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Refractive index sensor based on Vernier-effect and cascaded PANDA and single ring resonators

Bahram Azizi[1], S. Esmail Hosseini[*,2]
[1] MSc Student, School of Electrical and Computer Engineering, Shiraz University, Shiraz, Iran (Bahram.azizi@shirazu.ac.ir)
[2] Associate Professor, School of Electrical and Computer Engineering, Shiraz University, Shiraz, Iran (se.hosseini@shirazu.ac.ir)

Abstract-A novel optical refractive index sensor is proposed and theoretically investigated by cascading a PANDA and a single ring resonator (RR) based on the Vernier effect. The PANDA acts as a filter in this structure. Also, the RR is a function of the refractive index variation. Therefore, the RR structure acts as a refractive index sensing element in the proposed structure. Detailed modeling and instructions are provided for the design of such devices to increase the sensitivity of optical sensors. These are supposed to be manufactured on platforms compatible with silicon-on-insulator (SOI) complementary metal-oxide-semiconductor (CMOS). It is shown that the proposed sensor reaches ultra-high sensitivity (48.58 µm/RIU), which is more sensitive than the single ring resonator(0.63µm/RIU).

Keywords: Panda; refractive index sensor; ring resonator; Vernier effect.

[2] *se.hosseini@shirazu.ac.ir

1. Introduction

Over the last few years, optical sensors have been highly regarded by scientific researchers for their unique advantages and features, such as high sensitivity, fast response [1,2]. Besides, it can make it possible to sense a variety of parameters, including temperature, pressure, and refractive index changes [3,4]. Various optimization techniques, like the Vernier effect, have been proposed for improving the sensitivity of optical sensors [6]. Vernier effect can increase the sensing efficiency and involves the combination of two optical interferometers with different transmission functions Used as filters and sensors. By appropriately setting the ratio between the interferometer intervals, the overall device resolution can be improved through G_A times, with G_A the Vernier gain relative to the measurement resolutions achievable by any of the measurement scales considered stand-alone. Various configurations are proposed based on the Vernier effect, such as two cascaded MZIs [7],two cascaded silicon microring resonators[8]. The cascaded microring resonators method and cascaded MZI-ring sensor have been proposed by Jiang et al. [9]. This paper proposes a Vernier high-sensitivity microring sensor based on a cascaded PANDA and ring. Furthermore, Naznin and Sohel proposed a high-Q embedded dual microring resonator in order to improve the measuring range of microsensors [10]. Chen et al. designed a dual microring resonator optical biosensor based on lithium [11]. Theoretically, Wang and Dai [12] studied a high-Q MZI-coupled micro ring, which demonstrated in a NaCl aqueous solution [13]. This paper proposes a Vernier high-sensitivity microring sensor based on a cascaded PANDA and ring resonator.

2. Operation principle

The schematic diagram of the proposed refractive index sensor base on the cascaded is PANDA, and RR is shown in Fig. 1. The RR is exposed to the analyte in the sensing area, and the cladding layer covers the PANDA. Rr and Rr are cascaded as traditional, high-sensitivity microring resonators. The PANDA acts as a filter in this structure. Also, the RR is a function of the refractive index variation. The cladding layer completely covers the PANDA filter, preventing any contact between the optical field and the gas (liquid) or chemical analysis from being observed. The change of the effective index causes the transmittance peaks to change wavelengths can be calculated as

$$\Delta\lambda_{sensor} = \frac{\lambda_{m,sensor}}{n_{g,sensor}} S_w \Delta n_c \tag{1}$$

Where S_w is the waveguide sensitivity, Δn_c is the variation of the cladding refractive index of the sensing ring (due to the analyte or gas), $\lambda_{m,sensor}$ is the wavelength of the m-th transmission peak of the sensor resonator, and n_g is effective group index. the overall wavelength shift of the Vernier effect based sensor can be calculated as

$$\Delta\lambda_{tot} = (\frac{FSR_{filter}}{FSR_{sagnac} - FSR_{ring}})\Delta\lambda_{sensor} = G_A . \Delta\lambda_{sensor} \tag{2}$$

Where G_A could be defined as the Vernier architectural gain coefficient. PRR-RR Vernier is designed with the dimensions Rm=65 µm, Rl=39 µm, Rr=39 µm, RR=30.1 µm, Effective index for filter and sensor 1.9698,1.8615 respectively., Coupling coefficient K1,K2,K3,K4=0.5.The simulation of the outputs of the PANDA and RR by MATLAB are shown in Figure 2 and Figure 3.

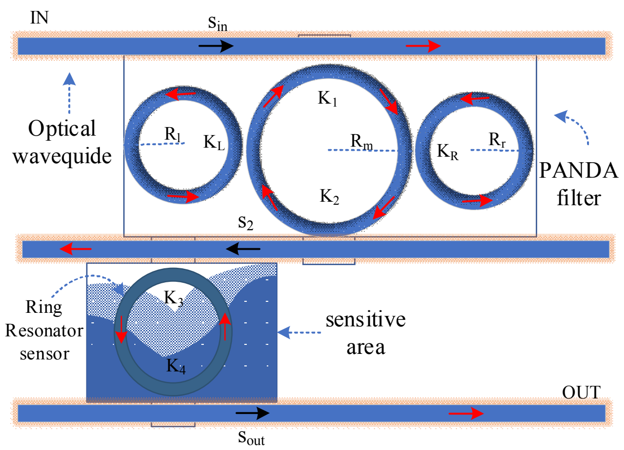

Figure. 1. Schematic of the PANDA-RR Vernier sensor

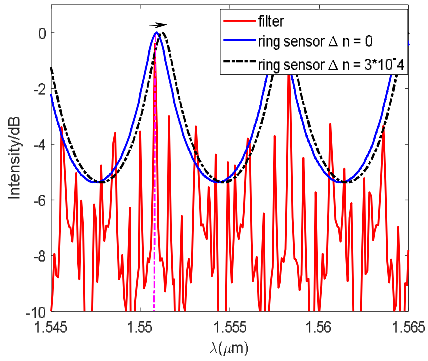

Figure. 2. The transmission spectrum of the sensor at rest (blue line) and a case of Δnc = 10-4 (black line)

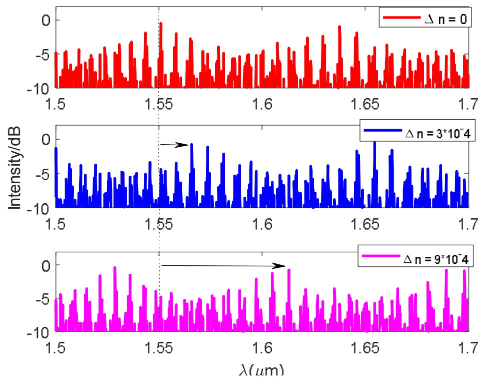

Figure. 3. Transmittance spectrum of the ring-enhanced Vernier sensor for $\Delta n_c = 10^{-4}$ RIU

The performance of the sensor can be described by several parameters, such as the sensitivity, FWHM, and FOM. the sensitivity S can be expressed as the ratio the resonance wavelengths variation and the variation of refractive index Expressed in this way Δλ /Δ n. The FWHM can be determined by calculating the full width at half maximum of the spectrum. Thus, the value of the FOM can be calculated by S/FWHM.

The simulated total wavelength shifts for the single ring sensor and the Vernier sensor are approximately 0.19 nm and 15 nm, respectively, Considering the variation of the refractive index of $\Delta n_c = 10^{-4}$ RIU. while the simulated sensitivity is approximately 0.630 µm/RIU , 48.54 µm /RIU respectively. Its FOM is also 3467 1/RIU.

3. Conclusion

In this study, in terms of sensitivity, the advantages of using PANDA instead of single RR were illustrated theoretically for sensing purposes. Theoretical results showed that the sensitivity of a single ring resonator is equal to 0.630 µm/RIU nm per $\Delta n = 1*10^{-4}$. On the other hand, thanks to the Vernier effect, the sensitivity increased to 48.54 µm/RIU per $\Delta n = 1*10^{-4}$. The purposed sensor has shown an increment in the sensitivity about 21 times more than the single ring resonator, which affects the measurement accuracy.

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