Photonic-Integrated and Highly-Scalable FMCW LiDAR Concept based on Titled Grating Couplers

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Abstract *Most Photonic-Integrated FMCW LiDAR systems rely on beam steering with optical phased arrays, which require complex control of the individual phase modulators in the array. We propose a fully-integrated LiDAR chip that relies on tilted grating couplers, and does not require any phase modulators.*

Introduction

The development of the Photonic Integrated Circuits (PIC) enables promising technologies to become available. One of these promising technologies is the LiDAR onchip for high precision distance measurement[1]. The advantages of making the LiDAR onchip are the smaller footprint and the large scale fabrication capacity which leads to the reduction of manufacturing cost per system. PIC LiDARs rely on Optical Phased Arrays (OPA) for beam shaping and beam steering. Steering in Optical Phased Arrays is achieved by applying a gradual phase change on each emitter element. The phase change is made by thermo (for Silicon technology) or electro (for InP) optic modulation. This can dramatically increase the complexity of the device and also make it difficult for the future characterization. In this paper, we present a new FMCW-LiDAR concept based on tilted grating couplers (Fig. 1), which does not require any fast phase modulators, and can be integrated on any photonic technology platform.

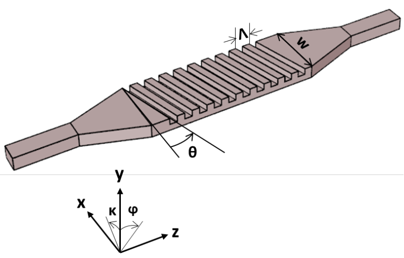

Fig. 1: Schematic of tilted grating coupler. θ is the tilted angle of the grating teeth and Λ is the period. κ zenith direction of radiation and ϕ azimuth direction of radiation

System Description

The proposed architecture is based on pure passive structures, as it does not require OPAs or a large number of individually-controlled phase shifters to accomplish 3D environmental mapping. Furthermore, we simultaneously illuminate and measure the light received from all angular directions to reduce the capture time of the point cloud. This work describes our concept for a LiDAR and presents results for the design of the tilted Grating Coupler.

Figure 2 illustrates the concept of our proposed FMCW LiDAR PIC based on tilted grating couplers. The concept relies on transmitting multiple beams towards all directions through a transmitter grating coupler (TxGC) and receiving the signal reflected from a target using a receiver (Rx) GC located directly next to the Tx-GC.

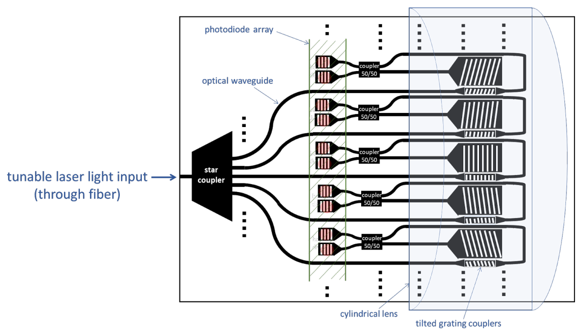

Fig. 2: Schematic overview of the FMCW LiDAR PIC showing the linear array of gradually-tilted grating couplers.

A cylindrical lens system is used to collimate the beam from the Tx-GC to achieve a very small diffraction angle. Similarly, an incoming signal from the same direction will focus on the Rx-GC situated directly next to the Tx-GC. Figure 2 shows a schematic of the complete FMCW LiDAR PIC. Light from a fast-tunable laser is passed through a phase modulator, and then divided by a star coupler among all the Tx-GCs. Each Tx-GC then radiates the light out of the PIC toward one specific direction determined by the tilting θ of the grating coupler and is collimated by the cylindrical lens. After reflection from a target, the light is reflected back to the PIC in the same direction, and therefore focused by the lens on almost the same location as the Tx-GC. In order

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to have a minimal deviation between the Tx-GC- and Rx-GC acceptance angle, we have designed the Tx-GC waveguide to be narrower than that of the Rx-GC. After the Rx-GC, the incoming signal is mixed with a portion of the signal that was left over after the Tx-GC in a 2x2 multi-mode interference (MMI) coupler and guided towards the balanced detector. Photodetectors are either flip-chipped on top of the chip, or integrated on the chip.

Tilted Grating Coupler Design

In order to test the feasibility of our architecture and calculate the field-of-view (FOV), we have simulated the slanted grating coupler performance for the SOI waveguide structure shown in the figure 3.

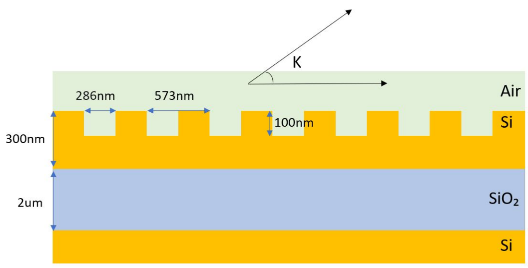

Fig. 3: Illustration of the slanted GC waveguide structure.

Fig. 1 shows top view of the slanted grating coupler illustrating how the tilt in the grating coupler was introduced. Fig. 4a shows the relation between the relation between the GC tilt angle theta and the radiation direction (see figure 1). Fig. 4b shows the far-field pattern of slanted GC for 2 different positive and negative slanting angles. This result shows that the radiation angle can be shifted up to $\pm 50^\circ$ by tilting the gratings up to $\pm 16^\circ$ before the radiated power starts dropping (see figure 4c). For this implementation in SOI technology only 30% is radiated upward, and therefore for future implementations more directional grating couplers are preferred such as the ones described in[2].

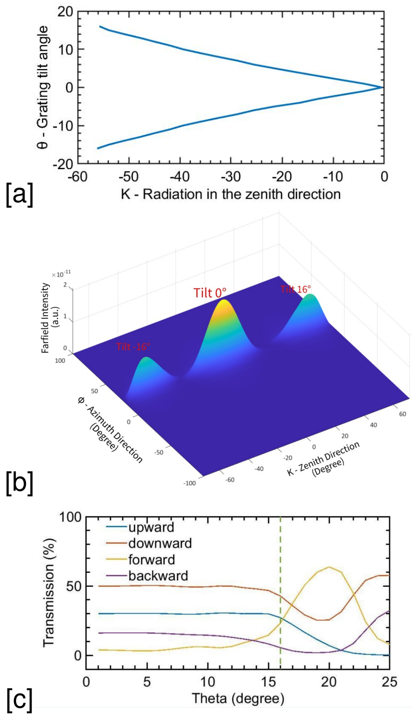

Fig. 4: a) Radiation angle versus tilt of the grating. b) Farfield pattern for 0 +16 -16 degrees. c) Simulated optical powers coupled out of the grating couplers in all direction

Fig. 5 shows the steering of the radiation angle in the azimuth direction ϕ which is controlled by the wavelength of the laser. This plot shows that the steering in this direction is limited to around 12° when changing the wavelength by 100nm.

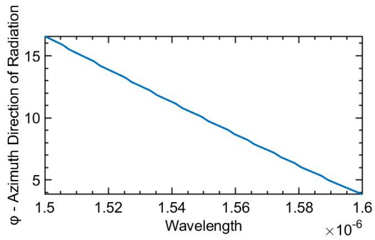

Fig. 5: Simulated diffraction angle versus wavelength

The comparison between different (grating coupler array, and edge fire[3]) of architectures was also made to test the steering capabilities of the proposed tilted grating coupler system. It was reported in[3] that the experimentally measured steering range for edge-fire is $\pm 34^\circ$. System with 250 waveguides, with the distance of 0.775μm between each elements and the width of 0.5μm was simulated. The figure 6a shows the farfield of the edge-fire array with the steering range of 19.76°. Another architecture that was compared is an array of untilted GCs. The farfield of the grating coupler array (GC OPA) is shown on the figure 6b. For GC OPA the simulated steering range is $\pm 20^\circ$ with 1000 GC antennas with the pitch distance of 1μm and the width of the grating coupler 0.5μm and the number grating teeth is 50. For the cases of OPA GC and edge-fire array undesirable side lobes appear while steering. The phase error distribution[4] that can decrease the quality of the steered beam by introducing noise is also taken into the account during the simulations of edge-fire and grating coupler array. Finally, the farfield distribution of the tilted grating array with 33 elements is shown the figure 6c.

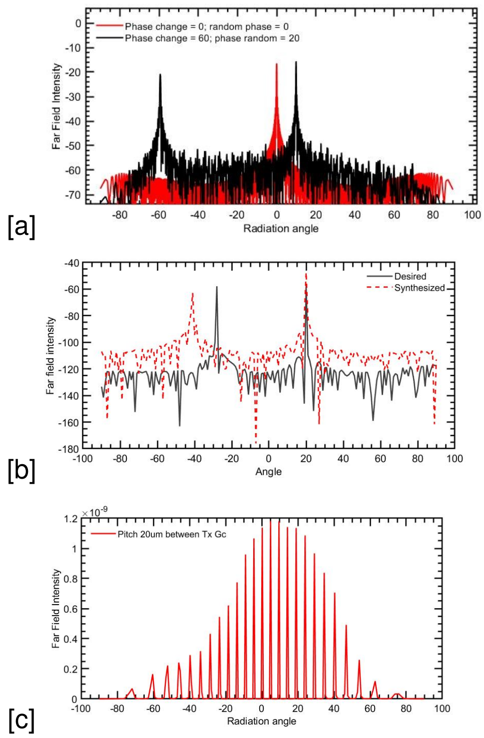

Fig. 6: a) Steering in edge fire array. b) Steering in grating coupler array. c) Farfield Tilted grating coupler array.

Optical System

In order to focus light at uniform distance on top of every single Rx Gc a fixed focal length mobile phone camera lens system was investigated (Fig. 7) using Zemax simulation software[5]. The size of camera lens is relatively small only 6.2mm which allows to make the system more compact. The simulated camera lens system can focus light from $\pm 34^{\circ}$.

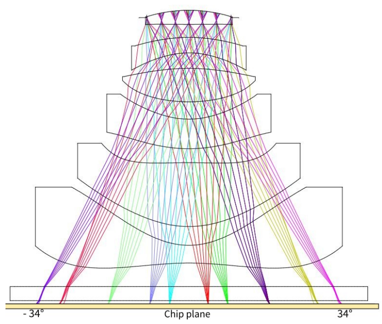

Fig. 7: Camera lens system for the chip.

The width of the Rx Gc-s are calculated from the FWHM of point spread functions from the focused collimated beams at different angles (Fig. 8).

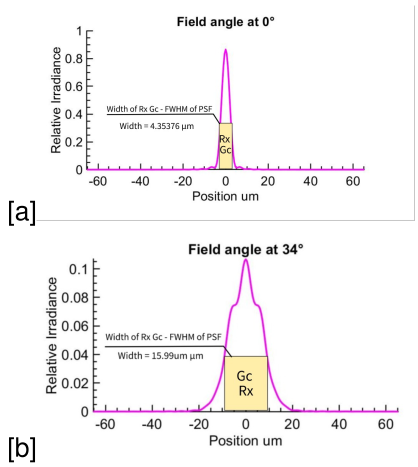

Fig. 8: a) Invistigated Lense system b)FWHM of PSF at 0 degrees. c) FWHM of PSF at 34 degrees.

For the experimental measurement of the system a commercially available Thorlabs lens system (MVL4WA) which is used to focus light on the sensor array will be used. ML4WA has high field of view that allows to focus light from $\pm 50^{\circ}$ Because of aberrations in the lens system the width of the Rx Gc-s will slightly increase at the highest angles (Fig. 9b).

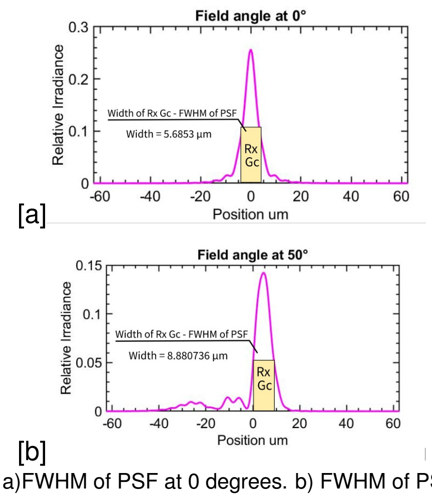

Fig. 9: a)FWHM of PSF at 0 degrees. b) FWHM of PSF at 50 degrees.

Conclusion

We have proposed and evaluated a concept for a FMCW LiDAR PIC, and show the feasibility of the conceptbased on simulations performed on slanted grating couplers. We have simulated a field-of-view of 100° by 12°.Our architecture offers many advantages over existing LiDAR architectures, such as highly scalable, flexibility of implementation on any waveguide platform since the laser and photodetectors can be placed off-chip.

Acknowledgements

H2020-MSCA-ITN-2019-DRIVE-IN N860763.

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