Iraqi J. Laser, issue 1, vol., 21, pp. 34-43 (2022)

IRAQI JOURNAL OF LASER

Temporal Pulse Compression Using Double Cladding Polarization Maintaining Fiber Nested Mach- Zehnder Interferometer

Ahmed U. Kareem[1] , Tahreer S. Mansour[1]

Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq

(Received 19/02/2022; accepted 11/04/2022)

.

Abstract: Narrow laser pulses have been essential sources in optical communication system. High data rate optical communication network system demands compressed laser source with unique optical property. In this work using pulsed duration (9) ns, peak power 1.2297mW, full width half maximum (FWHM) 286 pm, and wavelength center 1546.7 nm as compression laser source. Mach Zehnder interferometer (MZI) is built by considering two ways. First, polarization maintaining fiber (PMF) with 10 cm length is used to connect between laser source and fiber brag grating analysis (FBGA). Second, Nested Mach Zehnder interferometer (NMZI) was designed by using three PMFs with 10 cm length. These three Fibers are splicing to single mode fiber (SMF-28) that has 5cm length. Both designs are etching in Hydrofluoric acid HF 40 percent concentration with three different duration time (10,20 and 30) min. Tunability of this pulsed laser source can be chained after applying different mechanical weights (0,10,50,100,250,500) g are applied to two areas across the fiber; the cross section and splicing regions. It was possible to observe, the maximum excitation of higher order modes for compression factor (FC) was found in splicing region which it is 1.02. this value is recorded under 500g that subjected to the fiber that has 10cm length with 30 min etching. In addition, the thickness cladding was 72.8 µm. also, the maximum peak power for both designs is 90.124 µw and wavelength center is 1546.817 nm.

Keywords: pulse compression, nested fiber interferometer, HF fiber etching, Much Zehnder Interferometer, Polarization Maintaining fiber. Force weight

1. Introduction

optical systems have been an important target by many researchers. Because, it has been applied in many fields. Optical fibers are uses in different applications like fiber sensing, spectroscopic analysis, optical fiber laser, and optically filtering [1]. The Compressed laser source is an essential part for high data rate communication system in the applications of network fiber sensing and wavelength division multiplexing. In this experiment, panda polarization-maintaining fiber(PMF) was used, which is a special type of single mode fiber, designed to transmit only one polarization of the input light. It has a high birefringence with predetermined slow and fast axes. Specification (PMF)operating wavelength range (1440-1625) nm, cutoff wavelength (1370nm), extinction ratio (23) db. [2,3]. The interferometer was subjected to different mechanical forces to compress the optical pulse out from the interferometer and develop a low cost, narrow optical Hussain implemented a pulse compressor using a tunable Mach-Zehnder interferometer made of 7 and 19 hollow fiber optic photonic cells after applying mechanical forces along the fiber cross-sectional area to obtain a compression factor (FC) equal to 2 and 4 for 7- and 19-cell hollow core optical crystal fibers (HC-PCF) respectively [4]. In (2019), Haseda, Yuki Pulse wave signals were measured by POF-FBG and silica-FBG sensors for four subjects. After signal processing, a calibration curve was constructed by partial least squares regression[5]. In Ali A. Dawood used 7 and 19 HC-PCF cells to build the Mach-Zehnder interferometer, but they replaced the air holes with fibers with 25% dilute acrylic acid with 75% ethanol and were able to achieve FC = 4.9[6]. in (2021) using Bara H Muter a tunable narrow pulse laser source using polarization-preserving fibers using the comsol multi-physics dynamic simulation model, version (5.5) to obtain a compression factor (FC) equal to (1.1) [7].

In this paper, two ways are considered to design (MZI). The first method is single fiber (10) cm with different etching (10,20,30) min. The second method is (NMZI) with same etched that mentioned in first method. In section 2, the methodology and procedure are explained deeply. The results are discussed in section 3 with graphs. The paper ended with conclusion in section 4.

1. methodology and procedure

Optical pulse laser source launched to PM-Mach Zehnder Interferometer. PM-MZI was building by using PMF with three constant (10) lengths cm sandwiching between two standard single-mode optical fibers (SMF-28e) with length (5) cm with different etching (10,20,30) min. PMF is design in two ways. the first case the single fiber and other case (NMZI)with etched each two cases The single PM-MZI consists of one PM-MZI that means two micro cavity splicing regions (MCSRs), one cavity length (Lc), the mechanical force in (g) was varied from (0,10,50,100,250,500) (g) applied on the interferometer micro–cavities splicing regions in two cases. The mechanical force was used to tune the phase of the optical communication source. In (2018), Surat signal on one arm of the PM-MZI. The applied forces-imposed stress on the fiber caused elongation in the length of the fiber. The amount of the fiber elongation can be calculated using equations (1)(2),(3) [1].

$$\text{the strain} = \frac{\Delta L}{L} = \frac{stress}{young\ modulus} \qquad (1)$$

$$\text{stress} = \text{Force (N) / Area (m)} \qquad (2)$$

$$F = m \times G \qquad (3)$$

where:

L is the original length.

ΔL is the change in length.

F is the force applied in (N).

A is the cross-sectional area in (m^2).

M is the value of the standard weight mass used to induce mechanical force.

G is the gravitational acceleration.

The obtained experimental results of strain measurement will be divided according to the change length of Polarization maintaining fibers that used in interferometers. The values of the mass in g were converted to the force in N, this conversion process has been evaluated according to equation (3). The increase in the force that applied on the micro-cavity leads to an increase in the strain When the force was applied on PM-MZI cavity in case single PMF and NMZI The elongation for micro cavity splicing region will be reducing of the geometric parameters of PMF, this change of parameters caused decreased the group velocity for all modes which propagated through the core and cladding. In case NMZI switch has a balanced structure, in which the optical path lengths are equal in the three main interference arms, as a result, the bandwidth of the optical process is not limited by the converter structure, that is, broadband performance can be achieved. In general, the interference pattern depends on the optical path length, the offset between the two arms of the interferometer because the base mode has a higher effective index than cladding mode [8]. For the above reasons, we have to calculate the values of the phase differences that give us the three-arm synchronous photon propagation of the NMZI as equation (4) [9,10].

The phase different between the cladding and core mode is described by:

$$\Delta\Phi = \frac{2\pi}{\lambda \Delta n\, L} \quad (4)$$

Where L is the interaction length in cm.

The intensities the cladding and core modes measured function wavelength of physical length.

$$I(\lambda) = I_1 + I_2 + 2\sqrt{I_1 + I_2}\cos(\Delta\Phi) \quad (5)$$

Where I_1+I_2 are the mode intensities of core and cladding modes.

The change in the effective refractive index of the mode can calculated by.

$$\Delta n_{eff} = nx_{eff} - ny_{eff} \quad (6)$$

The beat length, LB, can be calculated in direct relation to the refraction B using equation (7).

$$LB = \frac{2\pi}{\Delta\beta} = \frac{\lambda}{B} \quad (7)$$

where $\Delta\beta$ is the difference between the x and y components of the wave propagation constant along the PMF and n_x, n_y is the effective refractive index as a function of the wavelength of both the x and y polarization component [11].

In other hand the important parameter as a part of fiber characteristics was fiber dispersion, because etching fibers and applied force cause multipath in fiber. There is multipath dispersion inside each arm of NMZI, Rays disperse in time at the output end of the fiber where they were coincident at the input end and traveled at the same speed inside the fiber, this can be estimated by considering the shortest and longest ray paths. The sensing area in the design is represented by the Multimode fiber because of use of different refractive index result etched PMF. the normalized frequency must be obtained according to the following equation (8):

$$V = 2\frac{\pi a}{\lambda}\sqrt{n_1^2 - n_2^2} \quad (8)$$

Where V is normalized frequency [12].

Where a is core radius, λ is wavelength central. In (nm).

The narrower pulse in time domain has the wider spectrum in spatial domain is a very well-known concept in communication. Therefor the figure of merit of this study is characterized by the Temporal compression factor which is the ratio of input signal full width at half maximum to the output signal full width at half maximum.

$$Fc = FWHM_{i/p} / FWHM_{o/p} \quad (9)$$

The temporal FWHM can be obtained from the spatial FWHM using the equation:

$$\text{FWHM (temporal)} = \frac{(\lambda C)^2}{C \times FWHM(\text{spatial})} \quad (10)$$

where: λc central wavelength in nm.

c is the speed of light in vacuum [13].

In this experiment In addition to the use of force applied to two areas in the fiber, the fibers were etched by Hydrochloric acid (HF) of 40 % concentration was used experimentally to etch the polarization maintaining fiber for three different time periods ranged from (10,20,30) min. each step 10min. polarization maintaining fiber has two stress cores parallel to each other. When etching period take longer duration a portion of the two stress cores will be removed and as a consequence; new form of optical fiber will be developed at the etching region. it is important to inform that only 2-3 cm of PMF was etched not the whole 10cm [14].

The work was the installation of two designs. The first is the single fibers, three fibers, each fiber 10 cm long, with different etching time of (10, 20, 30) min, and the authority of different weights (0,10,50 100, 250, 500) on each fiber and on two areas of the fibers (cross section and splicing region) It is the same as the above fibers (SMF), The second design is the same as the first case fibers with the same specifications mentioned and the supplied force, but in the design (NMZI) as block diagram in the below

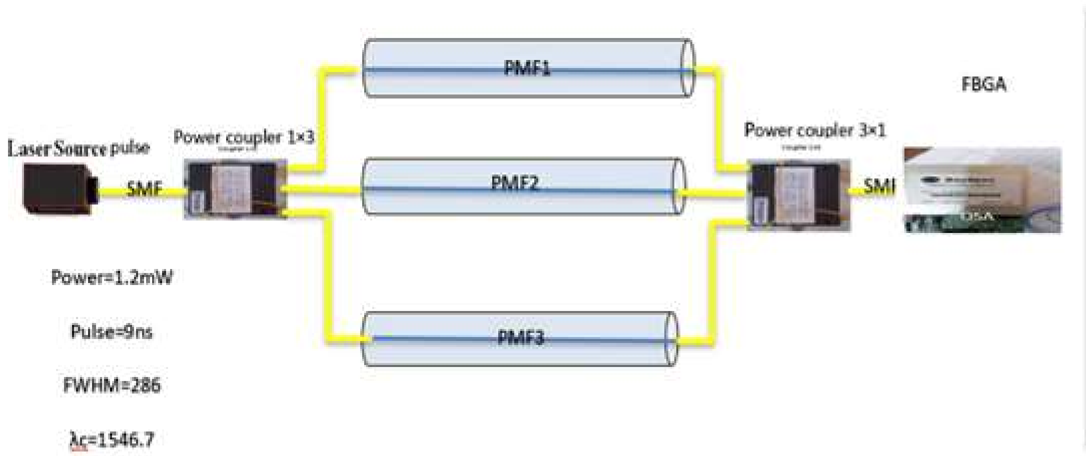


Figure (1): Schematic diagram of Nested PM-MZI

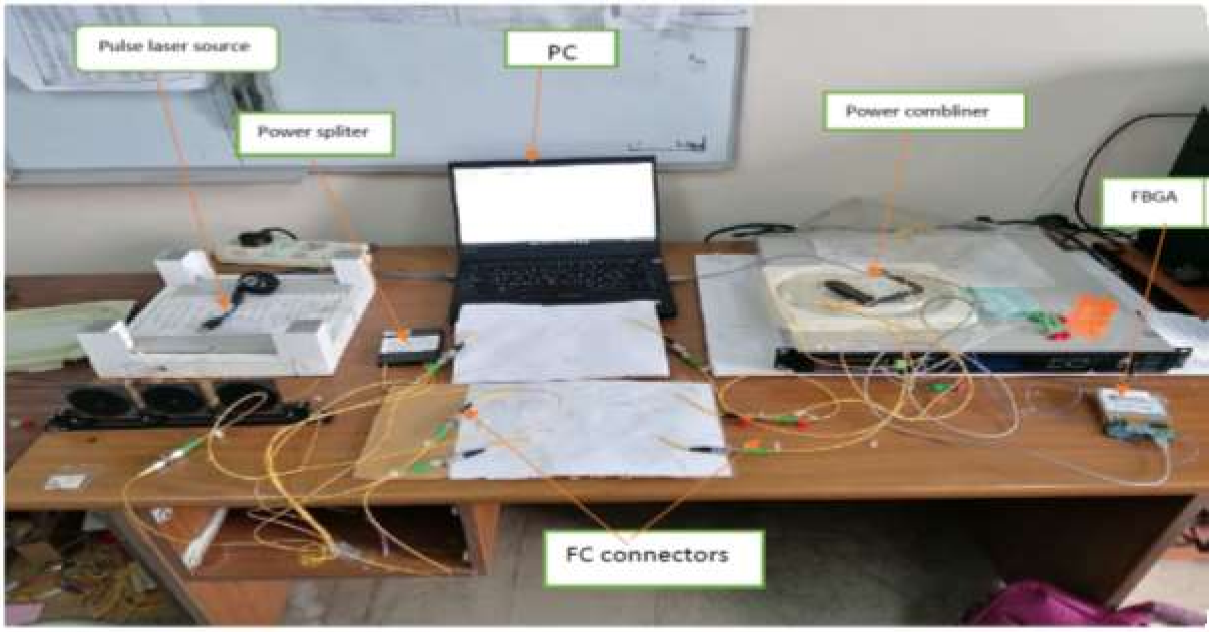


Figure (2): photograph image of the etched PM-NMZI experiment

In this study was used the pulse laser source has peak power 1.2297mW, full wave half maximum (FWHM) 286 pm, and wavelength centered at 1546.7 nm. The measured output wave length, peak power, FWHM, by type from Thorlabs (fiber Bragg grating analysis) Bay spec-FBGA, as in figure (2)

Result and Discussion

The result divide into two parts, the first part is the two designs (single fibers, NZMI) etched without applied force and the second part with applied force.

A. Results for etching effect

The laser beam profile is characterized by its linewidth which is calculated by taking the Full Width at Half Maximum (FWHM) of intensity distribution of laser beam versus wavelength. This work recorded the effect of etching on FWHM. which showed efficient temporal pulse compression for communication networks. The detected peak power was increased with etching for the whole constant fiber length samples, this result arises promising application for the etched PM-MZI in refractive index sensing because the etching process of PMF modified the effective refractive index for the optical fiber. In general, it is known for fiber sensors; the polarization rotation along optical fiber reduces the accuracy of them. Therefore, the obvious power increasing with longer etching duration while the central wavelength is almost fixed can provide more accurate measurements. Table (1) show the results the wavelength, peak power, FWHM and compression factor after the different time etched (10,20,30) to PMF single fiber and NMZI. Note that the length of the fiber used was (10) cm.

Table (1): The change of PMF and NMZI under the etching effect for three-time durations.

Etching period (min)	λc(nm)	Po(mW)	FWWH (pm)	FC	Normalized frequency (V)
10 min	1546.708	0.769	246	1.1	136.56
20 min	1546.725	0.752	227	1.2	158.44
30 min	1546.853	0.696	155	1.8	174.90
NMZI with etching (10,20,30) min	1546.884	0.188	210	1.3	-

When etched PMF the refractive index changes in the cladding. This phenomenon shows the Fiber diameter after etching is change causes different refractive index in the surrounding and can be applied to measure the RI new. When chemical etching ends- the cladding diameter of thinned PMF is obtained about 72.8μm after the etched 30 min. It is worth noticing that Δn is decreased after chemical etching. The benefit of this process is to make all the laser beam inside the core and thus increase temporal pulse compression for communication networks.

The effect of the time periods for etching on fiber we can observe in Figure (3-a,b,c) relationship with wavelength ,peak power and Fiber diameter.

Table (2): show the effect etching to the fiber thickness.

Time of etching	Fiber diameter after etching (μm)	Refractive index
10min	112.1	1.3876
20 min	88.3	1.36253
30min	72.8	1.34122

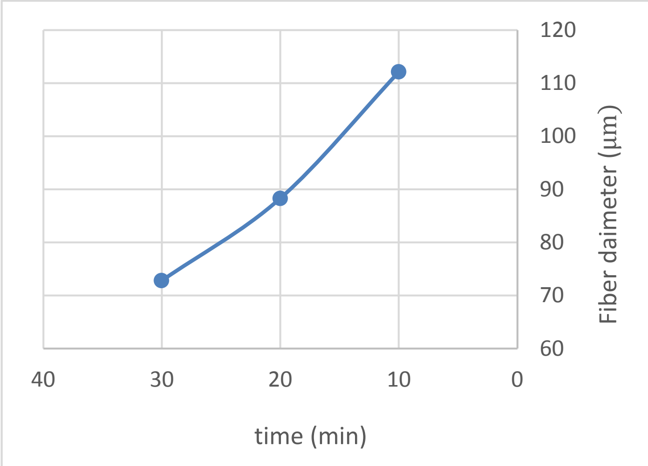


Figure (3-a): The relationship between time etching and fiber diameter (µm).

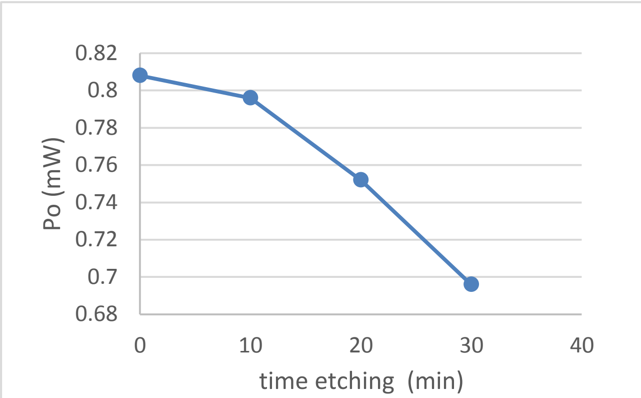


Figure (3-b): The relationship between time etching and peak power.

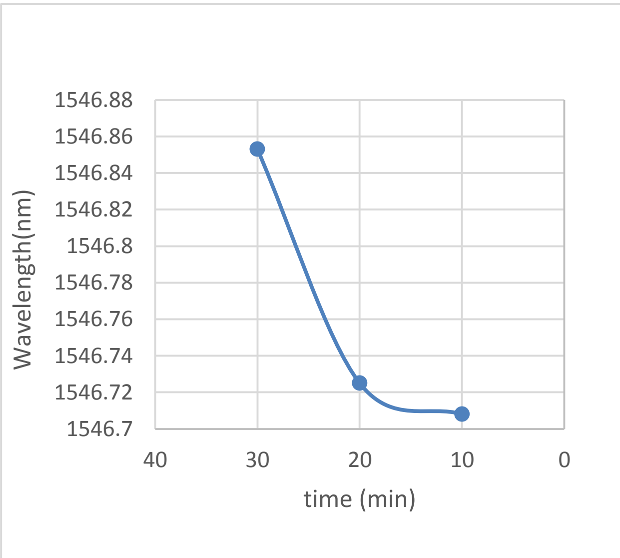


Figure (3-c): The relationship between time etching and wavelength

B. Results for force effect with etching fiber

When the force was applied on PM-MZI as single fiber and nested which is etching. The first case single fiber is the elongation for micro cavity splicing region of PM-MZI will be reducing of the geometric parameters of PMF, this change of parameters caused decreased the group velocity for all modes which propagated through the core and cladding for the fiber and the reducing in parameters of fiber will be changed on the parameters of pulse that propagated through the fiber. The output spectra of PM-Mach Zehnder Interferometer due to the force effect, that was obtained by applying different values of force (0,10,50,100,250,500) on the micro- cavity of PM-MZI with three constant length and different etching time (10,20,30). The increase in the force applied to the micro-cavity leads to an increase in the FWHM. The highest spectral width 280 (pm) has been gained when the PMF was 10 cm length and time etching 30 min applied weight 500 g on micro cavity splicing regions. The second case NMZI the high result record, when applied weight 500 g in splicing region which FWHM 271(PM), compression factor 1.05.

The output spectrum of the PM-Mach Zehnder interferometer was visualized by using Bay spec -FBGA, after applying different mechanical weights, on their micro cavities splicing regions, to measured optical power, wavelength center shift, FWHM, as shown in figure (4-a,b,c).

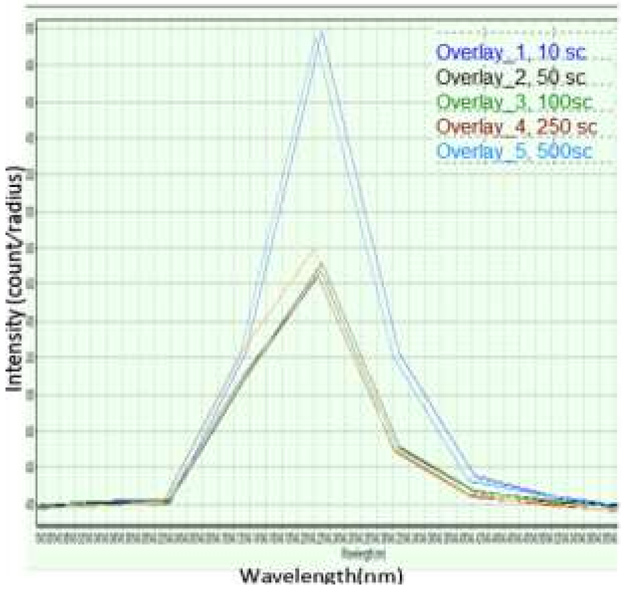


Figure (4-a): The spectrum of the output laser source PM-MZI after applying different weights in case PMF length 10cm and time Etching 10 min on micro cavities

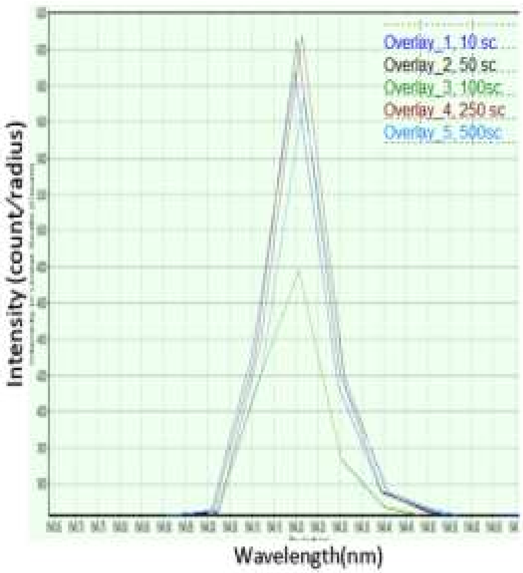


Figure (4-b): The spectrum of t ... fferent weights in case PMF length 10cm and time Etching 2

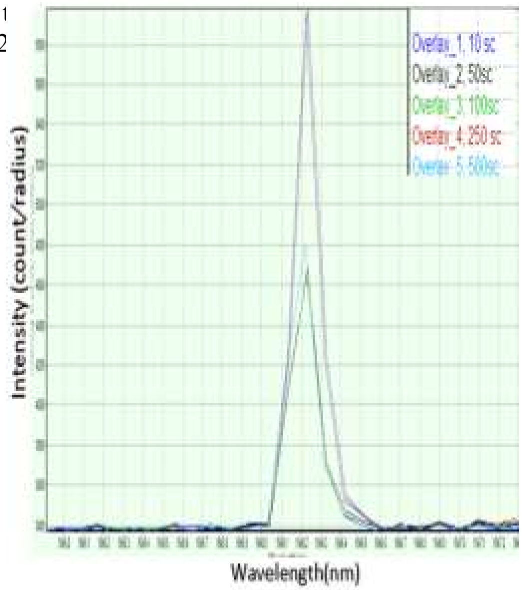
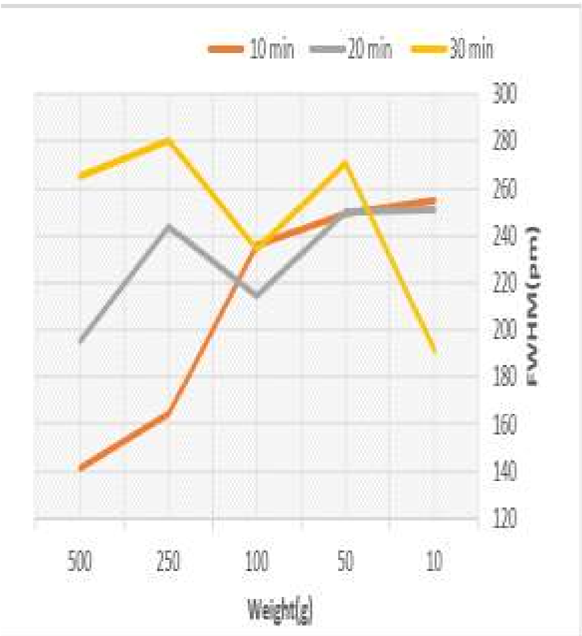
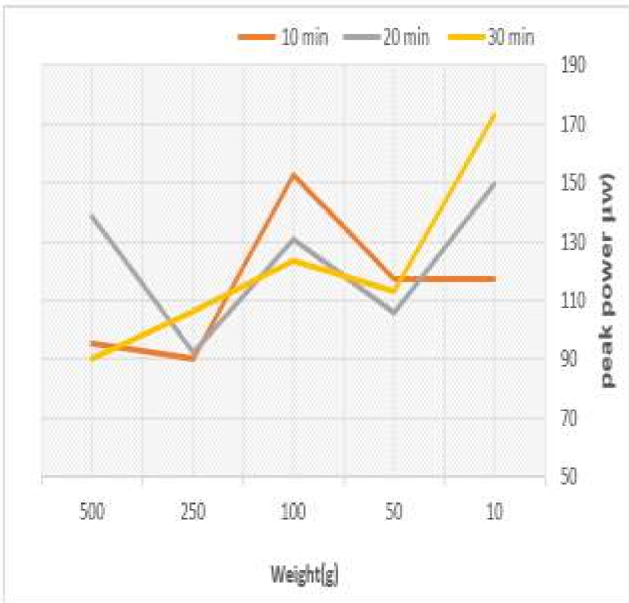


Figure (4-c): The spectrum of the output laser source PM-MZI after applying different weights in case PMF length 10cm and time Etching 30 min on micro cavities.

The increase in the force applied to the micro-cavity leads to an increase in the FWHM. The highest spectral width 280(pm) has been gained when the PMF was 10 cm length, time etching 30 min and 500 g weights applied on micro cavity splicing regions as show in figure (5-a).



Figure(5-a): The Full Width Half Maximum variation of PM-MZI with (10cm), time etched (10,20,30) and different forces applied on micro cavities splicing regions.



Figure(5-b): The peak power variation of PM-MZI with (10 cm),time etched (10,20,30)min and different weights applied on the micro cavities splicing regions.

Figure(5-c): The wavelength variation of PM-MZI with (10 cm) and time etched (10,20,30) different weights applied on the micro cavities splicing region

The wavelength shift of the PM-MZI spectrum is very clear due to the different values of weights applied on the micro-cavity splicing region as shown in figure (5-c).

4. Conclusion

The main points that can be concluded from this work are, the MZI micro-cavities shows high interference and good sensitivity and are thought to be caused by the large force that is applied to a small area and also because of the etch. After etch 10 cm from PMF with (HF) of 40 % concentration was used experimentally to etch the polarization maintaining fiber, these results to give rise to the possibility of getting narrower temporal pulses for communication applications. when the PMF was 10cm in length, etch 30 min and the force (0.00489N) applied on micro cavity splicing regions cause the compression factor 1.01 because this fiber has two stress members which make it highly sensitive to any physical effect. When comparing this experiment with previous experiments in the same field, the following becomes clear: The fibers used in this experiment are short in length and a small number of adaptors, and accordingly we get the least losses, less dispersion, the best temporal compassion factor, and a smaller size (MZI) in terms of the lengths of the linked fibers. In addition to using (NMZI) with applied weights and etch fiber. which gave good results in terms of wavelength, peak power and FWHM.

5. References

[1] A.T. Yahiya and T. S. Mansour, “Tunable band pass Filter based on Nested Mach-Zehnder interferometer,” J. Eng. Applied Sci., Vol.13.pp7450-7458, (2018).

[2] E. Schema, D. Tosi, P. Sacco mandi, E. Lewis, and T. Kim, “Fiber optic sensors for temperature monitoring during thermal treatments: an overview”, Sensors, vol. 16, no. 7, p. 1144, (2016).

[3] Y. Wang, S. Wang, L. Jiang, H. Huang, L. Zhang, P. Wang, L. Lv, and Z. Cao, “Temperature-insensitive refractive index sensor based on Mach-Zehnder interferometer with two micro cavities,” Chin. Opt. Lett., Vol.15, pp.020603, (2017).

[4]M. Sura Hussein, T. S. a. Mansour, H. Yousif Ibrahim, and M. Laith Tariq, “Pulse compression by using 7 and 19 cells 1550 hollow core photonic crystal fiber,” *J. Eng. Appl. Sci.*, vol. 13, no. 17, pp. 7198–7204, 2018, doi: 10.3923/jeasci.2018.7198.7204.

[5]Y. Haseda, J. Bonefacino, H.-Y. Tam, S. Chino, S. Koyama, and H. Ishizawa, “Measurement of pulse wave signals and blood pressure by a plastic optical fiber FBG sensor,” *Sensors*, vol. 19, no. 23, p. 5088, 2019.
[6]A. A. Dawood, T. S. Mansour, and Y. I. Hammadi, “Demonstration of All-Fiber Pulse Compression Using Hollow Core Photonic Crystal Fibers,” *Cont. Math. Sci*, vol. 14, no. 5, pp. 158–169, 2019.
[7]B. H. Mutar, N. F. Noori, Y. I. Hammadi, and T. S. Mansour, “In-line fiber tunable pulse compressor using PM-Mach Zehnder interferometer,” *J. Mech. Eng. Res. Dev.*, vol. 44, no. 5, pp. 287–297, 2021.
[8]A. M. Shrivastav, D. S. Gunawardena, Z. Liu and H. Tam, “Microstructured optical fiber based Fabry–Perot interferometer as a humidity sensor utilizing chitosan polymeric matrix for breath monitoring” Scientific Reports, Vol:10, (2020).
[9] S. Deng, H. Meng, X. Wang, X. Fan, Q. Wang, M. Zhou, X. Guo, Z. Wei, F. Wang, C. Tan, and X. Huang, “ Graphene oxide-film-coated splitting ratio adjustable Mach-Zehnder interferometer for relative humidity sensing”, optics express, Vol. 27, No. 6, (2019).
[10] Q. Wang, W. Wei, M. Guo and Y. Zhao, “Optimization of cascaded fiber tapered Mach–Zehnder interferometer and refractive index sensing technology”, Sensors and Actuators B: Chemical, Vol. 222, pp.159-165, (2016).
[11] M. Chena, Y. Zhao,_, H. Wei and Krishnaswamy, “Cascaded FPI/LPFG interferometer for high-precision simultaneous measurement of strain and temperature”, Elsevier, Vol. 53, No.102025 ,(2019).
[12] L. Zhang, S. Sun, M. Li, and N. Zhu, “All-optical temporal fractional order differentiator using an in-fiber ellipsoidal air-microcavity,” Journal of Semiconder., Vol. 38, No. 12, pp. 126001, (2017).
[13] F. Q. Mohammed, T,S. Mansour and A. W. Abdul wahhab, “ A tunable Mach–Zehnder interferometer based on dual micro‑ cavity photonic crystal fiber for load measurement, ” Photon Newt Common. Vol.38, pp. 270-279 (2019).
[14] X. Dong, H. Du, Z. Luo and J. Duan, “Highly Sensitive Strain Sensor Based on a Novel Mach-Zehnder Interferometer with TCF-PCF Structure” *Sensors*, Vol. 18, No. 1: 278, (2018).

ضغط النبض الزمني باستخدام استقطاب الكسوة المزدوجة للحفاظ على مقياس التداخل ماخ زندر المتداخل بالألياف

احمد عذافه كريم تحرير صفاء منصور

معهد الليزر للدراسات العليا، جامعة بغداد، بغداد، العراق

الخلاصة: كانت نبضات الليزر الضيقة من المصادر الأساسية في نظام الاتصال البصري. يتطلب نظام شبكة الاتصالات الضوئية ذات معدل البيانات العالي مصدر ليزر مضغوط بخاصية بصرية فريدة. في هذا العمل باستخدام مدة نبضيه (9) ns، وقوة الذروة mW1.2297، ونصف العرض الكاملة القصوى 286 (FWHM)، ومركز الطول الموجي 1546.7 نانومتر كمصدر ليزر للضغط. تم بناء مقياس التداخل Mach Zehnder (MZI) من خلال النظر في طريقتين. أولاً، يتم استخدام ألياف الحفاظ على الاستقطاب (PMF) بطول 10 سم للربط بين مصدر الليزر وتحليل شبكة الألياف الضوئية (FBGA). ثانيًا، تم تصميم مقياس التداخل Nested Mach Zehnder (NMZI) باستخدام ثلاثة PMFs بطول 10 سم. تقوم هذه الألياف الثلاثة بالربط إلى ألياف أحادية النمط (SMF-28) يبلغ طولها 5 سم. كلا التصميمين محفور في تركيز حمض الهيدروفلوريك 40 HF في المائة مع ثلاث فترات زمنية مختلفة (10، 20 و30) دقيقة. يمكن ضبط قابلية ضبط مصدر الليزر النبضي هذا بعد تطبيق أوزان ميكانيكية مختلفة (500،250،100،50،10،0) جم على منطقتين عبر الألياف؛ المقطع العرضي ومناطق الربط. كان من الممكن ملاحظة أن أقصى إثارة لأوضاع الترتيب الأعلى لعامل الضغط (FC) تم العثور عليها في منطقة الربط وهي 1.02. يتم تسجيل هذه القيمة تحت 500 جم التي تم تسليطها على الألياف التي يبلغ طولها 10 سم مع نقش 30 دقيقة. بالإضافة إلى ذلك، بلغت سماكة الكسوة 72.8 مايكرومتر. كما أن أقصى قدرة للذروة لكلا التصميمين هي μw 90.124 ومركز الطول الموجي 1546.817 نانومتر.