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Detection of Hydrogen Cyanide in Terahertz using Photonic Crystal Fiber

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Abstract

Cyanide is a toxic gas and it is harmful to human beings at low concentration (≥300ppm) under constant atmospheric pressure. In this paper, the Photonic Crystal Fiber (PCF) is used to discern a hydrogen cyanide (HCN) gas at low concentration with high sensitivity of 52.47 and its wavelength is 1.35µm. In this proposed PCF confinement loss (LC) is 0 dB/m, when the wavelength reaches 20µm the confinement loss is increased to 0.57 dB/m. The PCF arranged in a hexagonal structure of cladding and core arranged with a combination of different structure. It provides better sensitivity and low confinement loss. Our results provide detection of hydrogen cyanide gas in air pollution monitoring using terahertz spectrum.

Keywords: *HCN(Hydrogen cyanide), L_c(Confinement loss), Relative sensitivity, Effective area, HCN gas sensor , PCF*

I. INTRODUCTION

Cyanide (CN) is a fast acting, deadly chemical [1] and it is released from natural substances, it is combined with natural gas like hydrogen to form HCN, it is very less dense than air. HCN is very harmful for human beings to affect the heart and brain than other organs [2] [3]. It is mainly used as reagents in different industries such as mining, electroplating [4], plastics and steel manufacturing [5]. Many CN detection modes such as chromatography, calorimetric and electrometric [6] [7] techniques are developed, but these have some disadvantages like complex methodology and long-time analysis [8].

Terahertz (THz) spectroscopy is a rapidly emerging field with many applications in medical imaging [9], security monitoring [10], communication [11] and engineering, gas detection. This wave falls in between microwave and infrared region [12] is in the range of 0.1-10 THz (30µm-3mm) [13]. In THz, it has high absorption power so it does not use in traditional waveguides [14], but in traditional waveguide it has low power. A commercial available COMSOL Multi-physics 5.4 software is used to design the proposed method.

To design the PCF, the relative sensitivity, confinement, loss and effective area [15] are the most important factors are taken into account. The confinement, loss of a PCF is reduced, the sensitivity of a fiber increase. Bei Zhu et al. Proposed a PCF with low sensitivity of 26.12 %. Imran Hasan et al. Reported a PCF with sensitivity of

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27.58% [16]. Kawsar Ahmed et al. Proposed PCF shows sensitivity of 43.7% [17]. Moutusi De etal. Proposed a PCF with a sensible 49.42% [18].

In recent years, the discerning and reporting of nerve gases is very beneficial in an air pollution monitoring area, particularly HCN because it is combined with hydrogen gas to form harmful substance and this phenomenon leads to demise at low concentration at 300ppm in a few minutes [19]. Gas sensing is identified in two ways in THz region I). Based on physical properties II). Based on spectral characteristics of the gas. Thus the detection of gas is significant with high sensitivity and low confinement loss. It is a best approach to find HCN gas.

II. PROPOSED STRUCTURE

The addition of higher porosity reduces the confinement loss. So hollow core is introduced in the proposed method to study for detecting performance. Fig. 1 illustrates the proposed PCF structure. The air holes are composed of hexagonal structure in cladding, Fig 1.1 illustrates the combination of different structure are arranged in the core region. Porosity will decide the size of the holes at the core. The separation of adjacent air holes in the cladding is called Pitch (Λ=2.3µm)

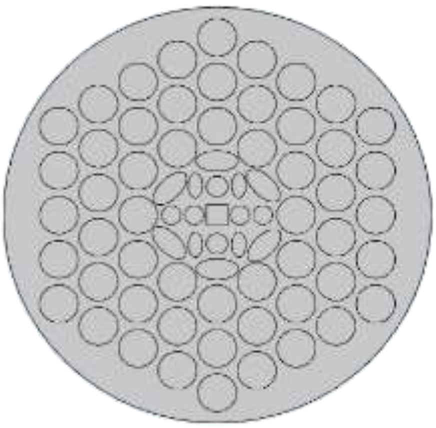


Fig.1 Proposed PCF structure

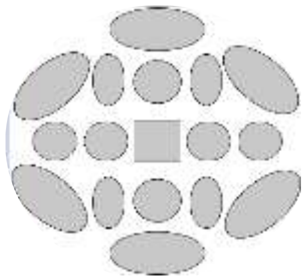


Fig 1.1 core structure

The diameter of the cladding is 1.95µm (d_o =1.95µm) and the core consists of ellipse, circular holes and square. The diameter of air holes in core is 1.066µm (d_{in} =1.066µm), the elliptical points are 0.533µm and 1.067µm but the only thing is to form the different elliptical structure is to rotate their angle.

Among different polymers such as PMMA, Teflon, Zeonex can use as materials for PCF but it has a high absorption loss in THz region. The refractive index of PML is Silica aerogel its index value is 1.26 in THz frequency and also have a low absorption loss. Therefore, Silica aerogel is used as the background material for proposed PCF. It is a lower refractive index of solid and efficient to absorbing the light.

Fig. 2 illustrates the mesh cells. In our proposed method the mesh cells are set to 288 in x and y directions.

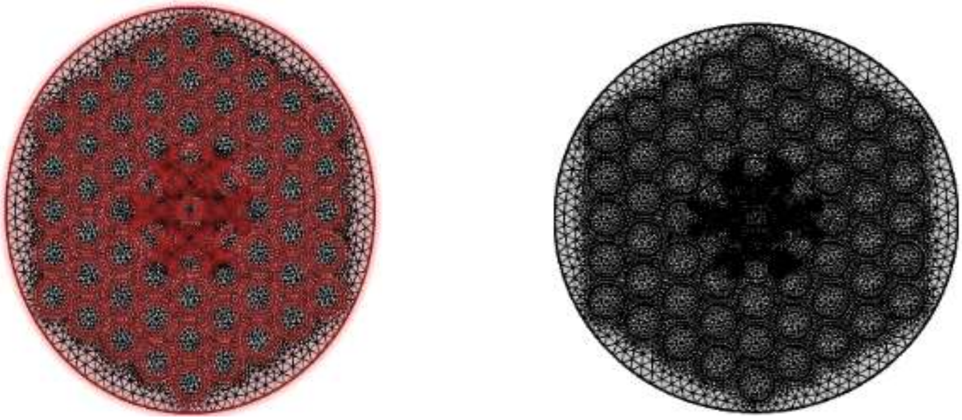
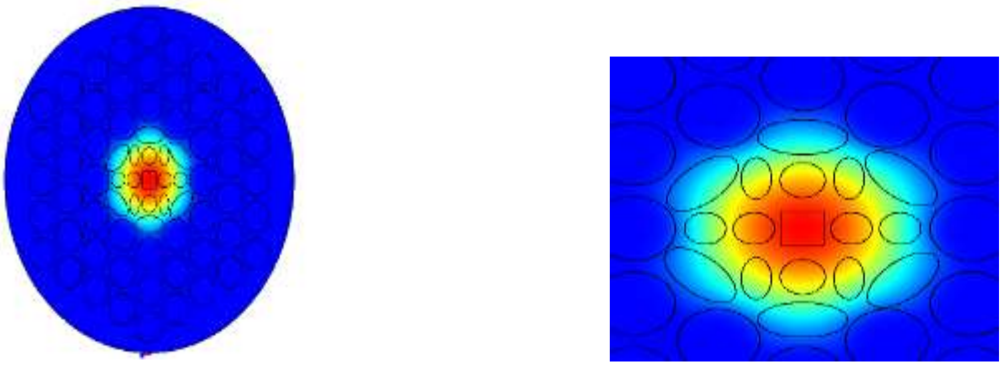


Fig. 2 Mesh cells

When the core region is fully filled with nerve gas i.e HCN at various levels and the loss is reduced by varying the background material of PCF. The refractive index of HCN is 1.2675 and its minimum transmittance is1239.9GHz.



(a) (b)

Fig. 3 Light propagate through the core

Fig. 3 (a) and (b) represents light confined in the center of the core, it gives high sensitivity

The highlight of the proposed work on the relative sensitivity of THz frequency and confinement, loss of PCF, it is used to detect the HCN gas in air pollution monitoring.

III. NUMERICAL ANALYSIS

The Finite Element method (FEM) is an accurate and efficient tool for analysis Maxwell's equation. Light propagates through core region and interact with HCN.

Equation (1) is relative sensitivity c o-efficient R is defined as the ratio of refractive index of gas to effective mode index with power factor (f)

$$R = \frac{\eta_r}{\eta_{eff}} * f \tag{1}$$

Where, R is relative sensitivity, η_r is the refractive index of gas, η_{eff} effective mode index.

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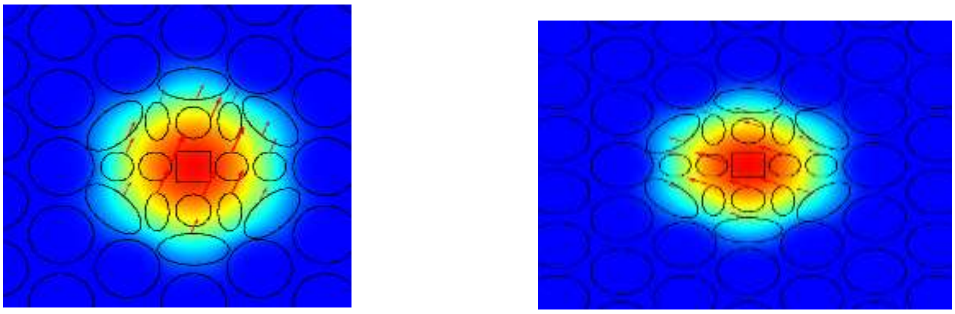
Confinement loss (L_c) is defined as when the light propagating inside core and some part of the light confined to the cladding region [20] [21]

$$L_c = 8.686\kappa_0 I_m(\eta_{eff}) \quad (2)$$

Where L_c is confinement, loss, I'm (η_{eff}) is the imaginary part of the effective refractive index.

$$\kappa_0 = \frac{2\pi}{\lambda} \quad (3)$$

Where λ is wavelength, κ_0 is free space number.



(a) (b)

Fig. 4 Polarized directions of (a) and (b)

Fig. 4 (a) illustrates the light propagation propagates in y-direction and 4 (b) illustrates the light propagates in x-direction. Light confined at core in a different polarized direction, such as x and y directions. If light confined outside the core is called L_c when the wavelength reaches 20μm the loss is 0.57dB-km^{-1}.

IV. SIMULATION RESULTS

The detection and analysis of PCF are described by HCN gas at certain concentration into the air holes in the core, it finds the sensitivity, value and calculate confinement, loss.

Table 1 illustrates the wavelength with relative sensitivity, effective area and effective mode index

λ (μm)	sensitivity (%)	Effective area (ms)	Effective mode index
0.9	52.24	9.71e-12	1.2636
0.95	52.27	9.78e-12	1.2632
1.0	52.29	9.85e-12	1.2628
1.05	52.32	9.91e-12	1.2623
1.10	52.35	9.98e-12	1.2618
1.15	52.37	10.05e-12	1.2613
1.20	52.38	10.12e-12	1.2598

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1.25	52.42	10.19e-12	1.2603
1.30	52.44	10.26e-12	1.2598
1.35	52.47	10.33e-12	1.2592

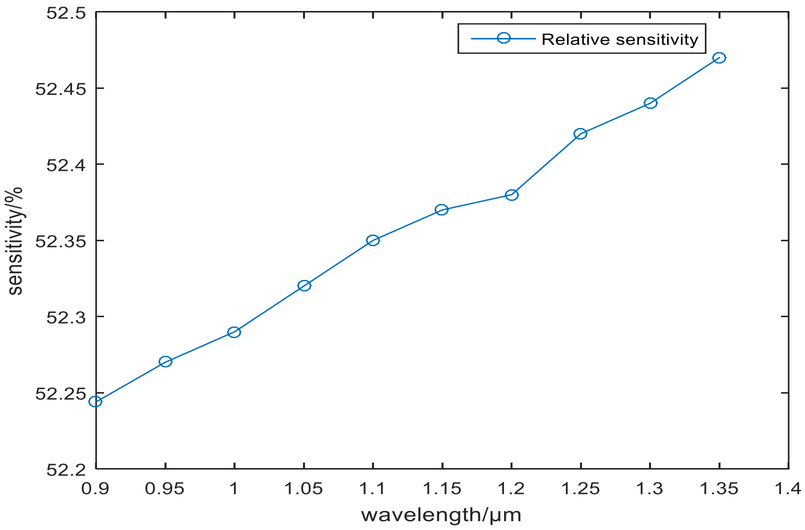

Fig. 6 wavelength vs Relative sensitivity

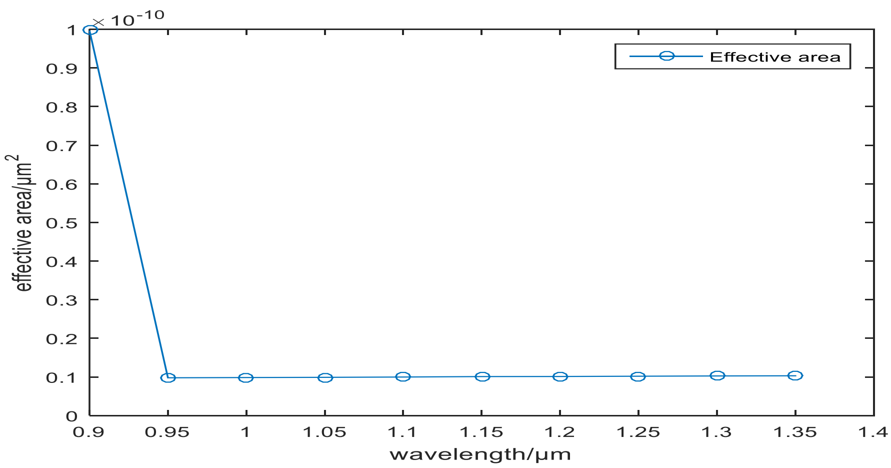

Fig.7 wavelength vs Effective area

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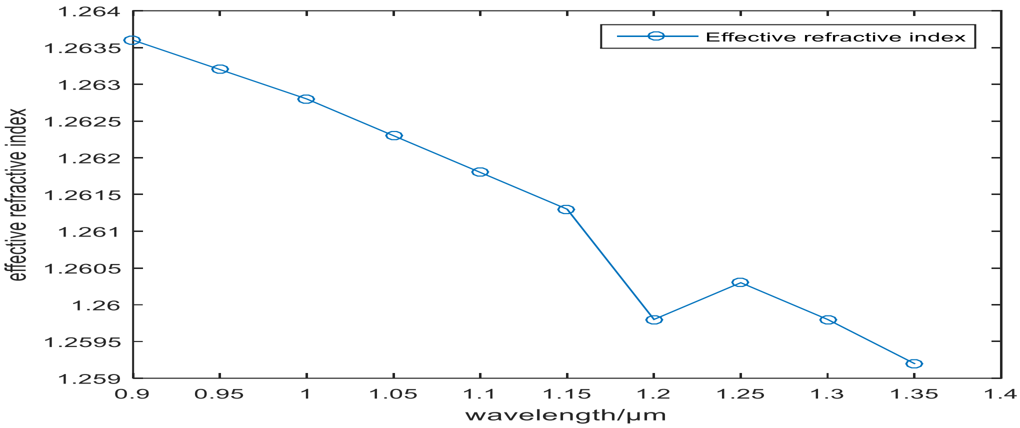

Fig.8 wavelength vs effective refractive index

Fig. 6,7,8 show the proposed outcome of sensitivity, area and effective mode index of a PCF with respect to different wavelengths. The main factor of PCF is confinement loss, if confinement loss is reduced the light confined of a fiber is high and reduces the propagation loss

Table. 2 demonstrates the confinement loss of PCF

Wavelength (μm)	**Confinement loss (x dB-km^{-1})**
0.9	0
1.0	0
2	0
5	0
10	0
15	0
20	0.57
30	4.2

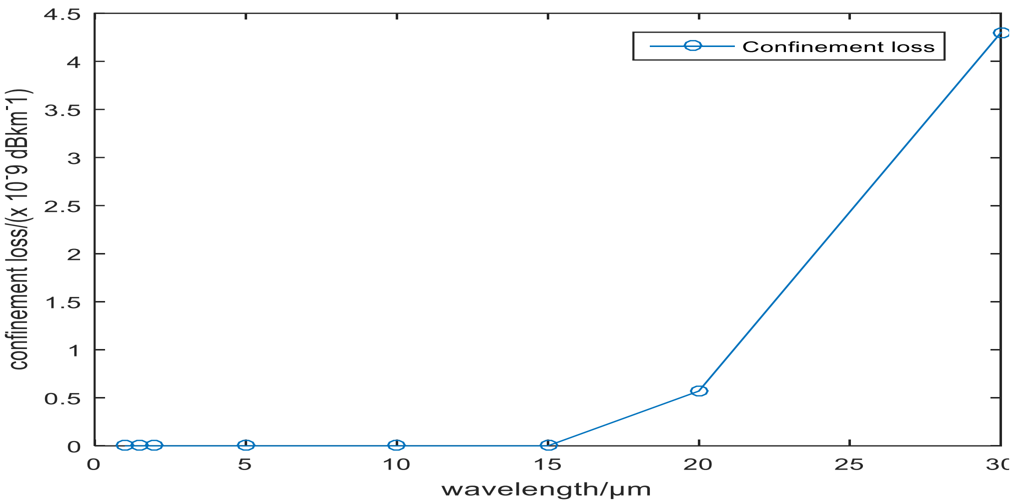

Fig. 9 confinement loss of proposed PCF vs wavelength

V. CONCLUSION

Thus the analysis of PCF, a new model is proposed for the discerning of HCN at low values. It is used as a sensor to analysis HCN gas at constant pressure. Thus the detection of HCN has relative sensitivity of 52.47% and L_c is 0 dB-km^{-1}when it reaches 20μm only the confinement loss is slightly increased to 0.57 dB-km^{-1}.It is more advantageous in traditional optical fiber.

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