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, with a FOV of 100° x 35° 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 be-come available. One of these promising technologies is the on chip LiDAR for high precision distance measurement [1]. The advantages of making the LiDAR on chip are the smaller footprint and the large-scale fabrication capacity which leads to the reduction of manufacturing cost per system. Most PIC based LiDARs rely on Optical Phased Arrays (OPA) for beam shaping and 2D 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 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.

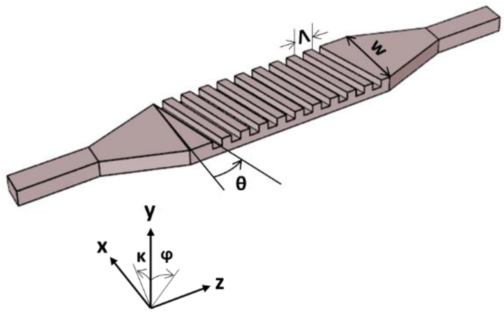
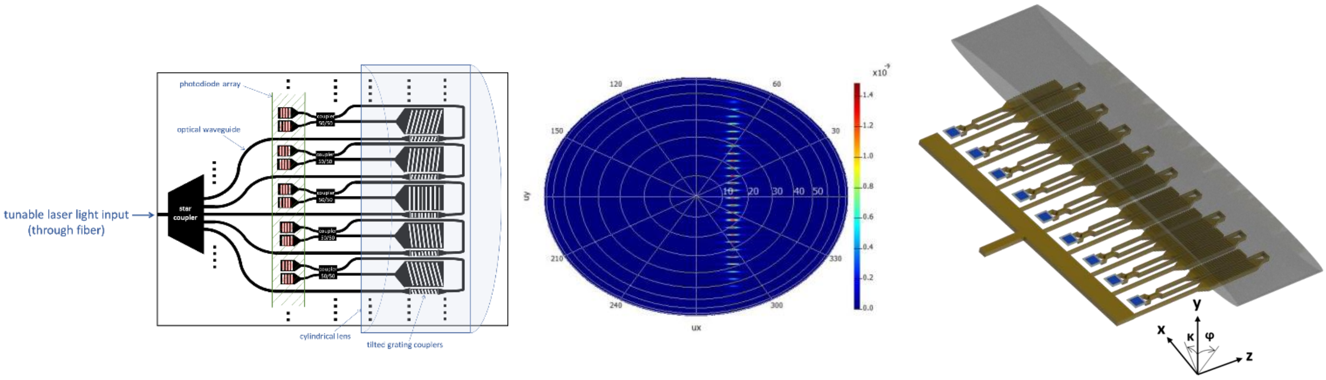


Fig. 1. *Schematic of tilted grating coupler. θ is the tilted angle of the grating teeth and Λ is the period. κ zenith direction of radiation and φ azimuth direction of radiation.*

System Description

The proposed architecture is based on pure passive structures, as it does not require OPAs or many 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 2a 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) (Fig. 2b) and receiving the signal reflected from a target using a receiver (Rx)GC located directly next to the Tx-GC.



a) b) c)

Fig. 2. *a) Schematic overview of the FMCW LiDAR PIC showing the linear array of gradually tilted grating couplers. b) The farfield plot from the proposed system with full environmental 3D mapping. c) 3D schematics of the system with cylindrical lens on top.*

A cylindrical lens system (Fig. 2c) 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 2a shows a schematic of the complete FMCW Li-DAR PIC. Light from a fast-tunable laser is 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 to the PIC in the same direction, and therefore focused by the lens on almost the same location as the Tx-GC. The incoming signal in Rx-GC is mixed with a portion of the signal that was left over in 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.

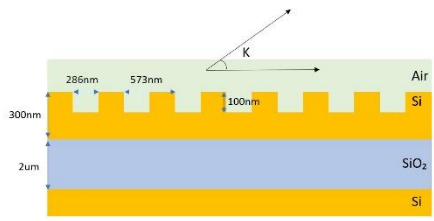


Fig. 3: *Illustration of the slanted GC waveguide structure.*

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 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 ±50° by tilting the gratings up to ±16° before the radiated power starts drop-ping (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].

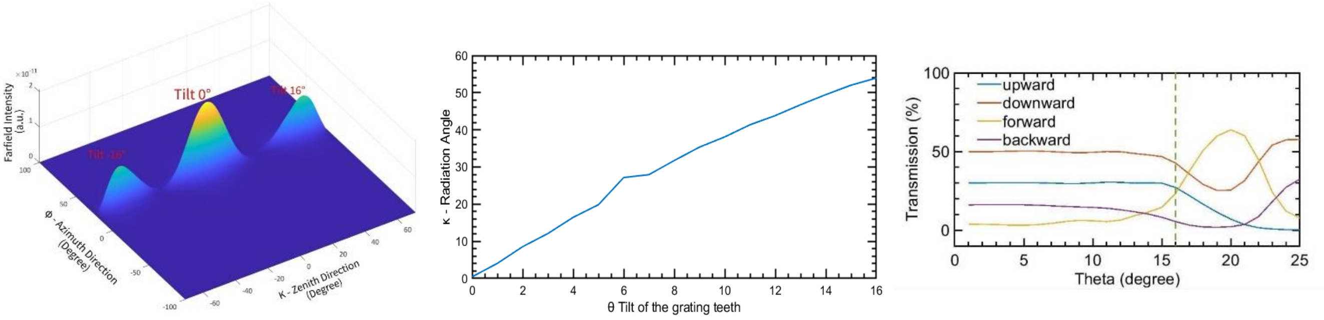


__Fig. 4__: a) Radiation angle versus tilt of the grating. b) Farfield pattern for 0 +16 -16 degrees. c) Simulated optical powers coupled out of the grating couplers in all direction.

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 35° when changing the wavelength by 100nm.

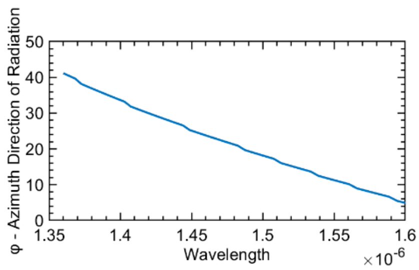


***Fig. 5:** Simulated diffraction angle versus wavelength*

To capture the maximum light along the z axis the length of the grating coupler was also calculated for different directions and radiations and for etch depths of 5nm and 10nm (Fig.6).

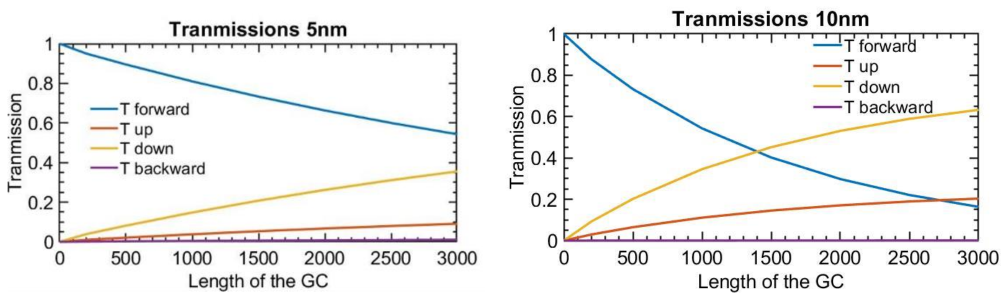
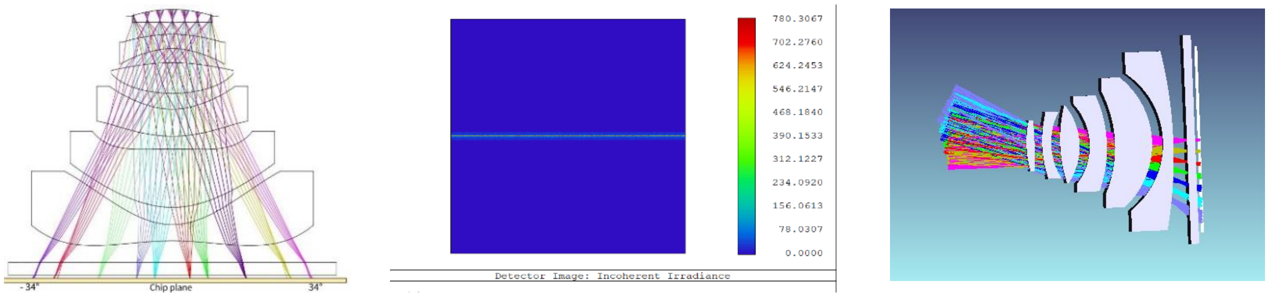


***Fig. 6:** The desired length of 3mm for 5nm and 10nm etch depth.*

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. 7a) 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 ±34°.



a) b) c)

Fig. 7: a) Camera lens system for the chip. b) Focusing of investigated camera along the z axis. c) extruded lens system

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).

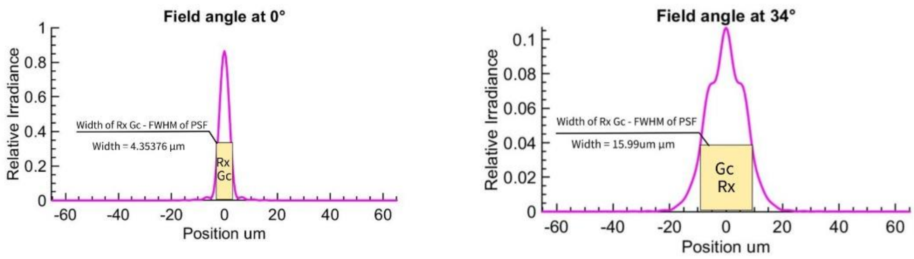


Fig. 7: a) Investigated lens system b) FWHM of PSF at 0 degrees. c) FWHM of PSF at 34 degrees.

Conclusion.

We have proposed and evaluated a concept for a FMCW LiDAR PIC and show the feasibility of the concept based on simulations performed on slanted grating couplers. We have simulated a field-of-view of 100° by 35°. 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.

References

[1] X. S. et al., “Si photonics for practical lidar solutions”,2019

[2] C. L. et al., “Grating couplers on silicon photonics: Design principles, emerging trends and practical issues.”,2020.

[3] C. R. Michael R. Kossey and A. C. Foster, End-fire silicon optical phased array with half wavelength spacing. APL Photonics 3, 2018.

[4] G. C. et al, “Effects on phased arrays radiation pattern due to phase error distribution in the phase shifter operation”, 2016.

[5] Y. T. Liu, Review and design a mobile phone camera lens for 21.4 megapixels image sensor, The University OF Arizona, 2017.