Novel Symmetrical Three-Branch Optical Waveguide with Equal Power Division

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***Abstract*—Symmetrical three-branch optical waveguide structures, which can divide power equally at each branch, are proposed from calculations by the beam propagation method. The structures are constructed with a triangular shaped spacing area in the central branch to control the transmission coefficient between each branch and the main waveguide. The proposed three-branch waveguides can be easily designed due to their simple configuration.**

I. Introduction

BRANCHING waveguides are important and essential components in optical integrated circuits. For instance, Y-branch waveguides that can divide power equally are employed as optical power dividers, switch arrays and interferometric modulators [1]–[3].

Symmetrical multibranch optical power dividers with equal power division, whose branch number is a power of 2, can be constructed using a cascade connection of Y-branch waveguides. However, they occupy a large circuit area. One of the most important problems in multibranch waveguides, with a branch number greater than two, is controlling the power ratio at each branch. Symmetrical three-branch waveguides with equal power division for optical power dividers have been investigated [4]–[6]. However, these three-branch waveguides are complicated and show large excess losses due to modifying the index distributions in the branches. In this letter, we propose a simple structure for a symmetrical three-branch waveguide with equal power division and also demonstrate the design curves.

II. Configuration

A conventional three-branch waveguide with a uniform index distribution, there is more power at the central branch, compared to the others. Therefore, the transmission coefficient between the central waveguide and the main waveguide is reduced by the spacing area in the central branch. The basic configurations of the proposed three-branch waveguides are shown in Fig. 1(a) and (b). In such cases, a two dimensional symmetrical slab geometry is assumed for simplicity. The proposed structures are different from the conventional structure in that the central branch has a triangular shaped spacing area. This area works to reduce the transmission coefficient between the main waveguide and the central branch. The

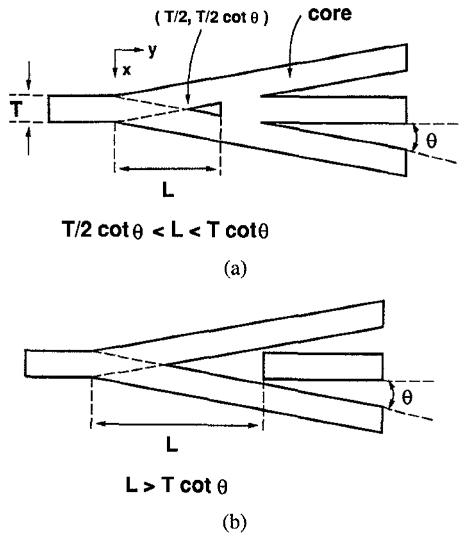

Fig. 1. Proposed three-branch waveguides. (a) Three-branch with triangular shaped spacing. (b) Three-coupled waveguide-like structure.

waveguide width, branching angle and total length from the branching point to the end of the triangle are denoted by T, θ and L, respectively. When the spacing area is zero, the structure becomes a conventional three-branch waveguide. When the spacing area is large the structure becomes a Y-branch-like structure, with a small transmission coefficient between the central waveguide and the main waveguide. Therefore, a symmetrical three-branch waveguide with equal power division is obtained by controlling the spacing area which is formed in the core region of the central branch. The structures are classified as follows:

1) conventional three–branch for $L < T/2 \cdot \cot\theta$;
2) three-branch with triangular shaped spacing for $T/2 \cdot \cot\theta < L < T \cdot \cot\theta$;
3) three-coupled waveguide-like structure for $L > T \cdot \cot\theta$.

The number of geometric parameters in the proposed structure is only one more than that of a conventional structure. Therefore, the proposed structures can easily be designed by the length L and can be fabricated utilizing semiconductor device processing technologies such as dry etching or ion implantation.

III. Numerical Analysis

To demonstrate the field distribution of the proposed three-branch structures, we employ the beam propagation method [7] (BPM) for numerical analysis. Each waveguide is assumed to

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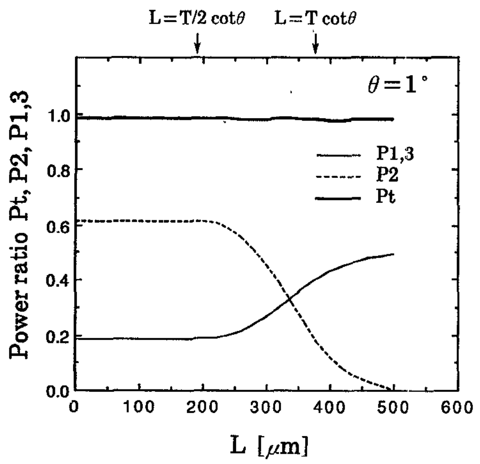

Fig. 2. Power distribution in the proposed three-branch structure as a function of spacing area length for $\theta = 1.0$ degree. (Propagation distance: 2000 μm, propagation step: 1 μm.)

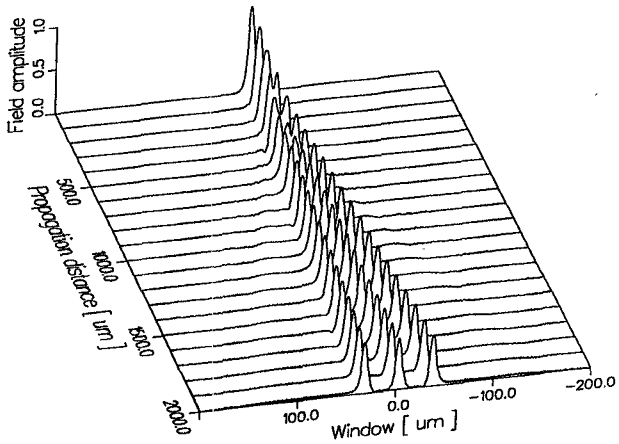

Fig. 3. Field amplitude distribution for equal power division in a three-branch with triangular spacing.

operate in the TE_0 mode, and the operating wavelength and waveguide width are 1.0 μm and 6.6 μm, respectively. The index values of core, cladding and substrate are 1.502, 1.500, and 1.500, respectively. The effective index can be substituted in the dispersion equation in a homogeneous slab waveguide. The optical power ratio, Pi, is given by

$$Pi = |Ai/Ain|^2 \quad (i = 1, 2, 3), \tag{1}$$

where the normalized field amplitude, Ain, in the main waveguide and Ai, in the ith branch are given by [4]. The optical power ratio of each branch as a function of length L when the branching angle is 1.0 degree is shown in Fig. 2. In a conventional three-branch waveguide (case 1), the power ratio of the central waveguide, $P2$, is greater than that of the other branches, $P1$ and $P3$. However, in the three-branch waveguide with a triangular shaped spacing area (case 2), the power ratio of the center branch is decreased from 0.6 to 0.0 due to the increase in the length L, and the power ratio of the other branches is increased from 0.2 to 0.5. Power is equally divided at each branch when the length L is 335 μm. The total power, Pt, of the various lengths L slightly decreases compared with that of a conventional structure. The proposed three-branch waveguides essentially have the antenna couples structure reported in [8]. The antenna coupled Y-branch achieves a low junction loss when the branching angle is large. Therefore, the proposed structure achieves low branching losses in various cases. The field distribution in this condition is shown in Fig. 3. The propagation distance and propagation steps are 2000 μm and 1 μm, respectively. The power ratio of each branch as a function of the length L when the branching angle is 0.5 degrees is shown in Fig. 4. In this condition, the design curve shows a power peak due to the resonance between the central branch and the outer branches. The radiation effect in the spacing area is also important, since the wavefront becomes circular. Equal power division is obtained when the structure becomes a three-coupled waveguides like structure (case 3). Consequently, equal power division is obtained between approximately 0.75 and 1.5 degrees with the three-branch, triangular shaped spacing structure, and is obtained at other branching angles with a three-coupled waveguide-like structure.

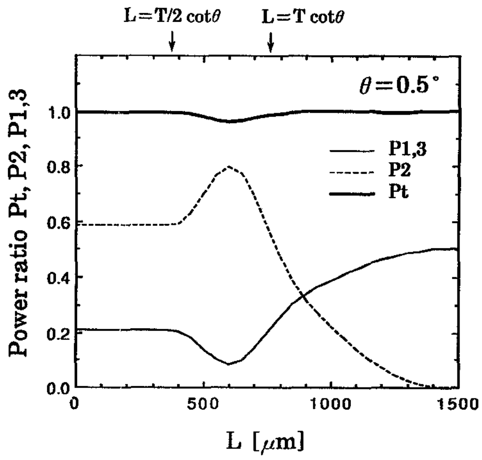

Fig. 4. Power distribution in the proposed three-branch structure as a function of spacing area length for $\theta = 0.5$ degrees. (Propagation distance: 4000 μm, propagation step: 1 μm.)

IV. Conclusion

A simple structure has been proposed to divide power equally in the three-branch waveguide. Equal power division was achieved by forming a triangular shaped spacing in the central branch. The proposed structures can be used for optical power dividers whose output port numbers are $2^N \times 3^M$. Furthermore, these structures can be applied to 4- or 5-branch waveguides by using a similar spacing area. Therefore, various optical power dividers and switches can be designed in a small circuit area.

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