INTRODUCTION OF A NEW SOFTWARE TOOL TO DESIGN ARRAYED WAVEGUIDE GRATINGS.

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1. Introduction

A new software tool and its application in the design of optical multiplexers/demultiplexers based on arrayed waveguide gratings (AWG) is presented. The reason for this work is the fact that when designing AWGs a set of the geometrical parameters must be first calculated. These parameters are crucial for the AWG design. They create the input for AWG design tools like R-Soft, Apollo Photonics, C2V or Optiwave, offered commercially on the market. To this purpose the AWG-Parameters tool based on the paper [1] was developed, applied in the AWG design and also technologically well-proven.

2. AWG Functionality

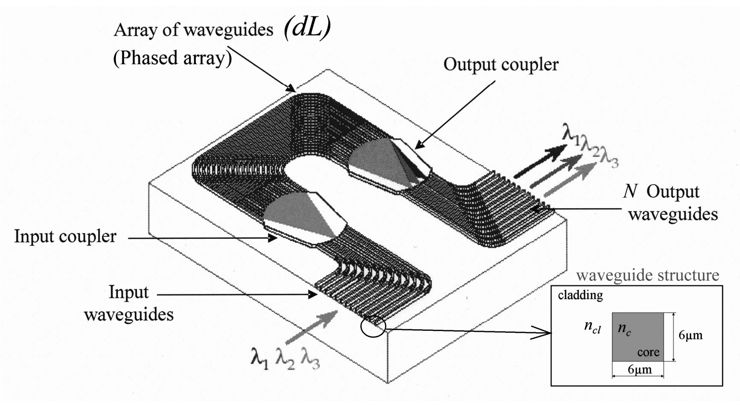


Fig.1: *Principle of an AWG.*

AWG consists of input/output waveguides, two couplers and an array of waveguides (called phased array) with the constant path-length difference *dL* as shown in Fig. 1. One of the input waveguides carries optical signal consisting of multiple wavelengths, λ_1 - λ_n. The input coupler distributes the light among the array of waveguides. Then the light propagates through the waveguides to the output coupler. The length of arrayed waveguides is chosen so that the optical path-length difference between adjacent waveguides, dL equals an integer multiple of AWG central wavelength λ_c of the demultiplexer. Linearly increasing dL will cause interference and diffraction when light mixes in the output coupler. As a result, each of the wavelengths λ_1–λ_n is focused into only one of the N output waveguides.

From technological point of view, the AWG is a planar waveguide structure with SiO_2 lower cladding oxide obtained using thermal oxidation of Si substrate (with refractive index n_{cl}). Chemical vapor deposition (CVD) process creates $GeSiO_2$ active layer (*core*) with higher refractive index (n_c). Lithography and dry etching define then AWG waveguide structure (Fig. 1). The growth of upper cladding with the same n_{cl} is the last technological step [2].

3. AWG Design

When designing AWGs three different sets of parameters have to be considered:

- Technological parameters: refractive indices of the core, n_c and cladding, n_{cl} and the size of waveguides creating input for the design of waveguide structure (see Fig. 1).
- AWG type parameters: the number of output waveguides (4, 8, 16 ...), channel spacing (100 GHz, 50 GHz, etc.) and AWG centre wavelength, λ_c (usually 1.55 µm).
- Any AWG is designed to achieve expected transmission parameters like uniformity over all the output channels, channel crosstalk and insertion loss. They define the performance of AWG and also determine its suitability for a particular application.

From above listed input design parameters the geometrical parameters have to be calculated. These create the input for AWG layout that will be then designed and simulated using commercial AWG tools (Fig. 2). The output of the design is AWG spectral response - AWG transmission characteristics shown in Fig. 2. They create the basis for the calculation of AWG transmission parameters. Since there is a strong relation between geometrical and input design parameters [1, 3] the geometrical parameters have to be calculated very carefully.

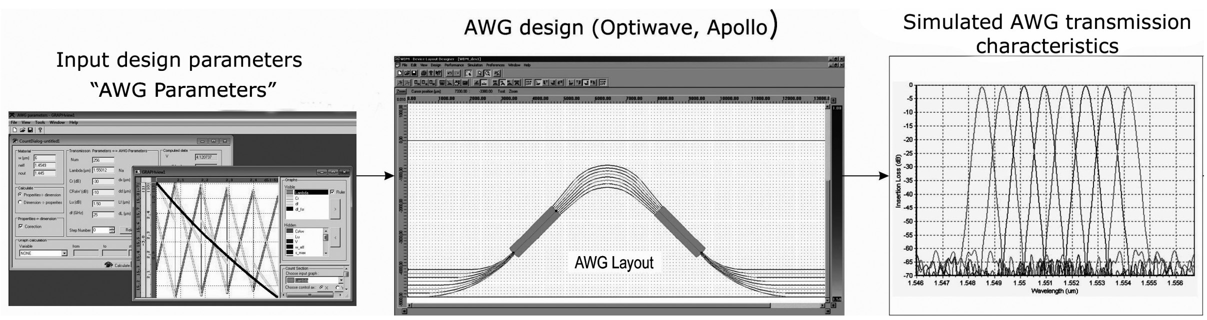


Fig.2: *Software tools used to design AWGs.*

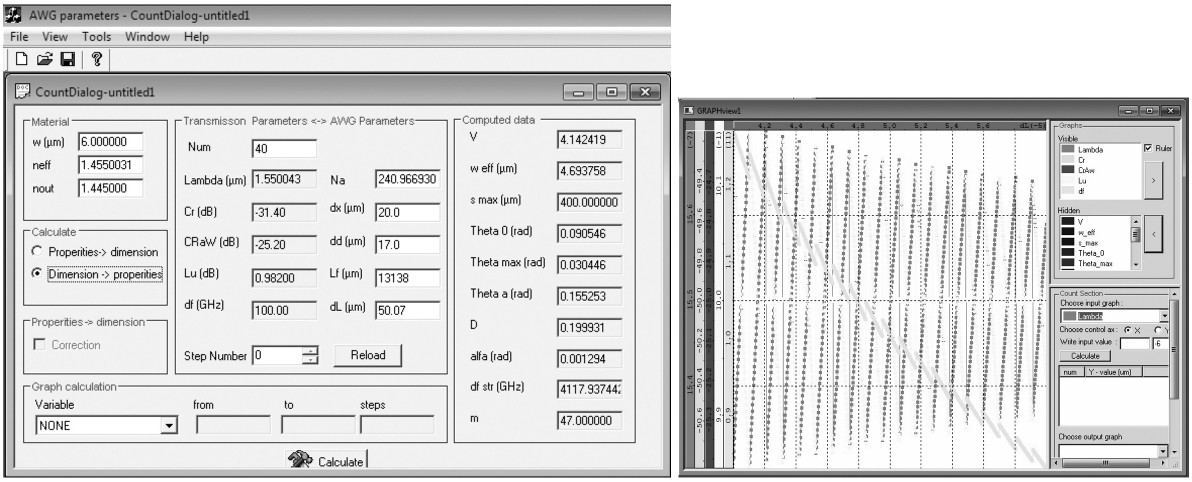


Fig. 3: *User interface of the "AWG-Parameters" tool.*

"AWG-Parameters" tool can easily solve this problem and this way strongly reduces the time needed for the AWG design. Figure 3 shows the user interface of this tool:

Technological parameters (see MATERIAL window in Fig. 3-left):

- Waveguide structure: waveguide width w (µm) = 6 µm
- Refractive indices: n_{eff} (effective index) = 1.455031, $n_{out} = n_{cl} = 1.445$

AWG type parameters (TRANSMISSION PARAMETERS ←→ AWG PARAMETERS):

- Number of output waveguides (channels): *Num* = 40
- AWG centre wavelength (λ_c): *Lambda* (µm) = 1.55 µm
- Channel spacing: *df* (GHz) = 100 GHz

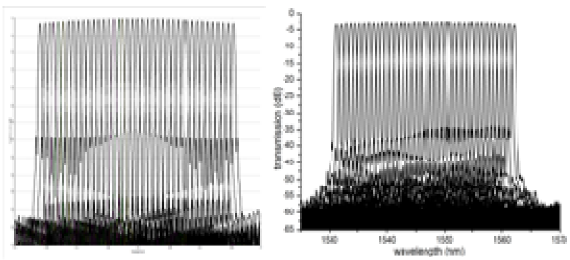
Transmission parameters (TRANSMISSION PARAMETERS ←→ AWG PARAMETERS):

- Adjacent channel crosstalk between output waveguides (channels): *Cr* (dB) =-31.4 dB
- Adjacent channel crosstalk between arrayed waveguides: *CRaW* (dB) = -25.2 dB
- Uniformity over all the output channels (also called non-uniformity): *Lu* = 0.982

Pressing "Calculate" the tool calculates all geometrical parameters in TRANSMISSION PARAMETERS ←→ AWG PARAMETERS window (see Figure 3):

- Number of arrayed waveguides: *Na* = 241
- Minimum waveguide separation at the input/output: *dx* (µm) = 20 µm
- Minimum waveguide separation in phased array: *dd* (µm) = 17 µm
- Coupler length: *Lf* (µm) = 13138 µm
- Length increment: *dL* (µm) = 50.07 µm

The tool also offers the scanning of the parameters and the possibility to display their behaviour together (each parameter having its own y-axis) in one graph (see Fig. 3-right).



Apollo simulation *Measurement*

	AWG-PARAM.	*SIMUL. PARAM.*	*MEASURED PARAM.*
N. of output ch.	40	40	40
λ_c *(μm)*	1.55012	1.55012	1.547
Non-uniformity	0.982 dB	1.32 dB	1.2 dB
Adj. crosstalk	-31.4 dB	-34 dB	-32 dB
Channel spacing	100 GHz	100 GHz	100 GHz

Fig. 4: *40-channel, 100 GHz AWG with its simulated and measured transmission characteristics. Table shows calculated, simulated and measured transmission parameters.*

4. Discussion and conclusion

The "AWG-Parameters" tool was used to calculate input parameters of various AWG designs. Fig. 4 shows the simulated and measured transmission characteristics of 40-channel 100 GHz AWG. The table on the right presents the transmission parameters. As shown in the column AWG-PARAMETERS the AWG was designed for AWG centre wavelength λ_c = 1.55012 μm, channel spacing = 100 GHz with N = 40 output channels. The theoretically calculated non-uniformity was 0.982 dB and adjacent channel crosstalk = -31.4 dB. Column SIMULATED PARAMETERS shows transmission parameters calculated from the simulated transmission characteristics (Apollo simulation). The column MEASURED PARAMETERS shows the transmission parameters calculated from the measured transmission characteristics of fabricated AWG. As can be seen very good agreement was achieved for the channel spacing (100 GHz) and adjacent channel crosstalk (about -32 dB). There is a week shift in the measured AWG centre wavelength (λ_c = 1.547 μm) in comparison to designed and simulated wavelength (1.55012 μm). The further calculations showed that the used AWG design tools do not calculate correctly the effective index causing this shift. Also theoretically calculated non-uniformity was lower (0.982 dB) in comparison to simulated (1.32 dB) and measured value (1.2 dB). The reason for this are the tapers used in the design. They alter the far field distribution at the end of the couplers determining the non-uniformity. This is also confirmed by very good agreement between the simulated (1.32 dB) and measured value (1.2 dB).

References:

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