Design of Microring Resonant Sensor Based on Mach Zehnder Interferometer

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Abstract. Ultra-high sensitivity (high quality factor) and low detection threshold are necessary for measuring a wide range of biosensors. To improve the sensitivity and measurement range of the sensor, this paper proposes a micro-ring model based on Mach-Zehnder. The finite element method is used to simulate the resonant wavelength corresponding to the commonly used refractive index. The device is available in sizes 6*32*85.948 μm³. The simulation results show that the transmission is stable at -2dB above the width of the waveguide at 4.8-5.1μm. The radius of the microring and the transmittance change into a damped oscillation curve with a period close to 1.6μm. The microring resonant sensor can detect the detected object by detecting the drift of the resonant wavelength. The microring resonators is easy to operate, simple in equipment, fast and accurate in measurement, and is suitable for medical, biological, and environmental monitoring.

Keywords: Integrated optics, The Si3N4, The sensors, Microring resonators.

1. Introduction
Integrated optics is to make a light source, an optical waveguide containing various active devices, and a photodetecting device on the substrate shape of the same material as the three to form a compact, compact and monolithic integrated optical path [1-3]. To the extent of the advantages of integrated optics. As a passivation layer on the surface of high-efficiency devices, silicon nitride film has been applied in semiconductor technology, with good insulation, compactness, stability and masking ability for impurity ions. Currently integrated silicon realizes silicon nitride photonic device It can perform multi-signal processing functions together with traditional photonic devices, and proposes some silicon nitride photonics (i.e., silicon nitride optical waveguide) components [4-6]. Therefore, silicon nitride photonics are of great importance in integrated optical applications. In this paper, a microring resonant sensor based on Mach-Zehnder interferometer [7-8] is proposed, which consists of a silicon nitride straight photon, a silicon nitride ring photonic, a silicon dioxide buffer, and a silicon dioxide overlay. The layer is composed of a silicon nitride substrate. The micro-ring sensor can detect different objects, mainly caused by the change of the refractive index of the measured object, which causes the change of the position of the micro-ring resonance peak. By detecting the drift of the resonant wavelength, the detection of the measured object can be realized.

2. The Basic Structure of the Mach-Zehnder Interferometer
The most basic model of the Mach-Zehnder interferometer is similar to the combination of a 3dB splitter axisymmetric. Figure 1 shows four basic models of the Mach-Zehnder interferometer. (a) The
structure will bring about a large loss of light energy; (b) The structure can achieve a stable transition; (c) The structure realizes equal division of energy; The structure satisfies the principle of self-image. Among the three models (a), (b) and (c), the results can be debugged in tens of micrometers and the transmittance is above 90%. For the (d) model, the optical path is complicated due to the interference region. The requirements are relatively high. Comprehensive comparison of the first three structures is relatively stable. Figure 2 is a corresponding simulation diagram.

Figure 1. Basic model

Figure 2. Basic model physical mode field diagram

Figure 2 that (a) the structure is subject to a sudden change in the angle of the optical path bifurcation, the length of the coupling, the spacing, and the stability is not very good; (c) the structure cannot extend the spacing of the arms, and the design is limited in use. (d) The model consumes too much size and is not suitable for use; (b) The model uses a curve design at the bifurcation part to provide a slow transition before the light wave is distributed, which will make the energy more concentrated, etc. The split effect is also more accurate than the other three.

3. Micro Ring Sensor Design

When the light wave enters the straight photon line from the incident port and is coupled to the ring photon line, the optical path difference generated after one week of transmission in the ring photon line is exactly an integer multiple of the wavelength. Interfering with each other and generating resonance enhancement effects. The basic resonance equation to be satisfied when a ring resonator resonates is:

\[ 2\pi R n_e = m\lambda \]  

(1)

Where (1) \( \lambda \) is the resonance wavelength, R is the radius of the microring, \( n_e \) is the effective refractive index of the guided wave mode in the ring photon line, and m is the resonance order (a positive integer). From the point of view of reducing loss, the Y-curve type Mach Zeder interferometer
is selected as the sensing platform. As shown in Figure 3, from left to right, the input straight waveguide, the tapered waveguide, and the output curved waveguide are sequentially arranged.

**Figure 3.** Structure diagram of the curve Y branch

Figure 3 H0 is the width of the input strip-shaped straight waveguide, which is 0.5um; W0 is the length of the input strip-shaped straight waveguide, which is 5um; W1 is the length of the tapered waveguide, which is 1.2um; r0 is the radius of the curved waveguide. The size is 18um, a is the bifurcation angle of the curved waveguide, and b is a number greater than zero. In this structure, b=4 is taken, and its value mainly plays a decisive role in the pitch of the bifurcation.\[
\begin{align*}
dx_{\text{bend}} &= 2(r_0-0.5H_0)\sin a = 11.747\text{um} \\
dy_{\text{bend}} &= H_0b = 2\text{um}
\end{align*}
\]

Figure 4 is a general structural diagram of a microring sensor. The structure is symmetric about the center of the microring. The microring radius r1=8um, the loop width d=0.5um, the signal arm half length L=25um, and the overall stretch is 0.73um. In the three-dimensional structure, a cover layer (2 um thickness), a buffer layer (2 um thick), a substrate (2 um thick) were laid, and a sensing area was added to the surface of the buffer layer. The sensing area has a length of S=25um, a width of 5um, and the same thickness as the cover layer. The width of the whole device in the x direction is \(2(W_0+W_1+2dx_{\text{bend}}+L)\), and the width in the y direction is \(4dy_{\text{bend}}+2r_1+8\) (the overlay layer is 4 um more than the light guide area). To facilitate the setting of boundary conditions. The microring is tangent to one of the signal arms. The overall size of the device is \(6*32*85.948\text{um}^3\).

**Figure 4.** Structure of the micro-ring sensor based on MZI structure

In Figure 4, when a light wave is input from the left port, it will be divided into two beams with the same light intensity in the trapezoidal transition area. The two light beams will interfere with each other in the trapezoidal area through the signal arm and the reference arm, and interference will occur. When the signal arm changes in strength and phase relative to another reference arm fiber in the S area due to temperature, cladding refractive index, etc., reinterference in the trapezoidal area will cause changes in output strength and phase, resulting in the same At frequency, the highest point of power moves. Due to the frequency offset corresponding to the highest point intensity at the output, the measured object can be reflected. The measurement object can be detected.

**4. Simulation Results**

Under the same wavelength condition, changing the refractive index of the sensing area will obviously cause the two optical path arms to have different phase and interference effects in the output cone region, thereby affecting the corresponding optical power output intensity. Because the micro-ring has periodicity, the highest point or the lowest point can be adopted as the sole index of refractive index induction. In this paper, the highest point of output is used as the resonance point. Figure 5 is a
simulation of the physical field at a refractive index of 1.33 at a wavelength of 1210 nm and a physical field effect diagram of light wave transmission at a refractive index of 1.35.

(a) Simulation of the physical field at a refractive index of 1.33 at a wavelength of 1210nm

(b) Simulation of the physical field at a refractive index of 1.35 at a wavelength of 1210nm

**Figure 5.** Physical field pattern of refractive index change at a wavelength of 1210 nm

Figure 5 at a wavelength of 1210 nm, the transmittance can reach more than ninety percent at a refractive index of 1.33, and at a refractive index of 1.35, some loss and scattering of the optical path in the output cone region will be caused.

Figure 6 is a graph of the resonance point effect curves at the wavelengths of 1210nm, 1225nm, and 1228nm.

**Figure 6.** Relationship between transmittance and wavelength at resonance

The simulation software based on finite element method is used for modeling, simulation and optimization. In order to facilitate the processing, the straight waveguide and the micro-ring are set as tangent in the model. After the modeling is completed, the micro-ring resonator only needs to adjust the micro-ring radius and micro-ring width to achieve the best working effect in the simulation optimization. As shown in Figure 7 the transmittance is stable above -2dB when the width of the waveguide is 4.8-5.1um. As shown in Figure 8 the radius of the microring changes with the transmittance to form a damping oscillation curve with a period close to 1.6um.
Figure 7. Relationship between transmittance and waveguide width

Figure 8. Relationship between transmittance and micro-ring radius

Compared with a sensor with a combination of a straight waveguide and a micro-ring, the micro-ring sensor based on the Mach-Zehnder interferometer has greatly improved the Q value, the peak value is very prominent, and the left and right curve trends will not confuse the resonance point. The detection process is simple.

5. Conclusion
In this paper, an ultra-small micro-ring resonator is designed and simulated by using finite element algorithm. The core part of the micro-ring resonator has only two components, and the structure is simple; and the two ports of the micro-ring resonator are on both sides of the device, which is convenient to connect; the micro-ring resonator can distinguish four kinds of DUTs with very similar refractive indexes On, high sensitivity. The overall size of the resonator is 6*32*85.948um$^3$. Considering that the refractive index of various materials will change with the change of wavelength, the resonance wavelength and the corresponding resonance refractive index and transmittance are not obviously linear, but the overall change trend is unchanged. The accuracy error of the resonator is within the allowable range. For process error within the allowable range, the width of the entire resonator in the x direction is $2 * (W0 + W1 + 2 * dx_{bend} + L)$, and the width in the y direction is $4 * dy_{bend} + 2 * r1 + 8$ (overlay 4um more than each of the light guide areas on average, which is convenient for setting the boundary conditions). The microring is tangent to one of the signal arms. If a particular biomolecule is known to absorb a particular wavelength, then the sensor can generate a resonance point at which it acts as a sensor. The maximum peak of the transmission spectrum is adjustable to set the desired wavelength. At present, high-sensitivity biosensors have already penetrated into various sectors of the national economy and are highly competitive in the market. The design of this sensor is useful for the follow-up in industrial production, environmental monitoring, marine detection, biological engineering, cultural relics protection and other fields. The research
provides a certain theoretical basis and plays a positive role in promoting the development of biological engineering.

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