Design of Polarization Maintaining Fiber Based on Polyethylene Terephthalat Polymer for Sensing Application

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***Abstract*— This study investigates a highly birefringent polymer photonic crystal fiber (PCF) designed for polarization-maintaining applications. The PCF features a triangular arrangement of circular air holes embedded in Polyethylene Terephthalate (PET), with a defected core structure to enhance birefringence. The fiber's optical properties are analyzed using a full-vector finite element method (FEM), incorporating a perfectly matched layer (PML) as the boundary condition. After optimization, the design achieves a notably high birefringence of 4.94×10^{-2} at a wavelength of 1550 nm. Additionally, it demonstrates a low confinement loss of approximately 10^{-7} dB/km and a negative chromatic dispersion of −448 ps/(nm·km) along the y-polarization. Owing to its excellent polarization-maintaining characteristics, the proposed PCF design shows strong potential for optical sensor applications and could also benefit dispersion-compensating devices in high bit-rate transmission networks.**

Keywords: Polarization Maintaining Fiber (PMF), Photonic Crystal Fiber (PCF), Polyethylene Terephthalate (PET), sensing applications.

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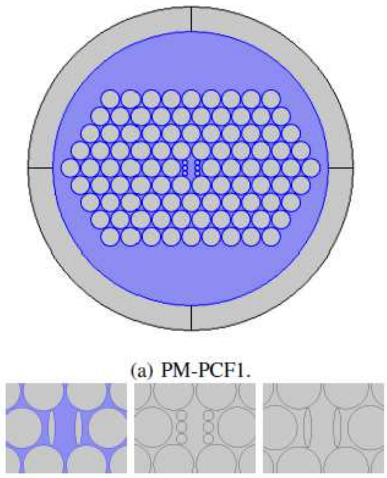
I. Introduction

The evolution of optical fibers from telecommunications to sensing applications has been pivotal, particularly with the emergence of photonic crystal fibers (PCFs). These fibers boast high birefringence and low confinement loss, making them ideal for chemical and biological sensing. Their inherent polarization maintaining (PM) properties enable precise control over light polarization, enhancing sensitivity and selectivity in detection. Polymer fibers, in particular, offer advantages over silica fibers due to their flexibility and biocompatibility, allowing for easier fabrication and interaction with biological samples [1]. In this study, a high birefringent PM-PCF based on PET polymer with low confinement loss is modeled for sensing purpose. The high birefringence of the proposed fiber enhances its sensitivity, while the polymer material ensures biocompatibility, rendering it suitable for sensing applications.

II. DESIGN AND SIMULATION RESULTS

The core region of optical fibers plays a significant role in birefringence. To achieve high birefringence, we have undertaken the modeling of a microstructured fiber by modifying the core region as shown in Figure 1. The initial PM-PCF design consist of hexagonal circular air holes of refractive index $n_{air}=1$ assembled with silica with a refractive index of nsilica = 1.45, as depicted in Figure 1a. The light is guided by total internal reflection mechanism into a silica core. Additionally, three small circular air holes are added vertically on the left and right sides along the x-axis of the core area to introduce asymmetry into the structure, impacting the propagation mode. This results in a faster variation along the x-axis, amplifying the difference between the effective refractive indices of the two orthogonal polarization modes, which gives rise to birefringence. Subsequently, for optimization purposes, we replace the three holes with an ellipse on each side, as illustrated in figure 1b.



(a) PM-PCF1.

(b) PM-PCF2. (c) PM-PCF3. (d) PM-PCF4.

Fig. 1: A cross-section of the different proposed PM-PCFs surrounded by PML as boundary condition with (a) PM-PCF1 circular air holes area and Silica background; (b) PM-PCF2 elliptical air holes area and Silica background; (c) PM-PCF3 circular air holes area and PET background; (d) PM-PCF4 elliptical air holes area and PET background.

Replacing the traditional silica core in optical fibers with polymers, specifically polyethylene terephthalate (PET), introduces several competitive advantages compared to conventional silica fibers. We have utilized PET instead of silica in PM-PCF3 and PM-PCF4, as depicted in Figure 1c and Figure 1d, to enhance biocompatibility and reduce costs. The proposed photonic crystal fibers (PCFs) exhibit specific geometrical parameters crucial for their optical functionality. In the cladding region, air holes are characterized by a diameter (d_1) of 1.5µm, arranged with a pitch of 1.6µm between adjacent holes. In the core region of PM-PCF1 and PM-PCF3, six small circles are organized with a diameter (d_2) of 0.4µm. To gain a better

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understanding of the performance characteristics of our proposed design, we performed FEM simulations. These simulations were specifically aimed at analyzing the modal profiles and modal effective indices of the two orthogonal polarization modes. Initially, we calculated the modal indices of the four designed PM-PCFs over a spectral range extending from 1000 nm to 1700 nm.

According to the simulations, the PET core with elliptical air holes exhibits superior confinement of the fundamental electric field for both x- and y-polarized modes, as depicted in Figure 2.

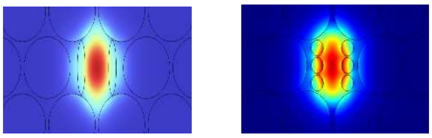

Fig. 2: Electric field distribution of x- and y –polarized modes of the *proposed PET fibers*.

Along the x-axis, the spacing (dx) between these circles measures 1.33μm, while along the y-axis, the spacing (dy) is 0.25μm. To increase the birefringence of the proposed fibers, we substitute the three holes in PM-PCF1 with ellipses on each side within PMF-PCF2 and PM-PCF4, as depicted in Figure 1b and Figure 1d. The major axis (Ax) of the elliptical air hole is fixed at 1 μm, while the semi-minor axis (Ay) is given by Ax/2.3.

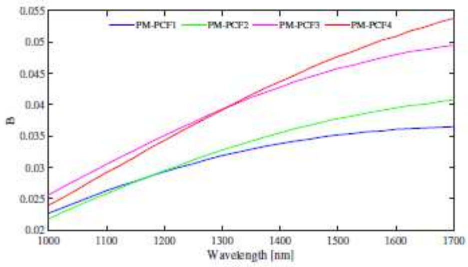

Fig. 3: Modal birefringence variation of the different proposed PM-PCFs as a function of wavelength.

The wavelength dependent modal birefringence of the different PM-PCF structures is presented in Figure3, demonstrating a visible increase with wavelength. This elevated birefringence is attributed to the asymmetry in the core area, which amplifies the difference between the effective refractive indices of the two polarization modes, consequently leading to an increase in modal birefringence. From the Figure 3, it is evident that the elliptical holes result in a higher degree of birefringence compared to the circular holes. In addition, birefringence is also impacted by the background material, and we can observe that PET yields higher birefringence than silica. Specifically, a high birefringence value of 4.94×10^{-2} is observed at 1550nm, while the highest value recorded is 5.38×10^{-2} at 1700nm in PM-PCF4.

Reducing confinement loss in photonic crystal fibers is crucial for improving their performance in various applications, which is why the number of rings has been carefully chosen to minimize it. The confinement losses of the proposed PM-PCFs for both x- and y-polarized modes are displayed in Figure 4 and 5, respectively. From the plot, we note that the confinement loss for the PM-PCF4 remains at the order of 10^{-7}dB/Km across the entire studied wavelength range. However, beyond 1550nm, an increase in confinement loss is observed in the first three structures.

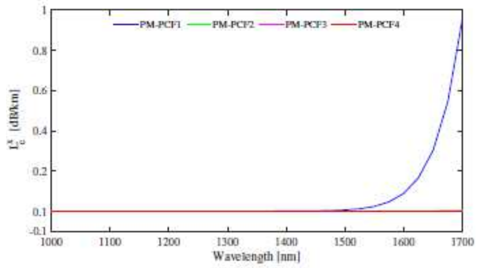

Fig. 4: Confinement loss of the proposed PM-PCFs for the x-polarized mode as a function of wavelength

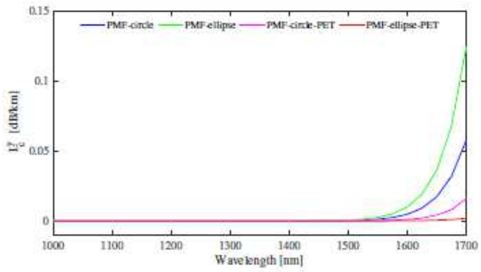

Fig. 5 : Confinement loss of the proposed PM-PCFs for the y-polarized mode as a function of wavelength.

TABLE I: Comparison of Characteristics of Optimized Fibers with those of Previous Works at 1550nm.

Ref	Birefringence, B	Confinement loss, L_c (dB/km)
Ref [2]	3.71×10^{-2}	10^{-7}
Ref [3]	4.51×10^{-2}	10^{-7}
Our work	4.94×10^{-2}	10^{-7}

III. CONCLUSION

A triangular high-birefringence Polyethylene Terephthalate (PET) photonic crystal fiber (PCF) for sensing applications is presented. The various characteristics of the proposed fiber are thoroughly investigated using FEM simulations. The results indicate that the design exhibits a high birefringence of 4.94×10^{-2}, a negative chromatic dispersion of -448 ps/(nm.km) for y-polarization, and a short beat length of 31 μm at a wavelength of 1.55 μm. Furthermore, the fiber demonstrates a low confinement loss of 10^{-7} dB/km. Overall, the proposed PM-PCF design based on PET shows promising characteristics, making it a suitable candidate for optical fiber sensor applications

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