

Designing a Helically Twisted Photonic Crystal Fiber for Gas Sensing in the Terahertz Region

Hassan Pakarzadeh¹, Hana Saberi¹, Jamileh Hajivandi² and Mohsen Keshavarzi³,

¹ Department of Physics, Shiraz University of Technology, Shiraz, Iran

² Nanophotonics Research Laboratory, Department of Electrical and Electronics Engineering, TOBB University of Economics and Technology, Ankara 06560, Turkey

³ Faculty of Physics, Shahid Bahonar University of Kerman, Kerman, Iran

Corresponding Author's e-mail address: pakarzadeh@sutech.ac.ir

Summary:

A simple and practical structure of helically twisted photonic crystal fiber (PCF) with Topas material is designed for the first time. The core of the fiber is air which is the most transparent material for transmitting terahertz (THz) waves while its cladding is proposed with a single ring of air holes. A complete twist along the 50cm fiber shows five low loss transmission bands in the ranges of 0.44-0.62, 0.87-1.42, 1.4-2.04, 1.98-2.48 and 2.7-3.0 THz. The proposed helically twisted PCF sensor with maximum sensitivity of 3125 GHz/RIU is shown to have great applications for gas sensing in the THz region.

Keywords: helically twisted fiber, terahertz, photonic crystal, sensor.

Background, Motivation an Objective

Terahertz (THz) frequency range in the electromagnetic spectrum is mostly known as 0.1-10 THz. In this paper, a simple and practical structure of a twisted photonic crystal fiber (PCF) sensor made of Topas as a polymer material is proposed. The fiber core is air which is the most transparent material for propagating terahertz waves, and the cladding of fiber is proposed to be an air-hole ring in the background material of Topas with perfect circular symmetry [1]. The purpose of designing this twisted PCF sensor is to propose a simple yet efficient structure in the THz range [2]. We designed and simulated the desired sensor with a complete twist over 50cm of fiber length provided five low loss transmission bands in the ranges of 0.44-0.62, 0.87-1.42, 1.4-2.04, 1.98-2.48 and 2.7-3.0 THz for five gases with refractive index (RI) including $n = 1$, $n = 1.02$, $n = 1.04$, $n = 1.06$ and $n = 1.08$. Near-flat dispersion across the five transmission bands and the sensitivity of 3125 GHz/RIU over 1.88-2.33 THz are unique features of the proposed THz PCF sensor, which may play a key role for gas detection in the terahertz region.

Description of the New Method or System

The proposed twisted PCF for mode propagation in the THz range is shown in Fig. 1. The idea is to place the rings of the air cavity array on concentric circles. so that the position of

each air cavity is obtained according to the following relationship:

$$\begin{aligned} x &= \Lambda N \cos\left(\frac{2N\pi}{6n}\right), \\ y &= \Lambda N \sin\left(\frac{2N\pi}{6n}\right), \\ n &= 1 \sim 6 \end{aligned} \quad (1)$$

where Λ and N represent the hole-to-hole distance (pitch) and the number of rings of the air hole array, respectively, and n is an integer from 1 to $6N$. The thickness and internal diameter of each cell of the structure are equal to t and d , respectively [3].

Fig. 1(a) has only one ring of the air hole array with $N = 2$, where the inner rings associated with $N = 0$ and $N = 1$ have been removed. In this design, the values of Λ , t , and d are determined as 2.2, 0.2, and 2 mm, respectively; in which the diameter of the central core of the air is approximately 6.4 mm. Topas is used as the polymer material and the refractive index of air is considered to be 1 [4].

With different simulations, the results show that twisting the PCF (along the z -axis) can offer a more uniform core as well as a more suitable substrate for propagating symmetric modes. Therefore, as shown in Fig. 1(b), the proposed structure has a complete helical twist over 50 cm which is an optimized value in our simulation. Finite-difference time-domain (FDTD) technique has been used to obtain the mode characteristics [3].

Results and Discussion

As it can be seen in Fig. 2, the proposed fiber has the fundamental mode well confined in the core.

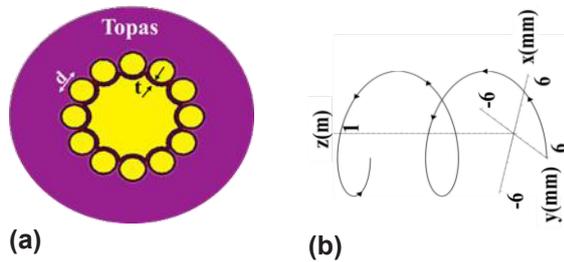


Fig. 1. The cross-section of the proposed twisted PCF; t shows the thickness of the polymer material between the core area and the air holes in the cladding and d shows the diameter of the air holes in the cladding. b) two full twists along 100cm fiber.

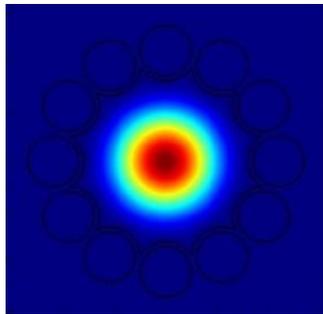


Fig. 2. The intensity profile of the fundamental mode confined in the core of the proposed twisted PCF.

Fig. 3. shows the loss spectrum of the helically twisted PCF when the holes are filled with air exhibiting five low-loss frequency bands from 0.44 to 3.0 THz.

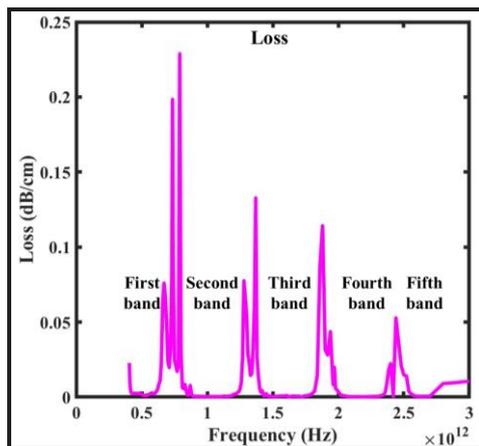


Fig. 3. Loss spectrum of the designed helically twisted PCF with five low-loss frequency bands.

Fig. 4. shows the sensitivity curves of the proposed sensor for five gases with RI of $n = 1.0$, $n = 1.02$, $n = 1.04$, $n = 1.06$ and $n = 1.08$ obtained using $S_f = \Delta f / \Delta n$ [5]. We have given the sensitivity values in Table 1.

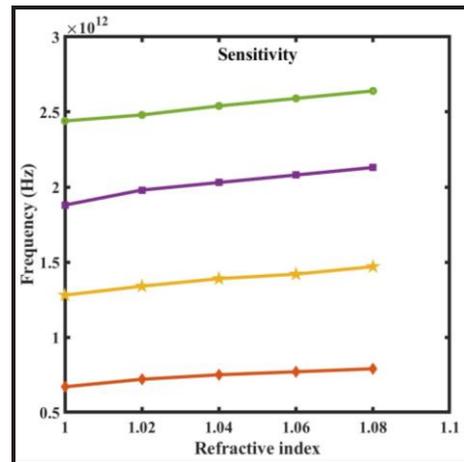


Fig. 4. Sensitivity curves calculated around four main peaks associated with Fig. 3.

Tab. 1: Sensitivities calculated around four frequency peaks.

Peak frequency range (THz)	Sensitivity (GHz/RIU)
0.67 – 0.79	1500
1.28 – 1.47	2375
1.88 – 2.13	3125
2.44 – 2.64	2500

References

- [1] G. Gallot, S. Jamison, R. McGowan, and D. Grischkowsky, "Terahertz waveguides," *JOSA B*, (vol). **17**, pp. 851-863, (2000).
- [2] Y.-H. Chen *et al.*, "Design fiber-to-waveguide coupling for photonic integrated circuits," in *Optical Interconnects XXIII*, (vol). **12427**: SPIE, pp. 71-74, (2023).
- [3] V. Sharif and H. Pakarzadeh, "Terahertz hollow-core optical fibers for efficient transmission of orbital angular momentum modes," *Journal of Lightwave Technology*, (vol). **39**, pp. 4462-4468, (2021).
- [4] B. Ung, A. Mazhorova, A. Dupuis, M. Rozé, and M. Skorobogatiy, "Polymer microstructured optical fibers for terahertz wave guiding," *Optics Express*, (vol). **19**, pp. B848-B861, (2011).
- [5] J. Sultana *et al.*, "Hollow core inhibited coupled antiresonant terahertz fiber: A numerical and experimental study," *IEEE Transactions on Terahertz Science and Technology*, (vol). **11**, pp. 245-260, (2020).