

Chapter Four

Results and Discussion

4.1 Introduction

When the laser pulse propagate inside the fiber its spectral width must be changed, either to be narrowing or broadening due to these physical phenomenon self phase modulation, cross phase modulation, group velocity dispersion and four wave mixing.

This chapter includes the experimental results and discussion, related to the spectral width of laser pulses in different temperatures before and after passing the fiber, the results are represented by tables and figures.

4.2 Omega xp laser results

In this section we presented the two wave lengths (675 and 820 nm) results from omega xp laser source with three repetition pulses (1, 5, 10 KHz) and three duration pulses (105, 35 and 25 μ s) respectively.

4.2.1 The 675 nm wavelength and 1 KHz results

We measured the pulse output spectrum at different temperatures using CCS 200 spectrometer from Thorlabs. In order to measure the spectral width variation, the laser output pulses from the fiber were directed towards the CCS 200 spectrometer.

The laser pulse with 675 nm and 30 mW average power entering the hollow core photonic crystal fiber with 0.27 m length has an initial pulse duration 105 μ s, 1 KHz repetition rate and **1.7247 nm** Bandwidth measured

with a resolution of 2 nm. The experimental shapes for different temperatures are shown in figs (4.1) - (4.5) here the black line represents the input pulse while the red line is output pulse

Figure (4.1): the spectral width of laser pulse with 105 μ s pulse duration before and after passing fiber at room temperature and 40°C

Figure (4.2): the spectral width of laser pulse with 105 μ s pulse duration before and after passing fiber at 45⁰C and 50⁰C

Figure (4.3): the spectral width of laser pulse with 105 μ s pulse duration before and after passing fiber at 55^oC and 60^oC

Figure (4.4): the spectral width of laser pulse with 105 μ s pulse duration before and after passing fiber at 65^oC and 70^oC

Figure (4.5): the spectral width of laser pulse with 105 μ s pulse duration before and after passing fiber at 75⁰C and 80⁰C

4.2.2 The 675 nm wavelength and 5 KHz results

The laser pulse with 675 nm and 30 mW average power launched to the hollow core photonic crystal fiber with 0.27 m length has an initial pulse duration 35 μ s, 5 KHz

repetition rate and 1.9658. The spectral lines for the laser pulses at different temperatures are shown in figures (4.6) to (4.10)

Figure (4.6): the spectral width of laser pulse with 35 μ s pulse duration before and after passing fiber at room temperature and 40°C

Figure (4.7): the spectral width of laser pulse with 35 μ s pulse duration before and after passing fiber at 45^oC and 50^oC

Figure (4.8): the spectral width of laser pulse with 35 μ s pulse duration before and after passing fiber at 55⁰C and 60⁰C

Figure (4.9): the spectral width of laser pulse with 35 μ s pulse duration before and after passing fiber at 65⁰C and 70⁰C

Figure (4.10): the spectral width of laser pulse with 35 μ s pulse duration before and after passing fiber at 75⁰C and 80⁰C

4.2.3 The 675 nm wavelength and 10 KHz results

The experimental figures (4.11) – (4.15) are representing the spectral width variation of 10 KHz repetition rate and 25 μ s pulse duration of laser operating at centered 675 nm wavelength after passing 0.27m fiber length .

Figure (4.11): the spectral width of laser pulse with 25 μ s pulse duration before and after passing fiber at

room temperature and 40°C

Figure (4.12): the spectral width of laser pulse with 25 μ s pulse duration before and after passing fiber at 45°C and 50°C

Figure (4.13): the spectral width of laser pulse with 25 μ s pulse duration before and after passing fiber at 55°C and 60°C

Figure (4.14): the spectral width of laser pulse with 25 μ s pulse duration before and after passing fiber at 65⁰C and 70⁰C

Figure (4.15): the spectral width of laser pulse with 25 μ s pulse duration before and after passing fiber at 75⁰C and 80⁰C

The spectral width of the pulse was broadened for all repetition rates and pulse durations due to Kerr effect. Figure (4.16) illustrates the relation between the variations in the spectral width for 675 nm and the temperature.

Figure (4.16): spectral width variation of laser pulse (675 nm) at three repetition rates in different temperatures.

Table (4.1): The numerical values of spectral width variation of 675 nm wavelength at 1, 5 and 10 KHz repetition rate with 105, 35 and 25 μ s pulse duration respectively.

T (°C)	$\Delta\lambda$ (nm) at 1KHz	$\Delta\lambda$ (nm) at 5 KHz	$\Delta\lambda$ (nm) at 10 KHz
80	2.0348	2.7266	2.4125
75	2.5307	2.6935	2.5555
70	1.9291	2.1159	2.2477
65	2.0690	2.1885	2.7216
60	2.3679	2.5888	2.1083
55	1.7434	2.1482	2.0985
50	2.1896	2.6059	2.7014
45	2.0433	2.4939	2.3570
40	2.2207	2.0870	1.4150
room	2.2270	3.7011	2.698
Initial bandwidth	1.7247	1.9658	1.7819

From the table one can see that the pulse spectral width is broadened always after injection in the fiber, but this broadening in spectral width is nonlinear, except the pulse width at 40°C for 10KHz was reduced from its initial value 1.7819 nm to 1.4150 nm because the self phase modulation (SPM) induced phase shift (down chirp), this shift lead to compress the pulse bandwidth at this point.

4.2.4 The 820 nm Wavelength and 1 KHz results

The Infra red spectrum from omega laser source was used. The wavelength is 820nm with 1 KHz repetition rate and 105 μ s pulse duration and 200 mW average power.

Figure (4.17): the spectral width of laser pulse with 105 μ s pulse duration before and after passing fiber at room temperature and 40°C.

Figure (4.18): the spectral width of laser pulse with 105 μ s pulse duration before and after passing fiber at 45⁰C and 50⁰C.

Figure (4.19): the spectral width of laser pulse with 105 μ s pulse duration before and after passing fiber at 55^oC and 60^oC.

Figure (4.20): the spectral width of laser pulse with 105 μ s pulse duration before and after passing fiber at 65^oC and 70^oC

Figure (4.21): the spectral width of laser pulse with 105 μ s pulse duration before and after passing fiber at 75⁰C and 80⁰C

4.2.5 The 820 nm Wavelength and 5 KHz results

The initial spectral width of the laser pulse is 1.8980 nm and after passing the fiber at room temperature the pulse spectral width became 4.2770 nm, as shown in figures (4.22) – (4.26)

Figure (4.22): the spectral width of laser pulse with 35 μ s pulse duration before and after passing fiber at room temperature and 40^oC

Figure (4.23): the spectral width of laser pulse with 35 μ s pulse duration before and after passing fiber at 45^oC and 50^oC

Figure (4.24): the spectral width of laser pulse with 35 μ s pulse duration before and after passing fiber at 55^oC and 60^oC

Figure (4.25): the spectral width of laser pulse with 35 μ s pulse duration before and after passing fiber at 65⁰C and 70⁰C

Figure (4.26): the spectral width of laser pulse with 35 μ s pulse duration before and after passing fiber at 75⁰C and 80⁰C

4.2.6 The 820 nm Wavelength and 10 KHz results

By using 10 KHz repetition rate with pulse duration 25 μ s at average power 200mW the experimental results of the pulse spectral width was broadening after propagating in fiber

with 0.27 m length, The initial spectral width of pulse is 1.8001 nm and became 4.2858 nm after passing the fiber in room temperature. Figure (4.27) – (4.31) shows the experimental shapes.

Figure (4.27): the spectral width of laser pulse with 25 μ s pulse duration before and after passing fiber at room temperature and 40°C

Figure (4.28): the spectral width of laser pulse with 25 μ s pulse duration before and after passing fiber at 45⁰C and 50⁰C

Figure (4.29): the spectral width of laser pulse with 25 μ s pulse duration before and after passing fiber at 55⁰C and 60⁰C

Figure (4.30): the spectral width of laser pulse with 25 μ s pulse duration before and after passing fiber at 65^oC and 70^oC

Figure (4.31): the spectral width of laser pulse with 25 μ s pulse duration before and after passing fiber at 75⁰C and 80⁰C

The spectral width of the pulse was broadened for all repetition rates and pulse durations due to Kerr effect. Figure (4.32) illustrates the relation between the variations in the spectral width for 820 nm and the temperature.

Figure (4.32): spectral width variation of laser pulse (820 nm) at three repetition rates in different temperatures.

Table (4.2): The numerical values of spectral width variation of 820 nm wavelength at 1, 5 and 10 KHz repetition rates with 105, 35 and 25 μ s pulse duration respectively.

T ($^{\circ}$ C)	$\Delta\lambda$ (nm) at 1KHz	$\Delta\lambda$ (nm) at 5 KHz	$\Delta\lambda$ (nm) at 10 KHz
80	3.8399	4.0552	2.8298
75	3.2033	3.0952	2.7871
70	2.2288	3.5173	3.3120
65	2.8824	3.7054	2.6641
60	2.7235	3.3297	3.1236
55	2.9049	2.6075	2.6358
50	2.8375	2.8259	2.7554
45	2.7366	2.8113	2.5873
40	3.0462	2.6019	2.6130

room	3.6572	4.2770	4.2858
Initial bandwidth	1.7681	1.8980	1.8001

It can be seen from the figures (4.1) – (4.32) and tables (4.1) and (4.2) the pulse spectral width is increased by the effect of SPM and GVD after the pulse passes the fiber at different temperatures.

The spectral broadening are arises from the fiber nonlinearities which generate phase shift compensation through the SPM by the optical Kerr effect. While GVD depends on the pulse wavelength, its effect on signal distortion increases the spectral width of pulse, this distortion is arises from the fiber refractive index as wavelength function.

The nonlinearity changes in pulse spectral width at different temperatures occurring due nonlinearity behavior of this fiber type.

by fitting the relation between the spectral width variation and the temperature the nonlinearity behavior of the fiber is clear as shown in figures (4.33) – (4.36).

In figure (4.33) the pulse spectral width is increased with the temperature rise, until the temperature reached 45⁰C, then the relation between the temperature and the spectral width looked as a fixed. The red line represents the fitting relation.

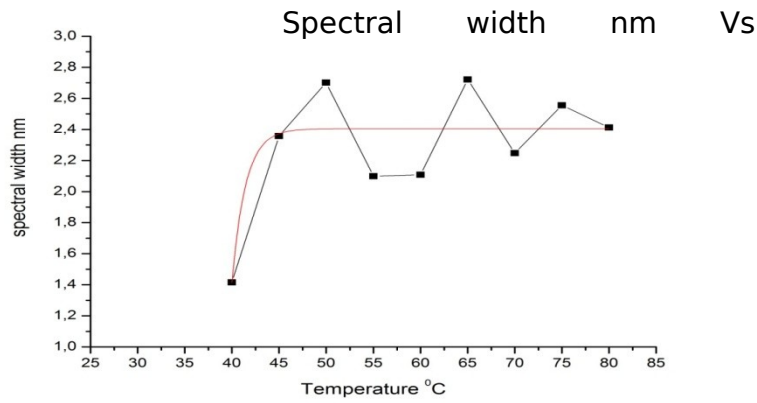


Figure (4.33): the Temperature and the spectral width relation of 675 nm wavelength with 10 KHz repetition rate and 25 μ s duration pulse.

In figure (4.34) the spectral width is broader at 40°C then, it is compressed from the degree 45°C until the 60°C degree, increasing in temperature leads the spectral width to be broadened from 65°C until the temperature reached the degree 80°C.

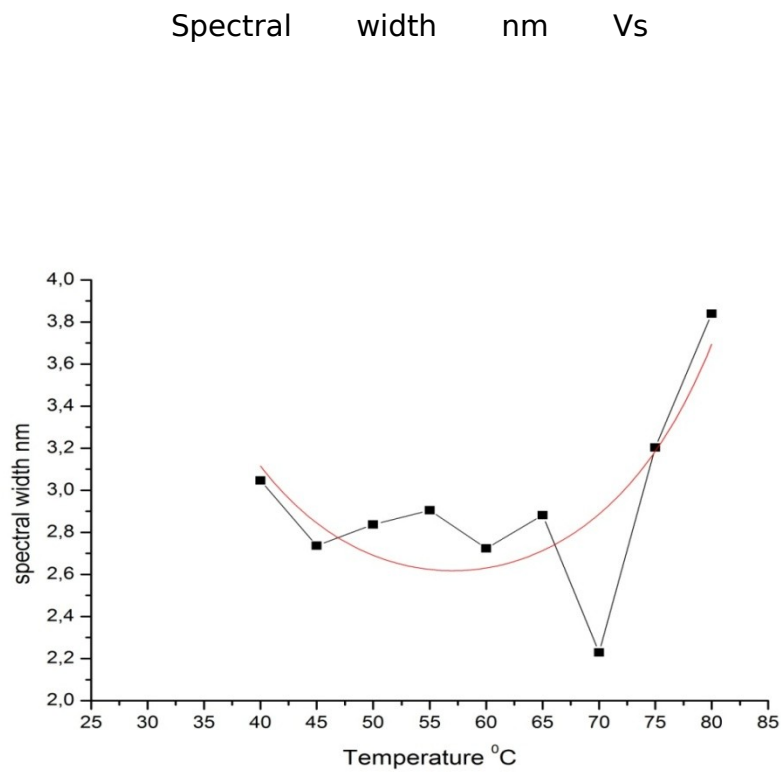


Figure (4.34): the Temperature and the spectral width relation of 820 nm wavelength with 1 KHz repetition rate and 105 μ s duration pulse.

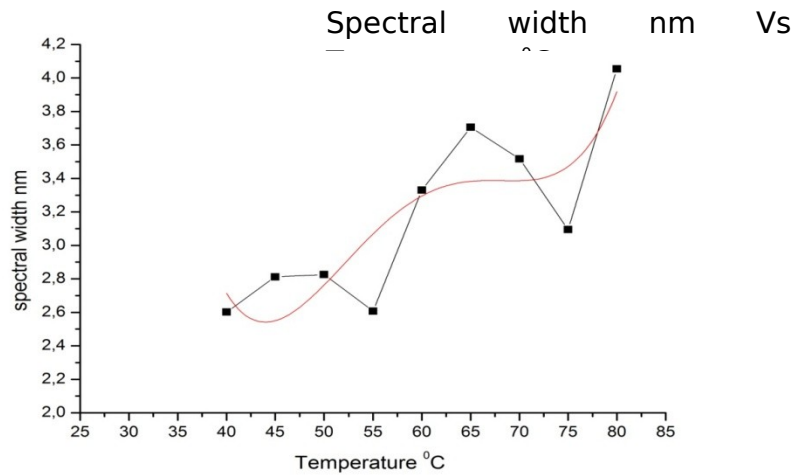


Figure (4.35): the Temperature and the spectral width relation of 820 nm wavelength with 5 KHz repetition rate and 35 μ s duration pulse.

In figure (4.35) we looked that the increased in temperature lead to decreased in spectral width from 40°C to 45°C, then by rise the temperature the spectral width is increased until 65°C, from 65°C to 75°C the relation is fixed then the spectral width increase again with the increase in temperature.

In figure (4.36) the relation between the temperature and the spectral width of the pulse is looked proportional until the temperature become 65°C, then the relation is fixed until 75°C after this degree of temperature the spectral width is decreased with the increase in temperature.

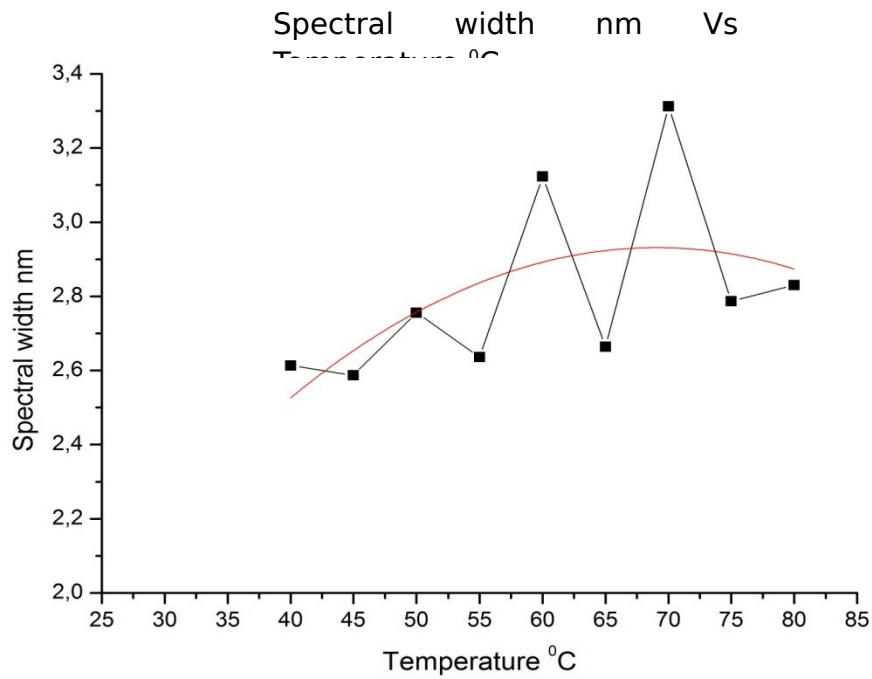


Figure (4.36): the Temperature and the spectral width relation of 820 nm wavelength with 10 KHz repetition rate and 25 μ s duration pulse.

When the pulse propagates inside the fiber, the refractive index changed with intensity due to the optical Kerr effect. The intensity rises at any point in the fiber and then falls as the pulse goes past, this produces a time varying refractive index, this variation in refractive index produces a phase shift this shift leads to produce SPM that generates extra frequencies, these frequencies must be in amplitude picture considered. The SPM, GVD and The Temperature interplay with other fiber nonlinearities to broadening the output pulse spectrum.

4.3 Conclusions

An analysis of the performance of the microsecond laser pulse that propagates in hollow core photonic crystal fiber has been represented.

The results showed that the pulse spectral width is affected with temperature

The spectral width of the pulse is broadened under different set of temperature nonlinearly.

The variation in pulse spectral width is independent for the pulse repetition rate.

The fluctuation in the spectral width variation in different temperature is due to the change in the refractive index which is wavelength function

4.4 Suggestions for future work

1- Study the spectral width narrowing due to Kerr Effect in nonlinear systems.

2- Study the photonic bandgap structure by using liquids to fill the hollow core fiber.

3- Build biosensor from photonic crystal fiber by using blood and urine filled the solid core of this fiber.

4- Study the effect of temperature on the bandgap structure of this type of fiber.