The Interferometer of Mach Zehnder and Its Applications

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Abstract

Fiber optic interferometers have been studied extensively for sensing various physical characteristics such as temperature, strain, pressure, and refractive index. Fabry-Perot, Mach-Zehnder, Michelson, and Sagnac are the four different types. In this case, in this study, the operational principles of Mach-Zehnder interferometric sensor are examined. fabrication techniques, as well as application sectors. The technologies of interferometric sensors are described in detail to demonstrate their great potential in practical uses.

Mach-Zehnder The interferometer is a device that measures the difference in phase shifts Between two coherent collimated beams. According to this fundamental Principle, various devices can be designed. Several devices, including various types of in-line MZI optical sensors, all-optical switches and modulator, can be created using this basic principle are discussed in this paper.

Key Words: All-optical Devices, Wavelength Division Multiplexing, Mach Zehnder Interferometer (MZI), Optical Communication Systems.

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Introduction

Optical fibers have been widely used in the telecommunications industry for decades due to their Best light guidance for optimal performance [Prerana, P.; Varshney, R.K.; Pal, B.P.; Nagaraju, B, 2010]. Moreover, as optical technology has advanced, optical fibers have been extensively studied in a variety of sensor fields. due of Excellent sensitivity, low production cost, their unique properties including multiplexing, distance sensing, flexibility and low cost. small form factor, accuracy, and simultaneous loss of transmission, electromagnetic interference immunity and sensory ability There have been many research papers to date. Optical fibers were designed to transmit temperature, pressure, and rotational signals. Ultrasound, displacement, RI, and polarization [Wang, X.; Xu, J.; Zhu, Y.; Cooper, K.L.; Wang, A.2006]. As interferometers provide many temporal and spectral data, it is possible to accurately detect changes in the wavelength, phase and measurement via various ways, Intense, frequency, bandwidth, etc. These sensor indications [Kim, Y.H.; Kim, M.J.; Rho, B.S.; Park, M.S.; Jang, J.-H.; Lee, B.H. 2011].

This development has been made possible by the new optoelectronic technologies are being developed used to take use of optical fiber's high bandwidth There are systems available today that run at data rate in the billions of bits per second. more than 100 Gb/s Optical signals are presently the most common mode of transmission. for the international dissemination of information, It possesses the power to meet the future demand for high speed and bandwidth networks. Several optical network advancements have Mach Zehnder's utilization has made this possible Interferometer.

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In the optical processing of signals, such as switching, add-on multiplexing or modulators, Mach Zehnder interferometric devices is used. These are all tools needed for highly rapid optical domain signal processing without electronic translation needed Returning to the optical signal and signaling [Rekha Mehra, Heena Shahani, Aslam Khan.2014]. Section 2 in this document focuses correspondingly with the MZI fundamentals. In the MZI applications for Section 3 and Section 4 are discussed the conclusion is presented.

MZI Principle

The MZI is an instrument used to determine the Phase change from a coherent light source between two collimated beams by changing the length of one Arm or positioning the sample in one. One of the beams pathway. MZI has 2 input and 2 input ports Output ports. Output ports. As seen in Fig.1 a basic MZI [Choi, H.Y., Park, K.S., Lee, B.H, 2008] is built One acts as a splitter employing two couplers at the input Another performs as a combiner at the output. The light is divided into two Input coupler and interferometer arms The output coupler recombines at the output.

The optical system The course of two arms is uniform to adjust the phase The wavelength function of the equivalent time Signal input. For many optical applications this characteristic is applied All-optical signal processing devices.

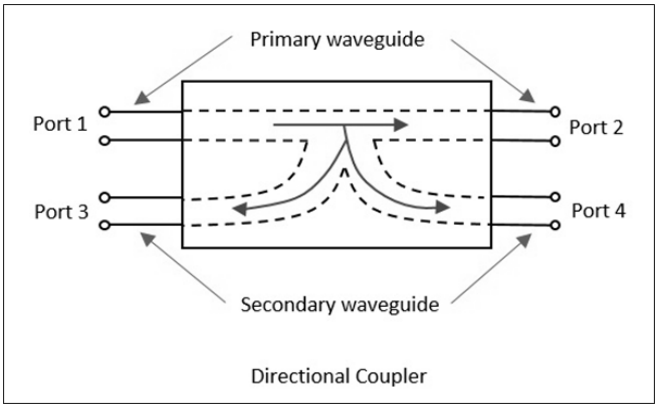

Fig. 1. MZI is made up of two 3dB directional couplers that are connected together

Early MZIs had two separate arms, the regular arm and the sensor arm, as shown in Figure 2. A fiber coupler splits an incident light into two arms and then recombines it through an other fiber coupler. In line with the OPD between the two arms, the recombined light is the interference component. The reference arm is separated from external variations for sensing applications and Change is exposed just to the sensing arm. Then the variations in the sensor arm, which can simply be recognized by examining the variation of the signal of interference, Temperature, stress and RI for example [Mehra R, Tripathi J, 2014].

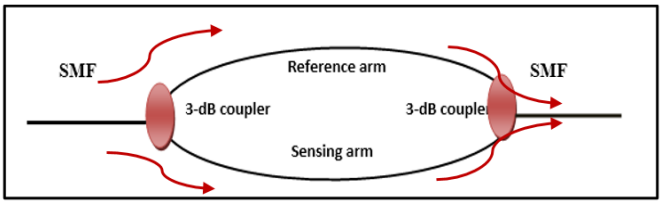

Fig. 2. The MZI's diagram. To split and recombine the signals, 2 connectors are used

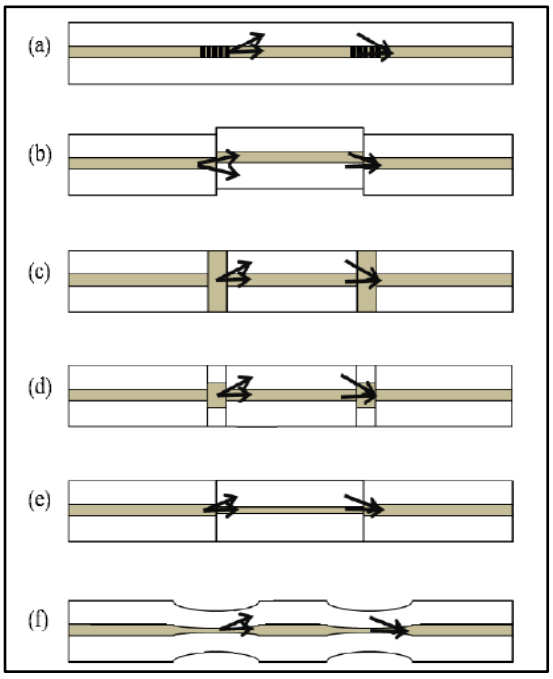

Fig. 3. Process of MZI Sensors can be constructed using (a) an LPG couple, (b) core malfunctioning, (c) PCF air-hole collapse, (d) MMF segment, (e) small core SMF and (f) fiber tapering. [2]

Applications

Sensors using Mach-Zehnder Interferometers

Mach-Zehnder interferometers (MZIs) were used for several sensing applications due to their Different configurations[Lee BH, Kim YH, Park KS, Eom JB, Kim MJ, Rho BS, Choi HY, 2012].

Since the appearance of a long period of fiber grating, the system of using two different arms has been replaced quickly with a design for in-line interferometer (LPGs). As indicated in **Figure 3(a),** the core mode in which a beam is controlled by SMF has been combined with the cladding modes The same fiber is combined by one LPG and then by a

different LPG to the core mode.

The combined beam and the uncoupled beam of the core cause a limited but highly efficient MZI interference. This inline shape of the MZIs is similar in physical length both the sensing arm and the reference arm, but because to the modal dispersion has the different lengths of optical paths. The LPGs are usually produced by the generation of periodic modulation by UV, CO2 or mechanical press in the RI of the fiber core. Even with a single-material pure photonic crystal fiber, the regular pressure on the PCF can generate a pair of LPGs [Lim, J.H.; Jang, H.S.; Lee, K.S.; Kim, J.C.; Lee, B.H, 2004].

A LPG-based MZI temperature sensor has been shown, with a pair of LPGs being used. were used to study the thermo-optic coefficient of the fiber core material. The small interference range allows even the influence of the wave length of the effective index of the core mode to be determined. It has also shown a higher thermo-optical coefficient than the doped core of Boron. A RI sensor based on the MZI that consists of a pair of LPGs has also been reported, which utilized the cladding mode sensitivity to the RI change in its surrounding media. The fiber tapering method was employed for the remote area between two LPGs to improve RI sensitivity. The LPG pair MZI, however, has a work wavelength challenge. Due to the phase-compared Fiber gratings phenomenon, the LPG works only at a limited wavelength. In addition, to get the best results, both LPGs should be the same [Lee, B.H.; Paek, U.C.2002].

Another technique to split a beam into the core and fiber splicing in two fibers, with one minute side offset, as illustrated in **Figure 3. (b),** Because of the offset, portion of the core mode beam is connected to various cladding modes without any wavelength significantly modified. Even a MZI with PCF can be constructed by simply fusing a part of PCF between tiny fibers. [Choi, H.Y.; Kim, M.J.; Lee, B.H.2007]. In comparison to the LPG pair approach, the offset process is cost-effective and quick. In addition, we can operate with any wavelength. Therefore, by modifying the offset amount, it is possible to manage the number of cover modes involved and Optical signal can be minimized by changing the compensation amount the mode coupling with one PCF cladding mode results in a splicing loss of as low as two dB.

Another good technique to create an in-line MZI is to collapsing the PCF air holes. The cleaning or alignment operation is easy and doesn't require trouble making In the collapsed air hole region, the core mode beam in the PCF is extended, allowing a part to be linked to the PCF's cladding modes as shown in **Figure 3. (c).**

However, it was apparent how many modes were connected in this case and the amount of modes involved was not possible to limit. By combining LPG with collapse methods [Choi, H.Y.; Kim, M.J.; Lee, B.H.2007], the loss of insertion can be reduced by 3 dB. These MZI sensors are based on PCF and have various advantages, including a high temperature and low cross-sensitivity. This is because of the presence of doped cores compared to standard SMF. The majority of fiber optic in-line MZIs, on the other hand, are based on multimode interference. Because the cladding component of an SMF is a multimode waveguide, there are more than one cladding modes involving the MZI in general In the majority of cases, the LPG pair uses only one cladding mode [Choi, H.Y.; Kim, M.J.; Lee, B.H.2007].

Because the sensitivity to environmental changes varies from one mode to another, multimode interference has an effect on sensing performance. As a result, the number of cladding modes that are involved must be kept to a minimum Multimode interference should be taken into account while fabricating sensors and performing analyses carefully.

Figure 3(d-e) shows another approach for splitting the beam in a fiber by using fibers with varying core sizes [] Zhu, J.J.; Zhang, A.P.; Xia, T.H.; He, S.; Xue, W.2010]. **Figure 3(d)** depicts one way for fusion splicing a short length of MMF into an SMF at two SMF locations. The light travelling through the lens in this example is The SMF's core is extended across the MMF region before being connected into the next's core and cladding SMF.

Another technique, shown in **Figure 3(e),** involves inserting a tiny core fiber between two conventional SMFs. The beam is not only guided as a core mode, but also in the small cladding mode, in the small core fiber area [Zhu, J.J.; Zhang, A.P.; Xia, T.H.; He, S.; Xue, W.2010]. By tapering fiber in two places, A effective in-line MZI can be designed., as shown in **Figure 3(f)** As a result of Tapering increases the core mode diameter, allowing part of the mode to be transferred to the cladding mode. It is really basic and easy, but mechanically weak, in particular in the tapering area.

With the in-line MZI, users can involve various measurement at the same time.. By using air-holes collapsing of PCF we can simultaneously measure Refractive Index Sensor. We propose and investigate a Mach-Zehnder interferometer refractive index sensor based on splicing a short solid-core photonic

crystal fiber between two single-mode fibers in this research.

The fully collapsed air- holes of PCF allow the splitting between core and cladding modes that makes a mach-zehnder interferometer. The core mode is guided by core-cladding interface of the fiber; therefore, its propagation is insensitive to the refractive index of the surrounding. But the cladding mode is guided by cladding-ambient interface. The adsorption of our liquids changes the effective refractive index of the cladding modes in the sensor head, but the effective refractive index of the photonic crystal fiber core is unaffected by the surrounding refractive index, and n is the variation of effective refractive index of photonic crystal fiber cladding along with surrounding refractive index [Q. Wang, L. Kong, Y. Dang, F. Xia, Y. Zhang, Y. Zhao, H. Hu, J. Li, 2016].

$$\Delta_{neff} = neff^{core} \_ neff^{cladding} \quad (1)$$

Where is the difference between effective refractive index of fiber core and cladding ($neff^{core} > neff^{cladding}$).

The interaction of the cladding mode with external refractive index change Δneff Thus, by depositing a liquid on the PCF surface. Consequently causes a change in the phase difference giving rise to a shift of the interference pattern. The phase difference.

$$\Phi = 2\pi \Delta_{neff\,L} / \lambda \quad (2)$$

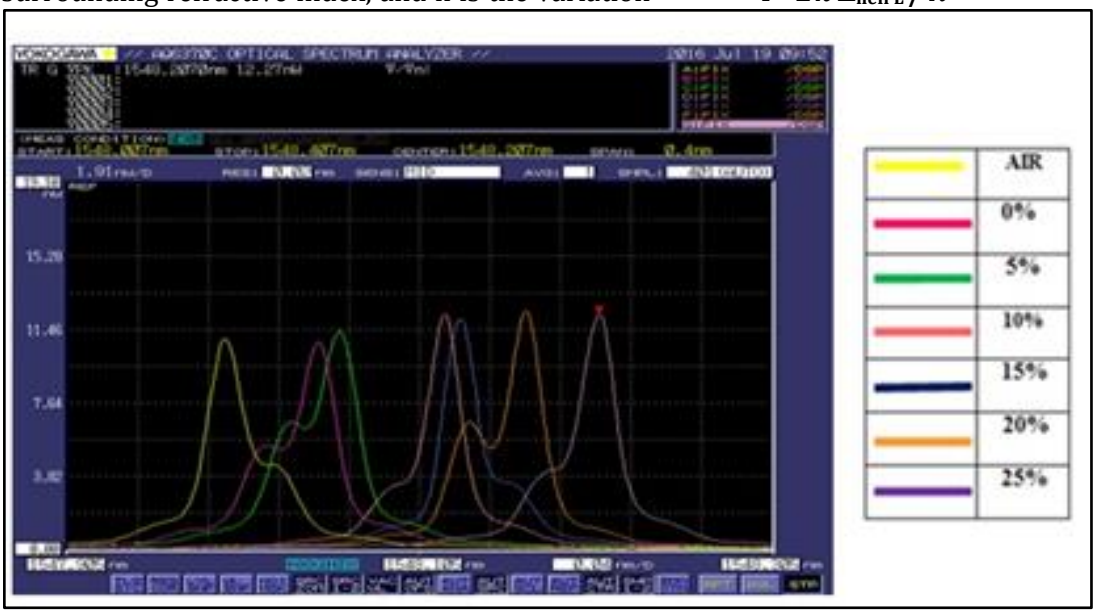

Fig. 4. Transmission spectra of 3cm PCF interferometer for sensing with different Rertactive index

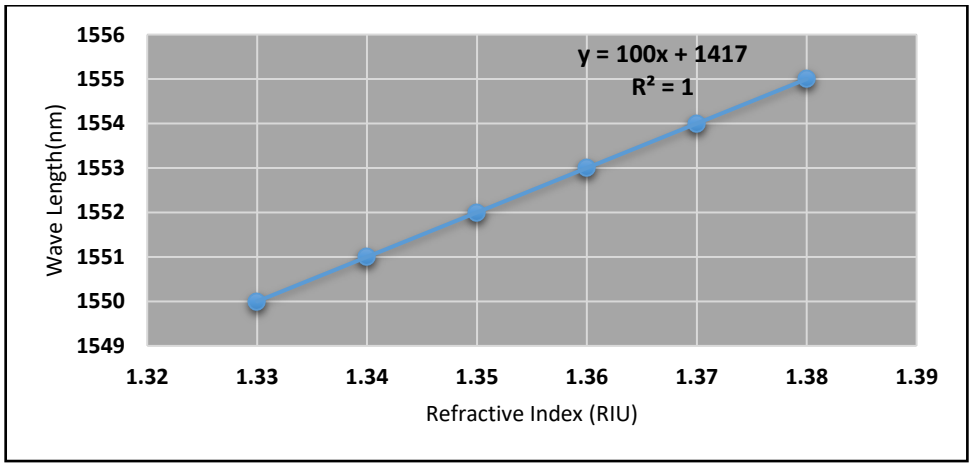

Fig. 5. Transmission spectra of 3cm PCF interferometer for sensing with different refractive index

Mach Zehnder Interferometer switches

Every day, the requirement for quicker communication develops. To meet this demand, greater and higher data rates are required, which can only be achieved if data remains in the server. the domain of light Advanced optical networks are required for this. Ultra - fast signal processing devices that are made entirely of light.

As a result, alloptical switches are increasingly replacing O-E-O switches. MZI switches are monolithically integrated. Due to their small size, thermal insulation is the most viable solution. stability operation (hundreds of fJ for control pulse) Figure 6 depicts. In a simple 2X2 MZI switch structure two MZI switch devices are connected. The interferometric arms are coupled in equal length.
The first coupler divides the signal into two beams that have the same phase as they pass through the arms interferometer.
This phase differential is produced by changing voltage across interferometrical arm electrodes which change refractive index. The output coupler is a 3dB coupler. mixes both beams with different phases and produces a final result The outputs are classified into categories of construction and destruction Interference [Papadimitriou, Georgios I., Chrisoula Papazoglou, and Andreas S. Pomportsis, 2003].
Lithium Niobate has been successfully employed in the design of switches based on the Mach Zehnder Interferometer or directional coupler. Symmetric MZI has demonstrated to be more flexible. as well as the shortest change over windows when compared to other Improvements in all optical switching configurations. MZI switches' performance and high-speed capability investigate into them, respectively.

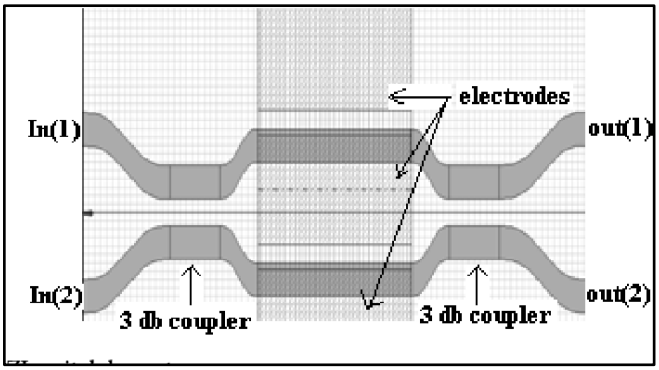

Fig. 6. Structure of a basic 2x2 MZI switch

Mach Zehnder Interferometer Moduleter

External modulation in optical transmission systems is becoming more important as the demand for high-speed communication increases. External possibilities are one of them. The use of a Mach-Zehnder structure in a material is called modulation. displaying a powerful electro-optic effect (such as LiNbO3).

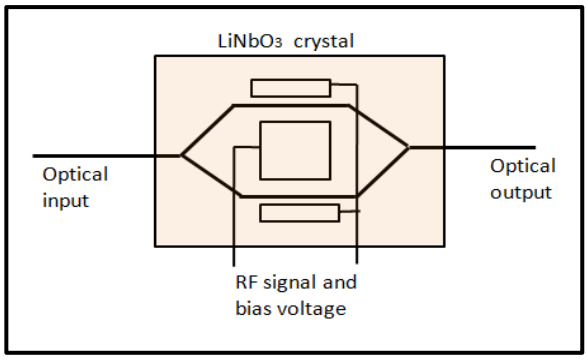

Fig. 7. Mach-Zehnder interferometer modulator

Mach Zehnder modulators give both the requisite bandwidth and the required efficiency. equally significant means of reducing the effects of One of the most important factors in limiting the size of the group is dispersion. high-speed fiber-optic transmission systems' performance The incoming light is split into two halves in Mach-Zehnder modulators. the interferometer's two arms Both are subjected to a voltage. according to the arms, generating a their refractive index has changed as a result of the electro-optic effect This period of changing refractive index controls the propagation of the beam through the arms of According to the applied voltage, an interferometer is created. This is the second stage. By converting modulation to intensity modulation, bringing the two paths together.

Conclusion

We presented an overview on the application of interferometric fiber-optic sensors. First, we provided a concise account of the interferometers Mach- Zehnder and their principle of operation. splicing short photonic fibre lengths between two single-mode fibre sections. By creating two collapsing points in PCFs, interferometers were completed.
As presents an overview of its design and usage in the Optical Communication Networks of the Mach Zehnder Interferometer. MZI is able to perform several all-optical functions necessary for future optical networks in practical applications. The application of MZIs increases with the advance of opto-electronic integrated circuit technology and reduces production costs.

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