

A CWDM/DWDM arrayed waveguide grating based on photodefinable polymer

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New design of conventional AWG structures for CWDM/DWDM application based on photodefinable BenzoCyclobutene (BCB 4024-40) polymer is presented. The devices are designed on BK7 glass substrate and thin layer of SiO₂ as cover and operated at 1550 nm window. The crosstalk level for CWDM_AWG is simulated to be less than -23 dB while the value is less than -33 dB for DWDM_AWG. The insertion loss is better than 5 dB and 6 dB for CWDM_AWG and DWDM_AWG, respectively. Meanwhile, the device size has been significantly reduced with recorded size of 21.5 mm × 10 mm and 17.8 mm × 5 mm for DWDM_AWG and CWDM_AWG, respectively. Although numbers of conventional AWG structures have been designed and implemented, this work is considered to be the first based on BCB polymer.

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1. Introduction

Wavelength-division multiplexing (WDM) plays a vital role in high capacity optical communication. It is the most prominent technology that provides multiple channel/wavelength multiplexing (combining) and demultiplexing (separating) on the same fiber which further maximize the fiber's information carrying capacity. Arrayed waveguide grating (AWG) is one of the most promising devices for (de)multiplexing in WDM system because of its low insertion loss, high stability and low cost [1]. Apart from that, it suits the costly large wavelength counts of metropolitan application, as it is independent of the number of multiplexed wavelengths. Furthermore, various kinds of AWGs can be fabricated in a similar manner due to the flexibility of selecting the channel number and spacing [2].

The concept of AWG was first proposed as a solution to the WDM problem by Smit [3] in 1988 and was further improved and developed by other researchers to cater for the high capacity and high speed optical WDM network. In view of the WDM network, currently there are two alternatives that emerge in current and future network infrastructure: dense WDM (DWDM) and coarse WDM (CWDM). In DWDM, the channel separation can be as small as 0.8 nm, for up to 80 optical channels at line rates up to 10 Gbps. Meanwhile, for CWDM technology, it offers solutions for 0.85, 1.31, and 1.55 μm applications at 10 and 40 Gbps on up to 15 optical channels spaced 20 nm apart. Although DWDM technology is meant for very high capacity WDM network, the high operating cost set the barrier for its implementation. Instead, the CWDM is emerging as a robust and economical solution due to its low cost optical components.

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 [4][5]. BenzoCyclobutene (BCB 4024-40), a product of DowTM, is a photodefinable polymer and is commonly used for board-level interconnects. The BCB 4024-40 polymer offers some advantages such as low birefringence, good thermal stability and low wavelength dispersion [6]. Due to this, BCB polymer becomes an attractive material and has been used for fabrication of various optical devices for instance splitter [7], cross coupler [8] and coarse wavelength demultiplexer [9].

In this paper, we report on two proposed designs of 4×4 channels conventional AWG which are able to operate at central wavelength of 1.55 μm with channel spacing of 100 GHz and 1200 GHz based on BCB-4024 polymer to cater for DWDM and CWDM applications, respectively. Prominently, the idea is to exhibit the ability of photodefinable type of polymer to be applied as the core material in future AWG development which will further produce low cost AWG device at tolerable performance for current and future requirement of optical network.

2. Device design

The schematic layout of the 4×4 channel AWG for DWDM with central wavelength 1.55 μm is shown in Fig. 1. 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 $1.55 \mu\text{m}$, with channel spacing of 0.8 nm and 9.6 nm , for DWDM_AWG and CWDM_AWG applications, respectively.

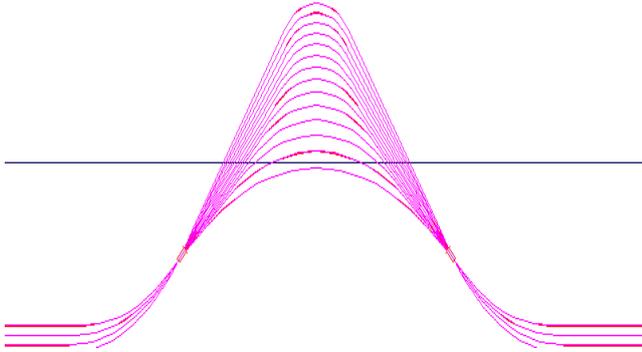


Fig. 1. Graphical layout of 4×4 channels AWG.

In our design, we consider an AWG structure based on a ridge waveguide of BCB 4024-40 polymer on BK7 glass as a substrate and a thin layer of SiO_2 as upper cladding. The polymer refractive index is taken to be 1.5556 , based on the measurement described in our previous work [7]. In order to allow only single mode propagation, the core size is calculated to have a dimension of $3 \mu\text{m} \times 4 \mu\text{m}$, as depicted in Fig. 2. The port separation of input/output is designed to be $250 \mu\text{m}$ with $100 \mu\text{m}$ connection offset for pigtailing to fiber ribbon.

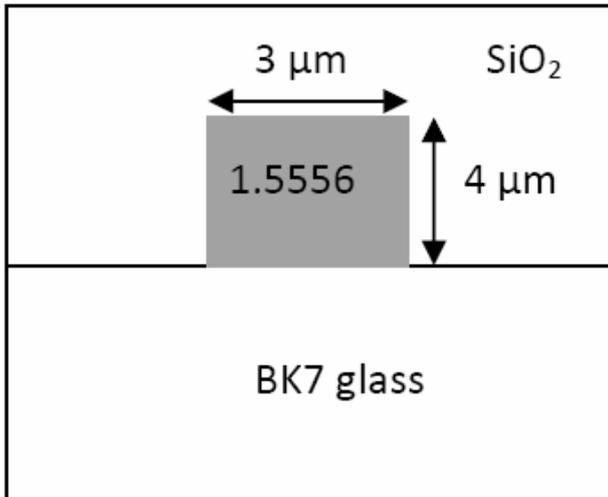


Fig. 2. Waveguide cross section.

All design parameters are listed in Table 1 and Table 2 for AWG, central wavelength $1.55 \mu\text{m}$ with channel spacing of 100 GHz and 1200 GHz respectively. In our design, the refractive index contrast between core and cladding is quite large ($\sim 1.2\%$), 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 $21.5 \times 10 \text{ mm}^2$ and $17.8 \times 5 \text{ mm}^2$ for AWG with 1200 GHz spacing. This difference is due to the path length increment in AWG with 100 GHz is greater than AWG with 1200 GHz , considering the same orientation angle.

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

Parameter	Value
Center wavelength	$1.55 \mu\text{m}$
Channel spacing	0.8 nm (100 GHz)
Diffraction Order	392
Path length different, ΔL	$392.895 \mu\text{m}$
No. of Arrayed waveguide	14
Effective index core	1.553210
FRP length	$425.9 \mu\text{m}$
Free Spectral Range	491.466 GHz

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

Parameter	Value
Center wavelength	$1.55 \mu\text{m}$
Channel spacing	9.6 nm (1200 GHz)
Diffraction Order	33
Path length different, ΔL	$33.075 \mu\text{m}$
No. of Arrayed waveguide	14
Effective index core	1.553210
FRP length	$425.9 \mu\text{m}$
Free Spectral Range	5937.61 GHz

3. Results and discussion

The simulation result of DWDM_AWG with channel spacing of 0.8 nm is shown in Fig. 3. It shows the power output distribution of the 4 channels output waveguide. The output channels are at wavelengths 1549.04 nm (λ_1), 1549.872 nm (λ_2), 1550.704 nm (λ_3) and 1551.360 nm (λ_4) 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. The maximum insertion loss of 5.04 dB is recorded at channel 4 and the minimum insertion loss of 3.88 dB is at channel 2. The crosstalk is less than -32.77 dB .

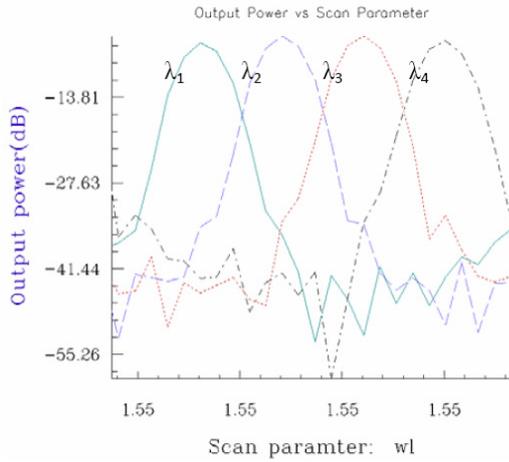


Fig. 3. Output spectral responses of 4 channels AWG with 100 GHz channel spacing.

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

Table 3. Output statistic for 4 channels 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 CWDM_AWG with channel spacing of 9.6 nm, the simulation result is shown in Fig. 4. The four output wavelengths λ_1 , λ_2 , λ_3 and λ_4 are at 1542 nm, 1552 nm, 1562 nm and 1572 nm respectively. It can be observed that 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 level is simulated to be less than -23 dB.

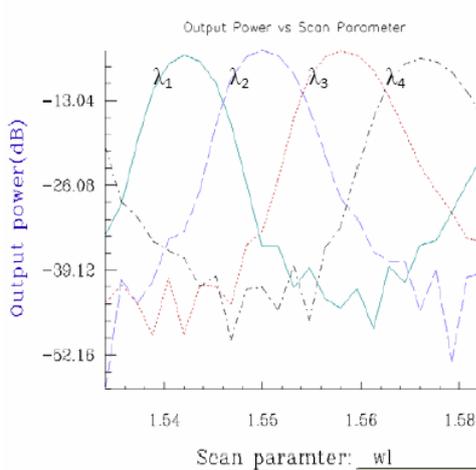


Fig. 4. Output spectral responses of 4 channels AWG with 1200 GHz channel spacing.

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.

Table 4. Output Statistic for 4 channels 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	

Based on these simulation results, it can be concluded that the designed structures of BCB polymer based AWG for both CWDM and DWDM applications are proved to work well. The crosstalk level and insertion loss values are bound to be acceptable for both applications which indicate promising results for their future development and implementation.

4. Performance comparison

Development of AWG polymer (de)multiplexer has become interest to many researchers. In order to verify the competitiveness of our designed BCB polymer based AWG, the results will be compared with other polymer based AWG, reported in the literature. The first polymer AWG was demonstrated by Hida, *et al.* [10] based on the 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.* [11] reported 16 channels polymeric AWG operated at 1550 nm, using a silicone resin waveguide. This AWG multiplexer has an insertion loss in the range of 9 to 13 dB, a crosstalk less than -20dB and low polarization dependent wavelength shift.

In 2003, Leo [12] demonstrated a 2×8 AWG polymer based on CWDM (20nm spacing) at center wavelength of 1520 nm with total device size of 23 mm × 2.5 mm. The insertion loss and crosstalk are found to be around 7 dB and -30 dB respectively. On the other hand, Woei, *et al.* [13] proposed a 4×4 AWG polymer with 0.8 nm (DWDM) spacing operated at center wavelength of 1570 nm. The device has insertion loss of 3 dB and crosstalk level less than -30dB. The device size is 31mm x 9 mm. This comparison with other similar polymer-based AWG shows that the BCB 4024-40 based AWG is competitive in terms of insertion loss and crosstalk level. Most importantly, the device size has been significantly reduced for both designs of CWDM_AWG and DWDM_AWG.

5. Conclusions

We have demonstrated two designs of AWG based on photodefinable BCB 4024-40 polymer for DWDM and CWDM applications. The designs have been simulated using the WDM_PHASAR tool from Optiwave[®]. For CWDM, the device insertion loss is better than 6 dB and crosstalk level is about -23 dB. Meanwhile, the DWDM_AWG design has been simulated to produce a crosstalk level of -33 dB and less than 5 dB of insertion loss. We have successfully design a smaller size of AWG which is recorded to be 21.5 mm × 10 mm for DWDM_AWG and 17.8 mm × 5 mm for CWDM_AWG device. Comparison with other polymer based AWG indicates that our BCB 4024-40 polymer based AWG is competitive and can be regarded as a suitable candidate for future actual device development.

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