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Design of Arrayed Waveguide Grating (AWG) for DWDM/CWDM Applications Based on BCB Polymer

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Abstract: Conventional AWG structures based on BenzoCyclobutene (BCB 4024-40) polymer for DWDM/CWDM application are proposed. AWGs are designed on silica substrate with the polymer waveguide refractive index of 1.5556 and layer refractive index of 1.537. An objective of this system is to multiply an optical fiber's transmission capacity by sending signals simultaneously at multiple wavelengths over a single fiber. Two types of four channels AWG have been successfully designed and operate well in 1550 nm communication window at their desired frequency spacing. Although numbers of AWG structure have been designed and implemented, this work is considered to be the first that based on BCB polymer.

Keywords: Array waveguide grating, polymer waveguide, coarse WDM, dense WDM, wavelength division multiplexing.

1. INTRODUCTION

Wavelength-division multiplexing (WDM) is an approach that can exploit the huge opto-electronic bandwidth mismatch by requiring that each end-user's equipment operate only at electronic rate, but multiple WDM channels from different end-users may be multiplexed on the same fiber [1].

There are two alternatives for WDM metro networks: dense WDM (DWDM) and coarse WDM (CWDM). In high capacity environments, DWDM is used. In DWDM, the channel separation can be as small as 0.8 or 0.4 nm, for up to 80 optical channels at line rates up to 10 Gbps. DWDM technologies is very expensive, so its application to access networks is difficult. Instead, CWDM is merging as a robust and economical solution. The advantage of CWDM technology lies in its low-cost optical components. CWDM offers solutions for 850, 1,300, and 1,500 nm applications at 10 and 40 Gbps on up to 15 optical channels spaced 20 nm apart. Both CWDM and DWDM technology have their place in current and emerging metro-network infrastructure. When these technologies are used in combination with appropriate optical fibers, the economic benefits, which help to lower system costs, are significant [2].

Arrayed waveguide grating (AWG) is one of the most promising devices for multi/demultiplexer in WDM system because of its low insertion loss, high stability and low cost [3]. The arrayed waveguide grating was first proposed a solution to the WDM problem by Smith [4] in 1988 and was further developed in the following years by Takahashi [5] who reported the first devices operating in the long wavelength window. Dragone[6], extended the concept from 1 x N demultiplexers to N x N wavelength routers which play an important role in multi-wavelength network application.

The key advantage of the AWG is that its cost is not dependent on wavelength count as in the dielectric filter solution. Therefore it suits metropolitan applications that require the cost-effective of large wavelength counts. Other advantage of the AWG is the flexibility of selecting its channel number and channel spacing and, as a result, various kinds of AWG's can be fabricated in a similar manner [7].

Polymers offer excellent potential for the realization of low cost WDM components because they can be fabricated easily at low temperature on various kinds of substrates. Polymeric AWG multi/demultiplexers have attracted much attention due to its easy fabrication, low cost, and the potential of integration with other devices such as polymer thermo-optic switches for add-drop multiplexer applications[8]-[9].

Since BenzoCylobutene (BCB4024-40) polymer offers some advantages such as low birefringence, good thermal stability and low wavelength dispersion [10], it has been chosen as core material in this project. BCB polymer becomes an attractive material and has been used for fabrication of various optical devices, for instance, optical switching [11], polymeric optical waveguide [12] and multimode interference optical splitter [13].

In this paper, a proposed design of 4x4 channels conventional AWG which able to operate at central wavelength of 1.55 μm with channel spacing of 100 GHz and 1200 GHz based on BCB-4024 polymer with refractive index of 1.5556 will be presented.

2. BASIC OPERATION

Generally, AWG device serve as multiplexers, demultiplexers, filters and add-drop devices in optical WDM applications. Figure 1 shows a schematic layout of an AWG demultiplexer. The device consists of three main parts which are multiple input and output waveguides, two slab waveguide star couplers (or free propagation region (FPR)), connected by a dispersive waveguide array with the equal length difference between adjacent waveguides. The operation principle of the AWG multiplexer/demultiplexer is described as follows.

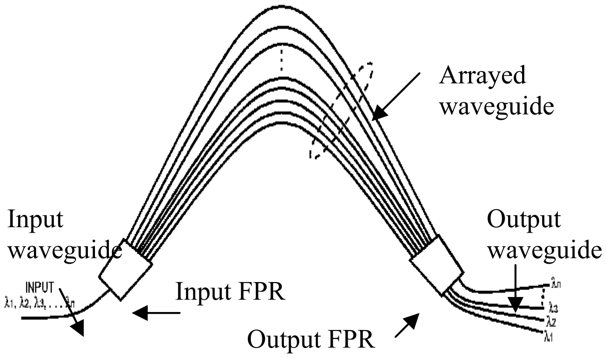

Figure 1. The structure of AWG demultiplexer

A DWDM/CWDM signal launched into one of the input waveguides will be diffracted in the first slab region and coupled into the arrayed waveguide by the first FPR. The length of the array waveguides has been designed such that the optical path length difference (ΔL) between adjacent array waveguides equals an integer (m) multiple of the central wavelength (λ_c) of the demultiplexer. As a consequence, the field distribution at the input aperture will be reproduced at the output aperture. Therefore, at this centre wavelength, the light focuses in the centre of the image plane (provided that the input waveguide is centred in the input plane) [14].

If the input wavelength is detuned from this central wavelength, phase changes occur in the array branches. Due to the constant path length difference between adjacent waveguides, this phase change increases linearly from the inner to outer array waveguides, which causes the wavefront to be tilted at the output aperture. Consequently, the focal point in the image plane is shifted away from the centre [9]. By placing receiver waveguides at proper positions along the image plane, spatial separation of the different wavelength channels is obtained.

3. DESIGN

The schematic layout of the 4x4 channel AWG for DWDM with central wavelength of 1.55 µm is shown in Figure 2. The position of input port and output port is symmetrically formed, which are identical. WDM_PHASAR design tool from Optiwave®, has been used to design two types of 4 channels AWG operating at central wavelength of 1.55 µm, with channel spacing of 0.8 nm and 9.6 nm, for DWDM and CWDM applications, respectively.

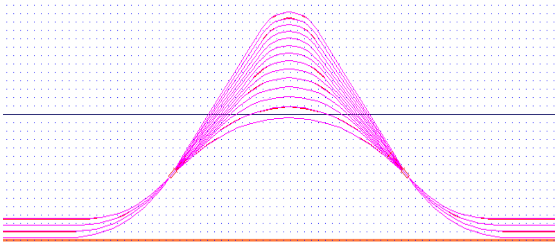

Figure 2. Graphical layout of 4x 4 channels AWG for DWDM

The refractive index of BCB polymer core at 1.55 µm is 1.5556 [15].The cladding is ORMOCER which is having a refractive index of 1.537, while the substrate is silicon which has been widely used in microelectronic and integrated circuit. ORMOCER (ORganically MOdified CERramics) is photopatternable inorganic-organic copolymers with negative resist behaviour [16]. The core size is 3 µm x 4 µm with buried type waveguide, as depicted in Figure 3. The port separation of input/output is designed to be 250 µm with 100 µm connection offset for pigtailing to fiber ribbon.

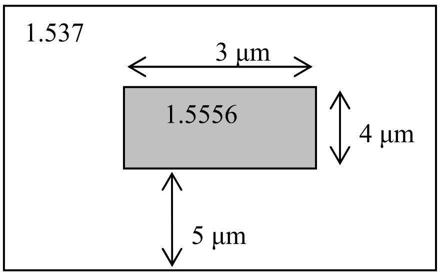

Figure 3. Waveguide structure

All design parameters are listed in Table 1 and Table 2 for AWG, central wavelength of 1.55 µm with channel spacing of 100 GHz and 1200 GHz, respectively. In the design, the refractive index contrast between core and cladding is quite large (~1.2%), which results in small bending radius and contributes to small chip size. However, the coupling loss between waveguide and fiber that result from mode-field mismatch increases. The total device size for AWG with 100 GHz spacing is 21.5 x 10 mm^2 and 17.8 x 5 mm^2 for AWG with 1200 GHz spacing. This difference is due to path length increment in AWG with 100GHz spacing is greater than AWG with 1200GHz spacing with same orientation angle.

Table 1. Design parameters for AWG with 0.8 nm channel spacing

Parameter	Value
Centre wavelength	1.55 um
Channel spacing	0.8 nm (100 GHz)
Diffraction Order	392
Path length different, ΔL	392.895 µm
No. of Arrayed waveguide	14
Effective index core	1.553210
FRP length	425.9 µm
Free Spectral Range	491.466 GHz

Table 2. Design parameters for AWG with 9.6 nm channel spacing

Parameter	Value
Centre wavelength	1.55 μm
Channel spacing	9.6 nm (1200 GHz)
Diffraction Order	33
Path length different, ΔL	33.075 μm
No. of Arrayed waveguide	14
Effective index core	1.553210
FRP length	425.9 μm
Free Spectral Range	5937.61 GHz

4. RESULTS AND DISCUSSION

The simulation result of AWG with channel spacing of 0.8 nm is shown in Figure 4. It shows the output distribution of the 4 channel output waveguides. The output channels are at wavelengths 1549.04 nm (λ1), 1549.872 nm (λ2), 1550.704 nm (λ3) and 1551.360 nm (λ4) respectively, which indicate the simulated channel spacing of 0.832 nm. Thus, output wavelength for each channel followed ITU specification, even it is slightly shifted 0.032 nm which is too small and can be neglected. However, the maximum insertion loss of 5.04 dB is at channel 4 and the minimum insertion loss of 3.88 dB is at channel 2. The crosstalk is less than -32.77 dB.

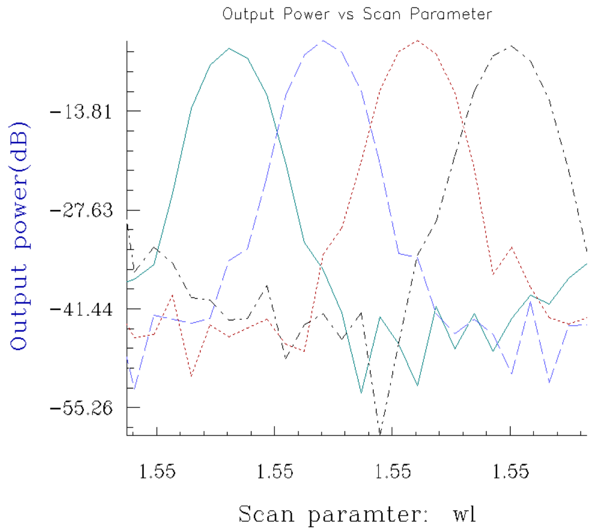

Figure 4: Output spectral responses of 4 channel AWG with 100 GHz channel spacing

Table 3 shows the computed output parameters of AWG with 0.8 nm channel spacing. These values have been computed at bandwidth level of -3 dB. The bandwidth level is used as the reference to define the bandwidths.

Table 3. Output Statistic for 4 channel AWG (100 GHZ)

Channel	Amplitude	Width (nm)	Crosstalk	Spacing (nm)
1	-4.736862	0.223	-32.771	0.832
2	-3.881419	0.091	-33.9052	0.832
3	-3.973235	0.082	-33.7722	0.832
4	-5.039440	0.146	-34.7470	

For AWG with channel spacing of 9.6 nm, the simulation result is shown in Figure 5. The four output wavelengths λ1, λ2, λ3 and λ4 are at 1542 nm, 1552 nm, 1562 nm and 1572 nm, respectively. Result for channel spacing is 10 nm which is slightly different from the design input parameter, which is 9.6 nm. Meanwhile, the maximum insertion loss of 6.63 dB is at channel 1 and the minimum insertion loss of 5.30 dB is at channel 3. The crosstalk is less than -23 dB.

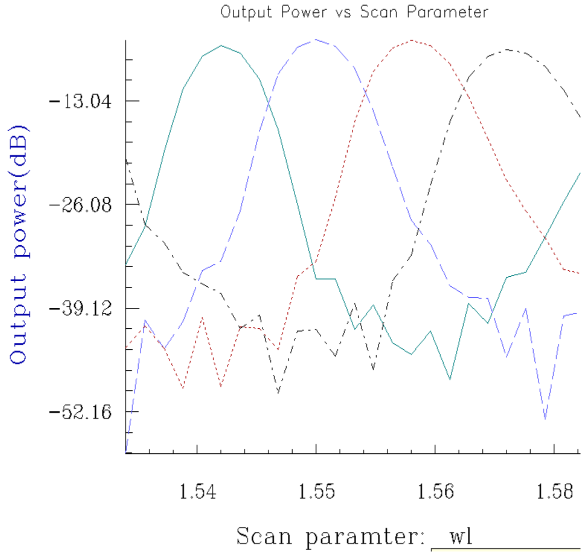

Figure 5. Output spectral responses of 4 channel AWG with 1200 GHz channel spacing

Table 4 shows the computed output parameters of AWG with 9.6 nm channel spacing. These values have been computed at bandwidth level of -3dB. The value for channel spacing obtained is 10 nm which is in the range of CWDM applications..According to the simulation results, we found out that these AWGs can work properly in DWDM and CWDM system.

Table 4. Output Statistic for 4 channel AWG (1200 GHZ)

Channel	Amplitude	Width (nm)	Crosstalk	Spacing (nm)
1	-6.63012	8.375	-23.0211	10.0
2	-5.47930	5.517	-28.0963	10.0
3	-5.29761	4.677	-33.2526	10.0
4	-6.04558	4.476	-33.2891	

5. PERFORMANCE COMPARISON

Development of AWG polymer multiplexer has become interest to many researchers. The first polymer AWG demonstrated by Hida *et al* [17] applying deuterated fluoro-methacrylate (d-PFMA) on silicone substrate. However this AWG only operated at 1300 nm window with some polarization dependence as small as 0.03 nm. Watanabe *et al* [18] reported 16 channels polymeric AWG operated at 1550 nm was realized using silicone resin waveguide. This AWG multiplexer has an insertion loss in the range of 9 to 13 dB, a crosstalk less than -20 dB and a low polarization dependent wavelength shift.

Leo [19] demonstrated 2 x 8 AWG polymer based on CWDM (20 nm) at centre wavelength of 1520 nm with total device size of 23 mm x 2.5 mm. The insertion loss and crosstalk are found to be around 7 dB and -30 dB, respectively. On the other hand, Razali [20] proposed 4 x 4 AWG polymer with 0.8 nm (DWDM) spacing operated at centre wavelength of 1570 nm. The device has insertion loss of 3 dB and crosstalk level less than -30 dB. The device size is 31 mm x 9 mm.

In this paper, the proposed designs are 4 x 4 AWGs polymer operated at central wavelength of 1550 nm with channel spacing of 0.8 nm and 9.6 nm. It is observed that the insertion losses of the corresponding channel spacing are -5 dB and -6 dB, respectively and the crosstalk level are -33 dB and -23 dB, respectively. The total device size is 21.5 mm x 10 mm for 0.8 nm spacing and 17.8 mm x 5 mm for 9.6 nm spacing. Inevitably, this shows that the AWGs for CWDM and DWDM application can be realized by utilizing BCB 4024-40 polymer as the guiding material.

6. CONCLUSION

AWGs based on BCB polymer for applications in DWDM/CWDM have been presented. Two designs of four channels AWG with crosstalk level below-32 dB and -23 dB have been demonstrated to operate in 1550 nm communication window for DWDM and CWDM application. It can be concluded that the BCB polymer can be considered as a suitable candidate for the development of AWG as it shows good performance for DWDM and CWDM applications.

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