High Resolution Silicon-Oxynitride Arrayed Waveguide Grating Spectrometers

B. Imran Akca, Nur Ismail, Gabriel Sengo, Fei Sun, Kerstin Wörhoff, Markus Pollnau,

and Rene M. de Ridder

Integrated Optical MicroSystems (IOMS) group, MESA+ Institute for Nanotechnology, University of Twente, the Netherlands

B.I.Akca@ewi.utwente.nl

Abstract *- We present experimental results of silicon-oxynitride (SiON) based arrayed waveguide grating (AWG) spectrometers operating around 800 nm and 1300 nm. A 100-channel AWG with 0.4 nm channel spacing centered at 1300 nm and a 125-channel AWG with 0.16 nm channel spacing centered at 800 nm have been fabricated and characterized. The measured crosstalk and insertion loss values near the central wavelengths were ranging between -22 and -32 dB and between 3.2 and 2 dB for 800-nm AWG and 1300-nm AWG, respectively. The highest wavelength resolution (0.16 nm) and the largest free spectral range value (38.8 nm) have been achieved in SiON technology so far.*

Introduction

Spectrometers have an important role in a wide variety of fields. The most important integrated optical implementation of a spectrometer is the AWG that, with its excellent performance and compactness, has a high potential for various spectroscopic applications [1]. It was first proposed by Smit in 1988 [1], and further developed by Takahashi [2] and Dragone [3], who extended the concept from 1 x *N* demultiplexers to *N* x *N* wavelength routers. Since then, many AWGs have been designed in order to improve the crosstalk level, insertion loss, channel spacing, polarization independence, and total device size by using different material systems [3-6].

Silica is one of the most important technologies used for realization of AWGs due to its good stability, low fiber coupling loss, good channel uniformity, and high wavelength accuracy. So far, the minimum channel spacing of 1 GHz was reported on a 16-channel silica AWG at 1.547 μm [3]. However, due to the low index contrast available in silica, and consequently the large required bending radius, the devices need to be quite big and a single one could fill almost all available space on a 100-mm wafer.

The silicon-on-insulator (SOI) material system provides a high index contrast, resulting in markedly reduced device size. Fukazawa et al. report a 6-nm-spaced 17-channel AWG at 1.55 μm, using silicon photonic wires, with an overall device size of 110 μm x 93 μm [4]. They achieved a free spectral range (FSR) of 90 nm, so far the largest value reported for SOI AWGs. Although SOI technology provides the opportunity of very small foot print, the crosstalk and fiber coupling loss suffer quite a lot from the high index contrast.

Silicon-oxynitride (SiON) is a very promising material considering the problems of insertion loss, crosstalk, and device size in the previously mentioned material technologies. The refractive index of that material can be chosen between the values of silicon dioxide (1.45) and silicon nitride (2.0), allowing flexible waveguide design [5]. The bending radius can be reduced to several microns by using the highest index contrast with a proper waveguide geometry. Furthermore, SiON is transparent in a broad wavelength range from 210 to beyond 2000 nm [5], so that AWGs can be fabricated for both visible and infrared wavelengths using the same material system, or even the same AWG structure could be used for both regions. In the literature, there is only limited data on SiON based AWG spectrometers [6,7].

In this work, we present two AWG spectrometers for the 800 nm and 1300 nm spectral ranges, using SiON technology. The operation of an AWG [1] is briefly explained, referring to Fig. 1a. Light from an input waveguide diverges in a first free propagation region (FPR) in order to illuminate the input facets of an array of waveguides with a linearly increasing length. At a central design wavelength, the phase difference at the output facets of adjacent array waveguides is an integer multiple of 2π. Since these facets are arranged on a circle, a cylindrical wavefront is formed at the beginning of a second FPR, which generates a focal spot at the central output channel. Since the phase shift, caused by the length differences between arrayed waveguides, is linearly dependent on wavelength, the resulting wavelength-dependent phase gradient implies a tilt of the cylindrical wavefront at the beginning of the second FPR, which causes the focal spot to shift to a different output waveguide.

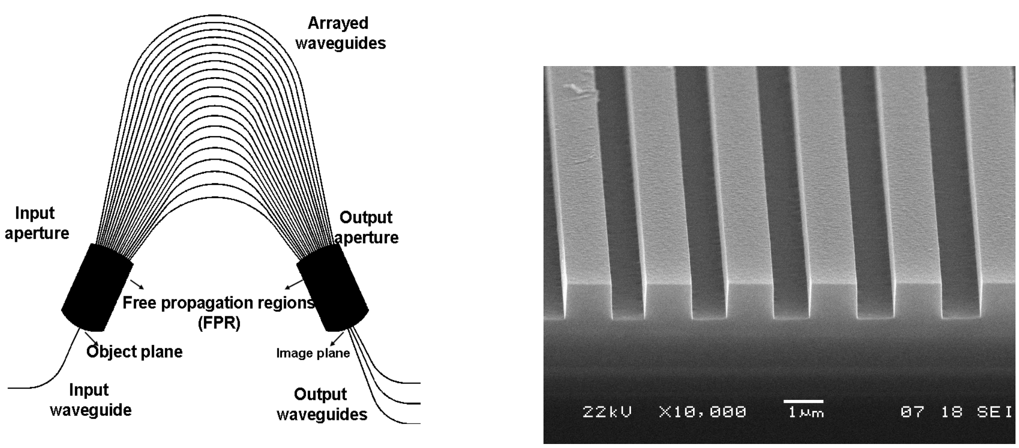

Fig. 1. a) Schematic layout of an AWG. **b)** SEM image of the arrayed waveguides before top oxide cladding deposition.

Design

For the AWG centred at 1300 nm, the waveguides were single-mode SiON channel waveguides with 2 μm width and 0.6 μm height. The core and cladding refractive indices were 1.55 and 1.4485 at 1.3 μm wavelength, respectively. The minimum bending radius of curved waveguides was calculated to be 500 μm. The arrayed waveguides were linearly tapered over a length of 200 μm to a width of 6 μm at the interfaces with the FPR to decrease the insertion loss. In order to reduce the crosstalk induced by phase errors, the spacing at the

FPR between arrayed waveguides has been chosen as 6 μm, and that between the output waveguides as 8 μm.

The AWG centred at 800 nm was designed with single-mode SiON channel waveguides of 1.5-μm width and 0.8-μm height. The core refractive index was 1.5 at 800 nm wavelength, resulting in a minimum bending radius of 700 μm. In this case the arrayed waveguides were linearly tapered over a length of 400 μm to a width of 5 μm at the interfaces with the FPR Arrayed waveguide spacing of 6 μm and output waveguide spacing of 8 μm were used.

Table I summarizes the design values of both AWGs.

Table I: Design parameters of the AWG spectrometers.

Parameters	**AWG @ 800 nm**	**AWG @ 1300 nm**
Channel spacing (Δλ)	0.16 nm	0.4 nm
Diffraction order (m)	40	33
Focal length (R)	1.1 mm	5.4 mm
Path length difference (ΔL)	21.8 μm	29.17 μm
Number of arrayed waveguides (M)	500	400
Number of output channels (N)	125	100

Characterization

The optical transmission measurements were performed by coupling TE-polarized light from a broadband source (Fianium SC450) into the input waveguide, using a single-mode polarization-maintaining fiber. The output signal was sent to an optical spectrum analyzer (iHR 550, Horiba Jobin Yvon) through a single-mode fiber. The transmission spectra measured at the output channels were normalized with respect to the transmission of a straight channel waveguide. The transmission spectrum of the 800-nm AWG and the 1300-nm AWG are given in Fig. 2. As predicted, each channel works as a bandpass wavelength filter. The resolution values of 0.16 nm and 0.38 nm, and FSR values of 38.8 nm and 19.4 nm have been obtained for the 800-nm AWG and 1300-nm AWG, respectively. The measured central channel crosstalk values were approximately –22 dB and –32 dB and the central insertion loss values were ~3.2 dB and 2 dB for the 800-nm AWG and 1300-nm AWG respectively.

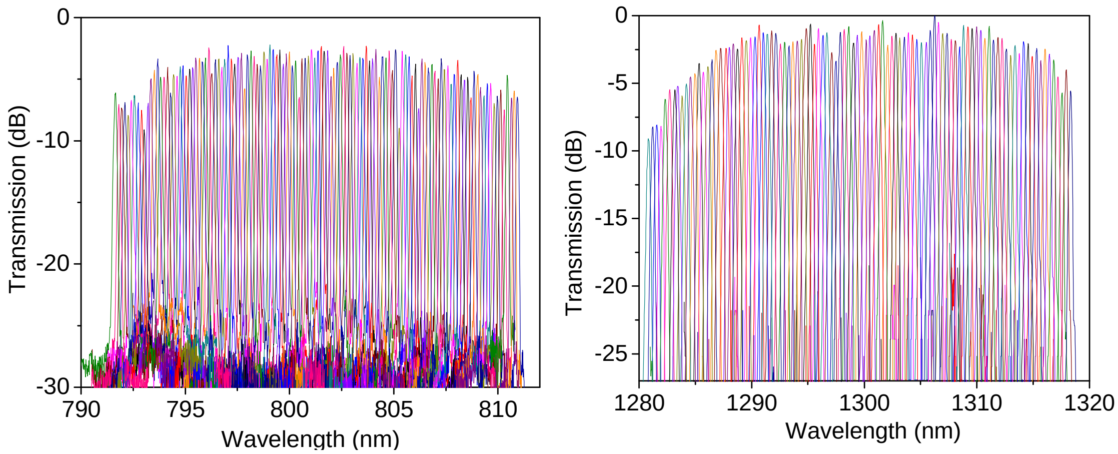

Fig.2. Optical transmission measurement results of **a)** 800-nm AWG and **b)** 1300-nm AWG for TE polarization.

Conclusion

We have designed, fabricated, and characterized SiON based AWGs for 800 nm and 1300 nm spectral regions with an overall chip size of 2.6 cm × 2.1 cm and 2.1 cm × 1.3 cm, respectively. The measurement results are in good agreement with the simulation results. Crosstalk values of -32 dB and -22 dB, insertion loss values of 2 dB and 3.2 dB have been obtained for 1300-nm-AWG and 800-nm-AWG, respectively. The highest wavelength resolution (0.16 nm) and the largest FSR value (38.8 nm) have been achieved in SiON technology so far.

Acknowledgement

The authors would like to thank Xaveer Leijtens for the fruitful discussions on arrayed waveguide grating measurements. This work is supported by the Dutch Senter-Novem MEMPHIS Project

References

[1] M. Smit, “New focusing and dispersive planar component based on an optical phased array,” *Electron. Lett.*, *vol.*24, no.7, pp.385-386, Mar. 1988.

[2] H. Takahashi, S. Suzuki, K. Kato, and I. Nishi. “Arrayed-waveguide grating for wavelength division multi/demultiplexer with nanometre resolution,” *Electron. Lett.*, *vol.*26, no.2, pp.87-88, Jan. 1990.

[3] K. Takada, et al., “1-GHz-spaced 16-channel arrayed-waveguide grating for a wavelength reference standard in DWDM network systems,” *IEEE J. Lightwave Technol.*, vol.20, no.5, pp. 850-853, May 2002.

[4] T. Fukazawa, F. Ohno, and T. Baba, “Very compact arrayed-waveguide-grating demultiplexer using Si photonic wire waveguides,” *Jpn. J. Appl. Phys*., vol.43, no.5B, pp.L673 - L675, 2004.

[5] K. Wörhoff, C. G. H. Roeloffzen, R. de Ridder, A. Driessen, and P. V. Lambeck, “Design and Application of Compact and Highly Tolerant Polarization-Independent Waveguides”, *IEEE J. Lightwave Technol.*, vol.25, pp.1276-1282, May 2007.

[6] B. Schauwecker, G. Przyrembel, B. Kuhlow, and C. Radehaus, “Small-size silicon-oxynitride AWG demultiplexer operating around 725 nm,” *IEEE Photon. Technol. Lett.*, vol.12, no.12, pp. 1645-1646, Dec. 2000.

[7] T. Shimoda, K. Suzuki, S. Takaesu, and A. Furukawa: “Low-loss, polarizationindependent, silicon-oxynitride waveguides for high-density integrated planar lightwave circuits,” *Proc. 28th Europ. Conf. Opt. Commun.* (ECOC’02), Copenhagen, Denmark, paper 4.2.2 (2002).