A high-resolution dual-microring-based silicon photonic sensor using electronic integrated circuit

Zhang, Haochi; Muhammad Faeyz Karim; Zheng, Shaonan; Cai, H.; Gu, Y. D.; Chen, Shou Shun; Yu, H.; Liu, Ai Qun

2018

Zhang, H., Muhammad Faeyz Karim, Zheng, S. N., Cai, H., Gu, Y. D., Chen, S. S., . . . Liu, A. Q. (2018). A high-resolution dual-microring-based silicon photonic sensor using electronic integrated circuit. 2018 Conference on Lasers and Electro-Optics (CLEO): Applications and Technology, ATh4O-4-. doi:10.1364/CLEO_AT.2018.ATh4O.4

<https://hdl.handle.net/10356/138855>

https://doi.org/10.1364/CLEO_AT.2018.ATh4O.4

© The Author(s). All rights reserved. This paper was published by Optical Society of America(OSA) in 2018 Conference on Lasers and Electro-Optics (CLEO): Applications and Technology and is made available with permission of the author(s).

Downloaded on 26 Apr 2023 19:18:37 SGT

A High-resolution Dual-microring-based Silicon Photonic Sensor using Electronic Integrated Circuit

H. Zhang¹, M. F. Karim^{1†}, S. N. Zheng^{1, 2}, H. Cai², Y. D. Gu², S. S. Chen¹, H. Yu³ and A. Q. Liu^{1†}

¹School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798

²Institute of Microelectronics, A*STAR, Singapore 117685

³Department of Electrical and Electronic Engineering, Southern University of Science and Technology, China 518055

[†]Email Address: faeyz@ntu.edu.sg, eaqliu@ntu.edu.sg

Abstract: A high-resolution dual-microring based silicon photonic sensor is demonstrated with an electronic integrated circuit. For refractive index sensing in sodium chloride solution, a high sensitivity of 0.153 RIU/W and a detection limit of 0.34 μ RIU are achieved.

OCIS codes: (280.4788) Optical sensing and sensors; (130.7408) Wavelength filtering devices; (130.6010) Sensors

1. Introduction

Microring resonator-based sensors are widely applied in detecting the changes in refractive index of liquids or gases [1]. Due to the inherently properties of ring resonator, such kind of sensor has the advantages of high resolution, ultra-low response time and controllable thermodynamically stability [2]. However, ring resonator sensors are expensive to use and difficult for integration since they have to be implemented with a high-resolution wavelength-tunable laser source [3] and a benchtop OSA as data acquisition part. Here, we propose a dual-microring based electronic integrated [4] sensor which consists of one tracing ring integrated with a thermal-optical tuning heater and a sensing ring in responding to the refractive index variations of target solutions, thus to replace expensive tunable laser and OSA to realize a highly-integrated low-cost sensing system for industry applications.

2. Design and theoretical analysis

Figure 1(a) displays the 3D schematic illustration of the silicon chip house. Figure 1(b) describes the system design and working principle of the dual-ring-resonator. A broadband light is coupled into the input port of sensing ring. We limit the wavelength bandwidth of the broadband light source within a single FSR by a bandpass filter so as to contain only one resonance peak for both rings. After transmitting through the thermal-tunable tracing ring, the light travels from the drop port into the sensing ring and finally comes into the photodetector (PD). The PD converts the optical signal to electrical signal which will be acquired by the DAQ circuit and transmitted to PC. Then sensing ring senses the variation in effective index. If the resonance of the two ring are not the same, the output coming from the drop port of sensing ring would remain at a low level. So we apply electrical power on the heater integrated on tracing ring to make it track the sensing ring on resonance wavelength shift accordingly. If and only if when both resonance peaks align with each other, the output intensity reaches the maximum. Figure 1(c) shows the SEM image of the microring system.

Fig.1. (a) 3D schematic illustration of the chip house. (b) Working principle of the dual-microring system. (c) SEM picture of design structure.

3. Results and Discussions

We test the sensing system with different concentrations of sodium chloride solution. Figure 2(a) shows the output spectrum of sensing ring and tracing ring. Figure 2(b) shows the thermo-optic efficiency of heater integrated on tracing ring which is $\sim 37.24\text{nm/W}$. A single FSR of tracing ring is $\sim 4.6\text{ nm}$ and the effective resistor is $\sim 210\Omega$. For the integrated circuit, the resolution of ADC which is for data acquisition is 0.1875 mV, while the resolution of

DAC which functions in heater control is 0.12 mV. The refractive index (n) of NaCl solution has a relationship with its concentration(c) as $n = 0.1867 c + 1.3343$. Figure 2(c) shows the relation between resonance wavelength and surrounding refractive index and implies a sensitivity of the sensing ring is ~ 243.75 nm/RIU.

Fig. 2. Experimental results of (a) the output spectrum of sensing ring and tracing ring and (b) the thermo-optic efficiency of heater integrated on tracing ring and (c) resonance wavelength under different refractive indices.

Figure 3(a) shows the amplified output voltage of PD when electrical power is varied on the tracing ring. Different colors represent sensing ring ranges in concentrations of sodium chloride solution. According to the OEIC specifications, the PD output voltage (V) has a relationship with optical power (P) as $V = 8 \times 10^6 P$. Figure 3(b) shows the zoom in around spectral peaks. The extracted 3σ is $\sim 2.23 \mu\text{W}$, where σ represents standard deviation. Therefore, the detection limit is $0.34 \mu\text{RIU}$. Here we relate the electrical power at the peak to the refractive indices of the test solution. Figure 3(c) presents the relation between electrical power and the corresponding effective refractive index. Red dots indicate the blind test result after calibration curve is established. The sensitivity of this optical-electronic sensing system is 0.153 RIU/W, and the mean error of blind test is 0.0015% .

Fig. 3. (a) Amplified output voltage of PD when electrical power is varied on the tracing ring at different concentrations for sensing ring. (b) The deviation of 20 measurements of electrical power. (c) The relationship between the refractive index and applied electrical power. In which the red dots indicate the blind test results when detecting smaller differences in concentrations of NaCl solutions. ($\Delta c = 0.005$ g/ml, $\Delta n = 0.0001$)

4. Summary

A highly-integrated low-cost dual-microring-based sensing system is demonstrated. The dual-microring structure successfully replace the expensive tunable laser and OSA by converting a frequency spectral to a time-series signal. System is tested with different concentrations of sodium chloride solution to demonstrate a sensitivity of 0.153 RIU/W and a detection limit of $0.34 \mu\text{RIU}$.

5. Acknowledgement

This work was supported by Singapore National Research Foundation under the Competitive Research Program (NRF-CRP13-2014-01).

6. References

- [1] K. D. Vos, I. Bartolozzi, E. Schacht, et al, "Silicon-on-Insulator microring resonator for sensitive and label-free biosensing," *Opt. Express* 15, 7610-7615 (2007).
- [2] J. Niehusmann, A. Vörckel, P. H. Bolivar, et al, "Ultrahigh-quality-factor silicon-on-insulator microring resonator," *Opt. Lett.* 29, 2861-2863 (2004).
- [3] M. Iqbal, M. A. Gleeson, B. Spaugh, et al. "Label-free biosensor arrays based on silicon ring resonators and high-speed optical scanning instrumentation." *IEEE Journal of Selected Topics in Quantum Electronics* 16, 654-661 (2010).
- [4] S. Grillanda, M. Carminati, F. Morichetti, et al. "Non-invasive monitoring and control in silicon photonics using CMOS integrated electronics." *Optica* 1, 129-136 (2014).