All-solid-state beam scanning based on the ultra-large-scale micro-ring optical switch array

Lei Yu
Key Laboratory of Semiconductor Materials Sciences
Institute of Semiconductors, Chinese Academy of Sciences
Beijing 100083, China
yulei@semi.ac.cn

Langlin Cui
Key Laboratory of Semiconductor Materials Sciences
Institute of Semiconductors, Chinese Academy of Sciences
Beijing 100083, China
cuilanglin@semi.ac.cn

Pengfei Wang
Key Laboratory of Semiconductor Materials Sciences
Institute of Semiconductors, Chinese Academy of Sciences
Beijing 100083, China
pfwang15@semi.ac.cn

Guangzhen Luo
Key Laboratory of Semiconductor Materials Sciences
Institute of Semiconductors, Chinese Academy of Sciences
Beijing 100083, China
gzhenluo@semi.ac.cn

Pengfei Ma
Key Laboratory of Semiconductor Materials Sciences
Institute of Semiconductors, Chinese Academy of Sciences
Beijing 100083, China
pfma@semi.ac.cn

Zheng Wang
Key Laboratory of Semiconductor Materials Sciences
Institute of Semiconductors, Chinese Academy of Sciences
Beijing 100083, China
wangzheng@semi.ac.cn

Yibo Yang
Key Laboratory of Semiconductor Materials Sciences
Institute of Semiconductors, Chinese Academy of Sciences
Beijing 100083, China
yangyibo@semi.ac.cn

Yejin Zhang
Key Laboratory of Semiconductor Materials Sciences
Institute of Semiconductors, Chinese Academy of Sciences
Beijing 100083, China
yjzhang@semi.ac.cn

Jiaoqing Pan
Key Laboratory of Semiconductor Materials Sciences
Institute of Semiconductors, Chinese Academy of Sciences
Beijing 100083, China
jqpan@semi.ac.cn

***Abstract*—We demonstrate a focal plane array chip with 2113 micro-rings and 1024 optical antennas integrated on it using field-of-view splicing technology and antenna multiplexing technology. This chip enables a two-dimensional quasi-continuous scanning (90.3° × 29.5°).**

Keywords—LiDAR, focal plane array, micro-ring optical switch array

I. Introduction

Light detection and ranging (LiDAR) technology is widely used in various fields such as unmanned vehicles due to its potential for three-dimensional imaging, high resolution and large distance range. Compared to conventional LiDAR systems that use mechanical components or micro-electro-mechanical systems for beam steering, all-solid-state beam scanning devices, especially optical phased arrays (OPA), are more stable, smaller, and better suited for mass production [1]–[3]. However, OPA has still not been practically adopted due to challenges such as power management, opto-electronic hybrid packaging, and complexity of control systems [4]. In contrast, focal plane array (FPA) based on lens-assisted beam steering technology has lower power consumption, optical loss, and system complexity [5]–[7]. Therefore FPA is considered as one of the most promising candidates. When the input light is coupled to the FPA chip, it will be routed to a specific antenna by the optical switch array and then emitted into free space. Meanwhile, a lens system will be fixed above the chip to act as a collimator and redirector.

In recent years, many FPA chips based on Mach-Zehnder interferometer (MZI) optical switch array have been reported, and great progress has been made in areas such as system complexity [8]–[10]. However, the number of the FPA antennas will be strictly limited due to the large size of the cascaded MZI optical switch array, which will severely limit the number of effective scanning points. In some reports, micro-ring optical switch array with higher integration density has been used to solve this problem. In addition, the use of micro-rings will also significantly reduce power consumption. For example, in the 1 × N micro-ring optical switch array shown in our previous work [11], only one switch needs to be adjusted for each routing, whereas an MZI optical switch array with the same number of channels would require $\log_2 N$ switches to be tuned at once. From the above results, we can find that FPAs based on micro-ring optical switch array have huge advantages in terms of power consumption.

In this paper, we demonstrate a FPA chip based on an ultra-large scale micro-ring optical switch array with 2113 micro-rings and 1024 optical antennas integrated on it. Relying on the FoV splicing technology and antenna multiplexing technology, this structure achieves a two-dimensional (2D) quasi-continuous scanning with a FoV of 90.3° × 29.5°. Additionally, this FPA chip requires the adjustment of three switches per routing, which is very beneficial for power management. Meanwhile, our design is scalable, allowing for better performance by increasing the number of channels without any more power consumption.

II. Design and Manufacturing

A. Architecture and Scanning Principle

The design diagram of our FPA chip is shown in Fig. 1(a). The overall structure can be divided into four parts: input coupler, antenna multiplexing switch, micro-ring 2D switch network and antenna array. In practice, a lens will be fixed on top of the FPA chip. In the structure we designed, a plano-convex columnar lens is used and the corresponding scanning

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principles are given in Fig. 1(b) and Fig. 1(c). The light from the different antennas on the chip is deflected by the lens to form a one-dimensional (1D) quasi-continuous scanning in the transversal direction (φ). Meanwhile, we can also adjust the wavelength to achieve 1D scanning in the longitudinal direction (θ).

The FPA will receive a limited vertical field of view (VFoV) due to the restricted transmission spectrum of the micro-ring. To solve this problem, we use FoV splicing technology and antenna multiplexing technology in the design. Firstly, we sequentially divide the equally spaced M antennas into N groups with identical design between groups, which means the FPA chip is equivalent to a N-line LiDAR. The M/N antennas within the same group are different, and they correspond to different longitudinal direction when operating at the same wavelength. Meanwhile, as shown in our previous work [11], the VFoVs of these 8 antennas can be overlapped by adjusting the antenna parameters. Antenna multiplexing technology is realized by the antenna multiplexing switch, which can switch the input light to enter the antenna from left or right. With this design, two far-field scanning points with opposite deflection angles can be achieved with one wavelength. This means that we can double the VFoV and effectively utilize the chip area. In summary, we can achieve a large longitudinal scanning in a limited wavelength range using the two designs mentioned above.

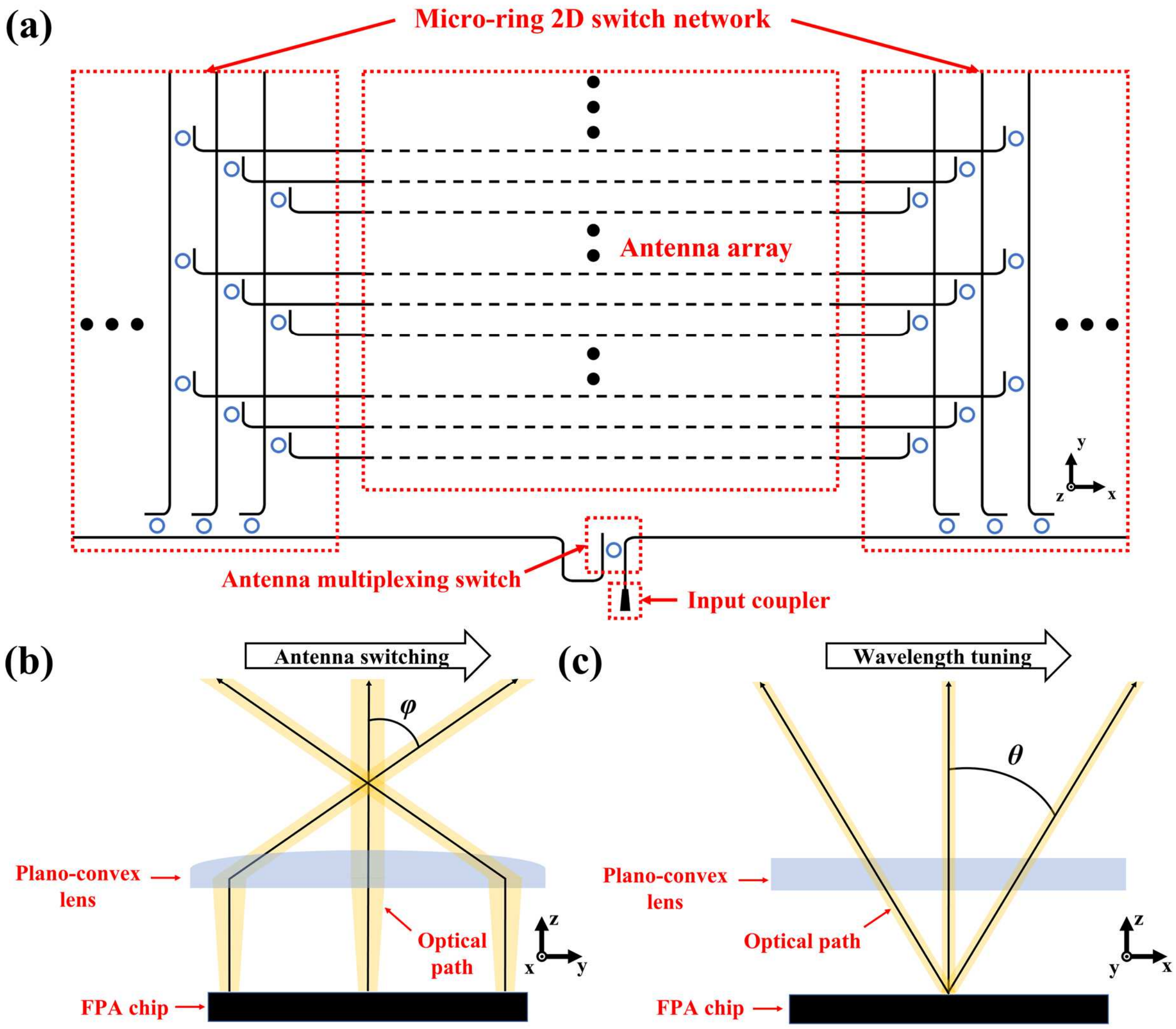

Fig. 1. (a) Design diagram of the FPA chip. (b) Schematic of the working principle in the transversal direction (φ). (c) Schematic of the working principle in the longitudinal direction (θ).

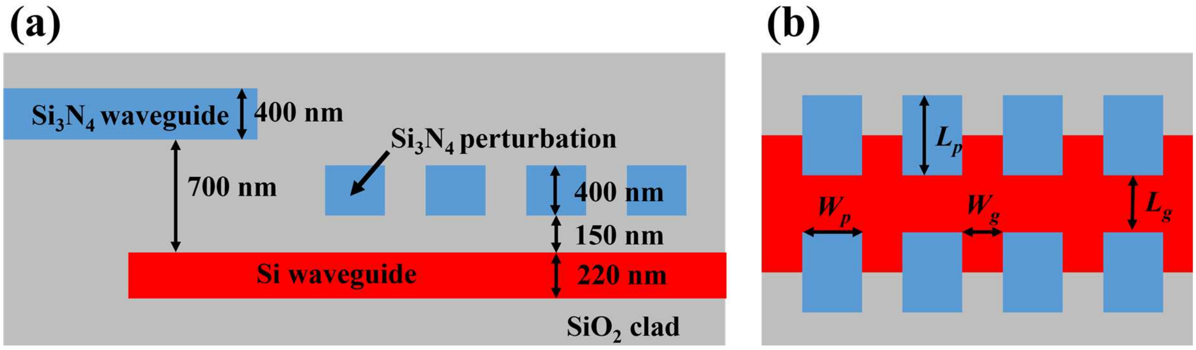

Fig. 2. (a) Side view of an antenna. (b) Top view of an antenna.

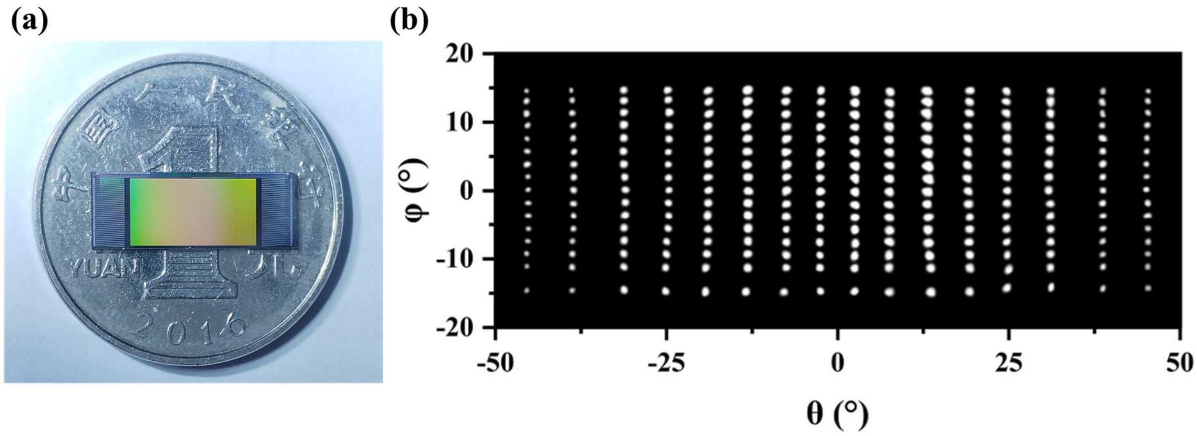

Fig. 3. (a) Photography of the fabricated chip. (b)Beam-steering pattern of the FPA beam scanner at 1550nm (16 lines selected from 128 lines).

B. Parameter and Manufacturing

Based on the above structure, we fabricated the FPA chip using AMF's silicon optical platform. The basic structure of the FPA chip mainly consists of a 33 × 32 × 2 micro-ring switch array and 1024 antennas which are equally spaced into 128 groups. To make the structure more compact, we use 220 nm-thick Si to fabricate the micro-rings. Meanwhile, we use two layers of waveguides spaced at 700 nm to reduce the optical loss of the crossed waveguides. As shown in Fig. 2, top layer is Si_3N_4-waveguide, bottom layer is Si-waveguide, and the optical transition between them is achieved by tapered structures. The antennas are made in the form of Si_3N_4-perturbations with a distance of 150 nm from the Si-waveguide to achieve a large effective length. We designed 8 antennas with overlapping VFoVs by varying the length (L_p), width (W_p) and spacings (L_g and W_g) of the perturbations.

III. CHARACTERIZATION

After packing the fabricated FPA chip, we characterized the beam steering pattern at 1550 nm. We tested 16 lines from the 128 lines in the φ-direction. As shown in Fig. 3(b), the chip achieves a FoV of 90.3° × 29.5°. The spots in the figure is approximately symmetric around $\theta = 0°$, which is because we use the antenna multiplexing technique. In the previous work [11], we have confirmed that the gap between the scan lines (θ-direction) in Fig. 2 can be filled by adjusting the wavelength of the input light. In future work, we will show the full 128 scanning lines of this FPA chip and other spots at different wavelengths.

IV. CONCLUSION

In this paper, we propose a FPA chip applying FoV splicing technology and antenna multiplexing technology. The chip integrates an ultra-large scale micro-ring optical switch array including 2113 micro-rings and 1024 optical antennas. By switching antennas and tuning wavelengths, this chip can achieve a 2D quasi-continuous scanning with a FoV of 90.3° × 29.5°. It is worth mentioning that the design only requires 3 micro-rings to be opened each time the antenna is switched. Overall, our design effectively utilizes the area of the FPA chip and significantly reduces its power consumption.

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