A study on frequency-time domain transformation through tracing-assisted dual microring integrated system

H. H. Ding[1, 2], H. Zhang[1], H. Cai[2] and A. Q. Liu[1]

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

[2]*Institute of Microelectronics, A*STAR (Agency for Science, Technology and Research), 2 Fusionopolis Way, #09-02 Innovis Tower, Singapore 138634*

Abstract: High-resolution and high-sensitivity transformation from frequency domain to time domain is demonstrated by a tracing-assisted dual microring integrated system. It is promising for applications in frequency follower, chemical or biological sensing in environmental monitoring.

1. Introduction

In order to acquire the spectra shift caused by the refractive index variation, we usually think about applying wavelength scanning method [1], which usually needs high resolution tunable laser as the light source. In such a method, the limitation of the detection is mainly determined by the resolution and sensitivity of the tunable laser and the photodetector, respectively. Neither small changes in resonance wavelength below scanning step nor weak output intensity below the detection limitation can be captured. Thus, in order to identify small wavelength shift caused through tiny changes of refractive index, we need to employ very high resolution tunable laser and high sensitivity photodetector, which are space-occupied, expensive for ubiquity and not sustainably optimizable.

To solve all these problems¸ earlier study of a tracing-assisted sensing dual microring integrated system was conducted [2]. A broadband light source is combined with a tunable filter to achieve a single FSR, function as the substitute of wavelength-tunable laser. And through the optical device, turn the frequency-domain information into time-domain, as well as the detection limit caused by laser resolution and PD sensitivity to the resolution of DAC acting on the heater of trace ring. The resolution of DAC can achieve an ultra-high level at relatively small cost. Also DAC control has the advantage of flexible with short response time. Furthermore, integrated the microring, photodetector with corresponding amplifier circuit for lab-on-chip application.

2. Design and working principles

The design schematic of the dual-microring associated sensor is shown Figure 1(a). In principle, sensing ring is termed as it senses the effective index variation. Another microring integrated with a heater, name as tracing ring. Through thermal-optic effect, it is able to trace the wavelength shift of the sensing ring accordingly. The input of this design is a broadband light source limited to one single. As it passes through the sensing ring and then goes into the tracing ring from the drop-port of the sensing one, when and only when both resonances align with each other, the output intensity reach a maximum. Otherwise, the output optical intensity should remain a low level. Through scanning the applied voltage to tracing ring, the two ring can align with each other anyway and the corresponding wavelength shift of the sensing ring is consequently monitored by the supplied power change along with the output intensity.

Figure 1(b) presents the schematic of the integrated system. In response to the ultra-small output optical power, two-stage amplifier circuit together with low-pass filter is designed to be applied on the photodetector to achieve high sensitivity.

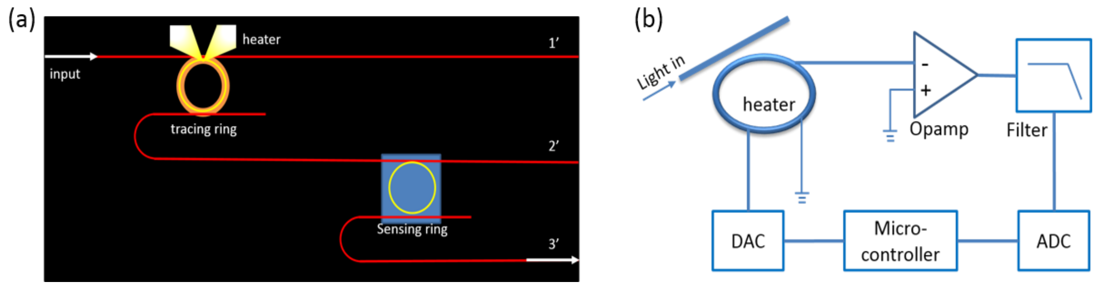

Fig. 1. (a) Schematic of the micro-ring based phootonic circuit, and (b) schematic of the integrated tracing system.

3. Results and discussions

The measured transmission spectra of the tracing ring is shown in Fig.2 (a). The free spectral range (FSR) is ~4.9 nm and the quality factor is ~11,000. When the applied voltage increases, the resonance wavelengths are red-shifted due to the TO effect. Figure 2(b) presents the measurement results of the resonance wavelength as function of the electrical power, indicating the resonance wavelength proportional to the applied electric power. From which, we extract that the resistance is about 20ohm. Thus, the power consumption can be calculated according to the applied voltage. Figure 2(c) shows the maximum output optical intensity of out integrated system. The maximum output optical intensity is -52dbm. The amplification factor of our correspondingly amplifier circuit is up to 107, we get the output voltage reach a peak at 1.08V supplied voltage, and the peak value is about 30mV.

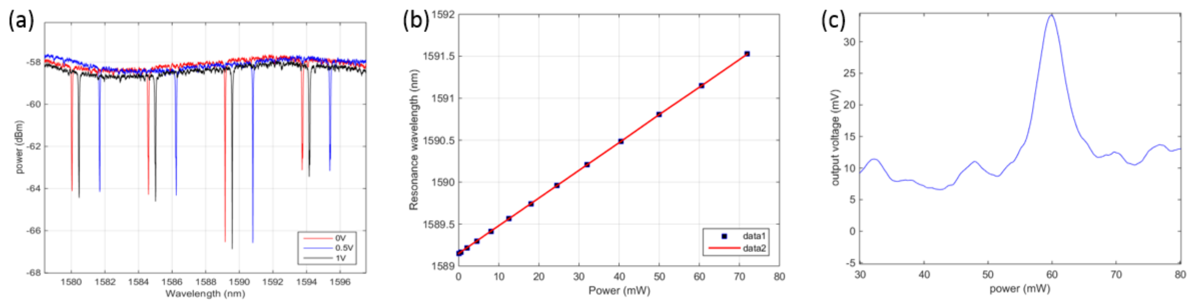

Fig. 2. (a) Transmission spectrum of the tracing ring and (b) relationship between the resonance wavelength and the electric power supplied to tracing ring, and (c) peak value when sensing ring and tracing ring align with each other.

3. Conclusions

A tracing-assisted sensing dual microring integrated system turns changes in frequency domain into changes in supplied voltage, which can be controlled in time domain. Thus, avoid using expensive and hard-to-integrate high resolution tunable laser. With the applying of easy-to-get, high-resolution, short-response time and small space DAC, precisely small steps in supplied voltage can be supplied. In other words, the resonance wavelength shift of sensing one can be captured by adjusting the voltage applied to the tracing ring. And with the integration of high-factor amplifier circuit, ultra-small signal even to 0.1nA can be accurately obtained through a common photodiode. This dual microring integrated system is promising for applications in frequency follower and chemical or biological sensing in environmental and water quality monitoring.

4. References

[1] Song, Junfeng, et al. "Silicon-based optoelectronic integrated circuit for label-free bio/chemical sensor." Optics express 21.15 (2013): 17931-17940.

[2] Kim, Kyung Woo, et al. "Label-free biosensor based on an electrical tracing-assisted silicon microring resonator with a low-cost broadband source." Biosensors and Bioelectronics 46 (2013): 15-21.

Acknowledgement

The work is mainly supported by Economic Development Board, Singapore (NRF2014SAS-SRP001-059).