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High Resolution Silicon Arrayed Waveguide Gratings for Photonic Signal Processing Applications

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Abstract: We design, fabricate and demonstrate the operation of a compact, 1 GHz resolution silicon arrayed waveguide grating. Active phase correction allows for low channel cross-talk, enabling the demonstration of spectral shaping and RF signal analysis.

OCIS codes: (130.7408) Wavelength filtering devices; (130.3120) Integrated optics devices;

1. Introduction

Spectral filtering is a critical operation in many optical signal processing applications, such as arbitrary waveform generation and RF signal channelization [1, 2]. High resolution filtering can be achieved in free space by long path length spectrometers or high finesse Fabry-Pérot cavities. Resonant cavities fabricated in silicon photonic devices, similar to a Fabry-Pérot cavity, can provide high resolutions and are easily tuned through the thermo-optic or electro-optic effects. However, the small mode volume of these cavities makes them susceptible to non-linear instabilities such as self-heating. For this reason, a non-resonant device, such as a grating, is desirable for many applications. The integrated equivalent of a ruled grating is the arrayed waveguide grating (AWG). An AWG uses a star coupler to split incoming light among an array of waveguides. Each waveguide is incrementally longer than the previous, providing the necessary dispersion. Light from each waveguide is then recombined at another star coupler, where the light interferes such that each output waveguide collects a different slice of the optical spectrum.

For many years AWG's have been fabricated in silica on silicon platforms for wavelength division multiplexing. This application requires a channel resolution of 25-100 GHz, or a wavelength resolution of 0.2-0.8 nm. Achieving resolutions higher than this requires an increase in the optical path lengths. Not only does this increase the footprint of the device, but also optical phase errors resulting from fabrication imperfections become a more significant issue [3]. Moving to a high index contrast platform, such as silicon, allows for more compact designs, however the unwanted phase errors become an even more substantial issue. For this reason, correction of waveguide phase error following fabrication is a necessity for high index contrast AWGs [4-6].

In this work we present the design, fabrication and optimization of a compact silicon photon arrayed waveguide grating. By using active thermo-optic phase error correction we're able to demonstrate a low crosstalk AWG with 1 GHz (8pm) channel spacing. Until now, 1 GHz channel spacing has only been demonstrated in silica on silicon platforms [7], while high index contrast AWGs have been limited to 10-25 GHz [8,9]. Using this device, we are able to show analysis of RF signals as well as more complex functionality such as arbitrary spectral shaping.

2. Design and Fabrication

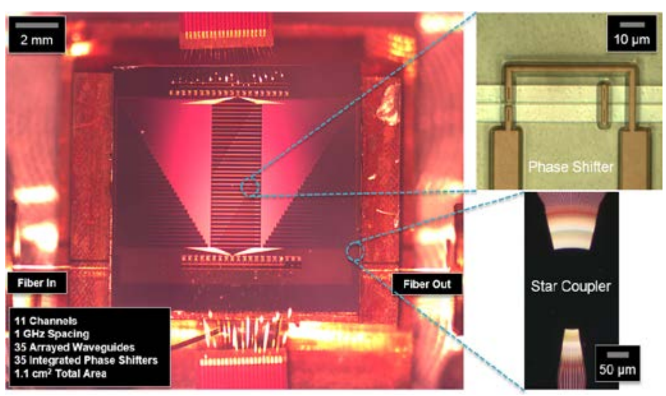

Figure 1 – (left) Image of a 1GHz Silicon AWG mounted to copper heatsink showing wire-bonding and fiber coupling. (top right) Close up of a phase shifter integrated with the silicon waveguide. (bottom right) Dark field image of a star coupler showing 11 inputs split into 35 outputs.

The AWG used in this work is shown in fig. 1, and occupies a footprint of approximately 9mm x 12 mm. Light is coupled into the left edge of the chip into one of 11 channels using inverse silicon waveguide tapers. The 11 inputs combine at a star coupler which divides the light into 35 waveguides. Each of the 35 waveguides travels up the left edge of the chip before turning to the right to travel across the chip. As the waveguide travels across the chip it makes a series of switchbacks (appearing as purple triangles in fig. 1) in order to reach the necessary path length. The longest of the 35 waveguides has a total path length exceeding 16 cm. At the center of the chip each waveguide has an integrated thermo-optic phase shifter consisting of an n+ doped silicon resistor. After reaching the right edge of the chip, the waveguide turns down and enters an identical star coupler which combines the light into 11 output channels.

The device is fabricated in the Sandia Microsystems and Engineering Sciences Applications (MESA) silicon microfabrication complex. Fabrication is completed on SOI wafers with a 250nm device layer and a 3 µm buried oxide in a fully CMOS compatible process. Following dicing, a chip is mounted with thermally conductive epoxy to a copper package with thermo-electric cooler and thermistor. Wire-bonding is used to connect to each of the 35 integrated phase shifters.

3. Phase Correction and Applications

Following fabrication, the transmission spectrum of the device is completely random due to the significant phase errors accumulated by light traveling through the long waveguides. In order to correct for this, the relative optical phase of each waveguide is measured using a swept wavelength interferometer technique [10]. This information is then used to calculate the appropriate current to apply to each of the phase shifters. The optimized transmission spectrum of each of the 11 channels is shown on the left of fig. 2. The standard deviation of the remaining phase error is measured to be 0.1 radians, providing an adjacent channel cross-talk in the range of -15 to -25 dB.

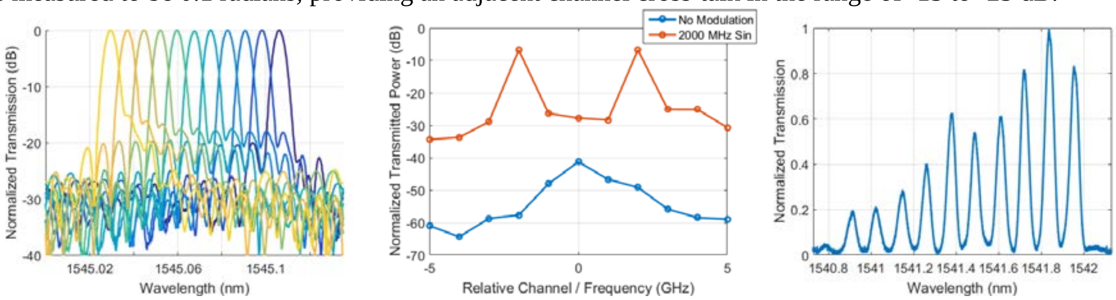

Figure 2 – (left) Normalized transmission of each of the 11 outputs of the AWG following active phase error correction. (middle) Demonstration of the detection of a 2GHz sinusoidal modulation using the AWG and (right) demonstration of arbitrary spectral shaping to produce 11 peaks with linearly increasing transmission.

In addition to correcting the optical phase error, the same technique can be used to apply arbitrary phases to the waveguides which allows for shaping of the optical transmission spectrum. Using the Gerchberg-Saxton algorithm the spectrum can be tuned towards a desired response. As an example of this, on the right of fig. 2, the transmission spectrum with a target shape of 11 peaks with linearly increasing transmission is shown. Finally, in the center of fig. 2, the use of the AWG as an RF signal analyzer is demonstrated. When a 2 GHz sinusoidal modulation is applied to a laser passing through the AWG, optical power is detected at the output channels corresponding to positive and negative 2 GHz with ~20dB of contrast.

4. Conclusions

In conclusion we demonstrate state-of-the-art performance from a silicon photonic AWG in terms of footprint, resolution and cross-talk. Using this device, we are able to demonstrate RF signal channelization and spectral shaping. Further integration of amplitude and phase modulation will allow for the realization of more complex optical signal processing such as arbitrary waveform generation.

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