Compact Polarization-insensitive Spectrometer with Large Bandwidths

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***Abstract*—We experimentally demonstrate an ultra-compact polarization-insensitive silicon spectrometer by combining a polarization splitter rotator and a tunable adiabatic elliptical-microring. The measured results show a broad operation window (36.5 nm) with a high resolution (0.17 nm) for both TE/TM polarization.**

Keywords—silicon; spectrometer; microring; polarization-insensitive

I. Introduction

Since the dawn of optics, the spectrometer have a dominant position and derived various usages in many applications [1]. With the increase in the demand for portable and miniaturized equipment, an on-chip spectrometer is to be vividly portrayed [2]. Nowadays, plentiful demonstrations at different material platforms have been reported successfully. Among them, silicon-on-insulator (SOI) stands out owing to the high refractive index-contrast and the CMOS compatibility, which makes it ideal for developing ultra-compact and low-cost systems-on-a-chip [3, 4].

Currently there are mainly three typical methods for realizing on-chip spectrometers. The first one is Fourier spectrometers [5, 6]. While, the resolutions of both traditional [5] and digital [6] on-chip Fourier spectrometers are dependent on the maximal optical path difference between the two interference arms. In this case, the resolution is often limited by the maximal heating temperature or complex spectral reconstruction process. The second one spectral-reconstruction method based on random scattering, this kind of spectrometer can realize light reconstruction from the different spectral response [7] functions , despite their compact device footprints, they often involve very small feature sizes, placing high requirements on the fabrication process. The last one is the spectrometers based on dispersive elements such as arrayed-waveguide gratings (AWGs) [8], etched diffraction gratings (EDGs) [9], and arrayed microrings [10]. However, these spectrometers usually have quite a limited bandwidth (determined by their free-spectral range (FSR)), huge footprint and can only work at a specifically polarization, since the polarization of the measure spectrums are remained changing.

In this paper, we propose and demonstrate a compact polarization-insensitive on-chip spectrometer by combining a polarization splitter rotators and an tunable adiabatic elliptical-microring. The edge coupler and photodetector also integrated for fully system package. The measured results show that the spectrometer can work without controlling the polarization of the input beam and it has a ultra-broad operation window of 36.5 nm as well as a high

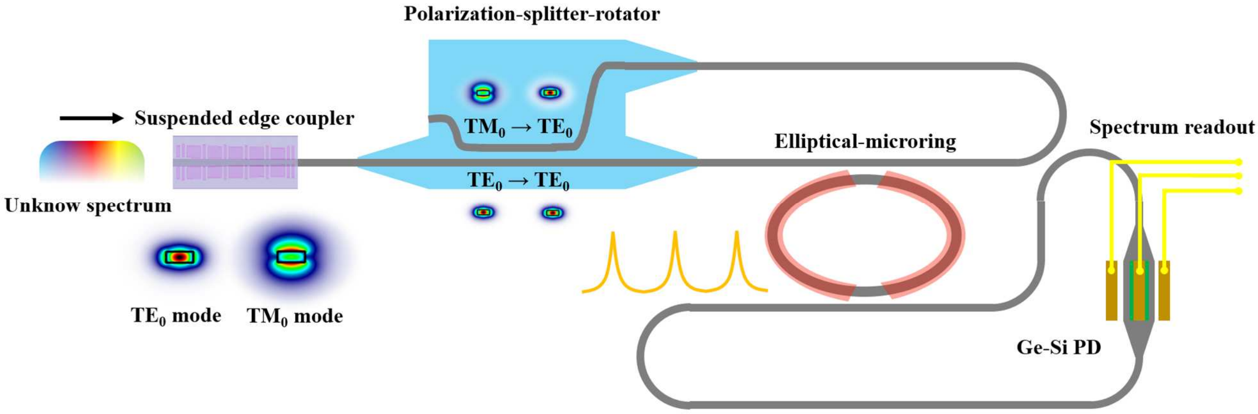

Fig. 1. (a)Schematic configuration of the proposed spectrometer. (b) Top-view micrograph of the spectrometer; (c) Photograph of the implemented fully on-chip spectrometer.

resolution of 0.17 nm. The fully package system allow it for many applications such as material characterization, medical imaging, and remote environmental monitoring.

II. Principle And Structures

The proposed polarization-insensitive spectrometer consists of a suspended edge coupler (SEC), a polarization splitter rotators (PSR), a tunable adiabatic elliptical-microring (AEM) and a Ge-Si photodetector (PD), as shown in Fig. 1. The incident light with unknow spectrum and uncertain polarization (TE_0 mode and TM_0 mode) launched from the SEC, which are then converted to the TE_0 mode by the PSR. The AEM acts as a filter and collecting the intensity at different wavelength by tuning the heating covering on the AEM. The dropped spectrums are detected by the on-chip PD and turned into electric signal for readout process. The dropped spectrum controlled thermally is defined as $T_r(\lambda, P_h)$, where P_h is the heating power and $\lambda=\lambda_0 + P_h(\partial\lambda/\partial P_h)$ where λ_0 is the resonance wavelength when no heating power is applied. By introducing the SEC and PSR, both polarized beam, ever hybrid polarized beam can be analyzed by a single system, which is more relevant to practical applications where the polarization of the measure spectrums are remained changing. Furthermore, the large free-spectral range (FSR) and narrow 3-dB bandwidth bring by the AEM to realize an on-chip spectrometer with large bandwidth and high resolution. Eventually, the on-chip high- efficiency PD can detected the dropped spectrums from the both side at the same time and make it possible to package the spectrometer as a complete system.

III. Fabrication And Package

The fabrication is started with a SOI wafer with a 220-nm-thick top-silicon layer and a 2-µm-thick silica buried box. The designed silicon spectrometer was fabricated by the Multi-Project Wafer (MPW) foundry (Compound Tek, Singapore) with the standard processes of deep UV lithography and inductively coupled plasma dry-etching. Here, the SEC and the PD are the PDK devices of the foundry. Our spectrometer has a compact footprint of 0.25 mm×1.2 mm.

IV. Measurements

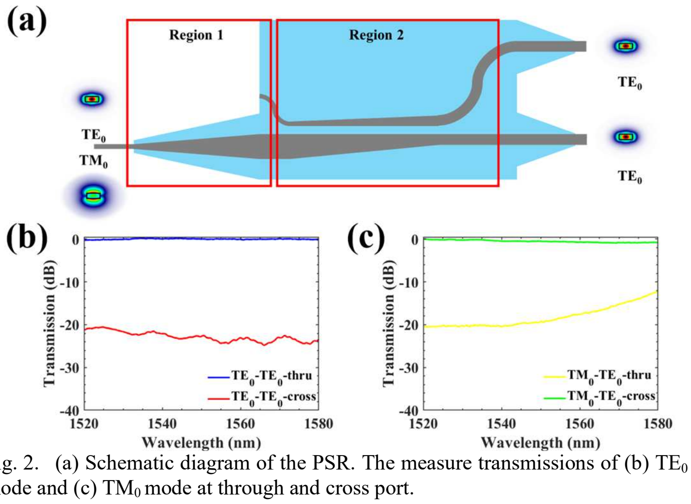

Fig. 2. (a) Schematic diagram of the PSR. The measure transmissions of (b) TE_0 mode and (c) TM_0 mode at through and cross port.

The PSR demultiplexes the input mode into TE_0 mode and works on the principle of mode hybridness of the ridge waveguide [11]. The schematic diagram of the PSR is shown as Fig. 2(a) and the blue region indicate the shallow etch area. The PSR contains the polarization rotation regions (Region 1) and the mode splitting region (Region 2). In Region 1, the mode hybridness effect lead by the linearly taper waveguide converts the TM_0 mode into TE_1 mode while the TE_0 mode passes through directly with a negligible loss. In Region 2, the TE_1 mode in the wide-core couples to the TE_0 mode in the narrow core access waveguide by using an asymmetric adiabatic coupler, while the TE_0 mode passes through this region without any notable coupling. The measured transmissions of TE_0 mode and TM_0 mode are shown as Figs. 2(b)-2(c), one can see that the both mode can convert to the TE_0 modes at the two output waveguides with a excess loss of <0.5dB and crosstalk <-14dB in the C band.

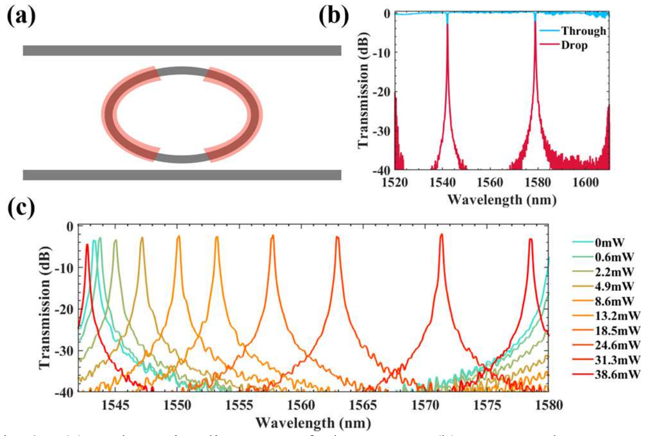

Fig. 3. (a) Schematic diagrams of the AEM. (b) Measured spectrum responses at the drop ports of the AEM. (c) The spectrum responses of the resonator peak with different applied heating powers.

As the core device of the spectrometer, the AEM can offer a large FSR and narrow 3-dB bandwidth to ensure the broadband and high resolution of the spectrometer by choosing the suitable parameters, as shown at Fig. 3(a). The detailed definition of the AEM can be found in the Ref.[12]. We cover the heater on the AEM for tuning the resonator peak across the entire FSR range with applied voltages. The measured spectrum responses of the AEM is shown in Fig. 3(b), one can find the AEM have an large FSR of about 36.8 nm and a 3-dB bandwidth of about 0.2 nm. Fig. 3(c) shows the wavelength shift of the resonator as the heating power increases. Here the resonator peak at 1542 nm is shown as an example. As shown in the inset, the wavelength is linearly shifted with the heating power and one has a wavelength shift as large as an FSR with a heating power of ~40 mW.

To demonstrate the performance of our spectrometer, we used two tunable lasers with the linewidth of about 0.8 *fm* as the measured sources to retrieve the single and the double spectral line. The wavelengths of the measured spectrum are set as 1550 nm for the single spectral line and 1550 nm and 1550.2 nm for the double spectral line. The measured spectral responses retrieved according to the monitored powers are shown in Figs. 4(a)-a(b). One can be seen that the retrieved spectrum is consistent with the original source while the small difference is partially due to the external temperature variation and the wavelength precision of the tunable laser. The retrieved single-peak spectrum has a 3-dB bandwidth of ~0.17nm, which is consistent with the linewidth of the AEM.

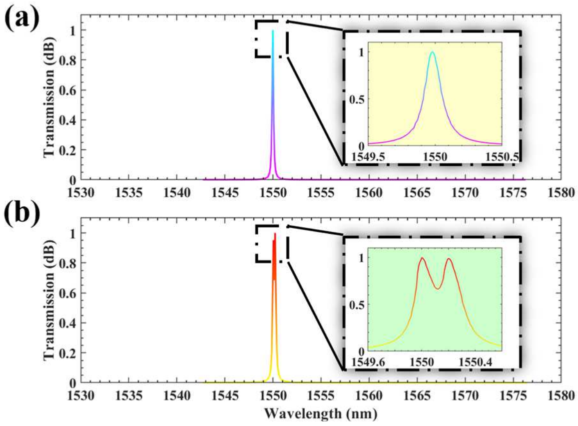

Fig. 4. (a) Retrieved spectrum for a given (a) single spectral line at 1550 nm, (b) dual spectral lines at 1550 nm and 1550.2 nm input.

V. CONCLUSION

As a conclusion, we propose and realized a compact polarization-insensitive on-chip spectrometer by combining a SEC, a PSR, a tunable AEM and an on-chip PD. The measure result shows that the spectrometer can work without controlling the polarization of the input beam and it has an ultra-broad operation window of 36.5 nm as well as a high resolution of 0.17 nm. We believe that our spectrometer will have potential in many applications such as material characterization, medical imaging, and remote environmental monitoring.

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