Experimental Demonstration of Compact
16 channels-50 GHz Si$_3$N$_4$
Arrayed Waveguide Grating

Shibnath Pathak $^*$, Kuanping Shang and S. J. B. Yoo
Department of Electrical Engineering and Computer Science, University of California, Davis, Davis, CA 95616, USA
*$snpathak@ucdavis.edu, sbyoo@ucdavis.edu

Abstract: We experimentally demonstrate 16 channel-50 GHz arrayed waveguide gratings (AWG) on Si$_3$N$_4$ for DWDM applications. The device achieves 1.8 dB loss, -20 dB crosstalk, phase errors below $\pm \frac{\pi}{10}$ on a 3.7×0.7 mm$^2$ footprint.

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1. Introduction

Arrayed waveguide gratings (AWGs) are one of the key components for dense wavelength division multiplexing (DWDM) systems enabling wavelength(de)multiplexing and routing scaling to a large number of channels with graceful increases in optical losses. AWGs are widely used in telecommunications, datacom, optical sensing, optical spectroscopy, and many other applications. Such a wide range of applicability drives the need to realize AWGs on various material platforms and across various wavelength ranges [1–3]. But different platforms impose different design restrictions for AWGs. For instance silica AWGs have low index contrast which help to achieve low loss and crosstalk [1]. However, this low index contrast also requires the minimum bending radius to be relatively large and as a result, silica AWGs have typically large footprints. On the other hand, the high contrast silicon-on-insulator (SOI) waveguides allows very compact silicon-photonic AWGs [4] with tight bending, but this high contrast is also the reason for relatively high loss and high crosstalk. Therefore, the Si$_3$N$_4$/SiO$_2$ waveguide platform with moderate index contrast [5] makes it an attractive alternative for low-loss, high-performance, and compact AWGs offering design flexibility and integrateability.

Fig. 1: Schematic diagram of 16×50 GHz Si$_3$N$_4$ AWG. (Red box) single mode 2µm wide Si$_3$N$_4$ waveguide. (Green box) multi-mode 3µm wide Si$_3$N$_4$ waveguide.
2. Design

An AWG consists of two star-couplers (also known as free propagation regions) and an array of waveguides with linear increment of their length. The length difference between two successive waveguides determines the free spectral range (FSR) of the AWG. High resolution AWGs are challenging because they require relatively large delay lengths, and optical phase errors accumulated over such long array arms need to remain relatively small (e.g. r.m.s. phase error \(< \frac{\pi}{10}\)) to achieve low crosstalk (e.g. \(< -20 \text{ dB}\)). We designed a 16 channel × 50 GHz Si₃N₄ AWG with 34 array waveguides. The designed AWG has 900 GHz FSR and the delay length of 186.5 \(\mu\text{m}\). The AWG also has 4 \(\mu\text{m}\) wide waveguide apertures at the junction between the slab and the arrayed waveguides, and has a 100 \(\mu\text{m}\) long adiabatic taper from 4 \(\mu\text{m}\) wide aperture to the 2 \(\mu\text{m}\) wide single mode waveguide. As Fig. 1 illustrates, the arrayed waveguides employ a combination of 2 \(\mu\text{m}\)-wide single mode and 3 \(\mu\text{m}\)-wide multi-mode waveguides with fixed bend radius of 150 \(\mu\text{m}\) to maintain low phase errors overcoming some fabrication tolerance. The layout of the designed AWG utilized the IPKISS tool.

3. Fabrication

Device fabrication took place at the University of California nano fabrication facilities. On a 150 mm silicon wafer, a 3 \(\mu\text{m}\) low temperature oxide (LTO) layer was deposited in a low pressure chemical vapor deposition (LPCVD) furnace as a bottom cladding, followed by a 200 nm stoichiometric nitride (Si₃N₄) layer deposition by LPCVD as a waveguide core. The waveguide definition utilized an ASML stepper lithography with a 248 nm laser source, followed by fully etching the 200 nm Si₃N₄ waveguide core in the unmasked region using an inductively coupled plasma (ICP) etching system with C₄F₈ and H₂ gases. As a top cladding a 3 \(\mu\text{m}\) low temperature oxide (LTO) is deposited on top of the Si₃N₄ waveguide. Figure 2 shows the optical image of the fabricated 16×50 GHz Si₃N₄ AWG.

![Optical image of the fabricated 16x50 GHz Si₃N₄ AWG.](image)

4. Results

The AWG is characterized using an optical vector network analyzer (OVNA). The OVNA has high spectral resolution and using a continuously-swept mode-hop-free laser to measure the transmission of the AWG coherently. The fiber-to-fiber loss measured on the straight test waveguide on the AWG chip was 3.5 dB when utilizing the lensed fiber couplers not optimized for this waveguides and the polished AWG chip facets with no optical coating. The waveguide propagation loss measured on the 2 \(\mu\text{m}\)-wide waveguide using a group of waveguide spirals was 0.5 dB/cm. Figure 3(a) shows the measured spectral response of the 16×50 GHz Si₃N₄ AWG. The measured insertion loss and the crosstalk of the AWG is 1.8 dB and -20 dB respectively. The measured channel spacing accurately matched the design value of 50 GHz, however, the center wavelength blue-shifted towards the lower wavelength, which is likely due to a combination of overall reduction in waveguide widths after fabrication and lower optical index of the dielectric material compared to the design parameters. Figure 3(b) shows the amplitude and the phase error over the arrayed waveguide of the 16×50 GHz Si₃N₄ AWG measured by OVNA at the 15th output channel. The figure clearly indicates more optical power at the array waveguides at the center compared to those at the edges correctly matching the Gaussian far-field projection of the waveguide aperture in the input star-coupler. The phase errors appear to be greater for longer array waveguides. The phase error variation over the first ten array waveguides (arm number 1-10) is ±0.1 rad, while the next ten array waveguides (arm number 11-20) had the phase error variations of ±0.2 rad and the rest of the array waveguides (arm number 21-34) had ±0.3 rad (or below ±\(\frac{\pi}{10}\)). These phase error values are considered reasonable, and they can be reduced by active tuning or trimming of the array waveguide arm optical index.
Fig. 3: (a) Measured spectral response of 16×50 GHz Si$_3$N$_4$ AWG. (b) Measured amplitude and phase error over the arrayed waveguide of the 16×50 GHz Si$_3$N$_4$ AWG.

5. Conclusion

We demonstrated a low loss (1.8 dB) and low crosstalk (-20 dB) 16×50 GHz Si$_3$N$_4$ AWG with 34 waveguides in array. The measured channel spacing matched well with the design channel spacing. The phase error of the arrayed waveguide was below ±$\pi$/10 and the footprint of the AWG was only 3.7×0.7 mm$^2$.

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References