

**THREE-DIMENSIONAL-MAPPING TWO-DIMENSIONAL-SCANNING LIDAR
BASED ON ONE-DIMENSIONAL-STEERING OPTICAL PHASED ARRAYS AND
METHOD OF USING SAME**

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Patent Application No. 14/460,369 filed on August 15, 2014, the contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to the field of environment sensing, and more particularly to the use of Time of Flight (ToF) lidar sensors for real-time three-dimensional mapping and object detection, tracking, identification and/or classification.

BACKGROUND OF THE INVENTION

A lidar sensor is a light detection and ranging sensor. It is an optical remote sensing module that can measure the distance to a target or objects in a scene, by irradiating the target or scene with light, using pulses (or alternatively a modulated signal) from a laser, and measuring the time it takes photons to travel to said target or landscape and return after reflection to a receiver in the lidar module. The reflected pulses (or modulated signals) are detected, with the time of flight and the intensity of the pulses (or modulated signals) being measures of the distance and the reflectivity of the sensed object, respectively.

Conventional lidar sensors utilize mechanically moving parts for scanning laser beams. In some systems, including certain systems used in automotive applications, such as advanced driver assist systems (ADAS) and autonomous driving systems, it is preferred to use solid state sensors for a variety of potential advantages including but not limited to higher sensor reliability, longer sensor lifetime, smaller sensor size, lower sensor weight, and lower sensor cost.

Radio frequency (RF) delay lines used for the creation of radar phased arrays were used several decades ago for the solid state steering of radar signals. Photonic integrated circuit (PIC) based delay lines combined with detectors and RF antenna arrays were used two decades ago to improve the precision of delays in the solid state steering of radar signals. PICs with microscale and nanoscale devices can be used to produce optical phased arrays

(OPAs), comprising tunable optical delay lines and optical antennas, for the solid state steering of laser beams.

Phased arrays in the optical domain that are produced to date are complex, costly and/or have a different purpose than beam forming and beam steering; some combine spatial filters, optical amplifiers and ring lasers (US 7,339,727), some involve a plurality of optical input beams (US 7,406,220), some involve volume diffraction gratings and a plurality of input directions (US 7,428,100), some combine beams of a plurality of wavelengths (US 7,436,588), some have optical phase reference sources and gain elements (US 7,489,870), some have predetermined areas in the field of view and a plurality of beam forming elements (US 7,532,311), and some have multiple frequencies and multiple optical phase reference sources (US 7,555,217).

Two-dimensional beam forming and steering phased arrays in the optical domain that are produced to date have low yields and are costly because they steer in two dimensions with a complex two-dimensional pixel array.

SUMMARY OF THE INVENTION

A plurality of one-dimensional (1D) planar beam, forming and steering optical phased array (OPA) chips, form a two-dimensional (2D) scanning solid-state lidar, may enable manufacturing of three-dimensional (3D) mapping time-of-flight lidars at high yield and low cost resulting from the simplicity of said 1D OPA chips.

According to a first aspect of the present invention, there is provided a three-dimensional mapping two-dimensional-scanning time-of-flight lidar ranging apparatus comprising a plurality of one-dimensional optical-phased-array-based laser beam forming and steering photonic integrated circuit chips.

According to a second aspect of the present invention, there is provided a method for three-dimensional mapping utilizing two-dimensional-scanning time-of-flight lidar ranging apparatus comprising a plurality of one-dimensional optical-phased-array-based laser beam forming and steering photonic integrated circuit chips.

DESCRIPTION OF THE DRAWINGS

The following drawings are illustrative of embodiments of the present invention and are not intended to limit the invention as encompassed by the claims forming part of the application.

The schematic diagram of Figure 1 depicts a plurality of 1D planar beam forming and steering optical phased array chips 10. The double-headed arrow 20 lies in the steering plane within the field of view. A graded-index (GRIN) lens 30 is used with each chip to reduce the spot size in the dimension perpendicular to the steering direction. Alternatively, a geometric refractive lens, a diffractive optical element (DOE), or a holographic optical element (HOE) could be used to achieve said spot size reduction.

The schematic diagram of Figure 2 depicts a plurality of 1D planar beam forming and steering optical phased array chips 10. The double-headed arrow 20 lies in the steering plane

within the field of view. The spot size in the dimension perpendicular to the steering direction is reduced with an on-chip grating 40.

DETAILED DESCRIPTION OF THE INVENTION

A lidar-based apparatus and method are used for the solid state steering of laser beams using Photonic Integrated Circuits (PICs). Integrated optic design and fabrication micro- and nanotechnologies are used for the production of chip-scale optical splitters that distribute an optical signal from a laser essentially uniformly to an array of pixels, said pixels comprising tunable optical delay lines and optical antennas. Said antennas achieve out-of-plane coupling of light.

As the delay lines of said antenna-containing pixels in said array are tuned, each antenna emits light of a specific phase to form a desired far-field radiation pattern through interference of these emissions. Said array serves the function of solid state optical phased array (OPA).

By incorporating a large number of antennas, high-resolution far-field patterns can be achieved by an OPA, supporting the radiation pattern beam forming and steering needed in solid state lidar, as well as the generation of arbitrary radiation patterns as needed in three-dimensional holography, optical memory, mode matching for optical space-division multiplexing, free space communications, and biomedical sciences. Whereas imaging from an array is conventionally transmitted through the intensity of the pixels, the OPA allows imaging through the control of the optical phase of pixels that receive coherent light waves from a single source.

A plurality of one-dimensional (1D) planar beam forming and steering optical phased array chips are simple building blocks of the transmitter in a solid-state lidar, enabling manufacturing of lidars with high yields and at low cost.

The vertical dimension (i.e., the dimension perpendicular to the steering direction) of the spot size of each said chip is reduced with at least one off-chip lens or at least one on-chip grating.

Types of said off-chip lens include but are not limited to:

- Refractive lens
- Graded-index (GRIN) lens
- Diffractive optical element (DOE)
- Holographic optical element (HOE)

Each chip containing an OPA PIC is preferably compatible with a complementary metal-oxide-semiconductor (CMOS) process.

The optical power coupled into the plurality of chips can originate from a single laser or from a plurality of lasers.

What is Claimed is:

1. A three-dimensional mapping two-dimensional-scanning time-of-flight lidar ranging apparatus comprising a plurality of one-dimensional optical-phased-array-based laser beam forming and steering photonic integrated circuit chips.
2. The apparatus of claim 1 wherein said plurality of photonic integrated circuit chips form and steer laser beams utilizing as means of beam size control in the direction normal to the steering plane of said one-dimensional optical phased array at least a subset of a set of elements comprising:
 - at least one off-chip lens; and
 - at least one on-chip grating.
3. The apparatus of claim 2 wherein said at least one off-chip lens comprise a subset of a set of elements including but not limited to:
 - at least one refractive lens;
 - at least one graded-index lens;
 - at least one diffractive optical element; and
 - at least one holographic optical element.
4. The apparatus of claim 1 wherein the light signals coupled into the said plurality of photonic integrated circuit chips are generated from a single laser.
5. The apparatus of claim 1 wherein the light signals coupled into the said plurality of photonic integrated circuit chips are generated from a plurality of lasers.
6. A method for three-dimensional mapping utilizing two-dimensional-scanning time-of-flight lidar ranging apparatus comprising a plurality of one-dimensional optical-phased-array-based laser beam forming and steering photonic integrated circuit chips.
7. The method of claim 6 wherein said plurality of photonic integrated circuit chips form and steer laser beams utilizing as means of beam size control in the direction normal to the steering plane of said one-dimensional optical phased array at least a subset of a set of elements comprising:

at least one off-chip lens; and
at least one on-chip grating.

8. The method of claim 7 wherein said at least one off-chip lens comprise a subset of a set of elements including but not limited to:

at least one refractive lens;
at least one graded-index lens;
at least one diffractive optical element; and
at least one holographic optical element.

9. The method of claim 6 wherein the light signals coupled into the said plurality of photonic integrated circuit chips are generate from a single laser.

10. The method of claim 6 wherein light signals coupled into the said plurality of photonic integrated circuit chips are generated from a plurality of lasers.