Simulation of Force Sensor and Analysis of its Characteristics Using Panda Ring Resonator

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ABSTRACT
Panda ring resonator is an highly sensitive and selective device which has many application in various field, like bio-sensing, communication etc. Here, the panda ring resonator act as a sensor for sensing change in the movements of the muscle contraction. The panda ring resonator consist of the optical add/drop filter which is connected to the two micro ring resonator, in which the right ring is the sensing unit and left ring is the reference unit. The change in the optical refractive index changes the wavelength due to the applied force, the optical path length will change, these will result in the change of wavelength (Δλ) that are obtained by the difference of the reference and sensing signals. The simulation is conducted using OPTIFDTD software.

KEYWORDS: Muscle sensor, Optical sensor, Panda ring resonator

INTRODUCTION
Optical device are rapidly developing and spreading, these have unique properties such as high sensitivity and selectivity, that are non-invasive and, small size amongst others, which have become attractive option for various applications, for instance, communication, microbiology, automotive industry and surveillance and monitoring domains and so on, [1]-[4].Furthermore the current trend of numerous health care methodology directly impact the research and development of optical sensor devices which enable these new technologies to reduce patient trauma and recovery times and lower healthcare costs. These properties have demonstrated great potential for medical applications for medical applications, such as use a tool for diagnosis or part of treatment and patience monitoring procedures [5],[6]. An optical sensor is an optical device that has been developed and the production of which has grown, which can be seen from the increase in the researchers who have proposed various concepts and new techniques in order to obtain suitable devices for applications.

Optical sensor properties which use photons as sensing elements have become an important tool in the field of non-invasive diagnosis and treatment. Recently, Yupain el al. [7]have shown extremely interesting results when using the small scale optical device known as a PANDA ring resonator circuit for developing a powerful optical device. A PANDA ring resonator is a modified optical add/drop filter, in which the optical required optical sensor can be generated and obtained by changing the structure of the PANDA i.e. (parameters) ring resonator input light signals and the different output signals.

The last 2-3 years, a PANDA ring resonator system has been proposed as an optical sensing system which can be developed and applied to a variety of applications such as distributed sensors [8], molecular sensors [9],...
gas sensors [10], and force sensing device which is a new sensing device for a force sensing application [11].

In this paper, we propose the extended capabilities of a force sensing device for muscle contraction and movement measurement. An optical ring resonator known as the PANDA ring circuit is proposed as the basic sensing device called Muscle Optical Sensor (MOS) system. The change in the optical path length within the sensing system is coupled with muscle contraction and movements, which are the different forces of the muscle contraction and movement which occur and can be measured. The experiment was conducted by using the OPTIFDTD software which indicated that the change in the sensing radius is associated with the change in the optical path length. Finally, the simulated result showed that this device has the ability to be applied to measure the signal of muscle contraction and is much more beneficial for muscle sensing application.

**Basic Principle Of Force Sensor:**

Almost all movements of the organs in the body are result of the muscle contraction. The coordinated action results of joints and bones and skeletal muscles produce obvious movements such as walking, running and other organ movements. In principle, the muscle contraction and force production is associated with the sliding filament theory, which is a sliding of the thin or acting filaments and the thick or the myosin filament [12], [13]. Forces are formed by the sliding to convergence of the muscle fibers which will cause muscle contraction in order to respond to various stimuli from the environment. The changes (contraction) occur and can be measured through the reaction of direct perturbation during a contraction or transfiguration of muscle, which these changes will affect the optical path length changes in the refractive index changes and the optical path length, which can be used to produce the required measurement parameters. The change in the optical path length \( L(\Delta L) \) is affected by the distortion or the change in the ring shape, which is introduced by the strain-optic effects due to change in the refractive index \( n \), by \( \Delta n \). Finally, the resonated wavelength \( \lambda_m \) shifted into \( \Delta \lambda_m \) given by,

\[
\Delta \lambda_m/\lambda_m=\Delta n/n+\Delta L/L
\]

here \( m \) is an integer, \( n \) is the refractive index of the guiding material, and \( L \) is the circumference of the ring resonator. the muscle sensing transducer using PANDA ring resonator by OPTIFDTD is given in Fig. 1, which consist of an optical add/drop filter connected to two micro ring resonator. In our experiments, we assumed that the muscle sensing probe (thin film) or other sensing parameters can exert force on or directly perturb the sensing unit\( (R_r) \), in which the obtained signal is measured as shown in Fig. 3 whereas the deformation or the contraction of muscle introduced to the sensing device by means of the elastic modulus of materials, which caused the wavelength shift (\( \Delta \lambda \)) in the peak spectrum of signals and described [8] by 2,

\[
Y_O=F/A*\Delta \lambda/L=\text{stress}/\text{strain}
\]

which is expressed by the relation between force and the change in the sensing device length is described by

\[
F=(Y_OA_O/L_O)*\Delta L
\]

where \( F \) is the applied force, \( Y_O \) is the young’s modulus that is the material parameters of InGaAs as 6.27×10^10 Pa[14], \( A_O \) is the initial cross section area, \( L_O \) is the initial length and \( \Delta L \) is the change in length. The simulation results were obtained by using the practical parameters, which are in the sensing range in terms of the wavelength shift(\( \Delta \lambda \)) with the muscle optical sensing resolution is measured by comparing the sensing and the reference signals is compared by the means of the mathematically rigorous approach for calibrating the high precision phase using the phase to calibrate itself.

**Simulation:**

Muscle optical sensor is responsible for monitoring the change of the signal which occurs and compares it with the difference between sensing and reference signals. In the simulation, the parameters of the PANDA ring resonator were fixed to the continuous wavelength of 1.55μm is introduced in the output port of the PANDA ring circuit. The photonic crystal materials used here is InGaAsP/InP, with core index is 3.24 [15], [16], the lattice constant \( a \) is given by 0.56 and the radius of the core and cladding is given by \( r = 0.125 \) and then the sensing unit which is right ring \( R_r \) is changed from 0.12μm to 0.140μm and the left ring \( R_l \) which is the reference unit is changed from 0.12μm to 0.140μm.
the above given Fig. 2 and Fig. 3 shows the simulation result of the PANDA ring resonator at the wavelength of 1.55μm and at the wave length of 1.43μm. The power intensity is high at the 1.5μm wavelength which is the resonating wavelength of the PANDA ring resonator.

**Result:**

The tabulation gives the relation between force and wavelength which is used for the calibration of the sensitivity of PANDA ring resonator. As the Table.1 shows that the sensitivity of the above structure is LINEAR. The sensitivity of PANDA ring resonator is 1666 m/N and Fig. 4 gives the linearity relationship between the applied force (contraction of muscles) and wavelength shift with is formed, which are shown in suitable linearity for muscle sensing application.

**Fig. 4:** relation between force and wavelength shift (Δλ) which is gives the sensitivity of PANDA ring resonator.
Table 1: Sensitivity Graph Calibrated Using The Relation Between Force And Wavelength

<table>
<thead>
<tr>
<th>FORCE (pN)</th>
<th>WAVELENGTH (nm) (Δλ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>0</td>
</tr>
<tr>
<td>6.2</td>
<td>5</td>
</tr>
<tr>
<td>9.3</td>
<td>10</td>
</tr>
<tr>
<td>12.4</td>
<td>15</td>
</tr>
<tr>
<td>15.5</td>
<td>20</td>
</tr>
<tr>
<td>18.6</td>
<td>25</td>
</tr>
<tr>
<td>21.7</td>
<td>30</td>
</tr>
<tr>
<td>24.8</td>
<td>35</td>
</tr>
</tbody>
</table>

Linearity for the sensitivity of PANDA ring resonator is very desirable quality for the muscle sensor operation. The Fig.5 gives the relationship between and power intensity and wavelength shift (Δλ) of sensing $E_R$ and reference signal $E_L$, which the self calibration sensing transducer.

Fig.5: (a) shows the relationship between sensitivity and wavelength of sensing ($E_R$) and (b) shows the relationship between sensitivity and wavelength of reference signal ($E_L$) with the radius $R_L$ and $R_R$ varying from 0.1μm-0.140μm.

Conclusion:

We have proposed the extended application of a force sensing device to be used in the measurement of muscle contraction and movement. In principle the MOS act as an optical sensor to measure and detect changes of the wavelength that leads to the refractive index change and optical path length, where the contraction or deformation of the muscle is directly perturbed into the sensing unit, which affects a optical path length changes. The simulation results show that a change in the sensing radius is associated with the change in the wavelength, which is measured and obtained by the difference between the sensing and reference signals.

REFERENCES