Tunable Band Pass Filter and Phase Modulator Based on Multimode Nested Mach-Zehnder Interferometer

Tahreer S. Mansour Alfalah
Institute of Laser for Postgraduate Studies
Iraq
tahreeralflah@yahoo.com

Ayah T. Yahiya Al-khalefa
Institute of Laser for Postgraduate Studies
Iraq
aya.thabit.khalefa@gmail.com

ABSTRACT: This paper presents a continuously tunable optical band pass filter based on nested MZI designed by two arms multimode Machzehnder interferometer was proposed. The tunability of the filter is achieved by wavelength tuning of the multimode fiber. Tunability of the filter can be generated by applying Mechanical effect which is strain on the sensing arm of MM-MZI. It has been shown from the simulated results, it is done by Optiwave soft wear obtained that the shifted central wavelength from (1546.01) to (1546.021) nm, full width at half maximum from (279.321) to (273.681) pm, maximum gain is 22.55 dB and phase shift from(0) to (6.0808) rad and in the practical results obtained to the shifted central wavelength from(1545.762)to (1545.764)nm, FWHM from (197.529) to (283081)pm, maximum gain is 21.66 dB, and phase shift from (0) to (6.059) rad. Observed from the results, the relation between the shifted central wavelength and strain is nonlinear.

Keywords: Fiber - Optic Sensors, Multimode Mach-Zehnder Interferometer (MM-MZI), Strain Measurement

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1. Introduction

We present a new tunable all-fiber compact multimode fiber (MMF)-based filter and its applications in fiber sensors. The expression of the transmission of the optical filter is the same as that of a regular Mach-Zehnder interferometer (MZI) but with an additional optical phase shift in the sinusoidal function, which makes the MMF-based filter tunable. The phase shift could be changed by properly adjusting of a mechanical effect i.e. (strain). The proposed tunable filter has been employed for intensity interrogation of a fiber Bragg grating (FBG)-based temperature sensor where the MMF-based filter serves as an band pass filter. With the tuning technique. Multimode fiber (MMF) based MZI has been proposed by our group for simultaneous measurement of strain [1].

2. Theoretical Overview

The schematic diagram of a MM-MZI is shown in figure 1. It consists of two multimode couplers; the first acts as a splitter to split light into two arms: reference and sensing arms, and the second acts as a combiner. When applied micro strain on the cross section area of multimode fiber on the sensing arm, resulting optical path difference between these arms. The light intensity of the output of MZI can be expressed as [2]:

$$I = I_r + I_s + 2\sqrt{I_r I_s} \cos(\Delta\phi) \quad (1)$$

Where I_r and I_s are the intensities of reference and sensing arm.

The phase difference between the sensing arm and reference arm is described by [2]:

$$\Delta\phi = \frac{2\pi\Delta L n_{eff}}{\lambda} \quad (2)$$

Where ΔL is the change in optical path length, λ is the wavelength in the vacuum, and n_{eff} is the effective refractive index of the mode.

Output power of Mach-Zehnder Interferometer is described by [2]:

$$P_{out} = P_{in} \cos^2(0.5\Delta\phi) \quad (3)$$

Figure 1. Schematic diagram of tunable optical fiber MM-MZI band pass filter

3. Experiments and Setup Assembly

3.1 Theoretical Optiwave

Figure (2) shows the simulation setup of the system utilizing OptiSystem software.

The system consists of a continuous laser source, two multimode optical couplers (the first acts as a splitter and the other acts as a combiner), and finally connects to the Optical spectrum analyzer (OSA) to see the output signal.

Figure 2. The designed model of simulated system with Optisystem software

Continues wave laser have specifications:

Wavelength nm	Power mW
1546	1.85

Figure 3. Signal of CW LASER source

3.2 Practical Setup

Figure 4 are photographic images of the experimental parts. It comprises of continues wave laser source (CW LASER), (1×2) input multimode fiber coupler acts as splitter, Dual multimode fiber reference and effect a arms respectively, (2×1) output multimode fiber coupler acts as combiner, and optical spectrum analyzer(OSA) to visualize phase shift in the spectrum of the source by applied manual elongation measuring instrument i.e. (micro strain) on the second arm of MM-MZI.

Figure 4. A photographic image for the experimental setup when applied micro strain on the cross section area of MMF

4. Results and Discussed

In this work, we designed and implemented a tunable optical band pass filter based on MM-MZI. the simulation and experiment work for this filter is demonstrated and constructed after designed using nested MZIs. From simulated work we obtained results such as figure 5.

Figure (a). Signal when applied zero strain

Figure (b). At strain=0.09mm

Figure (c). At strain=0.24mm

Figure (d). At strain=0.31mm

Figure 5. These figures obtained from optiwave software when applied varies value of strain on the cress section area of MMF

These figures it summarizes in the table (1)

Strain(mε)	Central wavelength (nm)	FWHM (pm)	$A_{dB} = 20 \log P_0$	$\Delta\phi(rad) \times 10^{-11}$
0	1546.01	279.321	22.55	0
0.09	1546.015	281.527	22.34	2.0269
0.24	1546.019	275.762	21.75	4.0519
0.31	1546.021	273.681	21.87	6.0808

Table 1. Effect different values of strain on the central wavelength, FWHM, gain and phase shift

In practically, when we are applied micro strain on the second arm of MM-MZI, the central wavelength (λ) is shifted to red shift as figure (6). The effected of micro strain on the central wavelength (λ), full width at half maximum (FWHM), gain (A) and phase shift ($\Delta\phi$) is listed in table (2).

Figure 6. Tunable optical band pass filter when applied different sets of strain on the cross section area of MMF

This figure brief in the table 2.

Strain(mε)	Central wavelength(nm)	FWHM(pm)	$A_{dB} = 20 \log P_0$	$\Delta\phi(rad) \times 10^{-11}$
0	1545.726	197.529	21.66	0
0.09	1545.736	216.389	21.51	.236
0.24	1545.750	233.607	20.98	.261
0.31	1545.764	238.081	20.83	.059

Table 2. Micro strain affected on the optical properties of band pass filter

It can be seen from this table, when there is no strain i.e.(zero strain) is applied the $\lambda = 1545.726\text{nm}$, FWHM= 197.529 pm, gain = 21.66dB and zero phase shift, when strain is applied with 0.09, $\lambda = 1545.736\text{nm}$, FWHM= 216.389pm, gain = 21.51 dB and (0.236) rad , and when applied strain with values (0.24 & 0.31) we can be seen that the λ , FWHM are increased and the gain is decreased while the phase shift increase when the length of the multimode fiber is increased, so we can be discussion results in generally, when we applied strain on the second arm of MM- MZI, when this strain is increased leads to λ and FWHM are increased gain is decreased and the phase shift increased.

- Comparison between the simulated and practical results can be observed in these figures.

Figure 7. Comparison between the practical and theoretical works with central wavelength, FWHM and phase shift results when applied different sets of strain effect on the cross section area of MMF on the two arms MM-MZI

6. Conclusion

Band pass filter and phase modulator was based on MM- MZI, illuminated with a CWLASER source and a fiber length used as dispersive element. When applied Mechanical effect which is micro strain on the second arm of MM-MZI i.e. (effected arm) the length of the fiber was changed can be concluded from the results multimode fiber is not a good band pass filter because of the excitation of higher order modes which effected on the quality of propagating fundamental mode via the core of fiber, but it was a good phase modulator because of the evanesce field. It observed from that, Practical results different from theoretical results because the practical results implemented at laboratory, the humidity in laboratory is large in which temperature up to 45C° and the optical fibers very sensitive to temperature, so changed the refractive index of these fibers. Also the presence of dust in FC connector of the MMF and in the laser pointer and these leads us to some differences between theoretical and practical results.

References

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