Design and Construct Nested Double Clad Multimode Fiber MZI (DC-MMF –NMZI) for Pregnancy Test

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ABSTRACT

Nested optical fiber MZI is an essential part for achieving high data rate network system. In line Double Cladding Multimode Nested Mach-Zehnder(DC MMF-NMZI) was designed for rapid pregnancy test using urine as abiological material. Three different cladding of MMF were implemented to construct nested MZI has capability to distinguish between many subscriber signals (sensing signals). Compression factor was figure of merit of this work; that indicate also to the maximum excitation to higher order modes in the cladding region in other words obtained maximum ratio of power to power core, FC=1.1 At fiber diameter is 112.392μm, and maximum peak power is 3.49μW at central wavelength was 1564.9nm and number of excitation to the higher order modes is 10874 also RIU/nm was obtained.

KEYWORDS

In-line Mach-Zander Interferometer, nested, double clad multimode Fiber, biological pregnancy test, simultaneous detection system.

INTRODUCTION

Fiber in-line Mach–Zehnder interferometers (MZIs) based on interference between the guided modes of the fiber including single-mode fiber (SMF), multimode fiber (MMF) and PCF, have been proposed for temperature measurement. The device usually contains two cascaded fiber components that function as beam splitter and combiner, the former, couples part of the core mode power into a forward-propagating cladding mode and the latter recombines the two modes, resulting in a sharp interference. The commonly used splitter/combiners include LPGs, taper, sections of MMF or PCF and other elements that may cause core diameter mismatch. However, these MZIs have relatively large size, in the order of millimeters or centimeters and the highest temperature measured is 1000°C [1].

In advanced optical fiber communication sciences for achieving high data rate many and wide researchers designed in line MZI in a lot of sciences fields such as simultaneous measurement of temperature and directional torsion [2], simultaneous measurement of refractive index and temperature using all-fiber in-line single-mode-multimode-thinned-single-mode (SMTS) fiber structures based on a small core and cladding diameters thinned fiber Mach–Zehnder interferometer (MZI) [3], In-Line Fiber Tunable Pulse Compressor using PM-Mach Zehnder Interferometer [4], load measurement application [5], MZI used to proposed multi wavelength laser [6], in line MZI can be achieved to pulse ompressor using high quality ultrashort pulses [7].

In other hand construction of optical fiber the in line MZI high impaited and has many applications in biosenser (biological detection system) because Optical fiber biosensors have attracted extensive research attention in fields such as public health research, environmental science, bioengineering, disease diagnosis and drug research. Accurate detection of biomolecules is essential to limit the extent of disease outbreaks and provide valuable guidance for regulatory agencies to take timely measures. Among many optical fiber sensors, optical fiber biosensors based on specialty fibers have the advantages of biocompatibility, small size, high measurement resolution, high stability and immunity to electromagnetic interference such as Biosensor as for Pregnancy Test [8]. The early detection and diagnosis diseases is of vital importance, both to manage patients’ conditions
and to provide them with adequate treatment. In cancer patients, for instance, early diagnosis has proven to be a very significant factor in increasing the chance of curative treatment and long-term survival[9]. The structure of MZI which consist of one piece of G.625.D single mode fiber was placed on the fiber holder of 3SAE LDS 2.5, parameters were set on the computer controlling LDS2.5 was so-called taper-in-taper structure to detect human sweat pH detection[10].

Although those applications in this time the novelty structures is more important and needed ,thus, The designers thought about nested which called "transversal filter or a nested MZI"[11] whose phase shifters are arranged in parallel. As well as an MZI itself, the crosstalk characteristics of the nested MZI optical switch is affected by a coupling ratio deviation of directional couplers (DC) arising from wavelength dependence and fabrication error[12], this theory of nested design will get many type of nested such as nested MZI switch and nested-ring MZI (NRMZI) that have interesting phase and transmission properties[13] phase generating couplers (PGCs)[14]. For optical fiber network sensing application nested MZI was highlighted to achieve simultaneous sensor signals that manipulate spatially and temporally after applying different physical effect on the sensing region (15). An a best property of nested structure is a simultaneous detection and measurement, many searchers works according this property to obtained many applications such as simultaneous measurement of temperature and torsion , simultaneous measurement of refractive index and temperature etc. In conventional MZI light beam is first split into two parts by a beams plitter and then ,recombined by a second beam splitter Depending on the relative phase acquired by the beam along the two paths the second beams plitter will reflect the beam with efficiency between 0 and 100 %The operation of conventional a Mach–Zehnder_interferometer, In line MZI where instead of two spread fiber the two separate light paths excite within the same fiber.

![Nested Mach-Zehnder interferometer (NMZI) structure.](image)

**Figure 1.** a- NMZI with 2arm ,b- NMZI with for arm

Nested Mach-Zehnder interferometer (NMZI) structure. Such a device consists of an input N× N coupler, an output N× N coupler, and two balanced main interference arms with each being a balanced N× NMZI, i.e., nested MZI ,a, and nested MZI b ,has shown in Fig. 1. Each nested MZI has two identical carrier injection phase shifters. The NMZI switch has a balanced architecture, in which the optical path lengths are equal in its three main interference arms; as a result, the optical operation bandwidth is not limited by the switch architecture, i.e., broadband performance can be achieved.[16] In general, interference pattern which is depending on the length of optical path shows in fig(1) the displacement between two arms of interferometer because core mode has a higher effective index than the cladding mode [17]. Therefore, the physical lengths of interferometer arms are similar; the phase different is directly related to the difference between the effective indices of the cladding and core mode [18], for above reasons we must calculate values of phase differences whom give us simultaneous photon propagate in three arms of NMZI.

know that when the interference signal reaches its minimum the phase of the cosine term can be written as:

\[ \phi_0 = (2\pi\Delta n_{\text{eff}} L) / \lambda_m + \phi_0 = (2m+1)\pi \]  

(1)

where \( \lambda_m \) is the center wavelength of the \( m \) th order interference valley. And it can be written as:

\[ \lambda_m = (2\pi\Delta n_{\text{eff}} L) / (2m+1)\pi \cdot \phi_0 \]  

(2)

The intensities of core and the cladding modes can be measured as function of a physical length (L), wavelength and phase difference (\( \phi \))
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\[ I(\lambda) = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos(\Delta \phi) \]  
(3)

Where, \( I_1, I_2 \) is the mode intensities of cladding and core mode. The phase difference between the sensing cladding and core modes is described by:

\[ \Delta \phi = \frac{2\pi}{\lambda} \Delta n L \]  
(4)

Where L is the interaction length, the sensing area length, in cm

\[ \Delta n = n_{eff1} - n_{eff2} \]  
(5)

is the change in the effective refractive index of the mode

When the refractive index of the environment surrounding the etched fiber increases, the effective refractive index of the cladding mode increases by an amount and that of the core mode refractive index hardly disturbed. Therefore the difference of the effective refractive indices between the core and the cladding modes due to the ambient refractive index will decrease, and from Eq. (5), we know the attenuation peak wavelength will change to a shorter wavelength. For different interference orders (m), we also can get that the amount of the wavelength shift will be different. As a result, the effective refractive index indices between the core and cladding modes increase and the attenuation peak wavelength will change to a longer wavelength. We also can obtain that the wavelength shift will be different if the interference orders are not the same. In nested design another type of interference of electric field component between these arms of MZI. The transfer matrix method is used to analyze the operation principle of the proposed NMZI. The relationship between the input and output electric fields of the nested MZIs can be expressed as [17]:

\[
\begin{align*}
E_c &= \begin{bmatrix} t & -jk \\ -jk & t \end{bmatrix} \begin{bmatrix} ae - j\phi_1 \\ ae - j\phi_2 \end{bmatrix} \begin{bmatrix} t & -jk \\ -jk & t \end{bmatrix} E_a \\
E_d &= \begin{bmatrix} t & -jk \\ -jk & t \end{bmatrix} \begin{bmatrix} t & -jk \\ -jk & t \end{bmatrix} E_b
\end{align*}
\]  
(6)

where \( E_x = a, b, c, ... \) is the electric field at port x of the nested MZIs, as illustrated in Fig. 1b; \( t \) and \( \kappa \) are through-coupling coefficient and cross-coupling coefficient for each \( 2 \times 2 \) coupler, respectively, and we assume that all the \( 2 \times 2 \) couplers in the BNMZI switch are identical and are lossless, i.e., \( \kappa^2 + 2 = 1 \); \( \phi_i = 1, 2, 3, 4 \) is the modulated optical phase shift of phase shifter \( i \); \( a_i, 1, 2, 3, 4 \) is optical field transmission factor of phase shifter \( i \), and it represents the optical attenuation due to free-carrier absorption. In other hand the important parameter as a part of fiber characteristics is fiber dispersion, when there are multipath in fiber must be 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, it must be obtain the number of excitation of higher modes according to the following equation

\[ M = V^2 / 2 \]  
(7)

\[ V = \frac{\pi a}{\lambda} \sqrt{n_1 - n_2} \]  
(8)

Where \( V \) is normalised frequency which calculated from following equation

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

The narrower pulse in time domain has the wider spectrum in spatial domain is a very well-known concept in communication. Therefore 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 using the equation below:

\[ \Delta \lambda_{(Tem)} = \frac{2 \lambda c}{\epsilon} \Delta \lambda_{(spatial)} \]  
(9)

\[ Fc = FWHM_{o/p} / FWHM_{i/p} \]  
(10)

Where: \( \lambda c \) central wavelength in (nm), and \( c \) is the speed of light in vacuum in m/s
In our work we introduce a novel design of Nested Mach Zehnder Interferometer NMZI for which mixing between biological application and NMZI using urine samples of three pregnant female and non-pregnant to contracted the biological detection system for changing the refractive index with respect to variance thickness of Multimode fiber MMF etching section. This design will be tested tree samples at the same time (simultaneously) this property is important goal of this work.

DESIGN AND EXPERIMENT PREGNANCY TEST BASED ON NMZI

![Figure 2. The schematic diagram of the NMZI fiber and detection system](image)

Nested MM-MZI was construct using three array MM-MZI that constructed individually after etched 5cm MMF with different etched diameter using water-bath filled with 40% HF acid. The length of etch interferometer was 2.5m with 50cm MMF and 2-coupled SMF each with 1m length. In fig (2) show a pulse laser source with a wavelength 1546nm is used to inject light into the structure, EDFA was used to amplified pulsed laser power to test nested cases. An optical spectrum analyzer (Bay Spec) is used to measure the transmission spectrum response of the sensor or detection. Since the core diameter of the MMF is much larger than that of the etching segment, the light injected into the etching segment which has urine sample from the MMF will excite multiple modes propagating within the cladding of the etching segment. The Etching segment cladding mode excited from the multimode fiber core would be much larger than that excited from the MMF with no urine sample. It is well known that when the cladding diameter is reduced, a thinned fiber can enhance the fraction of power in the evanescent wave in the cladding. Thus the light transmission from the cladding of the etching segment will interfere with the cladding mode more effectively. This with respect to one arm of the nested network, each MZI from this network will effect on one sample of one patient. Although another interference will be accrues in this structure which the coupler effects as an interferometer because the power ratio which was propagated in to fiber, this power splitting to three ports and re-combined it will be result an interferometer in addition to In Line MZIs (IL MZI). In this case hybrid interferometer will be achieved in structure. In this case we can use NMZI as a sensor or detection system for multi samples or multi signals in the same time (simultaneously).

RESULTS AND DISCUSSION

Absorption measurement for urine sample

UV-visible-NIR spectrophotometer (SP-8001) which runs in a wavelength range from 190 nm to 1100 nm has been applied to measure the Ultraviolet-Visible absorption spectra of the biological samples shown in Figure (3). The sample of urine has been put in the quartz cuvette to obtain the absorption spectrum. The laser source is selected according to the obtained absorption spectrum.
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Figure 3. Experimental setup for light absorption measurement

Refractive Index of the Selective Urine Samples

The results of general urine examination (GUE) and refractive index measurement for non-pregnant and pregnant female urine samples are shown in Table 1.

Table 1. The results of general urine examination (gue) and refractive index measurement for non-pregnant and pregnant female urine samples

<table>
<thead>
<tr>
<th>Statue Of The Female</th>
<th>Glucose</th>
<th>Protein</th>
<th>PH</th>
<th>Pus Cells</th>
<th>RBCs</th>
<th>Crystals</th>
<th>Epithelial Cells</th>
<th>Uric Acid</th>
<th>Refractive Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Pregnant no.1</td>
<td>Normal</td>
<td>Normal</td>
<td>Acidic</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>1.34005</td>
</tr>
<tr>
<td>Pregnant no.1</td>
<td>Normal</td>
<td>Normal</td>
<td>Acidic</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>1.34235</td>
</tr>
<tr>
<td>Pregnant no.2</td>
<td>Normal</td>
<td>Normal</td>
<td>Acidic</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>1.34135</td>
</tr>
<tr>
<td>Pregnant no3</td>
<td>Normal</td>
<td>Normal</td>
<td>Acidic</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>1.34123</td>
</tr>
</tbody>
</table>

According to Table 1, it can be noticed that although the selected urine samples have the same compositions rate but the refractive indices of the urine samples are proportionally increased in the cases of the pregnancy. This change is due to the pregnancy hormone, HCG, which increases in the pregnant urine sample. Experimentally when apply $P_{in}=1.33mW$ for each arm of this network, the $P_o$, $\lambda$, FWHM, number of modes, compression factor FC, normalized frequency of applying the RI of each patient will show in table II

Table 2. The results of refractive index measurement for pregnant female urine samples applied in NMZI

<table>
<thead>
<tr>
<th>PATIENTS</th>
<th>Etching time</th>
<th>Etching time</th>
<th>$\lambda_c$ (nm)</th>
<th>FWHM (pm)</th>
<th>FC</th>
<th>Normalized frequency(V)</th>
<th>Number of modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient pregnant 1</td>
<td>5min</td>
<td>0.65</td>
<td>1546.602</td>
<td>129</td>
<td>0.45</td>
<td>144</td>
<td>10342</td>
</tr>
<tr>
<td>RI =1.34235</td>
<td>10min</td>
<td>3.49</td>
<td>1546.9</td>
<td>32</td>
<td>0.11</td>
<td>147</td>
<td>10874</td>
</tr>
<tr>
<td>Patient pregnant 2</td>
<td>10min</td>
<td>0.918</td>
<td>1546.539</td>
<td>149</td>
<td>0.522</td>
<td>29</td>
<td>418</td>
</tr>
<tr>
<td>RI =1.34135</td>
<td>20min</td>
<td>0.496</td>
<td>1546.818</td>
<td>6.016</td>
<td>0.65</td>
<td>146</td>
<td>10364</td>
</tr>
<tr>
<td>Patient pregnant 3</td>
<td>5min</td>
<td>0.295</td>
<td>1546.816</td>
<td>0.317</td>
<td>1.108</td>
<td>145</td>
<td>10873</td>
</tr>
<tr>
<td>RI =1.34123</td>
<td>10min</td>
<td>1.55</td>
<td>1546.839</td>
<td>0.189</td>
<td>0.66</td>
<td>64</td>
<td>2047.5</td>
</tr>
<tr>
<td>Patient pregnant 3</td>
<td>5min</td>
<td>0.12</td>
<td>1546.835</td>
<td>0.237</td>
<td>0.82</td>
<td>145</td>
<td>10191</td>
</tr>
<tr>
<td>20min</td>
<td>0.28</td>
<td>1546.855</td>
<td>0.196</td>
<td>0.68</td>
<td>143</td>
<td>10770</td>
<td></td>
</tr>
<tr>
<td>RI =1.34123</td>
<td>20min</td>
<td>0.296</td>
<td>1546.857</td>
<td>0.195</td>
<td>0.67</td>
<td>90</td>
<td>4053</td>
</tr>
</tbody>
</table>

The higher peak power will be obtain in case of 10min etching at fiber diameter 112.3927μm for all urine samples, these because the removing layers at 10min was more than the 5min, 20 min, this was the selectable
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etching case, also, the phase shift was variance simultaneously with RI of urine samples and MMF cladding thickness there for the best detection will be at 10min etch MMF-MZI . fig(4-a,b,c) illustrates the relationship of Po, FWHM λc with respect RI of urine pregnancy samples ,in case of (5min,10min, 20min ) etching time fiber diameter 118.696μm,112.3927μm,72.532μm .

![Figure 4-a](image1.png)

**Figure 4-a.** The relationship of Po with respect RI (urine pregnancy samples)

![Figure 4-b](image2.png)

**Figure 4-b.** The relationship of FWHM with respect RI (urine pregnancy samples)

![Figure 4-c](image3.png)

**Figure 4-c.** The relationship of central wavelength with respect RI (urine pregnancy samples)

In other hand ,to achieve the simultaneous principle of pregnancy samples for NMZI ,each patient (RI) will be nested for each of fiber diameter at the same time thus, the Po ,λc, FWHM will be obtain the simultaneous
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Variance in the refractive index and cladding thickness reducing in fiber diameter at input power amplified by one stage=2.4mW using EDFA, in table (3) the resultant of NMZI for pregnancy samples. Figure (5-a,b,c) shown the phase shift between three pregnant compared with reference sample, non-pregnant. The effect of RI change has been appear in these result.

**Table 3.** The results of refractive index measurement with fiber diameter for pregnant urine samples applied in NMZI

<table>
<thead>
<tr>
<th>RI</th>
<th>P_c(NMZI) μW</th>
<th>c (nm) λ</th>
<th>FWHM (pm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.34235</td>
<td>7.873</td>
<td>1546.821</td>
<td>283</td>
</tr>
<tr>
<td>1.34135</td>
<td>7.514</td>
<td>1546.820</td>
<td>267</td>
</tr>
<tr>
<td>1.34123</td>
<td>7.66</td>
<td>1546.851</td>
<td>333</td>
</tr>
</tbody>
</table>

![Figure 5-a](image)

**Figure 5-a.** Output peak power spectrum of three pregnant with compared with non-pregnant at fiber diameter 118.69μm

![Figure 5-b](image)

**Figure 5-b.** Output peak power spectrum of three pregnant with compared with non-pregnant at fiber diameter 112.3927μm

![Figure 5-c](image)

**Figure 5-c.** Output peak power spectrum of three pregnant with compared with non-pregnant at fiber diameter 72.532μm

At input pulse laser power is 2.4mW, we compare these three samples with the sample of non-pregnancy with respect to (5min, 10min, 20min), from this comparison we obtain the effect of RI of urine samples of pregnancy and non-pregnancy on the etching MMF among NMZI networking and the difference in phase shift, FWHM, in...
resulted we obtained when the RI increase the FWHM will decrease spatially. From above figures the changed in phase is related to double clad of MMF which enhanced the $n_{eff}$ which represent new fiber diameter. The relationship between the time etching and fiber diameter after etching was expressed in Table 4.

Table 4. The Relationship between the time etching and MMF diameter the number of removal layers from 5cm MMF segment was shown in fig(5-d)

<table>
<thead>
<tr>
<th>Time of etching</th>
<th>Fiber diameter as a function of time etching (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5min</td>
<td>118.696</td>
</tr>
<tr>
<td>10min</td>
<td>112.3927</td>
</tr>
<tr>
<td>20min</td>
<td>72.532</td>
</tr>
</tbody>
</table>

Figure 5-d. The Relationship between time etching and fiber diameter

The $n_{eff}$ was improved the sensing region and obtained the best optimum case of etching time to get best result of shifted wavelength as shown in fig 5-e,f,g

Figure 5-e. The RI with central wavelength at etching time 5min and fiber diameter 118.696μm
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According to table (3) and fig(6) each of (pregnant 1, 2, 3) are connected nested by couplers, the peak power is decreases with increase the RI. At pregnant 1 with RI=1.3423 has nested peak power =7.873μW , λc=1546.821nm, FWHM=283 pm, and pregnant 2 with RI=1.34135 has Pp=8.614μw , λc =1546.820nm , FWHM = 267pm , and pregnant 3 with RI =1.34123 has Pp=7.66μW , λc =1546.851 nm, FWHM=299pm.

CONCLUSION

Multi stages of MZI were design to test the sensitivity change to the variance pregnancy refractive index. nested In Line Double Clad Multimode Mach-Zehnder was enhanced rapid pregnancy test using urine as a biological material. Three different cladding layers of MMF were used to construct nested MZI that has capability to distinguish between many subscribers signals, sensing signals.). In results we can measure an calculate major
nested parameter which is important to achieve enhanced detection system which based on high excitation to higher order modes in MMF cross section this lead to increase the sensitivity property. finally we conclude from this work that is when RI was increasing ,the excitation increased too ,compression factor was decreased.

REFERENCES


