Jyoti Int. Journal of Engineering Research and Applications www.ijera.com
ISSN : 2248-9622, Vol. 4, Issue 6(Version 5), June 2014, pp.22-27

RESEARCH ARTICLE OPEN ACCESS

Ultrahigh Birefringent Photonic Crystal Fiber with Ultralow Confinement Loss

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ABSTRACT
A photonic crystal fiber (PCF) with circular air holes in the fiber cladding and elliptical air holes in the fiber core is proposed. According to calculation, both ultrahigh birefringence (larger than 0.01) and ultralow confinement loss (less than 0.001dB/km) can be achieved simultaneously over a large wavelength range for a PCF with only four rings of circular air holes in the fiber cladding. The confinement loss in this PCF can be effectively reduced while the birefringence almost remains the same. The proposed design of the PCF is a solution to the tradeoff between the birefringence and the confinement loss for the originally reported highly birefringent elliptical-hole PCF. Moreover, an approach to modify the effective index of fiber core is also suggested in this letter.
Index Terms—Birefringence, confinement loss, elliptical hole, photonic crystal fiber (PCF).

I. INTRODUCTION

PHOTONIC-CRYSTAL fibers (PCFs)—fibers with a periodic transverse microstructure have been in practical existence as low loss waveguides since early 1996 . The initial demonstration took four years of technological development, and since then, the fabrication techniques have become more and more sophisticated. It is now possible to manufacture the microstructure in air-glass PCF to accuracies of 10 nm on the scale of 1 μm, which allows remarkable control of key optical properties such as dispersion, birefringence, nonlinearity, and the position and width of the PBGs in the periodic "photonic-crystal" cladding. PCF has, in this way, extended the range of possibilities in optical fibers, both by improving well established properties and introducing new features such as low loss guidance in a hollow core. Based on the design flexibility and the large index contrast, high birefringence can be easily realized in PCFs. So far, several designs of highly birefringent PCFs have been reported. The birefringence of the PCF can be improved by employing elliptical air holes in the fiber cladding. For the PCFs of this category, when the bulk of the mode energy is in the fiber cladding; thus the high birefringence is often accompanied with poor energy confinement. In this letter, an ultrahigh birefringent PCF with ultralow confinement loss is proposed by employing elliptical air holes in the fiber core (to induce the birefringence) but circular air holes in the fiber cladding (to reduce the confinement loss). We will show that such a design is able to offer a perfect solution to the tradeoff between the high birefringence and the confinement loss in elliptical-hole PCFs.

II. ELLIPTICAL-HOLE-INDUCED BIREFRINGENCE

To understand the birefringence induced by elliptical air holes in the fiber, the effective indexes of the two-dimensional (2-D) elliptical-hole photonic crystal (PhC) material should be studied carefully. The 2-D PhC we consider here consists of a hexagonal lattice of elliptical air holes (uniform along the axis of the air hole) in fused silica, as illustrated in the inset of Fig. 1. The major and minor axis of the elliptical air holes are $d1=0.6\Lambda$ and $d2=0.2\Lambda$ respectively, where Λ is the air hole pitch (center-to-center distance between the air holes), and the refractive index of the fused silica is set to be 1.45. A plane-wave expansion method is used to calculate

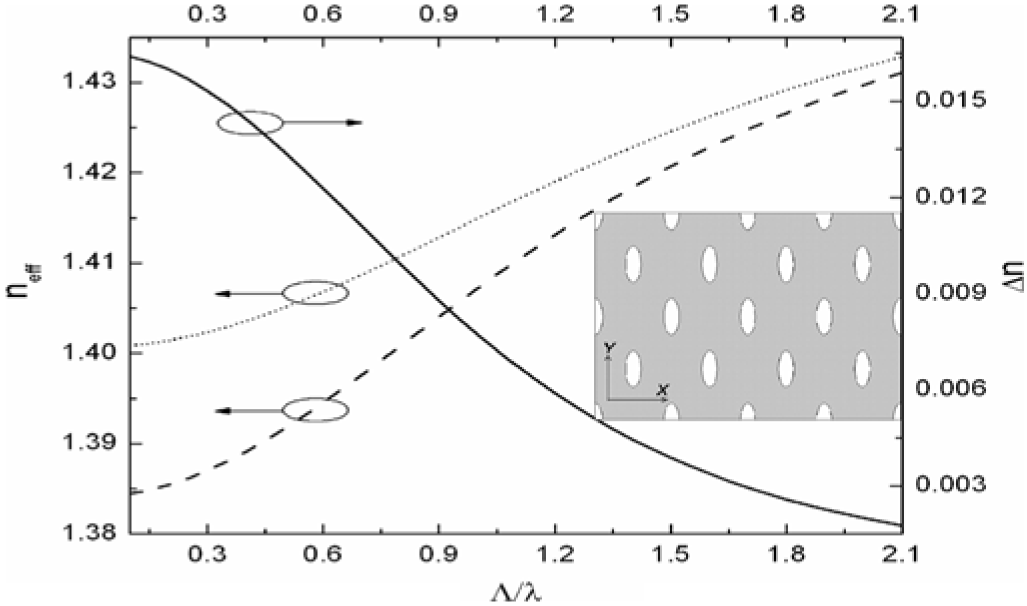

Fig1. Effective indexes of the 2-D PhC for the y-polarized (short dotted line) and x-polarized (dashed line) light waves propagating in the z-direction. The solid line represents the difference between the effective indexes for the differently polarized waves. The inset shows the cross section of the array of elliptical air holes in fused silica.

the effective indexes for the wave propagation along the direction in the PhC, and the results are shown as a function of the normalized frequency ν=Λ/λ (λ is the operating wavelength) in Fig.1where the short dotted line and dashed line represent the effective indexes for the y -polarized and x -polarized waves, respectively. A large difference (solid line) between the effective indexes for different polarizations is observed. The index difference reaches its maximum of about 0.017 as the normalized frequency approaches zero (namely ,tends to zero for a given wavelength). This indicates that for a given wavelength (e.g., in the optical communication window), high birefringence can high birefringence can be achieved

z

through reducing the structural sizes (but remain the geometric pattern) of the PhC; meanwhile, the PhC tends to act as an (dispersive) anisotropic medium.

. The known elliptical-hole PCF is formed by a 2-D PhC described above with one missing hole as fiber core. Consider a typical PCF of such a type as shown in the inset of Fig2, where there are eight rings of elliptical air holes surrounding the core.The length of the major and minor axes of the elliptical air holes are d1=0.6Λ and d2=0.2Λ respectively.We apply a full vector finite-element method and uniaxial perfectly matched layers to analyze the properties of this PCF. The confinement loss can be deduced from the imaginary part of the effective modal index.

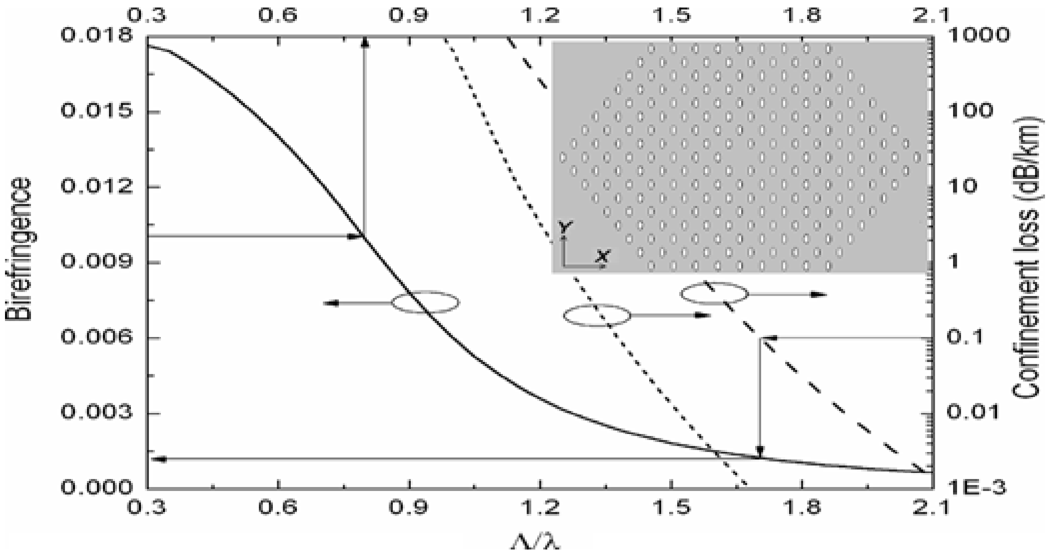

Fig.2. Birefringence (solid line) and confinement losses of the y- polarized (dashed) and x-polarized (dotted) fundamental modes for the elliptical-hole PCF with eight rings of elliptical air holes in the cladding. The inset shows the cross section of the PCF.

Fig. 2 shows the modal birefringence (solid line) (i.e., the difference between the effective ind -exes of the y - and x -polarized fundamental modes) and the confinement losses (dashed and dotted lines for the y - and x -polarized fundamental modes, respectively) as a function of the normalized frequency for the elliptical hole PCF. The birefringence increases with decreasing normalized frequency and high birefringence as high as 10^{-2} occurs at low frequencies. However, the confinement losses of both modes increase dramatically as the normalized frequency decreases. If the PCF is required to have an acceptable confinement loss less than 0.1 dB/km, the birefringence will reduce to a level below 0.001. Thus, there is a tradeoff between the confinement loss and the birefringence for an elliptical-hole PCF.

III. NOVEL DESIGN OF BIREFRINGENT PCF

Based on the anisotropy of the elliptical-hole PhC material, we propose a novel birefringent PCF by employing elliptical air holes in the fiber core. The fiber cladding still consists of a hexagonal lattice of circular air holes in fused silica.The elliptical air microholes in the fiber core are also arranged in a hexagonal lattice but with a shorter hole pitch, as shown in Fig. 3, where they are encompassed by four rings of circular air holes in the cladding. The 0.8Λ(where Λ is the circular air hole pitch) and the length of the major axis and minor axis of the elliptical air microholes is d4=0.6Λ' and d5=0.2Λ'(where center-to-center distance between the elliptical air holes is Λ'=0.1Λ) respectively.

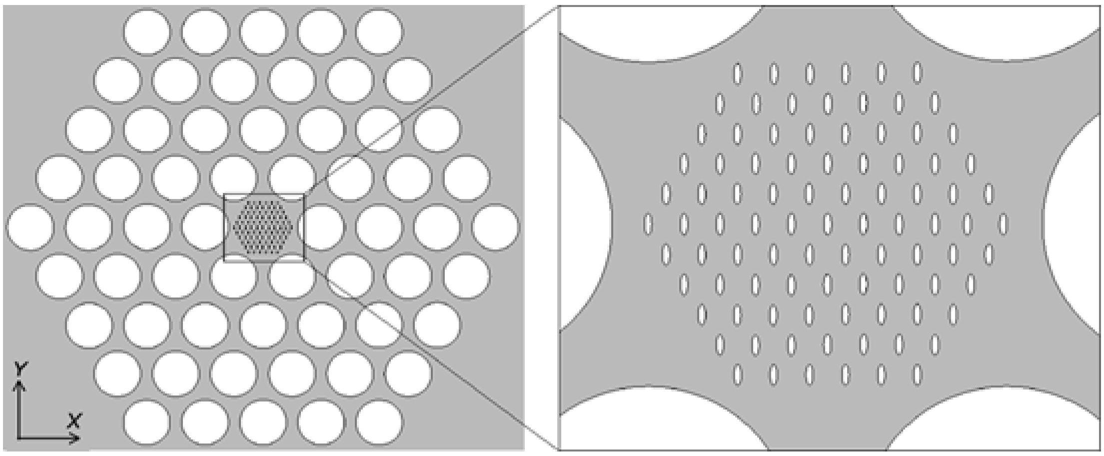

Fig. 3. Cross section of the proposed PCF with four rings of circular air holes in the fiber cladding and

elliptical air microholes in the fiber core.

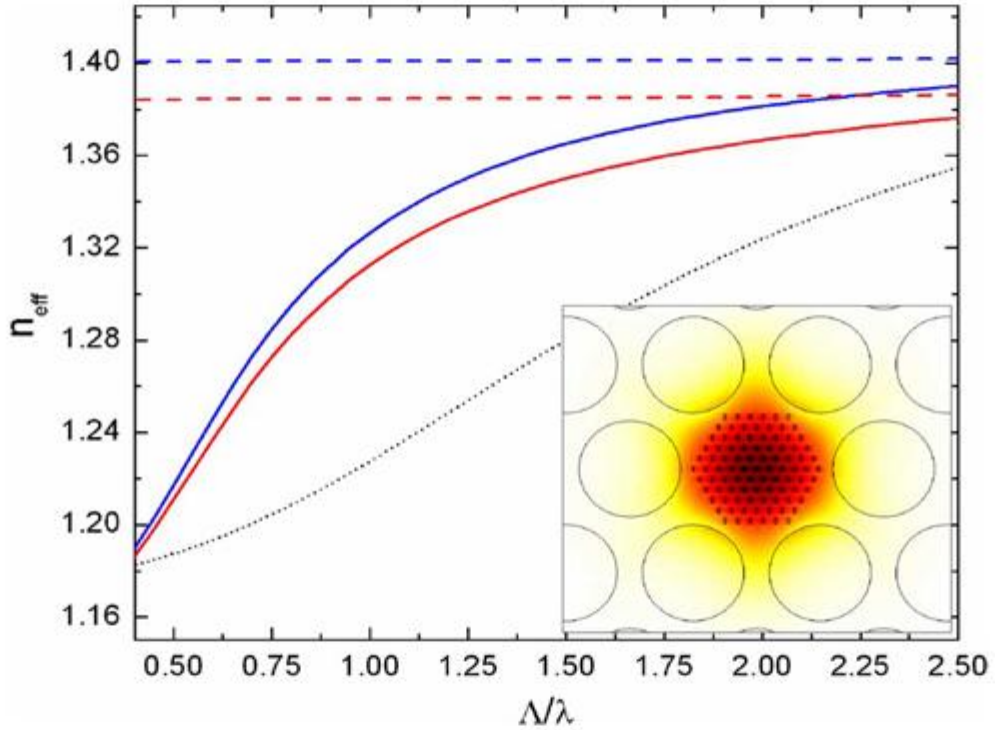

Fig. 4. Effective indexes of the y- and x-polarized fundamental modes (solid lines) of the proposed PCF, and the FSMs of the fiber cladding (short dotted line) and core (dashed lines). The inset shows the profile of the major electric field component of the y-polarized fundamental mode at a normalized frequency of 1.

Fig. 4 shows the effective indexes of the y-and x- polarized fundamental modes(solid line) ,the effective index for the fundamental space-filling mode(FSM) of the fiber cladding(short dotted line). Two dashed lines show the effective indexes of the elliptical-hole fiber core (when the normalized frequency ranges from 0.4 to 2.5, corresponding to the region from 0.04 to 0.25 in Fig. 1), which are about 1.401 and 1.385 for the y - and x -polarized light wave, respectively. The effective indexes of the fundamental modes tend to these of the elliptical-hole fiber core. The inset of Fig. 4 shows the mode profile of the y - component of the electric field of the y - polarized fundamental mode when the normalized frequency is 1.

Fig.5 shows the birefringence (solid line) of the proposed PCF and confinement loss for the y-polarized fundamental mode(dotted line) and the x-polarized fundamental mode (dashed line). Quite different from the elliptical-hole PCF shown as the inset of Fig. 2, the proposed PCF can achieve high and uniform birefringence for the large normalized frequency from 1.05 to 2.5. Although only four rings of circular air holes are employed in the fiber cladding, the confinement loss is ultralow (less than 0.001 dB/km with the normalized frequency above 1.25).

Furthermore, we consider a typical example with Λ=2.2μm and take into account the dependence of the silica index on frequency,and then find a uniform (with a ripple less than 0.0005),and ultrahigh birefringence (above 0.014) with ultralow confinement loss (below 0.001dB/km) in the wavelength range from 1.05 to 1.70 μm. Evidently ,the proposed PCF will further behave better if more rings of circular air holes are employed in the fiber cladding. The inset of Fig. 5 shows the confinement loss (solid lines) can be reduced effectively when with one more ring (in total fine rings) of circular air holes in the fiber cladding. Two lines connected by hollow circulars (for the PCF with four rings of circular air holes) and by solid circulars (for the PCF with five rings of circular air holes) show that the birefringence of the PCF is almost independent of the number of the rings of circular air holes in the fiber cladding. It is known that the confinement loss in a PCF decreases rapidly as more rings of air holes are introduced in the cladding. However, our simulation shows that compared to the elliptical-hole PCF (with eight rings of air holes) shown in the inset of Fig. 2, only two rings of air holes in the cladding are needed for the present PCF to obtain a same birefringence (about 0.01) and similar confinement loss (for the normalized frequency of 0.75). Finally, our simulation indicates that the proposed PCF (with four rings of circular holes in the cladding) has a second-order cutoff of ν=1, as marked by cross in Fig. 5. The cutoff frequency can be effectively increased through reducing the circular-hole size and adding the hole rings in the fiber cladding, while the confinement loss as well as the birefringence are maintained.

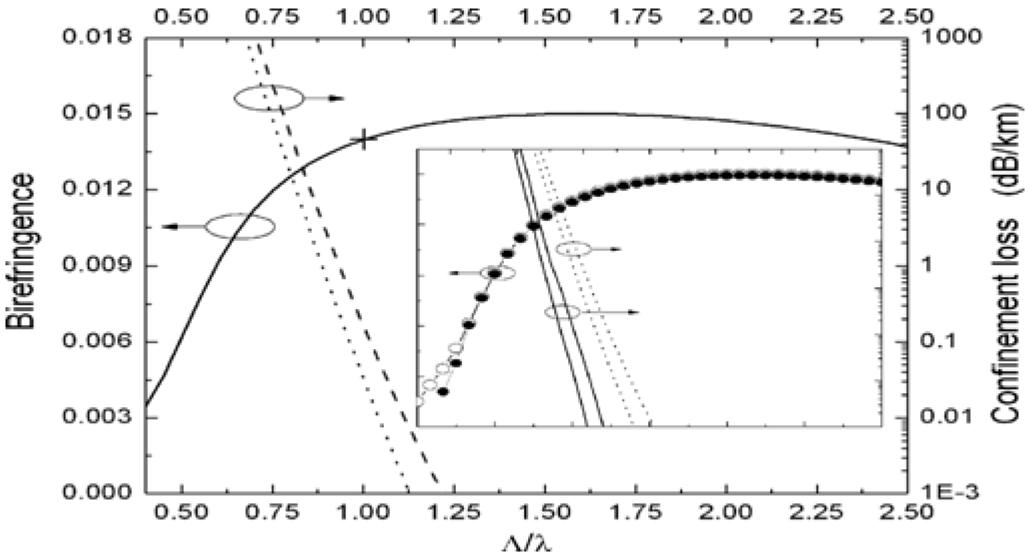

Fig. 5. Birefringence (solid line) and confinement losses of the y-polarized (dotted) and x--polarized (dashed) fundamental modes for the proposed PCF. Inset shows a comparison between the PCFs with four (dotted lines and line with solid circles) and five (solid lines and line with hollow circles) rings of circular air holes in the fiber cladding.

IV. DISCUSSION AND CONCLUSION

For the previous birefringent PCF with elliptical holes in the fiber cladding, high birefringence can be achieved only when the bulk of the mode energy is located in the fiber cladding, which inevitably results in the large confinement loss. In contrast, the present birefringent PCF is realized by introducing elliptical holes in the fiber core (but with much smaller hole pitch than that in the fiber cladding); thus, it possesses some advantages as follows: 1) high birefringence occurs when bulk of the modal energy is in the fiber core; 2) the fiber core with a hole pitch far less than wavelength acts approximately as an anisotropic medium, which enables the PCF to exhibit high birefringence over a large wavelength range; 3) ultrahigh birefringence and ultralow confinement loss can be easily achieved simultaneously. But the proposed PCF with a fine structure in the fiber core seems to be somewhat difficult for fabrication. In practice, if we apply larger sizes of elliptical holes and a correspondingly lower number of hole rings in the fiber core for fabrication purpose, the PCF can also exhibit high birefringence of the same order of magnitude, but its uniform birefringence wavelength interval will reduce apparently. In this case, the fabrication difficulty will be largely released. It is known that a PCF with a single elliptical air microhole in the fiber core has already been manufactured successfully, so the proposed PCF in this letter should be able to be fabricated in the near future.

In conclusion, an ultrahigh birefringent PCF with ultralow confinement loss has been designed and analyzed. Ultrahigh birefringence and ultralow confinement loss of the PCF can be achieved over a large wavelength range. Moreover, this letter first suggests an approach to modify the effective index of fiber core, which offers a new possibility to further optimize the dispersion characteristics of birefringent PCFs.

V. REFERENCES

[1] D. Chen and L. Shen "*Ultrahigh birefringent photonic crystal fiber with ultralow confinement loss*", 2008.

[2] X. Z. Sang, P. L. Chu, and C. X. Yu, "*Applications of nonlinear effects in highly nonlinear photonic crystal fiber to optical communications*," Opt. Quantum Electron.,vol. 37.

[3] A. Ortigosa-Blance, A. Diez, M. Delgado-Pinar, J. L. Cruz, and M. V. Andres, "*Ultrahigh birefringent nonlinear microstructured fiber*,"2009.

[4] T. P. Hansen, J. Broeng, S. E. B. Libori, E. Knudsen, A. Bjarklev, J. R. Jensen, and

H. Simonsen, "*Highly birefringent index-guiding photonic crystal fibers*," .

[5] P. G. Agrawal, Nonlinear Fiber Optics.

[6] N. A. Issa, M. A. V. Eijkelenborg, M. Fellew, F. Cox, G. Henry, and M. C. J. Large, "*Fabrication and study of microstructured optical fibers*.

[7] T. Matsui , J. Zhou , K. Nakajima and I. Sankawa "*Dispersion-flattened photonic crystal fiber with large effective area and low confinement loss*", J. Lightw. Technol., vol. 23, 2008.

[8] S. M. A. Razzak and Y. Namihira "*Proposal for highly nonlinear dispersion-flattened octagonal photonic crystal fibers*", 2008.

[9] Y. Yue , G. Y. Kai , Z. Wang , T. T. Sun , L. Jin , Y. F. Lu , C. S. Zhang , L. G. Liu , Y. Li , Y. G. Liu , S. Z. Yuan and X. Y. Dong "*Highly birefringent elliptical-hole photonic crystal fiber with squeezed hexagonal lattice*", Opt. Lett., vol. 32, 2007.

[10] A. Ortigosa-Blanch , J. C. Knight , W. J. Wadsworth , J. Arriaga , B. J. Mangan , T. A. Birks and P. S. J. Russell "*Highly birefringent photonic crystal fibers*", Opt. Lett., vol. 25.

[11] J. C. Knight , J. Broeng , T. A. Birks and P. S. J. Russell "*Photonic band gap guidance in optical fibers*", Science, vol. 282.

[12] P. R. Chaudhuri , V. Paulose , C. Zhao and C. Lu "*Near-elliptic core polarization-maintaining photonic crystal fiber: Modeling birefringence characteristics and realization*".