers cladding consisted with circular air hole and improved the relative sensitivity of 47.35% and at the same time demoted confinement loss of $5.28542 \times 10^{-14}$ dB/m compare to hexagonal and square PCF structure with 5-layerd cladding. Ortigosa-Blanch et al. [7] also proposed strongly an anisotropic photonic crystal fiber and achieved high birefringence by reducing polarization mode. In the article [34], hexagonal PCF has been proposed where three rings elliptical air holes are vertically arranged both core and cladding and exhibits sensitivity of 23.75% and confinement loss of $2.40 \times 10^{-04}$ dB/m with high birefringence. In 2016 Asaduzzaman et al. [29] reported a Hybrid-PCF structure with circular air holes based on three rings cladding and the elliptical air holes based on microstructure core which increased sensitivity 49.17% at the same time decreased confinement loss $2.75 \times 10^{-10}$ dB/m with high birefringence. In 2015 S. Olyaee et al. [10] also proposed a nanostructure index guiding PCF which indicates lower confinement loss, dispersion and nonlinear effect.

In this paper, micro structured [35] porous core porous cladding photonic crystal fiber (P-PCF) including five rings cladding and two rings core have been reported for liquid sensing application which shows high relative sensitivity and low confinement loss comparing with the article [29,34]. All effects on propagation characteristics can be examined applying Water, Ethanol and Benzene as analyst.

## 2. Geometries of proposed P-PCF

Fig. 1 exhibits the cross sectional view of the proposed P-PCF. The entire geometrical structure of the P-PCF is also distinctly delineated in this figure. The proposed PCF structure is porous where both core and cladding are porous shaped. Both the core and cladding vicinity, the vertices of the adjoining 6 air holes of first layer contain 60° angle which is formed in porous. Due to second, third, fourth and fifth layers the vertices of the adjoining air holes contain 30°, 20°, 15° and 12° angle; number of air holes are 12, 18, 24 and 30 respectively. For entire kinds of fibers and operations, pitch (space between the two air holes) in cladding is denoted by Λ. The diameter of air holes in each ring of cladding is denoted by $d_1$. All types of fibers are utilized pure silica as the background material and refractive index is picked out using Sellmeier equation [36]. In the core region, the diameter and pitch of among supplementary air holes are denoted by $d_c$ and $\Lambda_1$ respectively. According to several kinds analytes, in the core region all supplementary air holes are filled with three distinct thermo optic coefficients like Water ($n = 1.33$), Benzene ($n = 1.366$) and Ethanol ($n = 1.354$) where n is expressed as refractive index.

## 3. Synopsis of numerical method

Electromagnetic simulation of the proposed P-PCF has been computed using Finite Element Method (FEM). Maxwell's equations are applied to derive the relative sensitivity and the confinement loss.

Confinement loss is defined by the energy of light which is permeable into the cladding region from the core due to finite number of air holes. The confinement loss can be denoted by $L_c$ which is calculated through the visionary part of the refractive index $n_{eff}$ [37].

$$L_c = \frac{40\pi^* \mathrm{Im}[n_{eff}] \times 10^6}{\lambda^* \ \ln(10)} \ (\mathrm{dB/m}) \tag{1}$$

where, Im [$n_{eff}$] is known as the visionary part of the refractive index and λ is the wavelength of light. The relative sensitivity coefficient (r) can be measured by the interaction between light and the analyst

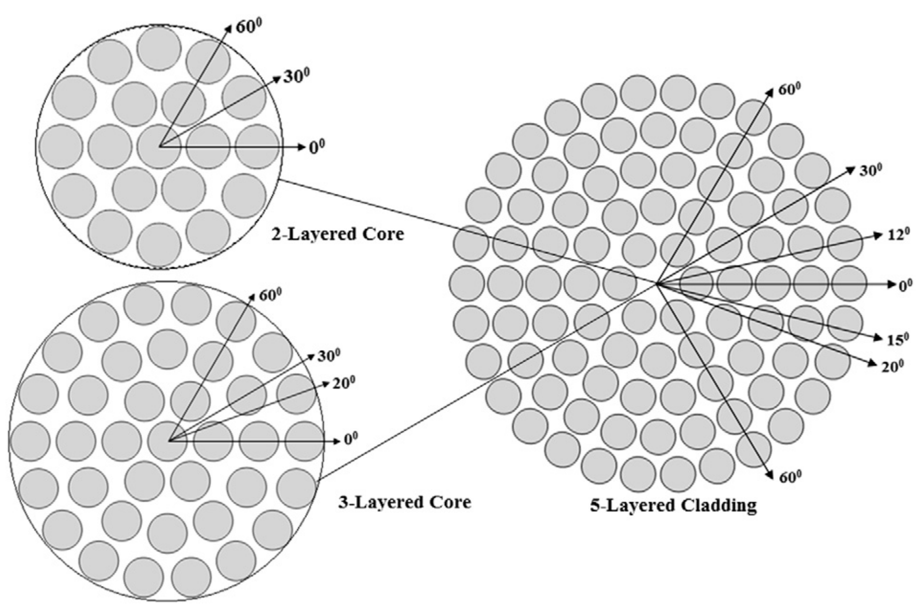


**Fig. 1.** Cross sectional view of the proposed porous cored porous cladding photonic crystal fiber (P-PCF) and enlarged view of its porous core with 2 and 3-layer.