Arrayed Waveguide Grating with Reusable Delay Lines (RDL-AWG) for High Resolving Power, Highly Compact, Photonic Spectrographs

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***Abstract*— Arrayed waveguide gratings with reusable delay lines (RDL-AWGs) are demonstrated as high resolving power integrated photonic spectrometers. One of the devices is 71 times more compact than the traditional AWG, which improves the performance of the spectrometer. A resolving power of 27,780 is experimentally demonstrated.**

***Keywords*— astrophotonics, arrayed waveguide grating, silicon photonics, photonics integrated circuits**

I. Introduction

In a traditional AWG, the arrayed waveguides are constructed to introduce a constant path difference between adjacent waveguides[1], [2]. The longest waveguide in the arrayed waveguides is at least $\lambda \cdot R$, where λ is the operating wavelength and the R is the resolving power. This implies that to achieve a high resolving power on-chip AWG spectrometer requires an increase in the optical path length of the arrayed waveguides. Not only does this result in an increase of the footprint of the device, but also, more importantly, it leads to optical phase errors that are generated by fabrication imperfections which can become a significant issue [3], [4]. These phase errors degrade the performance of the device by increasing insertion loss and cross-talk. For this reason, active correction of waveguide phase errors based on integrating electro-optic or thermo-optic phase shifters in high-R AWGs are typically used [5], [6]. However, incorporating a phase shifter into every waveguide of the device would significantly increase the size, weight, power consumption, and cost (Swap-C) of the device. It also brings complexity to the chip fabrication and the testing of the AWG.

To break the ultimate limitation in achieving high-R, we present the AWG with reusable delay lines, see Fig. 1. (a). Unlike the traditional AWGs, where the phase distribution is introduced by an array of waveguides with different lengths between two free propagation regions (FPRs), one single waveguide is used to provide the phase distribution by an array of embedded directional couplers (DCs). The footprint of the spectrometer is reduced by a factor of 71 (potentially more). It eliminates the need for making large AWGs and the associated step of actively compensating the phase error.

II. Device Design

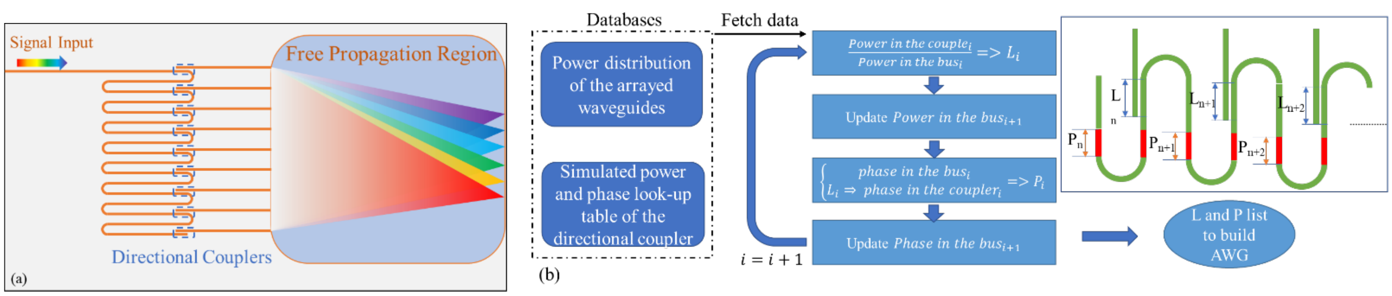

Fig. 1. (a) A schematic of the arrayed waveguide grating with reusable delay lines (RDL-AWG). (b) Flow chart to calculate the directional coupler array position and length.

The design flow of the embedded array of DCs is shown in Fig. 1. (b). The purpose of the DC array is to generate the power and phase distribution that feed into the FPR shown in Fig. 1. (a). Both the required power and phase distribution are the same as those of the output FPR in the traditional AWG. We can simulate the traditional AWG to get the proper distribution. The power distribution is simply a Gaussian distribution, while the phase distribution can be treated as an array of 0's at the central wavelength λ_0. The power and phase look-up table of the DCs is simulated by Beam Propagation Method in Rsoft. It contains the values of β, θ_1, θ_2 for different coupling length L, as shown in Fig. 2, where β is the remaining power coefficient, θ_1 is the extra phase introduced in the bus of the DC, θ_2 is the extra phase introduced in the coupler of the DC. Then, the two databases are used to calculate the lists of the length L

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and position P, shown in Fig. 1. (b). The optical path difference ΔL is set by the grating order m, which is directly related to the resolving power by R≈m×N. After the calculation of the L and P lists, to change the R value, the only parameter that needs to be changed is ΔL. This makes the design process simple and fast. We note that by adjusting both the phase and the power distribution of the light in the waveguides, we can generate different input profiles. An example of this is obtaining a flat top beam profile for each of the wavelength output channels.

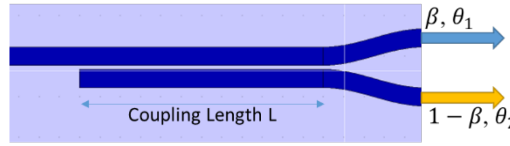

Fig. 2. Power and phase simulated in a directional coupler.

III. Experimental Results

Based on the above discussion, we have designed, fabricated, and characterized two AWGs with reusable delay lines (shown in Fig. 3. (a)). Both of them are fabricated on an ultra-low loss Si_3N_4/SiO_2 on a silicon platform [7]. The targeted R value are 10,000 and 29,600. The experimental data are shown in Fig. 3 (b). The measured R at 1550 nm is 8,812 and 27,780, respectively, which is in good agreement with the simulated results. The footprints of the devices compared to the traditional AWGs are reduced by factors of 22 and 71, respectively.

The relative high noise level in the experimental results is due to the phase distribution difference between the simulated results and real device. A characterization of the accurate phase in a directional coupler will be performed to further improve the performance, including the throughput and crosstalk.

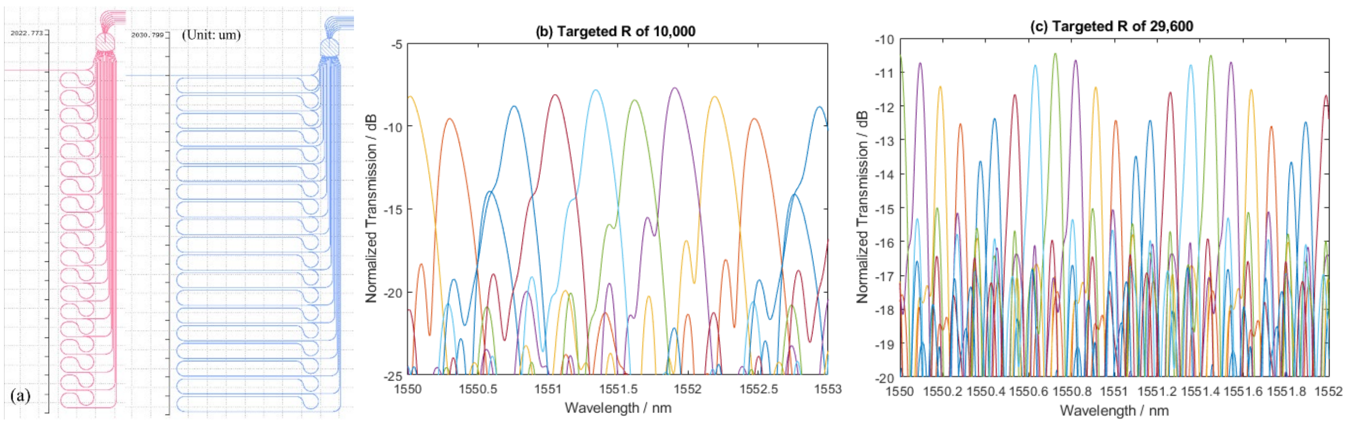

Fig. 3. (a) Two AWG with reusable delay lines designs. Experimental transmission spectra at the output channels of the AWGs with reusable delay lines in cases where the targeted spectral resolving powers R are 10,000 (b) and 29,600 (c) while the measured R are 8812 and 27,780, respectively.

IV. Conclusion

We introduced an innovative design of AWGs with reusable delay lines (RDL-AWGs), which has several unique advantages over traditional AWGs for achieving a high resolving power. An array of directional couplers is optimized to distribute the input signal from the delay line into the free propagation region. By making the AWGs more compact, it significantly reduces the impact of fabrication imperfections and uniformity issues which prevent traditional AWGs from achieving ultra-high resolving powers. The design theory is discussed in detail. We also experimentally demonstrate devices with resolving powers of 8812 and 27,780. These devices are respectively 22 and 71 times more compact than the traditional AWGs.

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