Interleaved Silicon Nitride AWG Spectrometers

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ABSTRACT

Interleaved arrayed waveguide gratings (AWGs) have a great potential in providing large channel counts and narrower channel spacings for many applications, including optical communication, spectroscopy, and imaging. Here, a 75-channel silicon nitride based interleaved AWG was experimentally demonstrated. The design is comprised of a 3-channel primary AWG with 1 nm of resolution and three 25-channel secondary AWGs each with 3 nm of resolution. The final device has a spectral resolution of 1 nm over 75 nm bandwidth centered at 1550 nm. Its performance is compared with a conventional AWG spectrometer with 75 nm of bandwidth and 1 nm of resolution. The interleaved AWG demultiplexer showed lower crosstalk and better uniformity in addition to being two times smaller than the conventional design.

Keywords: AWG spectrometers, compact, interleaved, better uniformity

1. INTRODUCTION

An arrayed waveguide grating (AWG) is a planar dispersive device, which is generally used as an on-chip spectrometer in many applications [1]. Combining high resolution and large free spectral range (FSR) in a single AWG is highly desirable for numerous applications, however it is rather difficult to implement. By applying different approaches, such as cascading several AWGs, the limitations on resolution and FSR of an AWG can be overcome. Even though the cascading configuration enables us to design flexible wavelength division multiplexing devices with high channel count and channel spacing, the device size will still be an issue [2-4]. Interleaving can solve the size problem. An AWG can be interleaved using its periodic routing property [5,6]. To do so, a high resolution AWG is used as the first stage, while several coarse filters are used in the second stage. Fig. 1a illustrates the working principle. The channel spacing of the secondary AWGs, i.e. $\Delta\lambda_S$, should be equal to the free spectral range (FSR) of the primary AWG, i.e. FSR_P. In this configuration, the FSR of the secondary AWGs, i.e. FSR_S, defines the FSR of the overall configuration whereas the channel spacing of the primary AWG, i.e. $\Delta\lambda_P$, defines the overall system resolution. In this method, the requirements on resolution and passband flatness of the secondary AWGs are relatively low, as the components in their prefiltered input spectra can be easily separated with very low adjacent-channel crosstalk. Moreover, the complete device size will be much smaller compared to one that is designed with the conventional cascading method, since high-resolution AWGs are generally bigger than low-resolution AWGs, therefore a multi-stage system with one high-resolution AWG and multiple low-resolution AWGs can be smaller in overall size than one with a low-resolution AWG and multiple high-resolution AWGs.

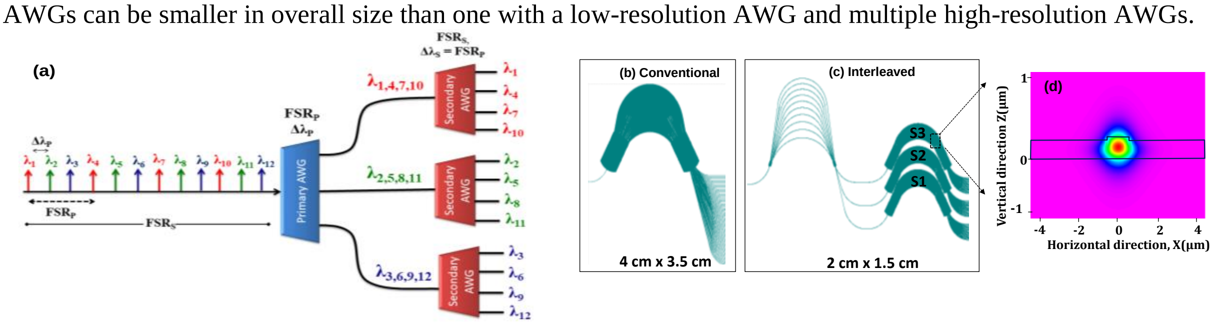

Figure 1 a. Schematic diagram of the interleaved AWG. Layout of the b. conventional and c. interleaved AWG spectrometers for the same resolution and bandwidth values. The size of the conventional design is ~ 2 times bigger than the interleaved design. d. Beam propagation method simulation of the optical mode. The blue outline shows the cross-sectional profile of the waveguide geometry.

A theoretical analysis on multi-stage WDM networks was made by Maier *et al*. including interleaved AWGs [7]. Chan *et al*. demonstrated a hybrid multiplexer by combining interleaved AWGs with free space gratings using free space configuration [8]. However, to the best of our knowledge, interleaved AWGs with large channel counts and narrow channel spacings in a CMOS compatible platform have not been experimentally demonstrated. Here, as a proof-of-principle, the performance of a two-stage interleaved AWG spectrometer with 1 nm resolution over 75 nm bandwidth centered at 1550 nm wavelength range was realized in silicon nitride (Si_3N_4) platform. A conventional AWG spectrometer with the same bandwidth and resolution values was realized in order to compare its performance with the interleaved AWG.

2. DESIGN

2.1 Waveguide geometry

The AWG spectrometers were realized using silicon nitride (Si_3N_4). The material system is a 200-nm-thick LPCVD Si_3N_4 film on an 8-µm-thick thermally-oxidized silicon wafer. A 4.0 µm thick SiO_2 layer (n = 1.47) was deposited by Plasma Enhanced CVD (PECVD) to complete the waveguiding cross-section. The refractive index of the thermal oxide and Si_3N_4 layer is 1.45 and 2.0 at 1550 nm, respectively. Single mode rib waveguides with 0.15 µm of slab height and 2.0 µm of waveguide width were designed. The effective refractive index of the fundamental transverse electric (TE) mode in the rib waveguide was calculated to be 1.55 by using beam propagation method (BPM) simulations. The optical mode profile is given in Fig. 1d. The minimum bending radius of the curved waveguides was calculated to be R = 150 µm with a bending loss of 0.1dB/cm

2.2 Demultiplexer design parameters and layout

As a proof-of-principle, an interleaved AWG spectrometer centered at λ_c = 1550 nm was designed with a channel spacing of $\Delta\lambda$ = 1 nm and a bandwidth of FSR = 75 nm. One primary and three secondary AWGs were used, which resulted in an overall device size of 2 cm x 1.5 cm. The size of a conventional AWG with the same bandwidth and resolution values is 4 cm x 3.5 cm. Size and layout comparisons of the conventional and interleaved AWG spectrometers are given in Figs. 1b and 1c. The effect of waveguide and material dispersion was included in each AWG design. The central wavelengths of the secondary AWGs were set to be the same as the output wavelength values of the primary AWG. The remaining design parameters of the devices were calculated using the standard equations for AWGs [6].

2.3 Beam propagation method (BPM) simulations

The performance of the AWGs was simulated using a 2D beam propagation method (BPM). According to BPM simulations for the conventional AWG, at the central channels, a crosstalk value of -28 dB and an excess loss of 4 dB were obtained. At the outermost channels these values are -25 dB and -16 dB, respectively. The adjacent crosstalk values for central and outer channels are 2.3 dB and 1.5 dB, respectively. The simulation results are given in Fig. 2a. The primary AWG of the interleaved design had a crosstalk value of -28 dB and excess loss value of 2.7 dB. The adjacent crosstalk value was obtained as -12 dB as shown in Fig. 2b. The simulation results of the secondary AWG centered at 1550 nm is given in Fig. 2c. Crosstalk values of -45 dB and -41 dB and excess loss values of 0.7 dB and 4.6 dB were obtained for the central and outer channels, respectively. Adjacent crosstalk value in the center is -11 dB.

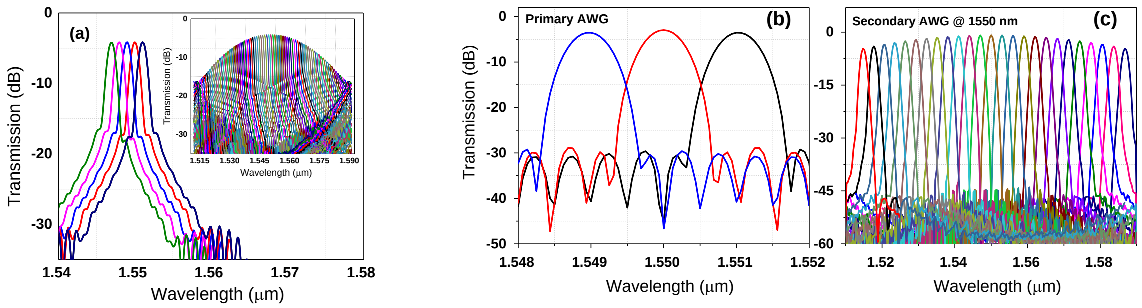

Figure 2. a. Simulation result of the central waveguides of the conventional AWG. Inset shows the complete spectrum. Simulation result of the (b) primary and (c) secondary AWG centered at 1550 nm.

3. MEASUREMENT RESULTS AND DISCUSSIONS

3.1 Measurement setup

Optical transmission measurements were performed by coupling TE-polarized light from a supercontinuum light source (NKT SuperK EXTREME, EXR4) into the input waveguide with a single-mode polarization-maintaining (PM) fiber. The output signal was sent to an optical spectrum analyzer (Yokogawa, AQ6370B) through a butt-coupled single-mode fiber. The transmission spectra measured at the output channels were normalized with respect to the transmission spectrum of a curved channel waveguide with the same radius and propagation length as the longest arrayed waveguide in the AWGs.

3.2 Conventional AWG transmission measurements

The measured transmission spectra of the central and outer waveguides of the conventional AWG are displayed in Fig. 3a. As predicted, each channel works as a band-pass wavelength filter. The measured values of resolution and FSR are consistent with the simulation results. However, a 5-dB difference between the simulated and measured crosstalk values was found which is mainly attributed to the fabrication-related phase errors. The excess loss values of 8 and 17 dB and crosstalk values of -23 and -18 dB were measured at central and outer channels, respectively.

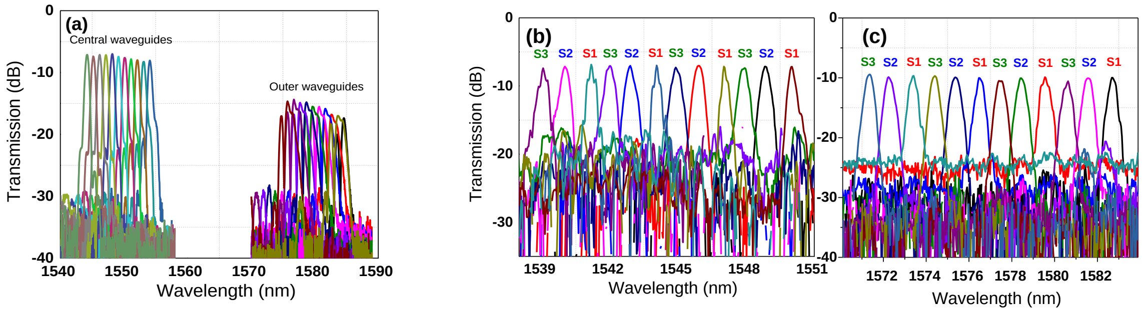

Figure 3 Measurement results of the central and outer channels of the a. conventional AWG, b. central channels of interleaved AWG, and c. outer channels of the interleaved AWG..

3.3 Interleaved AWG transmission measurements

Figures 3b and 3c display the measured transmission spectra of the central and outer output waveguides of the interleaved AWG spectrometer, respectively. S1, S2, and S3 indicates the secondary AWGs illustrated in Fig. 1c. As expected, interleaved AWG worked based on the cyclic nature and a fine resolution and large bandwidth were achieved. The overall crosstalk value of the central waveguides of the interleaved AWG is higher than predicted, because the uncoupled stray light coming from the input waveguide side contaminates the central waveguides more than the outer channels (see design of interleaved AWG in Fig. 1c). By adding a larger spatial offset between input waveguides with respect to the outer waveguides this issue can be solved easily. The adjacent crosstalk values of around -15 dB was measured for the whole range. Excess loss values of 7 dB and 10 dB were measured for the central and outer channels, respectively. A center wavelength shift of 3.3 nm was found which could be due to the insufficient etching of the rib waveguides. For this design, we did not use any on-chip heaters to tune the transmission spectrum of each sub AWG to align with the primary AWG spectrum; however, for an interleaved system with much finer resolution such heaters may be needed.

4. CONCLUSIONS

In summary, an interleaved Si_3N_4 AWG spectrometer centered at 1550 nm with 75 nm of bandwidth and 1 nm of resolution was demonstrated as a proof-of-principle. Its performance was compared with a conventional AWG having the same resolution and bandwidth specifications. Based on the measurement results, interleaved AWGs provide lower adjacent crosstalk values, and better channel uniformity especially at the outer channels in addition to its smaller device size. For a higher resolution and larger bandwidth, the size of the interleaved AWG demultiplexer becomes significantly smaller than a conventional AWG, which makes it very appealing also for many different applications including imaging, spectroscopy, astronomy, and so on.

ACKNOWLEDGEMENTS

The author thanks Assoc. Prof. Sonia M. Garcia Blanco and Meindert Dijkstra for their support in the device fabrication.

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