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NUMERICAL ANALYSIS OF THE FAR-FIELD PATTERN OF OPTICAL WAVEGUIDE ARRAY

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1 Introduction

An optical waveguide array is attractive for high-speed deflection of an optical beam, and of considerable importance in systems such as optical inter-satellite links. Moriki et al. [1] investigated an optical beam scanner with phase-variable waveguides. Recently, Wight et al. [2] demonstrated a phased array optical scanning device fabricated on GaAs. Subsequently, Inagaki et al. [3] and Murakami et al. [4] fabricated an optical phased array antenna using $LiNbO_3$ substrate. A fiber-type optical phased array was also studied [5]. However, the previous research has been mainly based on the experimental work, and the theoretical study has not taken into account the mutual coupling among the waveguides. From this viewpoint, the authors studied the basic characteristics of an optical waveguide array using the numerical technique [6].

The purpose of this paper is to numerically investigate the propagating field and the far-field pattern of an optical waveguide array which is composed of three slab waveguides. For the analysis, we adopt the improved finite-difference beam-propagation method (IFD-BPM) [7] [8], since the IFD-BPM allows us to evaluate the mutual coupling among the waveguides and the radiation mode generated in the waveguide. It is found that the radiation-mode field causes the ripples in the far-field pattern. We also study the case where the beam is deflected by about 5 degrees. The effects of the mutual coupling on the far-field pattern are discussed.

2 Configuration and numerical method

Fig.1 shows the configuration of an optical waveguide array. For simplicity, we consider the array of two-dimensional step-index slab waveguides. The array is composed of three single-mode waveguides, in which a straight waveguide is sandwiched with two S-shaped waveguides whose bending radius is designated as R. The wavelength is taken to be $\lambda = 1.55$ μm. The spacing among the output waveguides is chosen to be $W_1 = 0.9\lambda$ which satisfies the condition that a grating lobe does not appear at a deflection angle of 5 degrees. The spacing among the input waveguides is $W_2 = W_1 + 16$ μm. The core width is $2D = 0.736$ μm, and the refractive indices of the core and cladding are $N_{CO} = 3.45$ and $N_{CL} = 3.30$, respectively.

The propagating fields along the waveguides are calculated by the improved finite-difference beam-propagation method (IFD-BPM) [7] [8]. The BPM has the advantage over the conventional method in that the mutual coupling among the waveguides are fully taken into account. Furthermore, the IFD-BPM enables us to evaluate the propagating field in a bent waveguide. Using the propagating field at the output, we can evaluate the far-field pattern. The effect of the reflected field from the output on the radiation is ignored in this analysis. Numerical parameters are $\Delta x = D/14 (= 0.026$ μm$)$, $\Delta z = 0.05$ μm, and the number of sampling points is 3426. The input field is generated by superimposing the fields of the fundamental mode TE_0.

3 Results

We first investigate the case where the bending radius is relatively small, i.e., $R = 148$ μm. In this case the angle ϕ becomes 18.9 degrees, and the straight-waveguide length $L = 96$

μm. The length of the center waveguide is shorter than those of the side waveguides. Therefore, the center waveguide is excited with a phase which lags by the difference of the effective length of the waveguide. Fig.2(a) shows the propagating field distribution. It is observed that the propagating field has ripples. This effect is due to the radiation-mode field generated in the waveguide. The guided mode cannot be completely supported when the bending radius is too small. The ripples in the propagating field affect the field at the output with subsequent effect on the far-field pattern. Fig.2(b) shows that the far-field pattern has also ripples.

One way of reducing the radiation-mode field in the waveguide is to make the bending radius large. Hence, we next study the case where the bending radius is $R = 1300$ μm (corresponding to $L = 288$ μm and $\phi = 6.4$ degrees).

Fig.3 shows the propagating field, the phase distribution. and the far-field pattern in the case of zero deflection. It is noted that each field amplitude at the output waveguide is not the same due to the mutual coupling among the waveguides. Since the bending radius is taken to be larger than that in Fig.2. the radiation-mode field in the waveguide is suppressed. It follows that the ripples in the propagating field and in the far-field pattern are reduced.

One of the advantages of an optical waveguide array is that the beam can be deflected. Fig.4 shows the case where the input waveguides are excited with a phase which gives a 5-degree deflection. The phase difference among the waveguides can be observed in Fig.4(b), which contrasts with that in Fig.3(b). Although the excitation phase is adjusted to obtain a 5-degree deflection, the result presented in Fig.4(c) gives a 3.5-degree deflection. This is partly due to the mutual coupling among the waveguides.

For reference, the far-field patterns without the mutual coupling are shown in Fig.5. Comparison between the far-field patterns with and without the mutual coupling shows that the sidelobe level is increased by the coupling effect.

4 Conclusions

The radiation characteristics of an optical phased array composed of three slab waveguides have been investigated using the improved finite-difference beam-propagation method. It is found that the radiation-mode field generated in the waveguide causes the ripples in the far-field pattern. Further study shows the far-field pattern when the beam is deflected by 5 degrees.

References

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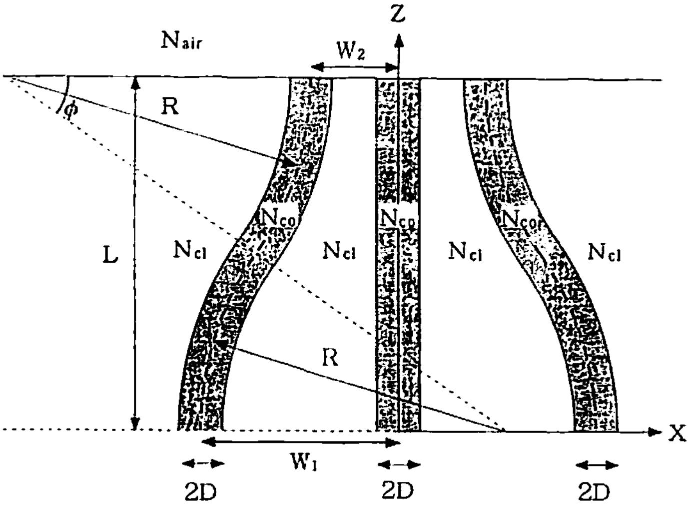
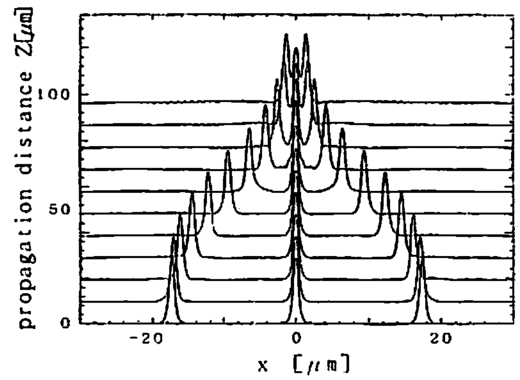
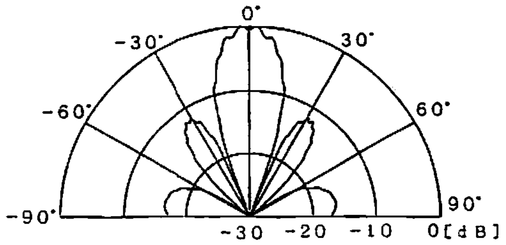


Fig. 1 Configuration of optical waveguide array.

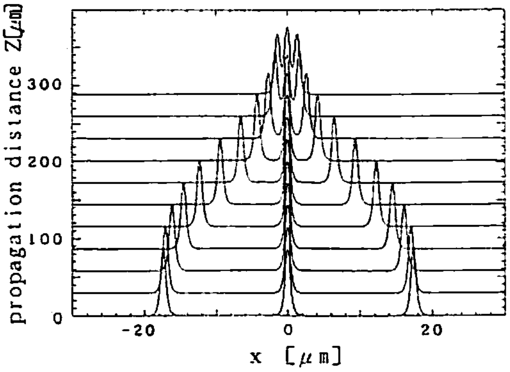


(a) Propagating field

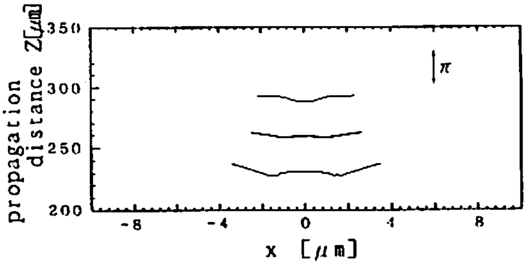


(b) Far-field pattern

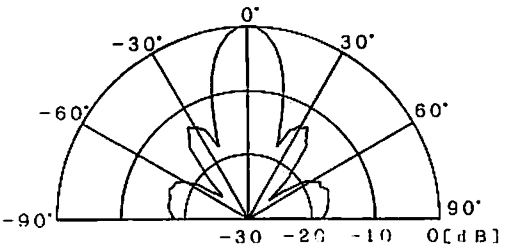
Fig.2 Characteristics for $R = 148\mu m$ and zero deflection.



(a) Propagating field

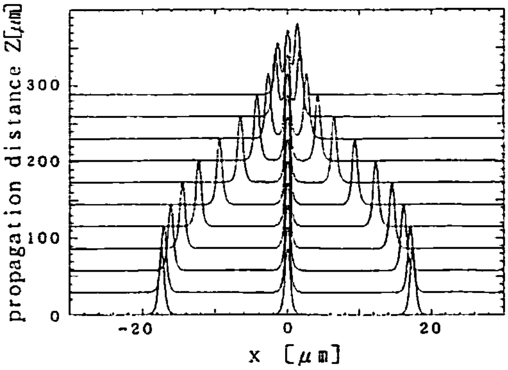


(b) Phase

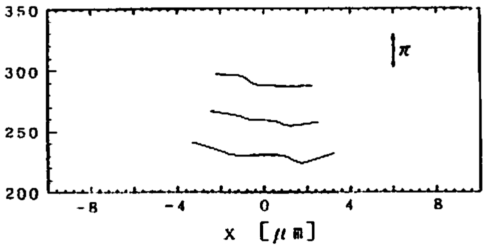


(c) Far-field pattern

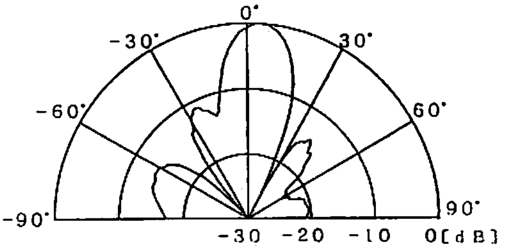
Fig.3 Characteristics for $R = 1300\mu m$ and zero deflection.



(a) Propagating field

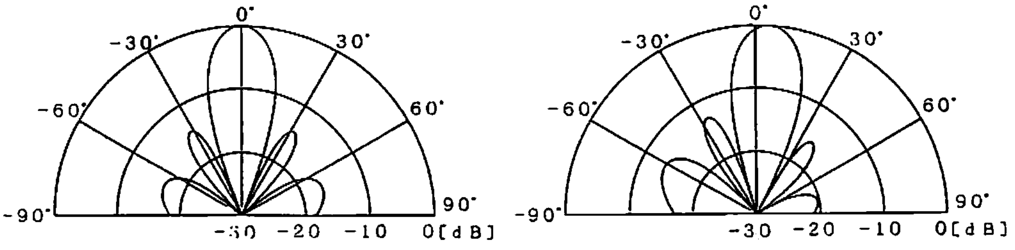


(b) Phase



(c) Far-field pattern

Fig.4 Characteristics for $R = 1300\mu m$ and 5-degree deflection.



(a) Zero deflection

(b) 5-degree deflection

Fig.5 Far-field pattern without mutual coupling.