Low crosstalk Arrayed Waveguide Grating with Cascaded Waveguide Grating Filter

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Abstract We propose a highly compact and low crosstalk arrayed waveguide grating (AWG) with cascaded waveguide grating (CWGF). The side lobes of the silicon nanowire AWG, which are normally introduced by fabrication errors, can be effectively suppressed by the CWGF. And the crosstalk can be improved about 15dB.

1. Introduction
In recent years, silicon based on arrayed waveguide grating (AWG) as wavelength division multiplexer/demultiplexer (MUX/ DeMUX) has drawn great interests for its low insertion loss, high stability and low cost [1-2]. And it has great potential in chip-scale optical interconnection to enhance the data traffic capacity [3]. With the development of silicon nanowire technique, shrinking the device size can be achieved. E-beam lithography and dry etching can be used to fabricate the silicon nanowire AWGs [4]. However due to the rapid growing phase error in nanowire waveguides brought by fabrication errors, measured crosstalk is normally larger than 15dB [2, 5]. Suppressing the crosstalk of nano sized AWG has been a very big challenge. In this paper, a novel cascaded waveguide grating filter (CWGF) is proposed to decrease the crosstalk of AWG caused by fabrication errors.

2. Structure design
The initial design of structure is N×N (N can be 8 or 16 in our initial design) AWG with channel spacing of 3.2nm cascaded with N waveguide grating filters. Figure1 (a) shows a schematic layout of an 8×8 AWG with 8 CWGFs. The AWG consists of three main parts, the multiple input and output waveguides, two free propagation regions (FPR), and a waveguide array with equal length difference between adjacent waveguides connecting two FPRs. The AWG is designed on the silicon-on-insulator (SOI) wafer with silica thickness of 2μm and top silicon thickness of 340nm. The widths of input and output waveguides are W_{in/out} = 450nm, the adjacent waveguide spacing is d_{in/out} = 2.5μm. The length of FPR, or the diameter of Rowland circle is D = 130.55μm. The number of arrayed waveguides is N_{array} = 39. In order to reduce fabrication induced phase errors, the arrayed waveguides are widen to 800nm. However, higher order modes will be excited in the 800nm wide rectangle waveguide, which will confuse the focusing on spot at the second FPR. Thus tapers from 800nm to 450nm are applied in all bending parts to remove the higher order modes excited in the 800nm wide waveguides. And another original design is to add waveguide grating filter with two phase shift regions at every output port of AWG. It provides a slightly wider spectrum than AWG, which could maintain the 3dB bandwidth in the last spectrum.

The CWGF consists of a coupling cavity with two equivalent phase shift regions, and the left and right lateral Bragg reflectors as shown in Figure1 (b). The Bragg reflector comprises alternative layers of narrow and wide waveguide segments, each with light path of λ/4 to fulfill the Bragg condition. The widths of the narrow and wide segments are 450nm and 800nm respectively. For the channel of central wavelength of 1550nm, the effective indices of
narrow and wide waveguides are 2.5933 and 2.9342 respectively, which determines their lengths to be 149.42nm and 131.79nm. And thus the grating period is 281.21nm. The left and right reflectors both include 11 periods, while the central reflector between two phase shift regions has 21 periods. The length and width of phase shift region are 1.9769μm and 800nm.

Figure 1. Schematic layout of (a) AWG with CWGF and (b) the magnifying view of CWGF.

All the parameters above are for the channel of central wavelength of 1550nm. The principle and design method of phase shifting region in this filter has been described in reference [6] and the other channels’ parameters can be got with the same method. Here we simply give the main parameters, which have been optimized.

3. Results of simulation and discussion.
Kirchhoff diffraction theory was used to calculate the transmission spectra of AWG. The calculated spectra for the central channel of AWG (with or without errors) and filter are shown in Figure 2. The crosstalk between the adjacent output channels of AWG is about -30.7dB. When we consider practical fabrication errors of random waveguide width variation of 4nm, the crosstalk will be degraded by about -15dB. This is due to the emergence of large side lobes brought by phase errors in arrayed waveguides. In order to improve the crosstalk level, CWGFs at the outputs of AWG are introduced to cut off the side lobes, as shown in Figure 1. The extinction ratio of the CWGF at two adjacent wavelengths of 1550nm and 1553.2nm is about -15.3dB. This high extinction ratio is utilized to suppress the side lobes of AWG.

Figure 2. Transmission spectrum of AWG (with or without errors) and CWGF for central wavelength of 1550nm.

Figure 3. Theoretical calculated transmission spectrum of AWG cascaded with grating filter.

Here we design eight different CWGFs. Every CWGF matches well in central wavelength
with the corresponding output channel of AWG. Through tuning the central coupled cavity structure in the CWGF, we can get flat-top spectrum to maintain 3dB bandwidth. The transmission spectrum of AWG with CGFs was calculated as shown in Figure3. The crosstalk at central wavelength of 1550nm is -43.3dB, which matches well with the estimation of -30dB for AWG plus -12dB for filter from Figure2.

The above analysis just refers to the theoretical calculations. In order to estimate the impact of fabrication errors, we simplified the waveguide width error with normal distributed random error model. According to the real fabrication errors in our experiments, we set the maximum waveguide width variation to be 4nm. Then we can numerically simulate the random width errors to estimate the “experimental” transmission spectrum, as shown in Figure4. From the spectrum, we can find the side lobes brought by the fabrication errors is very high. The crosstalk level is degraded from -30dB to -15dB. But the crosstalk level can be improved and the side lobes can be suppressed efficiently with the help of CWGFs. And the crosstalk level can be recovered again to below -30dB. It should be pointed out that the fabrication errors are involved into not only AWG but also CWGFs. Furthermore, the length of the grating filter is only 18µm, which is much more compact compared with the traditional AWG cascaded with AWGs design in Ref [7].

![Figure4](a)

![Figure4](b)

**Figure4.** Transmission spectra of AWGs with maximum random waveguide width error of 4nm (a) single AWG (b) AWG with CWGF.

4. Conclusions

In summary, an ultra compact AWG with low crosstalk has been achieved by introducing CWGFs at the output of the AWG. The fabrication errors induced crosstalk in silicon nanowire AWG is efficiently suppressed and the crosstalk improvement is as high as 15dB. At the same time, the size of CWGF is only 18µm, which is very compact and easy to fabricate. Now we are experimentally fabricating this device and measuring the crosstalk performance.

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