VIETNAM ACADEMY OF SCIENCE AND TECHNOLOGY
INSTITUTE OF PHYSICS

THE 7th
ACADEMIC CONFERENCE ON NATURAL SCIENCE FOR YOUNG SCIENTISTS, MASTER AND PhD. STUDENTS FROM ASEAN COUNTRIES

Ha Noi & Vinh City, Vietnam. 14-17 October 2021

PROCEEDINGS

Publishing House for Science and Technology

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PREFACE

The 7th Academic Conference on Natural Sciences for Young Scientists, Masters and PhD. Students from ASEAN countries (CASEAN-7) has been successfully held both online and offline on 14-17 October 2021, for a while the Covid situation in Vietnam and neighboring countries is complicated. The CASEAN-7 takes place at two locations, in Ha Noi and Vinh City, Nghe An Province, Vietnam.

The main purpose of the Conference is to provide a good opportunity for young scientists, Master and PhD. students, coming from universities and institutes in ASEAN countries to develop regional exchange activities, mutual understanding and cooperation as well as stimulate scientific training and education.

There were about 200 participants in different fields of natural sciences and from Cambodia, Laos, Malaysia, Myanmar, Philippines, Thailand, and Vietnam. More than 120 scientific reports were presented at the conference. Furthermore, some senior scientists and professors (from China, India, Japan, South Korea, New Zealand,...) were invited to give their talks. The Conference created favorable conditions for all participants to establish new cooperative linkages and also strengthen our friendship.

The CASEAN-7 Proceedings book has published the papers which were presented in the conference and selected by the editorial committee with a standard referee procedure.

We have to say that the success of the CASEAN-7 Conference was resulted from active contributions of all the conference committees, the session chairmen and the participants.

On this occasion, we express our deep thanks to the ASEAN Co-Organizers and Co-Sponsors. Specially, we sincerely thanks to International Centre of Physics (ICP), Institute of Physics (IOP), Vietnam Academy of Science and Technology (VAST) and Vinh University for all its wonderful cooperation and great contribution to CASEAN-7.

We would like to thank the conference secretariat and technicians for their dedication and hard works./.

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CONTENTS

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COMPARISON OF DISPERSION CHARACTERISTICS OF SILICA-BASED PHOTONIC CRYSTAL FIBERS WITH DIFFERENT LATTICES

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Abstract. We punctuate the ability to improve the dispersion characteristics of silica-based photonic crystal fibers (PCFs) with three types as circular, hexagonal, and square lattice with a new design in which the filling factor (d_1/Λ) of the first ring near the core is controlled differently from the others. When the lattice constant (Λ) varies from 0.7 to 1.5 µm, both all-normal and anomalous dispersion is achieved depending on d_1/Λ. The all-normal dispersions are found for PCFs with small lattice constants of 0.7 and 0.8 µm, the increase of Λ makes the anomalous dispersion more dominant in the investigated wavelength region. PCF with hexagonal structure owns all-normal dispersion which is flatter and closer to zero than others. Based on analysis of numerical simulation results, we have proposed structures with optimal dispersion characteristics and pump wavelength that is suitable for supercontinuum generation application.

Keywords: *Photonic crystal fibers (PCFs), All-normal dispersion, Anomalous dispersion, Optimal dispersion characteristics.*

I. INTRODUCTION

Photonic-crystal fiber (PCF) is a class of optical fiber-based on the properties of photonic crystals which has attracted the attention of many researchers over the past decades due to outstanding properties in light propagation compared to conventional optical fibers [1-4]. Its cladding consists of air holes as minuscule channels in a certain regular ordering that run through the whole length of the PCF. Propagation of light in PCF is governed by two principles namely total internal reflection in which refractive index (RI) of the core is higher as compared to RI of cladding while in photonic bandgap cladding RI is higher than that of core [5]. Numerous research and investigation of PCF suggest that the characteristics and guiding properties of the PCF can be flexibly adjusted by changing its geometrical configuration such as the shape and size of the core, cladding, air-holes, substrate material, or infiltration of liquid. Diversity in characteristics of PCFs makes it possible for people to find its application in wider domains like sensors fabrication, polarization sustaining devices, and biomedical fields of applications [6-9], supercontinuum generation [10-15]. Control of dispersion in PCFs has been an interesting challenge because it plays an important role in determining the spectral expansion efficiency of supercontinuum. To get desirable dispersion property, the dimension variables such as lattice constant (Λ) and diameter (d) of air-holes are tailored flexibly. In this way, the dispersion properties like flatness, dispersion slopes, zero-dispersion wavelength (ZDW) can be easily controlled [16]. Recently, various unique geometries structures of the PCF have been introduced such as triangular, circular, rectangular, square, elliptical, and hexagonal lattice [10-12,14,17-20]. Through the adjustment of the lattice parameters Λ and d, the dispersion characteristics of these structures have significant improvements include the flat dispersion, flat and near-zero dispersion, all-normal or anomalous dispersion, the shift of ZDW towards the longer wavelength. However, determining which structure gives the most optimal dispersion has not been mentioned by the researchers. Furthermore, the difference in the air-holes diameter of the rings in the cladding also strongly governs the dispersion properties of PCF [21].

In this paper, we present a new structural design of PCFs in which the difference in air-holes diameters between the first ring and the other rings in the cladding is emphasized to improve dispersion characteristics, one of the important factors of PCFs for SC application. Additionally, a comparison of dispersion characteristics has been made among circular, square, and hexagonal-lattice PCFs to find the structure giving the most optimal dispersion. The obtained all-normal and anomalous dispersions strongly depend on the variation of the lattice constant Λ and the filling factor d_1/Λ and the all-normal dispersions are achieved for PCFs with small lattice constants of 0.7 and 0.8 µm.

II. NUMERICAL MODELLING OF PCFs

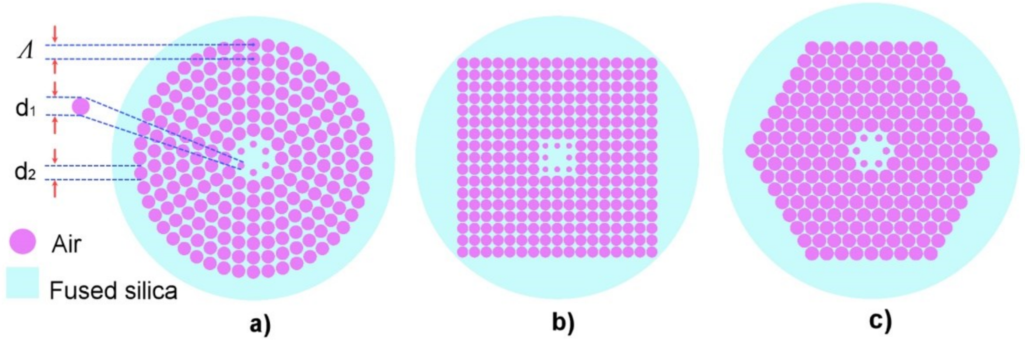

Fig. 1. *The cross-section of silica-based PCFs with different lattices a) CL, b) SL, and c) HL.*

The cross-sectional view of the designed silica-based PCFs has been presented in Fig. 1. The PCFs used in our study are circular (CL), square (SL), and hexagonal-lattice (HL) with eight rings of air-holes of a diameter d, the lattice constant Λ, and the linear filling factor d/Λ is in the photonic cladding. This way of designing creates a large difference in refractive index between the core and the cladding causes the light to be strongly confined in the core. We pay attention to the dissimilarity in the diameters of the air-holes in the first ring near the core and the other rings, as this has a strong effect on the characteristic quantities of the fibers. In which, the flatness, all-normal or anomalous properties of dispersions even the shift of ZDW are dominated mainly by the size of the first ring, while the other rings are responsible for the mode attenuation [21]. So we design the first ring with the d_1/Λ changing from 0.3 to 0.8 respectively with a step of 0.05, where

d_1 is the diameter of the air holes of the first ring. The values of Λ are 0.7 µm, 0.8 µm, 1.0 µm, and 1.5 µm. The filling factor $d_2/\Lambda = 0.95$ of the second and subsequent rings is kept a constant.

In this paper, the finite difference eigenmode method is used to design and calculate the dispersion curve over a wavelength range of 0.5-2.0 µm. The total dispersion (D) is a function of wavelength which depends on the effective indices of propagating mode and can be computed as follows [22]:

$$D = -\frac{\lambda}{c}\frac{d^2\left(\mathrm{Re}\left[n_{\mathrm{eff}}\right]\right)}{d\lambda^2}$$

here $\mathrm{Re}[n_{\mathrm{eff}}]$ stands for the real part of the effective indices obtained from simulations and c is the velocity of light in a vacuum.

III. SIMULATION RESULTS AND ANALYS

The dispersion properties of fiber demonstrate a dominant role in the propagation of short optical pulses that help expand the spectrum in SC generation. The dispersion curves corresponding to the effect of variation of Λ and d_1/Λ on fibers are exposed from Fig. 2 to Fig. 5. For the three structures, the shape of the dispersion curves is quite similar but the change of D with wavelength is diverse, the all-normal and anomalous dispersion with one or two ZDWs have been achieved in the studied wavelength region. Furthermore, the variation of the filling factor d_1/Λ and lattice constant Λ significantly dominates the dispersion characteristic of fibers and causes the ZDW to shift towards longer wavelengths. For small cores (Λ = 0.7 µm and 0.8 µm), the all-normal and anomalous dispersion with one or two ZDWs are found, and D tends to get smaller values as the filling factor rises, that means there are many parabolic dispersion curves in the narrow wavelength region. Fig. 2a (Λ = 0.7 µm) shows that, for the circular lattice structure, only fiber with $d_1/\Lambda = 0.3$ has the anomalous dispersion with one ZDW, when the filling factor increases the all-normal dispersion curves appears (d_1/Λ = 0.45-0.75), but PCFs with d_1/Λ is greater than 0.75 exhibits the anomalous dispersion with two ZDWs. While we get the all-normal dispersions in the range of 0.5-0.7 of d_1/Λ, and PCFs own the anomalous dispersion with one ZDW when $d_1/\Lambda \leq 0.4$ for the square lattice (Fig. 2b). The PCFs with hexagonal lattice structures operate in all-normal dispersion regions with the filling factor equals 0.45; 0.5; and 0.55; no anomalous dispersion with one ZDW is detected in this case. In particular, the fiber with $d_1/\Lambda = 0.45$, possesses very flatness dispersion and is close to the zero-dispersion curve (Fig.2c). When the lattice constant has a value of 0.8, the number of all-normal dispersions curves reduces for each lattice type. The circular lattice has four all-normal dispersion curves corresponding to 0.45-0.6 of the filling factor, while the square one shows only two structures with all-normal dispersions for d_1/Λ = 0.5 and 0.55. In contrast, no all-normal dispersion curves are received in the hexagonal lattice (Fig. 3). Therefore, we can conclude that dispersion features can be controlled more effectively in smaller core PCFs because of their strong light confinement ability.

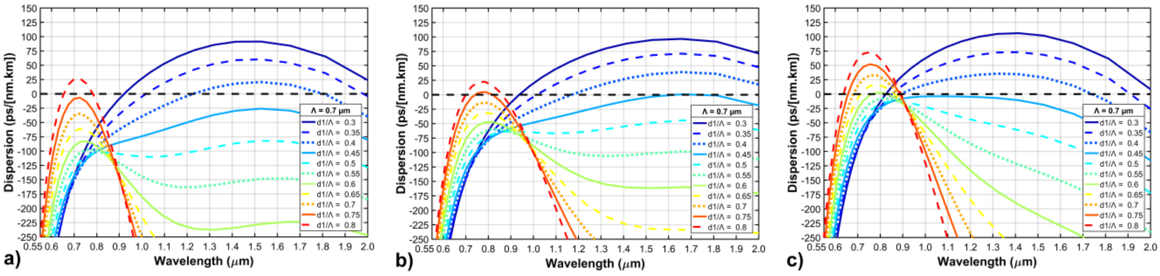

Fig. 2. *The dispersion properties of PCFs with various d_1/Λ and Λ = 0.7 µm for a) CL, b) SL, and c) HL.*

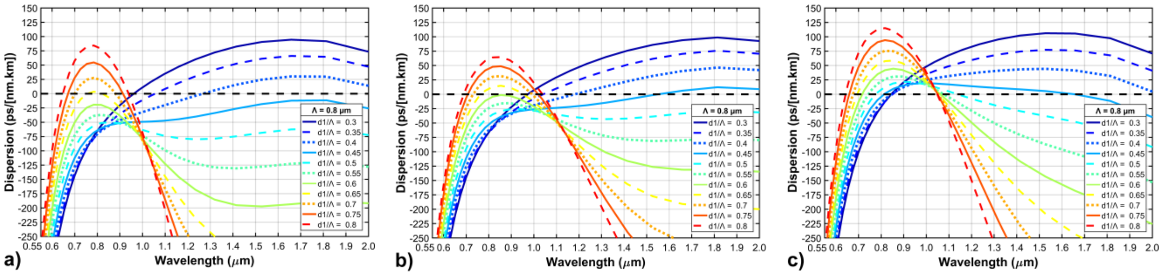

Fig. 3. *The dispersion properties of PCFs with various d_1/Λ and Λ = 0.8 µm for a) CL, b) SL, and c) HL.*

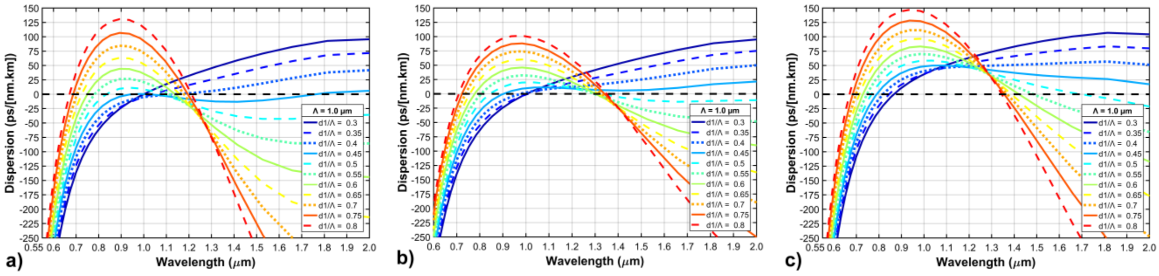

Fig. 4. *The dispersion properties of PCFs with various d_1/Λ and Λ = 1.0 µm for a) CL, b) SL, and c) HL.*

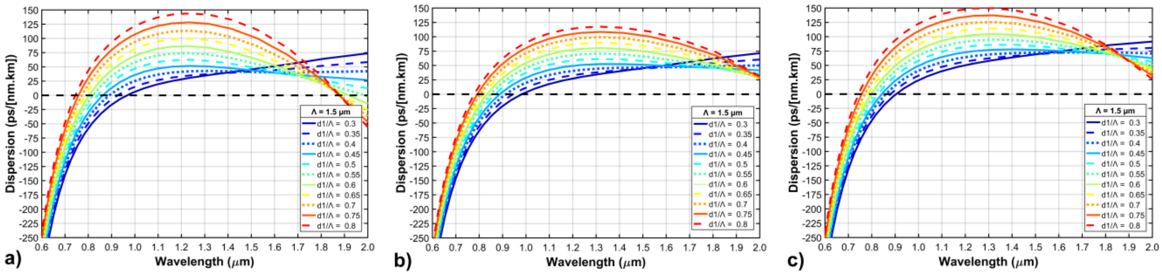

Fig. 5. *The dispersion properties of PCFs with various d_1/Λ and Λ = 1.5 µm for a) CL, b) SL, and c) HL.*

Obviously, the structure parameter Λ also strongly influences the properties of dispersion, a huge change in the nature of the dispersion profile has been observed with a larger lattice constant. As Λ is lifted, the all-normal dispersion does not appear anymore, the fibers exhibit anomalous dispersion with one and two ZDWs (Λ = 1.0 µm). When Λ = 1.5 µm, the anomalous dispersion with one ZDW completely dominates in the surveyed wavelength range for SL and HL structures (Fig. 4 and Fig. 5).

The difference between the size of the air-holes in the rings of the cladding, the geometrical structure, and the variation of the lattice structure parameters like our design are the important keys affecting the ability to confine light in the core, i.e. the value of effective indices that plays a major role in tuning the dispersion parameter. The flat, all-normal, and near-zero dispersion of fiber are the determining factors for the generation of an ultra-broadband SC. Because, the SC generation with all-normal dispersion PCF makes output pulses coherent, single, expansive, and flat when the fiber is pumped at the wavelength closest to that of the maximum dispersion or the flat dispersion point. Therefore, the three proposed structures satisfy the above features to analyze and compare their suitability in SC generation applications. Based on the numerical simulation results, we introduce three PCFs corresponding to CL, SL, and HL with Λ = 0.8 µm, d_1/Λ = 0.6 (CL), Λ = 0.8 µm, d_1/Λ = 0.55 (SL), and Λ = 0.7 µm, d_1/Λ = 0.45 (HL), they are named #F$_1$, #F$_2$ and #F$_3$, respectively. Their structural parameters are indicated in Table 1.

Table 1. *The structure parameters of proposed PCFs.*

#	Type	Λ (µm)	d_1/Λ	*Core diameter* (µm)
#F$_1$	CL	0.8	0.6	1.120
#F$_2$	SL	0.8	0.55	1.160
#F$_3$	HL	0.7	0.45	1.085

Fig. 6 evinces the all-normal dispersion characteristics of the proposed PCFs. Clearly, the dispersion curve (#F$_3$) of the hexagonal structure is flattest and closest to the horizontal axis, its flatness stretches from 0.9 to 1.3 µm, which is very valuable for SC. Fiber #F$_2$ has a lower dispersion curve and #F$_1$ shows an almost parabolic dispersion curve with maximum dispersion at 0.8 µm wavelength. The central wavelength of the laser pump source of these fibers is selected to be 0.8, 0.85, and 1.03 µm respectively.

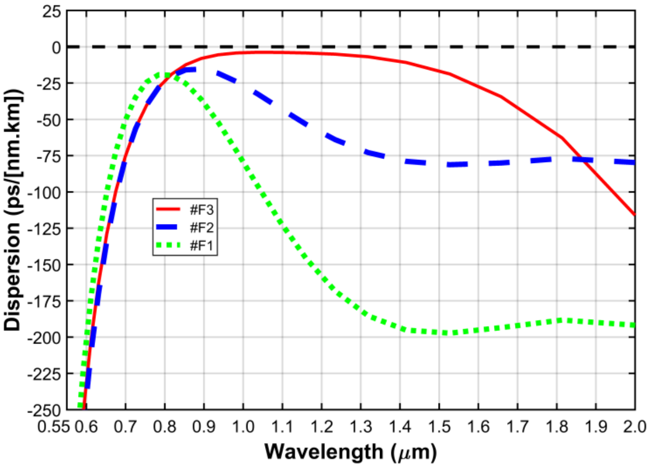

Fig. 6. *The dispersion properties of proposed PCFs.*

The value of dispersion calculated at the pump wavelength is quoted in Table 2. Among them, the dispersion value of #F$_3$ fiber with hexagonal lattice is the smallest because of the closest to the zero-dispersion line, its value is -3.809 ps.nm^{-1}.km^{-1} at the pump wavelength of 1.03 µm. While the dispersion values at the pump wavelength of #F$_1$ and #F$_2$ fibers are -19.407 ps.nm^{-1}.km^{-1} and -16.294 ps.nm^{-1}.km^{-1}, respectively.

Table 2. *The value of dispersion calculated at the pump wavelength of the proposed PCFs.*

#	Type	*The pump wavelength* (µm)	*D* (ps.(nm.km)$^{-1}$)
#F_1	CL	0.80	-19.407
#F_2	SL	0.85	-16.294
#F_3	HL	1.03	-3.809

IV. CONCLUSIONS

The dispersion characteristics of silica-based PCFs with three types such as circular, hexagonal, and square lattice with a new design have been evaluated and compared. The difference in the geometric structure of fibers makes the dispersion properties diverse, and the flexibility in controlling the dispersion parameters is fully achieved by the variation of the filling factor of the first ring near the core and the lattice constant. Although hexagonal lattice owns less all-normal dispersion curves than others they are very flat and near zero, which is very beneficial for SC generation. Among three fibers with optimal dispersion, the PCF with hexagonal structure gives the smallest value -3,809 ps.nm^{-1}.km^{-1} of dispersion at the pump wavelength of 1.03 µm in comparison with the other two structures. Our simulation results are valuable for fabricating optical fibers as an SC generation source with a wide, flat, and smooth spectrum.

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