Design and Simulation of Novel Optofluidic ring resonator for Biomolecular Detection

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ABSTRACT:
In This study, a label-free detection method by using a novel Optofluidic ring resonator sensor (OFRR) structure is presented. Optofluidic is a developed young research subject suitable to create an appropriate cooperation between optics and fluidics. The combination of fluidic and optical methods achievable. by using the optofluidic methods makes it expedient to obtain an inventive type of sensors, which have been tried to have an ameliorate sensitivity, denseness and adaptivity. OFRR is a recent detection method that integrates Optic and fluid technologies with low-limit and low-cost and small- sample volume detection sensitivity. The objective of this article is the detection of the tuberculosis by offering a unique and a novel useful structure that is able to fabricate. The material of the proposed structure is PDMA that is completely flexible polymer. The width of the waveguide, the waveguide length and width of the ring of the proposed structure respectively is 500nm, 250 nm, 1500 nm. Also, the inner radius of the resonator ring in 4700 nm. The simulation Result of proposed structure by Opti-FDTD software shown 649 nm/RIS for the slope of the sensitivity curve.

KEYWORDS: Optofluidic, Ring resonator, OFRR, Biomolecular Detection, PDMS, BRIS, Microfluidic.

1. INTRODUCTION

Fluid-optic ring resonator detection methods (OFRR) have emerged in the recent years. This method is known as a high accurate detection of biological and chemical methods.in the ring resonator, the emitted light from the source is coupled to the ring. Also, the dependence of the coupling coefficient to the environmental factors between the ring and waveguide, make it possible to be used as small-scale size structure as an accurate sensor. in the past previous methods, the inability to use the samples in small dimension was one of the major constraints. by using the OFRR this limitation has been overcome.in order to increase biomolecules detection sensitivity, OFRR with significant qualify structure should be used.

in the recent years, to improve OFRR, experimental methods have been used. Fluid-optic ring resonator applications including Free-labeled detections, Measuring the fluorescence by ring resonator, SERS-based sensors and Lasers microfluidic. Expensive and time consuming are the most important drawbacks of the experimental methods.

the light and liquids Integrating in order to utilize the benefits of fluid in the light-based devices will be done. microscopes and microfluidic lasers are the most obvious examples of devices made in that integration.

There are many benefits for fluids and fluid environments such as smooth mixed impossible surface of the fluids, optical control by infiltration phenomenon, fluid as excellent transmission environment that the solid environment doesn't have this advantage and fluid is suitable interface for floatation. Lithography without mask is another interest case of fluid as transmission interface. Easy transfer fluid has three major advantages; first, by changing the fluid in the optofluidic device, the properties of the device can be changed, with this advantage it is possible to fabricate adaptable devices.

Also, OFRR technology in gas analyzers due to portable, low-cost, fast functional reaction and high sensitivity has been beneficial. Detecting explosives materials such as TNT, ARD-X and detect and analyze specific indicators of human breath, are another application that can be improved by using OFRR.

An optofluidic ring resonator (ORR) for operation Detection based on fluid core ARROW has been established by Testa et al. [19]. A specific study method, stood on the development of each optical component consisting of the composite ring has been published [2]. generally, the development principle was the necessity of low distribution losses, for a high sensibility and high-quality factor ring resonator. Quality factor up to 4 × 10 has been determined by simulations and bulk RI detection limit of Δn = 3.7 × 10. Optofluidic resonators have been additionally fabricated using photonic crystals. they are a strong structure composite for optofluidic as the cavity, constructed to provide stable light bound, can also be utilized for fluid flowing [3]. There are four basic methods to stimulate the SPR, prism coupling [4], waveguide coupling [5], fiber optic coupling [6], and rubbing coupling [7], [8]. with the rubbing coupling, the incident light irradiates the metal surface as a result it requires the specimen fluid and microfluidic to be optically transparent. The detection of the SPR modification contained by the necessary of object molecules to the sensing surface can be achieved by controlling the resonant angle [9]. resonant wavelength [10] or resonant intensity change [11]., several team also investigated the detection of the variations in phase [12–13] or polarization. Recently in the study of Testa et al. [9], TiO deposition by atomic layer deposition (ALD) method was applied to construct the high index cover layer in order to enhance the comprehensive optical performance of these waveguides by accompanying benefit of developed conformality, uniformity and lowered surface roughness which are expected of ALD.

in this study, effort have been carried out to find an optimization distance between waveguide and ring, according to the sensor dimension. wavelength absorption of the output been measured by putting biological samples between the ring and waveguide and at another way, by placing samples inside the ring (BRI method). also by examining the usable material, and select the most appropriate material, significant output result is obtained. The proposed structure sensitivity compared to the previous studies, is much desirable.

2. DESIGN OF OPTOFLUIDIC RING RESONATOR

Meanwhile progress of the sensing applications, optofluidic become apparent from the necessity to provide up high sensitivity sensor with low consumption and miniaturized applications. the increasing requests of compact devices for performing the biochemical and biological investigation on micronized size have recently been presented. the growth, as a result, known as science laboratory on a chip (LOCs). [14], [15]. Fluids are often expeditiously used to transport cells or alternative biological molecules that are usually suspended in liquid solutions. especially, since the detection volumes are often very small, optofluidic micro sensors are ideally fitted to concluding single molecule detection [16]. Moreover, the possibility to drive fluids into and out of the fluidic handling system with endless piping network makes these devices very enticing for bio-threat detection [17]. Fig.1 shows a typical Optofluidic Ring resonator sensor.

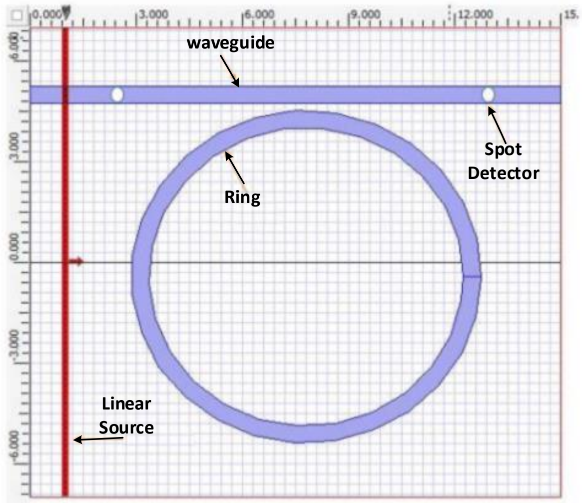

Fig. 1. Structure of Opto-Fluidic Ring Resonator Sensor.

OFRR quality is depended on the thickness of the ring, ring diameter, waveguide width and distance between the waveguides and ring. OFRR sensors are useful in the biologic field due to liquid is used as a light conductor, and liquid works as a light coupler. Most of the test samples are liquid and biological cells have the ability to carry coupled light. OFRR is a capillary-based optical cavity and works base on a capillary platform. The sensor output is based on the measured resonant frequency of the collisions between the light and samples. Optical-Fluid sensors have wide medical applications due to Light benefits, including Numerous techniques to detect with high sensitivity, Possibility to focus the light on the appropriate scale-required for biological and Manipulation the fluids and floating objects by the light. Optical micro-resonator structures are striking and talented for high sensibility miniaturized biological [18]. The major benefit of these structures is the recurrent collision between light and sample, due to the resonant frequency of light in the cavity hole. This phenomenon effect to enhance the coupling strength of light with the sample and in the sensing applications, to improve sensitivity. Optical resonator structure allows reducing this typical limitation happening in an MZI, i.e., a decreased interaction length diminished by the physical length of the sensing procedure. The effective light-sample collision length L is controlled by (1):

$$L = \frac{Q \times \lambda}{2\pi \times n} \quad (1)$$

where Q is the ring resonator quality factor, λ is the resonant wavelength, and n is the optical mode relative to the refractive index. The sensitivity and accuracy of the resonant frequency are depended on the thickness, dimeter and distance between the ring and resonator.

Optofluidic resonators for sensing structures have been recently demonstrated by using the same fluids as the only element to realize the resonant cavity, such as microdroplet resonators [19], or by properly combining fluidic ability in the photonic structure.

fabrication processes of OFRR started with create a capillary tube under high temperature to approach the outer diameter to about the 100 um and thickness of wall be less than $5\mu m$. as the wall, be thin such as mentioned, vanishing fields emitted from WGMs to the center of the cavity. at this point, WGM sensitivity to the center's cavity RI showed by (2).

$$\lambda = \frac{2\times\pi\times r\times n_{eff}}{m} \quad (2)$$

which r is radius of the ring and n_{eff} is experienced refractive index by WGM and λ is spectral WGM position and m is an integer which indicates times WGM phase.

Most of the optofluidic have a similar structure. Design, fabrication, and operation of the fluid system are in order to best use of them in the chemical and biological field.in this regard, have been tried to focus on the use of PDMS. PDMS is considered a transparent elastomer in the light vision.in term of stiffness, it can be controlled from a soft mode (can be bend by figure pressing) and totally stiff mode. Microfluidic system fabricating is very simple on the PDMS material. fabrication of the high performance and useful devices with wide functionality is possible due to Physical and chemical properties of PDMS. PDMS is flexible and have adjustable Young's modulus that is about 750KPa by default. Also, it is hydrophobic and its refractive index is about 1.41 and have very low internal reflection. Creating and blocking channels in PDMS is far easier than creation them in glass or silicon.

3. RESULT AND DISCUSSION

In the label-free detection, object molecules aren't labeled and are identified in their original shapes. this type of diagnostic is simple and low-cost to fabricate and allows for quantitative and dynamic mensuration of Molecular collision. in addition, as explained, some label-free detection mechanisms measure ratio (RI) change induced by molecular collision, which is described to the sample doping or surface density, Instead of total sample volume. As a conclusion, the recognition signal doesn't taper with the sample mass. This property is interesting when ultra-small detection volume is concerned.

Despite of above distinctions between tag-free and other detection method, each method is being widely utilized in optical sensors and provide important and complete data relating to collision among biomolecules, that makes optical sensors more adaptable than common methods of sensing Mechanism, such as surface acoustic wave and quartz microbalance where only label-free detection can be applied.

In this study, Optical simulation has been done by Opti-FDTD software. Diagnosis the tuberculosis-one of the diseases problem- is the purpose of the simulations. aspects of design and simulation selected in a way that could be fabricated in the light of practical implementation in this proposed structure a linear light source with rectangular form, is used in order to the input Signal covers the entire section of waveguide.as shown in the Fig.2 two spot-detector is used. One of them at the beginning and another at the end of the structure to detect input and output signal, been placed. in order to observe the signal absorbed through the different wavelength and expected wavelength shifting after changing the properties of the fluid in the center of the ring.

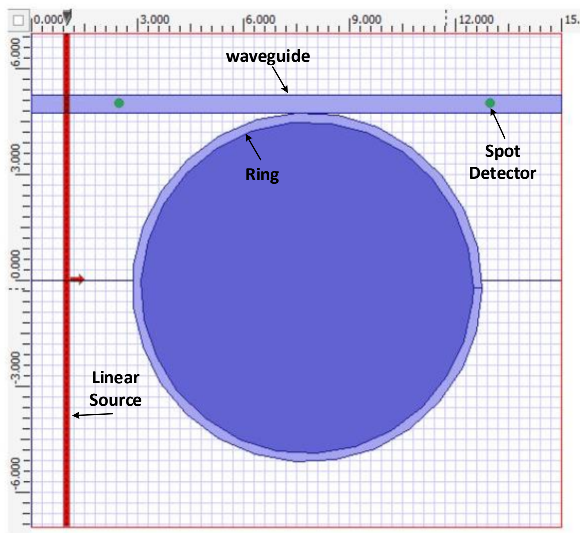

Fig. 2. Proposed Structure to detecting absorption spectrum, simulated in Opti-FTDT Software.

The dimension of the proposed structure is considered in realistic values based on the standard dimension that has exists in the conventional optic structures. The summary of used proposed structure dimension are listed in Table 1.

Table 1. Dimension and Material of the Proposed Structure.

Parameters	Value
Waveguide Width	500 nm
Ring Width	250 nm
Waveguide Length	15000 nm
Ring inner radius	4700 nm

Ring outer radius	4950 nm
Input spectrum	1-3 um
Material	PDMS
Mesh Size	50 nm

Material of the proposed structure is PDMS intended, that its refractive index is about 1. 412. albeit has a slightly changes, in the different wavelength. finally, with regard to the above conditions, the allowable stance between the ring and waveguide that coupling can be done properly, is considered 500 nm. In the Fig.3 normalized absorption spectrum of the input and output signal has been showed.

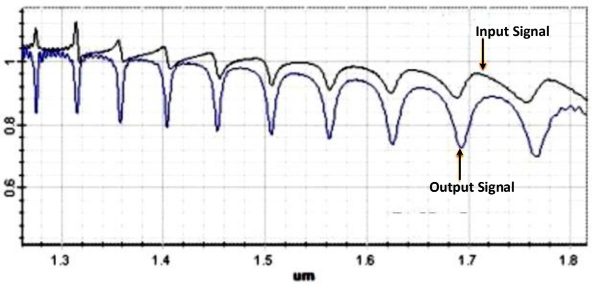

Fig. 3. Compare the Absorption peaks of input and output proposed ring resonator spectrum.

Since the effects of infectious diseases, primarily, shows in the urine and blood, therefore, the fluid examined in this study is the blood of people with tuberculosis.

According to the [20] the refractive index of a healthy person's blood plasma is about 1.351, while this value in the persons with TB is much lower and it is between 1.343 and 1.350.

The proposed method to detect the displacement of the spectrum at the output of the ring resonator, due to changing in refractive index of the assessed fluid, is putting the fluid in center region of the ring, that is called BRIS method.

Fig.1 shows the proposed design method is BRIS. the output is complying with the (2) question. basically, the ring should be in a certain distance from the waveguide.

Fig.4 illustrates Distribution Electromagnetic field when the wave reaches to the steady-state condition. The meaning of this express is that the signal, repeatedly, in the Ring rotated and re-interference between the divided optic signals, through ring and waveguide happened.

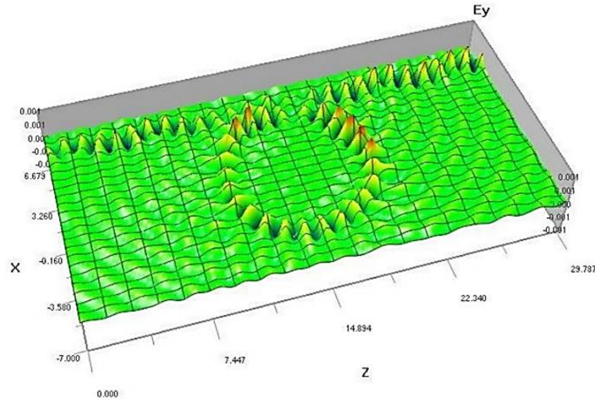

Fig. 4. The steady-state Ring Resonator Distribution Electromagnetic Field.

However, due to the range of blood plasma refractive index changes, to make a comparison between this method and the other method, by put the fluid, with both mode- minimum and maximum refractive index - at the middle of the ring, Results simulation has been investigated.

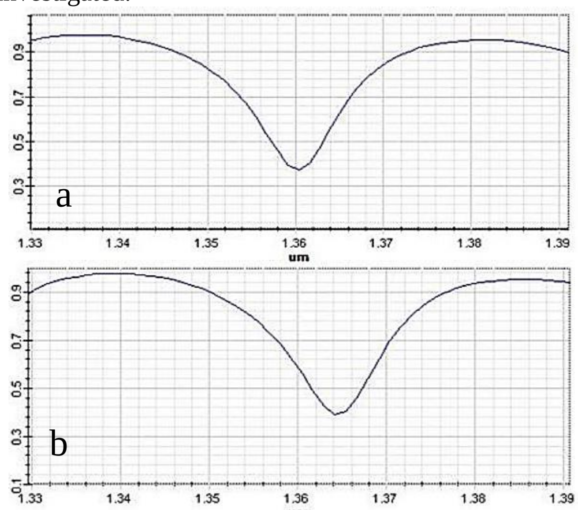

Fig. 5. Output BRIS Signal with a) fluid with refractive index=1.343, b) fluid with refractive index=1.351.

As can be seen in Fig.5, changes in the output, at range of minimum and maximum refractive index, occurs in Nano scale.at the above Figure, ring is tangent to the waveguide. The ring resonator absorption displacement according to the distance between the ring and waveguide, are listed in Table 2.

Table 2. The absorption displacement according to the distance between the ring and waveguide.

distance between Ring and waveguide	absorption peak displacement
-125 nm	3.866 nm
0	5.845 nm
125 nm	5.912 nm

250 nm	5.936 nm

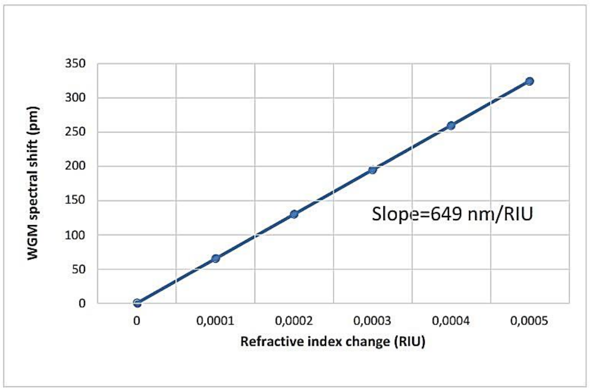

Fig. 6. OFRR sensitivity of BRIS curve (649 nm/RIU).

The shown slope in the Fig.6, represents the sensitivity of the designed structure. And according to the obtained value, it can be concluded, that is very benefice for the detection of the disease. because of, compared to the reported sensitivity in other sources, it is much reliable. The final proposed structure parameters and simulation result are summarized in the Table3.

Table 3. The Final Design and Result Parameter Value.

Parameters	Value
Waveguide Width	500 nm
Ring Width	250 nm
Waveguide Length	15000 nm
distance between Ring and Waveguide	Zero(tangent)
Sensitivity curve slope	649 nm/RIU

4. CONCLUTION

Ring resonator sensors are very required in the topic of electronics and optics technologies. They are highly accurate, low noise ratio and high reliability due to the light is used as source of energy. By employing the optical-fluid method, detection of defective molecules and cell can be done in biological diseases.

In this study, efforts have been made to proposed a novel functional and fabricable structure base on the optofluidic method for the diagnosis of tuberculosis diseases. Low-cost fabrication, simple structure, high sensitivity factor, and portability are Among of benefit of the proposed structure. These basic experimental results illustrate the power of the OFRR to detection specifically, biomolecules while using low-cost photonics and simple protocols. The using the PDMS polymer, optimizing the distance between the ring and waveguide and pick up standard dimension are such a done works to achieve the best possible output result that is 649 nm/RIS for BRIS sensitivity.

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