COMPARISON OF EFFECTIVE MODE AREA AND CONFINEMENT LOSS OF CHLOROFORM-CORE PHOTONIC CRYSTAL FIBERS WITH CIRCULAR AND HEXAGONAL LATTICES

Le Tran Bao Tran (1), Dang Van Trong (1), Truong Thi Chuyen Oanh (2), Nguyen Thi Thuy (3), Chu Van Lanh (1)

[1]*Department of Physics, College of Education, Vinh University, Nghe An Province, Vietnam*
[2]*Nguyen Quang Dieu High School for the Gifted, Dong Thap, Vietnam*
[3]*University of Education, Hue University, Thua Thien Hue, Vietnam*

Received on 23/6/2022, accepted for publication on 23/8/2022
DOI: https://doi.org/10.56824/vujs.2022nt13

Abstract: In this research, new circular and hexagonal photonic crystal fibers (PCFs) filled with chloroform have been designed considering the difference in air hole diameters to optimize the characteristics of the fiber simultaneously. Effective mode area and confinement loss of five PCFs with optimal dispersion have been further studied to find the fiber with a great application value for supercontinuum generation (SCG). Generally, circular PCFs are dominant over hexagonal lattices because of their small effective mode area, low loss, and small dispersion. #CF_1 fiber with a lattice constant (Λ) of 1.0 µm and filling factor (d_1/Λ) of 0.65 has an all-normal dispersion with a low value of -1.623 ps/nm/km, a small effective mode area of 1.43 µm^2, and a low loss of 2.472 dB/m at 0.945 µm. The effective mode area and confinement loss of #CF_2 (Λ = 1.0 µm, d_1/Λ = 0.7) are the smallest of proposed PCFs. #HF_1 fiber (Λ = 1.0 µm, d_1/Λ = 0.5) has a very flat dispersion curve in the 1-2 µm wavelength range and a rather small effective mode area. These are the most optimal fibers for two types of lattices, which are very suitable for near-infrared SCG.

Keywords: Circular lattice; hexagonal lattice; effective mode area; confinement loss; photonic crystal fibers; chloroform-core.

1. Introduction

Conventional optical fibers can perform very well in radio and telecommunications equipment but have many limitations regarding flexibility in their structure and design. In 1996, Russell proposed the first photonic crystal fiber, which attracted a lot of attention from researchers [1]. It is a kind of optical fiber with a cyclic structure made of small tubes (such as capillary tubes) filled with air arranged in the form of a circular, hexagonal, square lattice, etc. With a fixed cladding and region structure, it has good light confinement in the core region not only for solid-core fibers but also for hollow-core fibers, which is impossible with conventional optical fiber.

The light transmission mechanisms in solid-core PCFs and hollow-core PCFs are different. The research on solid-core PCF has given many important results and applications to science and technology [2]. Since 2006, studies on pumping liquid into the hollow core of PCF have always received special interest from scientists because it can overcome the limitations of solid-core fibers such as dispersion curves with high resolution and high slope, low nonlinearity, etc. At the same time, these PCFs open up

Email: letranbaotran212@gmail.com (L. T. B. Tran)

many new studies for the field of supercontinuum generation (SCG) [3]-[5]. By changing the arrangement of the air holes in the cladding and the geometric parameters such as lattice constant and the diameter of the air holes, the linear and nonlinear characteristics of fibers can be effectively tuned. Photonic crystal fibers with the optimal structure have been applied in many fields such as optical sensors, dispersion compensation fiber, interference measurement, etc.

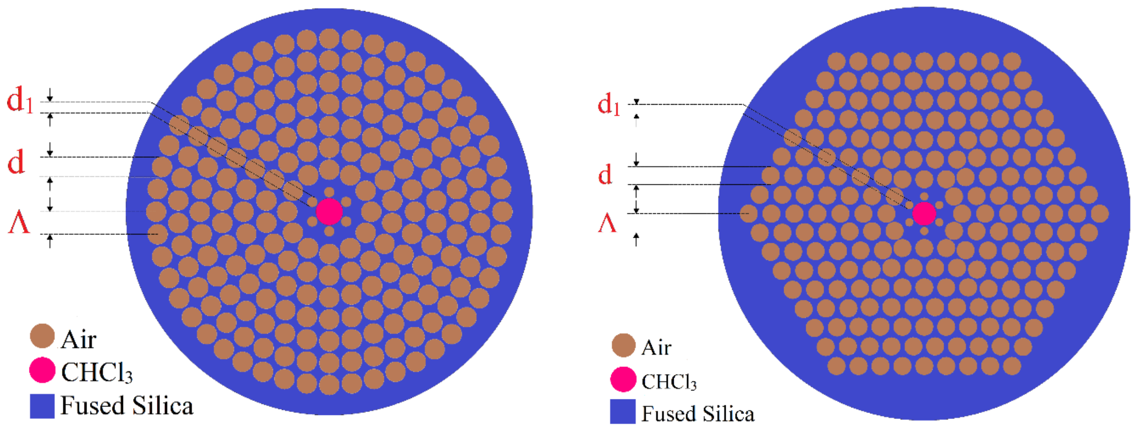
The flexible control of the characteristics of the liquid - filled PCFs, especially the dispersion curve, has made an important contribution to the study of SCG. Besides the flat and near-zero dispersion curve, a high nonlinearity coefficient, small effective mode area, and low loss are necessary to generate supercontinuum effectively.

Several works on studying the optical features of PCFs with different lattices have been reported to date [2]-[6]. Among them, studies using circular and hexagonal lattices are more prominent because of their ability to increase nonlinearity, optimize dispersion and minimize effective mode area. In this paper, a comparison of effective mode area and confinement loss between hexagonal and circular PCFs with chloroform-core ($CHCl_3$) has been performed to find a more optimal structure for SCG, overcoming the limitations of the works mentioned when only optimizing these quantities for one type of lattice. The recent publication [4] has also optimized dispersion, effective mode area, and attenuation characteristics for SCG application in PCFs with circular and hexagonal lattices (including square lattice), but their cores are filled with a relatively toxic liquid, nitrobenzene ($C_6H_5NO_2$). Meanwhile, $CHCl_3$ has much lower toxicity than $C_6H_5NO_2$ and higher nonlinearity compared to other liquids such as carbon tetrachloride CCl_4 [7]. In addition, the refractive index of $CHCl_3$ is very close to that of fused silica, which facilitates obtaining a single mode.

Lumerical Mode Solution software has been used to design circular and hexagonal PCF structures and simulate their properties with the variation of the lattice constant Λ and filling factor in the first ring d_1/Λ to select the PCF with the most optimal dispersion. The change in air hole diameter of the first ring allows to optimize the chromatic dispersion, effective mode area, and loss simultaneously compared with fibers which only optimize dispersion in the publications with the same size of the air holes in all rings [3], [6], [7]. The characteristics of effective mode area, nonlinear coefficients, and confinement loss of the two lattice structures has also been compared to select the most optimal PCFs for application in SCG.

2. Theoretical basis and numerical modeling of PCFs

The structure of the PCF with the circular lattice and hexagonal lattice is described as shown in Figure 1. Both lattice structures have eight air hole rings with their core filled with $CHCl_3$. The air hole diameter of the first ring d_1 can be changed compared with the remaining rings of diameter d by changing the filling factor d_1/Λ from 0.3 to 0.8. For the remaining rings, the filling factor is kept unchanged $d/\Lambda = 0.95$. The core diameter is determined by the formula $D_c = 2\Lambda - 1.1d_1$. These structures were designed based on the studied of V. K. Saitoh et al. [8]. The lattice parameters in the first ring herein are shown to leading influence the dispersion characteristics, while the other rings dominate the effective mode area and mode attenuation of the fiber. With the above models, it is easy to achieve the small effective mode area and minimum loss as well as desired dispersion, which is completely different from previous works [3], [6], [7]. To search for the optimal structures applied to SCG, we run simulations with lattice constants Λ = 1.0 µm, 1.5 µm, 2.0 µm, and 2.5 µm.



(a) (b)

Figure 1: *The geometrical structure of PCF with the circular lattice (a) and hexagonal lattice (b)*

The high nonlinear index of $CHCl_3$ is important for enhancing efficiency. Specifically, it has a value of 29.6×10^{-20} m^2/W which is nearly 11 times larger than SiO_2 with a refractive index of 2.74×10^{-20} m^2/W at 1053 nm [9], allowing reach a broad spectrum with low peak power over short propagation distances. The linear refractive index n of $CHCl_3$ as a function of wavelength is described by the Sellmeier equation [3]

$$n(\lambda)=\sqrt{1+\frac{B_1\lambda^2}{\lambda^2-C_1}+\frac{B_2\lambda^2}{\lambda^2-C_2}+\frac{B_3\lambda^2}{\lambda^2-C_3}}, \quad (1)$$

where the wavelength λ has the dimension of micrometer (µm) and the parameters B_1, B_2, B_3 and C_1, C_2, C_3 are listed in Table 1.

Table 1: *Sellmeier coefficients of SiO_2 and $CHCl_3$ [3]*

Material	B_1	B_2	B_3	C_1 (µm^2)	C_2 (µm^2)	C_3 (µm^2)
SiO_2	0.6694226	0.4345839	0.8716947	4.4801×10^{-3}	1.3285×10^{-2}	95.341482
$CHCl_3$	1.04647	0.003445		0.01048	0.15207	

It is noticeable that the generation of supercontinuum strongly depends on the nonlinear coefficient (γ), the larger the nonlinear coefficient, the more efficient SCG is. The nonlinear coefficient is calculated as the following equation [6]

$$\gamma(\lambda)=\frac{2\pi n_2}{\lambda A_{eff}}, \quad (2)$$

where A_{eff} is the effective mode area given by [6].

$$A_{eff} = \frac{\left(\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} |E(x,y)|^2 \, dxdy\right)^2}{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} |E(x,y)|^4 \, dxdy}. \quad (3)$$

On the other hand, confinement loss (L_c) is an important factor in designing structures with a finite number of air holes. L_c is formed by mode leakage and structural imperfections of the PCF. Due to the dependence on wavelength, the number of air hole rings, and the air hole size, the modes are guided by structure-dependent loss. L_c is determined by the formula [10]

$$L_c = 8.686 k_0 Im\left[n_{eff}\right], \quad (4)$$

where Im[n_{eff}] (dB/m) is the imaginary part of the effective refractive index.

In this paper, we compare the effective mode area, nonlinear coefficient, and confinement loss of two $CHCl_3$-core PCFs with the circular and hexagonal lattices with silica substrates. The object that we aim to conduct the comparison is the PCFs with flat and near-zero dispersion of these lattices.

3. Results and Discussion

Chromatic dispersion significantly affects the effectiveness of the SCG; the flatter the dispersion curve and the closer it is to the zero-dispersion line, the larger the supercontinuum bandwidth is. From analyzing the results of the simulations corresponding to the established lattice constants and filling factors, we select five PCFs with optimal dispersion including #CF_1 (Λ = 1.0 µm, d_1/Λ = 0.65, D_c = 1.285 µm), #CF_2 (Λ = 1.0 µm, d_1/Λ = 0.7, D_c = 1.23 µm), #CF_3 (Λ = 2.0 µm, d_1/Λ = 0.3, D_c = 3.34 µm) for the circular lattice and #HF_1 (Λ = 1.0 µm, d_1/Λ = 0.5, D_c = 1.45 µm), #HF_2 (Λ = 2.0 µm, d_1/Λ = 0.3, D_c = 3.34 µm) for the hexagonal lattice. The dispersion of these fibers is shown in Figure 2.

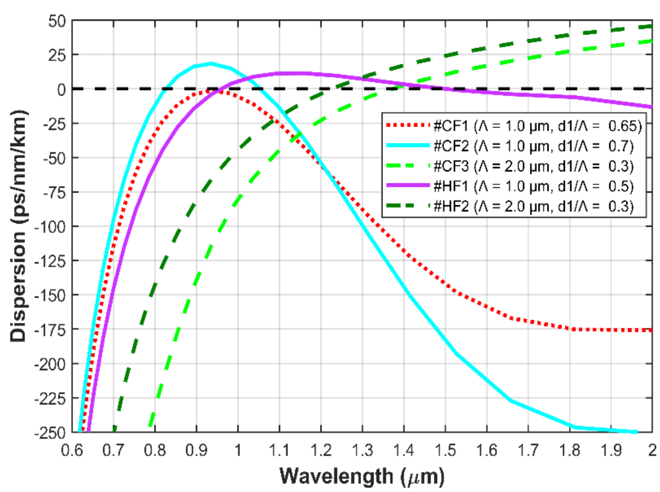


Figure 2: *The optimal dispersion curves synthesis of circular and hexagonal lattices PCFs infiltrated with* $CHCl_3$

Our proposed fibers operate in the normal and anomalous dispersion regions with a pump wavelength close to that at which the dispersion value is maximum or close to but greater than the zero-dispersion wavelength (ZDW). Although both have anomalous dispersion with one ZDW at the same parameters, the #F_3 structure has a flatter dispersion curve and is more asymptotic to the zero-dispersion line than HF_2. Its dispersion is also less than 5.598 ps/nm/km at the corresponding pump wavelength. On the other hand, the two fibers #CF_2 and #HF_1 have anomalous dispersion curves and intersect the zero-dispersion at two points. Two ZDWs of #HF_1 are 0.96 µm and 1.501 µm, respectively. Its dispersion curve is very flat over a wide region of 1 µm with a transition from anomalous dispersion to normal dispersion at about 1.5 µm. With this feature, the #HF_1 fiber is expected to pump at 1.3 µm; its dispersion value is 7.234 ps/nm/km. Meanwhile, #CF_2 exits two ZDWs at 0.827 µm and 1.053 µm and has a dispersion of 17.726 ps/nm/km at a pump wavelength of 0.954 µm, greater than #HF_1 by an amount of 10.492 ps/nm/km. In particular, the #CF_1 fiber exhibits all-normal dispersion with the peak of the dispersion curve asymptotic to the zero-dispersion line and a very low dispersion at the pump wavelength of 0.954 µm, -1.623 ps/nm/km. The dispersion values of the proposed structures at the pump wavelength are given in Table 2.

Table 2: *The dispersion characteristic of the optimal PCFs for the two lattices at the pump wavelength*

Types of lattice	**#**		**Pump wavelength (µm)**	***D* (ps/nm/km)**
Circular lattice	#CF_1	Λ = 1.0 µm, d_1/Λ = 0.65, D_c = 1.285 µm	0.945	-1.623
	#CF_2	Λ = 1.0 µm, d_1/Λ = 0.7, D_c = 1.23 µm	0.945	17.726
	#CF_3	Λ = 2.0 µm, d_1/Λ = 0.3, D_c = 3.34 µm	1.4	2.612
Hexagonal lattice	#HF_1	Λ = 1.0 µm, d_1/Λ = 0.5, D_c = 1.45 µm	1.3	7.234
	#HF_2	Λ = 2.0 µm, d_1/Λ = 0.3, D_c = 3.34 µm	1.3	8.21

In the next step, we carried out a comparison of the effective mode area, nonlinearity, and confinement loss of five selected structures. The effective mode area A_{eff} of #CF_1, #CF_2, #CF_3, #HF_1, and #HF_2 are depicted graphically in Figure 3.

From Figure 3, we can see that the #CF_3 fiber of the circular lattice has the effective mode area increasing as the wavelength increases between 0.5 µm and 0.7 µm, then decreasing rapidly until 1.3 µm and slightly increasing in the remaining wavelength region. With the same parameter Λ = 2.0 µm, d_1/Λ = 0.3, D_c = 3.34 µm as the #CF_3 fiber, the A_{eff} of #HF_2 is smaller due to the difference in lattice structure resulting in more energy concentrated in the core. At the pump wavelength of 1.3 µm, the #CF_3 structure has an effective area of 11.524 µm^2, which is larger than #HF_2 at 1.3 µm wavelength (8.976 µm^2). Structures #CF_1, #CF_2, and #HF_1 with small core diameters have significantly smaller effective mode areas than the two mentioned PCFs. Their curves almost overlap and increase slightly with increasing wavelength. In particular, the minimum effective mode area is observed in the #CF_2 fiber. Its value is 1.284 µm^2 at a pump wavelength of 0.945 µm, while the figures for #CF_1 and #HF_1 are 1.43 µm^2 and 2.205 µm^2 at 0.945 µm and 1.3 µm, respectively. The A_{eff} values of suggested fibers are shown in Table 3.

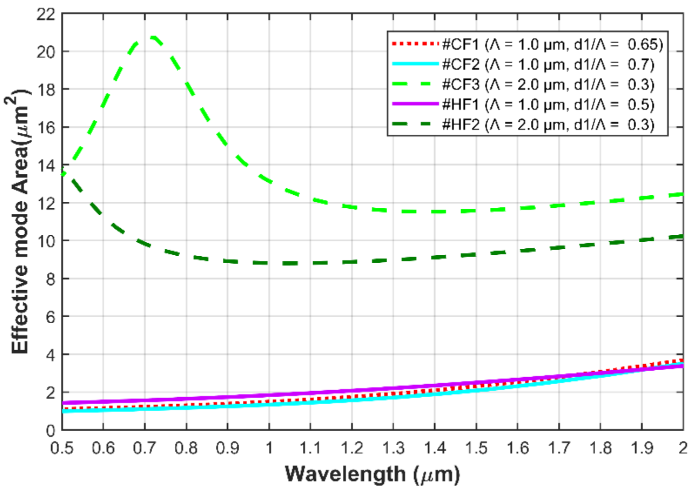


Figure 3: *The effective mode area of optimal PCFs for circular and hexagonal lattices*

Table 3: *The effective mode area of the optimal PCFs at the pump wavelength*

Types of lattice	#	Pump wavelength (µm)	A_{eff} (µm^2)
Circular lattice	#CF_1	0.945	1.43
	#CF_2	0.945	1.284
	#CF_3	1.4	11.524
Hexagonal lattice	#HF_1	1.3	2.205
	#HF_2	1.3	8.976

According to formula (2), the nonlinear coefficient γ is inversely proportional to the effective mode area. Thus, fibers with small A_{eff} will have a high nonlinearity which is very beneficial for SCG. The nonlinear coefficients of the proposed fibers are illustrated in Figure 4.

From Figure 4 it is shown that nonlinear coefficients of #CF3 and #HF2 structures are approximately the same and they are much lower than others; they are almost stable as the wavelength increases. Fibers with small nonlinearity usually own good signal transmission efficiency and large output power, so they are applied in information transmission. In contrast, #CF_1, #CF_2, and #HF_1 fibers with high nonlinear coefficients will expand the output pulses, facilitating the study of SCG.

Next, we are interested in confinement loss L_c inside the core of five selected structures. The loss graph due to light confinement of fibers #CF_1, #CF_2, #CF_3, #HF_1, and #HF_2 is depicted in Figure 5.

As shown in Figure 5, the confinement losses of #CF_3 and #HF_2 fibers decrease abruptly in the short wavelength region while that of small core fibers decreases slightly.

When the wavelength increases from 0.7 m to 1.2 m, all proposed PCFs have loss curves almost coincident with the horizontal axis, i.e., light is well confined in the core, increase slightly in the remaining wavelength range. With the same large core diameter D_c = 3.34 µm, the #CF_3 fiber of the circular lattice has a greater confinement loss than #HF_2 of the square lattice by an amount of 22.046 dB/m at the considered pumping wavelengths. This loss is because a small part of the light energy has passed through the air holes, besides most of which is confined inside the core. On the other hand, #CF_1 and #CF_2 fibers with small effective mode areas have very low losses of 2.472 dB/m and 2.291 dB/m at 0.945 µm, respectively, due to their small core diameter. The L_c values of five proposed structures at the pump wavelengths are indicated in Table 4.

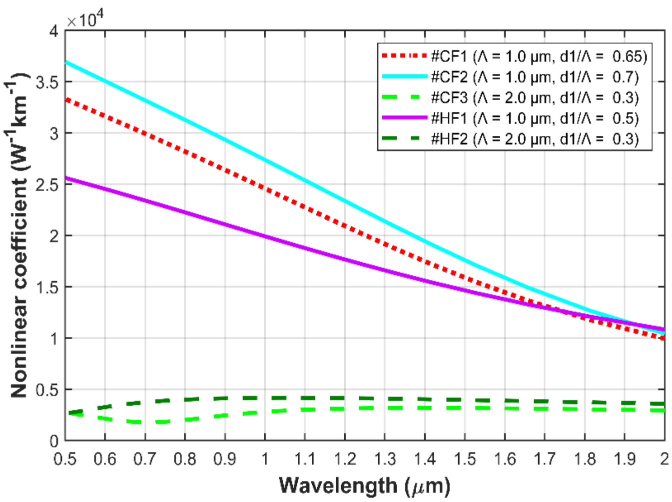


Figure 4: The *nonlinear coefficients of #CF_1, #CF_2, #CF_3, #HF_1, and #HF_2 fibers*

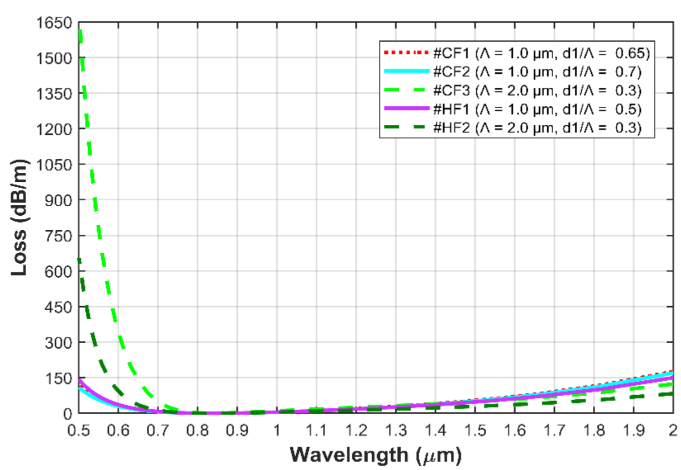


Figure 5: *The confinement loss of optimal PCFs for the circular lattice and hexagonal lattice*

The obtained results demonstrate that most of the circular lattice PCFs have lower confinement loss and smaller effective mode area than the hexagonal lattice due to their high symmetry and give a relatively small dispersion value. Compared with several previous works that did not consider the modification of the structural parameters in lattice rings, the proposed PCFs have a flatter and smaller dispersion [4], [6], and smaller effective mode area [6], including studies using $CHCl_3$ to fill the fiber core [3]. At the same dispersion regimes, the *D* curves in the publication [3] are further away from the zero-dispersion line and less flat than our fibers. While its dispersion value in the case of all-normal dispersion is -24 ps/nm/km, this figure is only -1.623 ps/nm/km for #CF_1. Besides, the effective mode area in [3] is also larger than most of the optimal structures in this modeling. The confinement loss obtained in the publication [6] is about 30 dB/m, which is equivalent to that of #CF_3 but 10 times larger than the L_c value of #CF_2 fiber. The reason is that the change in the diameter of the first ring in the structure leads to a considerable improvement in the fiber characteristics. Even when using heterogeneous air holes in the cladding, the publication [2] still possesses a much larger dispersion than our work. This once again proves the advantages of the proposed PCFs for SCG applications.

Table 4: *The value of confinement loss of optimal PCFs at the pump wavelength*

Types of lattice	#	Pump wavelength (µm)	L_c (dB/m)
Circular lattice	#CF_1	0.945	2.472
	#CF_2	0.945	2.291
	#CF_3	1.4	39.622
Hexagonal lattice	#HF_1	1.3	26.246
	#HF_2	1.3	17.576

4. Conclusion

In this paper, a series of simulations aimed at comparing effective mode area and confinement loss of $CHCl_3$-core PCFs with the circular lattice and hexagonal lattice is performed using Lumerical Mode Solution software. With the change of the lattice constant and the filling factor to vary the diameter of the first ring, we obtain the optimal dispersion structures of the circular and hexagonal lattices as the basis for comparing their effective mode area and confinement loss. In general, the circular lattice structure is more optimal than the hexagonal lattice in terms of low dispersion, smaller effective mode area, and lower confinement loss. The #CF_1 fiber has a low all-normal dispersion of -1.623 ps/nm/km at 0.945 µm pump wavelength, at the same time having a small effective mode area and low loss of 1.43 μm^2 and 2.472 dB/m, respectively, which is considered a good candidate for highly coherent SCG. At the same pumping wavelength as #CF_1, the #CF_2 fiber has the smallest effective mode area and lowest loss in all cases. These values are 1.284 μm^2 and 2.291 dB/m, respectively. Besides, the nonlinearity of #CF_1 and #CF_2 fibers is also higher than that of other fibers. In the case of the hexagonal lattice, the #HF_1 fiber is remarkable for its very flat dispersion curve over the wide wavelength range from 1 µm to 2 µm and its relatively small effective mode area of 2.205 μm^2 at 1.3 µm. These results confirm that the control of air hole diameter in the first ring near the core produces PCFs with optimized characteristic quantities simultaneously, which is an important basis for SCG applications in the near-infrared region.

Acknowledgment

This research was funded by Vingroup JSC and supported by the Master, PhD Scholarship Programme of Vingroup Innovation Foundation (VINIF), Institute of Big Data, code [VINIF.2021.TS.155].

REFERENCES

[1] J. C. Knight, T. A. Birks, P. St. J. Russell, and D. M. Atkin, "All-silica single-mode optical fiber with photonic crystal cladding," *Opt. Lett.*, vol. 21, pp. 1547-1549, 10/1996.

[2] H. T. Duc, D. V. Trong, L. T. B. Tran, C. V. Lanh, D. V. Hung, and N. T. Thuy, "Comparison of dispersion characteristic of silica-based photonic crystal fibers with different lattices," in *Proceedings of the 7th Academic Conference on Natural Science for Young Scientists, Master and PhD. Students from Asean Countries, CASEAN-7*, Ha Noi and Vinh City, Nghe An, Vietnam, October 14-17, 2021, pp. 317-323.

[3] C. V. Lanh, H. V. Thuy, C. L. Van, K. Borzycki, D. X. Khoa, T. Q. Vu, M. Trippenbach, R. Buczyński, and J. Pniewski, "Optimization of optical properties of photonic crystal fibers infiltrated with chloroform for supercontinuum generation," *Las. Phys.*, vol. 29, 5/2019.

[4] C. V. Lanh, N. T. Thuy, H. T. Duc, L. T. B. Tran, V. T. M. Ngoc, D. V. Trong, L. C. Trung, H. D. Quang, and D. Q. Khoa, "Comparison of supercontinuum spectrum generating by hollow core PCFs filled with nitrobenzene with different lattice types," *Opt. Quant. Electron.*, vol. 54, 300 (17pp), 4/2022.

[5] N. T. Thuy, H. T. Duc, L. T. B. Tran, D. V. Trong, and C. V. Lanh, "Optimization of optical properties of toluene-core photonic crystal fibers with circle lattice for supercontinuum generation," *J. Opt.*, 01/2022.

[6] H. Q. Quy and C. V. Lanh, "Spectrum Broadening of Supercontinuum Generation by fill Styrene in core of Photonic Crystal Fibers," *Indian J. Pur. Appl. Phys.*, vol. 59, pp. 522-527, Jul. 2021.

[7] H. D. Quang, J. Pniewski, L. V. Hieu, A. Ramaniuk, C. L. Van, K. Borzycki, D. X. Khoa, M. Klimczak, and R. Buczyński, "Optimization of optical properties of photonic crystal fibers infiltrated with carbon tetrachloride for supercontinuum generation with subnanojoule femtosecond pulses," *Appl. Opt.*, vol. 57, pp. 3738-3746, 5/2018.

[8] V K. Saitoh, M. Koshiba, T. Hasegawa, and E. Sasaoka, "Chromatic dispersion control in photonic crystal fibers: application to ultra-flattened dispersion," *Opt. Express*, vol. 11, pp. 843-852, 4/2003.

[9] P. P. Ho and R. R. Alfano, "Optical Kerr effect in liquids," *Phys. Rev. A*, vol. 20, pp. 2170-2187, 11/1979.

[10] J. Vijay and M. Sabir, "Low-flattened dispersion hexagonal photonic crystal fiber with low confinement loss," *Int. J. Emerging Tec. Advanced Engineering*, vol. 3, pp. 153-158, 01/2013.

TÓM TẮT

SO SÁNH DIỆN TÍCH MODE HIỆU DỤNG VÀ MẤT MÁT GIAM GIỮ CỦA SỢI TINH THỂ QUANG TỬ LÕI CHLOROFORM VỚI MẠNG TRÒN VÀ LỤC GIÁC

Lê Trần Bảo Trân (1), Đặng Văn Trọng (1), Trương Thị Chuyện Oanh (2), Nguyễn Thị Thuỷ (3), Chu Văn Lanh (1)
[1] *Khoa Vật lý, Trường Sư phạm, Trường Đại học Vinh, Nghệ An, Việt Nam*
[2] *Trường THPT Chuyên Nguyễn Quang Diêu, Đồng Tháp, Việt Nam*
[3] *Trường Đại học Sư phạm, Đại học Huế, Thừa Thiên Huế, Việt Nam*
Ngày nhận bài 23/6/2022, ngày nhận đăng 23/8/2022

Trong nghiên cứu này, các sợi tinh thể quang tử tròn và lục giác mới (PCFs) thẩm thấu chloroform đã được thiết kế có xét đến sự khác biệt đường kính lỗ khí để tối ưu hóa đồng thời các đặc trưng của sợi. Diện tích mode hiệu dụng và mất mát giam giữ của năm PCF với tán sắc tối ưu đã được nghiên cứu thêm để tìm ra sợi có giá trị ứng dụng lớn cho phát siêu liên tục (SCG). Nhìn chung, các PCF tròn chiếm ưu thế hơn mạng lục giác vì diện tích mode hiệu dụng nhỏ, mất mát thấp và tán sắc nhỏ. Sợi #CF_1 với hằng số mạng (Λ) 1,0 µm và hệ số lấp đầy (d_1/Λ) 0,65 có tán sắc hoàn toàn thường với giá trị thấp -1,623 ps/nm/km, diện tích mode hiệu dụng nhỏ 1,43 µm^2 và suy hao thấp 2,472 dB/m tại 0,945 µm. Diện tích mode hiệu dụng và mất mát giam giữ của #CF_2 (Λ = 1,0 µm, d_1/Λ = 0,7) nhỏ nhất trong các PCF được đề xuất. Sợi #HF_1 (Λ = 1,0 µm, d_1/Λ = 0,5) có đường cong tán sắc rất phẳng trong dải bước sóng 1-2 µm và diện tích mode hiệu dụng khá nhỏ. Đây là những sợi tối ưu nhất cho hai loại mạng, rất thích hợp cho SCG cận hồng ngoại.

Từ khóa: Mạng tròn; mạng lục giác; diện tích mode hiệu dụng; mất mát giam giữ; sợi tinh thể quang tử; lõi chloroform.