High Resolution and Wide Bandwidth Silicon Spectrometer based on Vernier Effect

Long Zhang[1], Zhihuan Ding[1], Shihan Hong[1], Gaopeng Wang[1], Dajian Liu[1,3] and Daoxin Dai[1,2]*
[1]*State Key Laboratory for Modern Optical Instrumentation, Center for Optical & Electromagnetic Research, College of Optical Science and Engineering, International Research Center for Zhejiang University, Zijingang Campus*
Hangzhou 310058, China.
[2]*Ningbo Research Institute, Zhejiang University*
Ningbo 315100. China.
[3]*ZJU-Hangzhou Global Scientific and Technological Innovation Center*
Hangzhou 311200, China
*dxdai@zju.edu.cn

***Abstract*—We experimentally demonstrated a silicon spectrometer based on the Vernier effect. The measured results show that its resolution is as high as 12 pm, and its bandwidth is greatly expanded to more than 100 nm.**

Keywords—silicon photonics; high resolution; broadband working range; Vernier effect; on-chip spectrometer;

I. INTRODUCTION

Spectrometer is of great importance in our scientific research and daily life, such as drug analysis, environmental monitoring, gas sensing, aerospace and so on [1]. Silicon-on-insulator (SOI) integration platform has high refractive index contrast and is compatible with CMOS process, which makes it an ideal platform to manufacture compact and low-cost lab-on-a-chip systems. For the spectrometer, a high resolution with large working window is highly desired [2]. Due to now, various on-chip spectrometer systems have been proposed, and there are mainly two kinds of on-chip spectrometers: dispersive spectrometer and calculating spectral reconstruction spectrometer [3]. For dispersive spectrometer, the commonly used schemes include arrayed waveguide grating(AWG) [4], etched diffraction grating(EDG) [5], microring array [6], and so on. For the diffraction grating based mechanism, the resolution is usually inversely proportional to the number of output channels. While, for the regular resonator array based system design, it has high requirements for fabrication accuracy, which makes it difficult to guarantee the robustness and yield, and its working window is limited to the Free Spectrum Range(FSR). Compared with the dispersive spectrometer, calculating-spectral-reconstruction based Fourier spectrometer can achieve high signal-to-noise ratio as only one detector is needed, while it is worth noting that its resolution is limited by the heating temperature for the traditional thermal-optical effect design, even with watt power applied, only nanoscale spectrum resolution is achieved [7]. The digital Fourier spectrometer is proposed for reducing the power consumption [8], in this case, the optical path difference manipulation is converting from temperature controlling to optical switch status controlling. However, the realization of high-resolution spectrometer still needs huge area and complex control procedures. Recently, the reported random scattering spectrometer can realize light reconstruction from the different spectral response functions [9], despite their compact device footprints, they often involve very small feature sizes, placing high requirements on the fabrication process. As we can see, there is a trade-off between spectral resolution and the working window, therefore, achieving a spectrometer with high resolution and large bandwidth is challenging but highly desired.

In this paper, we experimentally demonstrated an on-chip spectrometer with wide working window and ultrahigh resolution. The cascade adiabatic elliptical microrings(CAEMRs) and Vernier effect is applied for expanding working window, and the Euler curve based microrings(EMRs) is applied for achieving ultrahigh resolution. The measured results show that the resolution is as high as 12 pm and the working window is greatly expanded to more than 100 nm.

II. STRUCTURE AND DESIGN

Figure 1(a) shows the top view of the proposed spectrometer. For the design of the EMR, we focused on reducing the full width at half height (FWHH) of the resonator, which played an important role for spectral resolution. As shown in Fig. 1(b), there are two multimode straight waveguides and two multimode waveguide bends (MWBs) based on modified-Euler curves. In this way, the scattering loss due to the rough sidewalls can be significantly reduced [10]. Here, the waveguide width was chosen to be 1.6 μm for low transmission loss, the (R_{max}, R_{min}) of 180° Euler bend was optimized to be (600 μm, 15 μm) for minimizing the insertion loss and crosstalk.

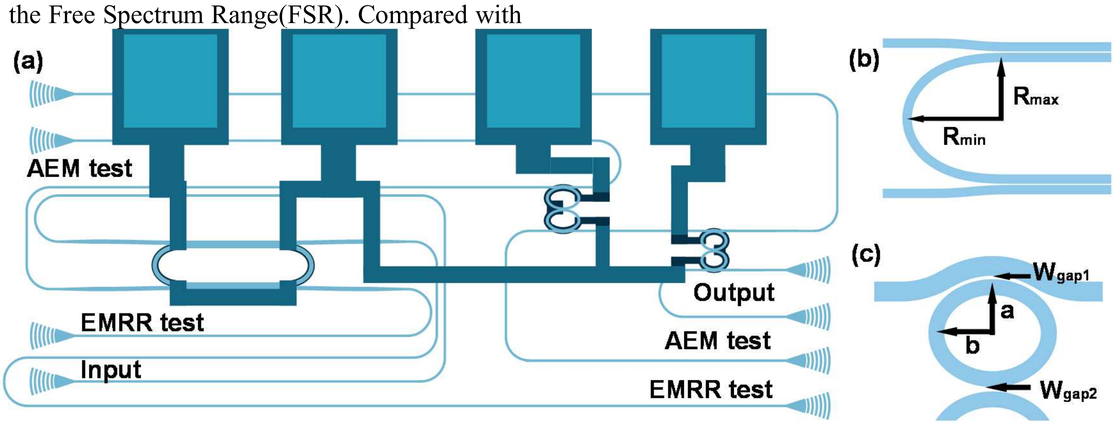

Fig. 1. Schematic configuration. (a) top view of the proposed spectrometer; (b) Euler curve based microring (EMR); (c) cascade adiabatic elliptical microrings(CAEMRs);.

For the wideband filter, the dual CAEMRs are applied, the adiabatic elliptical microrings is utilized to realize compact footprint, in this way, the FSR is large, which is advantageous to achieve a large working window. Meanwhile, each CAEMRs with optimized coupling coefficients are used to achieve flat-top responses, which is desired for easy restoration. Finally, the Vernier effect is applied for expanding the working window. Here, the FSR for dual CAEMRs was chosen as 18 nm and 22 nm, respectively, and the 3-dB bandwidth was set to be 1 nm, in this case, the working window can be greatly extended to more than 100 nm.

III. Fabrication and Measurement

The designed spectrometer was fabricated by the MPW foundry with a 220-nm-thick top silicon layer and a 2-μm-thick buried oxide(BOX) layer. A customized printed circuit board(PCB) is employed for bonding heater electrode to the PCB. The performance of the proposed spectrometer was shown in Fig. 2(a)-(d). Fig. 2(a) illustrates the spectral response of the EMRs, which revealed an FSR of approximately 4.1 nm and an FWHH of approximately 12 pm. The spectrum response for both CAEMRs are shown in Fig. 2(b), as we can see, the FSR is 18 nm and 22 nm, respectively, and the 3-dB bandwidth is of approximately 1 nm, which agrees well with our design. To capture the broad-band spectrum, both CAEMRs were precisely tuned together to combine multiple channels. Finally, the feasibility of the system was demonstrated by tuning the AEMs across multi-channels ranging from 1528 nm to 1600 nm(limited by the bandwidth of the grating couplers), as shown in Fig. 2(c). In order to characterize the recovery performance of the fabricated spectrometer, we demonstrated the spectral recovery performance for the single peak. Here, a tunable laser was used as the source to be measured, the wavelength position was randomly set to 1529 nm. Figure 2 shows the recovered spectrum, the single peak spectrum was recovered successfully and shows a good recovery accuracy.

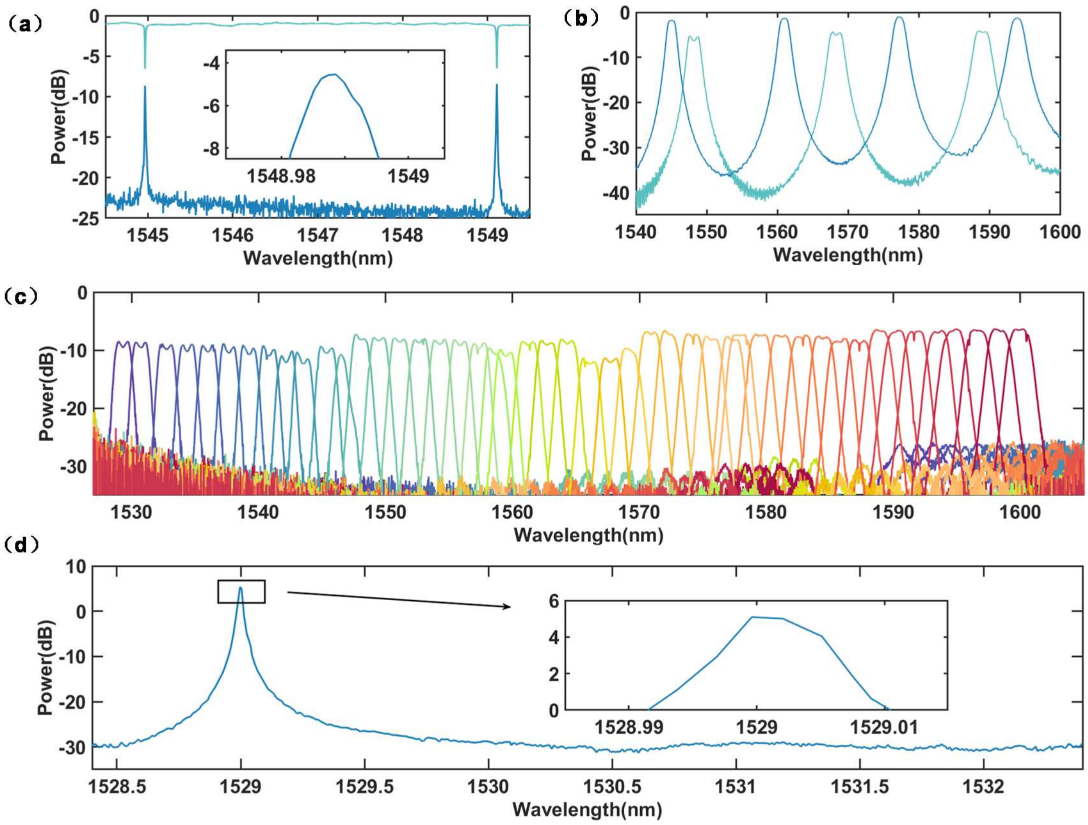

Fig. 2. Measurement results. (a) Spectral response of the EMRs; (b) Spectral response of the both CAEMRs; AEMs; (c) Spectral response of Multiple channels ; (d) Speectrum reconstruction result of a single peak.

IV. Conclusion

In summary, we have designed, fabricated, and experimentally demonstrated a novel on-chip spectrometer. The CAEMRs and Vernier effect is applied for expanding working window. The EMRs is applied for achieving ultrahigh resolution. The measured results show that the resolution is as high as 12 pm and the working window is greatly expanded to more than 100 nm.

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