Design and Simulation for Ultra High Soliton Pulse Compression through Photonic Crystal Fiber

R. Vasantha Jayakantha Raja, S. Sivabalan, and K. Porsezian

Citation: AIP Conference Proceedings **1055**, 163 (2008); doi: 10.1063/1.3002530
View online: http://dx.doi.org/10.1063/1.3002530
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1055?ver=pdfcov
Published by the AIP Publishing

Design and Simulation for Ultra High Soliton Pulse Compression through Photonic Crystal Fiber

R. Vasantha Jayakantha Raja[a], S.Sivabalan[b] and K. Porsezian[a*]

[a]*Department of Physics,Pondicherry University, Pondicherry-605 014, India*
[b]*School of Electrical Sciences, VIT University Vellore, Tamil nadu - 632 014, India*

Abstract. In this paper, we intend to investigate the pulse compression through liquid core photonic crystal fiber (LCPCF) by using both finite element method (FEM) and split step Fourier method (SSFM). In order to achieve ultra high pulse compression, we propose new LCPCF design with very high nonlinearity. By using numerical analysis, we investigate the pulse compression, compression ratio and pedestal energy for different core liquids in LCPCF using a generalised nonlinear Schrodinger equation (NLSE). Finally, we compare the results with different designing parameters of PCF.

Keywords: Soliton Pulse compression, split step Fourier method and photonic crystal fiber.
PACS: Replace this text with PACS numbers

INTRODUCTION

In recent years, significant attention has been drawn towards liquid core photonic crystal fiber (LCPCF) research, due to its potential applications in various fields of nonlinear application [1]. The filling of liquids in core region of PCF leads to unique optical properties such as ultra flattened dispersion, tailored mode area, broadband single-mode guidance, high birefringence, large or ultra small effective areas, large nonlinearity, etc [2]. It is possible to achieve different effective refractive indices by use of different liquids to fill in the core of PCF. Many properties of PCFs, such as dispersion, effective area and nonlinearity are adjustable by filling different liquids in the core. In LCPCF, the refractive index difference between core and cladding is much higher than in silica core PCF. The nonlinearity of the fiber is inversely proportional to the effective area of the mode of the LCPCF. In a PCF, it is well known that the size of the air hole and hence its effective area is the control parameter to adjust dispersion as well as nonlinearity. The recent widespread research on pulse compression in PCF was mainly motivated by their nonlinear optical applications. Among these applications, soliton pulse compression in PCF with different structure is attracting many researchers. It has been found that PCFs have large dispersion compared to silica fibers. Hence, the soliton dynamics could be studied on length scales of centimeters. The main objective of this paper is to propose new PCF design in order to achieve ultra high pulse compression. In this paper, we calculate the dispersion and nonlinear coefficients by using finite element method (FEM). The numerical method FEM which solves the vector wave equations and SSFM solves NLSE with exponentially decreasing dispersion profile for the different designing parameter are employed to investigate the pulse compression in PCF. We report all these effects for different core liquids.

DESIGNING HIGH NONLINEAR PHOTONIC CRYSTAL FIBER

We calculate the propagation constant of two different liquid PCFs where the core region is filled with nitrobenzene and carbon disulfide (CS_2). The FEM is a widely used numerical method that provides a full vectorial analysis of the electromagnetic field of the propagating modes in PCF. Here, we analyse effective refractive index of PCF on the basis of FEM. The PCF is characterized by the pitch of the air-holes (Λ) and the diameter of the air hole (d=2a). Previously, Raman lasing characteristics of PCFs have been investigated by Shalilendra et al., where the studied PCF showed high nonlinearity whose parameters are $d/\Lambda=0.8$ and $\Lambda=2.1\mu$m [3]. Adopting idea from that paper, we have designed new PCF by filling the liquid at the core region as shown in the Fig.1.

CP1055, *1st Workshop on Specialty Optical Fibers and Their Applications,* edited by C. M. B. Cordeiro and C. J. S. de Matos

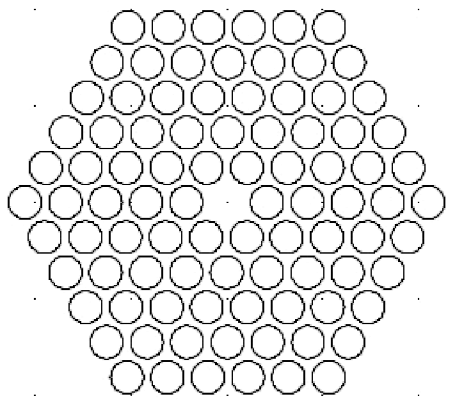

FIGURE 1. (a) Schematic diagram of the silica core PCF with air hole diameter d and Period Λ; (b) Liquid core PCF consisting CS2 or nitrobenzene at the core region

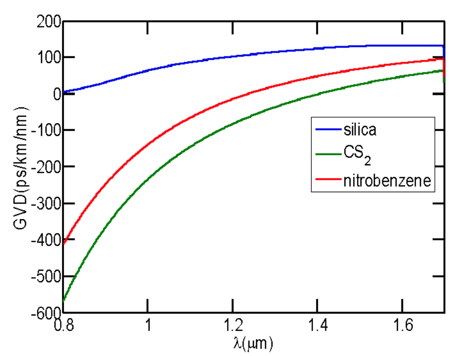

FIGURE. 2

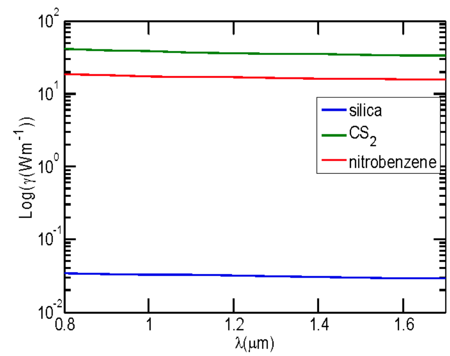

FIGURE.3

Variation of dispersion (Fig.2) and nonlinearity (Fig.3) for different core materials

Using the FEM, as the value of refractive index of nitrobenzene and CS_2 is high compared to that of silica, the effective refractive index of the liquid filled PCF is higher than the solid core PCF. From the dispersion relation, we have calculated group velocity dispersion (GVD) for nitrobenzene and CS_2. The change of GVD as a function of λ for different liquids with d/Λ= 0.8 and Λ=2.1μm is obtained as shown in Fig. 2. Fig. 3 shows the calculated wavelength dependence of the nonlinearity for various core region in PCF, where the nonlinearity is calculated in logarithmic scale due to high variation in LCPCF than in silica core PCF. The maximum effective area supported by a PCF depends on the liquid filled in the core and the wavelength λ. If the effective area is increased, then the influence of the intensity dependent nonlinearity is found to be reduced. From Fig. 3 it is concluded that the nonlinearity of the LCPCF is few hundred times higher than silica core PCF.

PULSE COMPRESSION IN PHOTONIC CRYSTAL FIBER

To understand the dynamics of pulse compression in PCF, we consider the following NLSE of the form [4]

$$\frac{\partial U}{\partial z} - \sum_{n\geq 2} \frac{i^{n+1}}{n!} \beta_n \frac{\partial^n U}{\partial T^n} = i\gamma |U^2| U \tag{1}$$

with

$$\beta_2(z) = \beta_{20} \exp[-2\alpha_{20}\beta_{20} z] \tag{2}$$

where U is the slowly varying envelope amplitude of the wave, z is the longitudinal coordinate along the fiber in meter, T is the time in the reference frame in ps. The parameter β_2 is the 2^{nd} order dispersion coefficient, α_{20} is the initial chirp. The parameter γ is the Kerr nonlinear coefficient. To investigate soliton propagation in PCF, we numerically solved the Eq. (1) using SSFM with initial envelope of the soliton at z=0 given by $U(0,T)=\sqrt{P_0}\,\mathrm{Sech}(T/T_0)\exp(i\alpha T^2/2)$. Fig. 4 shows the pulse compression for CS_2 and nitrobenzene at the wavelength of 1.5 μm. The impact of core liquids for pulse compression in PCF is shown in Fig.5, Fig. 6 and Fig.7 with different designing structures. In Fig.4 we plot a sequence of intensity pulses for different core materials where the first pulse is the input pulse. It is clear from this figure that the pulse compression due to induced nonlinear chirp is high with low amplitude for nitrobenzene filled PCF and widest pulse for CS_2 filled PCF. Since very high nonlinearity can be achieved through LCPCF, one can easily achieve ultra high pulse compression by filling the liquids at the core region as shown in Fig.6. Thus, it should be emphasized that our newly designed PCFs are particularly well suited for making nonlinear devices. In addition to the pulse compression, we also explore what is believed to be the existence of pedestal energy in PCF. Fig.7 shows the pedestal energy of the pulse compression in PCF for different liquids and we observed pedestal free compression.

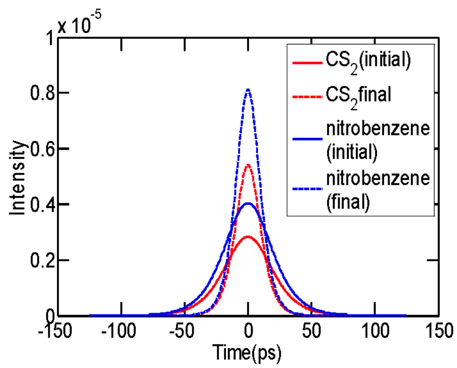

FIGURE.4
Pulse compression

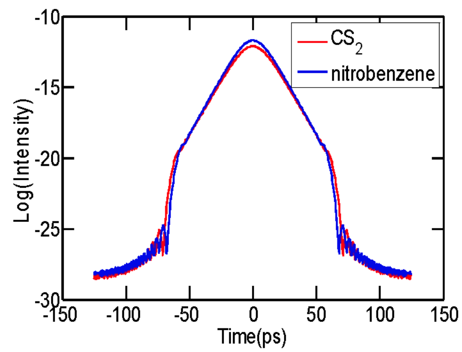

FIGURE. 5
Logrithmic intensity for different core liquids

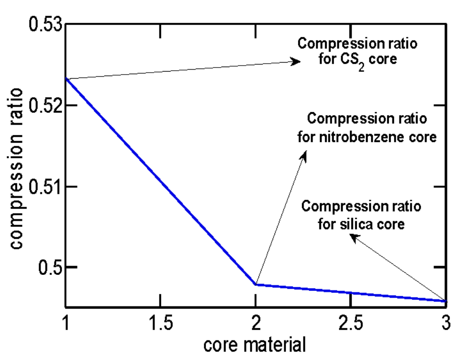

FIGURE.6

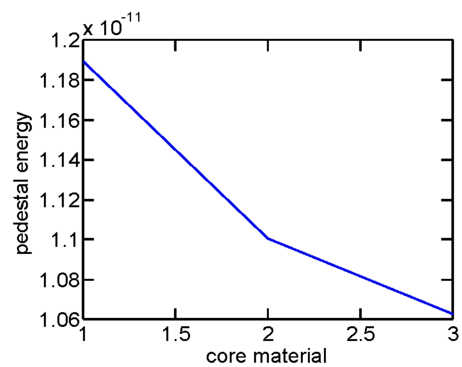

FIGURE.7

Compression ratio and Pedestal energy for different core material where 1, 2 and 3in the x axis for CS_2, nitrobenzene and silica respectively

CONCLUSION

In conclusion, we have applied a FEM and a SSFM to investigate the pulse compression in LCPCF with nitrobenzene and CS_2 core liquids. We have successfully demonstrated that the ultra high pulse compression in LCPCF can be achieved through our newly designed PCF in contrast to compression ratio of silica core PCF being very low. In addition, we have also analyzed the pedestal energy for different core liquids.

ACKNOWLEDGMENTS

KP wishes to thank the IFCPAR (No. IFC/3504-F/2005/2063), CSIR and DST Ramanna Fellowship, Government of India, for the financial support through major projects.

REFERENCES

1.R. Vasantha Jayakantha Raja and K. Porsezian, "A fully vectorial effective index method to analyse the propagation properties of microstuctured fiber," J. Phot. and NanoStruct **5**, 171-177 (2007).
2. R. Zhang, J. Teipel, and H. Giessen, “Theoretical design of a liquid core photonic crystal fiber for supercontinuum generation” Opt. Express, **14**, 6800 -6812 (2006).
3. S.K. Varshney, K.Sasaki, K. Saitoh, and M.Koshiba, “ Design and simulation of 1310nm and 1480nm single mode photonic crystal fiber Raman lasers”, Opt. Express, **16,** 549-559 (2008)
4. K. Senthilnathan, P.K.A. Wai and K.Nakkeeran “Pedestal free energy pulse compression in nonuniform fiber Bragg grating” USA, JWA 19 (1-3) (2007).