A Switch-based Integrated 2D Beam-steering device for Lidar Application

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Abstract: A switch-based integrated two-dimensional beam-steering device is demonstrated on a silicon nitride platform at 1550nm. The device has O(logN) power consumption for N emitters, allows digital control and achieves 19 dB background suppression.

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Light detection and ranging (Lidar) technology has attracted intense interest for autonomous driving, sensing, wind detection, etc. In Lidar devices, beam steering devices are key components to steer the light beam and scan the target. Conventional beam steering devices such as mechanical steering mirrors have limited steering speed. Recently, many compact beam steering technologies have been investigated including optical phased array (OPA), micro-mirror and liquid crystal. Among these technologies, OPA has become the leading technology and lidar based on integrated OPA has been reported [1]. A beam steering device based on planar lens has also been proposed and demonstrated [2]. It is noted that in many reported works beam steering at one direction is based on wavelength scanning. Wavelength scanning simplifies the device structure. However, for a lidar for medium-distance application such as autonomous driving, the peak power of the light beam can be up to a few hundred watts and it will be very challenging to make a laser with a-few-hundred-watt output peak power and 100-nm wavelength tuning range. Therefore, it is meaningful to develop a new technology to support 2D beam steering on a single wavelength while maintaining low power consumption, easy steering control, good background suppression and good power handling.

In this paper, we propose and demonstrate a switch based integrated 2D beam-steering device for Lidar application at 1550 nm. The device allows 2D beam steering at 1550 nm, has a power consumption of O(logN) (N is the number of on-chip emitters), digital control of beam steering, background suppression of 19 dB and good power handling due to the insulator material.

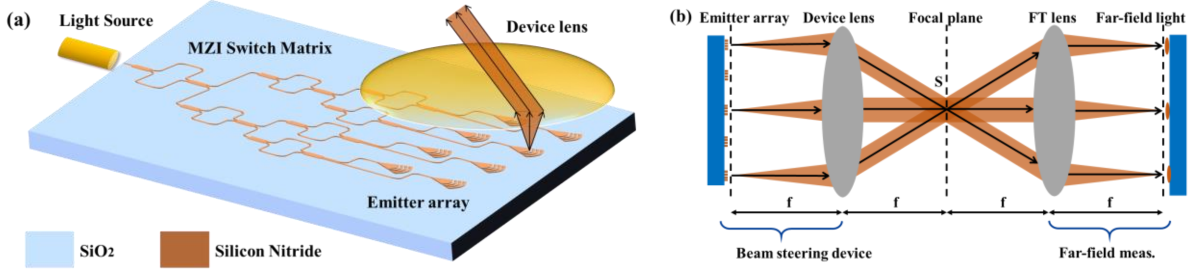

Fig.1 (a) Schematic diagram of the device. (b) Light steering principle of the device.

A schematic diagram of the chip is shown in Fig. 1(a). The device is designed on a silicon nitride (Si_3N_4) platform. The light is coupled to the input waveguide via a standard lensed fiber. The light is then sent to a 1xN switch. The 1xN switch is made of cascaded 1x2 Mach-Zehnder interferometer (MZI) switches with thermal tuning. Each time the light is guided to one output channel of the 1xN switch and emits to the free space via a grating emitter. On the top of the chip, there is a glass lens whose focal plane is overlapped with the surface of the grating emitter array. The principle of the device is shown in Fig. 1(b). The light beams from different emitters are parallel to each other. So they virtually intersect at one point (denoted as "S") on the focal plane of the lens on the other side. If we treat this "S" point as a virtual light source, light beams from different emitters become light beams pointing at different directions. This means beam steering can be achieved by switching light to different emitters on the chip. This beam steering is discrete which is different from the continuous beam steering of OPA. Moreover, the beam pattern near "S" point is the Fourier transform of the beam pattern on the emitter array due to the property of an ideal lens. Meanwhile, the beam pattern in the far field (FF) is the Fourier transform of the beam pattern near "S" point due to the far-field Fraunhofer diffraction. Therefore, the FF beam intensity pattern is fully determined by the beam pattern on the emitter array. This indicates that the beam divergence and beam direction can be engineered by properly choosing the beam diameter of the emitter, emitter spacing and focal length of the lens.

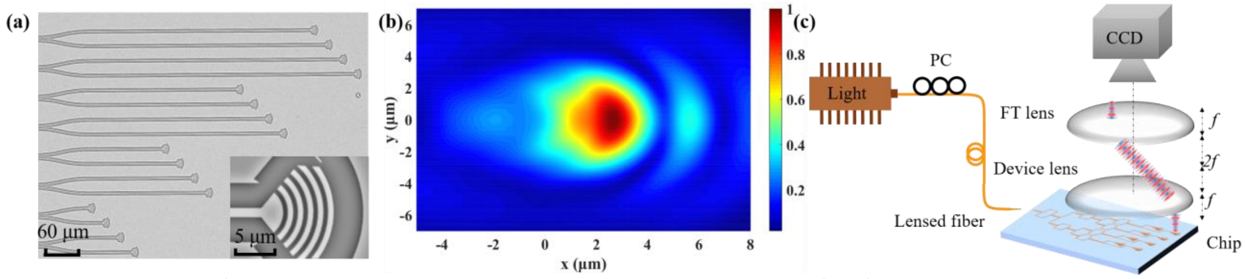

Fig.2 (a) SEM image of the grating emitter array. Inset: single emitter SEM. (b) Intensity profile of grating emitter simulated by FDTD. (c) Experimental setup for the far-field measurement.

This device is then fabricated and characterized. The 1x2 switch is based on MZI structure with thermal tuning. The control of switch is by digital signal with pre-biased voltage because the TiN heaters have fabrication error in each switch. The SEM image of the emitter array is shown in Fig. 2(a). Here a 4x4 array is fabricated, and the closest separation between emitters is 34 μm which can be less with better fabrication. The inset is a zoomed view of a single emitter. The emitter is approximately 8x10 μm large. The emission profile of the grating emitter is simulated with FDTD and the beam diameter is 4x6 μm as depicted in Fig. 2(b). The experimental setup of the far-field measurement is shown in Fig. 2(c). A 1550 nm CW light is coupled into the chip through a lensed fiber. The light is emitted to space by the grating after 1xN switch. As we have depicted in Fig. 1(b), two lenses are utilized in the setup. The device lens is set to steer the beam, and the other lens (denoted as "FT lens") is added to do the Fourier transform for far-field measurement. The microscope with InGaAs CCD is focused on the focal plane of the FT lens.

In the experiment, the FT lens has the same specifications as the device lens. So the device lens and FT lens form a 4f system with magnification equal to 1. And the image captured by the microscope is exactly the beam pattern of the emitter array, which is consistent with the above analysis that the FF pattern is determined by the beam pattern of the emitter array. Fig. 3(a) shows the intensity profile of a single spot. A background suppression of 19 dB (255:3) can be observed. In principle, the background suppression ratio in our device is only determined by the extinction ratio of the 1x2 switch, which is expected to exceed 20 dB. Fig. 3(b) shows a FF pattern when all the 1x2 switches are tuned to have 50:50 output as beam splitters and all the emitters emit light. Very good beam quality and clean background can be clearly observed. The spot sizes are slightly different because the focal plane of the lens is not ideally overlapped with the plane of the emitter array. The inset is the beam pattern with only one emitter switched on. Although our device steers beam discretely, the FF beam spots can also be connected to avoid blind zone by shifting the plane of the emitter array away from the focal plane of the lens (de-focusing). The corresponding FF pattern is shown in Fig. 3(c). The horizontal beam spots are connected. There exists interference pattern because all the emitters are switched on. In practical application, only one emitter will work each time and the beam pattern is shown in the inset of Fig. 3(c). For power consumption, only the switches on the optical path from the input to the desired output emitter are operated. So the power consumption is O(logN) for N emitters. The number of resolved points in the far field is equal to the number of emitters on the chip.

Fig.3 (a) Intensity profile of a single spot. (b) Measured far-field pattern of the grating emitter array. (c) Measured far-field pattern of grating emitter array by de-focusing the device lens. Insets of (b) and (c): Beam pattern with only one emitter switched on.

In conclusion, a switch-based integrated 2D beam-steering device is demonstrated at 1550 nm. 4x4 point beam steering have been achieved. The device has O(logN) power consumption for N emitters, digital control and 19 dB background suppression.

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