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Analysis of Integrated Optical Three Ring Resonator for Sensing Application

Shwetha M

Department of ECE, School of Engineering, Presidency University, Bengaluru, India

Article

Silicon photonics is an emerging photonics branch that provides a useful advantage over the electrical conductors used in semiconductors and high-speed transmission systems. It also provide faster ways to transmit signals when compared with standard data transmission methods. Such signals are transmitted in the form of light pulses in silicon photonic chips; this means data flow in silicon photonics is faster than conventional electrical signals . Silicon photonic devices has numerous advantages such as robustness, miniaturization and accuracy, which leads to perform various analysis in biological and clinical diagnostics. The most commonly used silicon photonic devices are based on nanophotonic devices like optical waveguide gratings and ring resonators. In the photonic sensors a silicon-on-insulator (SOI) technology based on optical ring resonators are placed on top of a buried oxide substrate is composed of a silicon-based waveguide. Micro-rings are very important, as the world is moving rapidly to replace electronic communication systems with optical communication systems. A generic ring resonator consists of an optical waveguide that is looped back onto itself, so that a resonance occurs when the resonator's optical path length is exactly a whole number of wavelengths. Therefore, ring resonators support multiple resonances and the distance between those resonances, the free spectral range (FSR), depends on the resonator length . When in near resonant wavelength, ring resonators have known to greatly enhance the phase changes in the signal. This has been used in numerous applications both in linear and nonlinear regions. Coupled resonator structures were also studied where lateral couplings are considered. Furthermore, the structure may obtain a high Q factor due to multiple passes in the cavity, and provide a substantial delay in light travel time . Output parameters of a typical micro-ring resonator includes the Free Spectral Range (FSR), full width half max, finesse and Q-factor. In , the two different methods that is serial and parallel cascading methods were discussed to characterize the effects of cascading the rings. The micro ring configuration was differentiated by the position of the micro rings. In parallel configuration, the structure is shaped in such a way that the rings do not interact with each other; however, the interaction between these consecutive rings is indirect through the waveguides between the rings, as a result, the light propagates in a particular way and the wave does not propagate the counter. In series combination, the arrangement is formed in such a way that the rings interact with each other, the interaction between the rings is direct in the form of propagation between the rings themselves, in this configuration, only 2 rings interact with the straight waveguides, the rest of the top and bottom rings are the rings which interact with the waveguides leading to the through-port and drop-port. A triple ring resonator is designed with an architecture of three single ring resonator with four directional coupler and are coupled in series. Optimized parameters were used to enhance the response with the larger ring length, wide FSR has obtained. Based on the performance with wide FSR, crosstalk was improved and resonance losses were reduced with FSR of 596GHz . The mathematical modeling of the configuration was performed on a delay line signal processing technique in the z domain. In the frequency response plot, obtained in MATLAB all possible input-output port configurations, FSR, group delay, and dispersion characteristics of the triple asymmetrical optical multiple ring resonator (TAOMRR) were evaluated. The field study of the configuration was carried out using the method of the finite difference time domain (FDTD). The circuit provides extended FSR as it uses three asymmetrical multiple ring resonators. In the proposed approach, it has been reported that structure has excellent capacity to manage data and would be useful in networks of optical communication. For different parameter analyzes, two rings were considered as a sensing ring with one of the rings as a reference ring. The phase shift in the transmission spectrum for the bio-sensing application was observed in the designed structure. In the ring resonator the sensor is based on the change in the refractive index. The alteration in the refractive index of the medium around will alter the effective refractive index. Consequently, the effective refractive index and the group index are monitored for the application of bio-sensing . In a design of triple ring resonator using silica waveguide, a FSR of 1050G Hz has been reported. The group delay and dispersion are the two important parameters which were reported with respect to resonant frequency and resonant peaks. The transmitter side of the system sometimes possess large and controllable dispersion due to the phase shift imparted by each resonator. The circulating power in each resonator can enhance the power carried by the waveguide at the resonance and leads to high nonlinear effects. The optical nonlinearities are found to be greatly enhanced when the resonator has kept near resonance state. The coupling of the resonator has been considered where the side wise coupling has been monitored. The initial resonance wavelength was chosen as per the requirement and in later stages it varies in accordance with the index change at different segments of the structure . 2. Design In this paper we analyze three rings, which are mutually coupled to one another. We have proposed a new three-ring cascade resonator structure with the same cavity size that does not allow precise perimeter measurement between the resonator cavities compared to other cascade structures, thus significantly reducing the design and preparation complexity. The current three-ring cascade resonator is important for optimizing the design of a resonator micro-ring structure, enhancing coupled resonator-induced effects and shortening the preparation time. It shows the schematic of the three ring resonator structure, three ring waveguides are placed between two straight waveguides. The ports are placed at all the ends of the straight waveguide in order to observe the transmission of light in the structure. Schematic of three ring resonator structure. 3. Result and Discussion The perspective view of the designed ring resonator is shown in , which has been designed using the Lumerical FDTD. In a ring resonator structure, the sharp variation in the output characteristics of the resonator is monitored when single pass phase shift is integral multiple of π. The single pass phase shift is given by $\varphi = 2\pi \lambda neffL$ ------ (1) Where λ is wavelength, neff is effective refractive index, and L is resonator circumference. Hence when the input wavelength of the given resonator changes, the output will also varies, which will also result in coupling factor variation. In later stages, with the constant ring length, there will be change in the single pass phase variation. All these can be achieved with the various effects with the nonlinear phenomenon and electro-optic effect. At the resonance region, there will be maximum intensity attained . The variation in the intensity levels are indicated in the right hand side of the figure, which represents the various levels at different wavelength. The coupling of the light in all the three rings along with the straight waveguides at various wavelengths are monitored. The transmission of the light measured . The transmission Port 3 Port 4 Port 1 Port 2 is monitored with respect to the wavelength, and is plotted to monitor the FSR of the designed structure. The power which enters at the input port (top left of bus waveguide) and the power which exits at the output port (bottom right of the bus waveguide) are plotted in the Three ring resonator's perspective view with three rings and two bus waveguides. (b) Coupling of light at 1550nm. The designed three ring resonator structure, transmits the light at the provided input port and it will couple the light with all the rings. The coupling can be monitored, when the light circulates in the ring it will be convenient to monitor the sensing element. Hence, the features of any sensing element can be observed and the design can be utilized for the sensing application. Due to this nature of the light circulating in the ring structure, it is most useful in the bio-chemical sensing application in the point of care devices. Transmission spectrum at two ports of the three ring resonator structure. (b) Power analysis at the various wavelengths indicated with and without sensing layers. The FSR is calculated as the difference between the two resonant peaks, here in the designed structure, it is calculated to be 30nm, 25nm, 20nm, 18nm. The FSR calculation will allow to find the nature of the sensing element which is placed in the cavity of the ring structure. The transmission spectrum is observed at both the input and output ports such that the variation at the wavelength can be noted. It is observed that there are four coupling regions with different coupling factors and the relations between the input and output fields are obtained. At the non coupling region, the phase change is added and the fields at the various function are converted into the matrix form. The fields are the important characteristics which will allow to find the output characteristics in the desired port position. The two bus waveguides are considered to analyze the properties of the structure with respect to transmitted and reflected light. Plot of Effective index versus wavelength. The plot of effective index versus wavelength . It can be observed from the figure that the there is a fall in the effective refractive index with respect to the wavelength. And this change is required in the sensing application.

Biography

Shwetha M worked in Department of ECE, School of Engineering, Presidency University, Bengaluru, India. She also work in the integrated optical ring resonator is designed with three ring structures and two bus waveguides.

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