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Research paper

Design and Development of Mach Zehnder Interferometer based Optical Sensors to Detection of Arsenic compound in Drinking Water

Shaikh Afzal Nehal1, Anindita Mukherjee2 and Dr. Manju Devi3

1Research Scholar, VTU-RRC, Belagavi, Karnataka, India
2M.Tech(VLSI and Embedded System), CMR Institute of Technology, BANGALORE, KARNATAKA, INDIA
aninditamukherjee84@gmail.com
3Prof. & HOD, Dept. of ECE, The Oxford College of Engineering, Bangalore, Karnataka, India
manju3devi@gmail.com

Abstract

Water, the inevitable need of any individual, must be monitored. Detection of the arsenic chemical present in water leads to contagious diseases. The legacy makes people difficult to survive. The consequences are cancer, other diseases. Employing photonic crystal waveguide with the rally round of mach Zehnder interferometer, it is feasible to correctly compute arsenic compound level in water. MZI sensor has many compensation, diminutive, least use of instrumentation, and ready to be used with CMOS technology. Follows in the paper, arsenic compound level of wavelength range of 1530–1565 nm is analyzed and detected. Experiential program from the band arrangement that for minute change in refractive index is accounted, subsequently logical shift in the frequency and amplitude will be evident enlarging mach Zehnder interferometer will behave as a sensor. Thus projected alternate included optical Mach Zehnder Interferometer (MZI), composed of graded index channel waveguide that can be frequently used as chemical and biological sensor in this manuscript. This dissertation describes how the MZI operates two arms predominantly to conquer the industrial challenges. Manuscript represents test data, graph and results that exemplify the performance of whole system.

Keywords: *Nanocavity-Coupled Waveguide; Hexagonal Sensor Meep; Mach Zehnder Interferometer Using Beam Prop*.

1. Introduction

Arsenic is a natural compound and present in water .This element found all over the environment. As a consequence, millions of people are in problem for long-time because of arsenic poisoning from the water they drink [1].For longer period obsessive of arsenic that can effect skin and lung cancers, as well as cancers of the urinary tract, kidney, and liver; Reproductive system and growth in child health can be effected. [2,3].

The main aim of this paper is to propose an evolution of a system that can be used at the establishment of scientist to continuously observe qualitative water parameters. In different laboratory tests, Simple and low-cost colorimetric kits are used to test arsenic testing range from drinking water. So these kind of tests in laboratory has lots of disadvantages such as lack of accuracy, superior limit of detection and used toxic chemicals as test reagents [4].We have been inspired by these clear advantages and proposed a optimum device which is an opto-photonics devices, that uses MZI for the detection of arsenic. Mach Zehnder Interferometer offered with good sensitivity with two arms of one is for sensitive and other arm for reference. The reference arm is comprising of a strip wave guide. We have exploited and came close to included optics for designing of the 2 dimensional photonic crystal based sensor for treating agents causing physical problem which is the source of water . Because of arsenic that present in water which causes many health issues in human body that can be detected using a combination of the clinical depiction. Many complex laboratory methods [10-12] is used to quantify accurate measurement of arsenic level in water. The occurrence of broadcasting of light within the Photonic crystal is explained and examined that has been quantified for the accurate measurement of arsenic compound level . These exclusive procedure present good sensitivity and accuracy, but needed particular laboratories, proper training and more time to perform the experiment. So these experiments are not accessible for monitor the arsenic levels on routine basis in field. So the enlargement of biosensors and chemical sensors for the recognition of arsenic compound in water that is an attractive alternative method to colorimetric detection. We have presented in this manuscript, that to design a lab-on-chip photonic crystal sensor using MZI sensor which is very simple to design and can be scalable yet reconfigurable. This lab on chip sensor can be able to identify inorganic compound arsenic in water. The proposed sensor can provide accurate spectral signatures for different compound of arsenic like indium arsenide, gallium arsenide, cadmium telluride, selenium etc that presence in water. This conventional hexagonal ring structure may be suitable for, Mach-Zehnder interferometer (MZI) based sensors that is easy to construct and fabricate .

We demonstrated photonic wave guide that based on defect process and controls the current of beam of glow inside the photonic crystal [10]. Photonic band structure can be referred as optical insulator where transmission of light beam wave travels and that can be prohibited because of presence of band structure photonic crystal. So the property of band gap can be altered by creating defect engineering . Defects can be classified into dot defect or row defect. The circulation of beam of light in photonic crystal is explained by the master equation (Eq1). The main equation is observed by solving Maxwell's electromagnetic equations

$$\nabla \times \left(\frac{1}{\epsilon}\nabla \times H\right) = (\frac{w}{c})^2 \times H \quad (1)$$

The glow beam is divided into two arm with one light path containing to be tested sample with hexagonal sensor and the other arm performing as a reference in a conventional MZI sensor configuration. Fig(1). Sio2 substrate [5-6] is present in MZI which is consisting of particular mode channel wave guide and made by photolithography process and come together with the ion exchange. The active arm of Sensors is made-up of using a silicon waveguide core layer over a SiO2 masked oxide layer. the increased wave length of MZI and hexagonal ring resonator offer sensitivity. The design of sensor is characterized by using TE polarization from light source with the wave length of λ=1550 nm into the sensor and measuring the waveguide output light to notice the analytic value .The interference of light beam is travelling through two arms of MZI result in intensity modulation at the output of the waveguide. The relationship between oscillating output is expressed by between input light intensity and output light intensity and that can be denoted by the equation of

$$\frac{Iout}{Iin} \infty 1 + Vcos(\Delta\emptyset + \Delta\emptyset 0) \quad (2)$$

Where $\Delta\emptyset 0$ is the initial phase change of normalized of two arm .After applying RI value of analyte $\Delta\emptyset$ is the changed of two arms .
Hexagonal ring resonators mechanisms have been included on the chip.

$$\emptyset = (\frac{2\prod L}{\lambda})N_{eff} \quad (3)$$

From equation 2 phase $\emptyset$ which depends on its effective refractive index value for a given wave lengthλ of the active arm of MZI sensor.Arm length is denoted by L. This kind of design and can be integrated with optical technique.

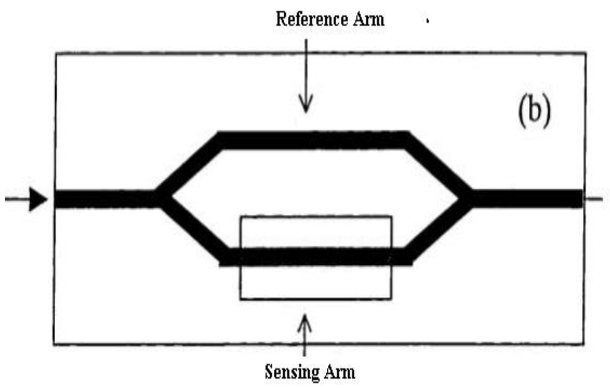


Fig-1: Schematic diagram Of MZI

In this paper, theoretical and tentative investigation of quality factor based on dissimilar value of refractive index of a photonic crystal (PhC) resonators are planned with the help of MEEP simulations, the change in refractive index, quality factor is observed. The use of biosensor for detection of bimolecular or chemical molecules has been observed quick growth since last two decades. Addition of sensor with microelectronics and wireless communication provides high sensitivity and that allow the real time monitoring. The various technique is used by biosensor to detection of various analyte and that bio sensing technique is used for their simplicity in fabrication, small footprint, low cost and real time detection and high sensitivity. A light beam is devided through MZI device into two identical arms ,sensor and reference arm by means of Y junction . Light beam will travel through distance of arms length L , by means another , by means another Y junction .In the sensor arm , the specific area is etched ,now electromagnetic waves interact with specified analyte. This kind of interaction causes change in effective refractive index of the sensor arm which will causes another parameter that is phase change between the light beam travelling through both the arms. Because of difference in effective refractive indices of the sensor and reference arm and on the interaction length of sensor area that produces phase difference .

2. Theory

Photonic crystals (PCs) comprising of a intermittent arrangement of regularly formed materials having different dielectric constants in a substrate [7]. Photonic crystals are divided into three types based on their structure as follows

i) 1-dimensional (1D) structures
ii) 2-dimensional (2D) structures and
iii) 3-dimensional (3D) structures.

There is insufficient band gap in 1-Dimensional photonic crystal structures and to make 3D structures is very difficult because of their small lattice size [8]. 2D structures are easy to create compared to 3D structure, because 2D structures are having complete band gap. By Solving the Maxwell equations, we can explain the propagation of light within the photonic crystals.
Photonic crystals have many applications in various fields like optical field. Photonic crystals are having many applications since they offer a common proposal to fabricate a huge number of optical components on an array configuration.
The working principle of both resonator and interferometer based on the changes of the effective refractive index (Neff) of the waveguide mode due to changes in the ambient refractive index via the passing field interaction.

$$\Delta Neff = \frac{\partial neff}{\partial nambient} \quad (3)$$

$$s = \frac{2\prod L}{\lambda}\frac{\partial Neff}{\partial nc} \quad (4)$$

From equation (4) sensitivity can be calculated by using Neff value from the practical graph which is shown in the graph 4. The coupling of the complete sensor is done with the help of two structure explained below:

A. HEXAGONAL RESONATOR:

Light beam can be passed into a hexagonal waveguide with circumference L using MZI. Silicon wave guide based hexagonal structure can be integrated with MZI optical wave guide by using mode conversion process.

B. Mach-Zehnder Interferometer (MZI) :

MZI device has been constructed using silicon-on-insulator (SOI) [10-12]. MZI is constructed using a strip waveguide and slot wave guide.MZI sensor uses slot waveguide instead of conventional sensor of a sensing path to achieved a high sensitivity. Strip wave guide is considered as reference arm and slot wave guide is considered as sensing arm. Mode converter converts strip wave guide into slot waveguide through sensing arm. The visibility factor depended on splitting ratios of the input and output Y junction and on the differential propagation loss of the strip waveguide and slot wave guide of the 2 (two) arms[9].

3. Sensor Design

MEEP simulation tool is applied to design and formed bio and chemical sensor. This kind of sensor is based on two dimensional square lattice photonic crystal structure with row defect. A two dimensional photonic crystal is periodic along two if its axes and homogeneous along the third axis [4]. We have designed a hexagonal resonator structure that is sensitive, we proposed two structures one is hexagonal structure and MZI sensor based on different RI value e.g. chemical RI value.

Design specification:

1. Configuration used- Rods in air.
2. Diameter of the Silicon rods used is = 20 nm.
3. The dielectric constant of the defect rods used is 12
4. Tallness of rods used is = infinity.
5. Beam resource used is: Gaussian Pulse.
6. Lattice constant of the crystal structure used and is denoted by, 'a'= 1 nm

Proposed Structure

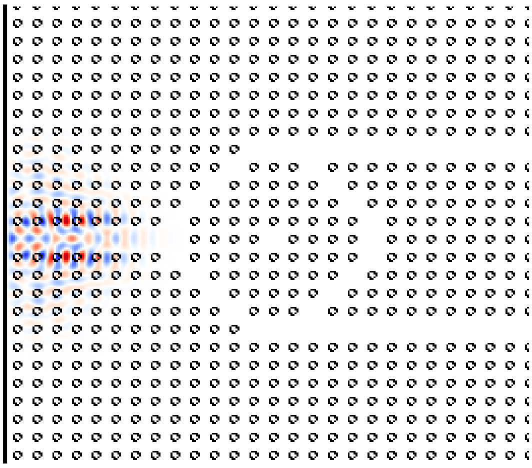


Fig-2: Hexagonal structure (Rods In Air)

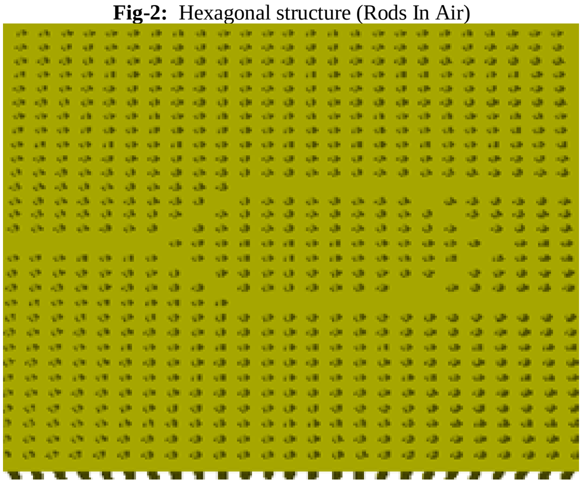


Fig-3: Structure of photonic Wave guide

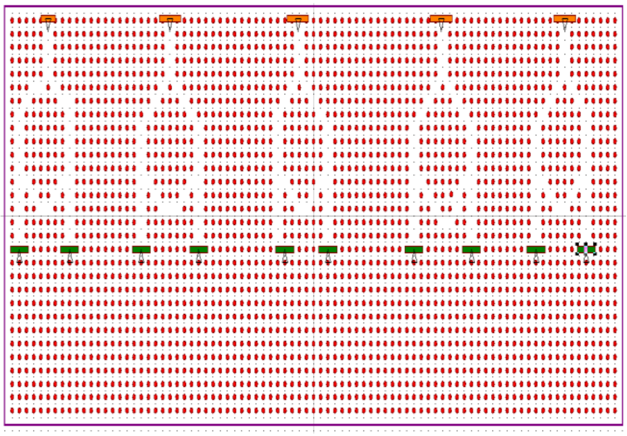


Fig-4: Array structure of wave guide

We have made array structure of photonic crystal sensor of hexagonal resonator to determine the arsenic compound in water. This array structure can be used for mass volume capacity construction to determine the large amount of arsenic compound.

Design description for MZI:

Table-1 Shows the specification of MZI Construction

Simulation Tool	Beam Prop
Excitation Wave Length	1.55um
Index Of Background	1.46
Width Of Component	5
Dimension	3-Dimension
Index Difference	1.98

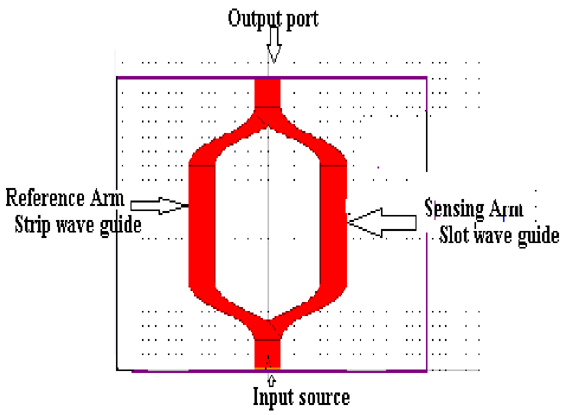


Fig -5: Structure of MZI and Structure of Strip Waveguide

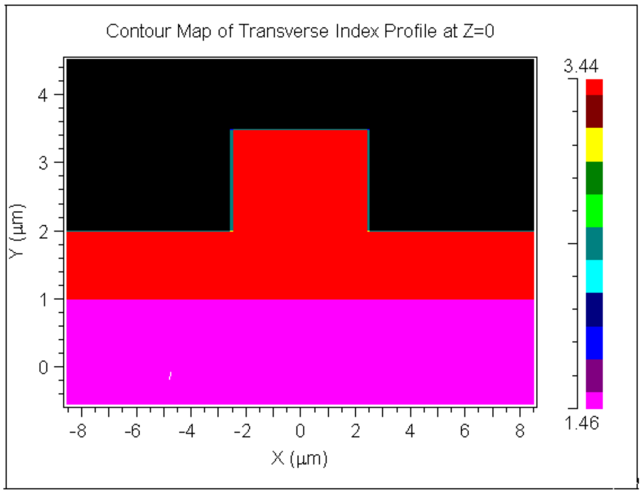


Fig 6: Strip Waveguide

From Fig.6 we can observe the structure of strip wave guide which is the part of reference arm of MZI. Fig. 4 shows that Material has taken for MZI construction that is SOI(silicon on insulator).To conclude (from the above figure 6) its inferred that 1.46 value indicate silicon di oxide material and 3.44 value indicate si material which is used for MZI construction.
The sensor MZI is designed and is done using Beam-prop technology, we carefully look after the manufactured acceptance of the MZI, especially with respect to the difference of the waveguide size and length and observed fabrication errors. Fabrication error variation in terms of width of waveguide causes a change in designed value. The material has taken as SOI for MZI configuration. MZI is about 7 nm, which for the two-channel MZI in Fig. 5.

4. Simulation Results

Table-2 Comparison of water and other arsenic compound and observe quality factor

Name Of Arsenic Compound	Amplitue (V)	Frequeny (Thz)	Quality Factor
Water	0.03	08449	19998
Indium Arsenide	0.031	0.861	
Gallium Arsenide	0.0249	0.854	

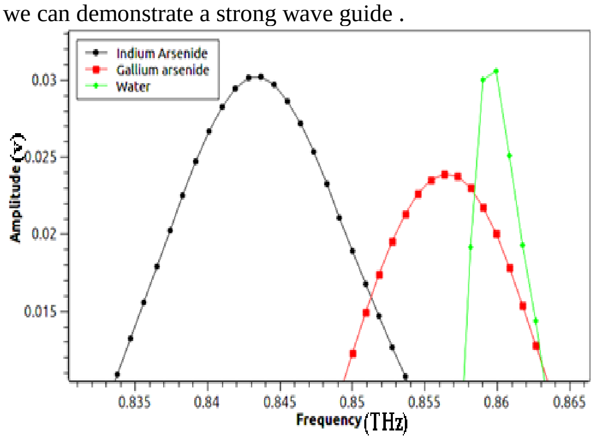
Table-3 Comparison of water and other arsenic compound and observe quality factor

Name Of Arsenic Compound	Amplitude (V)	Frequency (Thz)	`Quality Factor
Water	0.008	0.8179	19998
Cadmium Sulfide	0.000608	0.861	
Zinc Sulfide	0.0104	0.81509	

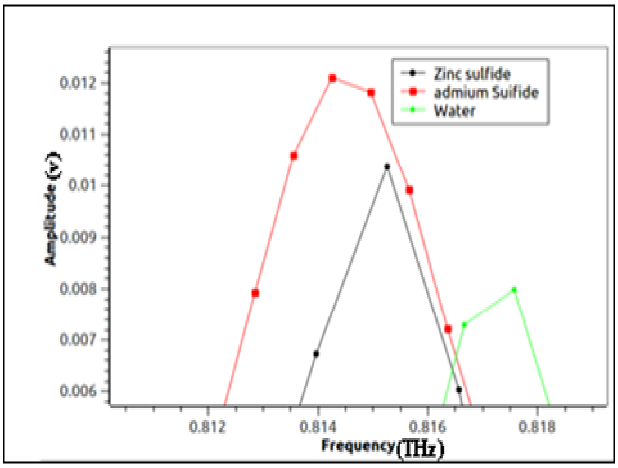
Table-4 Comparison of water and other arsenic compound and observe quality factor

Name Of Arsenic Compound	Amplitude (V)	Frequency (Thz)	Quality Factor
Water	0.12390	0.823	19998
Cadmium Telluride	0.031	0.8231	
Selenium	0.00066	0.8209	

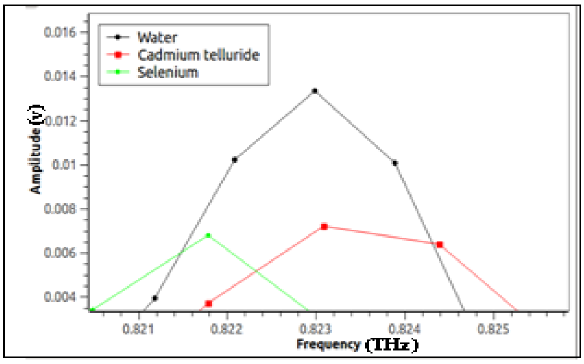
There is a variations in the resonant frequencies of arsenic present in water are obtained by using MEEP simulation tool and are shown in Table 2,3,4 and observed quality factor. Quality factor is observed by means of propagation of light through wave guide . we have to make sure that all the way through wave guide during propagation there will be very less loss or less scattering .So that we can demonstrate a strong wave guide .



Graph-1: Observe the peak amplitude of normal water and other peak amplitude of arsenic present in waetr with different R.I value of Arsenic



Graph-2: Observe the peak amplitude of normal water and other peak amplitude of arsenic present in waetr with different R.I value of Arsenic



Graph-3: Observe the peak amplitude of normal water and other peak amplitude of arsenic present in waetr with different R.I value of Arsenic

Graphs are presented here to show about arsenic present in water with different peak amplitude. For a particular frequency changes we have observed maximum peak value of amplitude for arsenic compound and water . Different arsenic compound has been observed which is present in the water with the help of their respective RI value . Silicon based material is used to fabricate high sensitive MZI sensor. RI value of si and sio2 is 3.45 and 1.44 has taken .

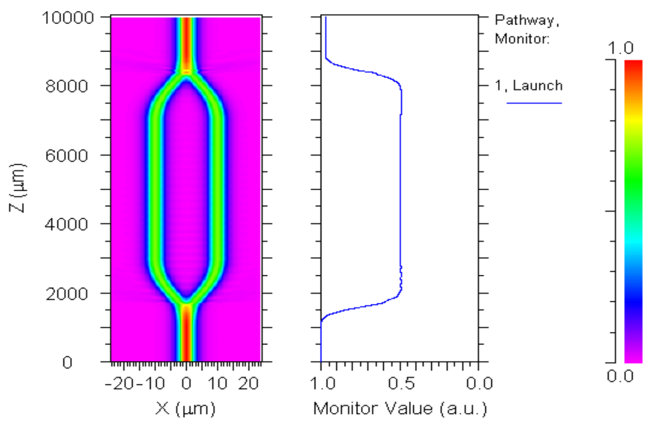
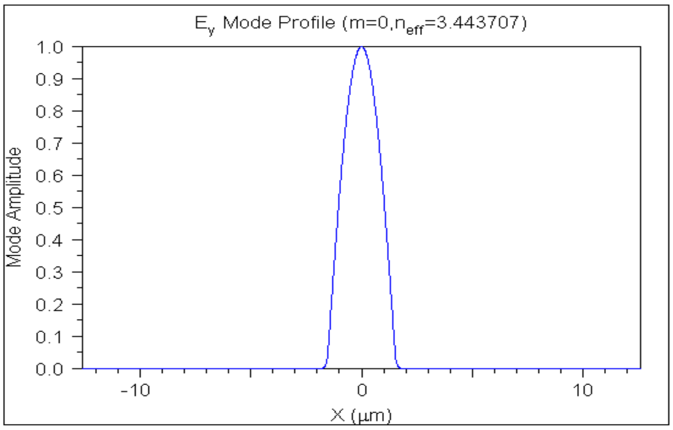


Fig-7: Light Propagation through MZI and observe the output power without sensing layer



Graph-4: Observe the Neff value for MZI calculation of Sensitivity

MZI waveguide sensor was experimented which can determine existence of arsenic compound in water. In this paper we have considered fundamental mode .Determination of arsenic compound in water is inevitable for the detection and identification of transferable or inborn diseases. By using equation 4 and from graph [4] Sensitivity of a common MZI for length of 7 nm of the channel length was accounted to be 78.5. So to achieve high sensitivity of MZI construction SOI material is used .

5. Conclusion

The design and optimization of a highly sensitive MZI of a waveguide biosensor is presented in this paper. MZI Biosensors comprises of slot wave guide and strip wave guide. This provides high sensitivity and high optical intensity region of MZI. The slot wave guide is integrated with sensing arm of MZI. From fig 7 we can conclude that this is normalized output power without sensing the arm with analyte . But after interact with sensor that is resonator, there will be change in propagation of light beam .This wave guide based MZI sensor has ability to perform in the platform for highly sensitive analytical device by combining the MZI's unique characteristic and photonic devices which are easier and simple to design. Design of a sensor should be cost effective ,small and possible to fabricate lab on chip. Both the proposed sensor are highly sensitive and with the help of both the sensor minute change can be detected when input refractive index of arsenic that is present in water is applied to the input terminal of sensor . Designed a photonic crystal sensor is part of sensing module but we have to monitor to represent a complete sensor that is complete lab on chip sensor that can be possible to implement by using MZI sensor.

References

[1] Ahuja, Satinder.;"The Problem of Arsenic contamination of groundwater."Arsenic Contamination of Ground water: Mechanism, Analysis, and Remediation (2008).

[2] R G Heidman,P.V. Lambeck,; "Remote opto with extreme sensitivity: Design , fabrication and performance of pigtailed integrated optical phase modulated Mach Zehnder Interferrometer system", sense actuat.B 61(1999)100-127

[3] Sarkar, I.Jamal, S.K Mitra,; "Analysis ,Design , and Fabrication of optical wave guide for Mach Zehnder Interferrometer" .Opt.Commun,311,(338-345)2013

[4] Marazaulela, M Moreno Bondi. Fibre optic.; "Biosensor overview.Anal .Bioanal,Chem". 372(5-6)

[5] S. Chandran,R . k . Gupta, and B. K. Das,; "Dispersion –free soi interleaver for dwdm application ,Journal lightwave technology",vol.30 no.1,pp.140-146,2012

[6] X. Fan, I. M. White, S. I. Shopova, H. Zhu, J. D. Suter, and Y. Sun. ;"Sensitive optical biosensors for unlabeled targets: A review," Anal. Chim. Acta 620, 8- 26 (2008).

[7] K.Zinoviev, L.G.carrascosa,J. Sanchen del Rio,B. Sepulveda,C. Dominenguiz,L.M Lekhuga, "In Advances in optical technology,2008,Silicon Photonic Biosensor for lab on chip application",2008

[8] Frazao , o.; Silva, S.F.O .; Viegas, J.; Baptista, J.M Santos , J.L.; Kobelke, J .; Schuster, K.;"All fibre Mach Zehnder Interferometer based on suspended twin-core fibre" . IEEE Photon . Technol. Lett.22,1300-1302,2010.

[9] Zhu,J.J; Zhag, A.P.; Xia, T.H.; He,S.;Xue,W. "Fibre optic High –temperature sensor based on thin-core fibre modal interferometer" IEEE sens, J.,10,1415-1418,2010

[10] D.aMarry-Arrioja, P. Likam WSa, J.J. Sanchez-Mondragon, R j Selvas Agular, and I. Torres –Gomez.; "A reconfigurable multimode interference splitterfor sensing application ,"meas Sci. Technol vol.18,no. 10pp.3241-3246,oct.

[11] S.K. Raghuwanish, V.Kumar, D. Chack, and Kumar .;" Propagation study of Y – junction optical splitter using BPM,"