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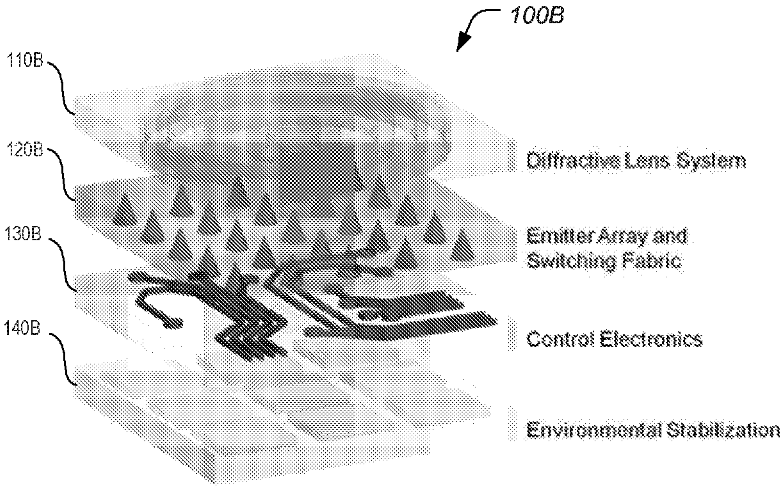

FIG. 1B

(57) **Abstract:** The technology disclosed in this patent document can be used to implement beam steering in optical systems and photonic devices, to provide a nonmechanical beam steering system for projecting optical energy and controlling the direction of the optical energy using a collection of devices and components that are fixed in position to selectively direct light from an array of different optical emitters at different locations.

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PHOTONIC BEAM STEERING AND APPLICATIONS FOR OPTICAL COMMUNICATIONS

PRIORITY CLAIMS AND RELATED PATENT APPLICATIONS

[0001] This patent document claims the priority and benefits of U.S. Provisional Application No. 62/651,025 entitled "Photonic Beam Steering and Applications in Wavelength-Division Multiplexed (WDM) Free-Space Transceivers for Optical Communications" and filed on March 30, 2018. The entirety of the above application is incorporated by reference as part of the disclosure of this patent document.

TECHNICAL FIELD

[0002] The technology disclosed in this patent document relates to beam steering in optical systems and photonic devices.

BACKGROUND

[0003] Steering of one or more optical beams is an important operation in many optical devices or systems and various beam steering mechanism are based on a physical or mechanical motion of an optical element, such as one or more mirrors, lenses, prisms, or a combination of different optical elements, to change the direction of an optical beam. Such beam steering designs tend to be bulky, are subject to tear and wear due to the motion between different components over time and are prone to reliability issues.

SUMMARY

[0004] The technology disclosed in this patent document relates to beam steering in optical systems and photonic devices.

[0005] In one aspect, for example, the disclosed technology can be implemented to provide a device including an array of light emitters located at different locations, each light emitter operable to produce an optical beam that is associated with a location of the light emitter and is different from another optical beam produced by another light emitter due to the location of the light emitter being different from a location of another light emitter, an optical projection device located at a fixed position relative to the array of light emitters in optical paths of the optical beams from the array of light emitters, the optical projection device operable to direct each optical beam to a particular beam direction that is associated with a location of each light emitter relative to the optical projection device and is different from any other beam directions, the optical projection device structured to include no moving part, and a control circuit coupled to the array of light emitters and operable to turn on or off the light emitters to project one or more optical beams from the light emitters to the optical projection device which in turn directs the received one or more optical beams to corresponding one or more particular beam directions, wherein the control circuit is operable to selectively turn on and off different laser diodes to project the different optical beams from the selected laser diodes to form a desired beam scanning pattern to effectuate an effect of scanning a single optical beam in different beam directions.

[0006] In another aspect, for example, the disclosed technology can be implemented to provide an optical transceiver device including an array of light emitters located at different locations, each light emitter operable to produce an optical beam that is associated with a location of the light emitter and is different from another optical beam produced by another light emitter due to the location of the light emitter being different from a location of another light emitter, an array of optical detectors that are distributed amongst the array of light emitters for detecting light, an optical projection device located at a fixed position relative to the array of light emitters in optical paths of the optical beams from the array of light emitters, the optical projection device operable to direct each optical beam to a particular beam direction that is associated with a location of each light emitter relative to the optical projection device and is different any other beam directions, the optical projection device operable to collect received light and directs the received light onto the optical detectors distributed amongst the array of light emitters for detecting light, the optical projection device structured to include no moving part, and a control circuit coupled to the array of light emitters and operable to turn on or off the light emitters to project one or more optical beams from the light emitters to the optical projection device which in turn directs the received one or more optical beams to corresponding one or more particular beam directions, wherein the control circuit is operable to selectively turn on and off different laser diodes to project the different optical beams from the selected laser diodes to form a desired beam scanning pattern to effectuate an effect of scanning a single optical beam in different beam directions.

[0007] In another aspect, for example, the disclosed technology can be implemented to provide a beam steering system including a light emission device including a light source array and a light source selector coupled to the light source array, the light source array including a plurality of light sources arranged in rows and columns, the light source selector being structured to select one or more light sources from the light source array to produce one or more optical beam, an optical device located at a fixed position relative to the light emission device in optical paths of the one or more optical beams from the light emission device such that, from the one or more selected optical beams, a collimated beam is produced at different angle depending on the location of incident light on the optical device, and a control circuit coupled to the light source selector of the light emission device to select the one or more light sources from the light source array based on address information indicative of the location of the light source associated with the location of incident light on the optical device.

[0008] In another aspect, for example, the disclosed technology can be implemented to provide a light emission device including a light source structured to generate a light beam and a light path selector coupled to the light source and configured to provide a plurality of light paths to direct the light beam generated by the light source to a desired location, an optical device located at a fixed position relative to the light emission device in optical paths of the one or more optical beams from the light emission device such that, from the one or more selected optical beams, a collimated beam is produced at different angle depending on the location of incident light on the optical device, and a control circuit coupled to the light source selector of the light emission device to select the one or more light sources from the light source array based on address information indicative of the location of the light source associated with the location of incident light on the optical device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1A shows an example of the beam steering system where angular steering is performed by sequential activation of the individual emitter elements such that the emitted radiation is collimated in each direction by the diffractive lens system. FIG. 1B shows an example configuration of the beam steering system including unit cell subsystems.

[0010] FIGS. 2A and 2B show a cross section of an optical beam steering device during light emission, including transmission of a collimated beam normal to the device plane (FIG. 2A), and transmission of a collimated beam at an angle to the device plane (FIG. 2B).

[0011] FIGS. 3A-3C show an example of an emitter subsystem architecture, including a vertical emitter formed by the angled termination of a waveguide segment used as an individual light emitter (FIG. 3A), an optical switching fabric formed by a network of waveguides and optical rings at different output waveguide segments (FIG. 3B), and guided mode displaying field localization in a nanostructured waveguide (FIG. 3C).

[0012] FIGS. 4A and 4B show an example of the beam steering system, including an angular steering is performed by sequential activation of the individual emitter elements (FIG. 4A) and an overview of the subsystems of the total device (FIG. 4B).

[0013] FIGS. 5A and 5B show a cross section of the optical beam steering device during light emission (FIG. 5A) and reception (FIG. 5B).

[0014] FIG. 6 shows an example of the beam steering system implemented based on an embodiment of the disclosed technology.

[0015] FIG. 7 shows another example of the beam steering system implemented based on another embodiment of the disclosed technology.

[0016] FIG. 8 shows another example of the beam steering system implemented based on another embodiment of the disclosed technology.

[0017] FIG. 9 shows another example of the beam steering system implemented based on an embodiment of the disclosed technology.

DETAILED DESCRIPTION

[0018] Disclosed are devices, systems and methods for beam steering in optical systems and photonic devices. In some applications, the disclosed technology may be used to implement a full duplex transceiver on a chip for free space optical communications (FSOC) systems exploiting Si -photonics manufacturing.

[0019] The photonic beam steering disclosed in this patent document is based on a nonmechanical beam steering system for projecting optical energy and controlling the direction of the optical energy using a collection of devices and components that are fixed in position to selectively direct light from an array of different optical emitters at different locations. For example, a planar imaging system may be combined with a uniform array of nanoscale optical emitters in one focal plane to allow for selective activation of an individual emitter to send out a collimated beam at an angle that depends on the position of the emitter within the focal plane.

Successive activation of emitters can thus be used to direct the beam across the entire aperture of the imaging system, effectively steering the optical beam.

[0020] The disclosed photonic beam steering can be used to construct a device that includes an array of light sources located at different locations and each light source is operable to produce an optical beam that is associated with a location of the light source and is different from another optical beam produced by another light source due to the location of the light source being different from a location of another light source. An optical projection device is located at a fixed position relative to the array of light sources in optical paths of the optical beams from the array of light sources, the optical projection device operable to direct each optical beam to a particular beam direction that is associated with a location of each light source relative to the optical projection device and is different any other beam directions, the optical projection device structured to include no moving part. A control circuit is coupled to the array of light sources and operable to turn on or off the light sources to project one or more optical beams from the light sources to the optical projection device which in turn directs the received one or more optical beams to corresponding one or more particular beam directions. The control circuit is operable to selectively turn on and off different laser diodes to project the different optical beams from the selected laser diodes to form a desired beam scanning pattern to effectuate an effect of scanning a single optical beam in different beam directions.

[0021] The disclosed beam steering can be used in a wide range of applications such as free space communications, RF photonics, LIDAR, etc. that requires changing a beam’s direction. There are numerous applications that would benefit from integration with this technology. They include LIDAR, RF photonics, medical imaging such as optical coherence tomography, and endoscopy, optical communications, optical networking, spatial multiplexing, switching, ranging and collision detection, and sensing. The input waveguide of this design is ideal for integration with devices for optical signal preprocessing (e.g. modulators for LIDAR and communications, filters for sensing, etc.) which can even be integrated on the same chip. In the same vein, the collection waveguide is ideal for optical signal postprocessing. This is of increasing relevance given the proliferation of advanced modulation schemes (e.g. phase shift keying, quadrature amplitude modulation, etc.) that rely on postprocessing techniques to compensate for noise and improve the bit error rate. For example, some designs of free-space communication systems may project optical energy of high power laser sources by using mechanical components, moving parts, and bulk optics and tend to be limited by their size, weight, reliability and cost. The disclosed beam steering can be used to provide a novel non-mechanical beam steering approach that lends itself to miniaturization as well as high power ultra-wideband operation.

[0022] The disclosed technology uses an array of laser emitters located at different positions without requiring coherence of the different laser emitters as in some phased array designs and, in some implementations, selects one single emitter from the array of different laser emitters to be active to output a laser beam at a desired direction at a particular time and different laser emitters can be activated to direction output beams at different locations. In some applications, the disclosed beam steering can be used to provide beam steering operation at multiple wavelengths through the use of broadband emitters. Likewise, simultaneous multi-beam, multi-spectral operation can be realized with our highly flexible approach. Compared to other beam steering approaches, the disclosed technology can be used to achieve one or more advantages, including, e.g., reduced size and weight, relaxed coherence requirements, improved robustness and reliability, or superior operating efficiency. For example, the disclosed technology can be implemented to provide an integrated, scalable, compact, non-mechanical broadband beam steering system for numerous free space optical systems applications.

[0023] In some implementations, the laser beam may be modulated to carry information to be transmitted outside the device. The device may further include one or more transmission components for signal collection and processing of collected signals.

[0024] The disclosed technology can be used to implement a birefringent planar optical system combined with a uniform array of interspersed nanoscale optical emitters and detectors in one focal plane, with transmission and reception occurring simultaneously on orthogonally polarized beams, thus allowing full duplex operation. Various embodiments of the disclosed technology may enable low cost, size, weight and power (CSWaP) FSOC systems that can operate with multiple WDM channels supporting various modulation and coding protocols operating in full duplex mode.

[0025] FIG. 1A shows an example of the beam steering system where angular steering is performed by sequential activation of the individual emitter elements such that the emitted radiation is collimated in each direction by the diffractive lens system. FIG. 1B shows an example configuration of the beam steering system including unit cell subsystems.

[0026] The beam steering system 100A implemented based on an embodiment of the disclosed technology may include an emitter array 120A of different light emitters to produce light beams and an optical module 110A for redirecting the light beams from the emitter array 120A. The optical module 110A can be implemented as an optical imaging module or a diffractive optical element such as a diffractive lens system. In an implementation, the beam steering system 100A may include one or more unit cells, each of which includes a plurality of discrete layers. For example, as illustrated in FIG. 1B, a beam steering system 100B includes an imaging system 110B, an emitter array 120B, and control electronics 130B. The emitter array 120B is configured to emit light towards the imaging system 110B under control of the control electronics 130B. The imaging system 110A, 110B may be a planar imaging system with an optical projection device for directing output optical beams out in directions, and the emitter array 120A, 120B may be an optical emitter layer having the array of light emitters or light sources. For example, the imaging system 110A, 110B may include a planar imaging system combined with a uniform array of nanoscale optical emitters in one focal plane, and the emitter array 120A, 120B may include an array of light sources located at different locations and operable to produce an optical beam that is associated with a location of the light source. The emitter array 120A, 120B selectively activates an individual emitter element so that the imaging system 110A, 110B can send out a collimated beam at an angle that depends on the position of the emitter within the focal plane. The control electronics 130B may include an electrical control system for selecting and controlling the emitter array 120B such that one or more light emitters selected from the light emitters of the emitter array 120B. The control electronics 130B may include transistor logic gates and appropriate amplifiers to provide adequate voltage levels to the emitter array 120B. In another embodiment of the disclosed technology, the beam steering system 100B may further include an environmental stabilization layer 140B. The imaging system 110A, 110B can be implemented to include diffractive lens elements as the optical projection device. The emitter array 120A, 120B may be implemented to include waveguides, optical switches (e.g., ring resonators), and vertical couplers. The emitter array 120 may include one or more laser sources coupled to waveguides to direct laser light to the different light emitters.

[0027] As illustrated in FIG. 1A, an input light beam (e.g., a laser beam) generated by an individual emitter element is directed through the diffractive lens system, and the resulting light radiation is collimated by the diffractive lens system. The direction of the collimated output beam is determined by the position of the activated emitter element in the array, and the beam may be steered by activating the desired sequence of emitters. This can be said an integrated chip-scale equivalent of a Rotman lens antenna. Although the diameter of a single unit cell will be limited by the available nanofabrication technology, multiple unit cells can be combined to form an aperture of any size.

[0028] Referring to FIG. 1B, each unit cell of the beam steering system 100B may include an imaging system 110B such as planar lens, an emitter array and associated photonic switching fabric 120B, control electronics 130B, and a stabilization system 140B which will monitor and compensate for environmental temperature fluctuations.

[0029] The control electronics 130B may be configured to selectively turn on and off different laser diodes to project the different optical beams from the selected laser diodes to form a desired beam scanning pattern. In selectively activating one single emitter from the emitter array 120A, 120B, any selection scheme may be used, including, e.g., ring resonator optical switches, cross-bar switches, and multistage switching networks.

[0030] FIGS. 2A and 2B show a cross section of an optical beam steering device during light emission. Specifically, FIG. 2A illustrates transmission of a collimated beam from a particular emitter along a direction normal to the device plane of or along the optic axis of the diffractive lens system, and FIG. 2B illustrates transmission of a collimated beam from another emitter at a different location that is incident to the diffractive lens system at an angle and thus is directed by the diffractive lens system to a different direction. Accordingly, with a proper design of the diffractive lens system, light beams from different emitters at different locations can be directed to different directions. Selectively activating emitters at different locations allow the system to output a light beam at different beam directions and thus allows for beam steering.

[0031] The planar lens system is used to transmit a collimated beam as follows. To begin, laser radiation emanates from an emitter element. This radiation is collected by the planar lens system and formed into a collimated beam. The direction of the collimated beams will depend on the position of the emitter elements in relation to the optical axis of the lens.

[0032] The planar lens system is used to produce a collimated beam at a particular angle depending on the location of incident light on the planar lens system. Examples of the planar lens system include graded index Fresnel zone plates. Such diffractive lenses in general display more chromatic dispersion than conventional lenses. This feature can be exploited to enable operation at multiple wavelengths. Since the focal length of the lens will vary with wavelength, multiple emitter arrays can be vertically stacked, and simultaneously operated at wavelengths corresponding to the different focal planes. This enables the steering of multiple beams of different wavelengths independently. The emitters may also similarly be discriminated by polarization if the lens system is designed to be birefringent.

[0033] In some embodiments of the disclosed technology, the planar lens system may include a lenslet array consisting of a set of lenslets in the same plane. Each lenslet may have the same focal length, or, alternatively, some of the lenslets may have a different focal length from others.

[0034] The array of the light emitters can be implemented in various ways. Different optical wavelengths may be provided in the light emitters to allow for wavelength-division multiplexing in various implementations.

[0035] In some embodiments of the disclosed technology, the light emitters may include laser diodes or LEDs located at different locations forming the array. For example, the light emitters may be arranged in rows and columns to form the array such that, in the array, each light emitter location has its own address. In this way, each light emitter in the array may be activated according to address information.

[0036] In some other embodiments of the disclosed technology, the emitter subsystem (e.g., an emitter array) may use a shared architecture where one or more lasers are used to provide a "master" laser beam and a network of waveguides to distribute the master laser beam to different light emitter locations so that different optical beams can be produced at the different emitter locations. This structure can be used to implement the emitter array shown in FIGS. 2A and 2B so that different optical beams produced at the different emitter locations can be directed to different directions as the optical output of the system. In this design the emitter spacing limits the spatial resolution of the beam steering system. High packing density nanoscale emitters and associated switching fabric may be provided to achieve this design. For maximum efficiency the emitter may possess a radiation pattern that is highly directional. For maximum stability the emitter may include a material system that minimizes absorptive loss and subsequent heating of the device during operation.

[0037] FIGS. 3A-3C show an example of an emitter subsystem architecture. Specifically, FIG. 3A shows a vertical emitter formed by the angled termination of a waveguide segment used as an individual light emitter, and FIG. 3B shows an optical switching fabric formed by a network of waveguides and optical rings at different output waveguide segments. Activation of an emitter occurs by operating the ring resonator switches associated with the corresponding row and column. An optical ring resonator switch can be turned on to couple the light received from a respective waveguide into a corresponding vertical emitter as an optical output. Each optical waveguide can be optically to each of the optical ring resonator switches via evanescent optical coupling and a tunable coupling element can be used to tune the coupling condition to turn on the optical coupling from a waveguide to an optical ring resonator switch or turn off the coupling. Each optical ring resonator switch is also optically coupled to a corresponding vertical emitter such as the waveguide emitter shown in FIG. 3A. The tunable coupling element between a waveguide and a ring resonator switch can be a thermal tuning element to change the coupling condition or other tuning mechanism such as an electro-optic device. The tunable coupling elements in the optical switching fabric can be individually controlled to route the master laser beam into one or more desired vertical emitter locations so the diffractive optical system placed above the optical switching fabric can direct the output light in a desired output beam direction or in a desired beam scanning path or pattern. FIG. 3C shows guided mode displaying field localization in a nanostructured waveguide.

[0038] In implementations, various directional couplers may be used to implement this design (such as grating couplers, plasmonic nanoantennas, et cetera). However, given that packing density improves the device beam steering precision, the emitter subsystem may be implemented to achieve extremely small footprint and high packing density that is particularly well suited to some embodiments of the disclosed technology. Specifically, the emitter subsystem may be implemented using an input single mode waveguide that is terminated at an angle, causing the guided mode to reflect in the desired direction as illustrated in FIG. 3A. This process is analogous to the phenomenon of the total internal reflection. In an implementation, this design may employ purely dielectric materials to possess negligible absorptive loss.

[0039] Referring to FIG. 3B, individual emitter elements may be selectively activated as follows. The emitter elements may be arranged in a rectangular array fed by waveguides. Laser light will be launched into a waveguide parallel to the bottom emitter row, and may then be directed into a desired column waveguide using a ring resonator switch. An identical switch may then be used to direct the laser light entirely into the desired emitter. In the illustrated example, in FIG. 3B, the switches may be thermally driven by resistive heating elements. In some embodiments of the disclosed technology where activation of an emitter occurs by operating the ring resonator switches associated with the corresponding row and column, only two switches are turned on. In some other embodiments of the disclosed technology, a multistage network topology can be also used.

[0040] Referring to FIG. 3C, a high power operation can be achieved using a nanostructured waveguides with transverse electric (TE)-like mode localized in low index gaps (SiN,TiO, etc.), potentially supporting operation with 24W CW laser power.

[0041] In some embodiments of the disclosed technology, any conventional waveguide switching technology can in principle be employed to create the switching fabric. For example, ring resonators can be used to implement a multiwavelength operation. In an implementation. the ring resonators can be configured to transmit at multiple resonance wavelengths, separated uniformly by a spacing known as the free spectral range. These resonators may be operated as switches because the resonant wavelengths depend on the temperature of the ring. Since each of these resonance wavelengths is tuned simultaneously when switching, it is possible to use a single ring to switch multiple wavelengths. This enables the device to efficiently steer a broadband beam using a single pair of switches.

[0042] In order to enable operation with high laser power, the emitter subsystem implemented based on an embodiment of the disclosed technology may employ nanoscale structured waveguides to provide a desired maximum power tolerance. These waveguides can be structured to improve power tolerance by localizing the optical field in gaps of the nanostructure that contain thermally resistant cladding. This will redirect the thermal stresses from the waveguide core as illustrated in FIG. 3C. Ordinary micron scale dielectric waveguides, in which the field is concentrated in the waveguide core, have been experimentally demonstrated to tolerate as much as 12W of CW power. Since the nanoscale structured waveguides implemented based on an embodiment of the disclosed technology can move a majority of the field out of the waveguide core, they can be expected to enable the transmission of CW optical power in excess of 24 W.

[0043] The proposed design may be applied to a suitable spectral regime. The appropriate fabrication technology is determined by the desired operating wavelength, which limits the material systems available for the optical elements based on the spectral absorption. Viable

CMOS compatible candidates are Si3N4 on SiO2 for operating wavelengths between 300 nm to 3.5 μm, and Si on SiO2 for 1.2 μm to 5 μm. In either case the fabrication process is similar.

[0044] In some embodiments of the disclosed technology, the planar lens systems may be fabricated from a double sided polished wafer using lithography and reactive-ion etching (RIE) such as RIE dry etching. The lenses may include deeply subwavelength nanoholes that function as a dielectric metasurface. The density of the nanoholes may be modulated on a deeply subwavelength scale in order to produce the index grading that is optimal for Fresnel zone plates. Anisotropic variation of the nanoholes may also make possible artificial birefringence within the zone plate elements. The waveguides may be patterned and etched through a similar process, and clad using, e.g., plasma-enhanced chemical vapor deposition (PECVD). The tuning of the switches may be performed thermally. For this, metallic resistive heating elements may be deposited above the waveguide cladding to locally modulate the refractive index via the thermos-optic effect.

[0045] One application of the disclosed beam steering is for use with various free-special optical communications (FSOC) systems. This combination of the disclosed beam steering technology and the FSOC applications can be used to mitigate technical issues associated with beam scanning with moving parts and other beam steering based on optical phased arrays (OPA), which in fact implement programmable diffractive optical element for beam forming. Although OPAs are an elegant non-mechanical beam steering approach, the technical and environmental challenges compared to millimeter wave and RF systems (thousands of times smaller wavelengths and tolerances) are daunting. Furthermore, multi-wavelength operation with acceptable losses poses additional technical challenges for such OPAs. For these reasons, various embodiments of the disclosed technology may provide alternative novel non-mechanical beam steering approaches for FSOCs that lend itself both to miniaturization as well as multispectral operation.

[0046] FIGS. 4A and 4B show an example of the beam steering system. Specifically, FIG. 4A shows that an angular steering is performed by sequential activation of the individual emitter elements. The emitted polarized radiation is collimated in each direction by the diffractive lens system. The birefringence of the imaging system enables the device to operate as a receiver for orthogonally polarized optical input signals. FIG. 4B shows an overview of the subsystems of the total device. The free space far field can be expressed as:

$$\delta(\xi-x_i, \eta-y_i)\, \exp[-j2\pi(f_x\xi+f_y\eta)]d\xi d\eta = \exp[-j2\pi(f_x x_i+f_y y_i)] \qquad \text{(Eq. 1)}$$

where $f_x = x/(\lambda f)$, $f_y = y/(\lambda f)$ with deflection angles $\Phi_x \sim x_i/f$, $\Phi_y \sim y_i/f$. Optimized lens can provide wide angular bandwidth (>100°) with high resolution (<0.1°).

[0047] In some embodiments of the disclosed technology, the beam steering system may include a birefringent planar imaging system combined with a uniform array of interspersed nanoscale optical emitters and detectors in one focal plane, with transmission and reception occurring on orthogonally polarized beams, as illustrated in FIGS. 4A and 4B. When operated in transmission mode, this is the integrated chip-scale equivalent of a Rotman lens antenna. More specifically, transmission occurs by the selective activation of an individual emitter, which will send out a collimated polarized beam at an angle that depends on the position of the emitter within the focal plane. The selective activation can be realized on a chip using various switching fabric architectures (e.g., cross-bar, multistage network, etc.). Successive activation of emitters can thus be used to direct the beam across the entire aperture of the transmission system as illustrated in FIG. 4A. It should be noted that an integrated modulator/encoder can be integrated on the same chip and be driven by electronics imposing various modulation and coding protocols. The device can also simultaneously act as a receiver over the same transmitter/receiver aperture, since the birefringent optical relay system will direct a beam with orthogonal polarization onto the detection elements, as illustrated in FIG. 4B. There are no coherence requirements on the sources within the array since only a single emitter is active at any time. Multi-spectral transmission is possible through the use of broadband emitters, while multi-spectral reception is possible through the use of dispersive optical elements that direct different wavelengths to different detectors or focal planes.

[0048] In some embodiments of the disclosed technology, the beam steering system may include a planar birefringent Fourier transform lens, an emitter/detector array and associated photonic switching fabric with integrated modulator integrated with external laser, an electrical control and signal processing electronics for modulation and detection, and a monitoring and environment stabilization system, as illustrated in FIG. 4B. The diameter (aperture) of a single unit cell may be limited by the available nanofabrication technology (~1 cm), but multiple unit cells can be combined to form an aperture of any size.

[0049] FIGS. 5A and 5B show a cross section of the optical beam steering device having both light emitters and optical detectors to enable light emission and beam steering (FIG. 5A) and optical reception (FIG. 5B). In this example, an array of light emitters is provided and optical detectors are spatially interleaved with the light emitters but are spatially offset from light emitters. The lateral offset of the transmission and reception optical paths of the emitters and detectors can be achieved by off centering the diffractive lens elements for each polarization, whereas vertical offset can be achieved by engineering the birefringence. In implementations, the light emitters may be arranged in rows and columns on the same focal plane as the plurality of light selectors.

[0050] In some implementations, a birefringent lens made of artificially engineered material can operate in a broad spectral range. Multi-beam broadcast operation can be realized with this highly flexible approach employing the switching fabric. Compared to more conventional designs this approach has reduced size and weight, relaxed coherence requirements, improved robustness and reliability, and superior operating efficiency. The result is an integrated, scalable, compact, non-mechanical broadband optical transceiver that can be manufactured with CMOS compatible process.

[0051] The transmission in a transverse electric (TE) field is Fourier transformed by the TE birefringent lens (f_{TE}) followed by quarter wave plate to transmit circularly polarized beam. Input (received) beam is converted by quarter wave plate to a transverse magnetic (TM) and focused by the TM birefringent lens (f_{TM}) onto a photodetector. The birefringent lenses are engineered such that centers of TE and TM lenses are shifted to accommodate the emitter-detector shift and $f_{TM} > f_{TE}$ to achieve vertical offset.

[0052] FIG. 6 shows an example of the beam steering system implemented based on an embodiment of the disclosed technology. The beam steering system 600 may include a control logic 610, a light emission device 620, and a diffractive optical device 630. The light emission device 620 may include a light source array consisting of a plurality of light sources located at different locations. Each light source can be selected according to a location of the light source, each of which is associated with a location on the diffractive optical device 630.

[0053] In some embodiments of the disclosed technology, the light emission device 620 includes a light source selector 622 and a light source array 624 coupled to the light source selector 622. The light source selector 622 is configured to select a light source element from the light source array 624 based on address information provided from the control logic 610. Here, the address information includes information on the locations of the light sources in the light source array 624.

[0054] In some embodiments of the disclosed technology, the control logic 610 is coupled to the light source selector 622 to turn on or off the light sources to project one or more optical beams from the light sources to the diffractive optical device 630 which in turn directs the received one or more optical beams to corresponding one or more particular beam directions. The control logic 610 is operable to selectively turn on and off different light sources in the light emission device 620 to project the different optical beams from the light source(s) selected by the light source selector 622 to form a desired beam scanning pattern.

[0055] The diffractive optical device 630 is located at a fixed position relative to the array of light sources of the light emission device 620 such that optical paths of the optical beams from the array of light sources are selected and a collimated beam is produced at different angle depending on the location of incident light on the diffractive optical device 630. The light beam output from the light emission device 620 is directed to the diffractive optical device 630, and the resulting light radiation is collimated by the diffractive lens system. The direction of the collimated output beam is determined by the position of the selected light source in the light emission device 620, and the light radiation may be steered by activating the light sources in the light emission device 620 in a desired sequence.

[0056] FIG. 7 shows another example of the beam steering system implemented based on another embodiment of the disclosed technology. The beam steering system 700 may include a control logic 710, a light emission device 720, and a diffractive optical device 730. Unlike the configuration illustrated in FIG. 6, the light emission device 720 may include a light source 722 configured to generate a light beam and a light path selector 724 configured to provide a plurality of light paths to direct the light beam generated by the light source 722 to a desired location on the diffractive optical device 730 by selecting one or more of the light paths. For example, the light path selector 724 may be implemented using a network of waveguides that distributes the light beam to different locations so that different optical beams can be output at the different locations.

[0057] In some embodiments of the disclosed technology, the control logic 710 is coupled to the light source 722 to turn on or off the light source 722 and is also coupled to the light path selector 724 to project, by selecting one or more light paths, one or more optical beams from the light source 722 to the diffractive optical device 730 structured to direct the received one or more optical beams to corresponding one or more particular beam directions to form a desired beam scanning pattern.

[0058] FIG. 8 shows another example of the beam steering system implemented based on another embodiment of the disclosed technology. The beam steering system 800 may include a control logic 810, a light emission device 820, and a birefringent diffractive optical device 830. The light emission device 820 may include a light source/detector array 824 including a light source array consisting of a plurality of light sources located at different locations and a light detector array consisting of a plurality of light detectors located at different locations. The light sources are used to transmit light through the birefringent diffractive optical device 830 and the light detectors are used to receive incoming light from the birefringent diffractive optical device 830.

[0059] FIG. 9 shows another example of the beam steering system implemented based on an embodiment of the disclosed technology. In this example, different arrays of light emitters at different optical wavelengths are provided at different layers. The first wavelength layer in this example includes a first light emitter layer having an array of light emitters at different locations to emit light at a first wavelength. A first diffractive optical element system is placed above the first light emitter layer to steer the output light at the first wavelength from the first light emitter array. One or more different wavelength layers are stacked over the first wavelength layer to provide output and beam steering at other wavelengths. In this example, a second light emitter layer having an array of light emitters at different locations is provided to emit light at a second wavelength. A second diffractive optical element system is placed above the second light emitter layer to steer the output light at the second wavelength from the second light emitter array. The light at the first wavelength can pass through the second wavelength layer so that light at different wavelengths can be generated. Unlike some phased array designs, this beam steering system implemented based on the disclosed technology does not rely on source coherence by turning on or activating a single emitter in a light emitter layer at a time, allowing operation at multiple wavelengths through the use of the wavelength-division multiplexed (WDM) channels. Simultaneous multi-beam, multi-spectral operation can be realized with the highly flexible approach disclosed in this patent document. For example, the output light at different wavelengths may be steered independently in certain applications while output light at the different wavelengths may also be steered together by synchronizing the control of the light emitters in the two different emitter layers.

[0060] Although a few variations have been described in detail above, other modifications or additions are possible. In particular, further features and/or variations may be provided in addition to those set forth herein. Moreover, the example embodiments described above may be directed to various combinations and subcombinations of the disclosed features and/or combinations and subcombinations of several further features disclosed above. In addition, the logic flow depicted in the accompanying figures and/or described herein does not require the particular order shown, or sequential order, to achieve desirable results. Other embodiments may be within the scope of the following claims.

[0061] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Moreover, the separation of various system components in the embodiments described in this patent document should not be understood as requiring such separation in all embodiments.

[0062] Only a few implementations and examples are described and other implementations, enhancements and variations can be made based on what is described and illustrated in this patent document. It should be noted, that this approach can also include additional components (e.g., modulators, filters, etc.) integrated on the same chip in support of such applications as digital communications, RF photonics, and LIDAR

[0063] Implementations of the subject matter and the functional operations described in this patent document can be implemented in various systems, digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Implementations of the subject matter described in this specification can be implemented as one or more computer program products, i.e., one or more modules of computer program instructions encoded on a tangible and non-transitory computer readable medium for execution by, or to control the operation of, data processing apparatus. The computer readable medium can be a machine-readable storage device, a machine-readable storage substrate, a memory device, a composition of matter effecting a machine-readable propagated signal, or a combination of one or more of them. The term “data processing unit” or “data processing apparatus” encompasses all apparatus, devices, and machines for processing data, including by way of example a programmable processor, a computer, or multiple processors or computers. The apparatus can include, in addition to hardware, code that creates an execution environment for the computer program in question, e.g., code that constitutes processor firmware, a protocol stack, a database management system, an operating system, or a combination of one or more of them.

[0064] A computer program (also known as a program, software, software application, script, or code) can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program does not necessarily correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a communication network.

[0065] The processes and logic flows described in this specification can be performed by one or more programmable processors executing one or more computer programs to perform functions by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus can also be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit).

[0066] Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor will receive instructions and data from a read only memory or a random access memory or both. The essential elements of a computer are a processor for performing instructions and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto optical disks, or optical disks. However, a computer need not have such devices. Computer readable media suitable for storing computer program instructions and data include all forms of nonvolatile memory, media and memory devices, including by way of example semiconductor memory devices, e.g., EPROM, EEPROM, and flash memory devices. The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

[0067] It is intended that the specification, together with the drawings, be considered exemplary only, where exemplary means an example. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. Additionally, the use of “or” is intended to include “and/or”, unless the context clearly indicates otherwise.

[0068] While this patent document contains many specifics, these should not be construed as limitations on the scope of any invention or of what may be claimed, but rather as descriptions of features that may be specific to particular embodiments of particular inventions. Certain features that are described in this patent document in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0069] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Moreover, the separation of various system components in the embodiments described in this patent document should not be understood as requiring such separation in all embodiments.

[0070] Only a few implementations and examples are described and other implementations, enhancements and variations can be made based on what is described and illustrated in this patent document.

CLAIMS

What is claimed is what is described and illustrated, including:

1. A device, comprising:

an array of light emitters located at different locations, each light emitter operable to produce an optical beam that is associated with a location of the light emitter and is different from another optical beam produced by another light emitter due to the location of the light emitter being different from a location of another light emitter;

an optical projection device located at a fixed position relative to the array of light emitters in optical paths of the optical beams from the array of light emitters, the optical projection device operable to direct each optical beam to a particular beam direction that is associated with a location of each light emitter relative to the optical projection device and is different from any other beam directions, the optical projection device structured to include no moving part; and

a control circuit coupled to the array of light emitters and operable to turn on or off the light emitters to project one or more optical beams from the light emitters to the optical projection device which in turn directs the received one or more optical beams to corresponding one or more particular beam directions, wherein the control circuit is operable to selectively turn on and off different laser diodes to project the different optical beams from the selected laser diodes to form a desired beam scanning pattern to effectuate an effect of scanning a single optical beam in different beam directions.

2. The device as in claim 1, wherein:

the array of the light emitters is in a plane; and

the optical projection device includes one or more lenses placed over the plane of the array of light emitters so that different light emitters are at different locations relative to an optical axis of the one or more lenses so that the one or more lenses direct different optical beams from different light emitters in different directions.

3. The device as in claim 2, wherein:

the one or more lenses include a planar diffractive lens.

4. The device as in claim 2, wherein:
the one or more lenses include a planar Fresnel lens.

5. The device as in claim 2, wherein:
the one or more lenses include a lens array.

6. The device as in claim 1, wherein:
the array of light emitters is an array of laser diodes fixed in position in a plane.

7. The device as in claim 1, wherein:

the array of light emitters includes an array of output waveguide segments formed over a substrate and each output waveguide segment includes an angled facet that directs guided light in each output waveguide segment to the angled facet as an optical beam from a light emitter, a network of waveguides formed over the substrate and coupled to the different output waveguide segments to direct light to the different output waveguide segments, coupling between each output waveguide segment to the network of waveguides being controlled by the control circuit to allow the coupling to be turned on and off; and

the laser diode is coupled to the network of waveguides to supply laser light to be coupled to the different output waveguide segments so that the different optical beams from the different output waveguide segments are from the laser light of the laser.

8. The device as in claim 7, wherein the laser light is modulated to carry information to be transmitted outside the device.

9. The device as in claim 7, further comprising one or more transmission components for signal collection and processing of collected signals.

10. The device as in claim 7, wherein:

the coupling between each output waveguide segment and network of waveguides includes an optical ring that is evanescently coupled to the network of waveguides and is evanescently coupled to the output waveguide segment to allow light coupling into the output waveguide segment, and a tunable device coupled to the output waveguide segment or the optical ring to allow for turning on or off the coupling between the optical ring and the output waveguide segment.

11. The device as in claim 10, wherein:

the tunable device includes a heater that thermally changes a distance between the optical ring and the output waveguide segment to control optical evanescent coupling between the optical ring and the output waveguide segment.

12. The device as in claim 10, wherein:

the tunable device includes a p-i-n (p-type, intrinsic, n-type semiconductors) junction device, a p-n (p-type, n-type semiconductors) junction device, or a combination of the p-i-n junction device and the p-n junction device with or without other electrooptic devices.

13. An optical transceiver device, comprising:

an array of light emitters located at different locations, each light emitter operable to produce an optical beam that is associated with a location of the light emitter and is different from another optical beam produced by another light emitter due to the location of the light emitter being different from a location of another light emitter;

an array of optical detectors that are distributed amongst the array of light emitters for detecting light;

an optical projection device located at a fixed position relative to the array of light emitters in optical paths of the optical beams from the array of light emitters, the optical projection device operable to direct each optical beam to a particular beam direction that is associated with a location of each light emitter relative to the optical projection device and is different any other beam directions, the optical projection device operable to collect received light and directs the received light onto the optical detectors distributed amongst the array of light emitters for detecting light, the optical projection device structured to include no moving part; and

a control circuit coupled to the array of light emitters and operable to turn on or off the light emitters to project one or more optical beams from the light emitters to the optical projection device which in turn directs the received one or more optical beams to corresponding one or more particular beam directions, wherein the control circuit is operable to selectively turn on and off different laser diodes to project the different optical beams from the selected laser diodes to form a desired beam scanning pattern to effectuate an effect of scanning a single optical beam in different beam directions.

14. The device as in claim 13, wherein:

the array of light emitters includes an array of output waveguide segments formed over a substrate and each output waveguide segment includes an angled facet that directs guided light in each output waveguide segment to the angled facet as an optical beam from a light emitter, a network of waveguides formed over the substrate and coupled to the different output waveguide segments to direct light to the different output waveguide segments, coupling between each output waveguide segment to the network of waveguides being controlled by the control circuit to allow the coupling to be turned on and off, and

a laser coupled to the network of waveguides to supply laser light to be coupled to the different output waveguide segments so that the different optical beams from the different output waveguide segments are from the laser light of the laser.

15. The device as in claim 14, wherein:

the coupling between each output waveguide segment and network of waveguides includes an optical ring that is evanescently coupled to the network of waveguides and is evanescently coupled to the output waveguide segment to allow light coupling into the output waveguide segment, and a tunable device coupled to the output waveguide segment or the optical ring to allow for turning on or off the coupling between the optical ring and the output waveguide segment.

16. The device as in claim 15, wherein:

the tunable device includes a heater that thermally changes a distance between the optical ring and the output waveguide segment to control optical evanescent coupling between the optical ring and the output waveguide segment.

17. The device as in claim 13, wherein:

the array of the light emitters is in a plane, and

the optical projection device is a lens placed at a position over the plane of the array of light emitters so the plane of the array of the light emitters is at a focal plane of the lens and the lens directs different optical beams from different light emitters as collimated optical beams in different directions.

18. A beam steering system, comprising:

a light emission device including a light source array and a light source selector coupled to the light source array, the light source array including a plurality of light sources arranged in rows and columns, the light source selector being structured to select one or more light sources from the light source array to produce one or more optical beam;

an optical device located at a fixed position relative to the light emission device in optical paths of the one or more optical beams from the light emission device such that, from the one or more selected optical beams, a collimated beam is produced at different angle depending on the location of incident light on the optical device; and

a control circuit coupled to the light source selector of the light emission device to select the one or more light sources from the light source array based on address information indicative of the location of the light source associated with the location of incident light on the optical device.

19. The system as in claim 18, wherein the light source selector includes an optical switching fabric formed by a network of waveguides and optical rings optically coupled to each other at different locations associated with the location of incident light on the optical device.

20. The system as in claim 18, wherein the light source includes a laser diode structured to be turned on and off based on a selection of the light source selector.

21. The system as in claim 18, wherein the optical device includes a diffractive optical element structured to generated patterns with different diffraction angles depending on the location of incident light on the optical device.

22. The system as in claim 18, wherein the optical device includes a lenslet array including a set of lenslets in the same plane, each lenslet having the same focal length.

23. The system as in claim 18, wherein the optical device includes a lenslet array including a set of lenslets in the same plane, each lenslet having different focal lengths from each other.

24. The system as in claim 18, wherein the optical device includes a birefringent planar optical platform.

25. The system as in claim 24, wherein the light emission device further comprises a plurality of light detectors arranged in rows and columns on the same focal plane as the plurality of light sources.

26. A beam steering system, comprising:

a light emission device including a light source structured to generate a light beam and a light path selector coupled to the light source and configured to provide a plurality of light paths to direct the light beam generated by the light source to a desired location;

an optical device located at a fixed position relative to the light emission device in optical paths of the one or more optical beams from the light emission device such that, from the one or more selected optical beams, a collimated beam is produced at different angle depending on the location of incident light on the optical device; and

a control circuit coupled to the light emission device to select one or more of the plurality of light paths based on address information indicative of the location of incident light on the optical device.

27. The system as in claim 26, wherein the light path selector includes a network of waveguides that distributes the light beam to different locations so that different optical beams can be output at the different locations.

28. The system as in claim 26, wherein the light source includes a laser diode structured to be turned on and off under control of the control circuit.

29. The system as in claim 26, wherein the optical device includes a diffractive optical element structured to generated patterns with different diffraction angles depending on the location of incident light on the optical device.

30. The system as in claim 26, wherein the optical device includes a lenslet array including a set of lenslets in the same plane, each lenslet having the same focal length.

31. The system as in claim 26, wherein the optical device includes a lenslet array including a set of lenslets in the same plane, each lenslet having different focal lengths from each other.

32. The system as in claim 26, wherein the optical device includes a birefringent planar optical platform.

33. The system as in claim 32, wherein the light emission device further comprises a plurality of light detectors arranged in rows and columns on the same focal plane as the plurality of light selectors.

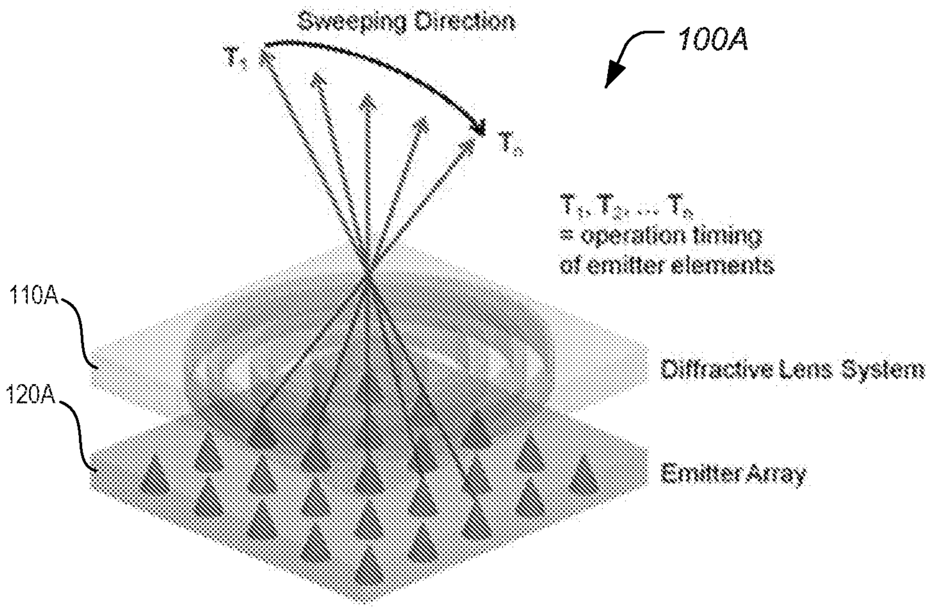
Sweeping Direction
100A
T_1
T_n
$T_1, T_2, \ldots T_n$
= operation timing
of emitter elements
110A
Diffractive Lens System
120A
Emitter Array

FIG. 1A

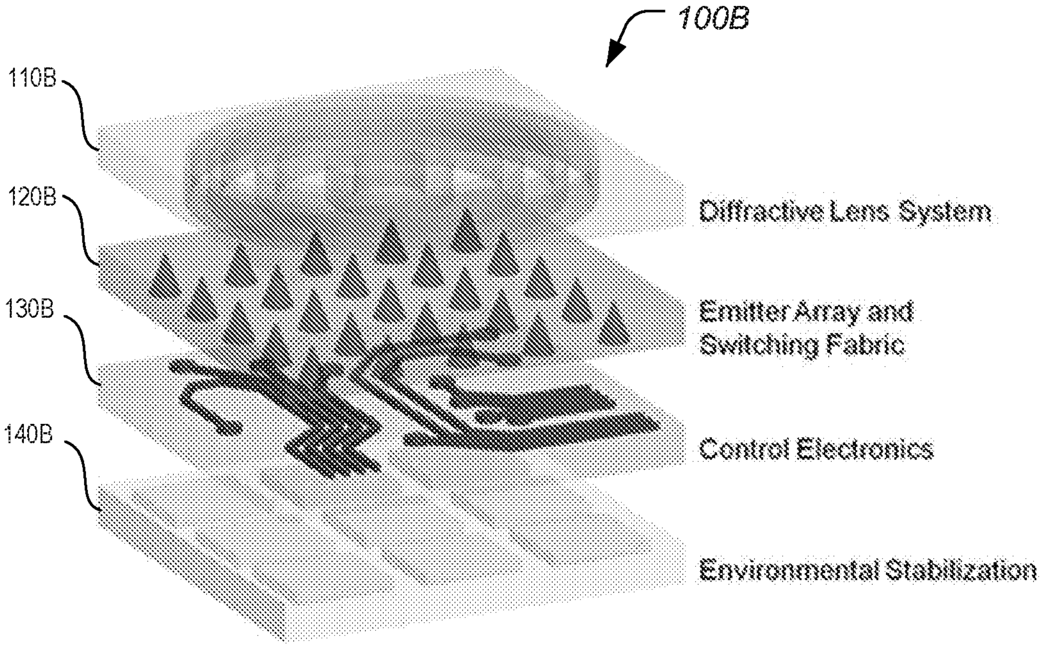
100B
110B
Diffractive Lens System
120B
Emitter Array and
Switching Fabric
130B
Control Electronics
140B
Environmental Stabilization

FIG. 1B

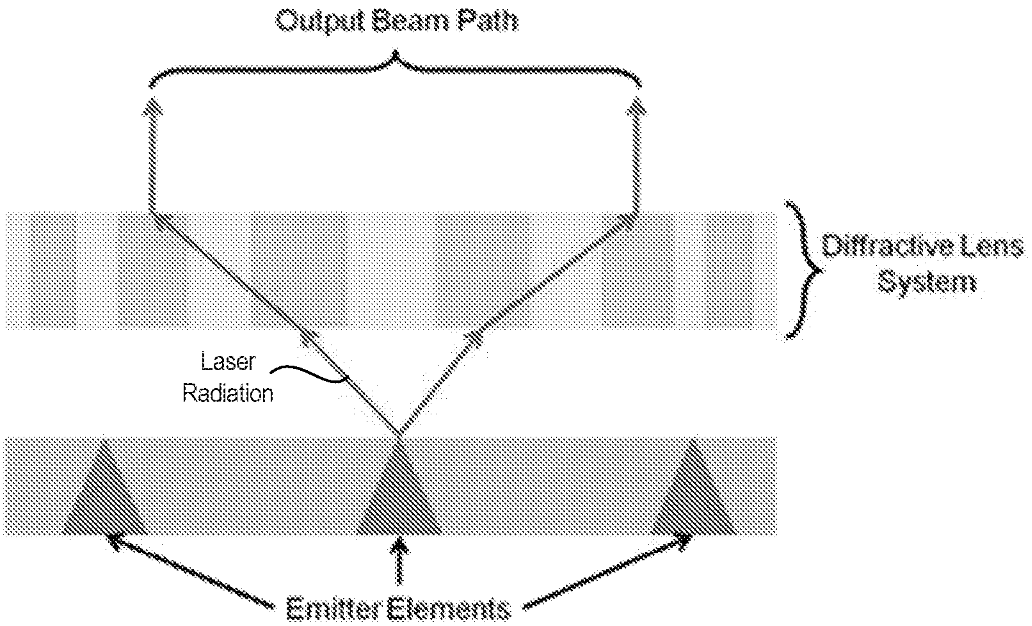
Output Beam Path
Diffractive Lens System
Laser Radiation
Emitter Elements

FIG. 2A

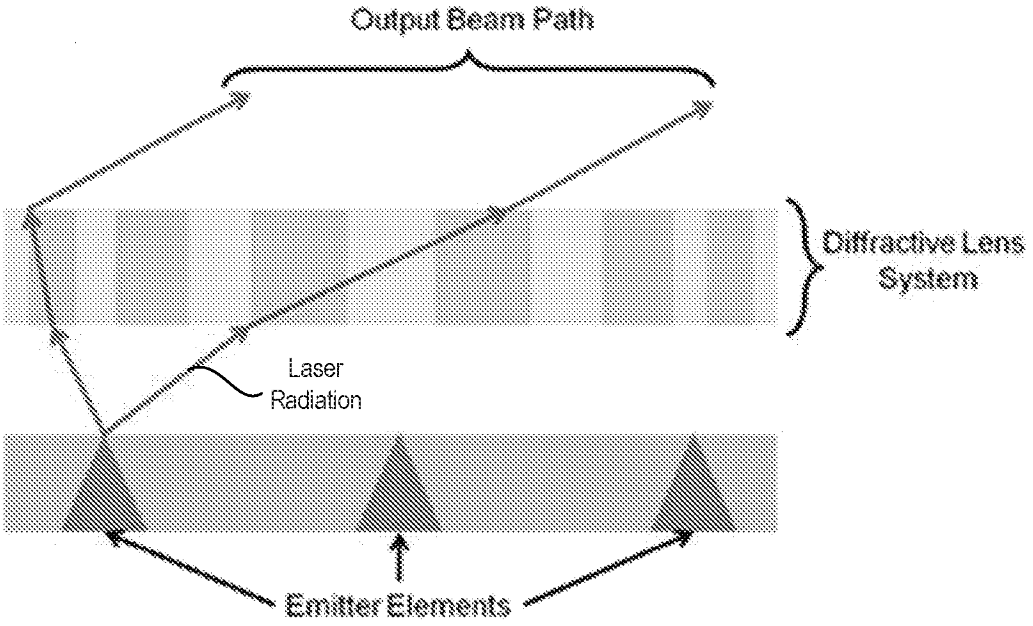
Output Beam Path
Diffractive Lens System
Laser Radiation
Emitter Elements

FIG. 2B

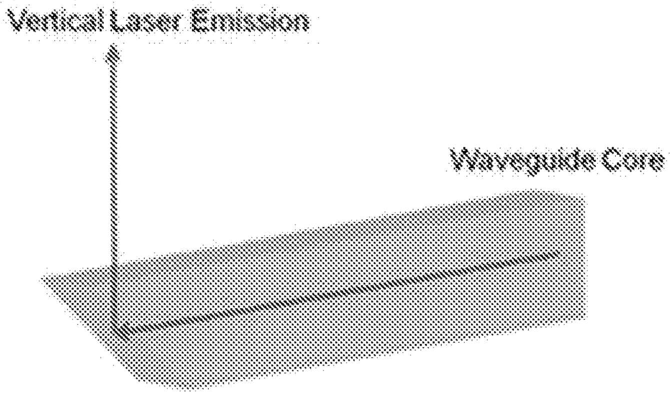

FIG. 3A

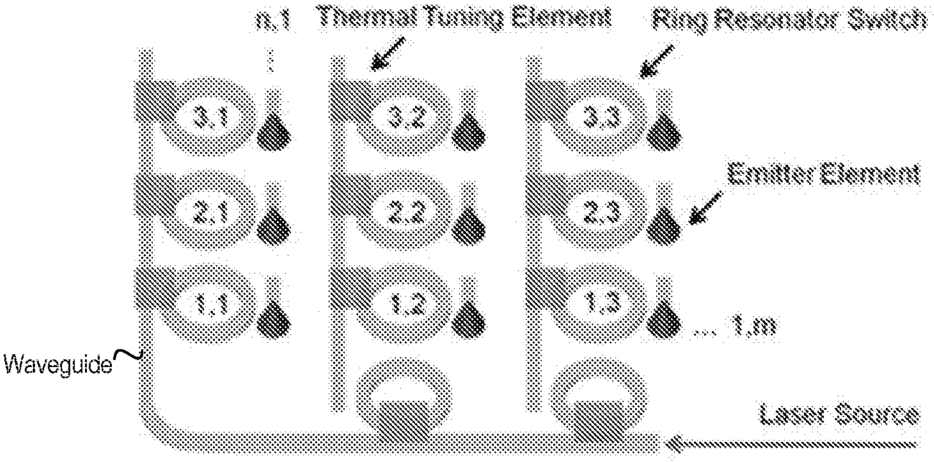

FIG. 3B

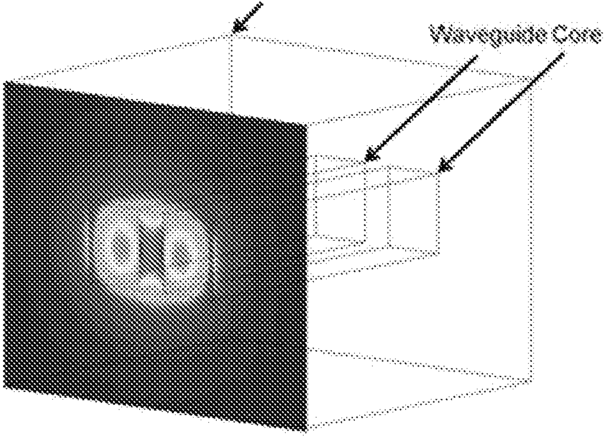

FIG. 3C

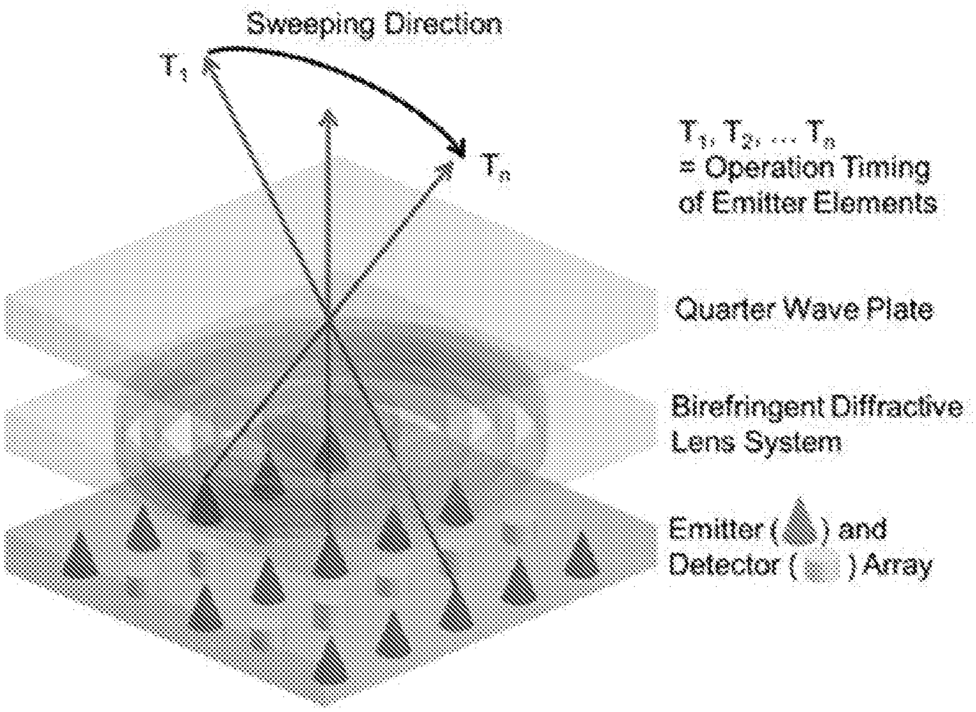
Sweeping Direction
T_1
T_n
$T_1, T_2, \ldots T_n$
= Operation Timing
of Emitter Elements
Quarter Wave Plate
Birefringent Diffractive
Lens System
Emitter (▲) and
Detector (■) Array

FIG. 4A

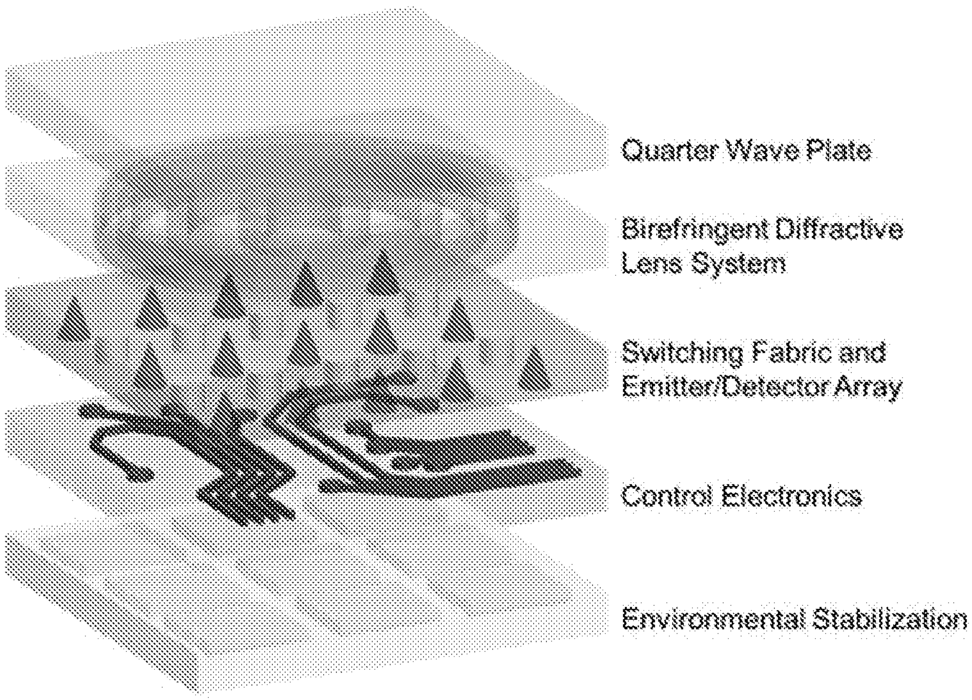
Quarter Wave Plate
Birefringent Diffractive
Lens System
Switching Fabric and
Emitter/Detector Array
Control Electronics
Environmental Stabilization

FIG. 4B

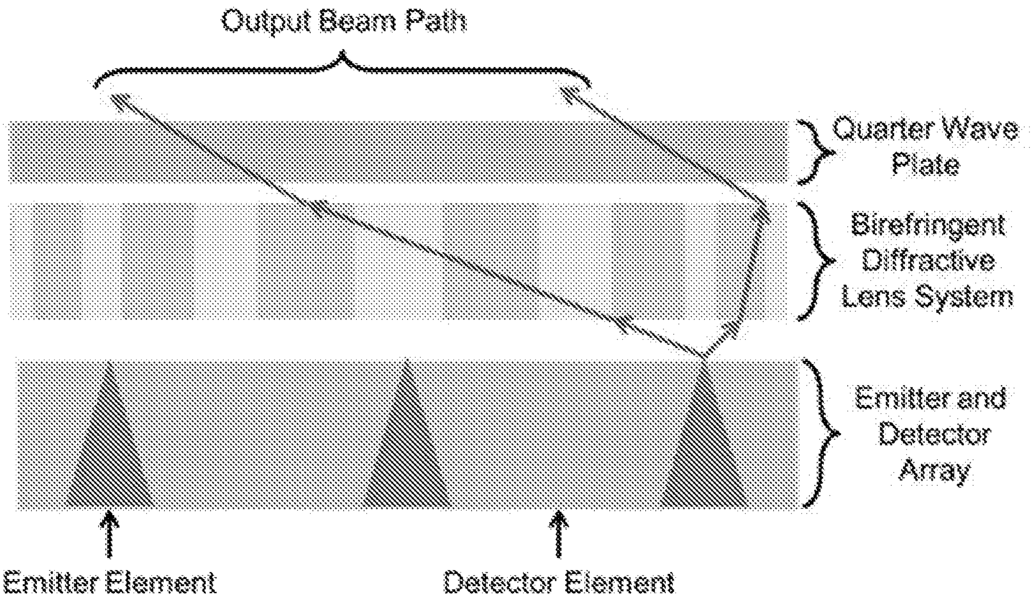
Output Beam Path
Quarter Wave Plate
Birefringent Diffractive Lens System
Emitter and Detector Array
Emitter Element
Detector Element

FIG. 5A

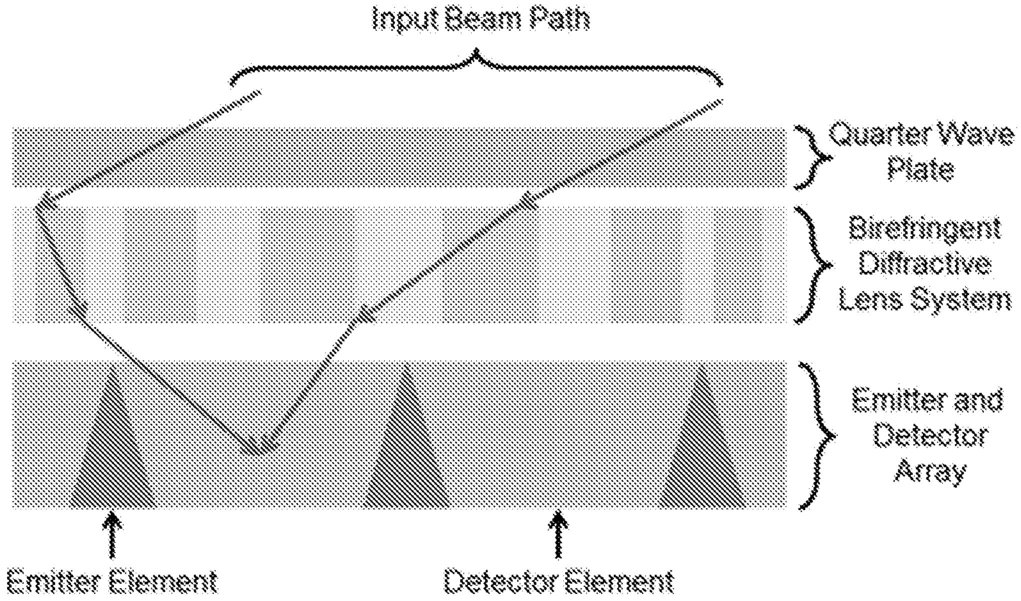
Input Beam Path
Quarter Wave Plate
Birefringent Diffractive Lens System
Emitter and Detector Array
Emitter Element
Detector Element

FIG. 5B

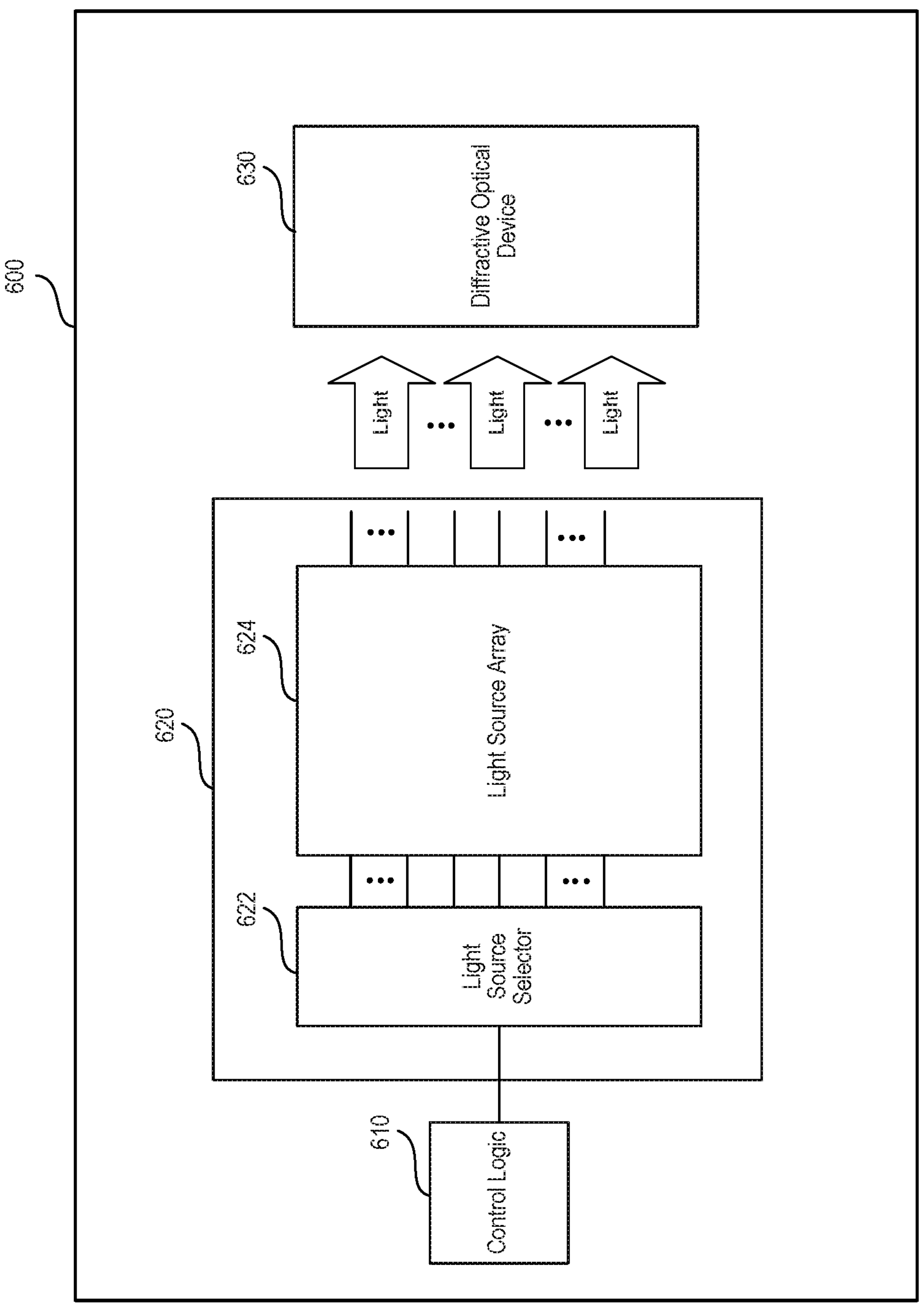
600
630
Diffractive Optical Device
Light
Light
Light
620
624
Light Source Array
622
Light Source Selector
610
Control Logic

FIG. 6

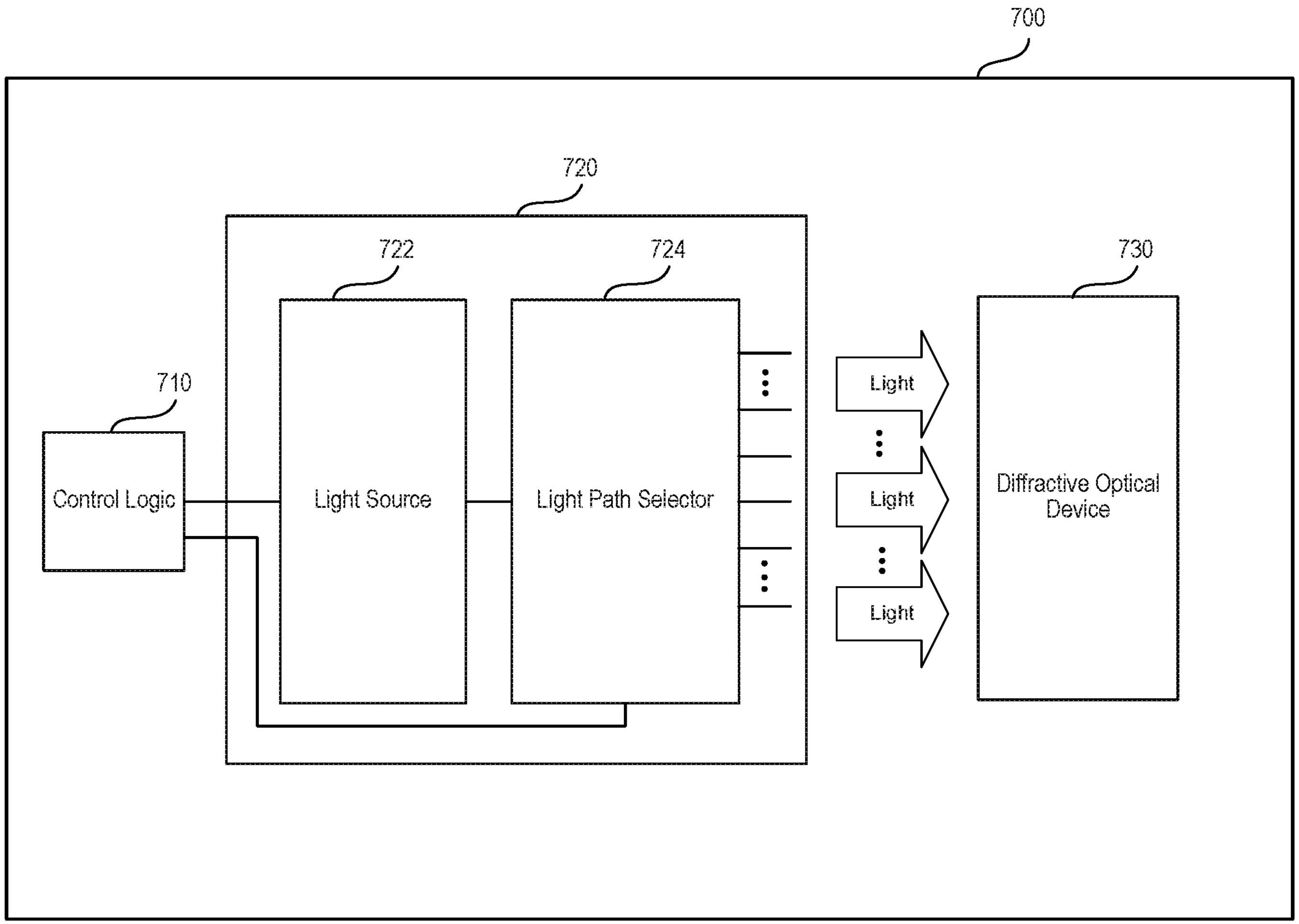
700
720
722
724
730
710
Control Logic
Light Source
Light Path Selector
Light
Light
Light
Diffractive Optical Device

FIG. 7

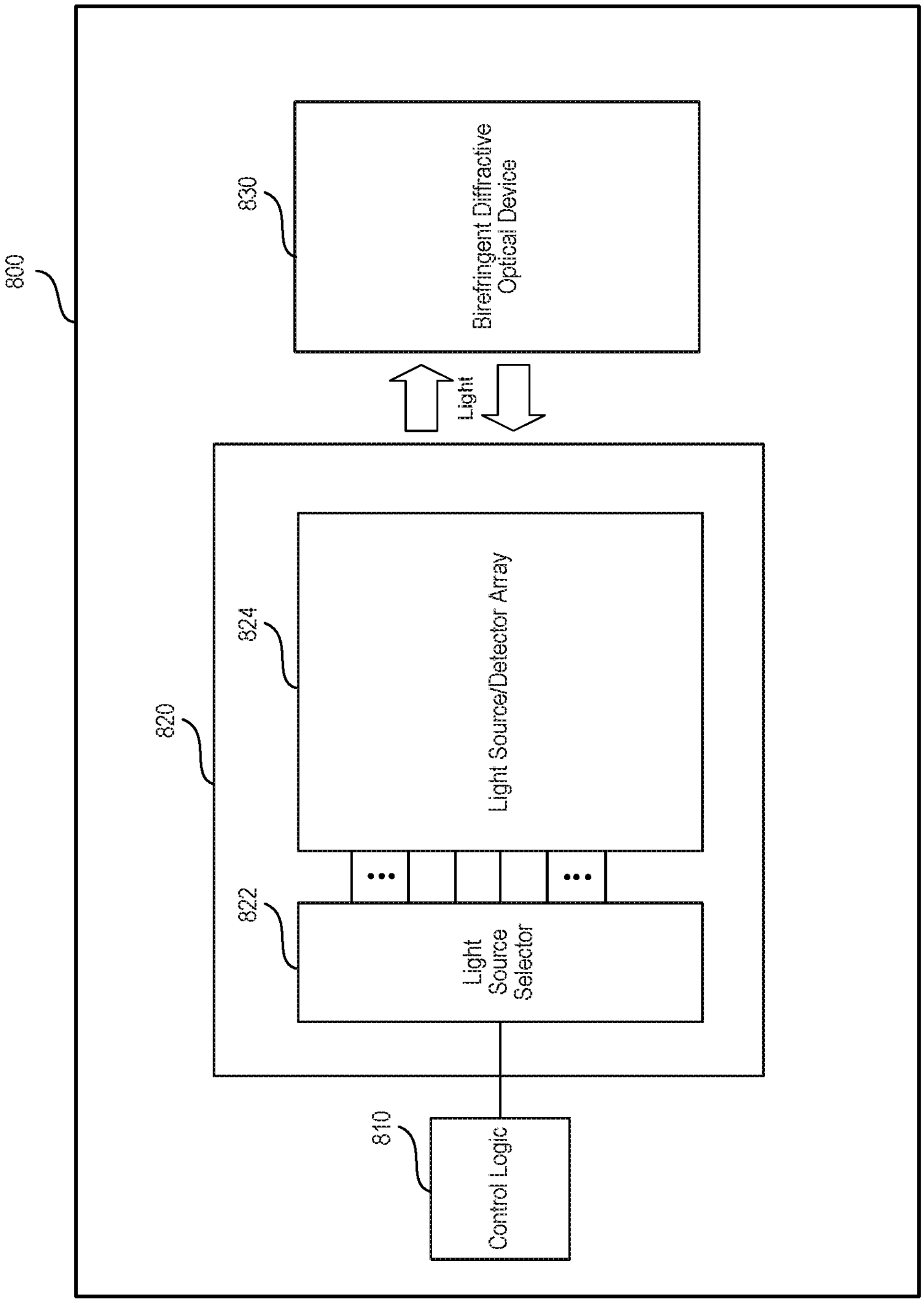
800
830
Birefringent Diffractive Optical Device
Light
820
824
Light Source/Detector Array
822
Light Source Selector
•••
•••
810
Control Logic

FIG. 8

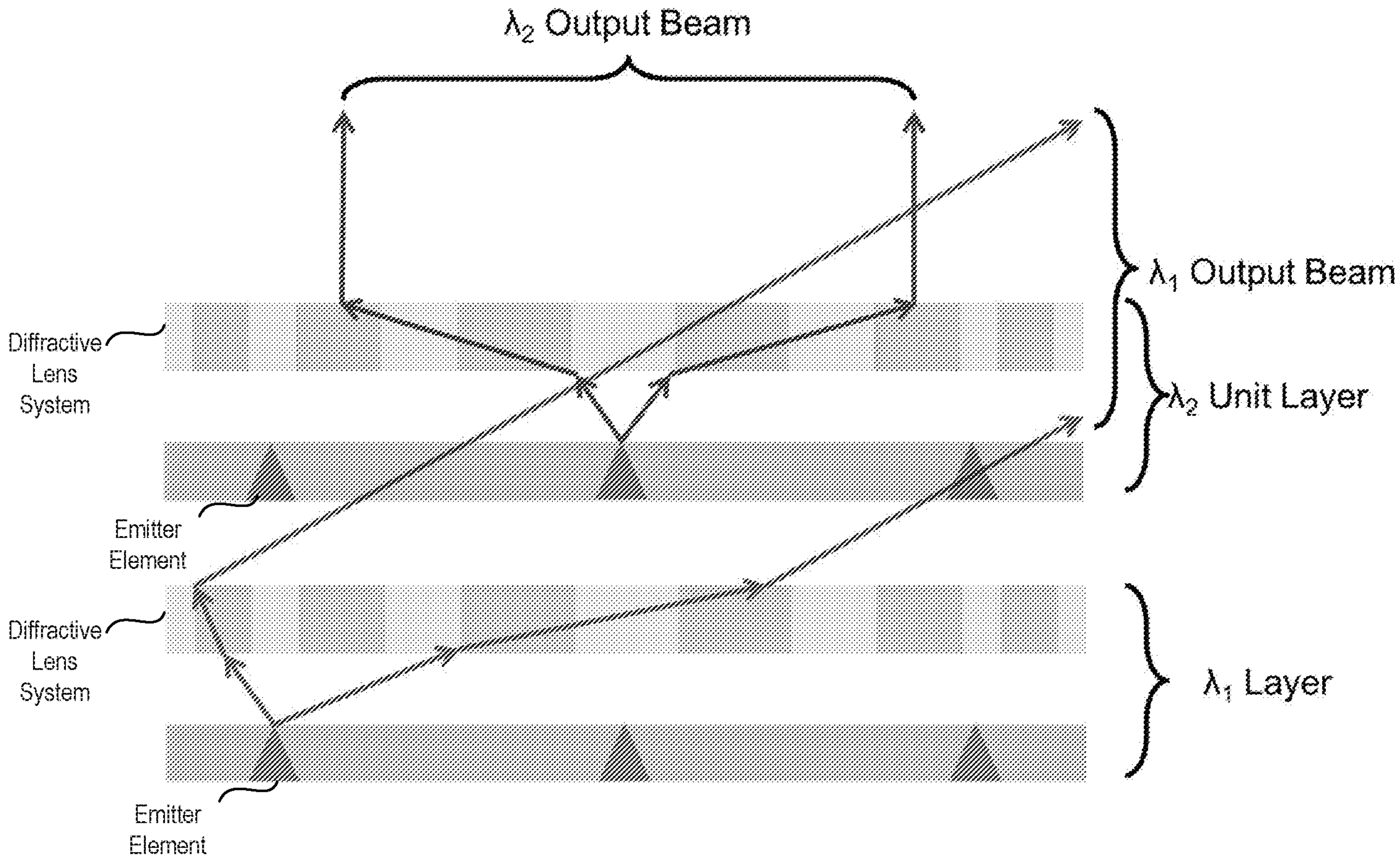
λ_2 Output Beam
λ_1 Output Beam
λ_2 Unit Layer
λ_1 Layer
Diffractive Lens System
Emitter Element
Diffractive Lens System
Emitter Element

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 19/25240

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G02F 1/31; H04B 10/112; H04B 10/114 (2019.01)

CPC - G02B 6/29331; G02F 1/0147; G02F 1/31; H01S 5/4075; H04B 11/1123; H04B 10/1143

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y --- A	US 8,301,027 B2 (SHAW et al.) 30 October 2012 (30.10.2012) Fig 2, 8C, abstract, col 5, ln 46-58, col 9, ln 20-36	1, 2, 5, 6 --------------- 3, 4, 13, 17 --------------- 7-12, 14-16
Y	US 5,966,399 A (JIANG et al.) 12 October 1999 (12.10.1999) Fig 1, 2, abstract, col 6, ln 43-63	3, 4
Y --- A	US 6,169,295 B1 (KOO) 02 January 2001 (02.01.2001) Fig 3, abstract, col 4, ln 8-54	13, 17 --------- 14-16
A	US 9,632,317 B2 (COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES) 25 April 2017 (25.04.2017) Fig 2, 3A, 3B, abstract, col 4, ln 40-col 6, ln 67	7-12, 14-16

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 23 July 2019	Date of mailing of the international search report 19 AUG 2019
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 19/25240

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-17 drawn to a device with selective control of an array of light emitters.

Group II: Claims 18-25 drawn to a beam steering system with a light source selector.

Group III: Claims 26-33 drawn to a beam steering system with a light path selector.

--see extra sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-17

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Continuation of Box No III -- Observations where unity of invention is lacking

The inventions listed in the above-mentioned groups do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special Technical Features
Group I includes the special technical feature of the control circuit is operable to selectively turn on and off different laser diodes to project the different optical beams from the selected laser diodes to form a desired beam scanning pattern to effectuate an effect of scanning a single optical beam in different beam directions, not included in the other groups.

Group II includes the special technical feature of a light source selector, not included in the other groups.

Group III includes the special technical feature of a light path selector, not included in the other groups.

Common Technical Features:
The only technical features shared by Groups I-III that would otherwise unify the groups, are a light emission device including a light source structured to generate a light beam, an optical device located at a fixed position relative to the light emission device in optical paths of the one or more optical beams from the light emission device such that, from the one or more selected optical beams, a collimated beam is produced at different angle depending on the location of incident light on the optical device and a control circuit coupled to the light emission. However, these shared technical features do not represent a contribution over prior art, because the shared technical features are disclosed by US 2010/0046953 A1 to Shaw et al. (hereinafter Shaw).
The only additional technical feature shared by Groups I and II that would otherwise unify the groups, is a light source array. However, these shared technical features do not represent a contribution over prior art, because the shared technical features are disclosed by Shaw.
The only additional technical feature shared by Groups II and III that would otherwise unify the groups, is the control circuit selecting based on address information indicative of the location of incident light on the optical device. However, these shared technical features do not represent a contribution over prior art, because the shared technical features are disclosed by Shaw.

Shaw discloses a light emission device including a light source structured to generate a light beam (para [0011], [0014]: an array of electromagnetic emitters, where the emitters are separated from each by a first separation pitch. Each emitter generates an electromagnetic beam... the emitters emit optical radiation and can be vertical-cavity surface-emitting lasers (VCSELs)), an optical device located at a fixed position relative to the light emission device in optical paths of the one or more optical beams from the light emission device such that, from the one or more selected optical beams, a collimated beam is produced at different angle depending on the location of incident light on the optical device (para [0011]: Each emitter generates an electromagnetic beam, which is collimated by a lens in an array of lenses with a separation pitch different from that of the emitter array. Because the emitter array and the lens array have different separation pitches, the transverse offset between the center of each emitter/lens pair is different. The lenses transform these differences in offsets into differences in angle among the collimated electromagnetic beams; propagation turns these differences in angle into differences in far-field position), the optical projection device structured to include no moving part (para [0009]: (Note: the device is disclosed with no moving parts)) and a control circuit coupled to the light emission device (para [0016], [0050], [0058]: a control circuit to control the emitters in a selectable manner) and a light source array (para [0011], [0014]: an array of electromagnetic emitters, where the emitters are separated from each by a first separation pitch. Each emitter generates an electromagnetic beam... the emitters emit optical radiation and can be vertical-cavity surface-emitting lasers (VCSELs)). Shaw further discloses selecting based on address information indicative of the location of incident light on the optical device (para [0062]).

As the common technical features were known in the art at the time of the invention, these cannot be considered special technical features that would otherwise unify the groups.

Therefore, Groups I-III lack unity under PCT Rule 13.