

# 2D Beam Scanned Optical Leaky Waveguide Antenna

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**Abstract**— This paper proposes an optical beam scanning antenna consisting of switched beam waveguide and leaky waveguide. Azimuth angle is changed by switching propagating direction inside waveguide and elevation scanning is given by sweeping the wavelength of tunable laser from 1500 to 1600 nm. The proposed antenna geometry is described in detail and wide angle beam scanning method in elevation plane is presented by introducing optical switches. A waffled leaky waveguide is designed and fabricated by silicon photonics process and its beam scanning is also demonstrated.

## I. INTRODUCTION

For 5G and beyond wireless communication systems, data transmission rate is expected to be more than 100GBps [1] or 1TBps. Frequency band width for high speed data transmission is required more than THz order, which needs to explore optical communication for short range systems with small spot coverage area. A massive MIMO concept is expected to increase data transmission rate with ultra-high speed digital processing. High speed beam scanning, equivalent to massive MIMO, is given by conventional frequency scanned array, which is an attractive antenna in optical frequency range. Fiber optics technologies have been developed well, then the next frequency band for the future system is optical range. Due to large propagation loss in optical range, narrow beam and high gain antennas are required to be developed for small cell base station antennas.

A combination of frequency sweep and phased array technique was proposed for optical beam scanning arrays [2], however its sensor application do not need wide scanning range. A thermal switched phase shifter for two-dimensional (2D) beam scanner was also proposed for display applications [3]. As another beam scanning array, this paper proposes a leaky waffled waveguide fabricated on silicon wafer excited by switched beam waveguide to scan in two orthogonal planes. Its beam scanning is given by frequency sweep and beam switching inside waveguide is given by Mach-Zehnder (MZ) type optical phase shifter [4].

## II. OPTICAL BEAM SCANNING ANTENNA

2D beam scanning antenna consists of a switched beam waveguide and a leaky waveguide as shown in Fig. 1. Optical signal excited in waveguide is split into two ways and is added after phase shifter to switch its propagating direction. The

propagated wave is coupled to the leaky waveguide and its radiated beam direction is controlled by sweeping optical frequency. This two stage beam control provides 2D beam scanning antenna. The beam switched waveguide is given by MZ phase shifter and silicon waveguide as shown in Fig. 2. Scanned beam range in yz plane is  $\pm 20^\circ$  by phase change of  $\pm 90^\circ$  between two waveguide. The leaky waveguide is fabricated by silicon photonics. The waveguide layer with 210nm thickness is sandwiched by SiO<sub>2</sub> substrate and 2 $\mu$ m thickness protection cover. To achieve high gain antenna, a waffled waveguide as shown in Fig. 3 is used in this paper. The period of cavity array determines the beam tilt angle changed by frequency sweep. Current tunable lasers have the potential of 100nm variable range in wavelength, which gives  $10^\circ$  beam scanning. To extend its range, 5 leaky waveguides with different tilt angles are fed through optical switches as shown in Fig. 4.

To demonstrate beam scanning of proposed waffled waveguide, a prototype antenna is fabricated by silicon photonics as shown in Fig. 5. Waveguide length is  $L=2000\Lambda$  and the number of cavity along y axis is  $N=20$ , where  $\Lambda$  is the period of the cavity. A tunable laser changes input optical wavelength from 1500 to 1600 nm and its radiation is detected through lens and multi-mode fiber terminated with optical power meter. Fig. 6 shows three output beam patterns in different input wavelength, which shows  $10^\circ$  beam scanning is given by proposed waffled waveguide.

## ACKNOWLEDGEMENT

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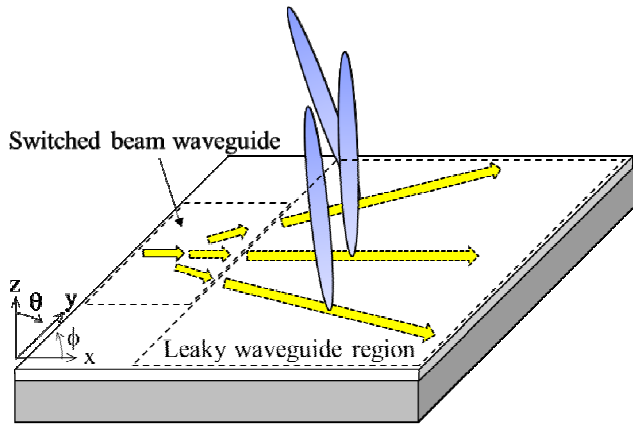


Fig. 1 2D beam scanning optical antenna.

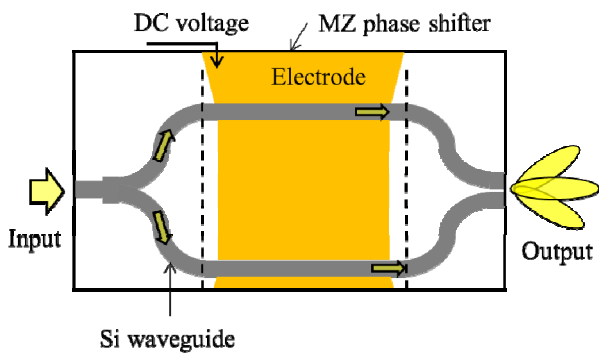


Fig. 2. Beam switch by MZ phase shifter.

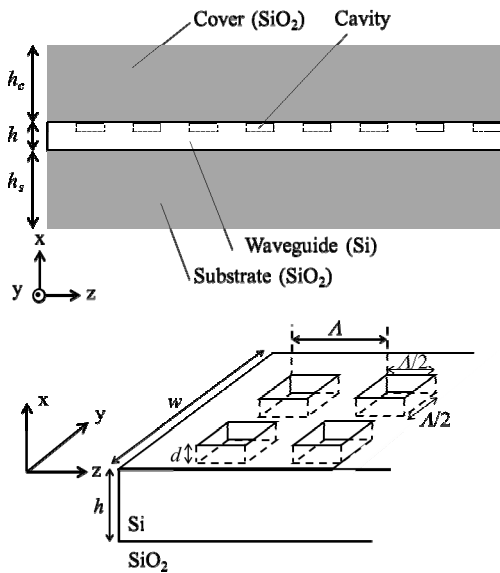


Fig. 3. Waffeled leaky waveguide array.

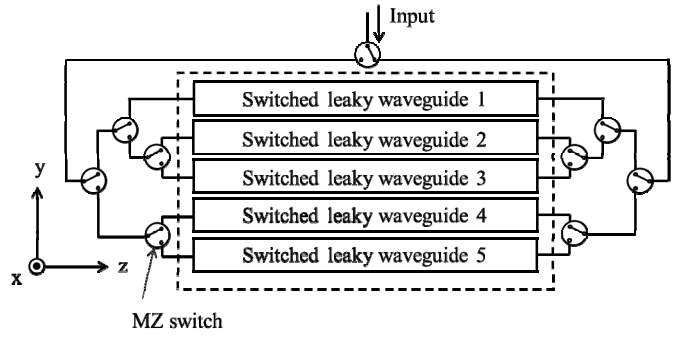


Fig. 4 Feed circuit for beam switching.

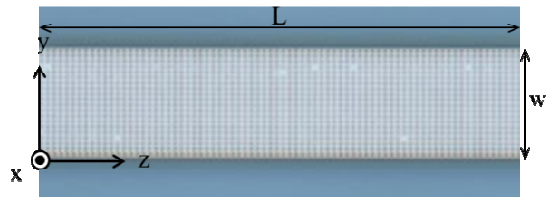
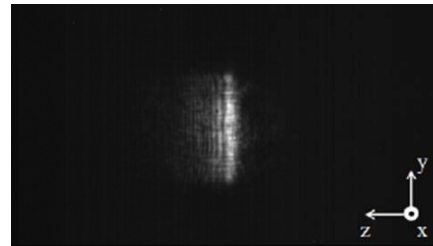
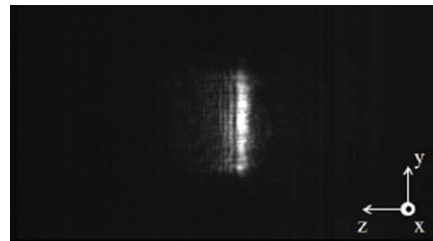


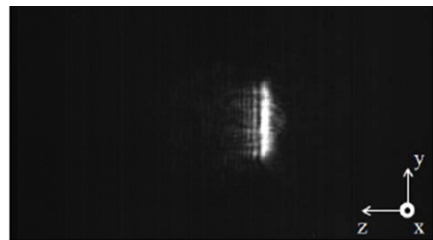
Fig. 5. Photo of waffle waveguide,  $w = 0.10$ ,  $d = 0.07$ ,  $h = 0.21$ ,  $\Lambda = 0.57$  [ $\mu\text{m}$ ].



(a)  $\lambda = 1510\text{nm}$



(b)  $\lambda = 1550\text{nm}$



(c)  $\lambda = 1590\text{nm}$

Fig. 6. Output beam patterns.