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Pulse Compression by Using 7 and 19 Cells 1550 Hollow Core Photonic Crystal Fiber

M. Sura Hussein, Tahreer Safa'a Mansour, H. Yousif Ibrahim and M. Laith Tariq
Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq

Abstract: Pulse compression can be generated high-quality ultrashort pulses at 1550 nm by applying force on the Photonic Crystal Fibers (PCFs). This study focused on the ability of discrimination between two laser pulses that generated by using two core Hollow Core Photonic Crystal Fibers (HC-PCFs) 19 and 7 cells. The first laser source has wavelength 1546.74 nm and FWHM 155.7 ps. While the second laser has wavelength 1551.95 nm and FWHM 183.3 pm. After these two laser pulses propagated via. the two cores of HC-PCFs and applying the mechanical force with different sets on the cross sections of these fibers. The central wavelength will be shifted and FWHM will be changed. The first laser pulse, minimum Full Width at Half Maximum (FWHM) was obtained that is 117.78 ps with central wavelength 1547.06 nm in the case of 2 kg weight applied on the cross section of 7 cells PCF with compression factor 1.3. But for the second laser source minimum FWHM and central wavelength were obtained when the mechanical force of 0.5kg applied on the cross section of 19 cells PCF that are 120.62 pm, 1550.101 nm, respectively with compression factor 1.5. The applying force on the PCF to achieve the exponentially decreasing dispersion and exponentially increasing nonlinearity profiles which turn out to be the fundamental requirements for generating the chirped self-similar pulses.

Key words: 19 cells, 7 cells, pulse, compression, ultrashort, FWHM

INTRODUCTION

Non-linear optical effects in Hollow-Core Photonic Bandgap Fibers (HC-PBGFs) are an active research topic (Knight, 2003). These fibers allow the propagation of light inan air core and have the property that their guided modes are only permitted for a range of wavelengths that are within the photonic bandgap of the cladding. Recently, HC-PBGFs have been used to deliver and compress high-intensity pulses due to the nature of their air core which presents low non-linearity. These characteristics make HC-PBGFs efficient non-linear tools to be used as soliton fiber compressors (Ouzounov *et al*., 2005; Gerome *et al*., 2007). In these fibers optical pulses propagate in the anomalous Group Velocity Dispersion (GVD) regime of the fiber in such a way compression takes place due to interplay between the effects of Self-Phase Modulation (SPM) and GVD. The compression factor depends on the peak power of the pulse which in turn, determines the soliton order (Agrawal, 2001a, b). The interest of the scientific community has been focused on the development of new technologies of light sources and applications based almost entirely in such kind of fibers.

Several research groups have made important advances both experimentally and theoretically in the understanding of soliton compression and soliton formation as well as its dynamics in HC-PBGFs (Ouzounov *et al*., 2003; Skryabin, 2004; Luan *et al*., 2004). For instance, Ouzounov *et al*. (2005) successfully compressed a 120 fs input pulse into 50 fs pulse by using a 24 cm Xe-filled HC-PBGF. G'erˆome *et al*. also reported the existence of soliton compression. They achieved output pulses of 90 fs from 195 fs input pulses by using 8 m of tapered fiber (Knight *et al*., 2007). Laegsgaard and Roberts studied numerically the soliton formation during the compression of chirped Gaussian pulses in HC-PBGFs. They concluded that the third-order dispersion, TOD is a crucial parameter that prevents the formation of shorter soliton pulses (Laegsgaard and Roberts, 2008; Laegsgaard, 2009). Welch and collaborators demonstrated a temporal compression factor of 12 in a seven-cell hollow-core tapered fiber with a length of 35 m, for picosecond input pulses (Welch *et al*., 2009). On the other hand, SSFS and their applications have also been studied (Ivanov *et al*., 2006; Liu *et al*., 2008). Ouzounov *et al*. (2005) for instance, reported a Soliton Self-Frequency (SSFS) from 1470-1530nm (Ouzounov *et al*., 2003). Making use of such phenomenon, G'erˆome reported a high power tunable femtosecond soliton source of 33 nm wavelength tuneability (Gerome *et al*., 2008). Gorbach and Skryabin studied the dynamics that accompany the soliton propagation in the femtosecond regime in HC-PBGFs. Their model included non-linear responses of both the silica, in the cladding and of the air. They concluded that the strong Raman response of air does not always result in a large SSFS in HC-PBGFs (Gorbach and Skryabin,

Corresponding Author: M. Sura Hussein, Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq

2008). Although, Solution Pulse Compression (SPC) and SSFS have been studied, those studies lack of an analysis of the quality of the output pulse. In a recent study, we studied the effects of tuning the cross-sectionsize of HC-PBGFs on the modal parameters in order to have a fiber structure which promotes pulse compression. The study includes an analysis of the pulse shape quality of the compressed pulse as it propagates along the fiber (Gonzalez-Baquedano *et al*., 2012). In this study, we intend to investigate the possibility of compressing the chirped self-similar solitary type pulses at 1550 nm in exponentially decreasing dispersion and exponentially increasing nonlinearity. The 1550 nm wavelength is chosen because of the low-absorption characteristics of the silica material used in fibers. To the best of results, only one weight from the forces applying on the fiber through self-similar conditions has been exploited for generating minimum pulses as possible. The pulse compression is quantified by the compression factor that defined by the relation (Agrawal, 2001a, b):

$$\text{Compression Factor}(\text{FC}) = \frac{\text{TFWHM}^{i}/\text{p}}{\text{TFWHM}^{o}/\text{p}}$$

where, $\text{TFWHM}^{i}/\text{p}$ and $\text{TFWHM}^{o}/\text{p}$ are the FWHM of input pulse and output compressed pulse, respectively.

MATERIALS AND METHODS

Experimental setup and operation principle: The experimental setup consists of four parts as shows in Fig. 1, the setup of pulse compression willmainly explain in next subsections.

Laser source: The two lasers diode sources used in this experiment, these sources from Wuhan Shengshi Optical Technology Company.

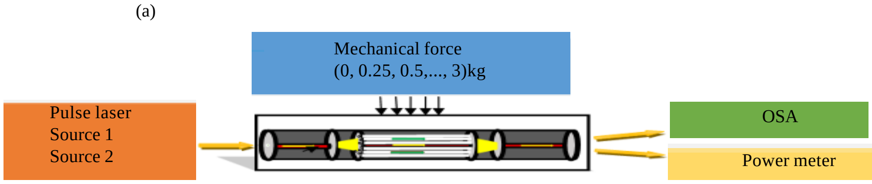
Chopped laser source: The first laser source is CW that chopped electronically. After chopping the laser began having properties as central wavelength was 1546.74 nm, FWHM was 155.7 pm and maximum power output was 3 mW. The electrical circuit which is using for chop and driving for this source consists of 74ls221 monostable multivibrator and different electrical component. The circuit that used for driving and chopping shown in Fig. 2.

Pulse laser source: The second laser source is pulsed laser output with central wavelength 1551.95 nm, FWHM is183.3 pm and having power 25.33 mW. Every laser diode must be controlled by using control circuit for controls values of the current and temperature. The output power depends on the value of the current and the heating device is a point of concern because heating on a certain levels according to the device characteristics is going to cause a mode hopping. Figure 3 explain laser control circuit for laser source 2.

Interferometer fibers: In these experiments two interferometers have been building by using different types of fibers there parameters summarized in Table 1 and these fibers are:

Single mode fiber: Every interferometer consists of two single mode fiber from Corning (SMF-28e) with length 20 cm located in the beginning and ending part of it.

(a)



(b)

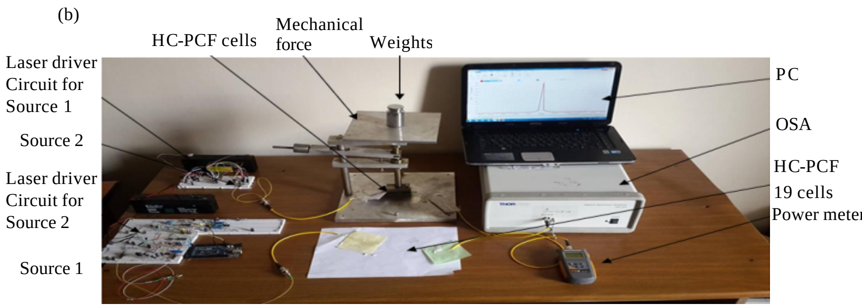


Fig. 1: Experimental setup of pulse compression: a) Schematic diagram and b) Photo of set up in lab

Table 1: Parameters of the fibers

Fibers	Core diameter (µm)	Clad diameter (µm)	Mode field diameter MFD (µm)	Numerical aperture NA (µm)	Air hole diameter	Λ Pitch (µm)
HC19-1550 (19cells)	21	111.856	14	0.4	3.2	4
HC-1550-02 (7cells)	10	116.778	9	0.2	3.2	4
SMF-28	8.2	125	11	0.14	-	-

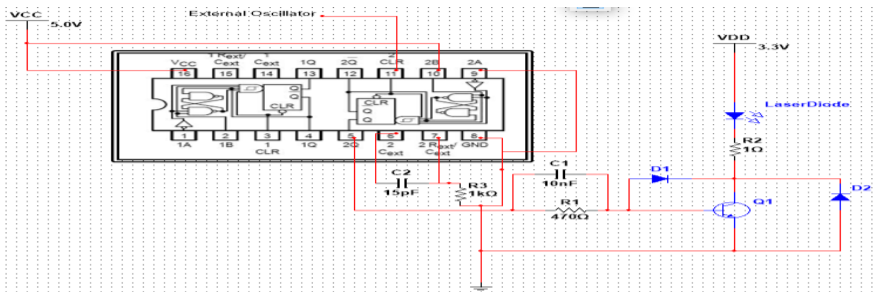


Fig. 2: Schematic for laser driver circuit to source 1

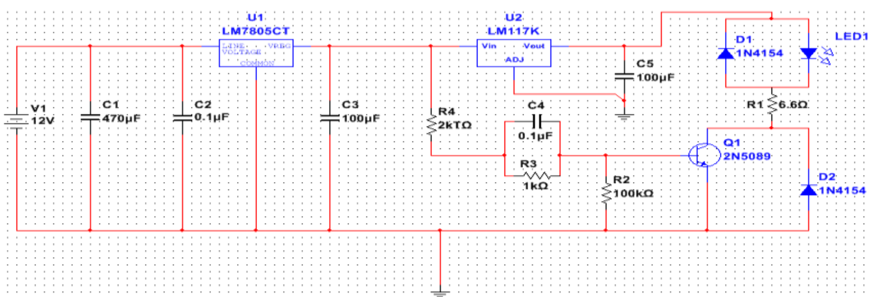


Fig. 3: Schematic for laser driver circuit to source 2

H-PCF (19 cells): In the first interferometer middle part of its used a popular hollow core PCF (HC19-1550) from NKT photonics. The light propagated inside it on the principle of the photonic bandgap effect which can provide very large in size single-mode operation, this fiber has been based on the 19-cell design core formed by omitting 19 central capillaries from the stack when it perform is being built and the Fig. 4 show the cross section of 19 cells HC-PCF under microscope.

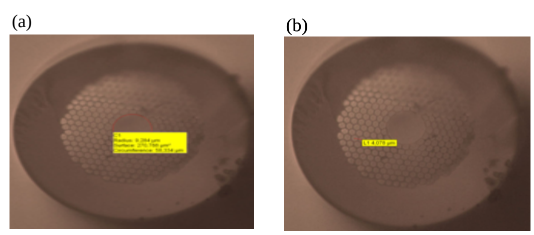


Fig. 4: Images for the cross section for 19 cells under microscope: a) Core diameter and b) The space between two holes (Λ)

H-PCF (7 cells): In the second interferometer used the popular hollow core PCF (HC-1550-02) from NKT Photonics. The light propagated inside it on the principle of the photonic bandgap effect, this fiber has been based on the 7-cells design core formed by omitting 7 central capillaries from the stack when it perform is being built and the Fig. 5 show the cross section of 7 cells HC-PCF under microscope.

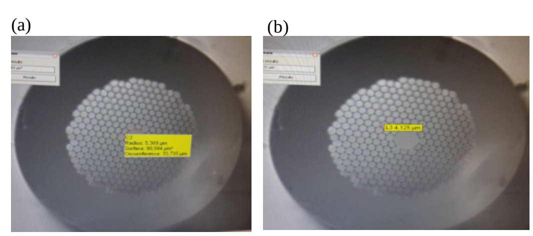


Fig. 5: Images for the cross section for 7 cells under microscope: a) Core diameter and b) The space between two holes (Λ)

During the splicing procedure, the lead-in SMF and HC-PCF were first aligned roughly center-to-center for two fibers cores (SMF and HC-PCF). The splicing was performed using a commercial splice machine under manual mode with arc power value and arc duration time. Thereafter, the same procedure was repeated for splicing other end of the HC-PCF with SMF to complete building for the interferometers.

Mechanical weights: The force is a physical effect applied vertically on the PCF to insure the compression for pulse which propagated through the HC-PCF. It consists of different dimensions of bases from aluminum. The big ground base is considered as bracketed tool. It consisted of two pieces of polished carbon steel or aluminum. Even is appropriate to dimensions of the used bare the PCF.

The purpose of it is to press the bear of the PCF. After pressing, the physical properties of HC-PCF will be changed. The other base is upper base it works as a balance where weights placed on it. The weights that used in these experiments are 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3 kg, Fig. 6 shows the image for mechanical force and different weights.

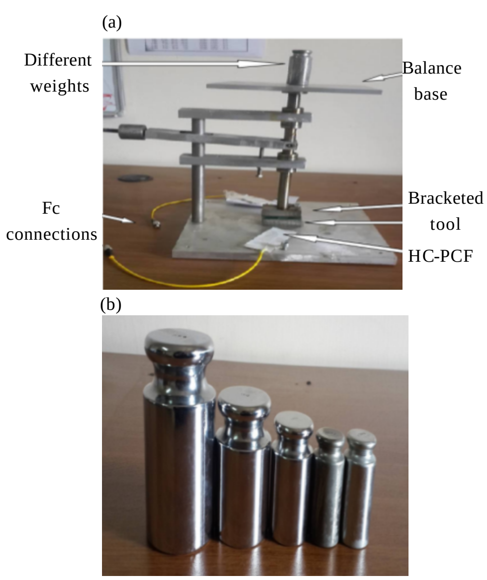


Fig. 6: Mechanical force: a) Image of machine and b) Different weights

Spatial light visualize: Optical Spectrum Analyzer (OSA) made from Thorlabs (202A) with wavelength range 600-1700 nm and the spectrum visualizer is connected to computer to control and visualize the system parameters. The other visualize is optical Power Meter (PM-102A) used to measured power output.

RESULTS AND DISCUSSION

In order to obtain the pulse compression the lunched pulses from sources 1 and 2 used with HC-PCF (19, 7) cells and applied physical effect on PCF. Figure 7 shows the transmission spectrum of laser source 1 and output pulse after propagated through 19 and 7 hollow core photonic crystal fibers.

Figure 8 shows the transmission spectrum of laser source 2 and output pulse after propagated through 19 and 7 hollow core photonic crystal fibers.

It's very clear from Fig. 7 and 8, the effect of the 19 and 7 cell on laser source is blue shifting in its spectrum for 19 cells and red shifting for cells. After applying the physical effect (mechanical force) with different weights the distance between the holes (pitch E) of these two photonic crystal fiber will be affected and we obtain a new fibers design that are also effect on the laser pulse that propagated via. these fiber. Figure 9 shows the comparison between the pulse of laser source 1 before propagate via. 19 cells and after propagate via. 19 cells and the minimum FWHM obtained from applying force from weight (0.25 kg) on 19 cells.

Figure 10 shows the spectrum of the pulse laser from source 1 which propagate via. 7 cells before applying weight on HC-PCF and minimum pulse obtained after applying force from weight (2 kg).

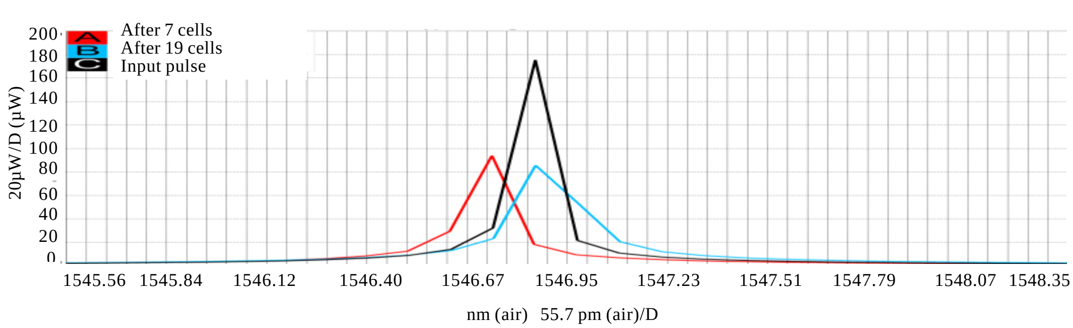


Fig. 7: The pulse of laser source1 before and after propagated in a 19 and 7 cell hollow core photonic crystal fiber: spectrum nm (air) Lin thoriabs OSA, Version 2.55.1299.3162

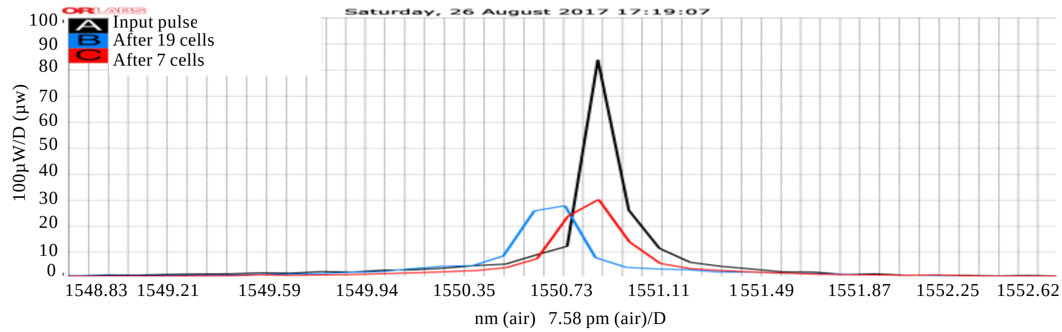


Fig. 8: The laser source 2 before and after propagated in a 19 and 7 cell hollow core photonic crystal fiber: spectrum nm (air) Lin thoriabs OSA, Version 2.55.1299.3162

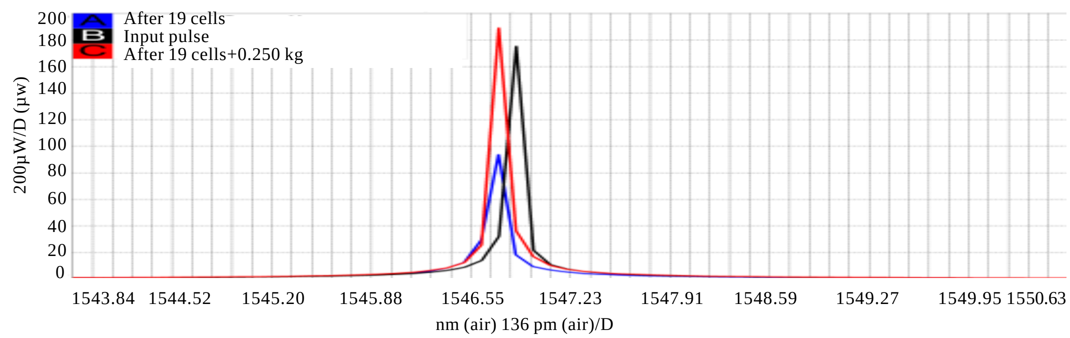


Fig. 9: Thespectrum for pulse laser of source 1 that propagate via. 19 cells: spectrum nm (air) Lin thoriabs OSA, Version 2.55.1299.3162

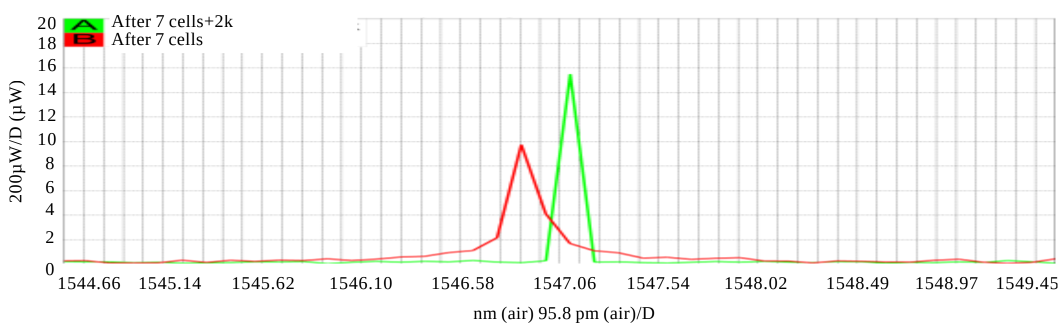


Fig. 10: The spectrum for pulse laser of source 1 that propagate via. 7 cells: Spectrum nm (air) Lin thoriabs OSA, Version 2.55.1299.3162

Figure 11 demonstrates the comparison between the pulse of laser source 2 before propagate via. 19 cells and after propagate 19 cells and the minimum FWHM obtained from applying force from weight (0.5 kg) on 19 cells.

Figure 12 demonstrates the spectrum of the pulse laser from source 2 which propagate via. 7 cells before applying weight on HC-PCF and minimum pulse obtained after applying force from weight (3 kg).

Figure 7-12 illustrate different pulses with different properties and in Table 2 will be recognizing the different between these pulses.

We can see from Table 2 the pulses of source 1 and 2 after propagated via. HC-PCF the transmission pulse will be shifted to inversely proportional (blue shift) for 19 cells, red shift for 7 cells and broadening the spectrum due to the optical properties of HC-PCF (high nonlinearities and high dispersion) and there is two splicing region (head and end) of interferometers which change the

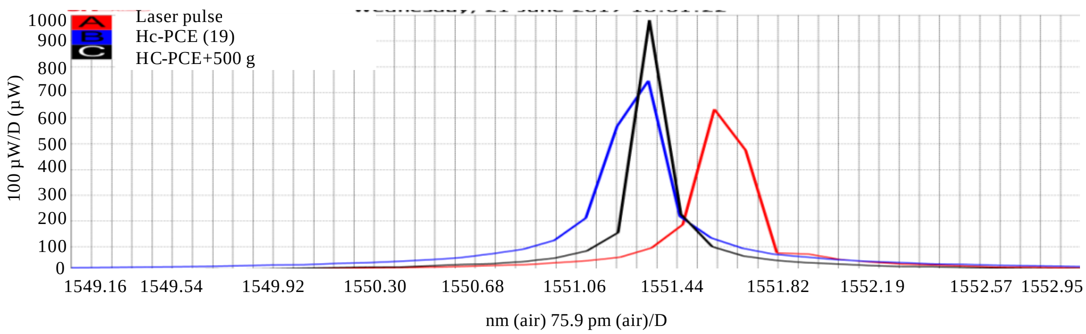


Fig. 11: The spectrum for pulse laser of source 2 before , after propagate via. 19 cells and with applying 500 g: spectrum nm (air) Lin thoriabs OSA, Version 2.55.1299.3162

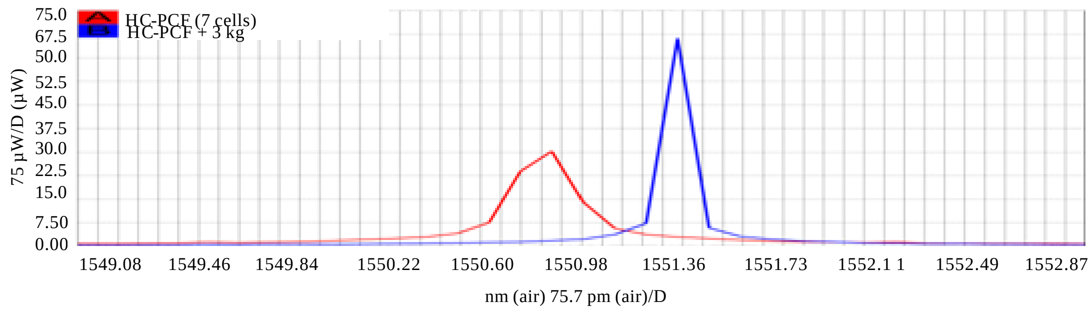


Fig. 12: The spectrum for pulse laser of source 2 that propagate via. 7 cells: spectrum nm (air) Lin thoriabs OSA, Version 2.55.1299.3162

Table 2: The properties of different pulses

Type of pulses	Central wavelength (nm)	FWHM (pm)	Power (mW)
Source 1 after 19 cells	1546.598	203.50	1.43
Source 1 after 7 cells	1546.841	181.97	0.52
Source 1 after 19 cells and 0.25 kg	1546.739	131.50	1.31
Source 1 after 7 cells and 2 kg	1547.06	117.78	0.51
Source 2 after 19 cells	1550.68	270.77	8.50
Source 2 after 7 cells	1550.82	281.00	6.30
Source 2 after 19 cells and 0.5 kg	1551.101	120.62	7.63
Source 2 after 7 cells and 3 kg	1551.217	129.69	6.07

polarization for the modes that transmitted via. PCF and caused polarization mode dispersion. But the broadening in the spectrum of the pulse when using source 2 more than when using source 1 because of different power of them make different nonlinearities for every source. After applying force from different weight the reduction of the cross-section size of HC-PCF results in that the non-linear parameters increased and (second-order, third-order) dispersion decreased and takes highly-anomalous value these get compressed with different compression factors for every case of weights as shown in Fig. 13 and 14 which illustrate for source 1 and 2, respectively.

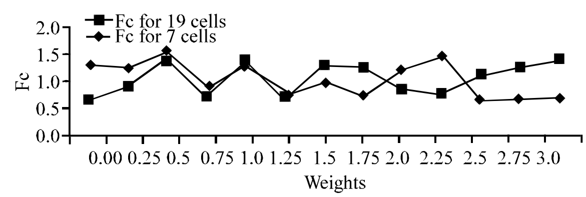


Fig. 13: The relation between weight and compression factor for source 1

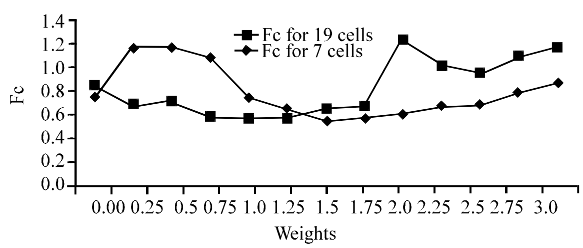


Fig. 14: The relation between weight and compression factor for source 2

Finally, Fig. 15 and 16 illustrate the relation between FWHM and weights these used for compression for source 1 and 2, respectively.

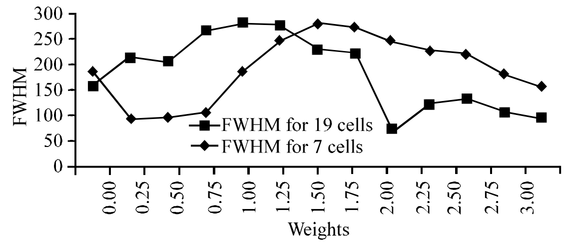


Fig. 15: The relation between FWHM and weight for source 1

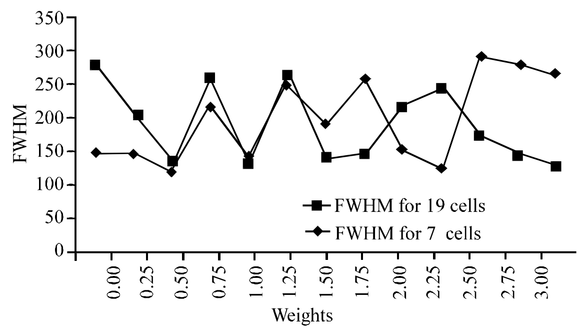


Fig. 16: Relation between FWHM and weight for source 2

CONCLUSION

Pulse compression was obtained using different core size of HC-PCF. Narrow laser pulses were obtained that are very useful in high data rate optical communication systems. Pulse compression factor is a good indication for obtaining a narrow laser pulse with different core size of HC-PCFs after controlling their parameters with external mechanical force. With laser source 1 a very narrow output optical pulse was obtained in the case of 7 cell and weights 2 kg with Fc equal to 1.3. But in the case of laser source 2 narrow pulse was obtained after applying 0.5 kg weight on 19 cells HC-PCF cross section with 1.5 compression factor. So, a very narrow laser pulse was obtained in the 7 cells core size HC-PCF.

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