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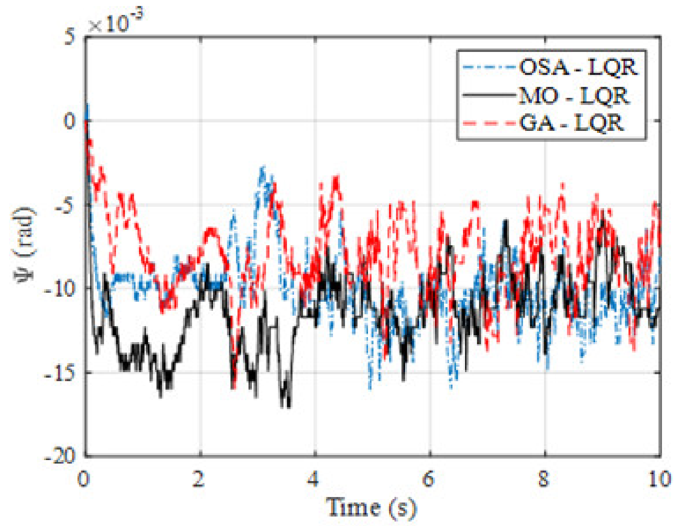

The yaw angle of the TWIPR with different methods.

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CONTENTS

SUPERCONTINUUM GENERATION IN SOLID-CORE PHOTONIC CRYSTAL FIBER INFILTRATED WITH WATER-ETHANOL MIXTURE

Le Van Hieu[1], Ho Dinh Quang[2*]

Abstract: *In this paper, we report a numerical study of the supercontinuum (SC) generation in solid-core photonic crystal fibers infiltrated with water-ethanol mixtures. A photonic crystal fiber is constructed as borosilicate glass NC21, which consists of 7 rings of air holes infiltrated with water-ethanol mixtures. We also considered numerically the influence of concentration of the ethanol solution on the dispersion of the fundamental mode. SC generation was demonstrated for the fiber long 20 cm with a pump pulse of 200 fs, the coupled energy of 0.5 nJ at the center wavelength of 1064 nm in the normal dispersion regime. The concentration of ethanol infiltrated to the fiber, the pulse of duration and the pump energy are investigated.*

Keywords: Photonic crystal fiber; Dispersion; Refractive index; Water-ethanol mixture; Borosilicate glass.

1. INTRODUCTION

Supercontinuum (SC) generation in PCFs has received the attention of many research groups over the past decade because of its novel properties and its important applications in many fields, including optical communication, diagnostic imaging, tomography, metrology, spectroscopy [1-4]. To achieve broadband SC, high power input pulses are generally launched near the zero dispersion wavelength (ZDW) in a highly nonlinear fiber.

The typical approach for that purpose is the development of SC sources based on PCFs made of silica or highly nonlinear soft glasses [5-9]. Silica fibers can be efficiently used for broadband SC generation covering the entirety of the visible and near-infrared (IR) spectrum. However, silica glass is not transparent in the mid-IR range and shows relatively low nonlinearity. Meanwhile, PCFs made of highly nonlinear soft glasses (for example, chalcogenide, tellurite glasses or lead-bismuth-galate glass) offer much higher nonlinear refractive index than silica and more broadband transmission into the mid-IR range. The highly nonlinear refractive indices of these materials lead to the SC are expected to generate on significantly shorter propagation scales. However, SC generation sources of PCFs from soft glasses with highly nonlinear solid core usually require complex pump systems, because this type of fiber usually has ZDW in the mid-IR range.

Looking for a new solution to achieve similar performance, another way has been shown to be practicable by using liquid-filled PCFs [10-14]. This phenomenon has demonstrated both numerically and experimentally, such as Li et al. reported highly coherent and broad continuum generation in a solid-core photonic crystal fiber by the compressed pulse and injected into a non-zero dispersion-shifted fiber (NZ-DSF) [10]; Hooper et al., was also generated an SC spectrum with a bandwidth of 0.8 μm in a photonic crystal fiber, which has an all-normal group velocity dispersion [11]; Stepniewski et al., was reported on octave-spanning supercontinuum generation in normal dispersion all-solid photonic crystal fiber under pumping with 1.36 µm, 120 fs pulses [12]; R.Bucynski et al., was demonstrated a two-octave spanning supercontinuum generation with a bandwidth of 0.7–3.0 µm in a single-mode photonic crystal fiber, which is made of lead-bismuth-gallate oxide glass (PBG-08) with zero dispersion wavelength (ZDW) of 1.46 µm, and the pump wavelength of 1,54 µm, pulse of duration of 150 fs in anomalous dispersion region [13]. Recently, H.V. Le et al. was proposed an ultra-flattened normal dispersion photonic crystal fiber infiltrated with ethanol, which is generated a flattened broadband SC spectrum of 0.945 µm in the range from 0.905 µm to 1.85 µm with a pulse energy of 4 nJ and 20 cm long fiber lengths, and the output pulse peak is very stable. This fiber promises to compensate for the dispersion, transmit ultra-short soliton pulse and perform wavelength-division multiplexing technique in the optical communication systems [14].

The water-ethanol mixture is the best choice because of the relatively high nonlinear refractive index in comparison to solids, so the nonlinear phenomena often show clearly and observe easily. In addition, water and ethanol are non-toxic in the process infiltration into the fiber and simple to manipulate, but the most important; it presents a zero-dispersion wavelength in the suitable range for supercontinuum generation. Last but not least, the PCF is made of borosilicate glass that has a high nonlinear refractive index (for example, the nonlinear refractive index (n_2) of borosilicate equals 1.1 x 10^{-7} ($\mu m^2/W$) at 1064 nm [15], while in the case of fused silica it is equal to 4.34 x 10^{-8} ($\mu m^2/W$) at the same wavelength [16], and good rheological properties that allow for thermal processing of the glass without crystallization [17].

In this work, we propose a PCF based on borosilicate glass (NC21), infiltrated with water-ethanol mixtures. We calculate numerically the dispersion of the fundamental mode with the helping of Lumerical MODE solutions with the volume concentration of ethanol in the mixtures ranges from 0 to 1.0 (v/v). We show that the designed fiber allows the generation of the SC spectrum in the normal dispersion region. We also investigate the effect of the volume concentration of ethanol infiltrated to the fiber, the pulse of duration and the pump energy in the supercontinuum generation.

2. DESIGN OF THE PCFs

For simulations, we propose a PCF made of borosilicate glass NC21 with weight compositions (55% SiO_2, 1% Al_2O_3, 26% B_2O_3, 3% Li_2O, 9.5% Na_2O, 5.5% K_2O and 0.8% As_2O_3) [18]. The PCFs are designed which bases on a real PCF labeled NL33B2, fabricated by the Institute of Electronic Material Technology (ITME), Poland. It includes 7 rings of air-holes ordered in a hexagonal lattice with a solid core in the center. The PCF has one outer air hole of the sixth ring is omitted, because of the mistake during the fabrication process.

The diameter of the solid core equals 5.024 µm. The cladding of the fiber is defined by the lattice pitch **Λ** and air holes diameter in the cladding d. The lattice pitch Λ of the fiber is 3.256 µm. The filling factor d/Λ for the first ring of holes in the cladding is 0.457, and varies in the range of 0.419-0.457 due to change of the diameter of outer air holes from 1.365 µm to 1.488 µm.

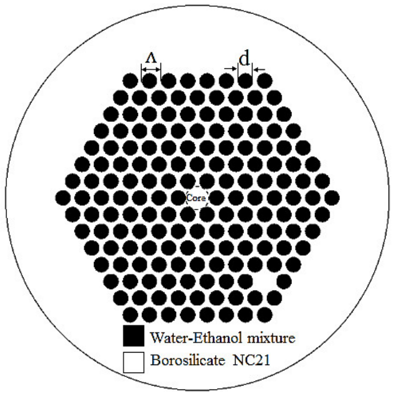

Figure 1. *The schematic of the modelled PCF structure.*

The geometrical parameters of the designed fiber are given in table 1.

Table 1. *Geometrical parameters of the proposed PCF.*

Geometrical parameters	NL33B2
Number ring of air holes	7
lattice constant - Λ [μm]	3.256
core diameter - d_{core} [μm]	5.024
air hole diameter 1st ring - d_1 [μm]	1.488
relative air-hole size 1st ring - d_1/Λ	0.457
air hole diameter 2nd ring - d_2 [μm]	1.365
relative air-hole size 2nd ring - d_2/Λ	0.419

The refractive index of borosilicate glass NC21 is modeled using the following Sellmeier relation as given below, where the C_i coefficients have dimensions of micrometers squared (μm^2) [19]:

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

with coefficients: B_1 = 0.6694226, B_2 = 0.4345839, B_3 = 0.8716947, C_1 = 4.4801 x 10^{-3} μm^2, C_2 = 1.3285 x 10^{-2} μm^2, and C_3 = 95.341482 μm^2.

3. NUMERICAL SIMULATIONS

Numerical analysis was performed with the help of Lumerical Mode Solution software. The PCF was infiltrated all the air holes with water-ethanol mixtures. We considered that the concentration of ethanol solution is changed volume concentration of 0, 0.5 and 1.0 (v/v) in the water-ethanol mixtures. The refractive index of water and ethanol are modelled using the following equation [20]:

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

where B_i and C_i are the coefficients, as illustrated in table 2.

Then, the refractive index of water-ethanol mixtures was a function of wavelength λ and volume concentration of ethanol c, which is given by [21]:

$$n_{w-e}(c)=c.n_e+(1-c).n_w \quad (3)$$

where n_{w-e} is the refractive index of water-ethanol mixture, c is the volume concentration of ethanol, n_e is the refractive index of ethanol, n_w is the refractive index of water.

***Table 2.** The coefficients of water and ethanol.*

Sellmeier coefficients	Water	Ethanol
B_1	0.75831	0.83189
B_2	0.08495	0.15582
C_1	0.01007	0.00930
C_2	8.91377	49.45200

We have calculated the dispersion characteristics as a function of the wavelength in the range of 0.6-1.6 µm for fundamental mode of the designed fiber infiltrated with water-ethanol mixtures. The volume concentration of ethanol is equal to 0.0, 0.5, and 1.0 (v/v).

4. RESULTS AND DISCUSSION

4.1. Dispersion properties of the designed PCFs

The effect of the volume concentration of ethanol on the dispersion properties is shown in figure 2.

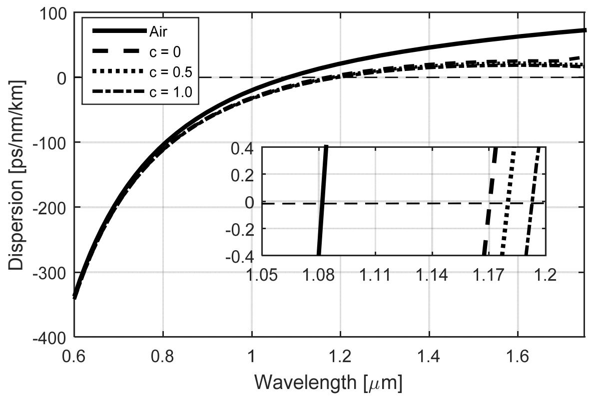

***Figure 2.** The dispersion characteristics of PCF with various volume concentration of ethanol.*

We observed that all fibers infiltrated with water-ethanol mixture have flatted dispersion characteristics in the near-infrared range from 1.3 µm to 1.6 µm, the value of dispersion is reduced by over 10 ps/nm/km. Simultaneously, the dispersion characteristic expresses in both normal and anomalous dispersion regions. Our results also showed that the dispersion characteristics, as well as ZDWs can be tuned by changing the volume concentration of ethanol, which are shifted toward longer waves and flattened with increasing c. This type of dispersion characteristics plays a very important role in the efficiency of supercontinuum generation. It indicated that the dispersion characteristics of PCF are better when air holes are infiltrated with the water-ethanol mixture.

The effective mode area A_{eff} is a very important parameter, because of increased optical intensity concentration in the core of the PCF, which is used to determine the non-linearity coefficient γ of medium for supercontinuum generation, is given by [22]:

$$\gamma = \frac{2\pi n_2}{\lambda A_{eff}} \tag{4}$$

where, A_{eff} denotes effective mode area of the fundamental mode and n_2 is nonlinear refractive index.

Figure 3 shows the effective mode area value of the fundamental mode as a function of wavelength in the range of 0.6-1.6 µm for different volume concentrations of ethanol. The results showed that A_{eff} values depend on the volume concentration of ethanol c, which increased linearly with increasing c values. For given c = 0.5, the effective mode area A_{eff} increased from 14.20 µm^2 to 23.50 µm^2 when the wavelength changed from 0.6 µm to 1.6 µm.

At the same time, the confinement loss of fiber increase with increasing the volume concentration of ethanol from 0.0 to 1.0. The lowest confinement losses were fiber infiltrated with water (c=0.0) and the highest losses were infiltrated with ethanol (c=1.0). This is consistent with the previous researches because ethanol can enhance a confinement loss of the fiber in transmission.

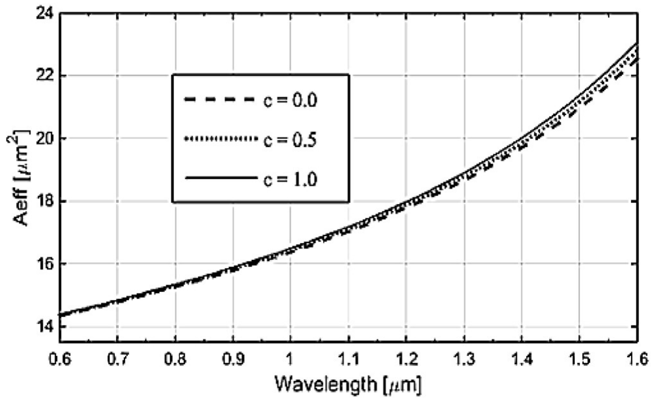

Figure 3. *The mode area of the fundamental mode with various volume concentration of ethanol 0.0, 0.5 and 1.0.*

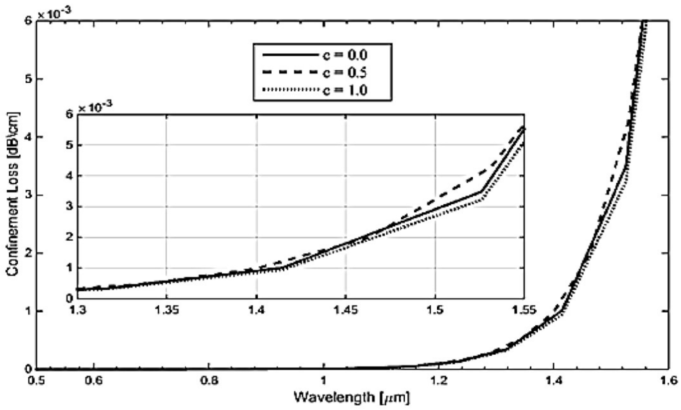

Figure 4. *The confinement loss of PCF with various volume concentration of ethanol 0.0, 0.5 and 1.0.*

4.2. Supercontinuum generation in solid-core PCF infiltrated with liquids.

Supercontinuum generation of selected fiber was performed by numerically solving the Generalized Nonlinear Schrödinger Equation (GNLSE) [23]:

$$\frac{\partial A}{\partial z}=-\frac{\alpha}{2}A+\sum_{n\geq 2}\beta_n\frac{i^{n+1}}{n!}\frac{\partial^n}{\partial T^n}A+i\gamma\frac{1}{\omega_0}\left(1+\frac{\partial}{\partial T}\right)\left[(1-f_R)\left|A\right|^2A+f_RA\int_0^\infty h_R(t)\left|A(z,T-t)\right|^2dt\right] \quad (5)$$

where, A = A(z, t) is the complex amplitude of the optical field, α is the total loss in the PCF, β_n is the dispersion coefficients associated with the Taylor series expansion, the nonlinear coefficient γ is defined by Eq.4, λ_c is the central wavelength, f_R is the Raman fraction response to nonlinear polarization, $h_R(t)$ represents the Raman response function which is given by [24]:

$$h_R(t)=(\tau_1^2+\tau_2^2)\tau_1^{-1}\tau_2^{-2}\exp(-t/\tau_2)\sin(-t/\tau_1)$$

where τ_1 and τ_2 are two adjustable parameters and are chosen to provide a good fit to the actual Raman-gain spectrum.

The analysis was simulated with parameters: the fiber length 20 cm, the Gaussian-shape pulse of duration 200 fs, the Raman fraction f_R = 0.18 [14], $\tau_1=12.2$ fs [14], $\tau_2=32$ fs [14], the nonlinear refractive index of borosilicate n_2 = 1.1 x 10^{-7} ($\mu m^2/W$) [15], and the coupled energy 0.5 nJ at the center wavelength 1064 nm.

Figure 5 shows the SC spectrum for structures with different concentrations of ethanol. The obtained results showed that the spectral width is extended with increasing the concentration of ethanol infiltrated to the fiber (for example: 807 nm, 830.2 nm, and 838.2 nm, respectively, for c = 0.0, c = 0.5, and c = 1.0). However, the output pulse shape is not changed too much. This can be explained that the difference between the refractive index of water and ethanol is not very large. Due to the environmental nonlinearity is fixed, so the infiltrated of the water-ethanol mixture into fiber only makes changing the dispersion properties of PCF but not much. This leads to change a little in the pulse shape.

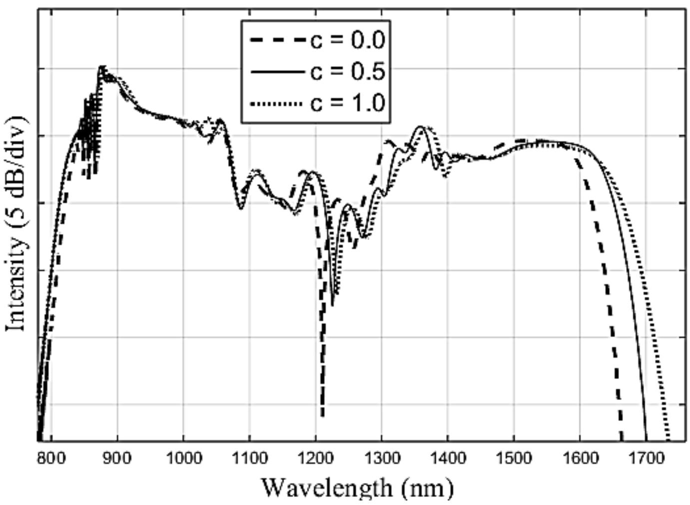

Figure 5. *The comparisons of the spectral intensity for the 20 cm PCF infiltrated with various volume concentration of ethanol 0.0, 0.5 and 1.0.*

Figure 6 shows the spectral profile of the supercontinuum generation of the fiber infiltrated with the ethanol concentration c = 0.5 when the pump energy increases in terms of 0.2 nJ, 0.5 nJ, and 0.8 nJ. The results showed that the increased pump energy not only widens the spectrum but it also changes the spectral shape. The results also showed that the widening pulse occurs very early in the first centimeter. In the first stage, the nonlinear effect plays the main role in the extended pulse, which is the phase modulation effect. Meanwhile, Figure 6. b-d showed that the widening pulse only occurs up to the first 5 cm distance, then it changes very small. However, due to the breaking solitons phenomenon leads to the pulse shape change.

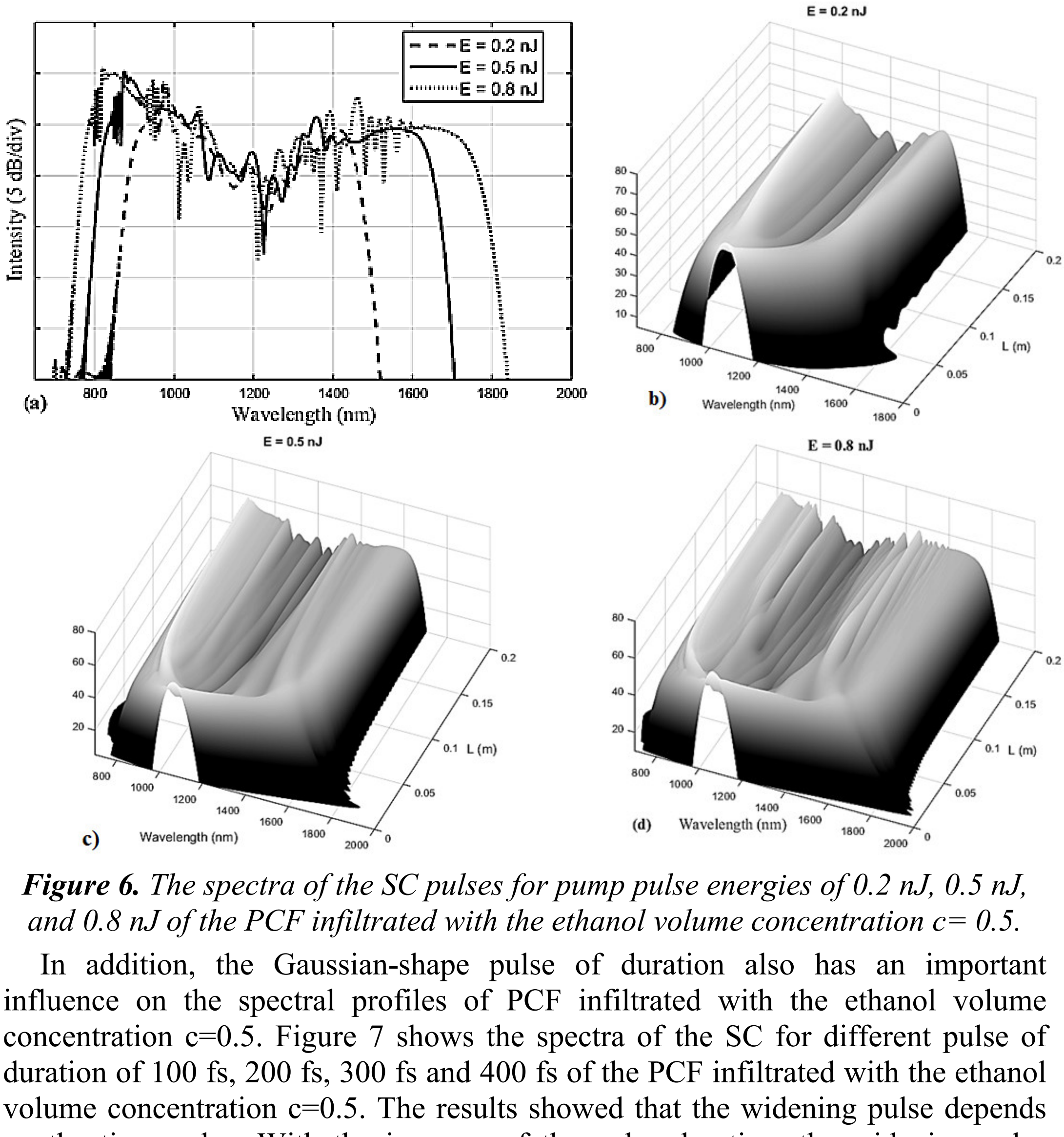

Figure 6. *The spectra of the SC pulses for pump pulse energies of 0.2 nJ, 0.5 nJ, and 0.8 nJ of the PCF infiltrated with the ethanol volume concentration c= 0.5.*

In addition, the Gaussian-shape pulse of duration also has an important influence on the spectral profiles of PCF infiltrated with the ethanol volume concentration c=0.5. Figure 7 shows the spectra of the SC for different pulse of duration of 100 fs, 200 fs, 300 fs and 400 fs of the PCF infiltrated with the ethanol volume concentration c=0.5. The results showed that the widening pulse depends on the time pulse. With the increase of the pulse duration, the widening pulse becomes smaller because of a stronger nonlinear effect for the narrower pulse. It can be seen that the maximum pulse extension corresponds to 100 fs time pulse and the smallest corresponding to 400 fs time pulse.

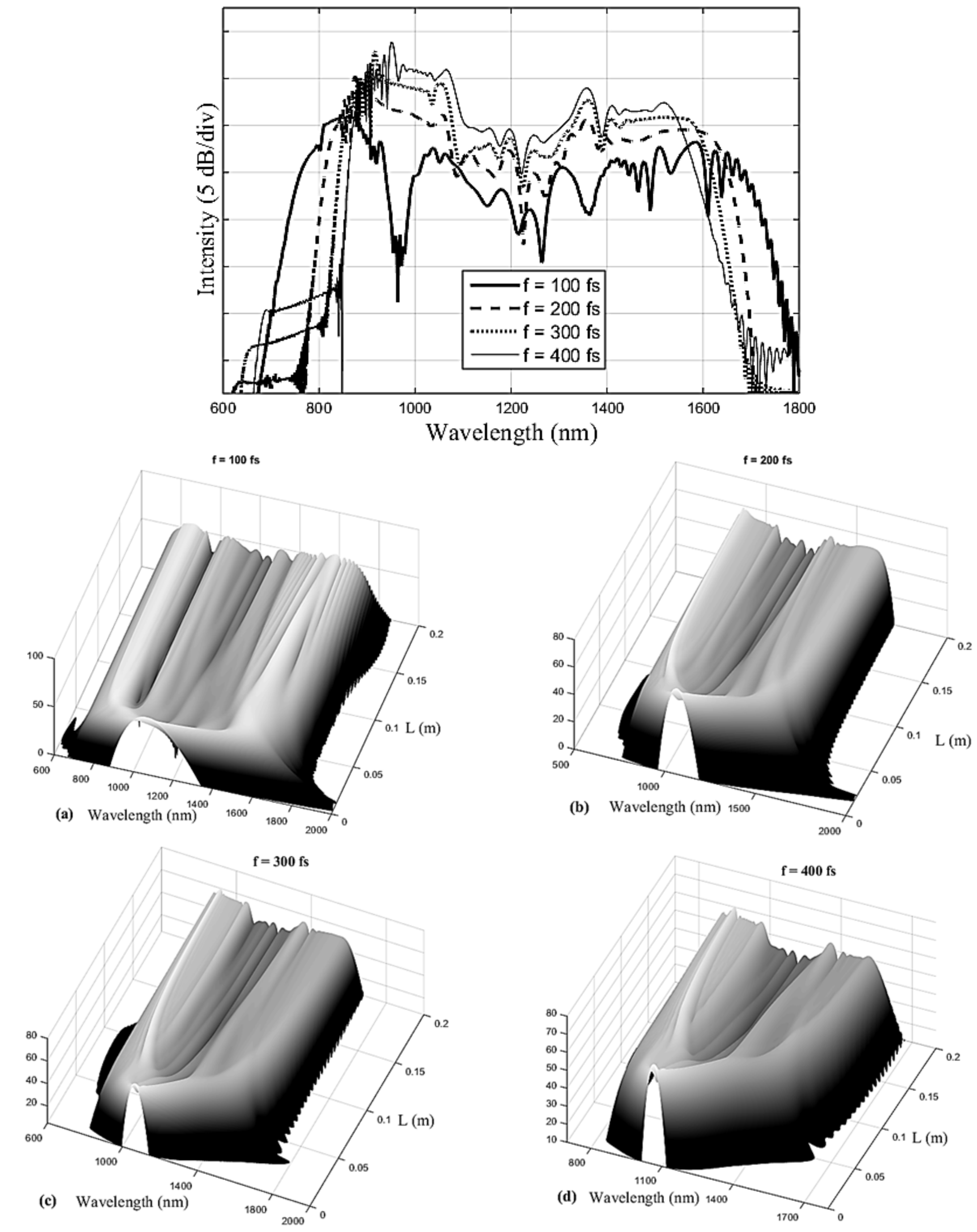

Figure 7. *The spectra of the SC for different pulse of duration of 100 fs, 200 fs, 300 fs and 400 fs of the PCF infiltrated with the ethanol volume concentration c=0.5.*

5. CONCLUSION

In summary, a PCF is designed which bases on a real PCF labeled NL33B2, is infiltrated with water-ethanol mixtures. PCF made of borosilicate glass NC21 consisting of 7 rings of air-holes ordered in a hexagonal lattice with a diameter of the core equals 5.024 µm. We have shown that the properties of PCF can be modified by changing the volume concentration of ethanol in the water-ethanol mixture. In addition, the obtained dispersion characteristics of PCF are better when air holes are filled with the water-ethanol mixture. SC generation was demonstrated for the wavelength of 1064 nm in the fiber long 20 cm. It is shown that the spectral bandwidth of the SC spectrum can be obtained 807 nm, 830.2 nm and 838.2 nm, respectively, for c = 0, c = 0.5 and c = 1.0 when a pump pulse with 200 fs and the coupled energy 0.5 nJ. We also investigate the nonlinear propagation dynamics with different the concentration of ethanol infiltrated to the fiber, the pulse of duration and the pump energy.

REFERENCES

[1]. H. Liu, Y. Yu, W. Song, Q. Jiang, and F. Pang, *"Recent development of flat supercontinuum generation in specialty optical fibers,"* Opto-Electronic Advances, **Vol. 2(2),** pp. 1800201-1800209, (2019).

[2]. R. Holzwarth, T. Udem,T. W. Hänsch, J. C. Knight, W. J. Wadsworth, and P. S. J. Russell, *"Optical frequency synthesizer for precision spectroscopy,"* Physical Review Letters, **Vol. 85(11)**, 2264-2267, (2000).

[3]. T. Udem, R. Holzwarth, and T. W. Hänsch, *"Optical frequency metrology,"* Nature, **Vol. 416**, pp. 233-237, (2002).

[4]. U. Sharma, E.W. Chang, and H.S. Yun, *"Long-wavelength optical coherence tomography at 1.7 µm for enhanced imaging depth"* Optics Express, **Vol. 16(24)**, pp.19712–19723, (2008).

[5]. V.R.K. Kumar, A.K. George, J.C. Knight, and P.S.J. Russell, *"Tellurite photonic crystal fiber,"* Optics Express, **Vol. 11**, pp.2641-2645, (2003).

[6]. Z. X. Jia, C. F. Yao, S. J. Jia, F. Wang, S. B. Wang, Z. P. Zhao, M. S. Liao, G. S. Qin, L. L. Hu, Y. Ohishi, and W. P. Qin, *"Supercontinuum generation covering the entire 0.4–5 µm transmission window in a tapered ultra-high numerical aperture all-solid fluorotellurite fiber,"* Laser Physics Letters, **Vol. 15(2)**, pp. 025102, (2018

[7]. S. Dai, Y. Wang, X. Peng, P. Zhang, X. Wang, and Y. Xu, *"A review of mid-infrared supercontinuum generation in chalcogenide glass fibers,"*Applied Sciences, **Vol. 8(5),** pp.707-1-28, (2018).

[8]. R. Buczynski, H. T. Bookey, D. Pysz, R. Stepien, I. Kujawa, J. E. McCarthy, A. J. Waddie, A. K. Kar, and M. R. Taghizadeh, *"Supercontinuum generation up to 2.5 mm in photonic crystal fiber made of lead-bismuth-galate glass"* Laser Physics Letters, **Vol. 7(9)**, pp. 666-672, (2010).

[9]. F. G. Omenetto, N. A. Wolchover, M. R. Wehner, M. Ross, A. Efimov, A. J. Taylor, V. V. R. K. Kumar, A. K. George, J. C. Knight, N. Y. Joly, and P. St. J. Russell, *"Spectrally smooth supercontinuum from 350 nm to 3 µm in sub-centimeter lengths of soft-glass photonic crystal fibers,"* Optics Express, **Vol. 14**, pp. 4928-4934, (2006).

[10]. F. Li, Q. Li, J. Yuan, and P.K.A. Wai, "*Highly coherent supercontinuum generation with picosecond pulses by using self-similar compression*,",

Optics Express, **Vol. 22**, pp. 1-16, (2014).

[11]. L. E. Hooper, P. J. Mosley, A. C. Muir, W. J. Wadsworth, and J. C. Knight, "*Coherent supercontinuum generation in photonic crystal fber with all-normal group velocity dispersion,*" Optics Express, **Vol. 19,** pp. 4902-4907, (2011).

[12]. G. Stepniewski, M. Klimczak, H. Bookey, B. Siwicki, D. Pysz , R. Stepien , A.K. Kar, A.J. Waddie, M.R. Taghizadeh and R. Buczynski, "*Broadband supercontinuum generation in normal dispersion all-solid photonic crystal fiber pumped near 1300nm*," Laser Physics Letter, **Vol. 11**, pp. 1-6, (2014).

[13]. R. Buczynski, H. Bookey, M. Klimczak, D. Pysz, R. Stepien, T. Martynkien, J.E. McCarthy, A.J. Waddie, A.K. Kar and M.R. Taghizadeh, "*Two octaves supercontinuum generation in lead-bismuth glass based photonic crystal fiber*," Materials, **Vol. 7**, pp. 4658-4668, (2014).

[14]. H.V. Le, V.L. Cao, H.T. Nguyen, A.M. Nguyen, R. Buczyński and R. Kasztelanic, "*Application of ethanol infiltration for ultraflattened normal dispersion in fused silica photonic crystal fibers*," Laser Physics, **Vol. 28** , pp. 1-8, (2018).

[15]. D. Lorenc, M. Aranyosiova, R. Buczynski, R. Stepien, I. Bugar, A. Vincze, and D. Velic, "*Nonlinear refractive index of multicomponent glasses designed for fabrication of photonic crystal fibers*", Applied Physics B, **Vol. 93**, pp.531-538, (2008).

[16]. E. Sani, and A. Dell'Oro, *"Spectral optical constants of ethanol and isopropanol from ultraviolet to far infrared,"* Optics Materials. **Vol. 60**, pp. 137–141, (2016).

[17]. D. Pysz, I. Kujawa, R. Stepien, M. Klimczak, A. Filipkowski, M. Franczyk, L. Kociszewski, J. Buniak, K. Harany, and R. Buczynski, "*Stack and draw fabrication of soft glass microstructured fiber optics*," Bulletin of the Polish Academy of Sciences, Technical Sciences, **Vol. 62(4)**, pp. 667-682, (2014).

[18]. R. Buczynski, I. Kujawa, R. Kasztelanic, D. Pysz, K. Borzycki, F. Berghmans, H. Thienpont, and R. Stepien, "*Supercontinuum generation in all-solid photonic crystal fiber with low index core,"* Laser Physics, **Vol. 22(4)**, pp. 784-790, (2012).

[19]. H.L.Van, H.T. Nguyen, Q.H. Dinh, and V.C.Long, "*Influence of temperature and concentration of ethanol on properties of borosilicate glass photonic crystal fiber infiltrated by water – ethanol mixture*," Communication in Physics, **Vol. 28(1)**, pp. 61-73, (2018).

[20]. S. Kedenburg, M. Vieweg, T. Gissibl, and H. Giessen, *"Linear refractive index and absorption measurements of nonlinear optical liquids in the visible and near-infrared spectral region,"* Optical Materials Express, **Vol. 2 (11)**, pp.1588-1611, (2012).

[21]. J.C. Reis, I.M. Lampreia, A.F. Santos, M.L. Moita, and G. Douheret, *"Refractive index of liquid mixtures: theory and experiment"*, ChemPhysChem, **Vol. 11(17)**, pp. 3722–3733, (2010).

[22]. V.T. Hoang, R. Kasztelanic, A. Anuszkiewicz, G. Stepniewski, A. Filipkowski, S. Ertman, D. Pysz, T. Wolinski, K.D. Xuan, M. Klimczak, and R. Buczynski, *"All-normal dispersion supercontinuum generation in photonic crystal fibers with large hollow cores infiltrated with toluene,"* Optics Materials Express, **Vol. 8**, pp. 3568-3582, (2018).

[23]. J.M. Dudley, G. Genty, and S. Coen, "*Supercontinuum generation is photonic crystal fiber,*" Review of Modern Physics, Vol. 78, pp.1135-1184, (2006).

[24]. K.J. Blow, and D. Wood, *"Theoretical description of transient stimulated Raman scattering in optical flbers,"* IEEE J. Quantum Electron., **Vol. 25**, pp. 2665-2673, (1989).

TÓM TẮT

PHÁT SIÊU LIÊN TỤC TRONG SỢI TINH THỂ QUANG TỬ LÕI ĐẶC ĐƯỢC LẤP ĐẦY BỞI HỖN HỢP CHẤT LỎNG NƯỚC-RƯỢU.

Trong bài báo này, chúng tôi trình bày kết quả nghiên cứu số sự phát siêu liên tục của sợi tinh thể quang tử lõi đặc được lấp đầy bởi hỗn hợp chất lỏng nước-rượu. Sợi tinh thể quang tử được chế tạo bằng thủy tinh mềm NC21, nó bao gồm 7 vòng lỗ khí được lấp đầy bởi hỗn hợp nước-rượu. Chúng tôi cũng xem xét ảnh hưởng của nồng độ rượu đối với độ tán sắc của mode cơ bản. Quá trình phát siêu liên tục được tiến hành trong chế độ tán sắc thường cho sợi tinh thể quang tử dài 20 cm với xung bơm 200 fs, năng lượng bơm 0,5 nJ ở bước sóng trung tâm 1064 nm. Nồng độ ethanol xâm nhập vào sợi tinh thể quang tử, xung thời gian và năng lượng bơm cũng được khảo sát.

Từ khóa: Sợi tinh thể quang tử; Tán sắc; Chiết suất; Hỗn hợp nước-rượu; Thủy tinh mềm.

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