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(54) TIME MULTIPLEXING FLASH LIGHT DETECTION AND RANGING APPARATUS AND OPERATING METHOD THEREOF

(71) Applicant: **Compertum Microsystems Inc.**, Hsinchu City (TW)

(72) Inventor: **Francis Piu MAN**, Hsinchu City (TW)

(73) Assignee: **Compertum Microsystems Inc.**, Hsinchu City (TW)

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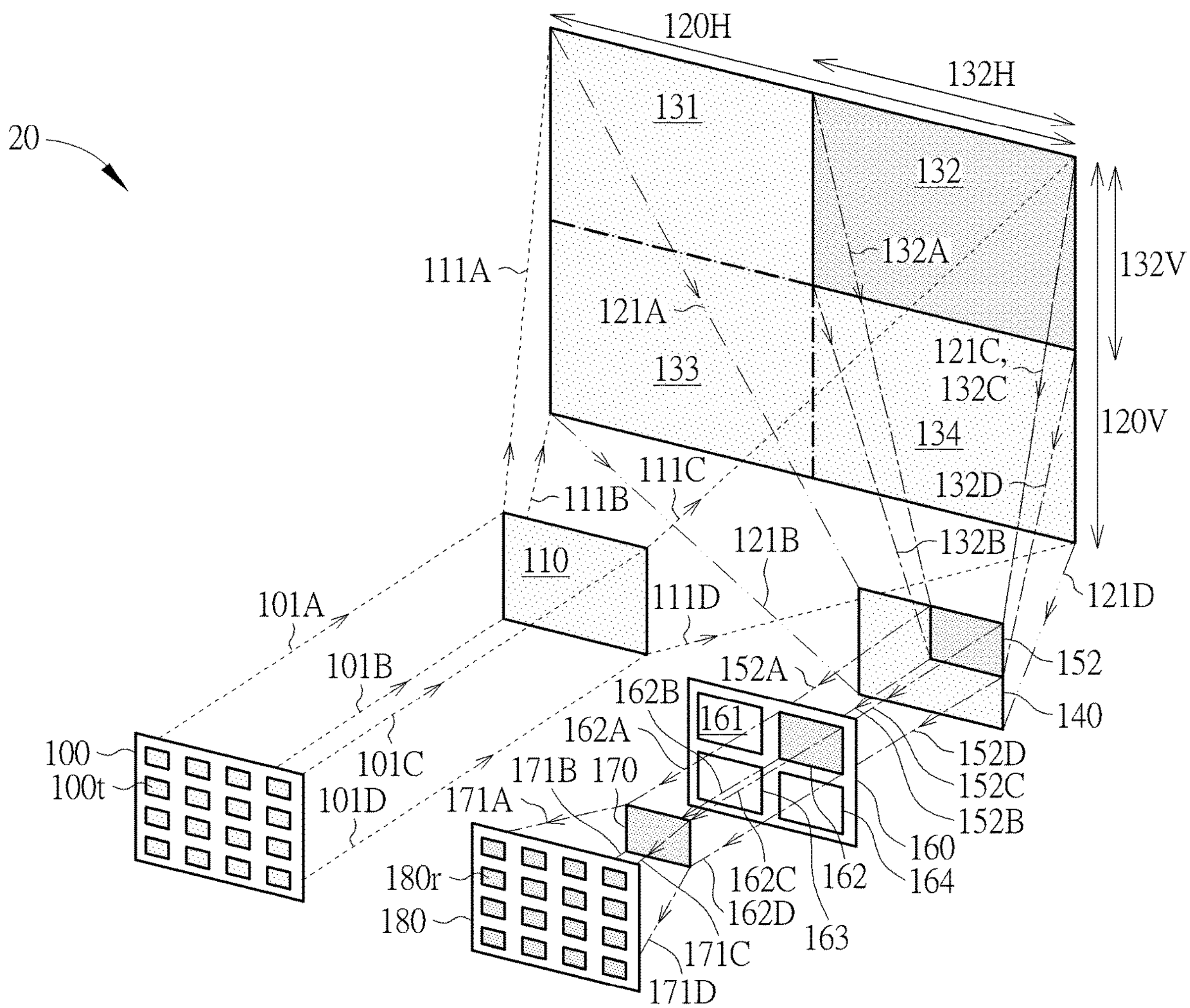
(57) **ABSTRACT**

A time multiplexing flash light detection and ranging apparatus includes a light transmitter configured to emit pulse light, a beam steering unit optically coupled to the light transmitter and including a plurality of beam steering components, and a light receiver optically coupled to the light transmitter and configured to capture a portion of reflected pulse light from one of the plurality of field of view at a time. The plurality of beam steering components are activated sequentially to multiplex the reflected pulse light from a plurality of field of views, and the reflected pulse light represents the pulse light reflected by at least one object.



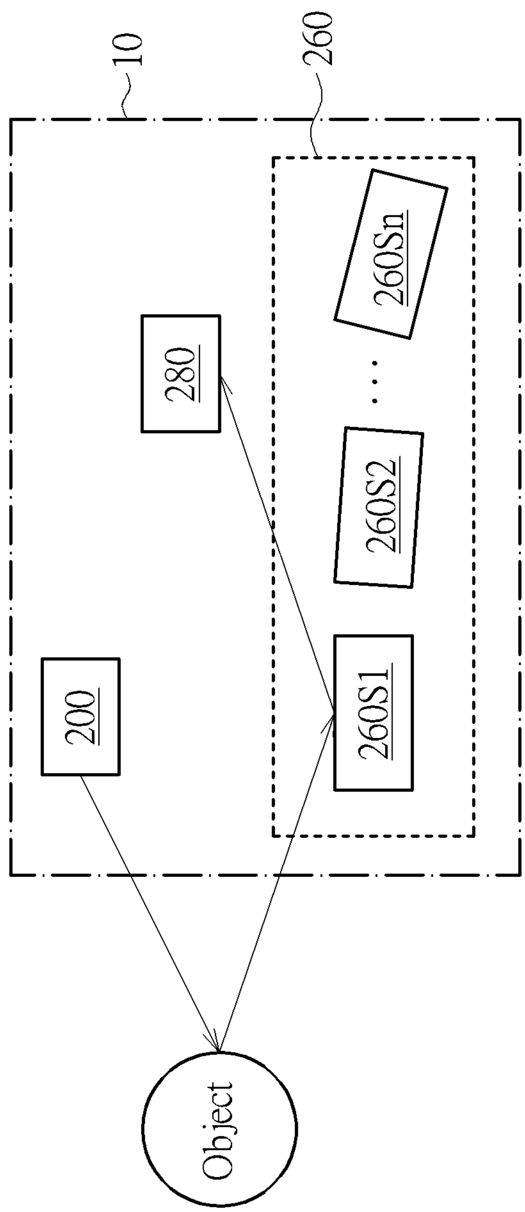


FIG. 1

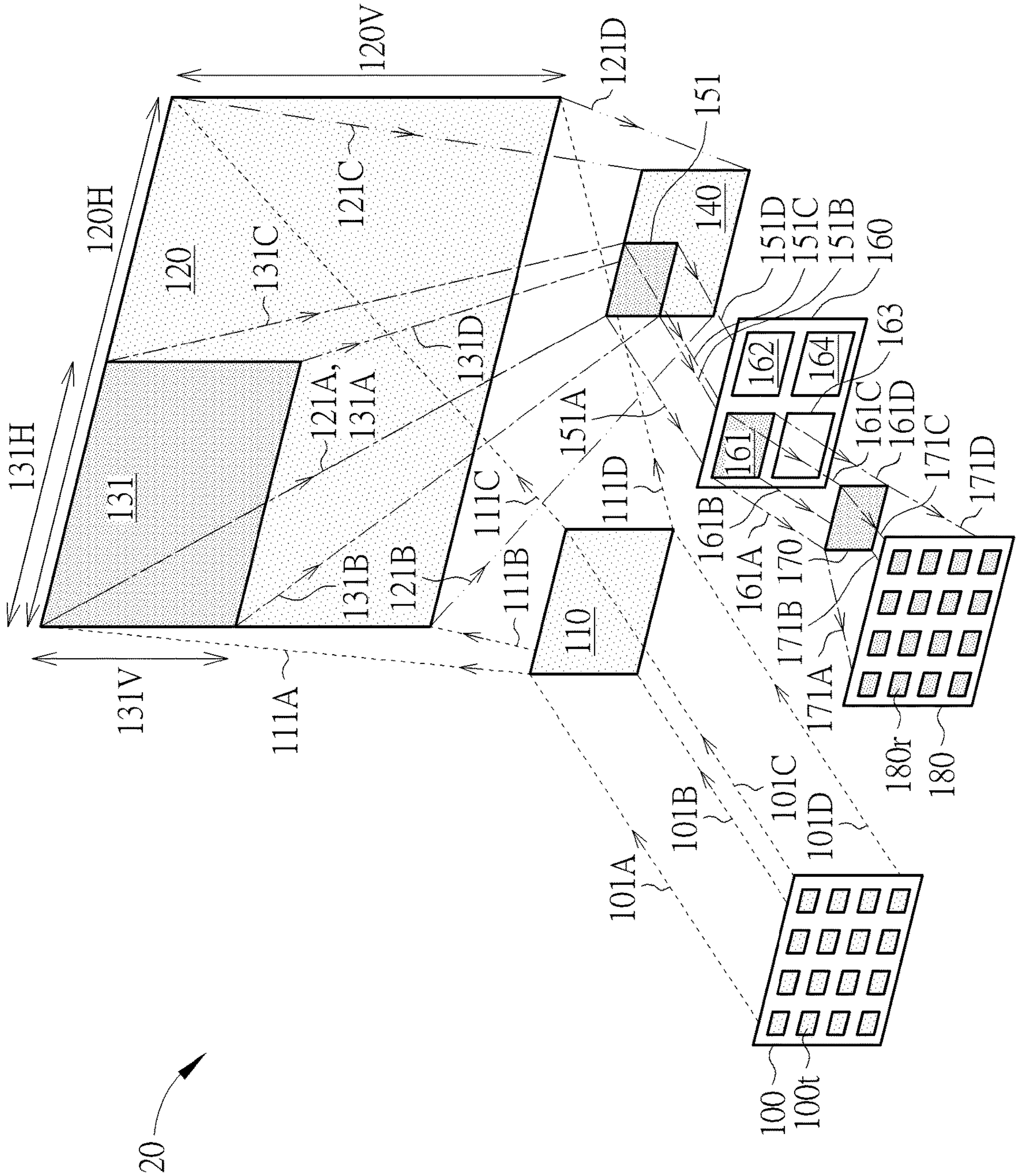

120V
121D
151
120H
120
131C
121C
140
151D
151C
151B
160
131H
131
121A,
131A
131D
162
164
163
151A
161
161C
161D
111D
111C
161B
161A
170
171C
171D
131V
111A
131B
121B
111B
110
171B
171A
180r
180
101A
101B
101C
101D
100
100t
20

FIG. 2

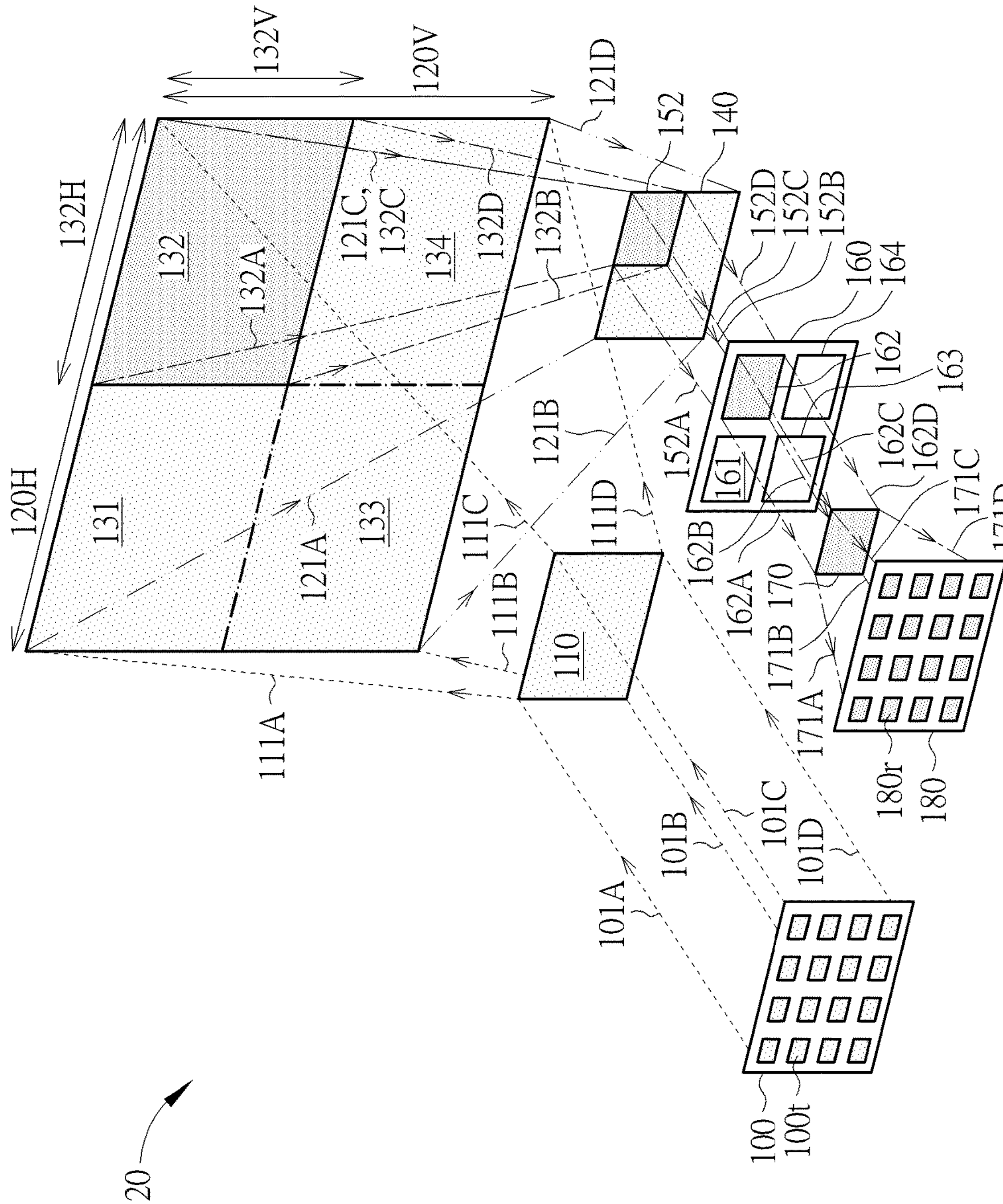

132V
120V
121D
132H
152
140
132
132A
121C,
132C
134
132D
132B
152D
152C
152B
160
164
162
163
120H
131
121A
133
121B
152A
161
162C
162D
171C
171D
111C
111D
162B
162A
170
171B
171A
111A
111B
110
180r
180
101A
101B
101C
101D
100
100t
20

FIG. 3

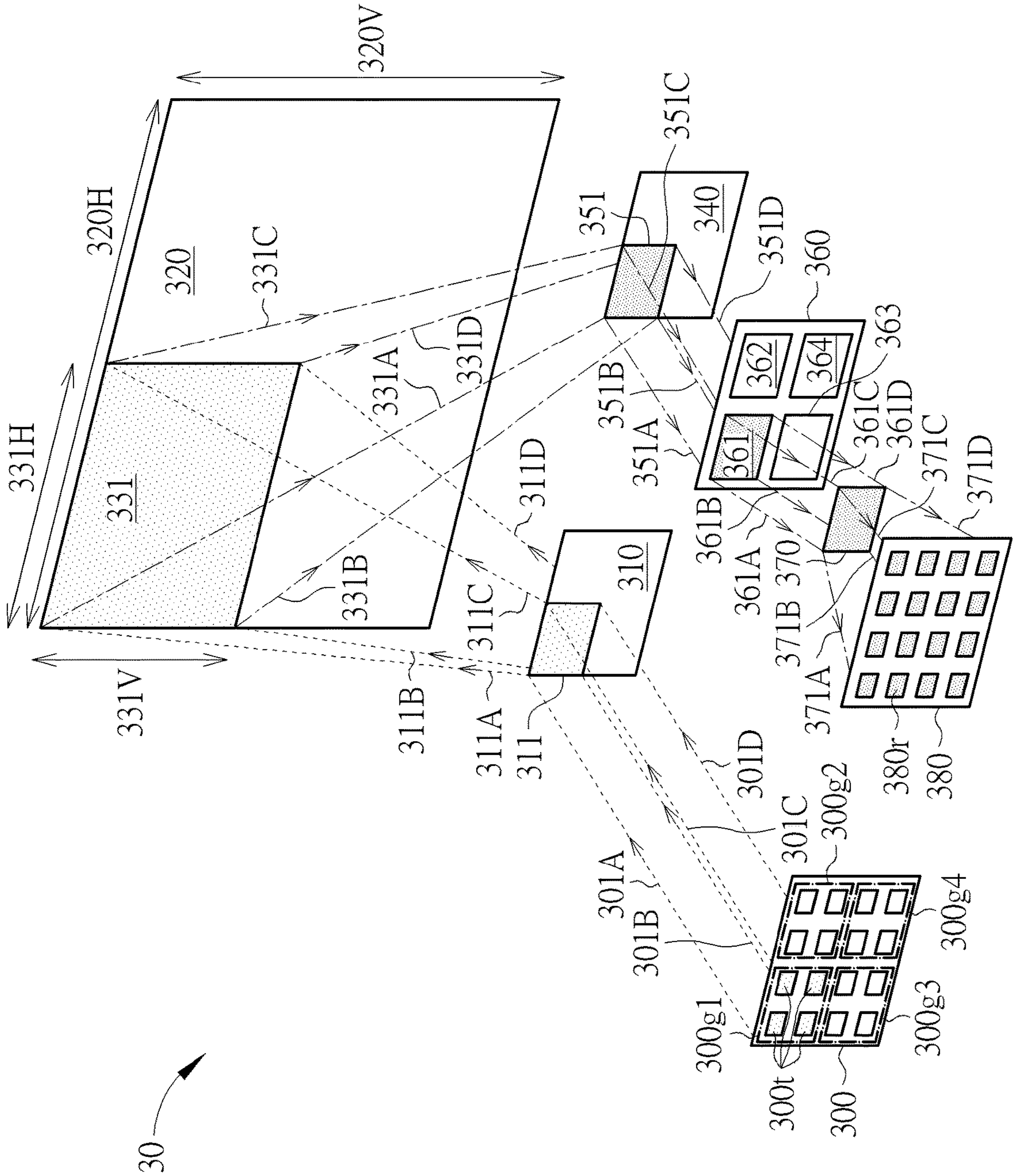

30
300
300t
300g1
300g2
300g3
300g4
301A
301B
301C
301D
310
311
311A
311B
311C
311D
320
320H
320V
331
331A
331B
331C
331D
331H
331V
340
351
351A
351B
351C
351D
360
361
361A
361B
361C
361D
362
363
364
370
371A
371B
371C
371D
380
380r

FIG. 4

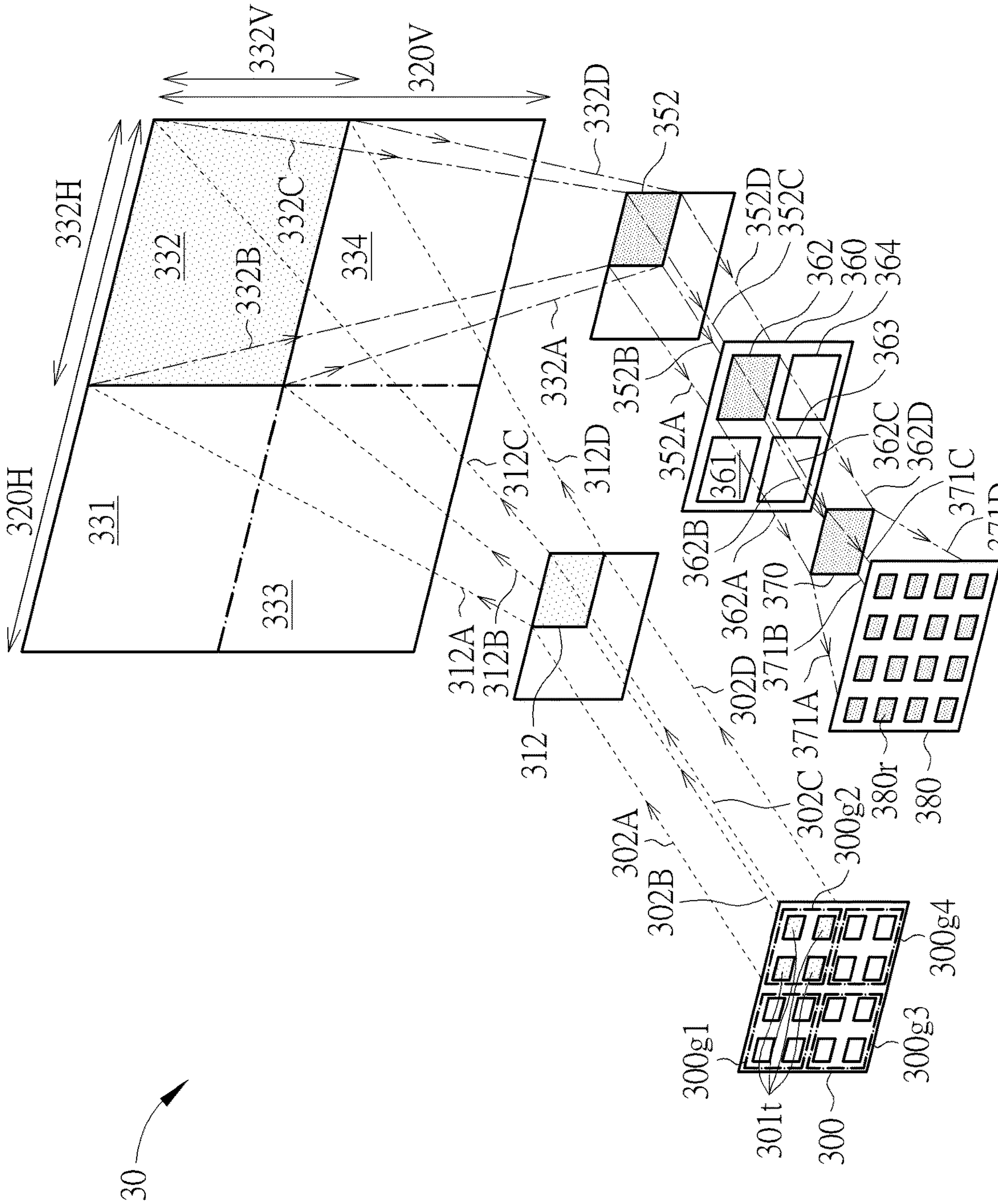

30
320H
320V
332V
332H
331
332
333
334
332B
332C
332D
332A
312
312A
312B
312C
312D
352
352A
352B
352C
352D
360
361
362
362A
362B
362C
362D
363
364
370
371A
371B
371C
371D
380
380r
300
300g1
300g2
300g3
300g4
301t
302A
302B
302C
302D

FIG. 5

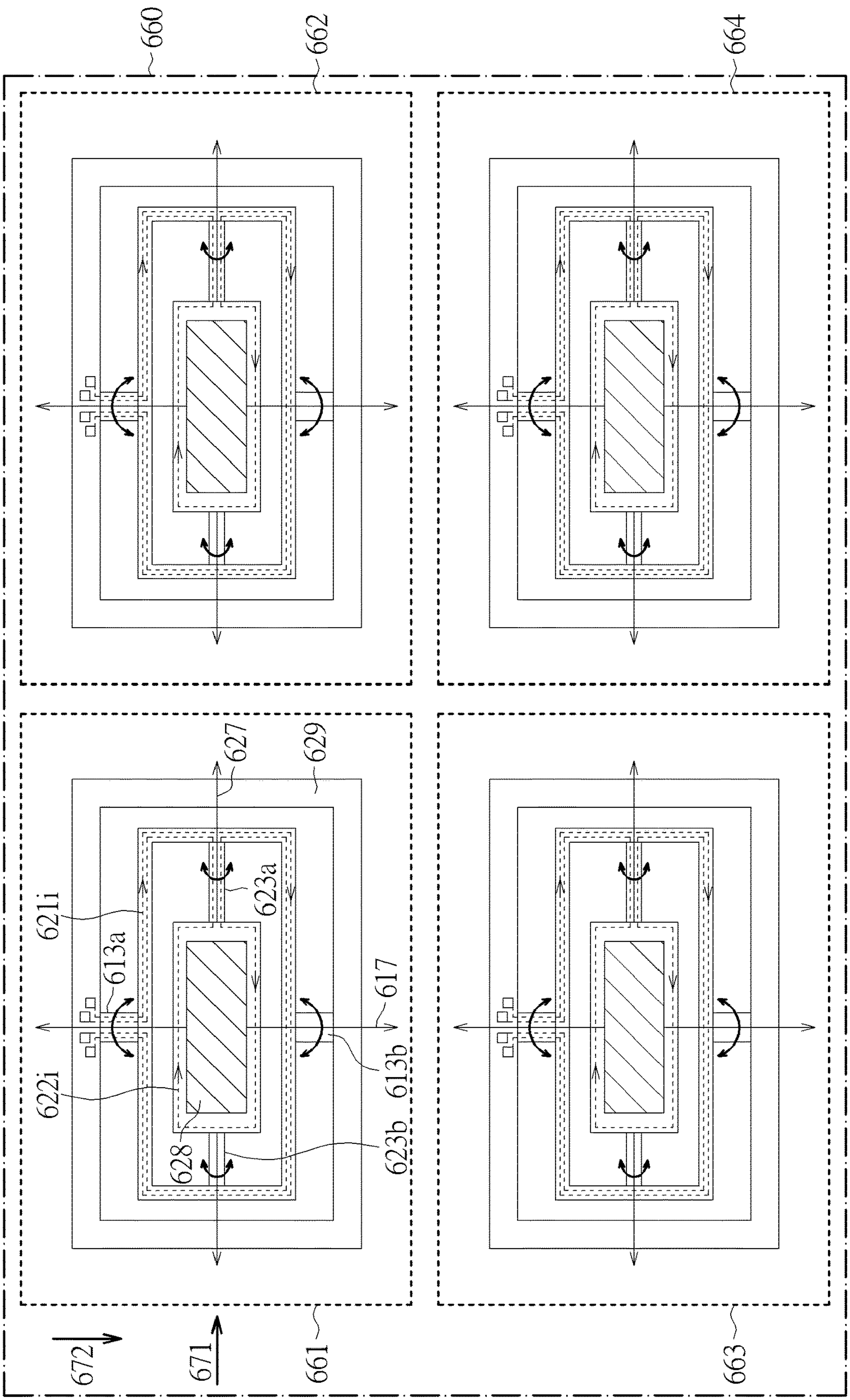

660
662
664
627
629
621i
613a
623a
617
613b
622i
628
623b
672
671
661
663

FIG. 6

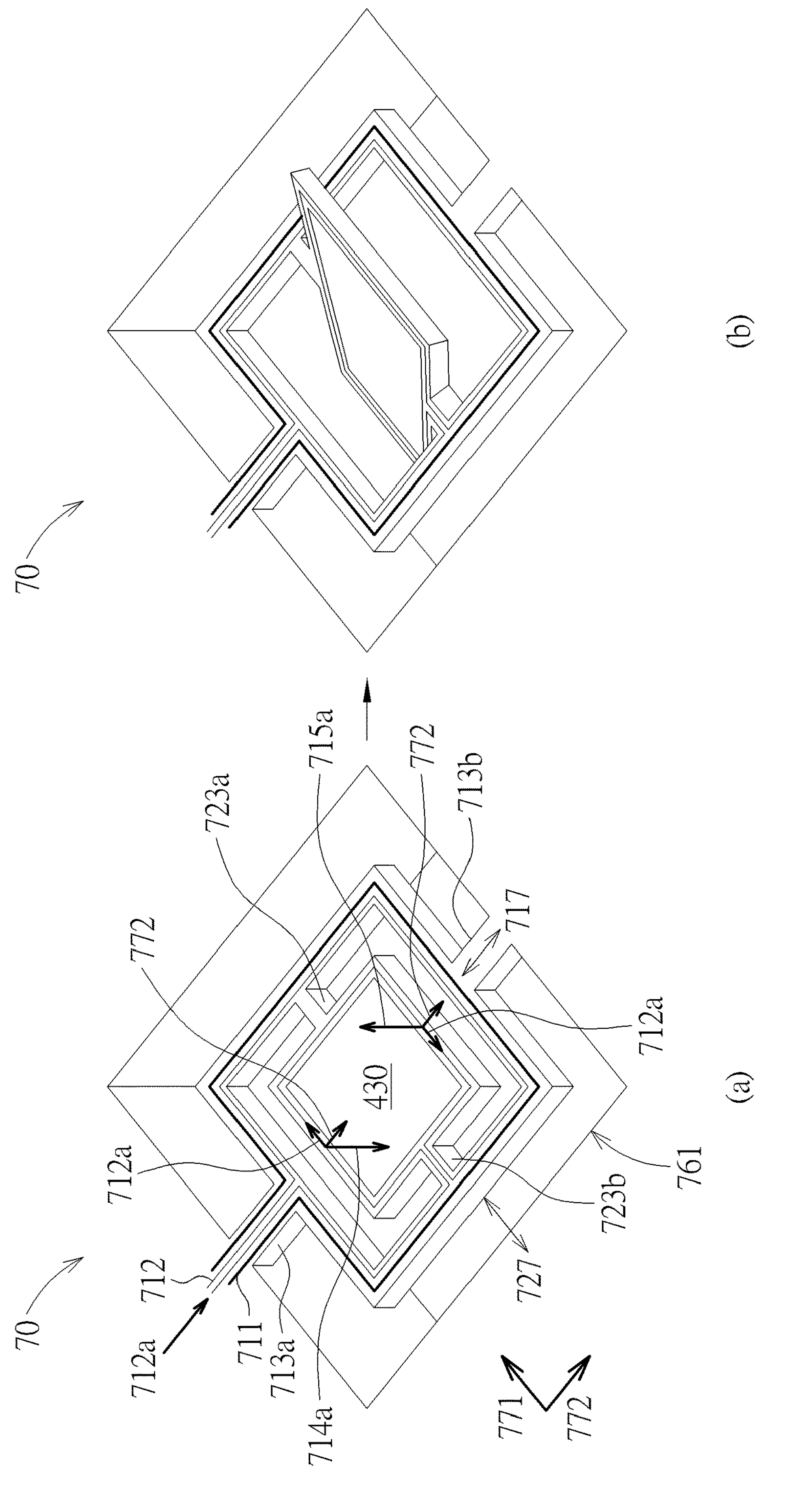

70
712a
712
711
713a
714a
712a
772
723a
715a
772
713b
717
712a
430
727
723b
761
771
772
(a)
70
(b)

FIG. 7

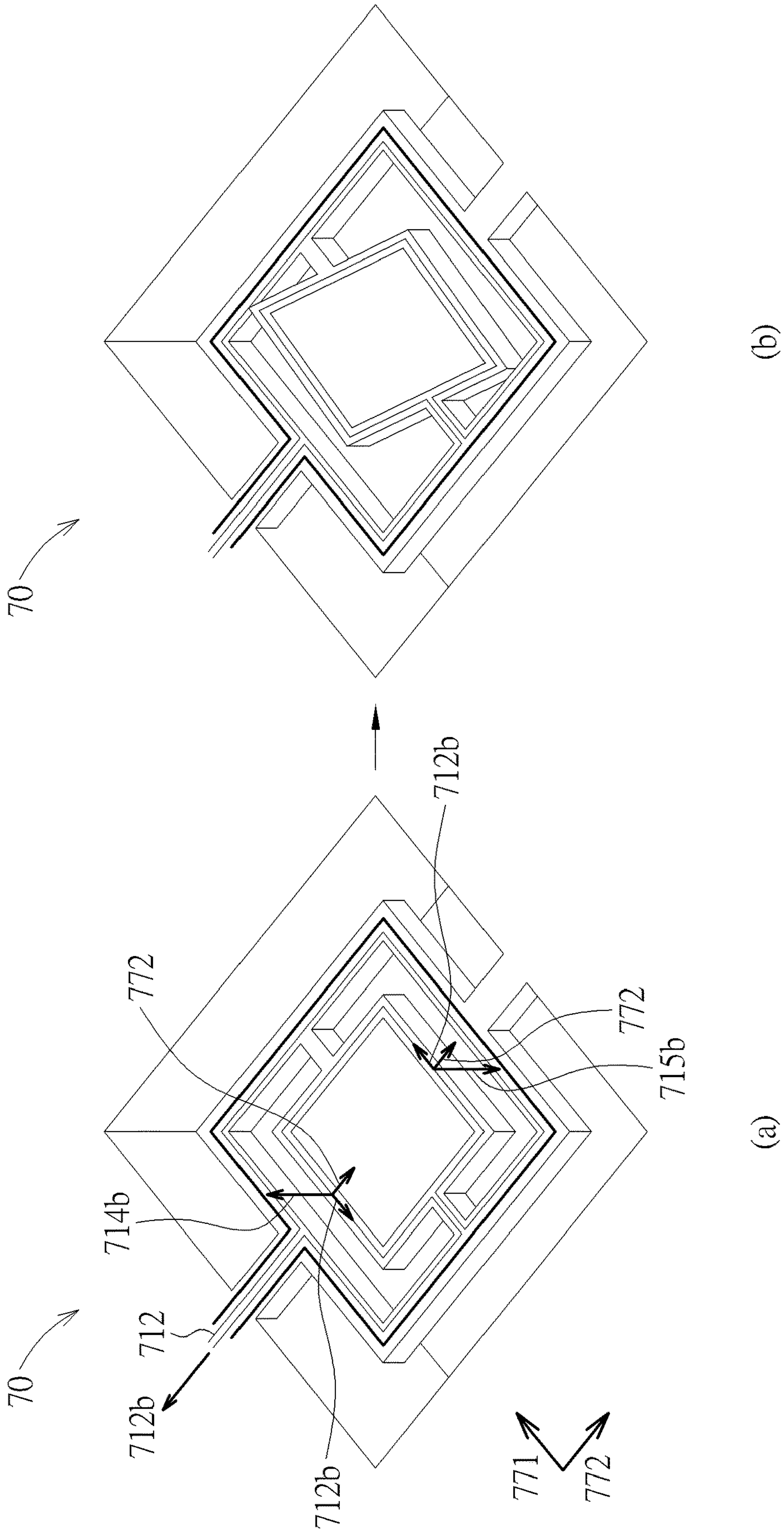


FIG. 8

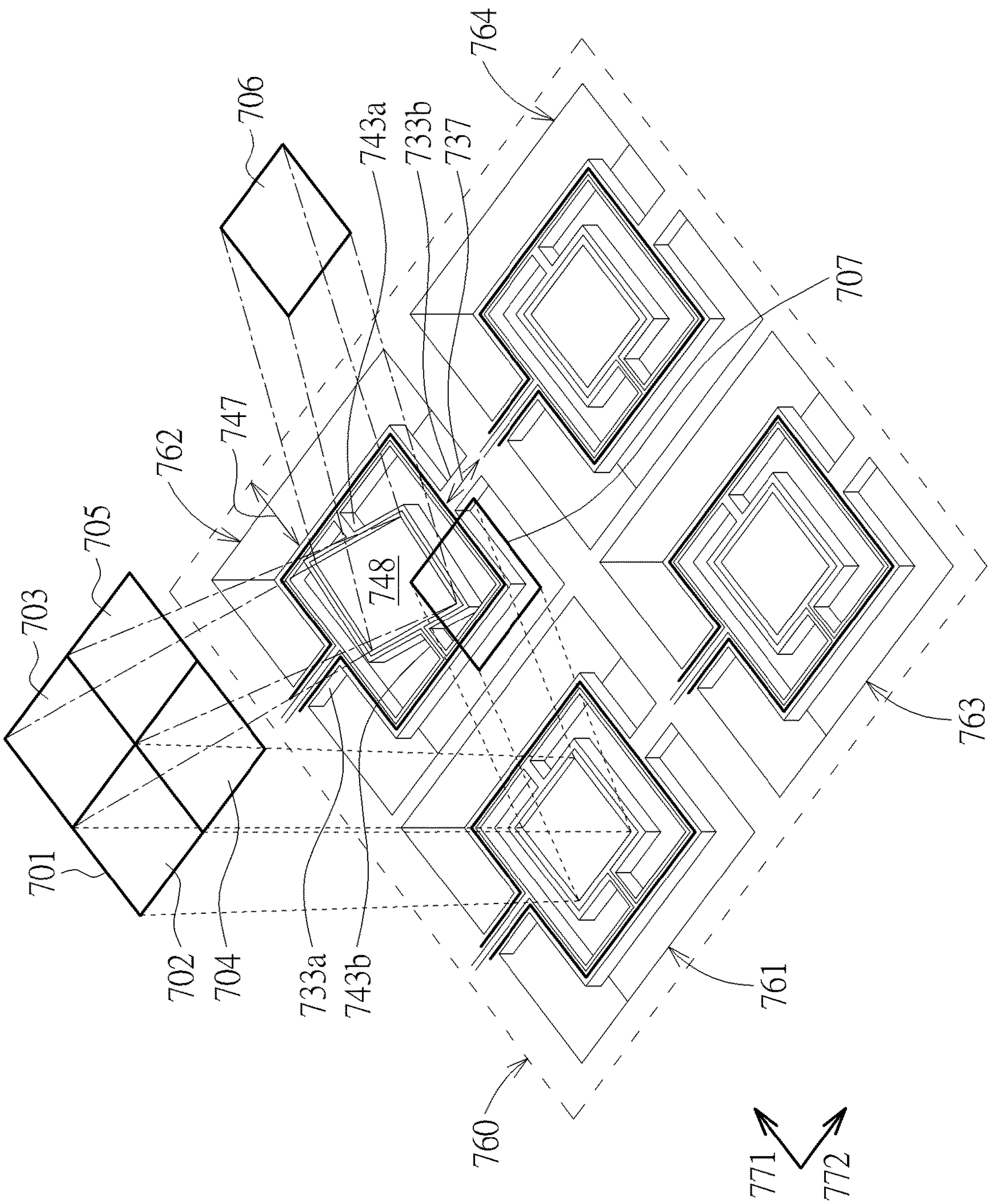

701
702
703
704
705
706
707
733a
733b
737
743a
743b
747
748
760
761
762
763
764
771
772

FIG. 9

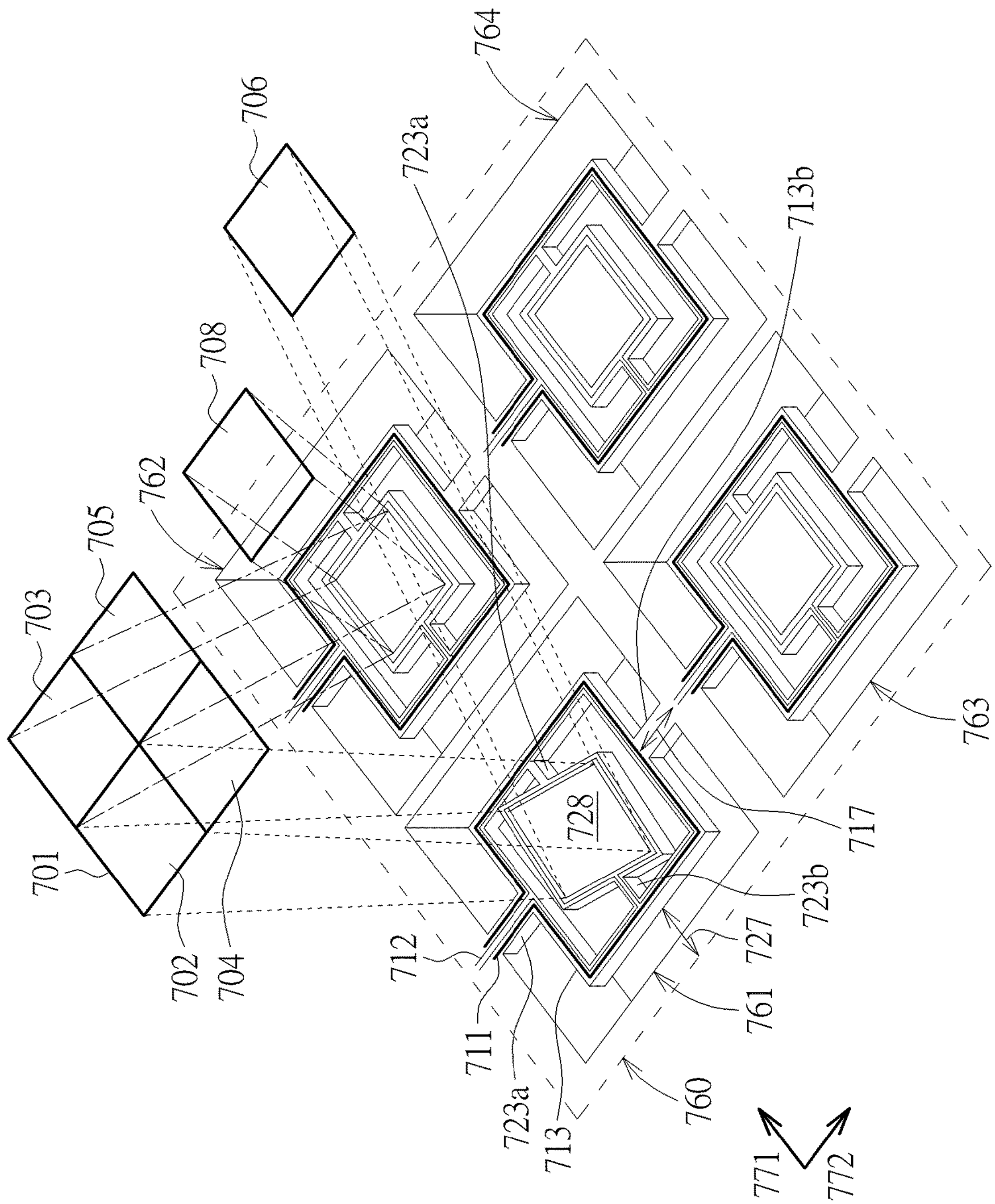

701
702
703
704
705
706
708
711
712
713
713b
717
723a
723b
727
728
760
761
762
763
764
771
772

FIG. 10

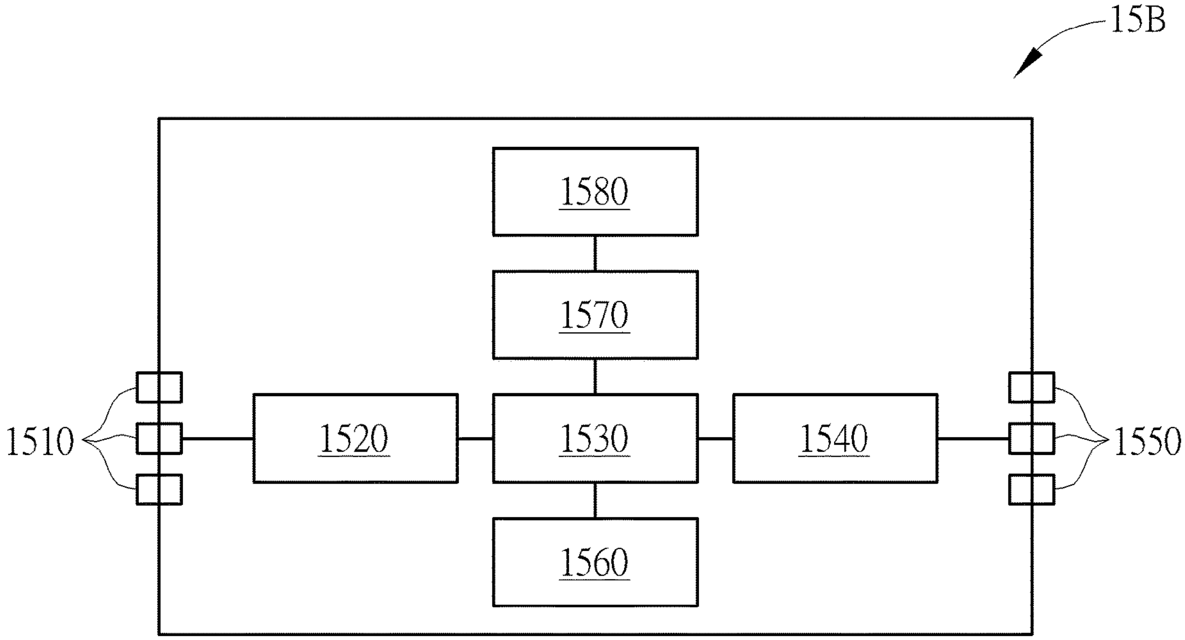

15B
1580
1570
1510
1520
1530
1540
1550
1560

FIG. 11

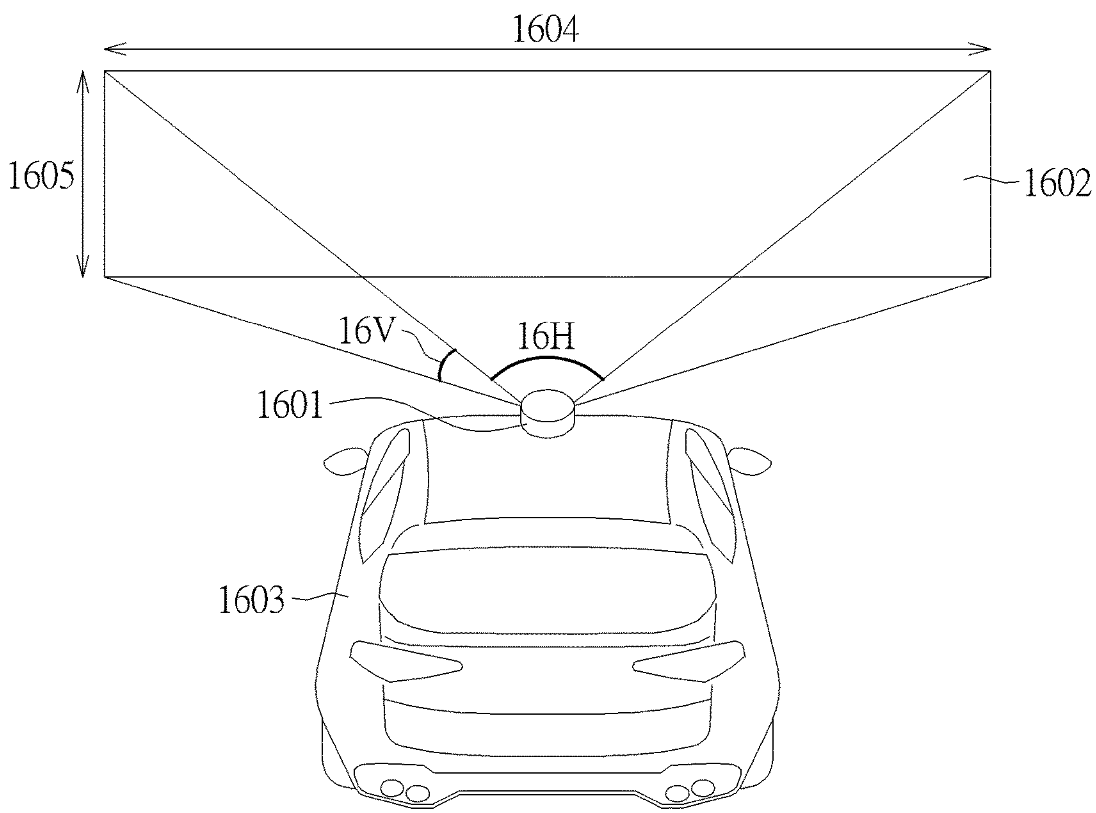

1604
1605
1602
16V
16H
1601
1603

FIG. 12

TIME MULTIPLEXING FLASH LIGHT DETECTION AND RANGING APPARATUS AND OPERATING METHOD THEREOF

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates generally to systems and methods that use time multiplexing device on Light Detection and Ranging (LiDAR) that use steering mirror for surveying a surrounding environment, and more particularly to systems and methods that use Micro-Electro-Mechanical Systems (MEMS) micro-mirror as time multiplexing device with flash LiDAR for obstacle detection and avoidance in a surrounding environment.

2. Description of the Prior Art

[0002] With the advent of Autonomous Driving Assist System (ADAS), automobiles demand systems capable of reliably sensing and identifying objects, hazards, and obstacles in navigation. Among all the systems, a Light Detection and Ranging (LiDAR) system measures distances to objects by emitting non-visible laser to objects within the Field of View (FOV) and receiving returned laser signal such that distances to objects are computed by measuring time delay between emitted and returned laser.

[0003] Among all specifications, spatial angle resolution is critical in LiDAR design. There is still room for improvement when it comes to LiDAR design.

SUMMARY OF THE INVENTION

[0004] It is therefore a primary objective of the present invention to disclose a time multiplexing flash LiDAR system and method that comprises a plurality of light transmitters, a plurality of time multiplexing opto-mechanical beam steering components and a plurality of Geiger mode avalanche photodiodes that generates high spatial angle resolutions within field of view where a plurality of time multiplexing opto-mechanical beam steering component could be an array of MEMS micro-mirror.

[0005] An embodiment of the present invention provides a time multiplexing flash light detection and ranging (LiDAR) apparatus, comprising a light transmitter, configured to emit pulse light; a beam steering unit, optically coupled to the light transmitter and comprising a plurality of beam steering components; and a light receiver, optically coupled to the light transmitter and configured to capture a portion of the reflected pulse light from one of the plurality of FOVs at a time. The plurality of beam steering components are activated sequentially to multiplex reflected pulse light from a plurality of field of views (FOV), and the reflected pulse light represents the pulse light reflected by at least one object.

[0006] Another embodiment of the present invention provides a light detection and ranging (LiDAR) operating method, for a time multiplexing flash LiDAR, comprising emitting pulse light from a light transmitter of the time multiplexing flash LiDAR; activating a plurality of beam steering components of a beam steering unit of the time multiplexing flash LiDAR sequentially to multiplexing reflected pulse light from a plurality of field of views (FOV); and by a light receiver of the time multiplexing flash LiDAR, capturing the reflected pulse light from one of the plurality of FOVs at a time. The reflected pulse light represents the pulse light reflected by at least one object

[0007] These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is a schematic diagram of a LiDAR apparatus according to an embodiment of the present invention.

[0009] FIGS. **2** and **3** are schematic diagrams of a time-multiplexing flash LiDAR apparatus according to an embodiment of the present invention.

[0010] FIGS. **4** and **5** are schematic diagrams of another time-multiplexing flash LiDAR apparatus according to another embodiment of the present invention.

[0011] FIG. **6** is a schematic diagram of a time multiplexing beam steering unit according to an embodiment of the present invention.

[0012] FIGS. **7** and **8** show a one-axis activation of a beam steering component according to an embodiment of the present invention.

[0013] FIGS. **9** and **10** show beam re-direction by activation of a beam steering component.

[0014] FIG. **11** is a schematic diagram of an electro-optical device according to an embodiment of the present invention.

[0015] FIG. **12** is a schematic diagram of a LiDAR system according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0016] FIG. **1** is a schematic diagram of a LiDAR apparatus **10** according to an embodiment of the present invention. The LiDAR apparatus **10**, which may be a flash LiDAR or a time multiplexing flash LiDAR, may include a light transmitter **200** configured to emit pulse light, a beam steering unit **260**, and a light receiver **280**.

[0017] The LiDAR apparatus **10** measures distances to object(s) by emitting at least a non-visible laser pulse or flash at the same time to object(s) in the surrounding environment, and receiving at least a returned pulse signal reflected from the object(s) by the light receiver **280**. The pulse light emitted and the reflected pulse light may be non-coaxial, but is not limited thereto. Distances to object(s) are computed using time of flight method by measuring time delay between the pulse light and the reflected pulse light. The LiDAR apparatus **10** may provide a three-dimensional representation of object(s) known as point cloud data which is formed by collecting distance-to-object-data in a two-dimensional space.

[0018] A flash LiDAR is desirable because it does not require mechanical parts. However, the spatial resolution of a flash LiDAR is not high since its spatial resolution is determined by the number of light detectors within the flash LiDAR. On the other hand, the LiDAR apparatus **10** may obtain high spatial resolution point cloud data as beam steering components **260S1-260**Sn of the beam steering unit **260** are activated sequentially to multiplex the reflected pulse light from different field of views (FOVs). The light receiver **280** may capture the reflected pulse light from one

FOV at a time. In a manner of multiplexing, the LiDAR apparatus **10** may generate point cloud data with high spatial resolution.

[0019] FIG. **2** is a schematic diagram of a time-multiplexing flash LiDAR apparatus **20** according to an embodiment of the present invention, which may include a light transmitter **100**, a transmitter deflector **110**, a receiver deflector **140**, a time multiplexing beam steering unit **160**, an intermediate deflector **170**, and a light receiver **180**. The light transmitter **100**, the transmitter deflector **110**, the receiver deflector **140**, the beam steering unit **160**, the intermediate deflector **170**, and the light receiver **180** are disposed corresponding to each other and optically coupled.

[0020] The light transmitter **100** includes individual light sources **100***t* configured to emit pulse light (e.g., pulse light beams **101**A, **101**B, **101**C, and **101**D) flashing at the same time within an entirety of field of views. The light sources **100***t* may be arranged in a two-dimensional array (or a one-dimensional array). For example, the light sources **110***t* may be arranged in column(s) or row(s). The light source **100***t* may illuminate homogeneously. The pulse light (beam) may be non-visible. The wavelength of the pulse light (beam) is but not limited to 840 nanometers (nm), 905 nm, 940 nm, 1060 nm, 1330 nm, or 1550 nm. The light transmitter **100** may be an edge emitting laser diode source transmitter, or a vertical cavity surface emitting laser (VCSEL) source transmitter, or a photonic crystal surface emitting laser (PCSEL) source transmitter, but is not limited thereto.

[0021] The transmitter deflector **110** is disposed in front of the light transmitter **100** and configured to project the pulse light (e.g., pulse light beams **101**A, **101**B, **101**C, and **101**D) to the external environment (and match an FOV **120**). The transmitter deflector **110** may increase the FOV of light transmission. The pulse light beams **101**A-**101**D exit the transmitter deflector **110** as pulse light beams **111**A, **111**B, **111**C, and **111**D. The angular distributions of the pulse light beams **101**A-**101**D with respect to their optical axis are different from the angular distributions of the pulse light beams **111**A-**111**D. The transmitter deflector **110** may include at least one lens to serve as a (divergent) lens unit. With the transmitter deflector **110**, the FOV **120** (a horizontal FOV **120**H by a vertical FOV **120**V) is increased.

[0022] Upon reflected/scattered by object(s) in the FOV **120**, the reflected pulse light (e.g., reflected pulse light beams **121**A, **121**B, **121**C, **121**D, **131**A, **131**B, **131**C, and **131**D) strikes on the receiver deflector **140** which is configured to receive/redirect reflected pulse light within the entire FOV **120**. The receiver deflector **140** disposed in front of the time multiplexing beam steering unit **160** may increase the FOV of light reception. The receiver deflector **140** may include at least one lens to serve as a (convergent) lens unit. In the LiDAR apparatus **20**, the emitted pulse light (e.g., the pulse light beams **111**A-**111**D) and the reflected pulse light (e.g., the reflected pulse light beams **121**A-**121**D) are non-coaxial.

[0023] The time multiplexing beam steering unit **160** includes beam steering components **161**, **162**, **163**, and **164** arranged in a two-dimensional array (or a one-dimensional array). The beam steering components **161**-**164** may have similar structure/elements/material/function. A beam steering component (e.g., the beam steering component **161**) is configured to steer a portion of the reflected pulse light (e.g., reflected pulse light beams **151**A, **151**B, **151**C, and **151**D) within an FOV **131** from a part (e.g., the part **151**) of the receiver deflector **140** to the intermediate deflector **170**. The reflected pulse light beams **151**A-**151**D comes from the reflected pulse light beams **131**A-**131**D which corresponds to the FOV **131** (a horizontal FOV **131**H by a vertical FOV **131**V) out of the FOV **120**. The reflected pulse light beams **151**A-**151**D undergo reflection/refraction to exit the beam steering component **161** as reflected pulse light beams **161**A, **161**B, **161**C, and **161**D.

[0024] The intermediate deflector **170** is disposed between the time multiplexing beam steering unit **160** and the light receiver **180**. The reflected pulse light beams **161**A-**161**D bend toward the light receiver **180** by the intermediate deflector **170** as reflected pulse light beams **171**A, **171**B, **171**C, and **171**D. The intermediate deflector **170** may include at least one lens to serve as a (convergent) lens unit.

[0025] The light receiver **180** is configured to capture the reflected pulse light (e.g., the reflected pulse light beams **171**A-**171**D). The reflected pulse light from one of the beam steering components **161**-**164** is all imaged onto the light receiver **180**. The time delay(s) between the pulse light emitted from the light transmitter **100** and the reflected pulse light received by the light receiver **180** is/are calculated for the light detectors **180***r*, respectively, to measure the distance (s) between the LiDAR apparatus **20** and the object(s). The light receiver **180** may be a Geiger mode avalanche photodiode receiver including individual light detectors **180***r* (e.g., Geiger mode avalanche photodiodes). A Geiger mode avalanche photodiode may be/include a silicon based single photon avalanche diode (SPAD), a silicon photomultiplier, a Germanium-on-silicon SPAD, or an InGaAs/InP SPAD. The light detectors **180***r* may be arranged in a two-dimensional array or a one-dimensional array (such as a row or column) and can be individually configured such that each light detector **180***r* collects the reflected pulse light beams reflected/scattered by object(s) in an array, in a column, or in a row.

[0026] Together FIG. **2** and FIG. **3** show the multiplexing operation of the time multiplexing flash LiDAR apparatus **20** according to an embodiment of the present invention. The FOV **120** may be divided into the FOV **131**-**134**. The time multiplexing beam steering unit **160** activates individual beam steering component (e.g., one of the beam steering components **161**-**164**) sequentially to achieve time multiplexing, which divides a period into time slots and allocates the time slots to the beam steering components **161**-**164** corresponding to the (partial) FOV **131**-**134**.

[0027] For example, FIG. **2** shows optical light paths of the LiDAR apparatus **20** in a first time slot where only the beam steering component **161** turns on. The light transmitter **100** illuminates with the pulse light (e.g., the pulse light beams **101**A-**101**D) emitted simultaneously. Within the FOV **120**, the reflected pulse light (e.g., the reflected pulse light beams **121**A-**121**D corresponding to the pulse light beams **101**A-**101**D) are reflected by the object(s), and a portion of the reflected pulse light (e.g., the reflected pulse light beams **131**A-**131**D) is incident on the part **151** of the receiver deflector **140**. As shown in FIG. **2**, since only the beam steering component **161** is activated during the first time slot, only the portion of the reflected pulse light within the FOV **131** out of the entire FOV **120** (e.g., the reflected pulse light beams **131**A-**131**D) is directed to the intermediate deflector **170** through activated beam steering component **161**. Finally, the intermediate deflector **170** directs all the reflected pulse light from the beam steering component **161** (e.g., the reflected pulse light beams **171**A-**171**D) to the light receiver **180** which captures a first point cloud data corresponding to the FOV **131** within the first time slot.

[0028] Similarly, when the beam steering component **162** is activated during a second time slot as shown in FIG. **3**, only a portion of the reflected pulse light within the FOV **132** out of the entire FOV **120** (e.g., the reflected pulse light beams **132**A-**132**D) is directed to the intermediate deflector **170** through activated beam steering component **162**. Reflected pulse light beams **152**A-**152**D undergo reflection/refraction to exit the beam steering component **162** as reflected pulse light beams **162**A-**162**D. The intermediate deflector **170** directs all the reflected pulse light from the beam steering component **162** (e.g., the reflected pulse light beams **171**A-**171**D) to the light receiver **180** which captures a second point cloud data corresponding to the FOV **132** within the second time slot.

[0029] Similarly, when the beam steering component **163** is activated during a third time slot, only a portion of the reflected pulse light within the FOV **133** out of the entire FOV **120** is directed to the intermediate deflector **170** through activated beam steering component **163**. The intermediate deflector **170** directs all the reflected pulse light from the beam steering component **163** to the light receiver **180** which captures a third point cloud data corresponding to the FOV **133** within the third time slot.

[0030] Similarly, when the beam steering component **164** is activated during a fourth time slot, only a portion of the reflected pulse light within the FOV **134** out of the entire FOV **120** is directed to the intermediate deflector **170** through activated beam steering component **164**. The intermediate deflector **170** directs all the reflected pulse light from the beam steering component **164** to the light receiver **180** which captures a fourth point cloud data corresponding to the FOV **134** within the fourth time slot.

[0031] All the point cloud data (i.e., the first to fourth point cloud data) collected by the light receiver **180** over the period (e.g., at least part of the length of time for the time multiplexing beam steering unit **160** to go through one cycle) may be processed. By integrating all the point cloud data within all the time slots (i.e., the period), an entirety of point cloud data is formed which correspond to the entirety of FOV (i.e., the FOV **120**) to present one image for a scene. The time multiplexing flash LiDAR apparatus **20**, which may be served as the LiDAR apparatus **10**, periodically alternates between the reflected pulse light from different FOVs **131**-**134** to achieve time multiplexing of the reflected pulse light from different FOVs **131**-**134**. Such time multiplexing of collecting point cloud data increases spatially resolution within the entirety of FOV.

[0032] FIG. **4** is a schematic diagram of another time-multiplexing Flash LiDAR apparatus **30** according to an embodiment of the present invention, which may include a light transmitter **300**, a transmitter deflector **310**, a receiver deflector **340**, a time multiplexing beam steering unit **360**, an intermediate deflector **370**, and a light receiver **380**. The LiDAR apparatus **20** and **30** may have similar structure/elements/material/function but perform different multiplexing operations.

[0033] The light transmitter **300** includes individual light sources **300***t* in a two-dimensional array (or a one-dimensional array). The light sources **300***t* divided into groups **300***g***1**, **300***g***2**, **300***g***3**, and **300***g***4** may be individually activated or able to be individually activated such that the light sources **300***t* of the groups **300***g***1**-**300***g***4** illuminate in sequence (i.e., scan-flashing). For example, instead of flashing all the groups **300***g***1**-**300***g***4** at the same time, the light sources **300***t* in the group **300***g***1** emit pulse light (e.g., pulse light beams **301**A, **301**B, **301**C, and **301**D) flashing at a first time slot.

[0034] The pulse light (e.g., the pulse light beams **301**A-**301**D) passes through only a part **311** of the transmitter deflector **310** and leaves the transmitter deflector **110** as pulse light beams **311**A, **311**B, **311**C, and **311**D to project an FOV **330** (a horizontal FOV **330**H by a vertical FOV **330**V) which is a portion of entire FOV **320** (a horizontal FOV **320**H by a vertical FOV **320**V). Upon reflected by object(s) in the FOV **330**, the reflected pulse light (e.g., reflected pulse light beams **331**A, **331**B, **331**C, and **331**D) reaches a part **351** of the receiver deflector **350**. In the LiDAR apparatus **30**, the emitted pulse light (e.g., the pulse light beams **311**A-**311**D) and the reflected pulse light (e.g., the reflected pulse light beams **331**A-**331**D) are non-coaxial.

[0035] The time multiplexing beam steering unit **360** includes beam steering components **361**, **362**, **363**, and **364**. The beam steering components **361**-**364** may be arranged in a (two-dimensional or one-dimensional) array similar to or coincide/correspond with another array in which the groups **300***g***1**-**300***g***4** are arranged. A beam steering component (e.g., the beam steering component **361**) is configured to steer the reflected pulse light (e.g., reflected pulse light beams **351**A, **351**B, **351**C, and **351**D) from a part (e.g., the part **351**) of the receiver deflector **340** to the intermediate deflector **370**. The reflected pulse light beams **351**A-**351**D corresponding to the reflected pulse light beams **331**A-**331**D undergo reflection/refraction to exit the beam steering component **361** as reflected pulse light beams **361**A, **361**B, **361**C, and **361**D.

[0036] The light receiver **380** including individual light detectors **380***r* collects the reflected pulse light (e.g., reflected pulse light beams **371**A, **371**B, **371**C, and **371**D).

[0037] Together FIG. **4** and FIG. **5** show the multiplexing operation of the time multiplexing flash LiDAR apparatus **30** according to an embodiment of the present invention. The light sources **300***t* in the groups **300***g***1**-**300***g***4** illuminate sequentially as the time multiplexing beam steering unit **360** activates individual beam steering component (e.g., one of the beam steering components **161**-**164**) sequentially to achieve time multiplexing, which divides a period into time slots and allocates the time slots to the beam steering components **361**-**364**.

[0038] For example, FIG. **4** shows optical light paths of the LiDAR apparatus **30** in a first time slot where only the light sources **300***t* of the group **300***g***1** emit pulse light (e.g., the pulse light beams **301**A-**301**D) flashing at a first time slot. The pulse light (e.g., the pulse light beams **301**A-**301**D) diverges to become the pulse light (e.g., the pulse light beams **311**A-**311**D) projecting the FOV **331**. All the reflected pulse light (e.g., the reflected pulse light beams **331**A-**331**D) corresponding to the pulse light (e.g., the pulse light beams **311**A-**311**D) is incident on the part **351** of the receiver deflector **340**. As shown in FIG. **4**, only the beam steering component **361** is activated during the first time slot, such that the reflected pulse light within the FOV **331** out of the entire FOV **320** (e.g., the reflected pulse light beams **331**A-**331**D) is directed to the intermediate deflector **370** through activated beam steering component **361**, and eventually captured by the receiver unit **380** to generate a first point cloud data corresponding to the FOV **331** within the first time slot.

[0039] Similarly, only the light sources **300***t* of the group **300***g***2** emit pulse light (e.g., the pulse light beams **302**A-**302**D) flashing at a second time slot as shown in FIG. **5**. The pulse light (e.g., the pulse light beams **302**A-**302**D) diverges to become the pulse light (e.g., the pulse light beams **312**A-**312**D) projecting the FOV **332**. As shown in FIG. **5**, only the beam steering component **362** is activated during the second time slot, such that the reflected pulse light within the FOV **332** out of the entire FOV **320** (e.g., the reflected pulse light beams **332**A-**332**D) is directed to the intermediate deflector **370** through activated beam steering component **362**, and eventually captured by the receiver unit **380** to generate a second point cloud data corresponding to the FOV **332** within the second time slot.

[0040] Similarly, when the light sources **300***t* of the group **300***g***3** flashes at a third time slot, only the beam steering component **363** is activated during the third time slot, such that the reflected pulse light within the FOV **333** out of the entire FOV **320** is directed to the intermediate deflector **370** through activated beam steering component **363**, and eventually captured by the receiver unit **380** to generate a third point cloud data corresponding to the FOV **333** within the third time slot.

[0041] Similarly, when the light sources **300***t* of the group **300***g***4** flashes at a fourth time slot, only the beam steering component **364** is activated during the fourth time slot, such that the reflected pulse light within the FOV **334** out of the entire FOV **320** is directed to the intermediate deflector **370** through activated beam steering component **364**, and eventually captured by the receiver unit **380** to generate a fourth point cloud data corresponding to the FOV **334** within the fourth time slot.

[0042] The last step is to convert all the point cloud data (i.e., the first to fourth point cloud data) within all the time slots (i.e., the period) into an entirety of point cloud data which correspond to the entirety of FOV (i.e., the FOV **320**). The time multiplexing flash LiDAR apparatus **30**, which may be served as the LiDAR apparatus **10**, periodically alternates between the light source **300***t* of different groups **300***g***1**-**300***g***4** to achieve time multiplexing of the reflected pulse light from different FOVs **331**-**334**. Such time multiplexing of collecting point cloud data increases spatially resolutions within the entirety of FOV. The advantage of this embodiment is the individual addressable light sources **300***t* at different time slots. Since only a portion of pulse light is emitted from the light transmitter **300**, it consumes less optical power. In another aspect, given maximum permissible power limit for eye safety, higher optical power of each light source **300***t* is allowed and thus possible detection range is longer.

[0043] Without the beam steering unit **260**/**160**/**360**, the spatial resolution is determined by the FOV over the number of Geiger mode avalanche photodiode pixels of a light receiver of a LiDAR apparatus. For example, the entire FOV of the LiDAR apparatus **10**/**20**/**30** may be 120 degrees (horizontal) (as shown by the horizontal FOV **120**H/**320**H)× 30 degrees (vertical) (as shown by the vertical FOV **120**V/**320**V) with the beam steering unit **260**/**160**/**360**. Without the beam steering unit **260**/**160**/**360**, if the entire FOV of a LiDAR apparatus is 120 degrees (horizontal)×30 degrees (vertical) and there are **192** (or M)×56 (or N) pixels of (Geiger mode avalanche photodiode) light detectors, the resolution is 0.625 degrees (horizontal) and 0.536 degrees (vertical).

[0044] In an embodiment, the transmitter deflector **310** and the receiver deflector **340** may be integrated, such that the pulse light emitted and the reflected pulse light may be coaxial to achieve coaxial configuration.

[0045] FIG. **6** is a schematic diagram of a time multiplexing beam steering unit **660** according to an embodiment of the present invention. The time multiplexing beam steering unit **660**, which may be served as the time multiplexing beam steering unit **160**/**260**/**360**, may include beam steering components **661**, **662**, **663**, and **664** arranged in a two-dimensional array (or a one-dimensional array). Each of the beam steering components **661**-**664** may be a two-dimensional MEMS micro-mirror device including flexures **613***a*, **613***b*, **623***a*, **623***b*, a reflective mirror surface **628**, and a substrate **629**. The four substrates **629** may merge into one substrate.

[0046] Each beam steering component may be an electromagnetic driven beam steering mirror. Take the beam steering component **661** as an example. In response to a current **621***i*, the flexures **613***a*-**613***b* may rotate around another axis **617**. Under a magnetic field **672** and in response to a current **622***i*, the flexures **623***a*-**623***b* together with the reflective mirror surface **628** may rotate around an axis **627**, which is orthogonal to the axis **617**. Similarly, under the magnetic field **671** ad in response to a current **621***i*, the flexures **613***a*-**613***b* together with the reflective mirror surface **628** may rotate around the axis **617**. That is, the beam steering component **661** is able to redirect the reflected pulse light (e.g., the reflected pulse light beams **151**A-**154**D or **351**A-**354**D) toward the intermediate deflector **170**/**370** when the beam steering component **661** is activated (during the first time slot). The beam steering component **661** may bend the reflected pulse light (e.g., the reflected pulse light beams **151**A-**154**D or **351**A-**354**D) away from the intermediate deflector **170**/**370** (and the light receiver **180**/**380**) when the beam steering component **661** is turned off (during the second, third, and fourth time slots).

[0047] FIGS. **7** and **8** show a one-axis activation of a beam steering component **70** according to an embodiment of the present invention. The beam steering component **70** may be served as any of the beam steering components **260S1**-**260**Sn, **161**-**164**, or **361**-**364**. The beam steering component **70** may be a two-dimensional electromagnetic-driven MEMS micro-mirror. Under a magnetic field **772** (as show in (a) of FIG. **7**), when a direct current (DC) current **712***a* is applied to a coil **712** that resides around a mirror **430**, Lorentz forces **714***a* and **715***a*, which are equal in magnitude but opposite in direction, are generated out of the plane (parallel to the mirror **430**) causing the mirror **430** and flexure **723***a*, **723***b* to rotate anti-clockwise around an axis **727**. Eventually, the mirror **430** stops at an angle as the Lorentz forces (**714***a*, **715***a*) are counter-balanced by the torsional forces of the flexure **723***a* and **723***b* (as show in (b) of FIG. **7**). On the contrary, under a magnetic field **771** (as show in (a) of FIG. **8**), when a DC current **711***b* is applied to a coil **711**, Lorentz forces **714***b* and **715***b*, which are equal in magnitude but opposite in direction, are generated out of the plane causing the mirror **430** and flexure **723***a*, **723***b* to rotate clockwise around the axis **727**. Eventually, the mirror surface **430** stops at an angle as the Lorentz forces (**714***b*,

715*b*) are counter-balanced by the torsional forces of the flexure **723***a* and **723***b* (as show in (b) of FIG. **8**).

[0048] FIGS. **9** and **10** show beam re-direction by activation (turning on) of an (electromagnetic driven) beam steering component. A time multiplexing beam steering unit **760**, which may be served as the time multiplexing beam steering unit **160**/**260**/**360**, may include beam steering components **761**, **762**, **763**, and **764**. When the beam steering component **761** (i.e., one of the beam steering components **760**) is in off-state (as shown in FIG. **9**) in a first time slot, no corresponding DC current is applied to the beam steering component **761** such that the beam steering component **761** directs reflected pulse light that associates with a FOV **702** to an arbitrary area **707**. A mirror **728** of the beam steering component **761** in off-state may be parallel to the main surface of the time multiplexing beam steering unit **760**. In the next time slot, the beam steering component **761** is activated to on-state (as shown in FIG. **10**), it directs the reflected pulse light that associates with the FOV **702** to an intermediate deflector **706**. The mirror **728** of the beam steering component **761** in on-state may be tilted with respect to the main surface of the time multiplexing beam steering unit **760**.

[0049] However, when the beam steering component **762** is in on-state (as shown in FIG. **9**) in the first time slot, a corresponding DC current is applied such that the beam steering component **762** directs reflect pulse light that associates with a FOV **703** to the intermediate deflector **706**. In the next time slot, the beam steering component **762** is deactivated to off-state (as shown in FIG. **10**), it directs the reflected pulse light that associated with the FOV **703** back to an arbitrary area **708**. In an embodiment, the mirror **748** of the beam steering component **762** in off-state may be parallel to the main surface of the time multiplexing beam steering unit **760**. The mirror **748** of the beam steering component **762** in off-state may be parallel or nonparallel to the mirror **728** of the beam steering component **761** in off-state.

[0050] A beam steering component may not be limited to a two-axis MEMS micro-mirror device. Each beam steering component in a time multiplexing beam steering unit may include a (one-axis or two-axis) MEMS micro-mirror, or a MEMS based resonant mirror, which may be driven by electrostatic mechanism, electromagnetic mechanism, thermal mechanism, or piezoelectric mechanism, a mechanical driven mirror, a mechanical driven prism, or a lens. The mechanical driven mirror may be a polygon mirror. The mechanical driven prism may be a Risley prism. Each beam steering component may be opto-mechanical. For example, a beam steering component may include the flexures **613***a*-**623***b* and the substrate **629**, while a lens for the beam steering component may replace the reflective mirror surface **628**.

[0051] A time multiplexing beam steering unit may include four beam steering components but is not limited thereto. In fact, a time multiplexing beam steering unit may include N beam steering components, where N is an integer greater than 1.

[0052] FIG. **11** is a schematic diagram of an electro-optical device **15**B according to an embodiment of the present invention. The electro-optical device **15**B includes ingress ports **1510** and at least one transmitting unit (Tx) **1520**, a central processing unit **1530**, at least one receiving unit (Rx) **1540**, egress ports **1550**, a memory unit **1560**, a MEMS control unit **1570**, and a MEMS apparatus **1580**.

[0053] The central processing unit **1530** processes data implementing by one or more computer chip(s) such as field programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), digital signal processors (DSPs). The processing unit **1530** inputs data or control signals from the ingress ports **1510** through the egress ports **1550**. The processing unit **1530** also stores and retrieves data, or program to and from the memory unit **1560**. The memory unit **1560** may be in form of tape drives, solid state drives, or flash memory. The memory unit **1560** may be volatile, non-volatile, read-only memory (ROM), random access memory (RAM), ternary content-addressable memory (TCAM), static random-access memory (SRAM) and combination thereof. The processing unit **1530** also exports data to egress ports **1550** through transmitting unit **1540**. The processing unit **1530** communicates with the MEMS control unit **1570** which in turns controls the MEMS apparatus **1580**, which may be served as the time multiplexing beam steering unit **160**/**260**/**360**/**660**.

[0054] FIG. **12** is a schematic diagram of a LiDAR system according to an embodiment of the present invention. A LiDAR apparatus **1601** may be mountable on a vehicle **1603** to scan environment **1602** around a vehicle **1603**. The LiDAR apparatus **1601** may be attached or mounted to any part of the vehicle **1603**.

[0055] The LiDAR apparatus **1601** may coordinate operation of a light transmitter or a light receiver with the movement of a beam steering unit in two axes (e.g., a horizontal axis **1604** and a vertical axis **1605**) in order to rotate or stop at a fixed angle. The beam steering unit may direct light projected towards the FOVs **16**H and **16**V. The light receiver may receive light reflected from the surroundings of the vehicle **1603** in the FOVs **16**H and **16**V and transfer reflection signals indicative of light reflected from object(s) in the FOVs **16**H and **16**V to a central processing unit.

[0056] To sum up, a time multiplexing beam steering unit of the invention selects a portion of the entire FOV to be focused onto a light receiver by activating one/some of its beam steering component(s) and inactivating the other beam steering component(s) so as to collect point cloud data corresponding to the portion of the entire FOV in a time slot. The point cloud data collected over all the time slots is converted into an entirety of point cloud data corresponding to the entire FOV. Such time multiplexing of collecting point cloud data increases spatially resolutions within the entirety of field of view.

[0057] Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. A time multiplexing flash light detection and ranging (LiDAR) apparatus, comprising:

a light transmitter, configured to emit pulse light;

a beam steering unit, optically coupled to the light transmitter and comprising a plurality of beam steering components, wherein the plurality of beam steering components are activated sequentially to multiplex reflected pulse light from a plurality of field of views

(FOV), and the reflected pulse light represents the pulse light reflected by at least one object; and

a light receiver, optically coupled to the light transmitter and configured to capture a portion of the reflected pulse light from one of the plurality of FOVs at a time.

2. The time multiplexing flash LiDAR apparatus of claim **1**, wherein at least a first beam steering component of the plurality of beam steering components is configured to steer the reflected pulse light within a first FOV of the plurality of FOVs toward the light receiver at a first time slot, the time multiplexing flash LiDAR apparatus generates a first point cloud data corresponding to the first FOV at the first time slot, at least a second beam steering component of the plurality of beam steering components is configured to steer the reflected pulse light within a second FOV of the plurality of FOVs toward the light receiver at a second time slot, and the time multiplexing flash LiDAR apparatus generates a second point cloud data corresponding to the second FOV at the second time slot.

3. The time multiplexing flash LiDAR apparatus of claim **1**, wherein an entirety of point cloud data corresponding to an entirety of the plurality of FOVs is formed by integrating at least a plurality of point cloud data corresponding to the plurality of FOV at a plurality of time slots.

4. The time multiplexing flash LiDAR apparatus of claim **1**, wherein the light transmitter comprises a plurality of light sources, and all the plurality of light sources emit the pulse light flashing simultaneously within an entirety of the plurality of FOVs.

5. The time multiplexing flash LiDAR apparatus of claim **1**, wherein the light transmitter comprises a plurality of light sources, the plurality of light sources are divided into a plurality of groups, each of the plurality of groups is corresponding to one of the plurality of FOVs, and the plurality of groups are activated sequentially to emit the pulse light according to how the plurality of beam steering components are activated.

6. The time multiplexing flash LiDAR apparatus of claim **1**, wherein the light transmitter comprises a plurality of light sources, the plurality of light sources are divided into a plurality of groups, a first group of the plurality of groups is configured to emit the pulse light flashing at a first time slot within one of the plurality of FOVs, and a second group of the plurality of groups is configured to emit the pulse light flashing at a second time slot within another of the plurality of FOVs.

7. The time multiplexing flash LiDAR apparatus of claim **1**, wherein the light transmitter comprises a plurality of light sources, the plurality of light sources are divided into a plurality of groups, the plurality of groups are arranged in a first array, the plurality of beam steering components are arranged in a second array, the first array is similar to or coincide with the second array, and the first array and the second array are two-dimensional arrays or one-dimensional arrays.

8. The time multiplexing flash LiDAR apparatus of claim **1**, wherein each of the plurality of beam steering components comprises a microelectromechanical systems (MEMS) micro-mirror or a MEMS based resonant mirror driven by electrostatic mechanism, electromagnetic mechanism, thermal mechanism, or piezoelectric mechanism, a mechanical driven mirror, a mechanical driven prism, or a lens, the mechanical driven mirror is a polygon mirror, and the mechanical driven prism is a Risley prism.

9. The time multiplexing flash LiDAR apparatus of claim **1**, further comprising:

a transmitter deflector, configured to deflect the pulse light;

a receiver deflector, configured to deflect the reflected pulse light; or

an intermediate deflector, configured to deflect the reflected pulse light.

10. The time multiplexing flash LiDAR apparatus of claim **1**, wherein the pulse light incident on the at least one object and the reflected pulse light coming back from the at least one object are non-coaxial.

11. The time multiplexing flash LiDAR apparatus of claim **1**, wherein the light transmitter is an edge-emitting laser source transmitter, a vertical cavity surface emitting laser (VCSEL) source transmitter emitting the pulse light, a fiber laser, or a photonic crystal surface emitting laser (PCSEL) source transmitter.

12. The time multiplexing flash LiDAR apparatus of claim **1**, wherein the light receiver is a Geiger mode avalanche photodiode receiver comprising a plurality of light detectors.

13. The time multiplexing flash LiDAR apparatus of claim **1**, wherein the pulse light is non-visible, and a wavelength of the pulse light is 840 nm, 905 nm, 940 nm, 1330 nm, or 1550 nm.

14. The time multiplexing flash LiDAR apparatus of claim **1**, wherein the light transmitter comprises a plurality of light sources, and the plurality of light sources is individually activated, able to be individually activated, or illuminates homogeneously.

15. The time multiplexing flash LiDAR apparatus of claim **1**, wherein a distance between the time multiplexing flash LiDAR apparatus and one of the at least one object is calculated by measuring a time delay between the pulse light and the reflected pulse light.

16. The time multiplexing flash LiDAR apparatus of claim **1**, wherein the light receiver comprises a plurality of light detectors, the plurality of light detectors are arranged in a two-dimensional array or a one-dimensional array, wherein each of the plurality of light detectors is individually activated, able to be individually activated to receive the reflected pulse light individually or homogeneously.

17. A light detection and ranging (LiDAR) operating method, for a time multiplexing flash LiDAR, comprising:

emitting pulse light from a light transmitter of the time multiplexing flash LiDAR;

activating a plurality of beam steering components of a beam steering unit of the time multiplexing flash LiDAR sequentially to multiplexing reflected pulse light from a plurality of field of views (FOV), wherein the reflected pulse light represents the pulse light reflected by at least one object; and

by a light receiver of the time multiplexing flash LiDAR, capturing the reflected pulse light from one of the plurality of FOVs at a time.

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