Si PIC Based on Photonic Crystal for LiDAR Applications

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Abstract: Wide-range nonmechanical beam steering is available by an array of Si photonic crystal slow-light waveguides and their switching without complicated control. FMCW LiDAR action is obtained with this beam steering on a Si photonics chip.

1. Introduction

LiDAR is developed worldwide as a 3D sensor for autonomous vehicles, robots/drones, security, mapping, survey, capture entertainment, etc. In particular, solid-state LiDAR has attracted great attention due to its potential of compact size, low-cost production, high-speed and flexible operation, and stability against vibrations in mobiles. Here, the biggest challenge is nonmechanical beam steering, and for this purpose, many groups are now studying optical phased array fabricated by Si photonics [1–6]. It is attractive on the point that arbitrary optical beams are formed by a flat device with no additional components and their alignment, while remaining challenges in the integration of a number of optical antennas, precise and complicated control of their phases with a low power, and solving the tradeoff between a steering range, beam divergence and efficiency.

As an alternative approach, we have proposed to use slow light in an array of Si photonic crystal waveguide gratings [7,8]. Slow light shows large angular dispersion so that it makes the gratings sensitive to the wavelength and waveguide refractive index and allows wide range beam steering. It is independent of the beam divergence, which can be reduced by increasing the beam aperture. In this presentation, we present the design and fabrication of such a device and demonstrate the 2D beam steering, as well as the FMCW LiDAR action, which is under testing in a full-integrated Si photonics PIC, as shown in Fig. 1.

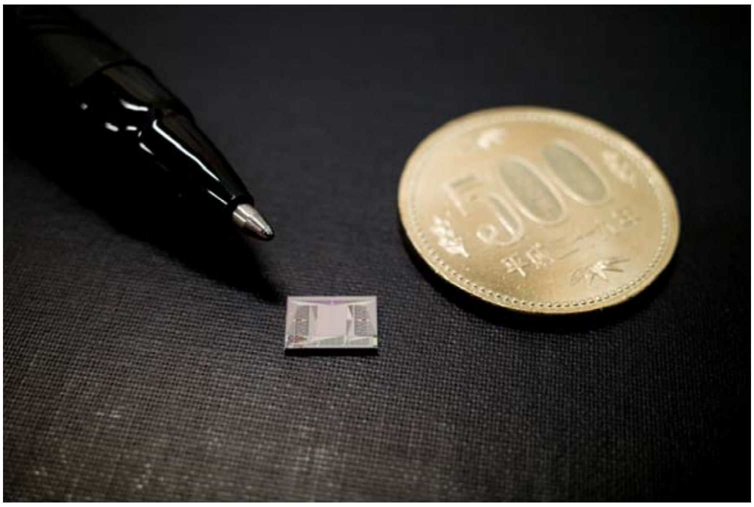

Fig. 1 Si photonics FMCW LiDAR chip equipped with nonmechanical beam steering device, modulator and PDs.

2. Beam Steering

For the nonmechanical beam steering, we employed Si lattice-shifted photonic crystal waveguides (LSPCWs) with a shallow diffraction grating, which is formed at the surface of the Si layer and radiates guided slow light into the free space as a fan beam. Fine design of the grating enhances the upward emission with reducing the internal reflection loss and divergence of the fan beam in the direction across the LSPCW. The beam divergence in the direction along the LSPCW is reduced by moderately suppressing the emission rate so that the beam aperture is increased. The beam divergence of 0.1° and 0.03° are obtainable by setting reasonable rates in 1 mm and 3 mm long devices, respectively. The fan beam is collimated in the direction across the LSPCW into a spot profile by a particularly designed prism lens. It maintains the collimation condition, even though the beam angle is changed by sweeping the wavelength and/or changing the waveguide index by, e.g., thermo-optic (TO) effect. Large angular dispersion of slow light increases the steering range ~7 times wider than that of a simple Si waveguide grating. Theoretically, the beam steering range is limited by the band edge and light line of the total internal reflection condition in this waveguide to 0°–30°. But, since the waveguide loss increases and the emission efficiency decreases in the range of 0°–5°, the effective range becomes 5°–30°. When the light propagation direction is switched and the angles are converted by the prism lens, the final steering range expected is from –25° to +25° (50° in total). If the beam divergence is reduced to 0.03°, the number of resolution points becomes 1660. The lateral beam steering is carried out by selecting one LSPCW from the array so that the relative position is changed against the prism lens. Here, the number of resolution points corresponds to the number of LSPCWs in the array.

Figure 2 shows the 2D beam steering by this concept, where the beam is steered in the lateral direction by the wavelength sweep as well as the switching of the light propagation direction, while in the vertical direction, by the selection of the LSPCW from 16 array using a TO switch tree. Thanks to the prism lens, the continuous steering is available without adjustment of the lens position. In this preliminary experiment, the steering range was 26° × 4.5° and the beam divergence was 0.16°, meaning that the number of resolution points was 162 × 16 = 2,600. This value will be increased to more than 20,000 mainly by reducing the fabrication error of the prism lens. Flexible beam steering was also observed by simply controlling the wavelength and switch. The TO heating of the LSPCW instead of the wavelength sweep also showed comparable performance with a response speed of 100 kHz order [9].

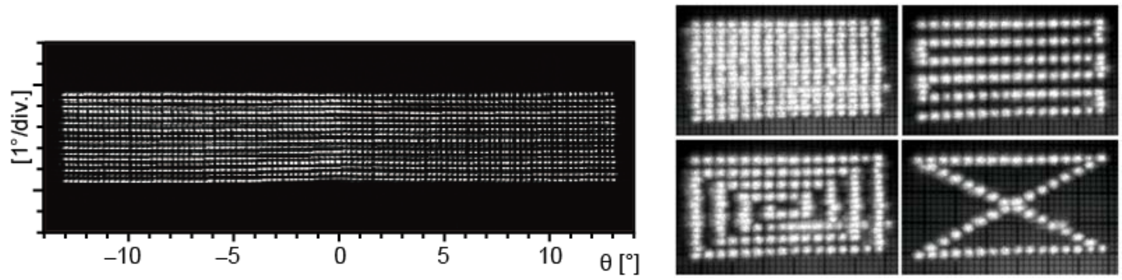

Fig. 2 Wide 2D beam steering (left) and flexible steering (right).

3. LiDAR Operation

Si photonics particularly fits to FMCW LiDAR because FMCW LiDAR does not use a 10 W order high-power pulse like that of TOF LiDAR, which is not acceptable in Si due to the two photon absorption, but uses 10 mW order CW light at eye-safe wavelengths around 1.55 μm [10, 11]. FMCW based on the coherent detection has a high sensitivity and detects both the range and speed of objects. The chip in Fig. 1, which was fabricated by using 200 mm CMOS process (minimum feature size of 130 nm), is equipped with all the FMCW's components except for active devices, i.e., modulator, interferometric circuit, and balanced PDs as well as the beam steering device. Previously, the ranging action using the modulator and beam steering device has been observed with a fiber delay line [12]. Now, it is also observed with a free-space round-trip beam. We started testing the LiDAR operation of the Fig. 1 chip, and some results will be presented at the conference.

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