Si_3N_4 BASED 40-CH, 50-GHZ AWG FOR MEDICAL APPLICATIONS

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Received 26 April 2017; accepted 05 May 2017

1. Abstract

We present the design and simulation of 40-channel, 50-GHz Si_3N_4 based AWG. To calculate the input design parameters we used our proprietary AWG-Parameters tool. For the simulations of AWG layouts we used PHASAR photonics tool from Optiwave and RSoft tool from Synopsis. The simulated transmission characteristics were then evaluated. The AWG was designed for TM-polarized light with a central wavelength of 850 nm and will later be used in a photonic integrated circuit dedicated to medical diagnostic imaging applications.

2. Introduction

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 (SOI) based waveguide devices or devices based on Si_3N_4 material platform, use a high refractive index contrast between core and cladding. In such high index contrast material waveguide composition it is possible to guide light in waveguides with a 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 (Silica-on-Silicon (SoS) based waveguide devices). 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 [2,3]. In this paper we present the design and simulation of Si_3N_4 based 40-ch, 50-GHz AWG that will later be used in a photonic integrated chip in the use for medical applications.

3. AWG principle

An AWG consists of an array of waveguides (also called phased array, PA) and two star couplers (Fig. 1). One of the input waveguides launches the light consisting of multiple wavelengths λ_1 - λ_n into the input coupler which then distributes the light amongst an array of waveguides. The light subsequently propagates through the waveguides to the output coupler. The length of these waveguides is chosen such that the optical path length difference between adjacent waveguides dL equals an integer multiple of the central wavelength λ_c of the demultiplexer. For this wavelength, the fields in the individual arrayed waveguides will arrive at the input of the output coupler with equal phase, and the field distribution at the output of the input coupler will be reproduced at the input of the output coupler. In the output star coupler the light beams interfere constructively and converge at one single focal point on the focal line in the image plane. In this way, for the central wavelength λ_c the input field at the object plane of the input star coupler is transferred to the centre of the image plane of the output star coupler. If the wavelength is shifted to $\lambda_c \pm \Delta\lambda$ (i.e. λ_1, λ_2,..), there will be a phase change in the individual PA waveguides that increases linearly from the lower to the upper channel. As a result, the phase front at the input aperture of the output star coupler will be slightly tilted, causing the beam to be focused on a different position in the image plane. The positioning of the output waveguides at the focal points in the image plane allows the spatial separation of the different wavelengths [4].

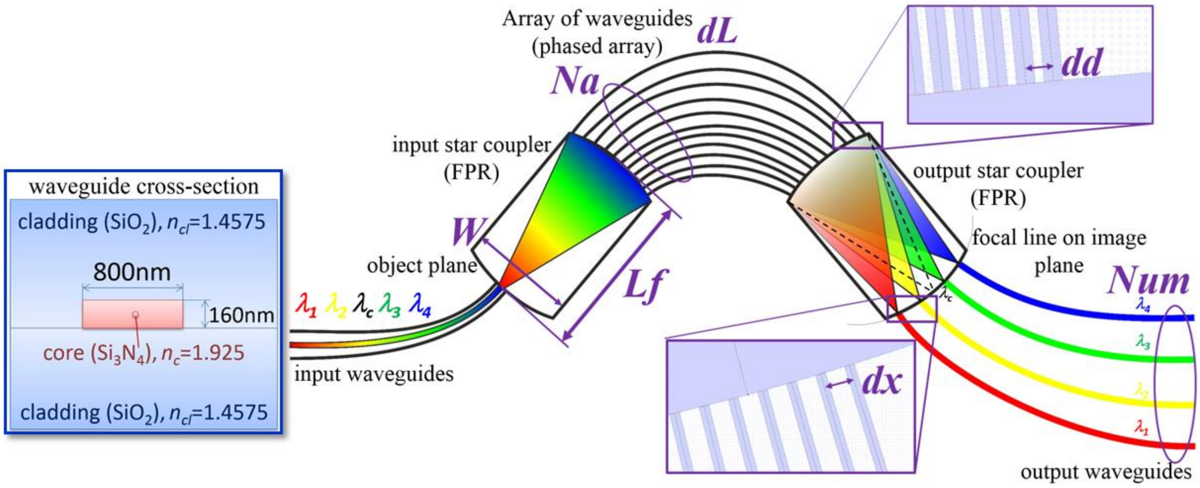


Fig.1: *Principle of an AWG with its design parameters and used waveguide cross-section.*

4. AWG design

The AWG design begins with the calculation of its dimensions, which are essential to create the AWG layout [5]. The dimensions of the structure are given by geometrical parameters, as shown in Fig. 1:

1. minimum waveguide separation between PA waveguides (parameter *dd*),
2. minimum waveguide separation between input/output waveguides (parameter *dx*),
3. length of the star coupler (parameter *Lf*), and
4. optical path length difference between adjacent waveguides in the phased array (parameter *dL*).

The width of the coupler *W* 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.

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 the 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 array waveguides (parameter *dd*) or by adding linear tapers; hence has to be considered already in the AWG design. Therefore in the first designs (8-channel, 100-GHz AWGs) we studied the influence of minimum waveguide separation between PA waveguides (*dd* design parameter) on AWG performance, mainly on the losses [6]. We varied this parameter starting from 1 μm to 1.2 μm, 2 μm and 2.5 μm. The design parameter *dx* was kept sufficiently large, *dx* = 4 μm. Parameters *dL* and *Lf* were accordingly calculated. The simulations were performed by three different photonic tools (PHASAR photonic tool from Optiwave Systems Inc [7], APSS from Apollo Photonics [8] and RSoft photonics tool from Synopsis [9]). To this purpose we created identical waveguide structures (as presented in Fig. 1 (left)) and AWG layouts and performed BPM simulations. For all simulations the same calculation conditions were used. Form all simulations is evident that decreasing the minimum waveguide separation between PA waveguides leads to a strong reduction of the insertion loss, *IL* by about 4 dB. In comparison, the linear tapers, which were applied in the PA waveguides, reduced losses by less than 1 dB. Based on this study and considering a waveguide width, *w* = 0.8 µm together with the fabrication limitations we fixed this parameter to *dd* = 1.2 µm.

Minimum waveguide separation between input/output waveguides (*dx*): In the second step it was necessary to fix the design parameter *dx*, i.e. the minimum waveguide separation between input/output waveguides. This parameter has an impact on the crosstalk between adjacent and non-adjacent transmitting channels. To 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 [10]. The simulations showed that there is some minimum waveguide separation *dx* necessary to keep the crosstalk between transmitting channels sufficiently low (in our AWG design with *dx* = 3.5 µm). At this separation, the output waveguides are positioned far enough from each other, to prevent the focusing of the power from selected channel into the neighbor output waveguides and vice versa. This implies that increasing this value the performance of the AWG did not change much (case of *dx* = 4 µm). If the waveguide separation is too small, the crosstalk between transmitting channels strongly increases. This is in particular the case of waveguide separation *dx* = 2.5 µm and partially *dx* = 3 µm, where the AWG spectral response consists of side-lobes inducing high channel crosstalk. Based on this study we fixed this parameter to *dx* = 3.5 µm.

5. Design and simulation of 40-channel, 50-GHz AWG

Based on the study described above we have designed 40-channel, 50-GHz AWG. To calculate the input design parameters we used our proprietary AWG-Parameters tool [11]. According to it the parameters are as follows:

1. minimum waveguide separation between PA waveguides: parameter *dd* = 1.2 µm,
2. minimum waveguide separation between input/output waveguides: parameter *dx* = 3.5 µm,
3. length of the star coupler: parameter *Lf* = 797.286 µm,
4. optical path length difference between PA adjacent waveguides: parameter *dL* = 37.286 µm.

All four calculated design parameters create the input for the commercial photonics design tools like PHASAR from Optiwave and RSoft from Synopsis. Figure 2 presents the layout of the designed AWG in PHASAR photonics tool.

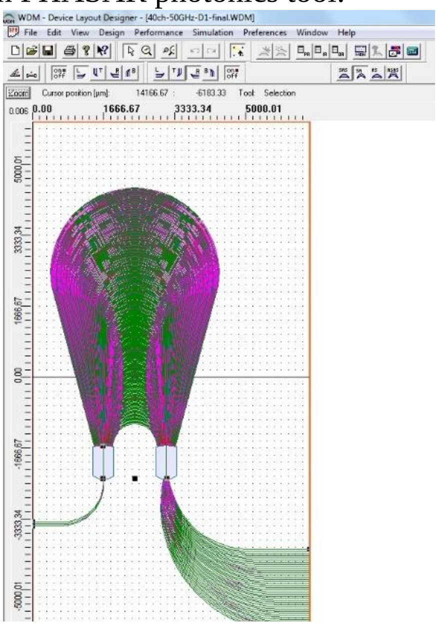
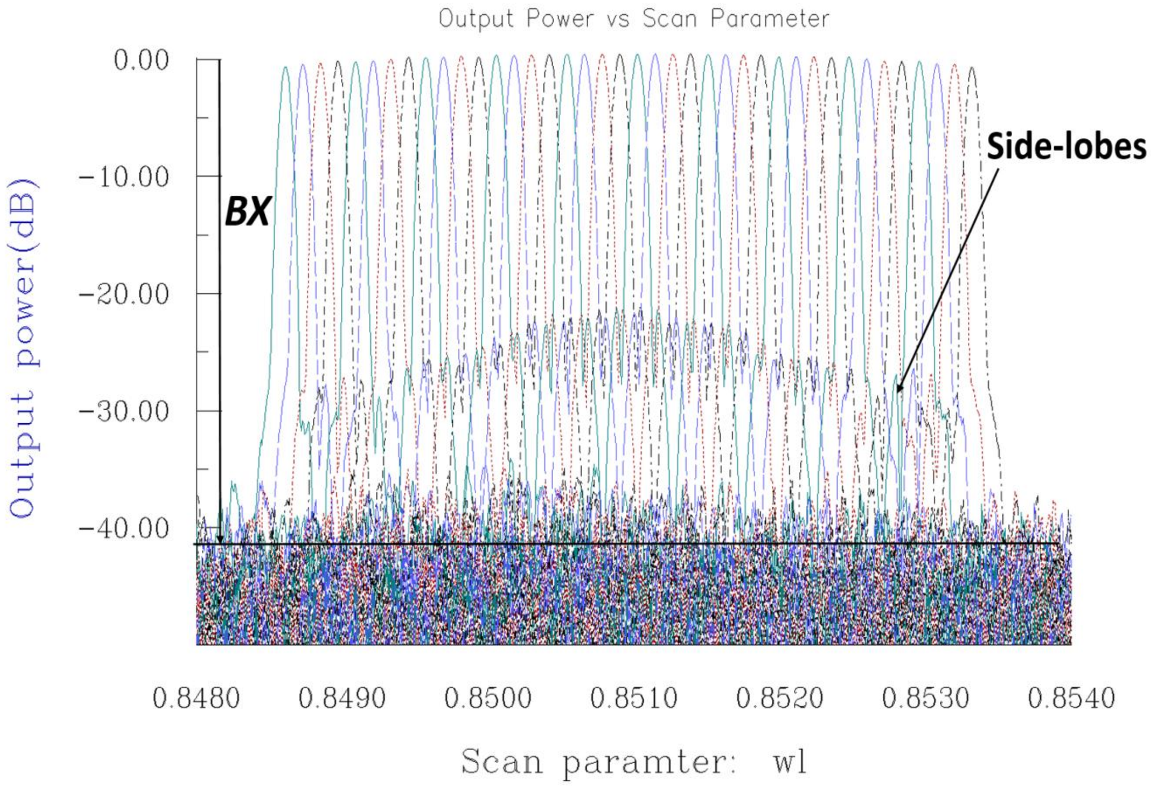
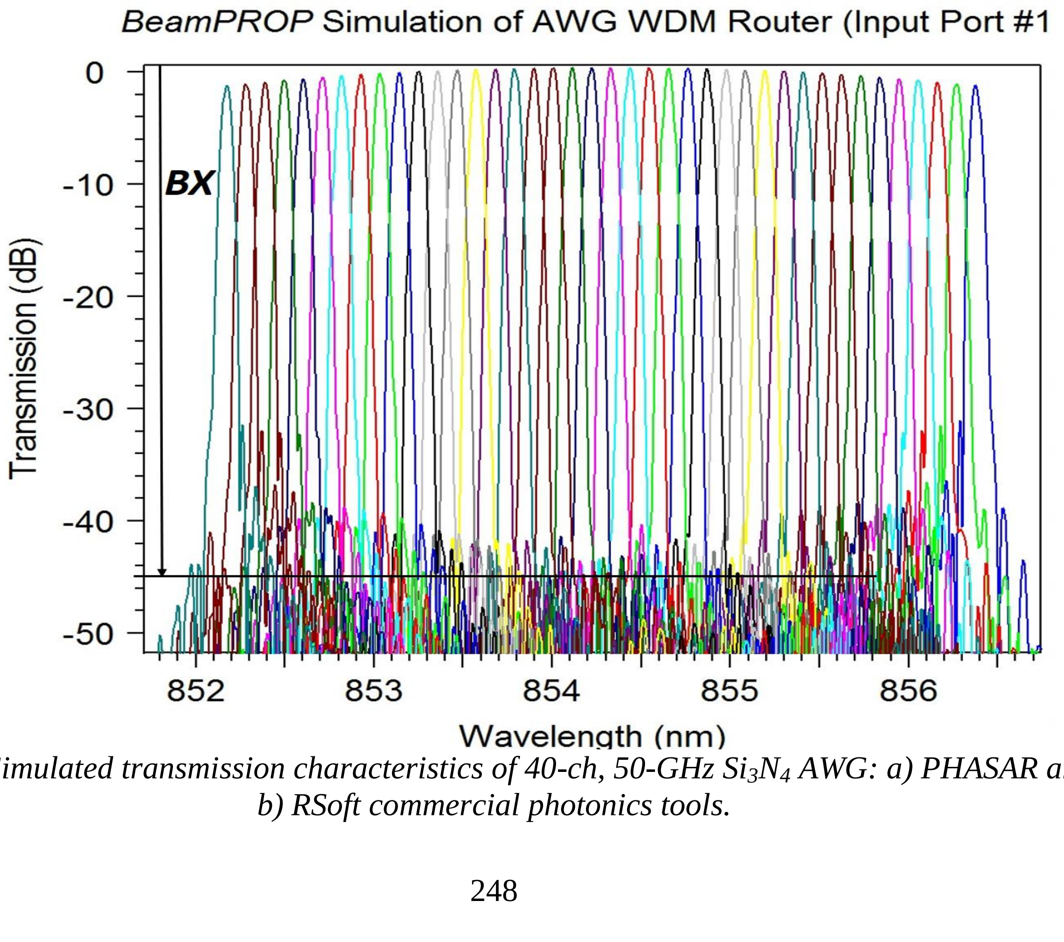


Fig. 2*: Layout of 40-channel, 50-GHz AWG designed in PHASAR photonics tool.*

The AWG structure was then simulated with both photonics tools keeping the same calculation conditions. The simulated spectral responses (so-called transmission characteristics) are shown in Fig. 3.

a)





b)

Fig. 3: *Simulated transmission characteristics of 40-ch, 50-GHz Si_3N_4 AWG: a) PHASAR and b) RSoft commercial photonics tools.*

6. Discussion of the results

From Fig. 3 is evident that the simulated transmission characteristics, achieved from RSoft photonics tool, feature superior optical properties. As can be seen, the transmitted optical signals are better separated from each other; without so-called side-lobes causing the higher crosstalk between transmitting channels, *AX* (as is the case of PHASAR characteristics, see Fig. 3a). The background crosstalk, *BX* is also slightly lower in RSoft transmission characteristics compared to PHASAR characteristics. On the other hand, the losses are nearly identical and very low in both simulated characteristics. There are no losses in the middle of the characteristics (the highest peaks) and there is about 1.2 dB loss at the lowest peaks. This loss is mainly a result of the non-uniformity i.e. difference between the highest and lowest peaks in the characteristics; so-called insertion loss uniformity, *ILu*. The discussed optical properties are also confirmed by the transmission parameters calculated from the transmission characteristics and summarized in Table 1.

Tab. 1. *Transmission parameters calculated from the simulated transmission characteristics depicted in Fig. 3.*

40-ch, 50-GHz AWG	Insertion loss, *IL*	Insertion loss uniformity, *ILu*	Channel crosstalk, *AX*	Background crosstalk, *BX*
PHASAR	-1.15 dB	1.12 dB	-22.17 dB	-42.32 dB
RSoft	-1.2 dB	1.105 dB	-33.86 dB	-44.89 dB

7. Conclusion

We presented a design of 40-ch, 50-GHz AWG which is based on the previous study of the design parameters in order to eliminate losses and crosstalk between the transmitted channels. The simulations showed that applying the optimized design parameters the insertion loss was suppressed nearly to zero and also the channel crosstalk was strongly reduced.

Acknowledgements

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

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