Ultracompact 40-Channels Arrayed Waveguide Grating on Silicon Nitride Platform at 850nm

(Student Paper)

Zunyue Zhang[1], Yi Wang[1], Hon Ki Tsang[1]
[1] Dept. of Electronic Engineering, The Chinese University of Hong Kong, Shatin NT, Hong Kong SAR, China
e-mail: hktsang@ee.cuhk.edu.hk

ABSTRACT

We propose and demonstrate a 40-channels arrayed waveguide grating (AWG) on silicon nitride platform at 850nm. The total size of the AWG is $910\times 680\ \mu m^2$. The transmission spectrum is measured. The AWG has an operating bandwidth of 60nm and has a measured insertion loss of 0.6dB. The channel crosstalk is 20dB.

Keywords: Arrayed waveguide grating, ultracompact, very near infrared, silicon nitride platform.

1. INTRODUCTION

Optical coherence tomography (OCT) is a 3D imaging technique which is widely used in ophthalmology, gastroenterology, and cardiology [1]. Time-domain OCT (TD-OCT) performs a time domain measurement of the interference signals from the mechanically scanning reference arm and the reflection from different depth of the samples. Spectral-domain OCT (SD-OCT), alternatively, fixes the reference arm and measures the optical spectrum, thus shows a faster imaging speed and higher sensitivity [2]. The key component in a SD-OCT system is the broadband spectrometer with high spectral resolution. The broad operating bandwidth make it possible to build a high-axial-resolution SD-OCT and the high spectral resolution determines the large imaging depth [3].

SD-OCT system with integrated spectrometer was recently demonstrated at 1310nm [4]. While for ophthalmology, 850nm is a better choice because tissue absorption is dominated by haemoglobin in 200-600nm and by water at the wavelength range above 1000nm [5]. Silicon nitride has a large wavelength range of transparency from about 400nm wavelength to the mid-infrared and is thus a suitable platform for integrated spectrometers operating around the 850nm wavelength range.

The basic principle for the separation of different wavelengths in an AWG was originally introduced in 1988 by M.K. Smit [6], and a large, centimetre scale, silicon oxynitride AWG spectrometer was previously reported for use in an integrated spectrometer in SD-OCT system [7]. Use of high refractive index- silicon nitride for AWG may lead to more compact designs but previous work on this platform was limited to 12 channels around the target wavelength range [8-9].

In this paper, we design and demonstrate a 40-channels AWG on silicon nitride platform at 850nm with a small footprint of only $910\times 680\ \mu m^2$. The measured transmission spectrum of the AWG shows an operating bandwidth of 60nm with low insertion loss of 0.6dB and low channel crosstalk of 20dB.

2. DEVICE DESIGN

The device is design on 300nm thick silicon nitride wafer with 3.3 μm buried oxide and air cladding, waveguide width is designed to be 800nm to make sure single mode transmission at 850nm, in the meanwhile reduce the scattering loss and phase errors caused by the sidewall roughness. Fundamental TE mode is used in the AWG design. The effective index of the silicon nitride slab n_s and arrayed waveguides n_{wg} are simulated by

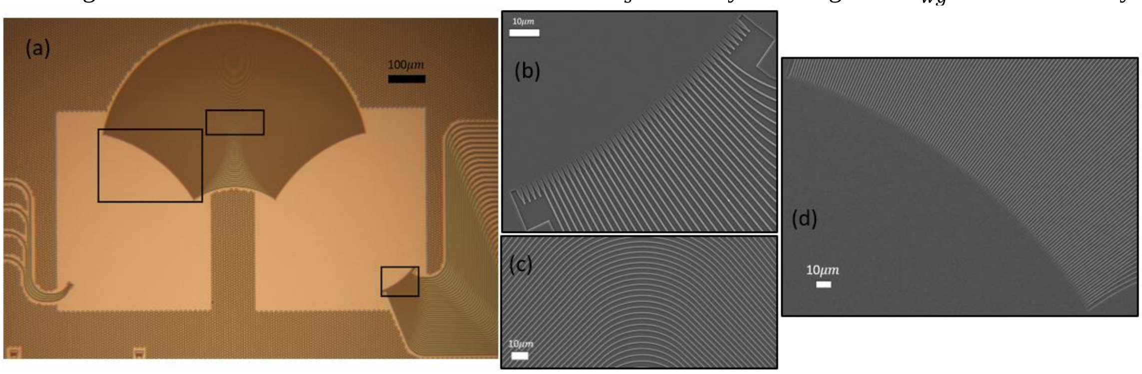

Fig. 1. (a) Microscope image of the 40-channels AWG. (b) SEM image of the output channels, parabolic tapers are used to reduce the coupling loss from FPR to waveguides. (c)SEM image of the arrayed waveguides, curve profiles are carefully designed to reduce the systematic phase errors. (d)SEM image of the interface between FPR and arrayed waveguides.

commercial Lumerical Mode Solutions and the group index of the arrayed waveguides N_g is 1.99. Due to the spectral nonuniformity [10], we start the design with a 50-channels AWG and use the central 40 channels as a spectrometer to make a more flatten transmission spectrum. 150 arrayed waveguides are used in the design. The arrayed waveguide length increment ΔL is designed to be $4.92\ \mu m$ to make the free spectral range (FSR) $75\ nm$. The waveguide aperture of input/output waveguide and arrayed waveguides are both $2\ \mu m$. Parabolic tapers are designed and simulated to minimize the coupling loss from FPR to arrayed waveguides and input/output waveguides. The length of the free propagation region (FPR), i.e. the diameter of the Rowland circle is $386.5\ \mu m$, which determines the channel spacing of the designed AWG to be 1.5nm. We use Semi-analytical AWG model [11] to simulate the light propagation in the AWG. The simulated transmission spectrum shows the 40-channels AWG has 0.45dB insertion loss and 22dB inter-channel crosstalk. For the arrayed waveguides layout, we carefully design the radius profiles of the curves and the length of straight waveguides to minimize the systematic phase errors and the crosstalk induced, at the same time ensure the minimum total size. The overall size of the AWG is $910\times 680\ \mu m^2$.

3. RESULTS AND DISCUSSION

The device is fabricated by IMEC on silicon nitride- silicon nitride multi-project wafer (MPW) platform, which shows its great potential for large-scale photonic integrated circuits and integrated spectrometers for SD-OCT system. Microscope image of the device and the enlarged SEM images are shown in Fig.1.

The AWG is tested with broadband light from a superluminescent diode (SLD) and optical spectrum analyser. Fibre-chip grating couplers designed at 850nm are used to couple light into and out of the chip. The transmission spectrum is normalized to a short straight waveguide with input and output grating couplers as shown in Fig. 2 (a). The zoom-in view of the central channel (#20) compared with the simulation spectra is shown in Fig. 2 (b).

After normalizing out the coupling losses of the grating couplers, the insertion loss of the AWG was 0.6dB. This result is only about 0.15dB higher than the simulation results. The central channels show the best inter-channel crosstalk of -20dB, which is 2dB worse than the simulation results. The difference comes from the phase errors caused by the sidewall roughness and waveguide crosstalk. The channels at short and long wavelength side show higher crosstalk which is due to the sharp drop of the SLD output power below 835nm and the grating coupling efficiency drop over 885nm, as shown in Fig.2 (c), while the lowest power can be measured is limited by the noise floor of the optical spectrum analyser of -78dBm at 850nm. The operating bandwidth of the AWG is 60nm and the channel spacing is 1.5nm, which match well with the simulation results.

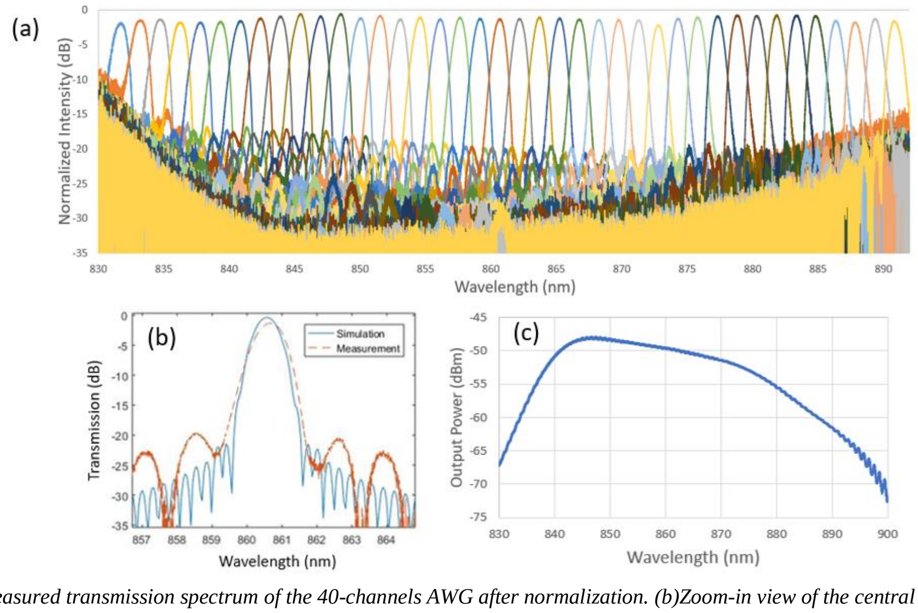

Fig. 2. (a) Measured transmission spectrum of the 40-channels AWG after normalization. (b)Zoom-in view of the central channel (#20) compared with the simulation spectrum. (c) Waveguide transmission with grating coupled in and out, used to normalize the AWG transmission spectrum, sharp power drops are shown below 835nm and over 885nm.

As a comparison, another AWG is also designed following the same design method while the waveguide width is changed to 560nm. We tested the AWG with the same experimental setup. The worst inter-channel crosstalk of the fabricated device was 13dB and the insertion loss also increases to 5dB. The degradation of the AWG performance is ascribed to the narrower width of arrayed waveguides. As the waveguide becomes narrower, the guiding mode in the waveguide has larger overlapping with the sidewall of the waveguide, thus suffering more from the sidewall roughness, which not only increases the scattering loss but also induces larger phase errors. On the other hand, the coupling between adjacent arrayed waveguides also increase for narrower waveguides because of the weaker mode confinement. For this reason, air cladding rather than SiO_2 cladding was used.

4. CONCLUSIONS

We propose and demonstrate an ultracompact 40-channels AWG on silicon nitride platform at 850nm with an overall size of $910\times 680\ \mu m^2$. The AWG, with an operating bandwidth of 60nm and channel spacing of 1.5nm, has an insertion loss of 0.6dB and inter-channel crosstalk of 20dB, which shows its great potential for large-scale photonic integrated circuits and ultracompact integrated spectrometers for SD-OCT system. A tunable laser with wider tuning range to below 830nm, and broadband fibre-chip coupling methods will be needed for further testing of the device. Higher spectral resolution and more channels can be achieved by combining this AWG with other integrated wavelength filters.

ACKNOWLEDGEMENTS

The author would like to thank IMEC for device fabrication in the BioPix program and funding from ITF grant ITS/433/17FX.

REFERENCES

[1] J. G. Fujimoto, W. Drexler: Introduction to OCT, in *Optical Coherence Tomography Technology and Applications*, W. Drexler, J. G. Fujimoto, Ed., New York: Springer-Verlag, 2008.
[2] Z. Yaqoob, J. Wu, C. Yang: Spectral domain optical coherence tomography: a better OCT imaging strategy, *Biotechniques*, vol. 39. pp. 6-13, Dec. 2005.
[3] B. I. Akca, *et al.*: Toward Spectral-Domain Optical Coherence Tomography on a Chip, *IEEE J. Sel. Top. Quantum Electron*, vol. 18. pp. 1223-1233, May/Jun. 2012.
[4] B. I. Akca, *et al.*: Miniature spectrometer and beam splitter for an optical coherence tomography on a silicon chip, *Opt. Express*, vol. 21. pp. 16648–16656, July 2013.
[5] M. E. J. van Velthoven, *et al.*: Recent developments in optical coherence tomography for imaging the retina, *Prog. Retina Eye Res*., vol. 26. pp. 57–77, Jan. 2007.
[6] M. K. Smit: New focusing and dispersive planar component based on an optical phased-array, *Electron. Lett*., vol. 24. pp. 385–386, Mar. 1988.
[7] V. D. Nguyen, *et al.*: Spectral domain optical coherence tomography imaging with an integrated optics spectrometer, *Opt. Lett*., vol. 36. pp. 1293–1295, Apr. 2011.
[8] D. Martens, *et al.*: Compact silicon nitride arrayed waveguide gratings for very near-infrared wavelengths, *IEEE Photon. Technol. Lett*., vol. 27. pp. 137–140, Jan. 2015.
[9] E. J. Stanton, *et al.*: Low-loss arrayed waveguide grating at 760 nm, *Opt. Lett.*, vol. 41. pp. 803-806, Apr. 2016.
[10] M. K. Smit, C. van Dam: PHASAR-based WDM-devices: principles, design and applications, *IEEE J. Select. Topics Quantum. Electron*, vol. 2. pp. 236–250, Jun. 1996.
[11] S. Pathak: Silicon Nano-Photonics based Arrayed Waveguide Gratings, PhD dissertation, Univ. of Ghent, 2014.