Improvement in the performance of a passive optical AWG-WDM

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Abstract

In this paper AWG was optimized for its applications in WDM networks, wavelength selective switch as multiplexer/demultiplexer. With the new method of optimization proposed here, higher bandwidth and better crosstalk and insertion loss can be achieved .The procedure of optimization for finding the best parameters such as the waveguide separation at output circle, a new structure for Rowland circle and displacement of foci from the foci of the standard Rowland circle construction are presented and the results are discussed. As we know by increasing the waveguide separation at output circle, the bandwidth is reduced but the insertion loss of AWG is increased. For solving this problem we have changed the structure of Rowland circle from its standard, and we observed that this structure reduced the insertion loss effectively. We have used commercial software BeamPROP (Rsoft Design Group, Inc.) to design a silica-based 8 channel AWGs with the channel spacing of 1.6 nm and the central wavelength 1550 nm. The occupied area of the phased arrayed waveguide is $2.1\times1cm^2$, and the total device size is $3.6\times1.4cm^2$. The 3-dB bandwidth of AWG is $3.31\times10^{-4}\mu m$, the insertion loss of the side channels (1 and 8) is about 2.65 dB for this design which is about 3.77 dB for the one with the standard Rowland circle structure. Reduction of insertion loss about 1dB shows a good improvement in the performance of the device.

Key words: Array Waveguide Grating, Rowland circle, Wavelength Division Multiplexing

1. Introduction

Arrayed waveguide grating (AWG) is one of the most promising passive devices as optical multiplexer and demultiplexer in Wavelength Division Multiplexing (WDM) system due to its low insertion loss, high stability and low cost [1]. The cost of AWG is independent of the number of wavelengths (channels). Therefore, it is appropriate for metropolitan applications, where the effective-cost of very large number of wavelengths (channels) must be low. The other advantages of the AWG are: the possibility of fabricating full optic devices, the flexibility of selecting its channel number and the channel spacing [2].
Silica-based AWG wavelength multi/demultiplexers are now widely used in dense wavelength division multiplexing (DWDM) optical communication systems owing to their good optical characteristics, massproducibility and long-term reliability [3]. The AWG application range has now been extended beyond the backbone network to metro/local area networks. As their use has spread, the requirements as regards improving AWG performance have become stricter with a view to constructing higher capacity, more flexible and lower cost DWDM systems. Extensive studies have adopted various approaches to achieve further improvements in AWG characteristics [4].
In fact, the optical AWG-WDM is an important building block in the development of multiple channel integrated devices for routing and channel add-drop specially, it is very useful in DWDM interconnection systems [5].
Several methods have already been reported to improve the loss uniformity, namely, decreasing the loss difference between the center and marginal wavelength channels. Among all the methods, the design approaches using an star coupler with uniform power splitting proposed by Dragone et al. (1989) and Okamoto et al. (1991) are cited as pioneering researches [6], [7]. In a similar report, Sun et al. (2007) [8] have concluded that the band pass of the AWG-WDM reduces as the spacing of the receiver waveguides increases.
In this paper, we investigate the effect of change in the structure of AWG-WDM on the output parameters such as crosstalk, bandwidth and insertion loss. We optimize the displacement of Rowland foci (center of the Rowland circle) from the standard Rowland circle construction and also the waveguide separation at the input circle.

2. Theory

Fig. 1 shows the schematic layout of an AWG-WDM. The operation is understood as follows. When the beam propagating through the transmitter waveguide enters the free propagation region (FPR) it is no longer laterally confined and becomes divergent. On arriving at the input aperture the beam is coupled into the waveguide array and propagates through the individual array waveguides to the output aperture. The length of the array waveguides is chosen such that the optical path length difference between adjacent waveguides equals an integer multiple of the central wavelength of the demultiplexer. For this wavelength the fields in the individual waveguides will arrive at the output aperture with equal phase (apart from an integer multiple of 2π), and the field distribution at the input aperture will be reproduced at the output aperture. The divergent beam at the input aperture is thus transformed into a convergent one with equal amplitude and phase distribution, and an image of the input field at the object plane will be formed at the center of the image plane. The dispersion of the AWG is due to the linearly increasing length of the array waveguides, which will cause the phase change induced by a change in the wavelength to vary linearly along the output aperture. As a consequence, the outgoing beam will be tilted and the focal point will shift along the image plane. By placing receiver waveguides at proper positions along the image plane, spatial separation of the different wavelength channels is obtained [9].

The optical path length difference between adjacent waveguides (ΔL) must be equal to an integer multiple of the central wavelength in the waveguide:

$$\Delta L = \frac{m\,\lambda_c}{N_{guide}} \qquad (1)$$

Where m is an integer called grating order, λ_c is the central wavelength and N_{guide} is the effective refractive index of the array waveguide.

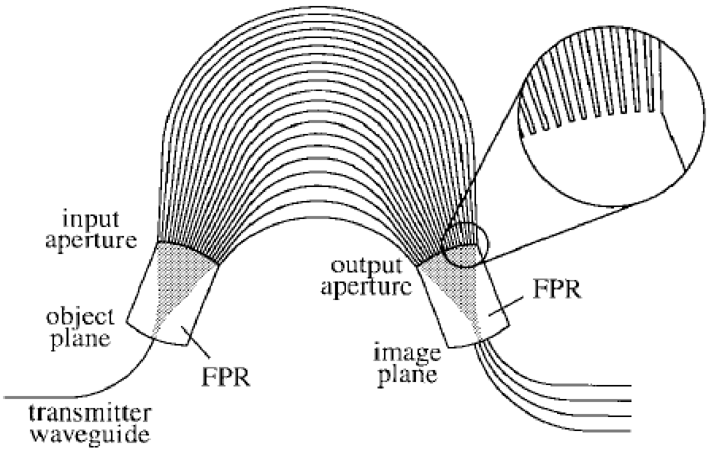


Fig 1: The schematic diagram of Array Waveguide Grating (AWG) [9].

The response of the phased array is periodical. After each change of 2π in Δϕ (phase difference) the field will be imaged at the same position. The period in the frequency domain is called the free spectral range (FSR). It is found as the frequency shift for which the phase shift Δϕ equals 2π:

$$\frac{2\pi\Delta f_{FSR}}{c} N_{guide} \Delta L = 2\pi \qquad (2)$$

From which we find:

$$\Delta f_{FSR} = \frac{c}{N_{guide}\Delta L} \qquad (3)$$

3. Design

In this work an 8×1 AWG-WDM is designed and simulated. The device includes the input/output ports, two star couplers and the phased arrayed waveguides. The path length

difference *ΔL* is calculated using the following equation (Eq.1) and is equal to 129μm. By calculation, the corresponding grating order at λ_C = 1.55μm is 121. A free spectral range of 15 nm (1.6THz) is implemented. This AWG is designed with a channel spacing of 1.6nm (200GHz) for DWDM applications. The occupied area of the phased arrayed waveguide is 2.1×1 cm^2, and the total device size is 3.6×1.4cm^2.
In our designed AWG, two focusing slab regions with arc length of 3471.6 μm and a phase array of 29 waveguides with the constant path length difference of 129μm between the neighboring waveguides [2].
Table 1 shows our calculated design parameters for 8×1 AWG MUX/DeMUX.
According to F.G. Sun [8], by increasing the receiver waveguide spacing, the bandwidth of the AWG will be reduced, so we appoint 25 for the waveguide separation at input circle, where it is confirmed by modeling results.

symbol	Quantity	Description
N_{ch}	8	Number of output waveguide
N_a	29	Number of waveguide in the phase array
L_{FPR}	3471.6 μm	Free propagation region length
N_{slab}	1.4532	Refractive index of free propagation region
N_{guide}	1.4512	effective index of the phase array waveguide
N_b	1.4482	Background refractive index
m	121	Grating order
λ_0	1.55 μm	Central wavelength
w	6 μm	Waveguide width
ΔL	129 μm	The length difference between adjacent phase array
L_M	36.99 mm	Middle phase array waveguide
D_i	25 μm	Waveguide separation at input circle
D_z	10 μm	Displacement of foci from standard Rowland circle
D_o	18.5 μm	Waveguide separation at output circle

Table 1.The design parameters of an 8 × 1 AWG-WDM

Rowland circle is used to design the slab structure as it can be seen in Fig. 2(a). According to theses designs, the structure is changed in the way that the two circles are not in each other (Fig. 2(b)).

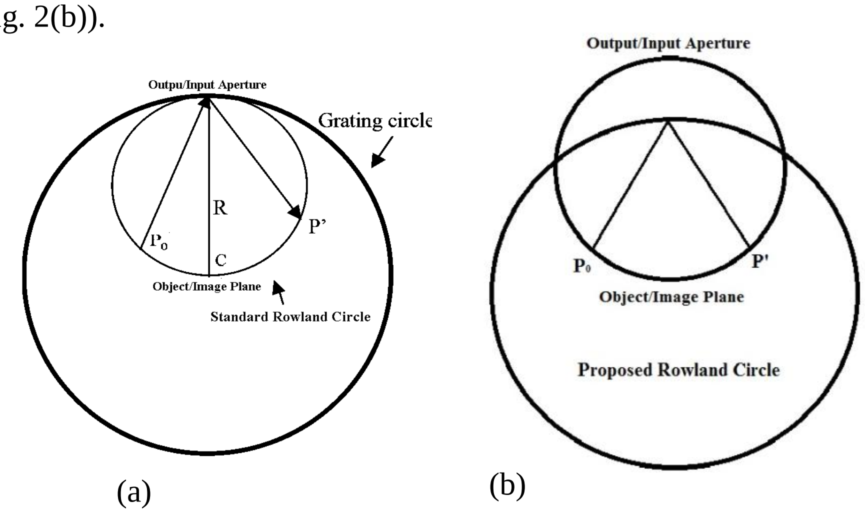


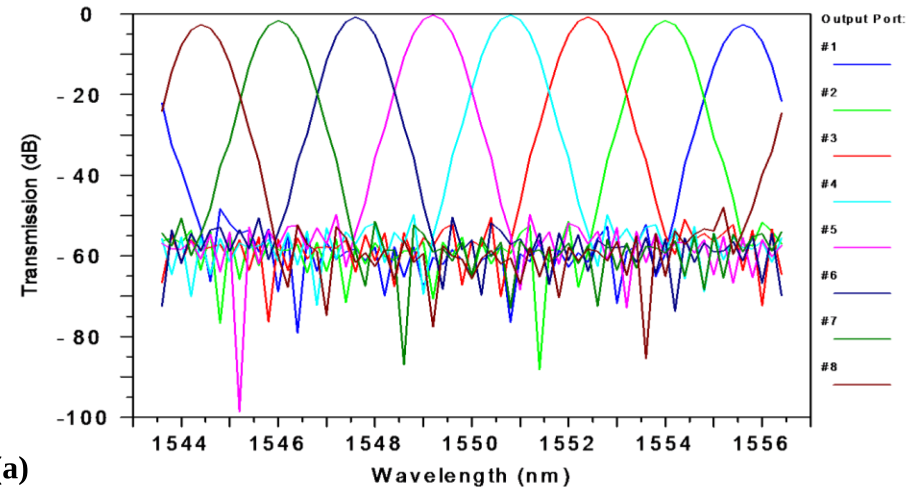
Fig 2: The Rowland structures, (a) old, and (b) new.

4. Results

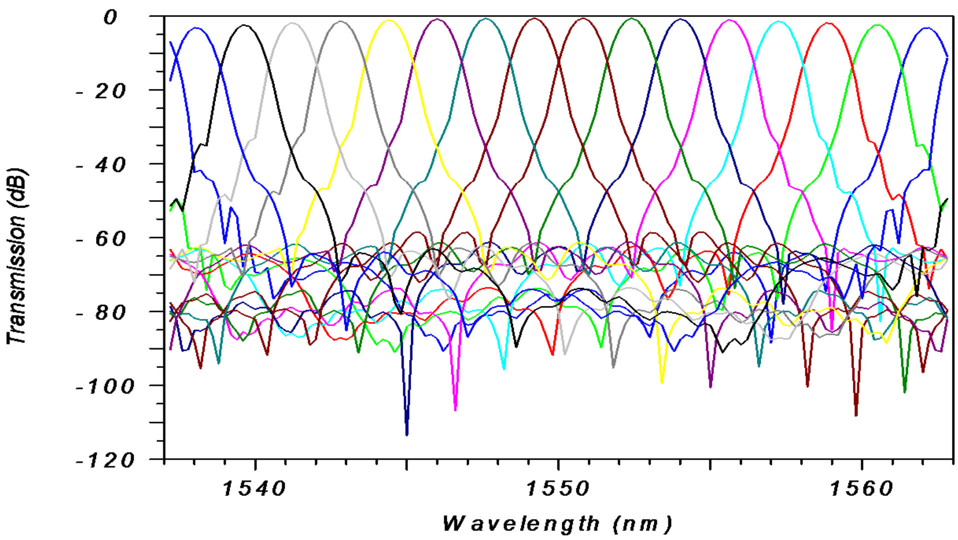
We used commercial software BeamPROP (Rsoft Design Group, Inc.) to design silica-based 8 channel AWGs at the central wavelength of 1550 nm and channel spacing of 1.6 nm. The computation method of the software is based on the finite difference beam propagation method.

Fig. 3 shows the simulation results of spectral response of the AWG-WDM with receiving waveguide spacing 25 µm, the displacement of foci from standard Rowland construction (D_z) is equal to 10µm and Rowland circle structure such as shown in Fig. 2(b). The 3-dB bandwidth of AWG is about 3.31×10^{-4} µm. The insertion loss at the end channels (1 and 8) is about 2.65 dB for this design which is about 3.77 dB for the one with the standard Rowland circle structure as shown in Fig. 2.

To indicate the influence of proposed Rowland circle on insertion loss, we also test it on 16 channels AWG-WDM. In a 16 channels AWG-WDM, without using this structure, the insertion loss is about 4.32 dB and with using the proposed Rowland circle, it's about 3.16 dB. This shows that, the new structure reduces the insertion loss significantly.



(a)



(b)

Fig 3: The simulation results of spectral response for the (a) 8, (b) 16 channels AWGs.

It can be seen in Fig. 4(a) that the bandwidth is improved by increasing D_i, whereas the crosstalk is increased. Due to the fact that the slab size increases with increasing D_i, and so the material loss increases, the best size of D_i considering the bandwidth and the crosstalk is equal to 25 µm. Also the modeling results (Fig. 4(a)) confirmed this value. The variation in bandwidth and crosstalk with D_z are shown the proper value for D_z is 10µm (Fig 4(b)).

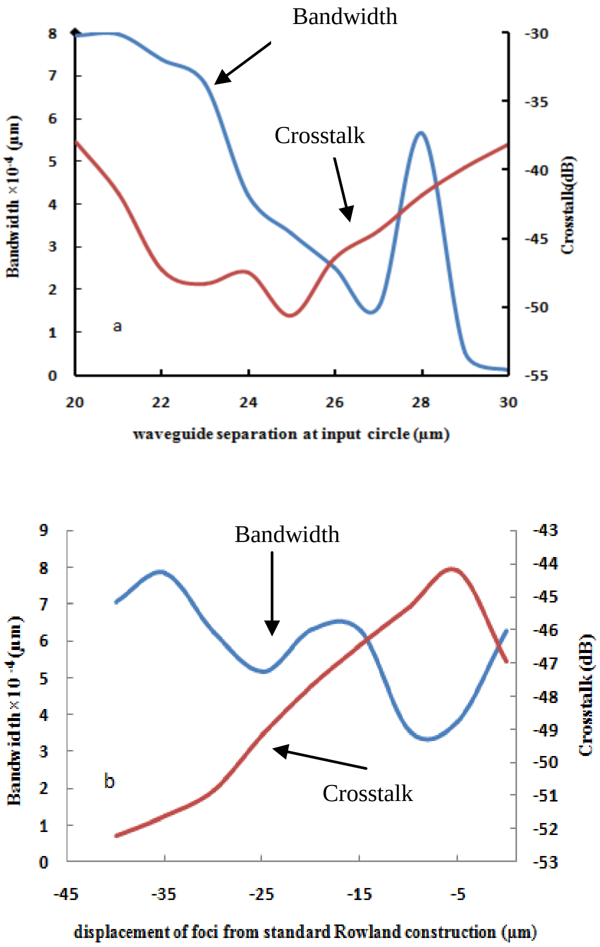


Fig 4: The Bandwidth and the crosstalk versus waveguide separation at input circle (a), displacement of foci from standard Rowland construction (b).

5. Conclusion

An 8×1 AWG-WDM with low insertion loss and appropriate bandwidth and crosstalk for WDM applications has been presented. Two designs of 8 and 16 channels AWG-WDM show that the new structure of Rowland circle has a good effect on insertion loss. It can be concluded that these two modifications in the FPR structure can be considered as a suitable candidate for the development of AWG for good performance of the DWDM applications.

6. References

1. W.H. Wong and E.Y.B. Pun, "Design and fabrication of a polymeric flat focal field arrayed waveguide grating", *Optics Express*, Vol. 13, 9982-9994, 2005.
2. Sahbudin Shaari and Mah Siew Kien, "Design implementation of up to 20 channel silica-based arrayed waveguide WDM", ICSE2000 Proceedings, Nov. 2000.
3. A. Himeno, K. Kato, and T. Miya, "Silica-based planar lightwave circuits," *IEEE J. Sel. Topics Quantum Electron.*, Vol. 4, No. 6, pp. 913–924, Nov./Dec. 1998.
4. C. R. Doerr and K. Okamoto, "Advances in silica planar lightwave circuits," *J. Lightwave Technol.*, Vol. 24, No. 12, pp. 4763–4789, Dec. 2006.
5. M. Kohtoku, H. Sanjoh, S. Oku, Y. Kadota, Y. Yoshikuni and Y. Shibata, "InP-based 64-channel arrayed waveguide grating with 50 GHz channel spacing and up to –20dB crosstalk," *Electron.Lett.*, Vol. 33, pp. 1786-1787 , 1997.
6. C. Dragone, C. H. Henry, I. P. Kaminow, and R. C. Kistler, "Efficient multichannel integrated optics star coupler on silicon," IEEE Photon. Technol. Lett., vol. 1, no. 8, pp. 479–489, 1989.
7. K. Okamoto, H. Takahashi, S. Suzuki, A. Sugita, and Y. Ohmori,"Design and fabrication of integrated 8×8 star coupler", Electron. Lett., vol. 27, pp. 774–775,1991.
8. F.G. Sun, G.Z. Xiao, Z.Y. Zhang, Z.G. Lu, "Modeling of arrayed waveguide grating for wavelength interrogation application", Optics Communications, Vol 271, 105–108, 2007.
9. Meint K. Smit, Cor van Dam,"PHASAR-Based WDM-Devices: Principles, Design and Applications", IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 2, NO. 2,236-250, 1996.