Brain Signal Monitoring Model Using THz Whispering Gallery Modes Generated by Micro-conjugate Mirror Probe

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Abstract: In this paper, a brain signal monitoring system using micro-optical conjugate mirror based on whispering gallery modes (WGMs) of light within a PANDA ring circuit is modeled and proposed. WGMs are generated by the PANDA ring circuit, which can be used to perform the brain signal connection using WGM probe, which is a 3D light probe. Simulation results obtained have shown that the THz WGMs can be generated and used as a probe to penetrate and connect to the brain cells and signals, which can be useful for brain signal monitoring and investigation. In applications, the various features such as smart multimedia devices, disability assisted and rehabilitation system, brain signal monitoring, robotic control and medical etc. using the THz 3D imaging probe can be plausible. Copyright © 2015 IFSA Publishing, S. L.

Keywords: Brain signal monitoring, Brain sensor, Medical sensor, Whispering Gallery Modes (WGM), Optical Device, 3D imaging.

1. Introduction

Brain signals as a result of electrical activity that can be detected from the brain and also the primary sources for all communications by human perception, which is displayed in the form of brainwaves. They are very important to keep them with top security and fast link to the required destinations, for instance human organs and external link. Brain signals have been the important issue of research and investigations because they are the primary sources that can be used to perform all human communications [1]. One of the challenges and interesting is the use of brain signals to control various functions by the brain control system, which is known as brain computer interface (BCI), in which the developments of brain signals and related activities for various fields including cognitive neuroscience, medical, cognitive science, computer science, and psychology etc. are the important targets [2]. In addition, the new advances in computer technology and medical care have been expanded and become an integration of following technologies such as artificial intelligence, simulation, systems engineering and management knowledge [3]. These insights have been integrated to develop the ways to overcome health problems and become a modern medicine, where the use such as computer-assisted
surgery (CAS) approach for optical intra-operative 3D reconstruction in laparoscopic surgery [4], computer-mediated medical information [5] has been reported.

New technologies that should be studied and developed for use with brain signal can be formed by various models, which require a high level of security. The application of specific properties of terahertz technology will be satisfied and discussed in the next paragraphs. Terahertz technology has become a tool that is very interesting in order to model and contribute the 3D image investigations, where the use such as the fabrication and testing of terahertz computer-generated volume holograms [6], terahertz imaging system [7] based on a quantum cascade laser (QCL) have been reported. THz has a terahertz imaging system [7] based on a quantum computer-generated volume holograms [6], where the use such as the fabrication and testing of terahertz computer-generated volume holograms [6], terahertz imaging system [7] based on a quantum cascade laser (QCL) have been reported. THz has a frequency range from 0.3 THz to 10 THz in the electromagnetic spectrum, which is the range of frequencies that they are invisible to naked eye. One of the interesting features is the benefit of using terahertz waves that can penetrate through clothing, paper, or even into human tissue, which can be very useful for medical sensing applications [8] and especially, when they are combined with the knowledge in biomedical researches [9-12], which have shown the results with higher promising applications, including brain, breast, skin, and hard tissue imaging / spectroscopy researches and investigations [13]. In addition, terahertz technology has been improved and continued development with techniques for testing and proof in order to obtain the results with 3D image presentation, for instance, the THz 3D imaging strategy using synthetic aperture radar (SAR) technique [14]. Till date, the new technique of 3D image presentation is still the challenge. Recently, WGM generated by optical resonators have demonstrated the interesting results, which have been the focus of an increasing amount of scientific researches in recent years [15]. Since 1991, InGaAsP/InP thin circular disks by chemical etching, which was demonstrated that the WGM lasing action at wavelength of 1.3 and 1.5 μm could be achieved [16]. After that the WGM has presented that the low cost and sensitive sensor [17] can be obtained and very useful to detect and distinguish between two biological such as DNA segments with slight difference in dielectric properties. The use of WGMs has been more successful after the announcement of Nobel Prize 2012 in Physics on the WGMs, where Yupapin, et al. have confirmed that WGMs can be generated due to coupling effects of the two nonlinear side rings of wave in PANDA ring [18]. In application, the PANDA ring can be experienced to be many devices such as the accuracy and precision on small scale optical devices of the applied sensors, which has shown the potential of using for such requirements [19-20], the wave particle duality (WPD) probe using THz light pulse propagation within a micro-optical device system for consciousness and sub-consciousness investigations [21], where the model of space-time paradox concept is useful for possible mind and dream investigations [22]. Moreover, the nested nonlinear micro-ring resonators (NMRs) and gratings can be useful for Cerenkov radiation investigation, imaging, and sensing applications [23], which is useful for consciousness and sub-consciousness investigations under the Cerenkov radiation. In this paper, we have proposed the small scale optical device system that can be processed with the principles of signal processing and monitoring brain signals in the form of a signal into a 3D image. By using the advantage of THz WGM signals, which can be formed by using the PANDA ring circuit, in which the brain signals can be probed and connected to the electronic instruments. Moreover, the brain signal can also be formed by the 3D image by using the conjugate mirror construction, which can be useful for many applications such as computer, multimedia devices, robotic control and medical etc.

2. Theoretical Background

A “PANDA” ring resonator is a modified add/drop optical filter that was proposed by Yupapin, et al. [23] that can be applied to many applications by changing the structure of PANDA and signal, as a suitable candidate for sensing device construction [19-20].

The schematic diagram of a PANDA ring resonator system for transfer function is shown in Fig. 1, which the calculation of the intensity relation does not take into account coupling losses can be written as

\[ E_1 = j\sqrt{K_{x_1}E_1 + j\sqrt{K_{x_1}y_1^2 + x_2E_2 \times e^{\frac{aL}{2}}}} \]

\[ E_2 = E_1 \times E_1 \times e^{\frac{aL}{2}} \]

\[ E_3 = jx_2E_2 + x_2y_2E_2 \times e^{\frac{aL}{2}} \]

\[ E_4 = j\sqrt{K_{x_1}x_2E_4 + x_2y_2E_2 \times E_4 \times e^{\frac{aL}{2}}} \]

![Fig. 1. A schematic diagram of a PANDA ring resonator system.](image-url)
where \( x_1 = \sqrt{1 - \gamma_1}, x_2 = \sqrt{1 - \gamma_2}, y_1 = \sqrt{1 - K_1}, \) and \( y_2 = \sqrt{1 - K_2}. \)

\[
E_{11} = AE_{11} - BE_{12}e^{\frac{-\alpha L}{2} + \beta L} - \left[ CE_{11}\left(e^{\frac{-\alpha L}{2} + \beta L}\right)^2 + DE_{12}\left(e^{\frac{-\alpha L}{2} + \beta L}\right)^3\right]
\]

\[1 - F\left(e^{\frac{-\alpha L}{2} + \beta L}\right)\],

where

\[
A = \sqrt{(1 - K_1)(1 - \gamma_1)}, \quad B = \sqrt{(1 - \gamma_1)(1 - \gamma_2)K_2(1 - K_1)}E_E, \quad C = K_1(1 - \gamma_1)\sqrt{(1 - \gamma_2)K_2E_E}, \quad D = (1 - \gamma_1)(1 - \gamma_2)\sqrt{(1 - K_1)(1 - K_2)}E_E, \quad E = (1 - \gamma_1)(1 - \gamma_2)\sqrt{(1 - \gamma_1)(1 - \gamma_2)(1 - K_1)(1 - K_2)}E_E, \]

and \( E_{11} \) and \( E_{12} \) are the optical fields of the through and drop ports respectively, \( \beta = kn_{\text{eff}} \) is the propagation constant, \( n_{\text{eff}} \) is the effective refractive index of the waveguide, and the circumference of the ring is \( R_L = \pi R \). The fractional coupler intensity loss is \( \gamma = 1.0 \).

The power output (\( P_{12} \)) at the drop port is:

\[
P_{12} = |E_{12}|^2
\]

### 3. THz WGM Signals

A PANDA ring circuit was modified as a micro-conjugate mirror device system as shown in Fig. 2, where the micro-optical device system can form the 3D pixel which is seen in the form of THz whispering gallery modes (WGM). The important device that can be used to construct the 3D images are the object and reference beams can be formed by the reflected light beams from the PANDA ring through and drop ports. The interference between these two beams forms the 3D pixel by the four-wave mixing behavior coupled by the two nonlinear side rings. It can be described by time-dependent Maxwell’s equations and given by reference [24], where more details and references can be found in references [25-26].

![Fig. 2. A schematic structure of PANDA ring conjugate mirror.](image)

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In simulation, THz whispering gallery modes are obtained by using the Opti-wave program with finite-difference time-domain (FDTD). The parameters of the PANDA ring resonator are fixed to be the Gaussian beams wavelength of 3.0 \( \mu \)m and power of 10 mN are introduced into the input port of the PANDA ring circuit. The waveguide core \( n = 3.14, n_2 = 1.3 \times 10^{-13} \) cm²/W, core area of the waveguides is \( A_{\text{eff}} = 0.3 \) µm² and waveguide loss coefficient is \( \alpha = 0.1 \) dB/mm. The parameters for add-drop optical multiplexer and both micro-rings on the left and right hand sides of the PANDA ring are set at \( R_L = R_R = 0.775 \) µm and radius of the center ring is \( R_a = 1.565 \) µm. The coupling coefficient ratios are \( K_0 = K_3 = 0.5, K_1 = K_2 = 0.5 \) µm.

The 3D pixel is seen in the form of THz whispering gallery modes at the PANDA ring center, which is the real image as shown in Fig. 3. In addition, the conjugated mirror position was varied to obtain
the appropriate positions for good 3D image quality as shown in Fig. 4. In Fig. 4 shows result of the mirror manipulation in the appropriate position, which shows in the form of graphs that are characteristic of four-wave mixing with base on almost balanced or symmetric side band frequency, which is a frequency ranges from 175 - 215 THz. The balance ($\Delta f$) of upper side band ($\Delta f_R$) and lower band ($\Delta f_L$) frequencies are obtained. The nice display of the reflector within a propose device, in which the center signal will display the real time 3D images, which is the same as the Add port output signals.

4. Brain Signal Monitoring Model

In Fig. 5 shows the area of interaction between the electromagnetic field caused by the coupling within the PANDA ring resonator circuit and that occur within the brain when a human body is performed in response to stimuli, either within the body or outside the body, where these activities are executed in electrical form via the nerve cells to stimulate or to commit out the order in accordance with the desire. Hence, images of the brain in three dimension patterns generated by the micro-conjugate mirror appears to be the difference of pattern features based on the results obtained from the interaction of electromagnetic fields. The result of THz whispering gallery modes signal, which is the coupling effects can be measured by the output probe at the Add port (terminal output port) of the PANDA ring, where the use of probe array with also be available for a large area, i.e., distributed sensing applications as show in Fig. 6.

The proposed system of application is as shown in Fig. 7, which consists of four main parts, where they are:
1) Sensing device site selection and placement;
2) 3D image signal acquisition;
3) Signal processing and 3D image pattern recognition;
4) Application interface.
In operation, the optical sensing devices are placed by the thin film optical probe, which can penetrate to penetrate the skin, muscle, and skull into the brain without jeopardizing the brain tissue or other organs. The brain signals (coherent lights) are commonly constructed of the thought, calculation, happiness, sadness, suffering, which cannot not be visible in the normal appearance. Propagation of the 3D light probe (electromagnetic field) is continuously emitted and affects the signal occurring within optical devices, which can be obtained by measuring output. Basically, when the brain signals are in normal state, the measured value of the signals can be neglected, which they are considered as the offset value. In this case, the sensor system is implemented as the transmitter of the 3D light probe, where the exchange or communicate among brain cells can be determined in terms of electrical signals, whereas the signal received from the sensor system can be a form of signals that are not appropriated for the applications. Thus, the received signals are required to be processed based on the signal processing in order to obtain the suitable brain signals, which comprise the sub-steps including:

1) Preprocessing to verify the integrity of the signal;
2) Feature extraction to obtain a qualified pattern according to the process of classification. Additionally
3) Classification (specific model) of the signal is also required, which will lead to the final step is application interface is to take a signal has applications in various fields.

![Fig. 7. A schematic diagram of brain signal and WGMs interconnection.](image)

**5. Conclusions**

In this work, we have demonstrated the new system of 3D brain signal monitoring and processing using micro-optical conjugate mirror based on whispering gallery modes of light within a PANDA ring circuit. Brain signals are presented in order to be used as a decision support analysis of brain abnormalities using 3D image signal information, which is formed by the THz probe signals. The THz frequency regime can be generated and formed by the micro-conjugate mirror device, which can be used to perform the brain signal connection for 3D imaging brain signal processing and interpretation. These probes (signals) can penetrate and connect to the brain cells (signals). The results can be used to form the 3D image pattern recognition study and development for the human machine interface, human computer interface, which is very useful for medical applications.

**References**


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