Two-dimensional Beam Scanning of Optical Antenna by Circular Waffle Waveguide

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Abstract **– This paper proposes a two-dimensional beam scanning of optical antenna by waffle waveguide on a silicon wafer. The beam in azimuth is steered by changing the input direction of propagating wave into waveguide. Four silicon wires are excited with phase difference to switch the propagating direction. The elevation beam angle is steered by sweeping input wavelength of leaky waffle waveguide. The design of leaky waveguide and beam switching method are presented for 2-D beam scanning.**

Index Terms **— Optical leaky waveguide antenna, Two-dimensional beam scan, Circular waffle waveguide.**

1. Introduction

To increase wireless data transmission speed, optical wireless communication is proposed. High gain and narrow beam antennas are required for optical transmission due to large propagation loss in optical region. Beam scanning is necessary for mobile communication to track a moving target. Various scanning methods were proposed e.g. MEMS mirrors, optical array [1] and phased array by 16 grating waveguides [2] for sensing or transmission, which were not focused on their antenna performance. Beam scanning of optical antenna by a waffle waveguide on silicon substrate was proposed in [3] and 1-D beam scanning was provided by sweeping input wavelength. This paper proposes the design of 2-D beam scanning for the optical antenna by circular waffle waveguide (CWWG) [4].

2. Structure of CWWG and Proposed Antenna

Design parameters of CWWG are shown in Fig. 1. A silicon waveguide is periodically etched with multiple circular holes. CWWG radiates guided waves along x-direction by periodic refractive index modulation. Beam scanning on the zx-plane is given by sweeping input wavelength, where the period of holes in z-direction Λ_z defines radiation angle.

The proposed antenna consists of phase shifters, 4 silicon wire waveguides and leaky waveguide region by CWWG. Phase shifters can be designed with using the Mach-Zehnder optical modulator as shown in [5]. Phase shift is generated by carrier plasma dispersion in p-n-doped waveguides applied voltages. Design parameters of the proposed antenna are shown in Fig. 2. Wire waveguides switch the propagating direction in the leaky waveguide region by

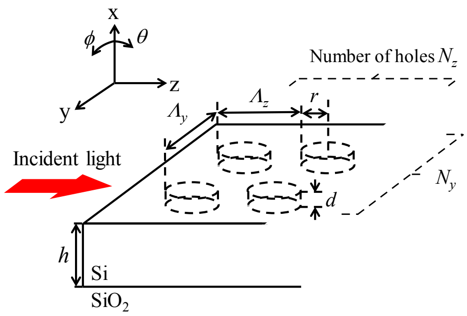


Fig. 1. Design parameters of circular waffle waveguide. $d = 0.07$, $h = 0.21$, $\Lambda_y = 0.41$, $\Lambda_z = 0.54$, $r = \Lambda_z/4$ [μm]

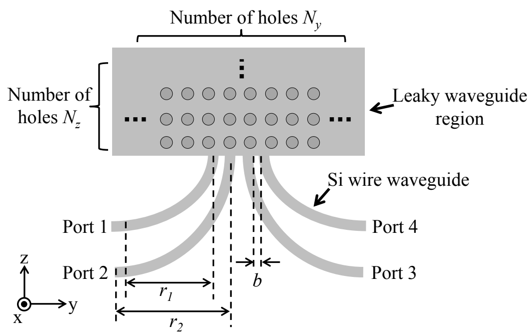
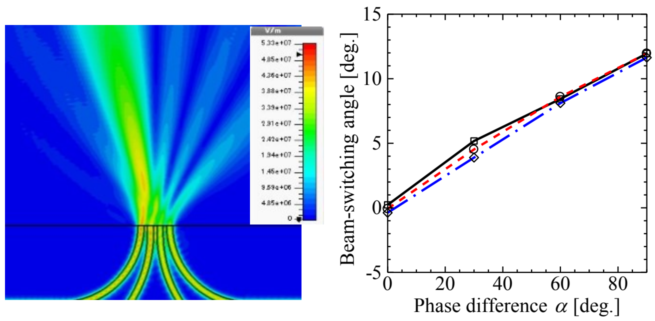


Fig. 2. Design parameters of proposed antenna. $r_1 = 0.5$, $r_2 = 0.8$, $b = 0.2$ [μm]



(a) (b)

Fig. 3. Beam switching by wire waveguides. (a) Electric field distribution of wires connected to a slab waveguide excited with phase difference. (b) Switching angle of the propagating direction when input wavelength are 1500 nm (solid), 1550 nm (dash) and 1600 nm (chain).

adjusting the phase difference in Fig. 3. Denoting the phase difference between adjacent wire waveguides as α°, excitation phases of port1 - port4 are 0°, α°, 2α° and 3α°. Radiation from the leaky waveguide region can be steered on the xy-plane.

3. Analysis of Proposed Antenna

The proposed antenna is simulated by CST MW STUDIO [6]. We simulated the antenna in which number of holes of the leaky waveguide region are N_z = 50 and N_y = 60. Fig. 4 shows 3-D radiation patterns of the proposed antenna excited with phase difference α = 90°. Its beam is steered on the xy-plane. Fig. 5 shows 2-D radiation pattern by exciting the antenna at 1500 - 1600 nm of input wavelength and changing phase. The beam is radiated toward the direction of zenith at 1500 nm without phase difference. The pattern shows 2-D beam scanning by sweeping input waveguides and changing phase difference as shown in Table I.

Fig. 6 shows the directivity gain of proposed antenna excited at 1550 nm. We varied the number of holes in z direction N_z as fixing the number in y direction N_y = 200. The proposed antenna obtains 27.7 dBi of the directivity gain, saturated by the propagation loss in the waveguide.

We fix the depth of holes as d = 0.07 μm because of a constraint for fabricating. Reducing the radiation amount per unit length of leaky waveguides region increases effective antenna area. A blue line in Fig. 5 shows that we can improve the directivity by using the small depth of holes.

4. Conclusion

We proposed 2-D beam scanning of optical antenna by CWWG. We simulated the antenna and showed 2-D beam scanning by sweeping input wavelength and changing excitation phase difference. Its radiation pattern has the angle of 26.6° at 1500 nm and 22.3° at 1600 nm on the xy-plane by exciting with phase difference of α = 90°.

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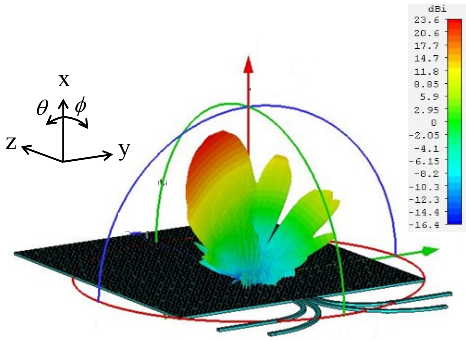

Fig. 4. 3-D radiation pattern by the proposed antenna (N_z = 50 and N_y = 60) at 1550 nm by exciting with phase difference.

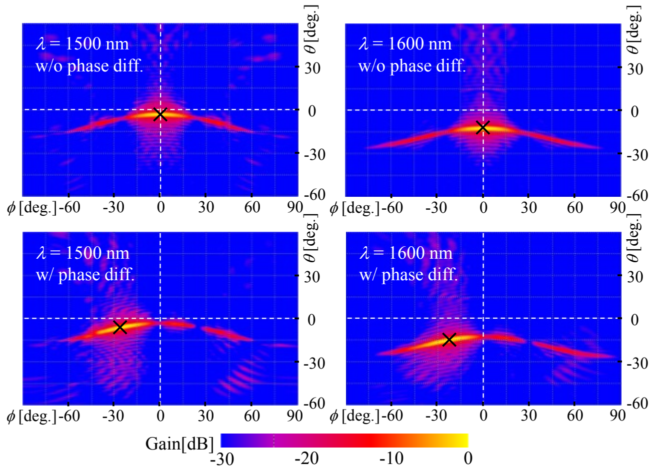

Fig. 5. 2-D radiation pattern by the proposed antenna (N_z = 50 and N_y = 60). X marks express the peak of radiation.

TABLE I
Radiation Angle of Proposed Antenna

Excitation phase	w/o phase diff.		w/ phase diff.	
Input wavelength [nm]	1500	1600	1500	1600
Radiation angle ϕ [deg.]	0	0	–26.6	–22.3
Radiation angle θ [deg.]	–3.4	–12.7	–6.4	–15.0

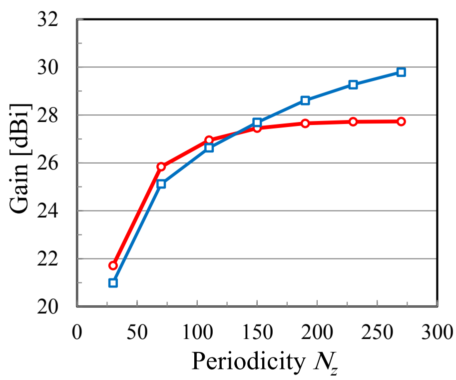

Fig. 6. Directivity gain when depth of holes is d = 0.07 μm (red circle) and d = 0.03 μm (blue square).