Design of 160-Channel Si_3N_4 based AWG-Spectrometer for Medical Applications

D. Seyringer[1], C. Burtscher[1], J. Edlinger[1], A. Maese-Novo[2], P. Muellner[2], R. Hainberger[2], J. Kraft[3], G. Koppitsch[3], G. Meinhardt[3] and M. Sagmeister[3]

[1]Research Centre for Microtechnology, Vorarlberg University of Applied Sciences, Hochschulstr. 1, 6850 Dornbirn, Austria, dana.seyringer@fhv.at
[2]AIT Austrian Institute of Technology GmbH, Giefingg. 4, 1210 Vienna, Austria
[3]ams AG, Tobelbader Strasse 30, 8141 Premstätten, Austria

ABSTRACT

We present the design of a 160-channel, 50-GHz Si_3N_4 based AWG-spectrometer applying our proprietary AWG-Parameters tool. For simulating the AWG layout, we used Optiwave's WDM PHASAR photonic tool. The simulated spectral response was evaluated applying our in-house developed AWG-Analyzer tool. The AWG was designed for TM-polarized light with a central wavelength of 850 nm. This design is based on the previous study of various AWG designs (8-channel, 100-GHz; 20-channel, 50-GHz; 40-channel, 50-GHz and 80-channel, 50-GHz AWGs), which were also technologically verified. The simulated results show satisfying optical properties of the designed AWG-spectrometer.

Keywords: arrayed waveguide gratings, AWG design, optical coherence tomography, OCT-spectrometer

1 INTRODUCTION

Low-index contrast silica-on-silicon based Arrayed Waveguide Gratings (AWGs) are considered an attractive Dense Wavelength Division Multiplexing (DWDM) solution because they represent a compact means of offering higher channel count technology, have good performance characteristics, and can be more cost-effective per channel than other methods [1].

High-index contrast AWGs, such as Silicon-On-Insulator based waveguide devices or devices employing silicon nitride waveguides, have a high refractive index contrast between core and cladding. With such high-index contrast waveguide material composition it is possible to guide light in waveguides with far smaller bending radius, which leads to a significant reduction in the size of AWGs by more than two orders of magnitude when compared to low-index contrast AWGs [2]. Such compact devices can easily be implemented on-chip and have already found applications in WDM systems and also in emerging applications such as optical sensors, devices for DNA diagnostics and optical spectrometers for infrared spectroscopy [3, 4].

The goal of the silicon nitride waveguide based 160-channel, 50-GHz AWG-spectrometer design reported in this paper is to take a significant step towards the integration of spectral domain optical coherence tomography (SD-OCT) system operating in a wavelength range of 800 nm to 900 nm and having 0.1 nm resolution. OCT is a contact-free imaging method, which has become important in ophthalmology to visualize the retina. In the course of the project, key-components of an SD-OCT system will be integrated on a single photonic chip employing CMOS compatible processes.

2 AWG DESIGN

An AWG consists of an array of waveguides called phased array (PA), two star couplers, and input/output waveguides as depicted in Fig. 1. The dimensions of the AWG are defined by the following parameters: minimum waveguide separation between input/output waveguides, *dx*, minimum waveguide separation in the phased array, *dd,* length of the coupler, *Lf,* and PA waveguide length increment, *dL*. The width *W* of the coupler is not a dominant parameter and can be freely changed. In order to minimize the loss of light capture in the arrayed waveguides, the number of arrayed waveguides *Na* should be sufficiently large. *Num* is a number of output waveguides (transmitting channels) that the AWG is designed for. All these parameters are essential to create the AWG layout [5, 6].

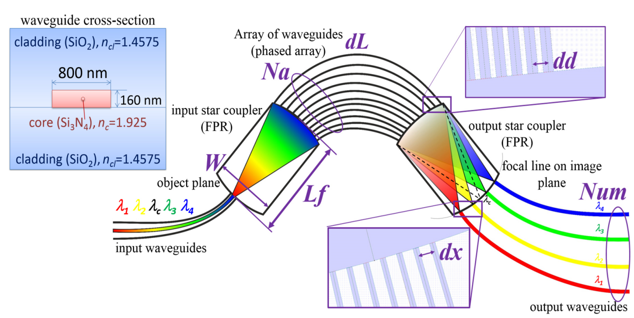

Figure 1: Topological structure and principle of AWG together with used waveguide structure.

It is important to note that all AWGs presented in this paper were designed for TM-polarized light with a central wavelength of 850 nm. A cross-section of the used waveguide geometry is shown in Fig. 1. The refractive index of the waveguide core is n_c = 1.925 and that of the cladding n_{cl} = 1.4575. The waveguide size is 800 nm x 160 nm.

For the parameter calculations, we used our in-house developed design tool AWG-Parameters [5], which is based on [6]. The tool was already applied in various AWG designs and experimentally well proven [5]. Figure 2 shows the user interface of this tool presenting the design of a Si_3N_4 based 8-channel, 100-GHz AWG.

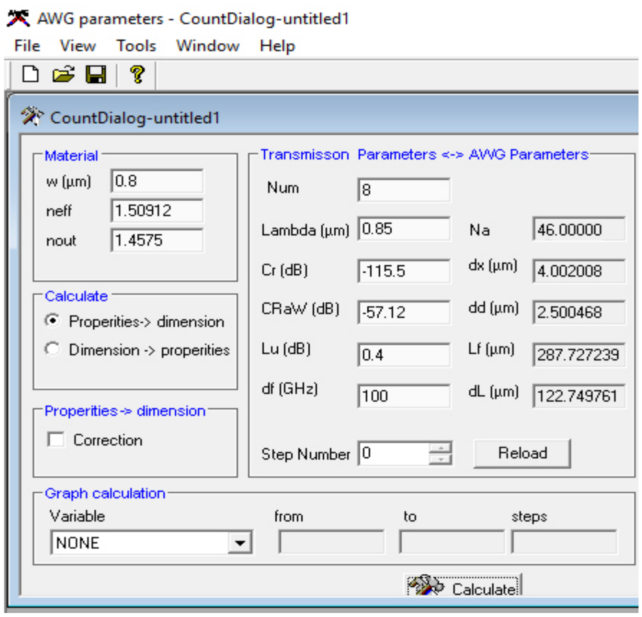

Figure 2: Design of 8-channel, 100-GHz AWG using AWG-Parameters tool.

The following set of input parameters is used for the calculation:

Technological parameters used to design waveguide structure ("Material" window in Fig. 2):

- Waveguide structure: width w = 0.8 µm.
- Effective index of the TM-like mode, $n_{eff,TM}$ = 1.50912.
- n_{out} is a refractive index of the cladding (n_{cl}) = 1.4575.

AWG type parameters ("Transmission Parameters ←→ AWG Parameters" window in Fig. 2):

- Number of output waveguides: *Num* = 8.
- AWG central wavelength (λ_c): *Lambda* (µm) = 0.85.
- Channel spacing (resolution): *df* (GHz) = 100.

Transmission parameters ("Transmission Parameters ←→ AWG Parameters" window in Fig. 2):

- Adjacent channel crosstalk between output waveguides: *Cr* (dB) = -115.5.
- Adjacent channel crosstalk between PA waveguides: *CRaW* (dB) = -57.12.
- Uniformity over all output channels (also called non-uniformity): *Lu* (dB) = 0.4.

When the "Calculate" button is pressed, the tool calculates all necessary dimensional parameters given in Fig. 1 and displays them in the "Transmission Parameters ←→ AWG Parameters" window (Fig. 2):

- Number of arrayed waveguides: *Na* = 46.
- Minimum waveguide separation between I/O waveguides: *dx* (µm) = 4.002008.
- Minimum waveguide separation between PA waveguides: *dd* (µm) = 2.500468.
- Coupler length: *Lf* (µm) = 287.727239.
- PA waveguide length difference: *dL* (µm) = 122.749761.

The calculated parameters (i.e. *dx, dd, Lf, dL, Na*) were then used as an input in the WDM PHASAR tool from Optiwave to create and to simulate the AWG structure. The output of the simulation is a spectral response (Fig. 3).

Minimum waveguide separation between PA waveguides (*dd*): One of the most important AWG performance parameters is insertion loss. This loss occurs due to reflection of light at the facets of interspaces between the individual PA waveguides. Light penetrating the cladding material at these facets is usually absorbed. This loss can be minimized by maintaining only a small distance between the arrayed waveguides (parameter *dd*) or by adding linear tapers; hence, it has to be considered already in the AWG design. Therefore, in the first designs (8-channel, 100-GHz AWGs) we studied the influence of the *dd* parameter on the AWG performance, in particular the losses. We varied this parameter from 2.5 µm (Design 1) to 2 µm (Design 2), 1.2 µm (Design 3) and 1 µm (Design 4) applying the AWG-Parameters tool. The design parameter *dx* was kept sufficiently large with *dx* = 4 µm (Fig. 2 shows Design 1). The parameters *dL* and *Lf* were calculated accordingly. From the simulations it is evident that decreasing the separation between PA waveguides leads to a strong reduction of the insertion loss, *IL* by about 4 dB (see simulated spectral responses in Fig. 3). In comparison, the linear tapers, applied in PA waveguides, reduced losses by less than 1 dB [7]. The proposed designs were fabricated and measured data confirm the simulated results, i.e., a loss reduction by more than 4 dB (see measured spectral responses in Fig. 3).

We would like to point out that the insertion loss uniformity parameter, *ILu* (difference between the highest and the lowest peaks in the spectrum) lies between 0.38 dB and 0.65 dB for all eight optical spectra (two examples are shown in Fig 3: Design 1 – simulated spectrum and in Design 4 – measured spectrum). This is in a strong correlation with the design value, *Lu* (dB) = 0.4 dB (input parameter in AWG-Parameters tool, see Fig. 2). Table 1 summarizes all insertion loss and non-uniformity values.

Based on this study and taking into account the waveguide width w = 0.8 µm as well as the fabrication limitations we fixed this parameter to dd = 1.2 µm.

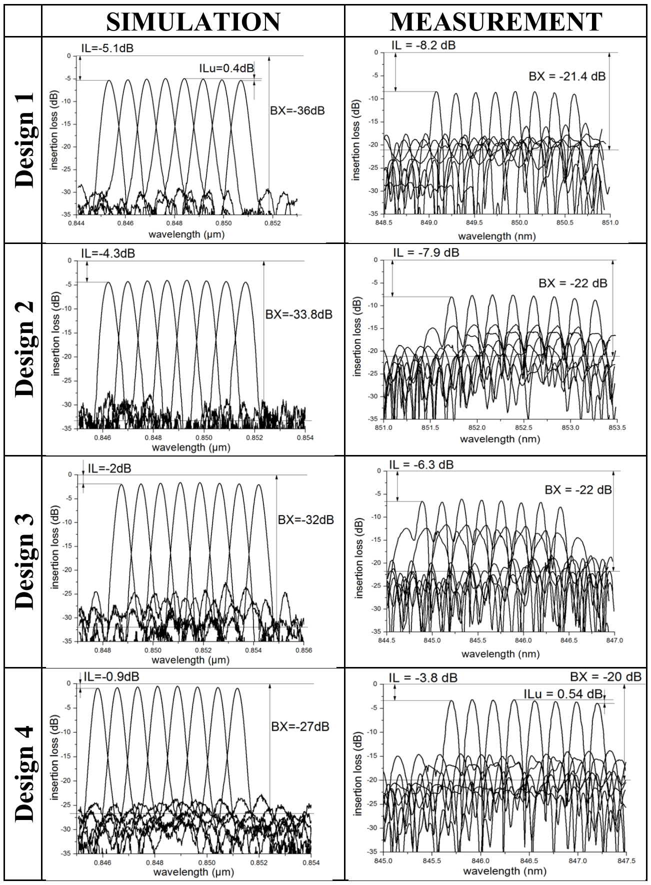

Figure 3: Simulated/measured spectral responses of four 8-channel, 100-GHz Si_3N_4 based AWGs.

8-ch, 100-GHz AWG	Design 1	Design 2	Design 3	Design 4
dd parameter	2.5 µm	2.0 µm	1.2 µm	1.0 µm
IL (simulation)	-5.1 dB	-4.3 dB	-2 dB	0.9 dB
IL (measurement)	-8.2 dB	-7.9 dB	-6.3 dB	-3.8 dB
ILu (simulation)	0.4 dB	0.4 dB	0.39 dB	0.41 dB
ILu (measurement)	0.53 dB	0.6 dB	0.65 dB	0.54 dB

Table 1: *IL* and *ILu* values calculated from simulated and measured optical spectra in Fig. 3.

Minimum waveguide separation between input/ output waveguides (*dx*): In the second step, it was necessary to fix the design parameter *dx*. This parameter has an impact on the crosstalk between adjacent output channels. For this purpose, four 20-channel, 50-GHz AWGs with different output waveguide separations were designed: *dx* = 2.5 µm, 3 µm, 3.5 µm and 4 µm and simulated. The simulations showed that there is some minimum waveguide separation *dx* necessary to keep the crosstalk between output channels sufficiently low (based on this study we fixed this parameter to *dx* = 3.5 µm) [8]. These AWGs were also fabricated and the measurement results confirm the simulations.

Number of output channels (*Num*): While the standard channel count AWGs (up to 40 output channels) feature very good optical properties and are relatively easy to design, increasing the channel counts leads to a rapid increase in the size of AWG-structure and this, in turn, causes the deterioration in optical performance such as higher insertion loss and, in particular, higher channel crosstalk [9]. This problem and its solution (for 80-channel, 50-GHz AWG) are described in detail in [10].

3 DESIGN OF 160-CHANNEL, 50-GHZ AWG-SPECTROMETER

Based on the previous study we designed a 160-channel, 50-GHz AWG-spectrometer, again using the AWG-Parameters tool. The parameters *dd* and *dx* were set as described in the previous section. The parameters *Lf* and *dL* were calculated accordingly. The AWG was designed to have a non-uniformity of *Lu* = 1 dB. The size of the AWG structure reached less than (1 x 1.5) cm^2 and the simulation took about four months.

The simulated spectral response was evaluated applying our in-house AWG-Analyzer tool [5]. This tool was originally developed to evaluate the spectral response of AWGs for telecom applications but can be used to analyze any AWG. The user interface of this tool is shown in Fig. 4. The simulated results from the PHASAR tool can be found in the “Raw-Data” window, the graphical representation of the data is shown in the “Diagram” window. There are nineteen calculated performance (transmission) parameters, listed in the “AWG Transmission Parameters” window. For our applications only few of these parameters are important: *Nr. Channels* = 160, *Ch. Spacing* = 50 GHz, *IL* (insertion loss) = -2.718 dB, *ILu* (insertion loss uniformity) = 1.551 dB, *BX* (background crosstalk) = -52.019 dB, *AX* (adjacent channel crosstalk) = 20.79 dB, *nAX* (non-adjacent channel crosstalk) = 31.948 dB. The definitions of these parameters can be found in [5]. The graphical representation of the parameters *IL* and *ILu* are shown in Fig. 5a. The parameter *AX* is shown in Fig. 5b where only 25 optical signals, in the middle of the spectrum, are presented.

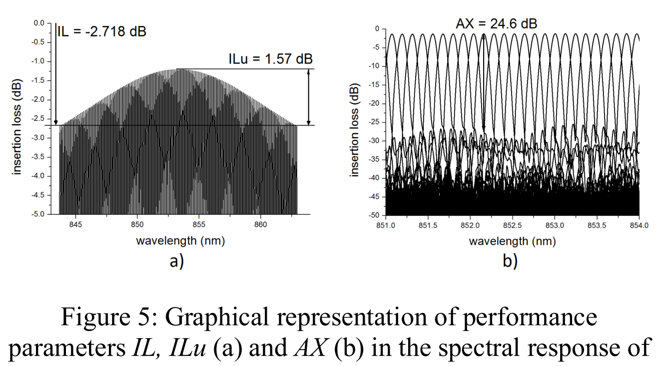

Figure 5: Graphical representation of performance parameters *IL, ILu* (a) and *AX* (b) in the spectral response of 160-channel, 50-GHz Si_3N_4 based AWG.

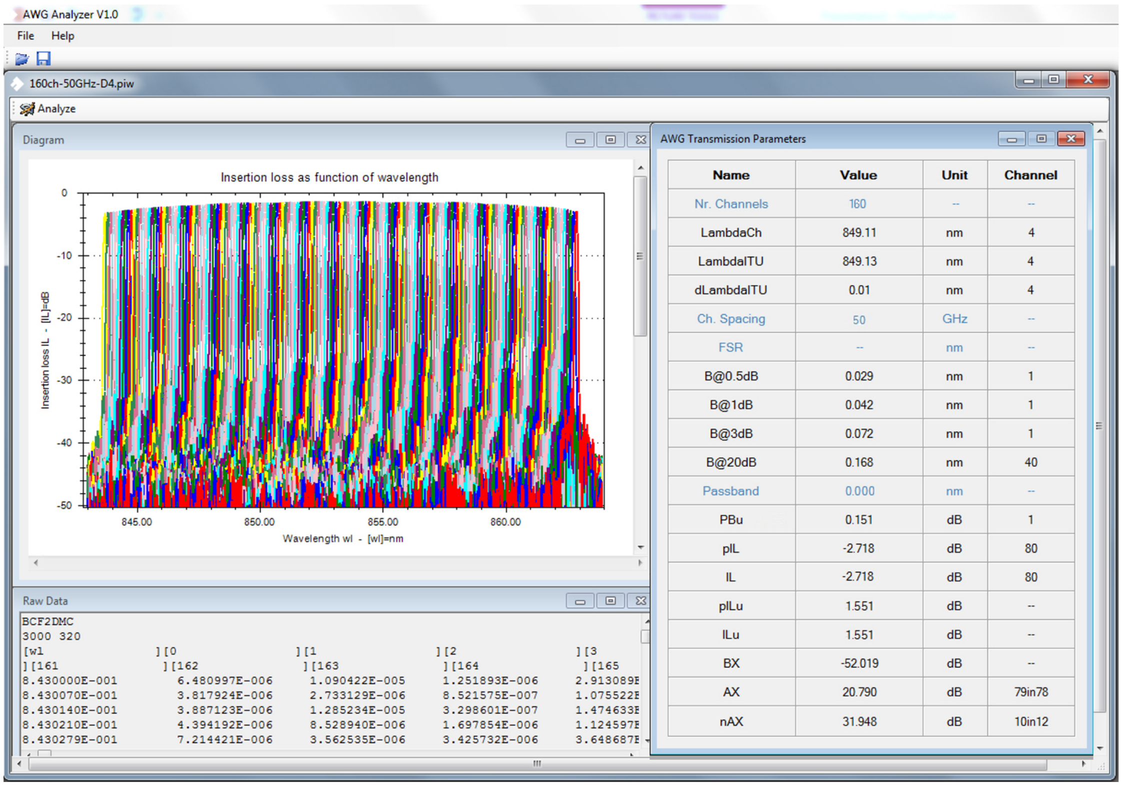

Figure 4: Calculation of performance parameters of 160-channel AWG–spectrometer applying AWG-Analyzer tool.

As can be seen from Fig. 5a, the simulated non-uniformity *ILu* is slightly higher (1.551 dB) compared to the design target (*Lu* = 1 dB). The insertion loss reached 2.718 dB, where 1.551 dB came from *ILu*. On the other hand, the optical channels are well separated from each other (Fig. 5b). A channel crosstalk of *AX* = 24.6 dB was calculated for that particular channel. The channel crosstalk parameter presented in Fig. 4 (*AX* = 20.79 dB) is the worst case calculated over all the 160 channels.

4 CONCLUSION

In this paper, we presented the design and simulation of a 160-channel, 50-GHz AWG-spectrometer. This design is based on the previous study of various AWG designs (8-channel, 100-GHz; 20-channel, 50-GHz; 40-channel, 50-GHz and 80-channel, 50-GHz AWGs), which were also technologically verified. The simulated results show satisfying optical properties of the designed AWG-spectrometer which will be later used in an SD-OCT system integrated on a single optical waveguide chip employing CMOS compatible processes.

ACKNOWLEDGEMENTS

This work was carried out in the framework of the project COHESION, no. 848588, funded by the Austrian Research Promotion Agency (FFG).

REFERENCES

[1] A. Kaneko et al., IEEE J. Sel. Topics Quantum Electron., vol. 5, p. 1227, 2002.
[2] L. Pavesi, D. J. Lockwood, Silicon Photonics, Springer, Berlin, 2004.
[3] J. T. Bradshaw et al., Anal. Chem., vol. 77, p. 29, 2005.
[4] D. Martens, et al., IEEE Photon. Technol. Lett., vol. 27 (2), p. 137, 2015.
[5] D. Seyringer, Arrayed waveguide gratings, in SPIE Spotlights - New e-book series, SPIE Press, P.O. Box 10, Bellingham, Washington 98227-0010 USA.
[6] M. K. Smit, et al., IEEE J. Sel. Topics Quantum Electron., vol. 2 (2), p. 236, 1996.
[7] D. Seyringer et al., "Design and Simulation of Si3N4 Based Arrayed Waveguide Gratings Applying AWG-Parameters Tool," In ICTON 2016, 978-1-5090-1466-8/16, We.C5.5., Trento, Italy.
[8] D. Seyringer et al., "Design and simulation of 20-channel, 50-GHz Si3N4 based arrayed waveguide grating applying AWG-Parameters tool," in Proc. SPIE 10106, Integrated Optics: Devices, Materials, and Technologies XXI, 101061L, 2017.
[9] K. Okamoto, "Planar lightwave circuits," in Fundamentals of Optical Waveguides, Academic Press, Chap. 9, 2000.
[10] D. Seyringer, et al., "Design and Optimization of High-Channel Si3N4 based AWGs for Medical Applications," PHOTOPTICS 2018, Funchal, Madeira, Portugal, 2018.