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 one-dimensional (1D) planar beam forming and steering optical phased array chip is a simple building block of a two-dimensional (2D) beam forming and steering solid-state lidar, enabling manufacturing of said lidars at high yield and low cost through the use of a plurality of said chips. Innovative Photonic Integrated Circuit (PIC) chip architectures that follow Design for Manufacturing (DFM) rules enable said building blocks.

According to a first aspect of the present invention, there is provided an optical-phased-array-based one-dimensional beam forming and steering photonic integrated circuit apparatus comprising: at least one optical power splitter; at least one optical phase shifter; and at least one out-of-plane optical coupler laid out in a pixel array configuration.

According to a second aspect of the present invention, there is provided a method for optical-phased-array-based one-dimensional beam forming and steering utilizing a photonic integrated circuit apparatus comprising: at least one optical power splitter; at least one optical phase shifter; and at least one out-of-plane optical coupler laid out in a pixel array configuration.

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 the splitting section of a 1D planar beam forming and steering optical phased array chip, said splitting section comprising a 1xL Y-branch tree **20** followed by 1xM multimode interference couplers **30**, resulting in a 1xN splitter (where LxM=N, e.g., 8x128=1024).

The schematic diagram of Figure 2 depicts a 1D planar beam forming and steering optical phased array chip, said chip comprising a laser **10**, a splitting section comprising a Y-branch tree **20** and multimode interference couplers **30**, optical phase shifters **40**, and out-of-plane optical couplers **120** laid out in a one-dimensional pixel array configuration. A graded-index (GRIN) lens **140** is used to reduce the spot size in the dimension perpendicular to the steering direction. Alternatively, a standard geometric refractive lens, a diffractive optical

19. The method of claim 16 wherein each pixel has associated with it an independent phase shifter.

20. The method of claim 16 wherein a plurality of said pixels are banded by having combined phase shifters.