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# Design of hybrid photonic crystal fiber: Polarization and dispersion properties

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**Abstract**

A highly birefringent dispersion compensating hybrid photonic crystal fiber is presented. This fiber successfully compensates the chromatic dispersion of standard single mode fiber over E- to L-communication bands. Simulation results reveal that it is possible to obtain a large negative dispersion coefficient of about $-1054.4$ ps/(nm km) and a relative dispersion slope of 0.0036 nm$^{-1}$ at the 1550 nm wavelength. The proposed fiber simultaneously provides a high birefringence of order $3.45 \times 10^{-2}$ at the 1550 nm. Moreover, it is confirmed that the designed fiber successfully operates as a single mode in the entire band of interest. For practical conditions, the sensitivity of the fibers dispersion properties to a $\pm 2\%$ variation around the optimum values is carefully studied and the nonlinearity of the proposed fiber is also reported and discussed. Such fibers are essential for high speed transmission system as a dispersion compensator, sensing applications, fiber loop mirrors as well as maintaining single polarization, and many nonlinear applications such as four-wave mixing, etc.


*Keywords:* Fiber nonlinearity; Finite element method; Polarization maintaining fiber; Photonic crystal fiber

## 1. Introduction

Photonic crystal fiber (PCF) [1] has a microscopic array of air channels running down the fiber length that offer design flexibility in tuning many useful properties such as chromatic dispersion, nonlinearity, birefringent. In optical fiber communication systems, chromatic dispersion in single-mode fibers (SMFs) induces temporal optical pulse broadening, resulting in serious restrictions in the transmission data rates. Although wavelength division multiplexing (WDM) technique having higher bit-rate transmissions of more than 40 Gbps have widely been adopted to handle increasing data capacity, but the transmission impairment caused by dispersion in a SMF is severe for such high-bit-rate transmissions. This has made dispersion compensation techniques essential because dispersion compensating fiber (DCF) are extensively used to compensate the chromatic dispersion and improves the transmission length without the need for using electronic regeneration of signals [2]. To minimize the insertion loss and for reduced cost, DCFs should be as short as possible and the magnitude of negative dispersion should be as large as possible [3].

The idea of using PCF for dispersion compensation (DC) was first proposed by Birks et al. [4]. However, the

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design suffers from its low compensation bandwidth. A similar approach was used whereby the designed PCF was optimized for broadband DC with a dispersion coefficient of approximately −475 ps/(nm km) [5]. Again, the idea of using dual-core conventional fiber for dispersion compensation was introduced in [6,7].

Highly birefringence photonic crystal fibers (HB-PCFs) on the other hand are suitable for various novel applications including high-bit-rate communication systems, gyroscopes, sensing, and in fiber lasers with single polarization output [8]. For such PCFs, high birefringence with high negative dispersion coefficient is crucial. Again, highly birefringent fibers are extensively used in fiber loop mirrors as a major component for optical fiber sensing applications; the added property of high negative dispersion would provide better performance for the fiber sensor design and also in long distance data transmission system [9]. So far, several HB-PCFs have been demonstrated to achieve high birefringence based on the large index contrast of the silica and the air by introducing an asymmetric solid fiber core surrounded by air holes, using a fiber core with double defect or triple defect of the photonic crystal structure [10–12].

In addition to nonlinearities, improvement of highly birefringent fibers remains one of the most promising applications of photonic crystal fibers. Besides, HB-PCFs with nonlinear properties have received momentous attention in telecommunication and supercontinuum generation (SCG) applications [13]. Lee et al. [14] has demonstrated a birefringent PCF having nonlinear coefficient of 31 $W^{-1}\,km^{-1}$ for the use of optical code division multiple access (OCDMA) applications.

With this context, in this paper, we propose and demonstrate a simple hybrid PCF structure that exhibits ultra high birefringence of the order $3.45 \times 10^{-2}$, nonlinearity of about 39 $W^{-1}\,km^{-1}$ at 1550 nm. Simulation result shows that dispersion coefficient varies about −356 to −1189 ps/(nm km) for wavelength ranging from 1350 to 1630 nm covering more than E + S + C + L-bands. In addition, the main advantages of our proposed structure is the design simplicity along with simultaneously wideband high birefringence, large nonlinearity, and high negative dispersion which are very crucial in 40 Gbps WDM transmission network, nonlinear optics and polarization maintaining applications.

## 2. Design guidelines of the proposed PCF

Fig. 1 shows the transverse cross section of the proposed PCF which contains five air-hole rings. The artificial defect hybrid photonic crystal fiber (AD-HyPCF) can be designed simply by introducing defects into the core by omitting two air holes from first ring of the fiber. To induce extra birefringence, we choose hybrid structure. The main advantage of making artificial defect with hybrid cladding is the increasing asymmetry in core region. This will produce high birefringence of the PCF. The propose PCF is hybrid in the sense that first two air-hole rings are arranged in hexagonal pattern and others are given a circular shape with optimized air-hole diameters $d$, $d_1$ and pitch $\Lambda$.

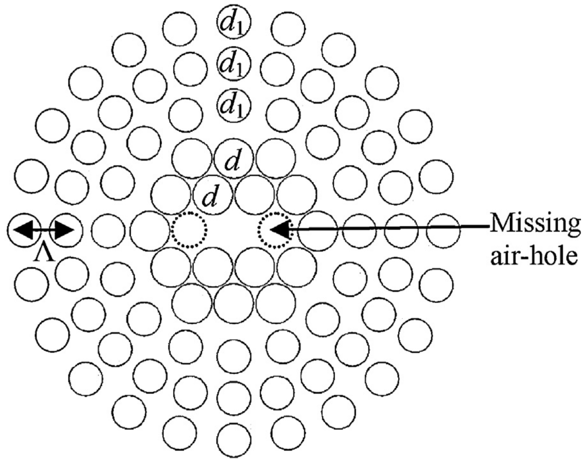


Fig. 1. Transverse cross section of the designed AD-HyPCF showing pitch $\Lambda$, air-hole channels with diameter $d$ and $d_1$. The dotted circle on the first ring represents the missing air-hole.

The cladding material of the AD-HyPCF is pure silica with circular air-holes. The total number of air-holes for rings 1, 2, 3, 4, and 5 are 4, 12, 16, 24, and 24 respectively. The air-holes on the 3rd, 4th, and 5th rings are rotated at an angle 22.5°, 15°, and 15° respectively. There are three regulating parameters namely pitch $\Lambda$, $d$ and $d_1$ to achieve high negative dispersion with slope match, high nonlinear coefficient, and high birefringence in particular frequency regimes.

## 3. Numerical method

The finite element method (FEM) with perfectly matched layer boundary condition is used to investigate the guiding properties of the PCF. Commercial full-vector finite-element software (COMSOL) with first-order triangular vector edge elements was used to calculate the modal properties of the proposed fiber. The Sellmeier equation was used to evaluate the silica refractive index. The wavelength-dependent refractive index of the silica was included in the simulation from