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Design and Analysis of BIMD Double Clad MMF -MZI Using Optiwave Simulation

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Abstract This work focused on principle of higher order mode excitation using in- line Double Clad Multi-Mode Mach-Zehnder Interferometer (DC-MM-MZI). The DC-MM-MZI was designed with 50 cm etched MMF. The etching length is 5cm. The tenability of this interferometer was studied using opt grating ver.4.2.2 and optiwave ver. 7 simulator. After removing (25, 35, 45, 55) µm from MMF and immersing this segment of MMF with water bath contained distilled water and ethanol, in addition to, air. Pulsed laser source centered at 1546.7nm ,pulse width 10ns and peak power 1.33mW was propagated via this interferometer Maximum modes were obtained in case of air surrounded media which are 9800 and 25 um removed cladding layer, with peak power 49.800 mW, FWHM 192 pm, and the transmitted laser was blue shifted with central wavelength λ_c 1547.193 nm.

Keywords: In-line BIMD fiber Mach-Zander Interferometer, multimode Fiber, maximum modes, FWHM, central wavelength and double clad ,peak power.

1. Introduction:

Many advantages of using fiber interferometers in communication like modulation, pulse compression [1], sensing application is their ability to measure a different types of parameters, for example; Strain measurement, pressure, force, acceleration Electric and magnetic fields [2] due to their high sensitivity, immunity to electromagnetic interference, as well as simple structure [3]. In conventional interferometer the interference is normally obtain: reference channel and sensing channel. The sensing channel can receive the pulse signal and then modulates the output power after interference. In order to prevent the coupling between the two channels, enough spatial separation is necessary [4,5]. The most significant type of recently investigated researches were of inline fiber interferometers, i.e. the inline fiber Mach-Zehnder interferometer because of the capability of easy and compact implementation as well as good coupling efficiency [2-4], for this MZI where instead of two spread fiber the two separate light paths excite within the same fiber (i.e, MMF with SMF, PCF with SMF, two in line long period grating, small core SMF spliced with standard SMF [6]. Recently a novel waveguide structure interferometer bimodal based interferometer proposed, which unlike conventional interferometer in last time, this refer to the interferometer of BIMD occurs between the two modes of bimodal waveguide: the fundamental mode and first higher modes [5].

In BIMD- MZI configuration in principle offers several advantages over standard signal mode waveguide MZIs, the single step mode converter has some intrinsic short coming, also the rapid change in the waveguide cross section at the points of mode conversion cannot excite both modes with the same power, therefore, scattering losses occurs at the mode conversion and connectors losses, splicing losses, etching regions power losses also obtain in interface region [7]. a multi-mode optical fiber (MMF) was used to demonstrate chemical temperature sensing, The aim of reaches to the highest excitation of higher modes in order to reach the highest received capacity of the signal, the compression factor of the pulse signal is visually and all of above will simulation by optiwave and opt grating software.

2. Theory:

Interferometers are mainly explained by superimposing two or more of same frequency light beams and measuring the phase difference between them [2]. Fibers with different core sizes can be used for beam splitting [6]. One method is splicing a short piece of multimode fiber between two single-mode fibers. The light exiting the single-mode fiber is spread at the multimode region and then coupled into the core and cladding of the next single-mode fiber. In this work we can culculate the n_{eff} of MMF etching in different surounded material according to imprical equation:

$$n2 = P1 * n1 + P2 * n2 \qquad (1)$$

from this equation (1) we can obtain the number of excitation of hiegher modes according to the following equation

$$M = V^2/2 \qquad (2)$$

Where V is the normalysed frequency which calculated from following equation

$$V = (2\pi a/\lambda)\sqrt{n1 - \mathrm{n2}} \qquad (3)$$

Where a is core radius, λ is operating wavelengh.

$$c = FWHMi/pFWHMo/p \qquad (4)$$

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 compression factor which is the ratio of input signal full width at half maximum to the output signal full width at half maximum.

Temporal FWHM can be obtained from the spatial FWHM as using the equation below

$$\Delta\lambda\ (Temp) = \frac{2\lambda_c}{c}\ \Delta\lambda spatial \qquad (5)$$

Where λ_c central wavelength in (nm), and c is the speed of light in vacuum.

In practically the overall losses will affected on output power therefor we depend to calculate overall losses (adapter losses) connectors, EDFA noise, etching region losses, and fiber length.

3. Experiments and Setup assembly:

The main schematic of the ***Double cladd – MMF-MZI*** is shown in Figure (1). This figure shows the main components that used in setups, it consists of pulsed laser source, Erbium-doped fiber amplifier, interferometer, , and visualizers.

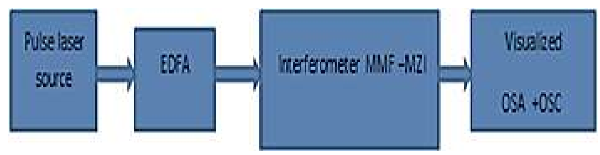

Figure (1): schematic diagram of the ***Double cladd – MMF-MZ***

3.1 Laser source

The experimental setup was consisting from pulsed laser source, this source redesign by simulation optiwave system with center wavelength of 1546 nm and pulse mode operation time duration 10 ns as shown below in figure (2)

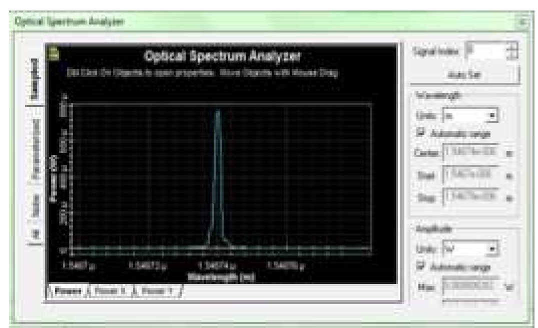

Figure (2): optiwave system simulation

3.2 Interferometer design by optiwave

The interferometer was consist of SMF (8.5 core & 125 µm cladding) with length 100 cm for both sides of MZI connected with 5 cm MMF (50 µm core & 125 µm cladding), this MMF etching for different thickness for different times

In Line Etching MMF only by using opt grating software

(D1, D2, D3, D4 is refer to the fiber diameter for (5, 10, 20, 30 min) time etching shown in figure (3) below

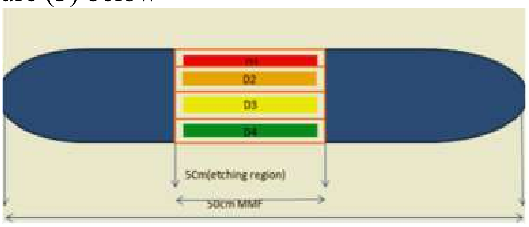

Figure (3): etched MMF of segment 5 cm lengh with cavity length 50 cm (for 5, 10, 20, 30 min)

The thickness of MMFs cladding with lengh segment (5 cm) varied from (125 µm to 100, 90, 80, 70 µm**)** by using simulation opt grating as show in table (1)

Table (1): fiber diameter with respect to etching time

Time etching in min	Fiber diameter in µm
5	100
10	90
20	80
30	70

The effect of removing amount of cladding layers with different cavities (air, distilled water and ethanol) that have refractive indices (1.0003, 1.33, 1.36) respectively on input laser pulse**,** this MMF which etching is coupled by (1.33 mw, 1546 nm, 10 ns pulsed laser after amplified it with 4 stages EDFA to produced 56.604 nw) as shown in figure (4).

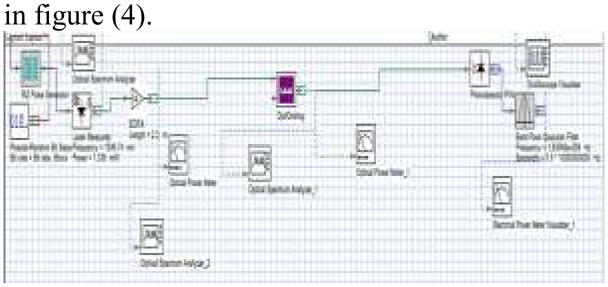

Figure (4): etched MMF of segment 5cm lengh with cavity length 50cm applied with opt wave

3-3 Optically Visualizers (opt wave simulation)

The optical signal was visualized by optical spectrum analyzer (OSA), it is a device that designed to measure and displays the distribution of power of an optical signal over specified wavelength span, OSA was used to monitor the interference spectra.

4. Results and discussed:

In this work, we designed and implemented a BIMD interferometer based on double clad MMF-MZI. the simulation work for this setup is demonstrated and constructed after designed using MZIs ,the theory of designing of MZI is based on the difference of modes alonge the fiber length ,also the number of modes in MMF for distance (1 – 22 cm)and (28 – 50 cm) on both sides of etching region about (149 modes at $\lambda = 1546\,nm$, in other hands, the modes number which excitated in the etching region for length (5 cm) was about (4000 - 10000), in case of air cavity, this difference will effect on the pulse signal by wide range of spectrum in etching region, but on two sides of this region there will be narrow band of spectrum in compare with etching region, for this reasonse we will testing different surrounding mediums as shown in table (2) to find the number of modes in fixed four diameter of (5 cm) MMF segment with respect to RI of these mediums, this MMF etching for by using simulation opt grating to show the effect of removing amount of cladding layers with different cavities (air, water, and ethanol) as shown in figure (6) (a, b, c, and d) where the red color is refer to the strength amount of power central in core, also the yellow color refer to the power less than central power, this same with respect to another colors .

Table (2): the refractive indices at operating wavelength

material	RI at $\boldsymbol{\lambda = 1546\,nm}$
air	0.0085
Distilled water	1.3246
ethanol	1.325

Set λ at 1546 nm and T = 25 C° of system**,** these values of RI in table (3) was calculated by using cauchy equation for material refractive index

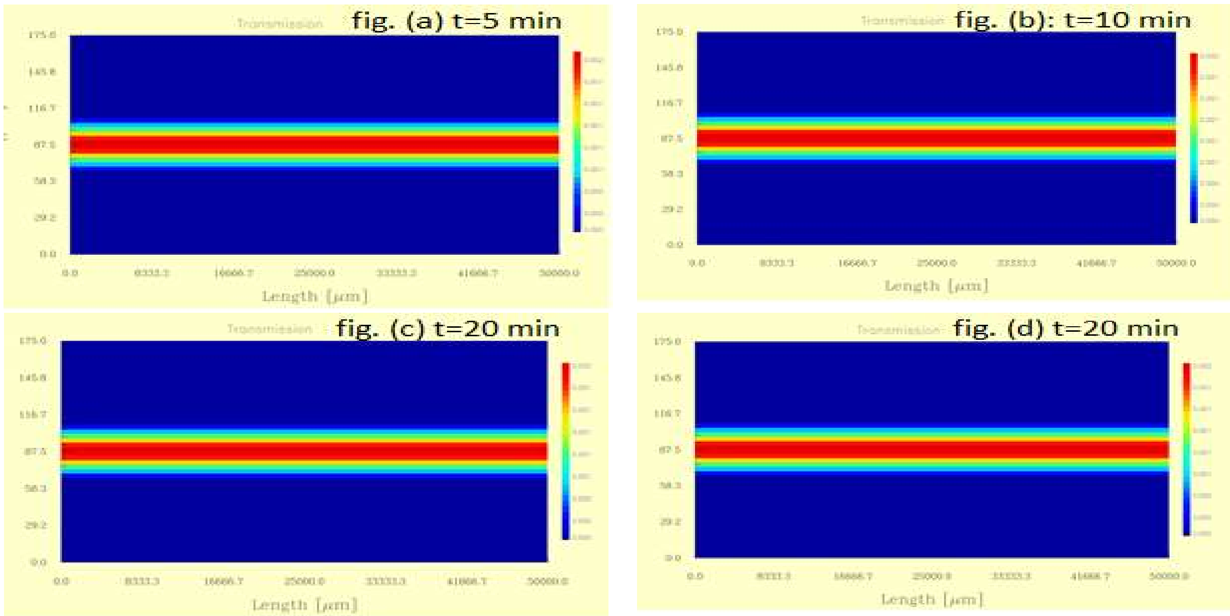

Figure (5): Double cladding MMF etching at air,water and ethanol for a- t=5, b- 0, c-20, and d-30 min.

we will discussed the effect of (air, water, and ethanol) cavities on the MMF etching cross section and the number of excitation modes which it is excited in 5 cm MMF etching and compare this results with number of modes in 50 cm MMF without etching which equal to 149 modes at wavelength 1546 nm, therefore the following figures (5-a, -b, and -c) shown the relationship of the number of modes with the refractive indices of the material with respect to the etching time. Finally, we compare the number of excitation of higher order modes with respect to the time etching and refractive indices of surrounding mediums as shown in table (4) and figure (8).

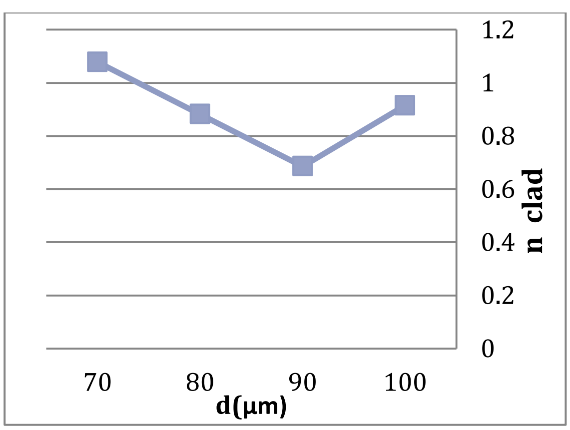

Figure (6): shown the relationship of the fiber diameter with (Neff -air)of cladding

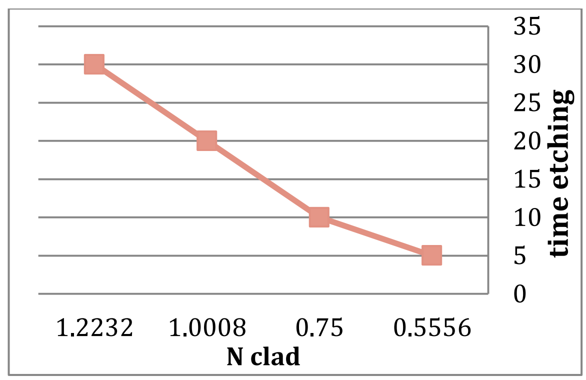

Figure (7): shown the relationship of the fiber diameter with (N*eff* -water)of cladding.

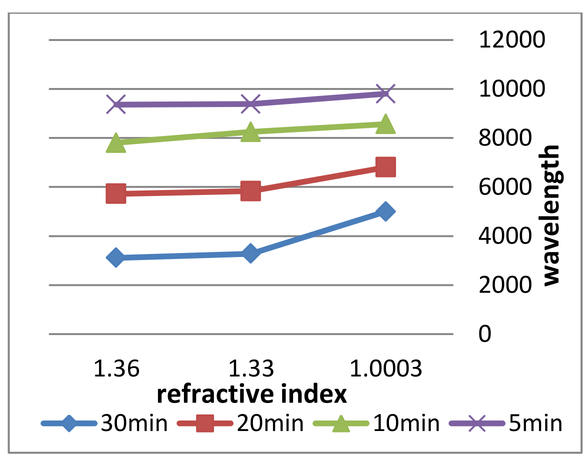

Figure (8): shown the relationship of the fiber diameter with modes number with respect to the refractive indices (air, water, and ethanol).

Table (4): Number of excitation modes with respect to RI and etching time

	Cladding etched (d in µm)			
RI	**5 min**	**10 min**	**20 min**	**30 min**
0.00085	9800	8564	8602	4999
1.3246	9383	8243	5834	3278
1.3254	9362	7799	5720	3109

5. Conclusion:

A generalized theory has been developed to analyze the implementation optical double clad MMF-MZI when the effects of the relevant in the propagation of the optical signal within applied 5cm etching (multimode fiber) MMF cross section. The MMF- MZI, illuminated with a PULSE LASER source and a fiber length used as dispersive element. When we different cavities (air, water, and ethanol) effect which change the number of excitation modes in (5 cm) MMF etching section in theoretical optical wave, in resulted we can calculate the maximum number of excitation of higher order modes of double clad MMF is obtain is (9800) in the case of 5 min etching for fiber diameter (100 µm) and RI = (1.0003) air surrounding media and N (clad after etching) = 0.915.

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تصميم وتحليل مقياس التداخل ثنائي النسق باستخدام برنامج المحاكاة Optiwave

اسماء عبد الوهاب   تحرير صفاء منصور

معهد الليزر للدراسات العليا / جامعة بغداد– بغداد / العراق

الخلاصة: في هذا العمل سلط ضوء الليزر على مبدا تحفيز الأنماط المتعددة باستعمال متداخل الليف البصري ذو الانماط المتعددة والمزدوج القشرة. تم تقشير 5سم من الليف المتعدد الانماط بعد ازالة (25 و35 و45 و55) مايكرومتر منه وغمره بحمام مائي يحتوي مرة على الايثانول ومرة اخرى على الماء المقطر بعد تسليط ليزر نبضي بطول موجي 1546 نانومتر, وعرض نطاق 10 نانو وتم الحصول على انماط محفزة والتي هي 9800 في حالة (5 ثانية) وتم ازاحة الطول الموجي نحو الاطوال الموجية الاقصر Blue shift بقيمة $\lambda_c = 1547.193$ nm و FWHM = 193 pm و Pp = 49.800