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Arrayed-Waveguide Layout for AWG Design*

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Abstract The key issue of the complex geometry for arrayed-waveguide grating (AWG) is the design of length difference. Conventional-type scheme and improved -type scheme of the arrayed-waveguide layout are proposed. For each scheme, the layout rules were given and one example was presented. At last, the two schemes were compared with each other.

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1 Introduction

The optical wavelength division multiplexing (WDM) network system is very attractive in increasing the transmission capacity and improving the flexibility of optical fiber networks. Arrayed-waveguide gratings (AWGs) based on planar lightwave circuit (PLC) technology are promising devices as filters or multi/demultiplexers in WDM network systems because of their low insertion loss, high stability and suitability for mass-production[1~5].

An AWG multi/demultiplexer is composed of an arrayed-waveguide grating, input-output (I-O) waveguides and focusing slab waveguides. The AWG consists of regular-arranged waveguides that join two slabs and with different lengths of adjacent waveguides

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from the constant value. The length difference ΔL results in the wavelength-dependent wavefront tilting, so the light convergence in the output slab is wavelength-dependent, and the AWG is operated like a diffraction grating. Therefore, the key issue for AWG is the design of length difference ΔL.

In this paper, two types of arrayed-waveguide layouts used widely, conventional type and improved type, were presented. The design rules were given respectively. For either schemes, the design parameters were calculated in detail. At last two types of schemes were compared with each other.

2 Model

Arrayed waveguide layout is very important for the device performance. There are several schemes to realize the length difference. Among these, two main schemes are called conventional type acheme and improved type scheme.

2.1 Conventional type scheme[2]

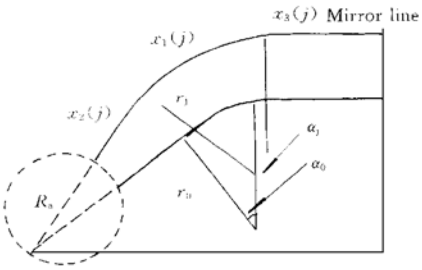

FIG. 1 Design Layout of the Conventional Type AWG

Half waveguide in the array consists of two straight waveguide segments and one curved segment, as shown in Fig. 1. Analytic equations for the length of the straight waveguides and the radii of the curved segments are determined so that the path length difference between the adjacent waveguides is kept constant ($= 1/2\ \Delta L$), that is,

$$L(j) = x_2(j) + r_j\alpha_j + x_3(j) = L(j+1) - \frac{1}{2}\Delta L \qquad (1)$$

Where $x_2(j)$ is the length of the first straight waveguide segment, $j = 0, 1, 2, \cdots, 2M$ ($2M + 1$ is the number of arrayed waveguides); $x_1(j)$ is the curved segment length in the j-th waveguide and given as $r_j\alpha_j$, where r_j is the curvature radius and α_j is the angle of the first straight waveguide segment against the line normal to the mirror line; $x_3(j)$ is the second straight waveguide length in the j-th waveguide length. For all lengths, radius r_j and angle α_j are functions of waveguide numbers in the array. An iterative method is used for Eq. (1) to calculate all these parameters after setting the initial values of α_0, r_0, $x_2(0)$, and $x_3(0)$. Device parameters in the future masks may be easily varied by changing the parameters in the programs.

The second straight waveguide segment provides adjustment for the polarization insensitivity[3], phase error[6] and temperature insensitivity[7].

2.2 Improved type scheme[4]

Half waveguide in improved type scheme array consists of one straight waveguide segment, with length of $x_2(j)$ and one curved segment, with length of $x_1(j)$ or $r_j\alpha_j$, where r_j is the curvature radius in the j-th waveguide and α_j is the angle of the straight waveguide segment against the line normal to the mirror line in the j-th waveguide ($j = 0, 1, 2, \cdots 2M+1$), as shown in Fig. 2. θ is the angle of the center waveguide's straight segment against the line normal to the mirror line. L_{slab} is the distance between two foci. R_a is the focal length of the slab region.

Parameters being predetermined are θ, L_{slab} and $(4M+1)$ parameters unknown, which can be determined by $(4M+1)$ basic equations:

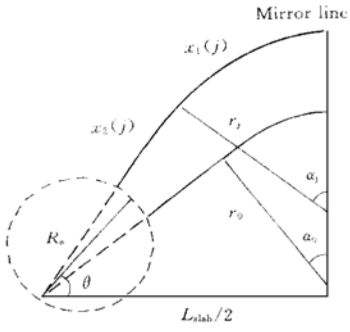

FIG. 2 Design Layout of the Improved Type AWG

$$\begin{cases} x_2(j) + r_j\alpha_j = x_2(0) + r_0\alpha_0 + j \times \dfrac{\Delta L}{2} \quad (j = 1, 2, \cdots, 2M) \\ (R_a + x_2(j))\cos\alpha_j + r_j\sin\alpha_j = \dfrac{L_{slab}}{2} \quad (j = 0, 1, \cdots, 2M) \\ \alpha_j = \theta + \Psi_j \\ \Psi_j = j \times \Psi_0 \\ \Psi_0 = 2\sin^{-1}\left(\dfrac{d}{2R_a}\right) \end{cases} \tag{2}$$

As for $(4M+1)$ Equations for $(4M+3)$ unknown values, solutions can be chosen under the following constraints: (a) Minimum radius $\geqslant r_{min}$, r_{min} is the radius per 90° bend with loss less than 0.1dB; (b) $x_2(j) \geqslant 0$; (c) Minimum waveguide separation $\geqslant s_{min}$. s_{min} is the minimum spacing of the decoupling distance between waveguides.

3 Numerical Calculation

Table 1 presents the values used in the following numerical calculation. All the symbols in Tab. 1 and their physical meaning are the same as in paper [8].

Table 1 Values for the Calculation of the Arrayed-Waveguide Layout for a 1×8 AWG DMUX

Symbol	Parameter	Value
a	The size of square waveguide	6.1μm
d	Arrayed-waveguide grating pitch	28μm
R_a	Focal length of slab region	8841.06μm
ΔL	Path length difference	83.428μm
$2M+1$	Number of array waveguides	91
r_{min}	The minimum radius of curvature with bending loss less than 0.1dB for a 90° bend	3mm
s_{min}	The minimum spacing of the decoupling distance between waveguides	28μm

3.1 Conventional type AWG

Given R_a, ΔL and d, a number of combinations of θ, $x_1(j)$, $x_2(j)$ and $x_3(j)$ solutions meet the constraints of Eq. (1). Table 2 gives one solution combination with $L(0) = 7000\mu m$, $\theta = 60°$, $x_2(0) = 2000\mu m$ and $r_0 = 3000\mu m$ as predetermined.

Table 2 One Combination of Parameters of Conventional Type Scheme (单位: μm)

r_j	$x_2(j)$	$x_3(j)$	r_j	$x_2(j)$	$x_3(j)$	r_j	$x_2(j)$	$x_3(j)$
3000.00	2000.000	6571.917	6244.790	1374.274	2642.896	7898.146	748.548	965.000
3146.647	1979.142	6390.935	6319.908	1353.416	2556.960	7935.943	727.691	936.269
3290.061	1958.285	6213.988	6393.363	1332.559	2473.422	7972.858	706.833	908.999
3430.315	1937.427	6041.000	6465.186	1311.701	2392.248	8008.911	685.976	883.166
3567.480	1916.570	5871.902	6535.412	1290.844	2313.395	8044.118	665.118	858.750
3701.629	1895.712	5706.623	6604.080	1269.986	2236.821	8078.499	644.261	835.723
3832.820	1874.855	5545.104	6671.212	1249.128	2162.501	8112.073	623.403	814.058
3961.124	1853.997	5387.279	6736.848	1228.271	2090.392	8144.851	602.546	793.746
4086.602	1833.140	5233.082	6801.019	1207.413	2020.454	8176.851	581.688	774.761
4209.321	1812.282	5082.446	6863.754	1186.556	1952.655	8208.091	560.831	757.077
4329.338	1791.425	4935.315	6925.085	1165.698	1886.958	8238.578	539.973	740.692
4446.719	1770.567	4791.618	6985.047	1144.84	1823.317	8268.344	519.116	725.552
4561.512	1749.709	4651.312	7043.659	1123.983	1761.719	8297.398	498.258	711.648
4673.779	1728.852	4514.330	7100.953	1103.126	1702.120	8325.75	477.401	698.972
4783.575	1707.994	4380.616	7156.950	1082.268	1644.503	8353.415	456.543	687.499
4890.954	1687.137	4250.114	7211.693	1061.411	1588.804	8380.411	435.686	677.205
4995.970	1666.279	4122.768	7265.200	1040.553	1535.008	8406.749	414.828	668.077
5098.672	1645.422	3998.525	7317.503	1019.696	1483.073	8432.444	393.971	660.091
5199.117	1624.564	3877.325	7368.617	998.838	1432.988	8457.510	373.113	653.230
5297.345	1603.707	3759.130	7418.570	977.981	1384.713	8481.962	352.256	647.470
5393.408	1582.849	3643.881	7467.390	957.123	1338.217	8505.806	331.398	642.808
5487.353	1561.992	3531.531	7515.098	936.266	1293.472	8529.058	310.541	639.218
5579.226	1541.134	3422.026	7561.718	915.408	1250.450	8551.730	289.683	636.682
5669.072	1520.277	3315.321	7607.272	894.551	1209.124	8573.829	268.826	635.198
5756.938	1499.419	3211.363	7651.790	873.693	1169.454	8595.379	247.968	634.720
5842.859	1478.561	3110.116	7695.280	852.836	1131.433	8616.388	227.111	635.242
5926.883	1457.704	3011.528	7737.771	831.978	1095.024	8636.861	206.253	636.756
6009.050	1436.846	2915.552	7779.276	811.121	1060.215	8656.813	185.396	639.244
6089.393	1415.989	2822.159	7819.830	790.263	1026.953	8676.252	164.538	642.689
6167.963	1395.131	2731.282	7859.446	769.406	995.225	8695.191	143.681	647.076
						8713.641	122.823	652.388

From Table 2 the curvature radius varies between 3mm and 8.71mm, $x_2(j)$ varies between 2000μm and 122.8μm, and $x_3(j)$ varies between 6571.92μm and 634.72μm. The total size of the layout is about 2.345cm×1.373cm. With input-output (I-O) waveguides and focusing slab waveguides, the device size will become even larger. Usually, one device or two devices with cross slab waveguides can be produced on a silicon chip with diameter of 5.08cm. In order to fabricate good-performanced device, the uniformity of the refractive index and the thickness of the waveguide layers must be controlled precisely.

3.2 Improved type AWG

For improved type AWG, a number of solution combinations can also be obtained from Eqs(2) and their constraints. Given $L_{slab}=16000\mu m$, $\theta=60°$, $x_2(0)=0\mu m$, a combination of solutions were obtained. From the solution, the r_j varies between 3114.009μm and 4590.186μm and $x_2(j)$ varies between 0 and 1296.338μm. The total size of the layout is about 1.6cm×1.221cm, which is smaller than that the conventional type. But it has no convenient adjustment for polarization insensitivity, phase error and temperature insensitivity as conventional type does. In this scheme, transition junctions between the straight waveguide and curved one are reduced and the curvature loss is reduced, too.

4 Conclusion

Conventional type scheme and improved type scheme are two main schemes used in the design of length difference for AWG. Each scheme has a number of solution combinations to Eq.(1) and Eqs (2). It means the layout is versatile. For conventional type scheme, the second straight waveguide segment provides with more flexible θ value, the adjustment of polarization insensitivity, phase error and temperature insensitivity. But it requires larger chip size. For improved type scheme, transition junctions between the straight waveguide and curved one are reduced and the curvature loss is reduced too. Usually, we choose optimal solution combination accosding to the processing and chip size.

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