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(71) Applicant(s):
Canon Kabushiki Kaisha
30-2, Shimomaruko 3-chome, Ohta-ku,
Tokyo 146-8501, Japan

(72) Inventor(s):
Takashi Hanasaka
Koichi Fukuda
Kohei Okamoto
Shunichi Wakashima

(74) Agent and/or Address for Service:
Canon Europe Limited
European Intellectual Property Group,
4 Roundwood Avenue, Stockley Park, Uxbridge,
Middlesex, UB11 1AF, United Kingdom

(51) INT CL:
G01S 7/4863 (2020.01)

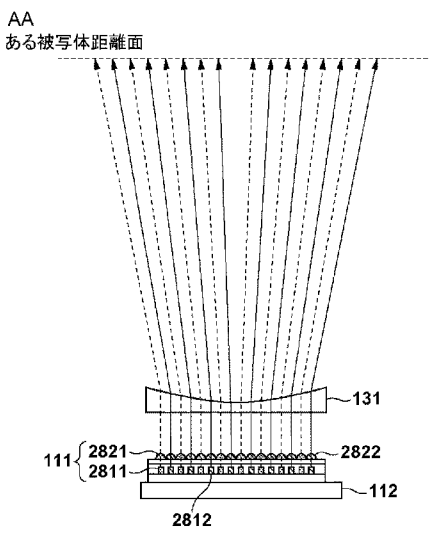
(56) Documents Cited:
US 20200057151 A1 US 20180160103 A1
JP 201978748
US 10983197
JP 201947486

(58) Field of Search:
INT CL G01B, G01C, G01S
Other: Public JP utililty model applns (examined 1922-1996),(unexamined 1971-2022); JP utility models (regst specs 1996-2022),(public regst applns 1994-2022)

(54) Title of the Invention: **Distance measurement device**
Abstract Title: **Distance measurement device**

(57) Disclosed is a distance measurement device that can efficiently perform distance measurement that uses light of different wavelengths. According to the present invention, a distance measurement device has a light source unit that can simultaneously radiate light of a first wavelength and light of a second wavelength that is longer than the first wavelength. The distance measurement device calculates distance information on the basis of the time from the beginning of distance measurement to the detection of the incidence of light at the pixels of a light-receiving unit. A pixel array of the light-receiving unit is a two-dimensional array of first pixels that are configured to receive light of the first wavelength and second pixels that are configured to receive light of the second wavelength.

[図19C]



AA Subject distance plane

GB 2621766 A

FIG. 1

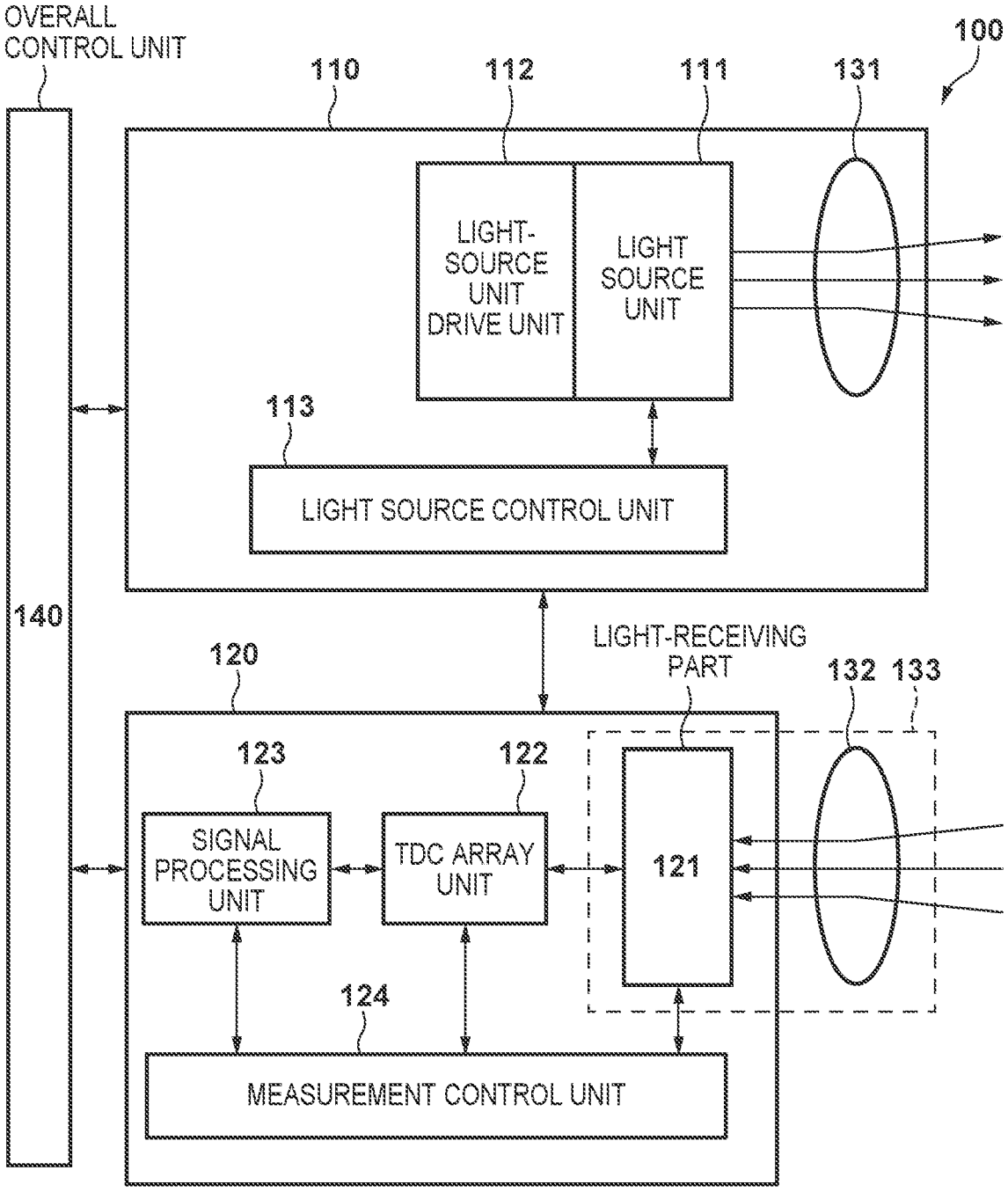

OVERALL CONTROL UNIT
100
110
112
111
131
LIGHT-SOURCE UNIT DRIVE UNIT
LIGHT SOURCE UNIT
113
LIGHT SOURCE CONTROL UNIT
140
120
LIGHT-RECEIVING PART
132
133
123
122
SIGNAL PROCESSING UNIT
TDC ARRAY UNIT
121
124
MEASUREMENT CONTROL UNIT

FIG. 2A

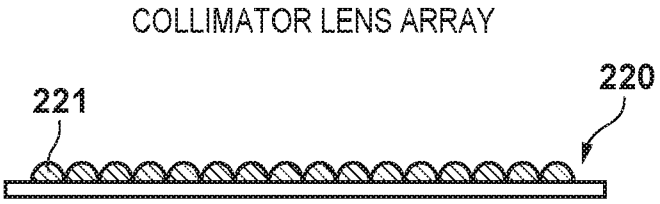


FIG. 2B

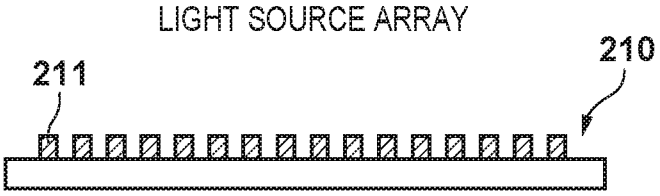


FIG. 2C

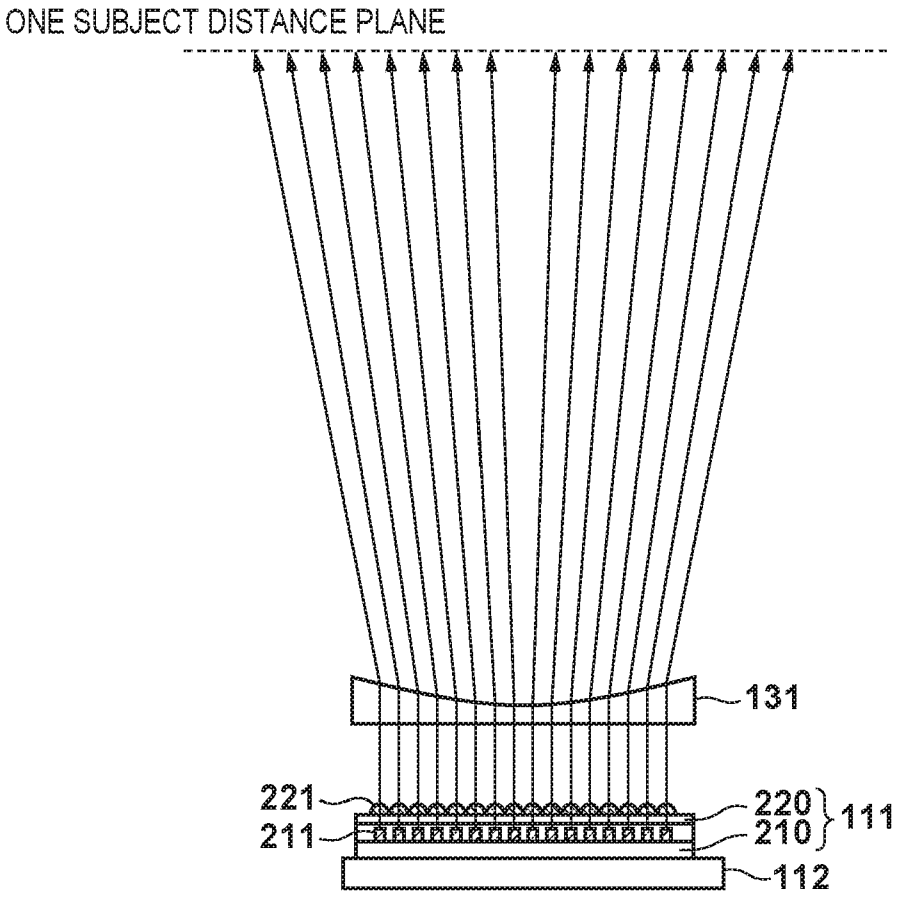


FIG. 3A

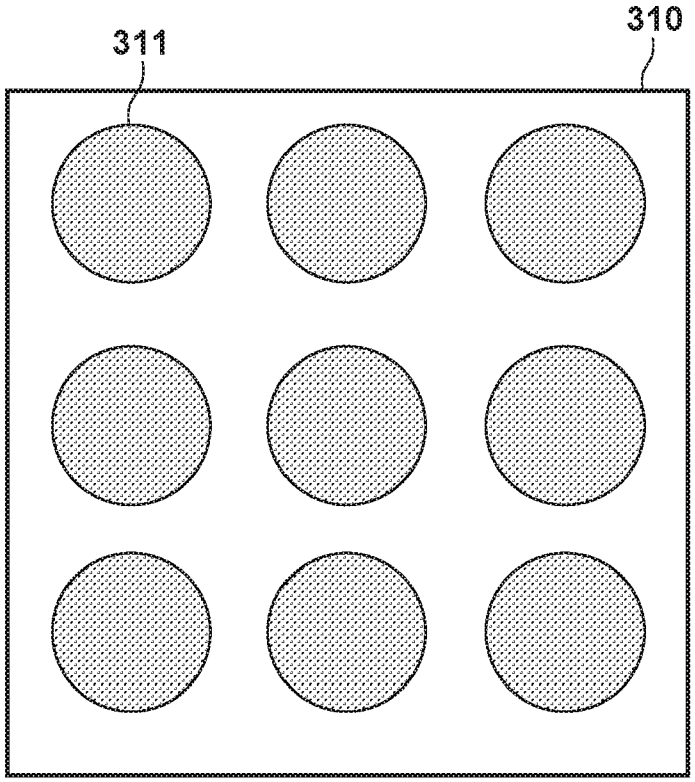


FIG. 3B

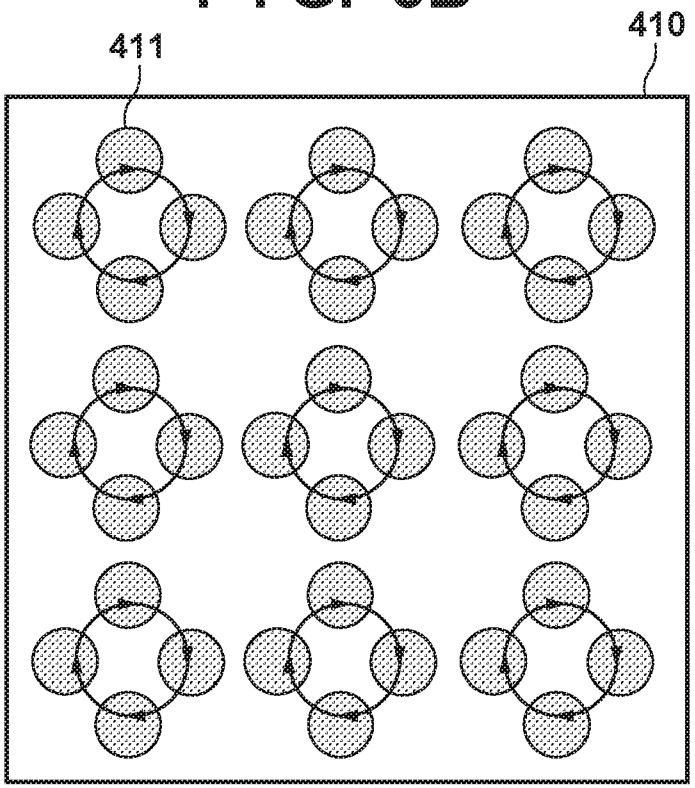
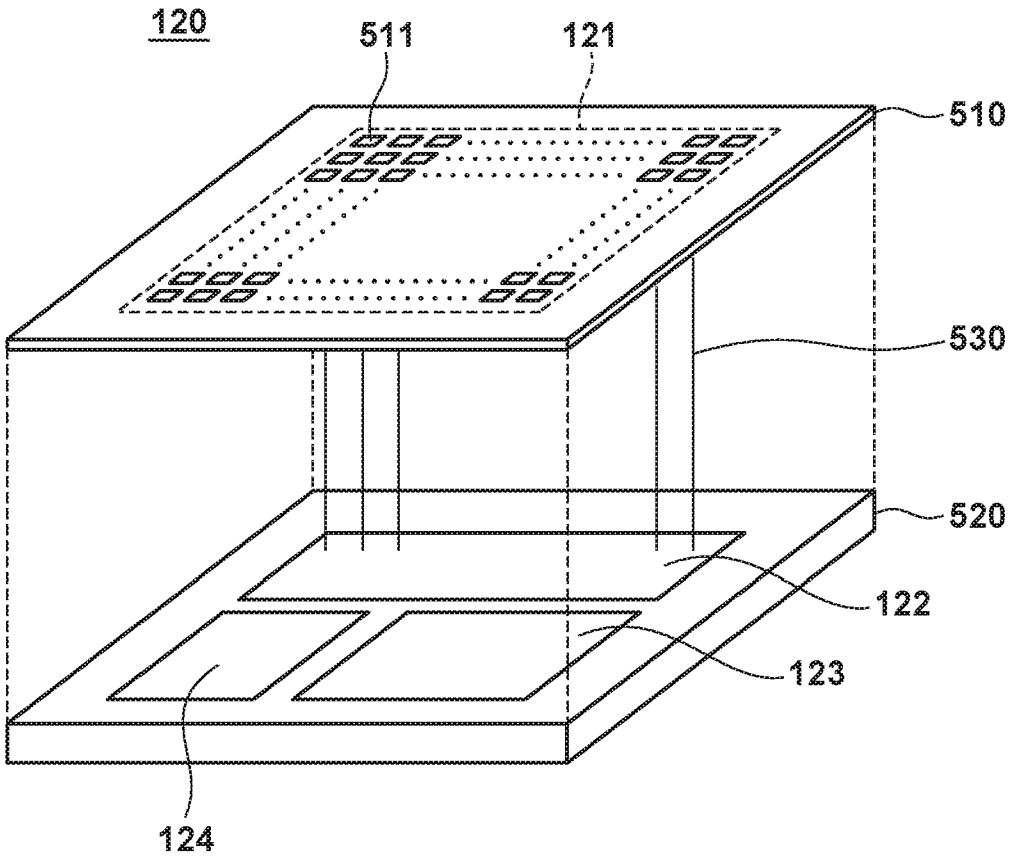


FIG. 4



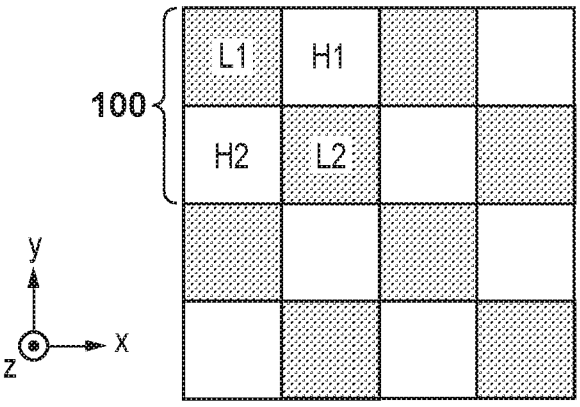


FIG. 5A

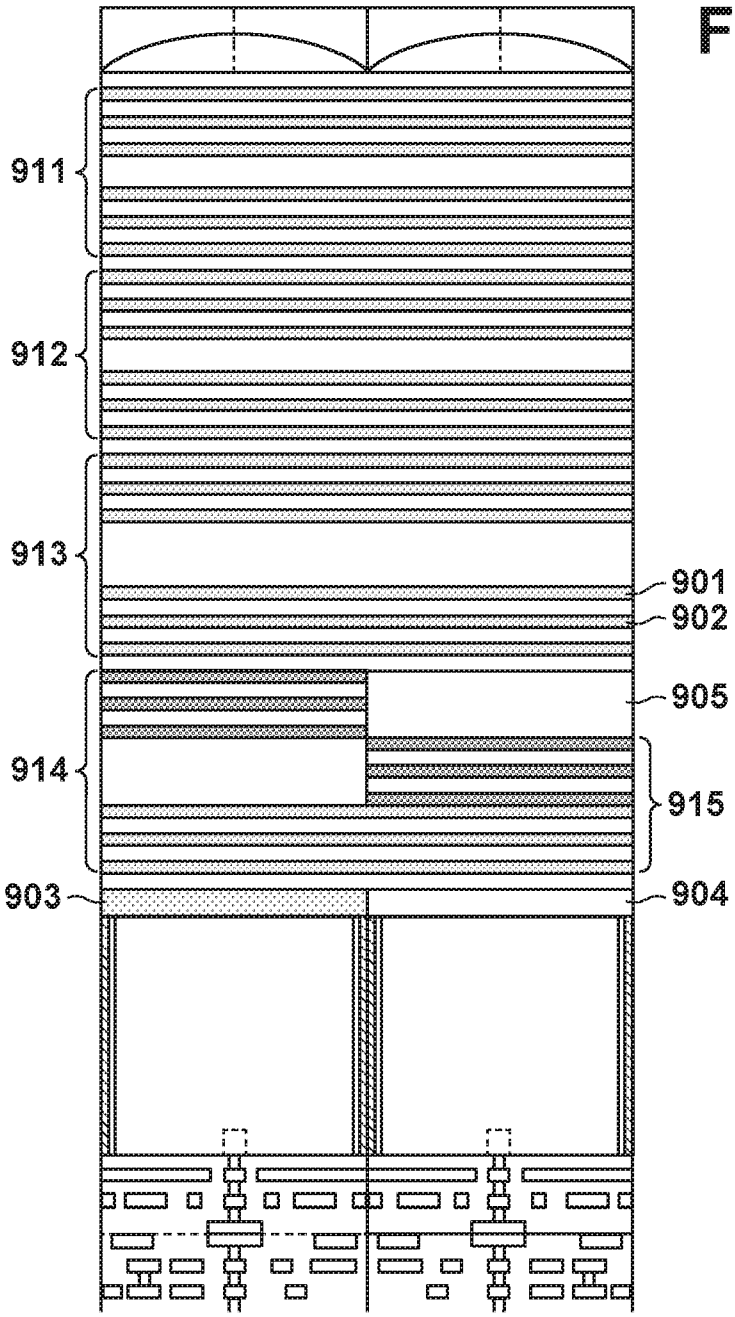


FIG. 5B

FIG. 6A

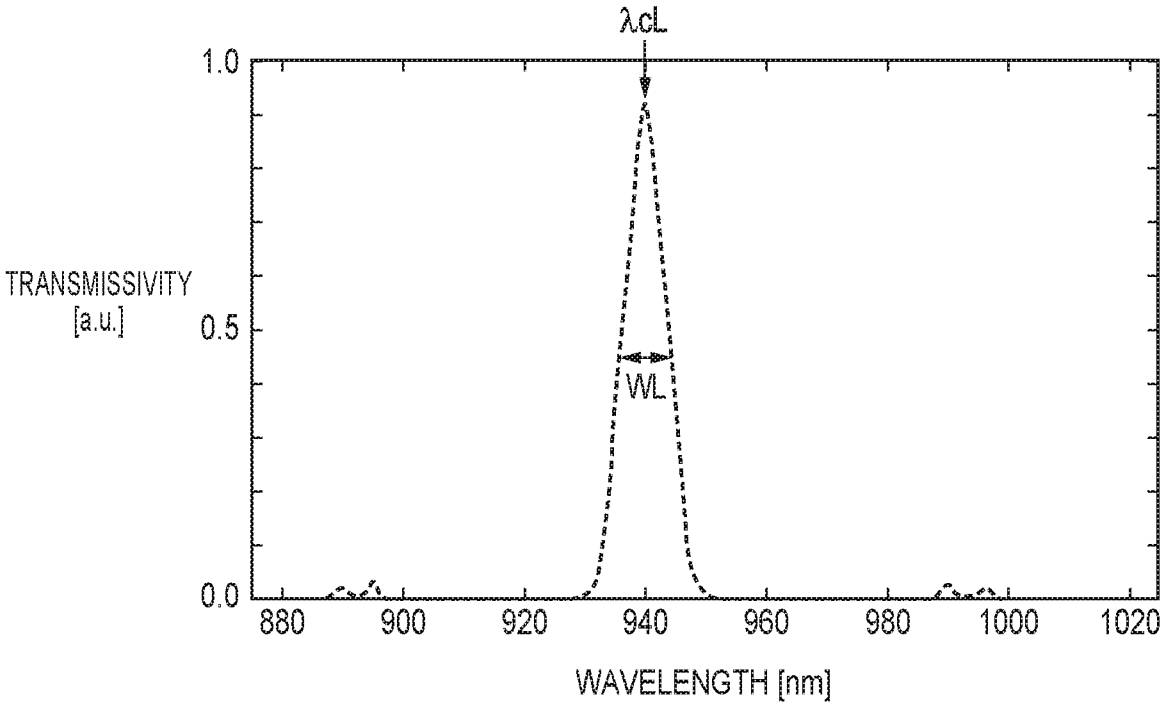

λcL
1.0
0.5
0.0
TRANSMISSIVITY
[a.u.]
WL
880
900
920
940
960
980
1000
1020
WAVELENGTH [nm]

FIG. 6B

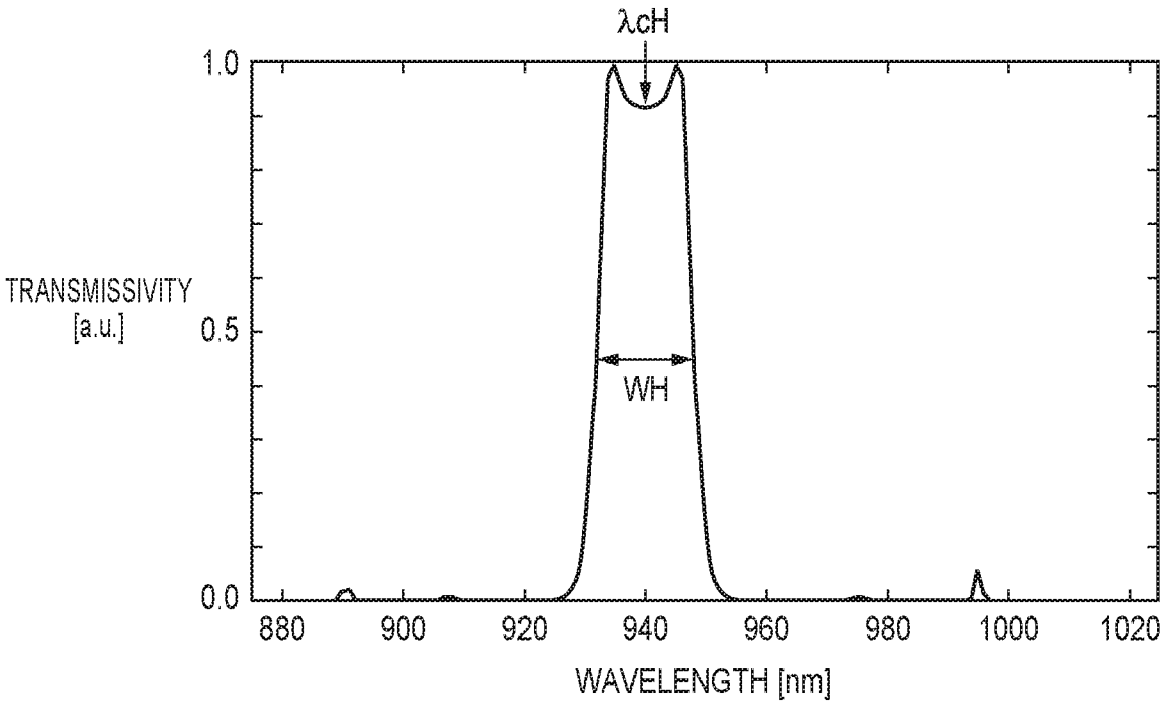

λcH
1.0
0.5
0.0
TRANSMISSIVITY
[a.u.]
WH
880
900
920
940
960
980
1000
1020
WAVELENGTH [nm]

FIG. 7

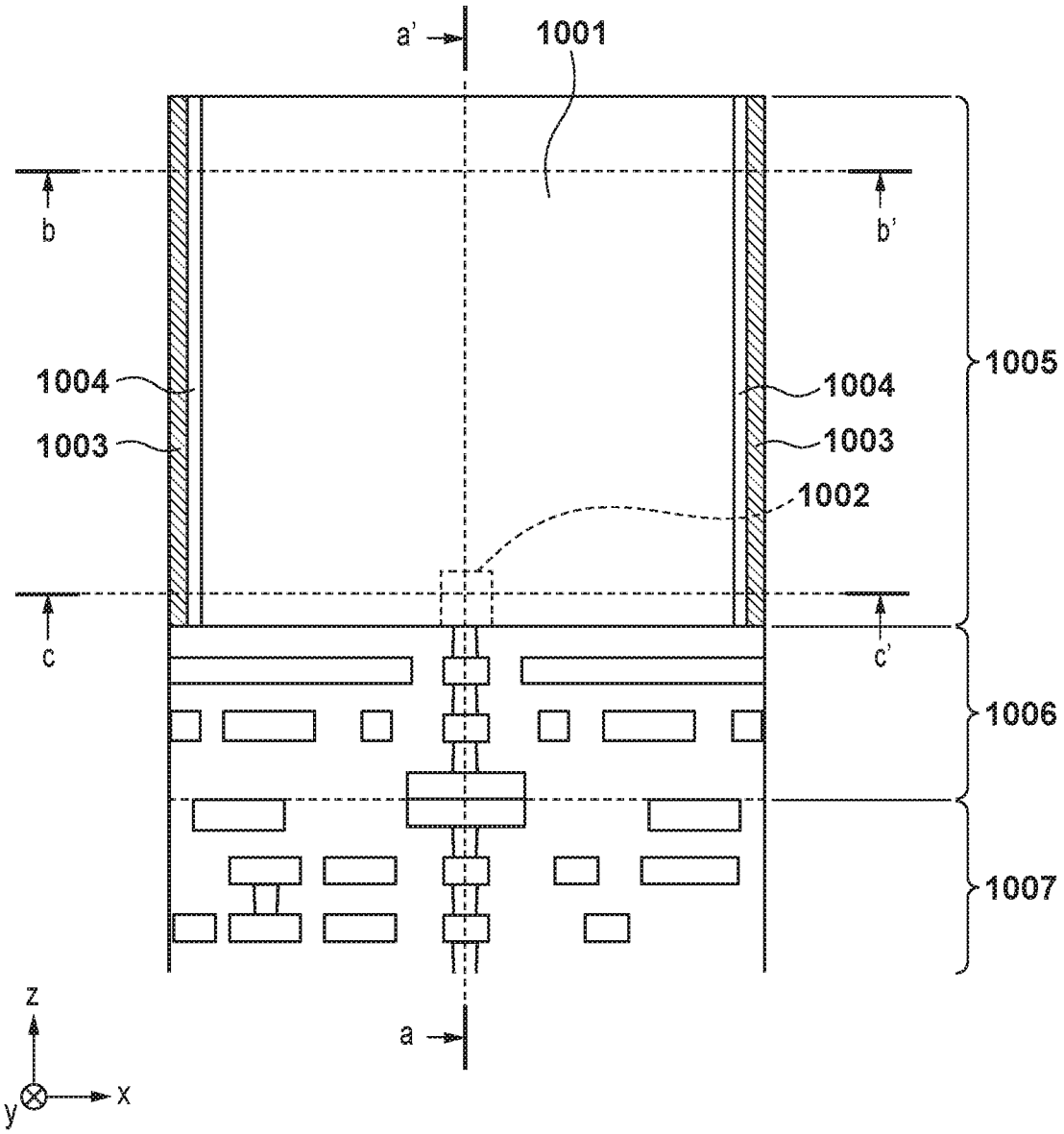


FIG. 8A

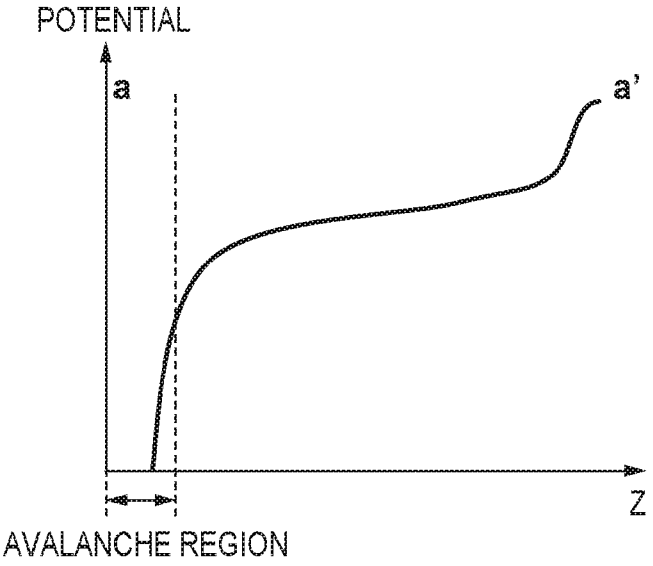


FIG. 8B

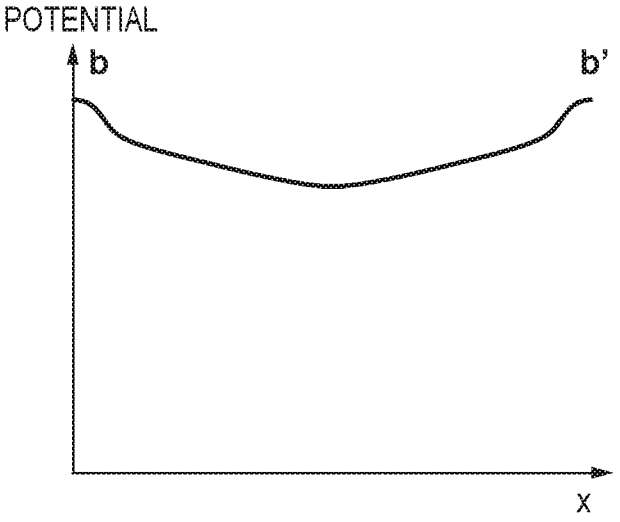


FIG. 8C

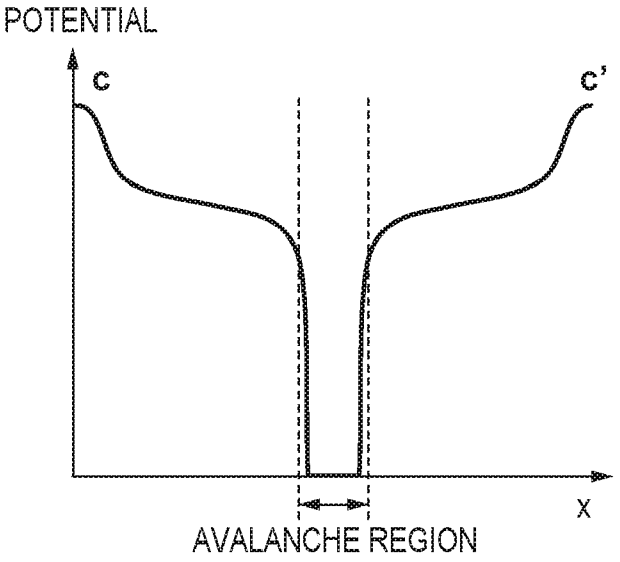
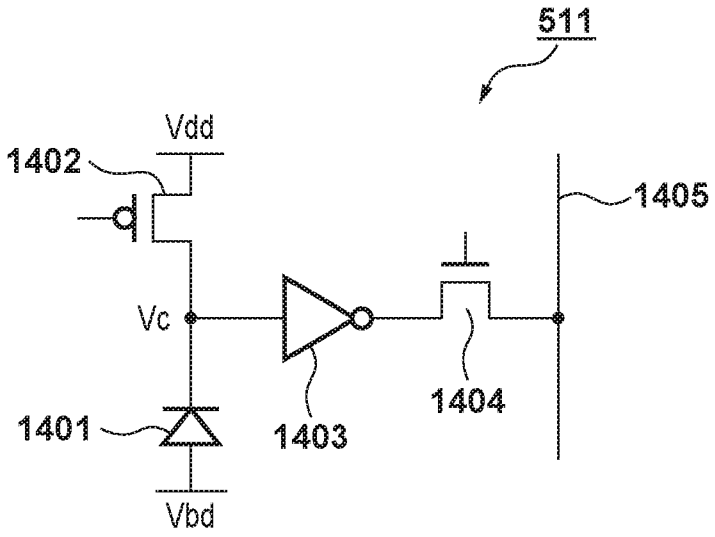


FIG. 9



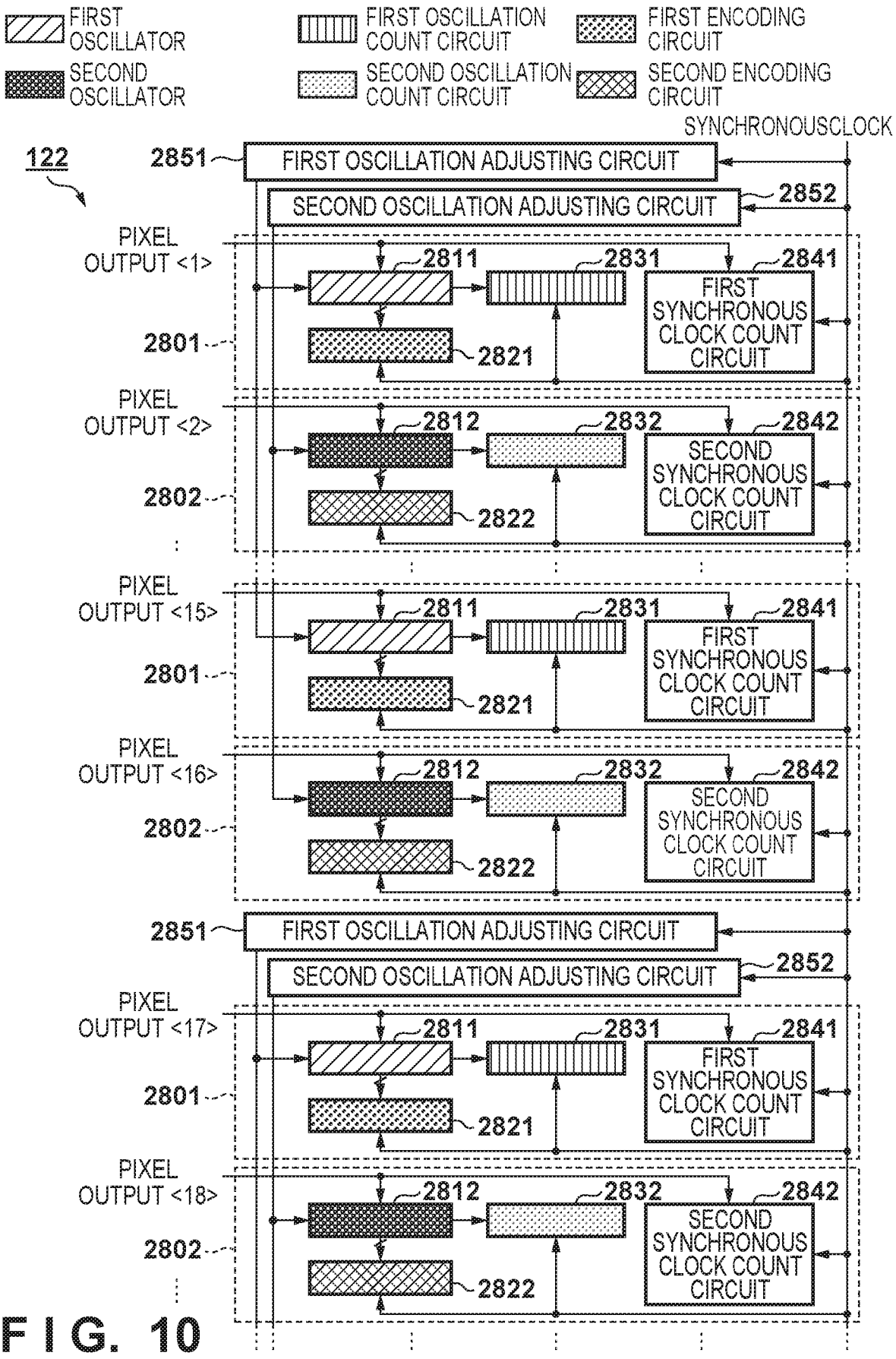

FIRST OSCILLATOR
SECOND OSCILLATOR
FIRST OSCILLATION COUNT CIRCUIT
SECOND OSCILLATION COUNT CIRCUIT
FIRST ENCODING CIRCUIT
SECOND ENCODING CIRCUIT
SYNCHRONOUSCLOCK
122
2851
FIRST OSCILLATION ADJUSTING CIRCUIT
2852
SECOND OSCILLATION ADJUSTING CIRCUIT
PIXEL OUTPUT <1>
2811
2831
2841
FIRST SYNCHRONOUS CLOCK COUNT CIRCUIT
2801
2821
PIXEL OUTPUT <2>
2812
2832
2842
SECOND SYNCHRONOUS CLOCK COUNT CIRCUIT
2802
2822
PIXEL OUTPUT <15>
2811
2831
2841
FIRST SYNCHRONOUS CLOCK COUNT CIRCUIT
2801
2821
PIXEL OUTPUT <16>
2812
2832
2842
SECOND SYNCHRONOUS CLOCK COUNT CIRCUIT
2802
2822
2851
FIRST OSCILLATION ADJUSTING CIRCUIT
2852
SECOND OSCILLATION ADJUSTING CIRCUIT
PIXEL OUTPUT <17>
2811
2831
2841
FIRST SYNCHRONOUS CLOCK COUNT CIRCUIT
2801
2821
PIXEL OUTPUT <18>
2812
2832
2842
SECOND SYNCHRONOUS CLOCK COUNT CIRCUIT
2802
2822

FIG. 10

FIG. 11

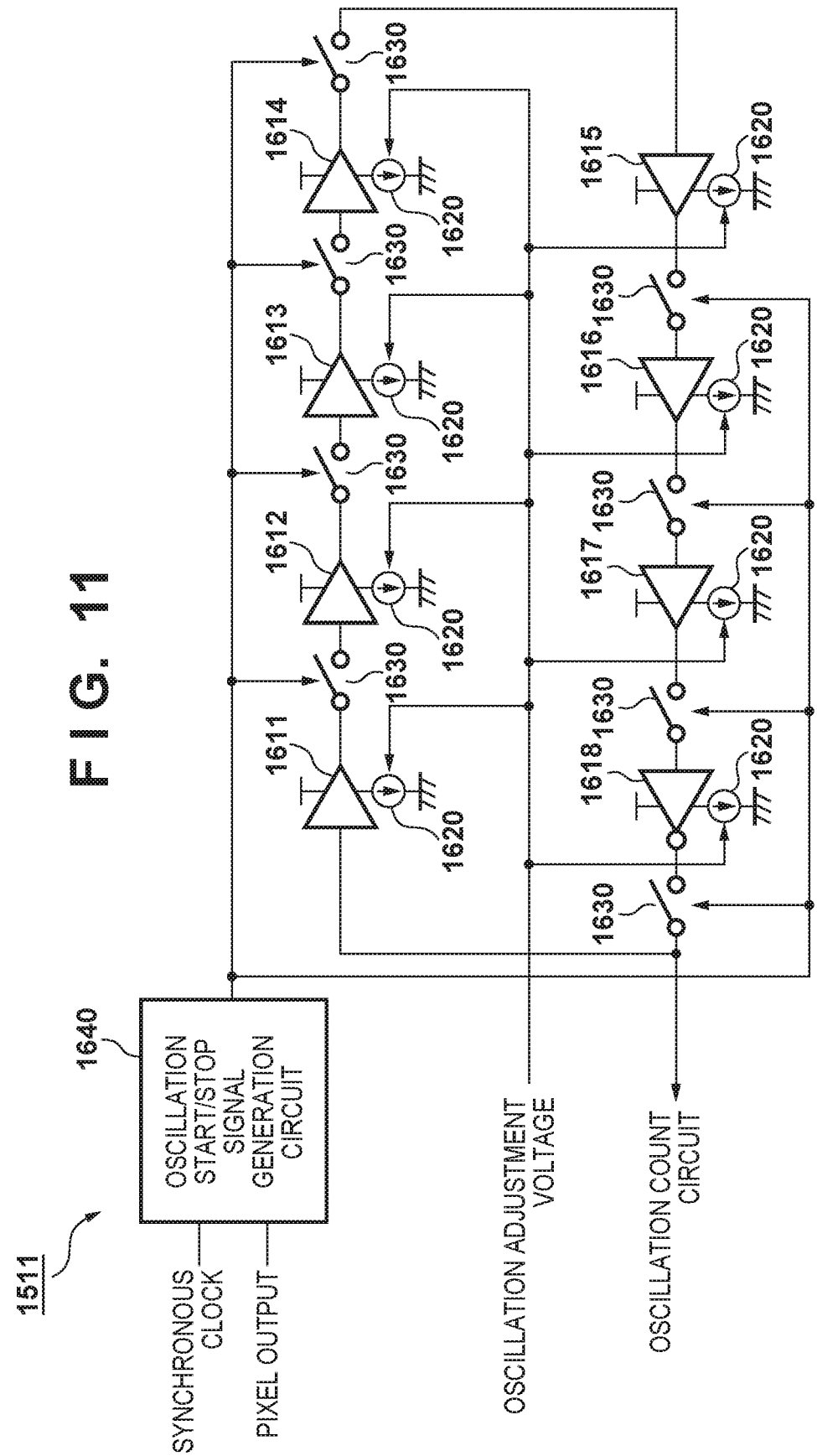

1511
1640
OSCILLATION START/STOP SIGNAL GENERATION CIRCUIT
SYNCHRONOUS CLOCK
PIXEL OUTPUT
OSCILLATION ADJUSTMENT VOLTAGE
OSCILLATION COUNT CIRCUIT
1611
1612
1613
1614
1615
1616
1617
1618
1620
1630

FIG. 12

	WI11 OUTPUT	WI12 OUTPUT	WI13 OUTPUT	WI14 OUTPUT	WI15 OUTPUT	WI16 OUTPUT	WI17 OUTPUT	WI18 OUTPUT	OSCILLATOR INTERNAL SIGNAL
RESET	0	0	0	0	0	0	0	1	0
AFTER 1×t_{buff}	1	0	0	0	0	0	0	1	1
AFTER 2×t_{buff}	1	1	0	0	0	0	0	1	2
AFTER 3×t_{buff}	1	1	1	0	0	0	0	1	3
AFTER 4×t_{buff}	1	1	1	1	0	0	0	1	4
AFTER 5×t_{buff}	1	1	1	1	1	0	0	1	5
AFTER 6×t_{buff}	1	1	1	1	1	1	0	1	6
AFTER 7×t_{buff}	1	1	1	1	1	1	1	1	7
AFTER 8×t_{buff}	1	1	1	1	1	1	1	0	8
AFTER 9×t_{buff}	0	1	1	1	1	1	1	0	9
AFTER 10×t_{buff}	0	0	1	1	1	1	1	0	10
AFTER 11×t_{buff}	0	0	0	1	1	1	1	0	11
AFTER 12×t_{buff}	0	0	0	0	1	1	1	0	12
AFTER 13×t_{buff}	0	0	0	0	0	1	1	0	13
AFTER 14×t_{buff}	0	0	0	0	0	0	1	0	14
AFTER 15×t_{buff}	0	0	0	0	0	0	0	0	15
AFTER 16×t_{buff}	0	0	0	0	0	0	0	1	0
AFTER 17×t_{buff}	1	0	0	0	0	0	0	1	1
AFTER 18×t_{buff}	1	1	0	0	0	0	0	1	2

FIG. 13

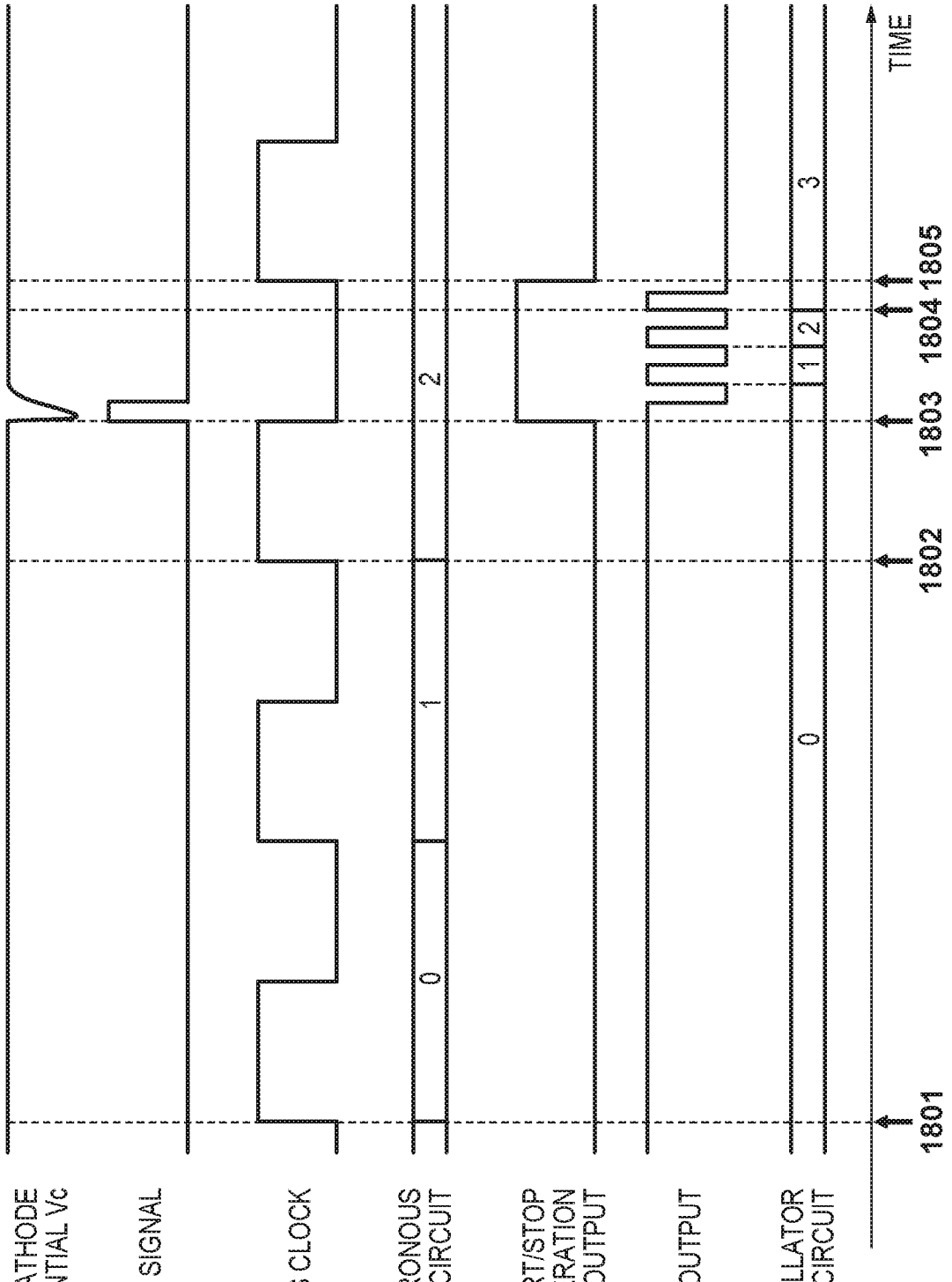

CATHODE POTENTIAL Vc
PIXEL OUTPUT SIGNAL
SYNCHRONOUS CLOCK
SYNCHRONOUS CLOCK COUNT CIRCUIT
OSCILLATOR START/STOP SIGNAL GENERATION CIRCUIT OUTPUT
OSCILLATOR OUTPUT
OSCILLATOR COUNT CIRCUIT
0
1
2
0
1
2
3
TIME
1801
1802
1803
1804
1805

FIG. 14

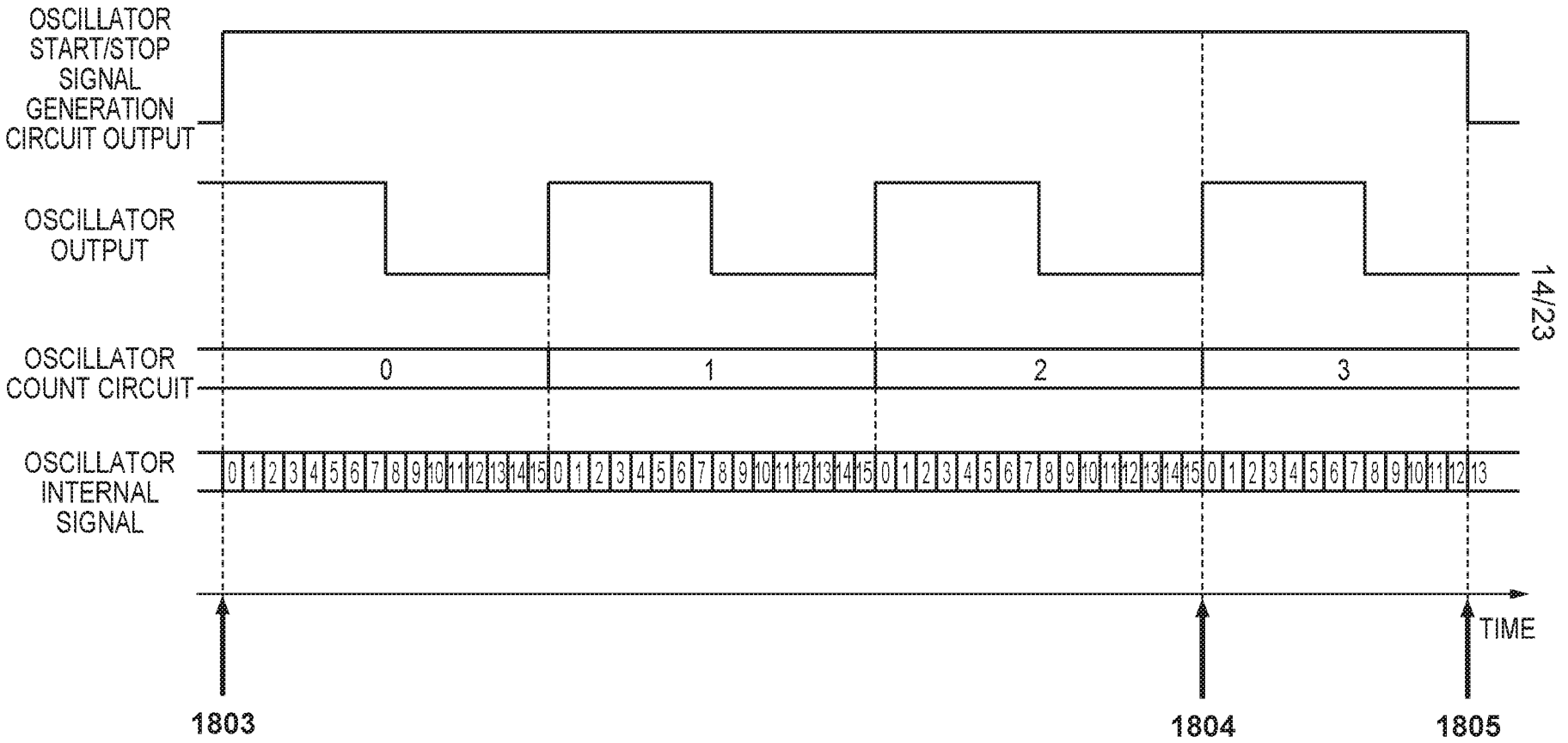

OSCILLATOR START/STOP SIGNAL GENERATION CIRCUIT OUTPUT
OSCILLATOR OUTPUT
OSCILLATOR COUNT CIRCUIT
0
1
2
3
OSCILLATOR INTERNAL SIGNAL
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 0 1 2 3 4 5 6 7 8 9 10 11 12 13
TIME
1803
1804
1805

FIG. 15

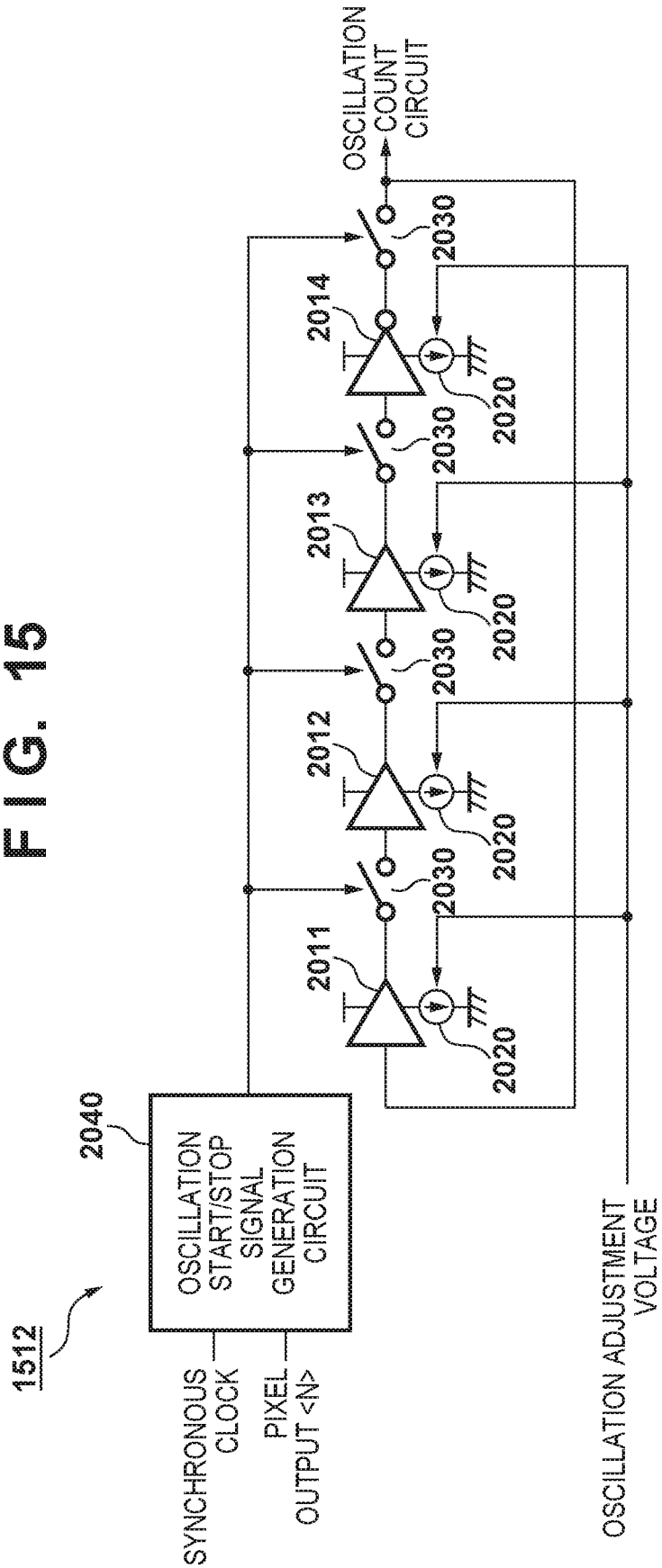

1512
2040
OSCILLATION START/STOP SIGNAL GENERATION CIRCUIT
SYNCHRONOUS CLOCK
PIXEL OUTPUT <N>
OSCILLATION ADJUSTMENT VOLTAGE
OSCILLATION COUNT CIRCUIT
2011
2012
2013
2014
2020
2030

FIG. 16

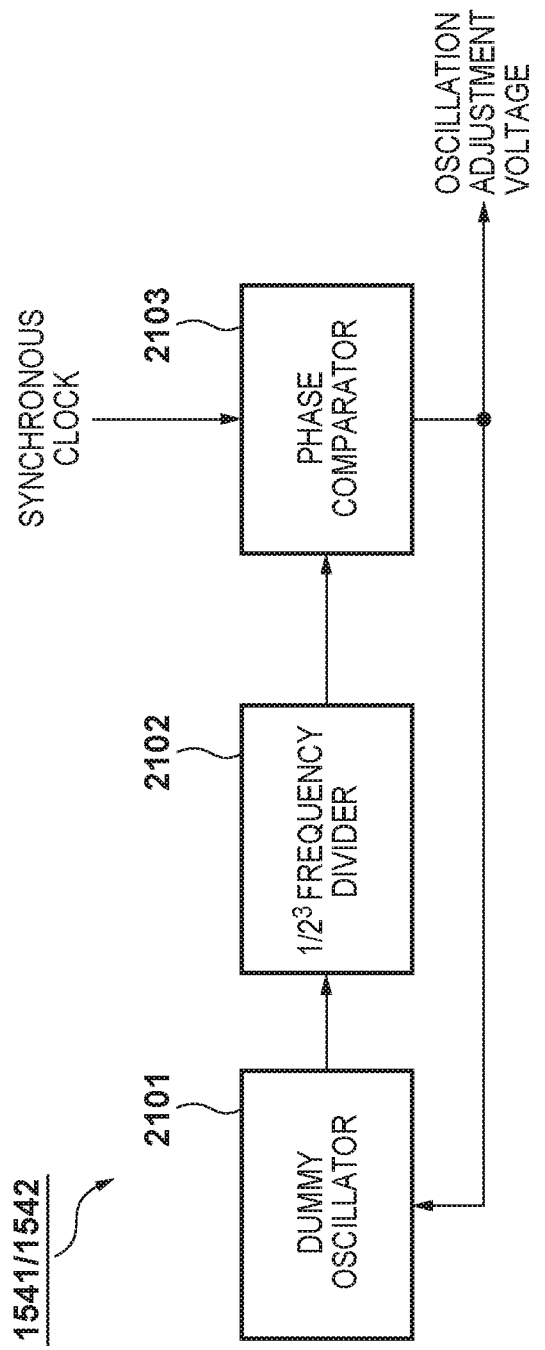

1541/1542
2101
DUMMY OSCILLATOR
2102
1/2^3 FREQUENCY DIVIDER
2103
PHASE COMPARATOR
SYNCHRONOUS CLOCK
OSCILLATION ADJUSTMENT VOLTAGE

FIG. 17

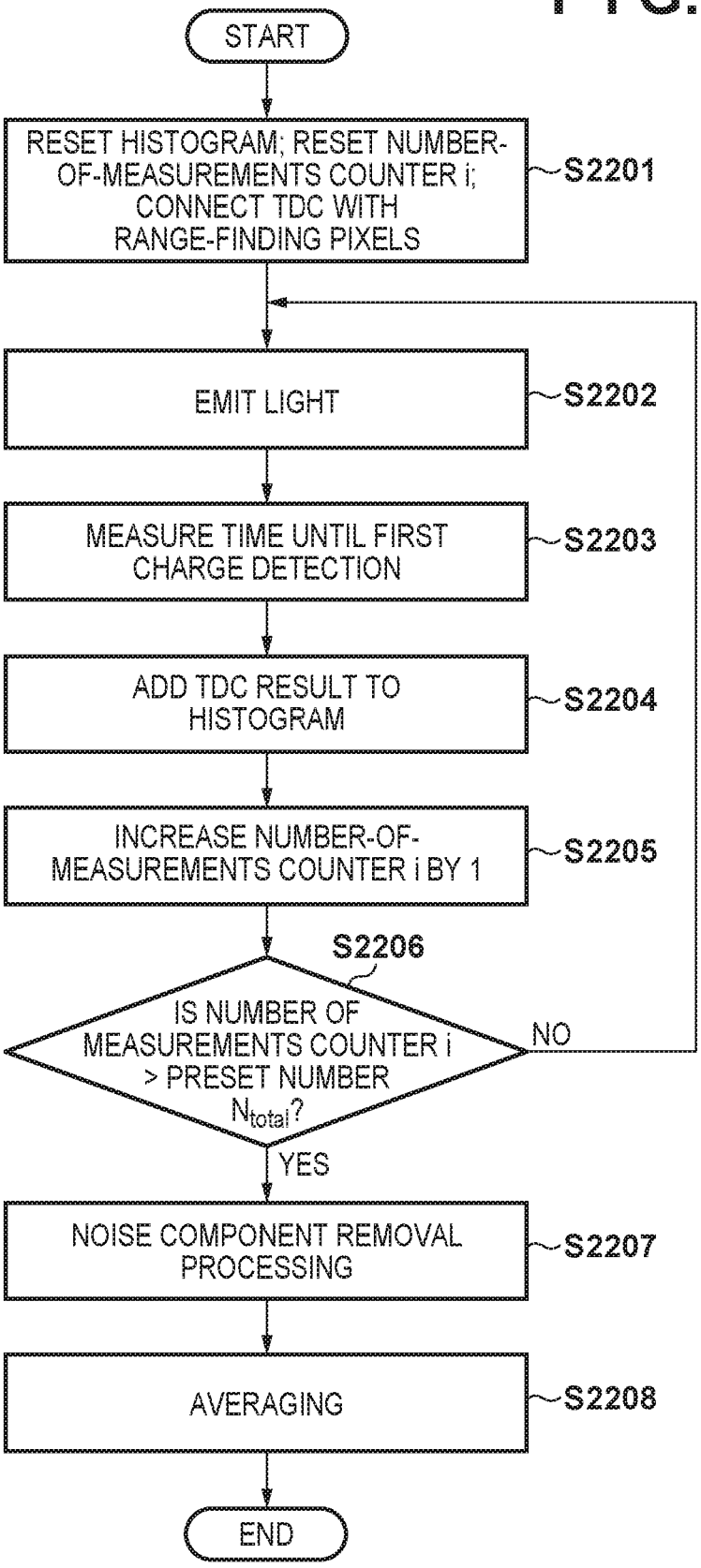

START
RESET HISTOGRAM; RESET NUMBER-OF-MEASUREMENTS COUNTER i; CONNECT TDC WITH RANGE-FINDING PIXELS
S2201
EMIT LIGHT
S2202
MEASURE TIME UNTIL FIRST CHARGE DETECTION
S2203
ADD TDC RESULT TO HISTOGRAM
S2204
INCREASE NUMBER-OF-MEASUREMENTS COUNTER i BY 1
S2205
S2206
IS NUMBER OF MEASUREMENTS COUNTER i > PRESET NUMBER N_{total}?
NO
YES
NOISE COMPONENT REMOVAL PROCESSING
S2207
AVERAGING
S2208
END

FIG. 18A

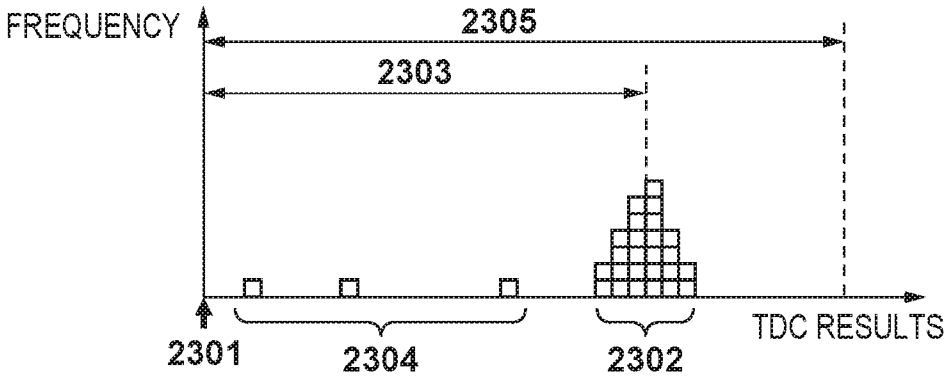


FIG. 18B

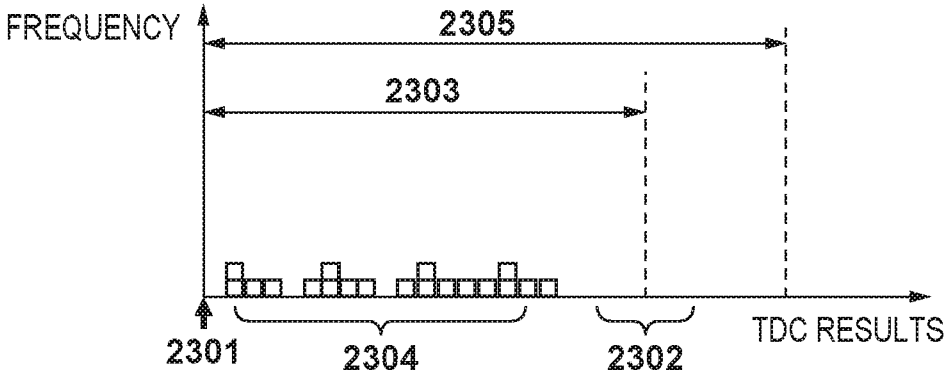


FIG. 18C

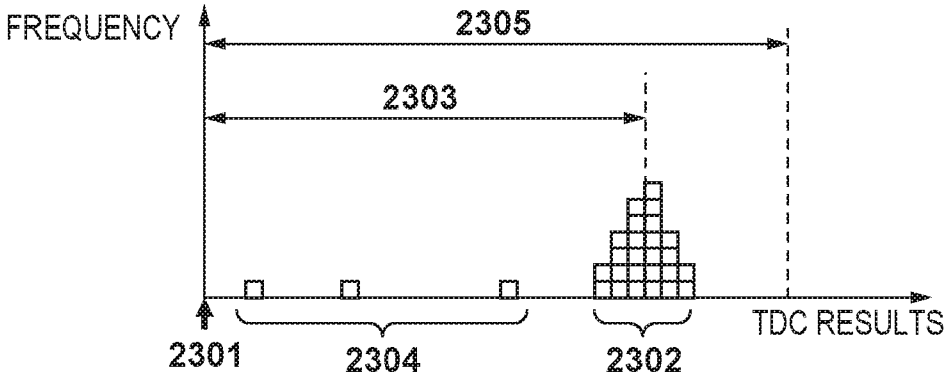


FIG. 18D

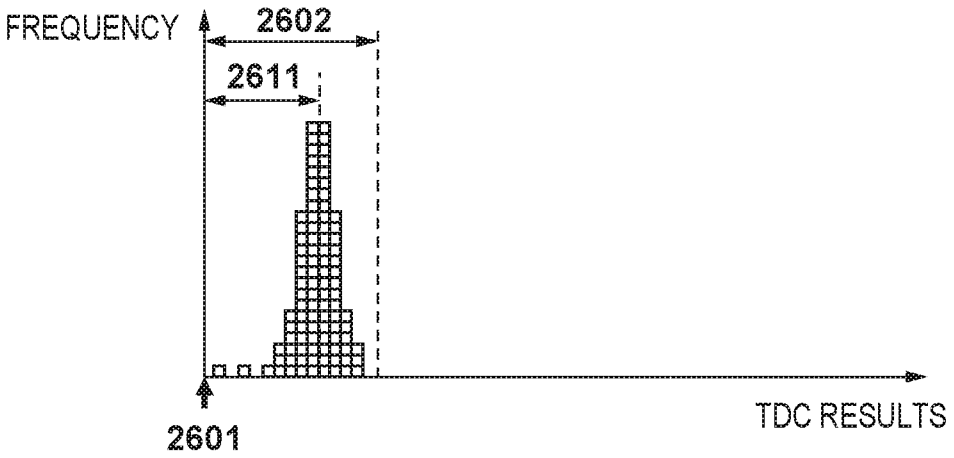


FIG. 18E

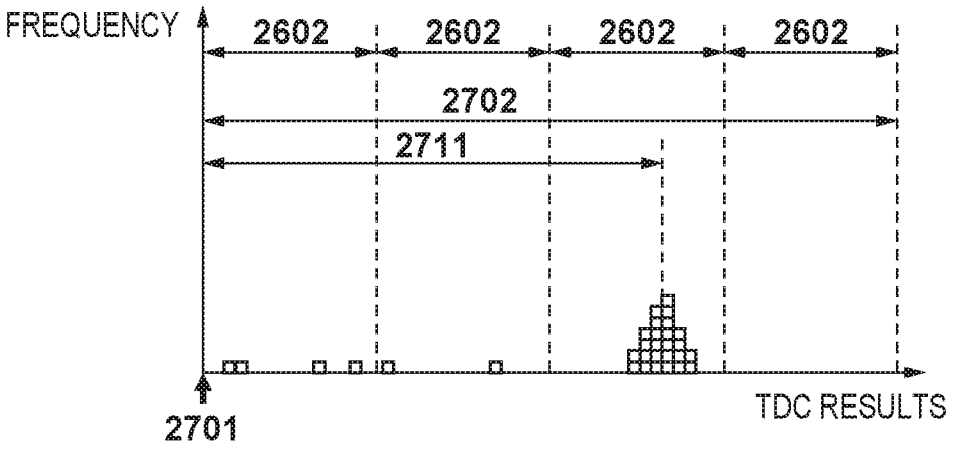


FIG. 19A

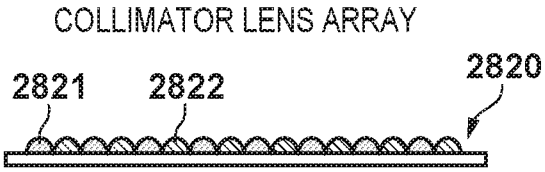


FIG. 19B

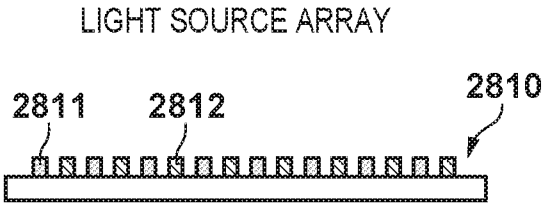


FIG. 19C

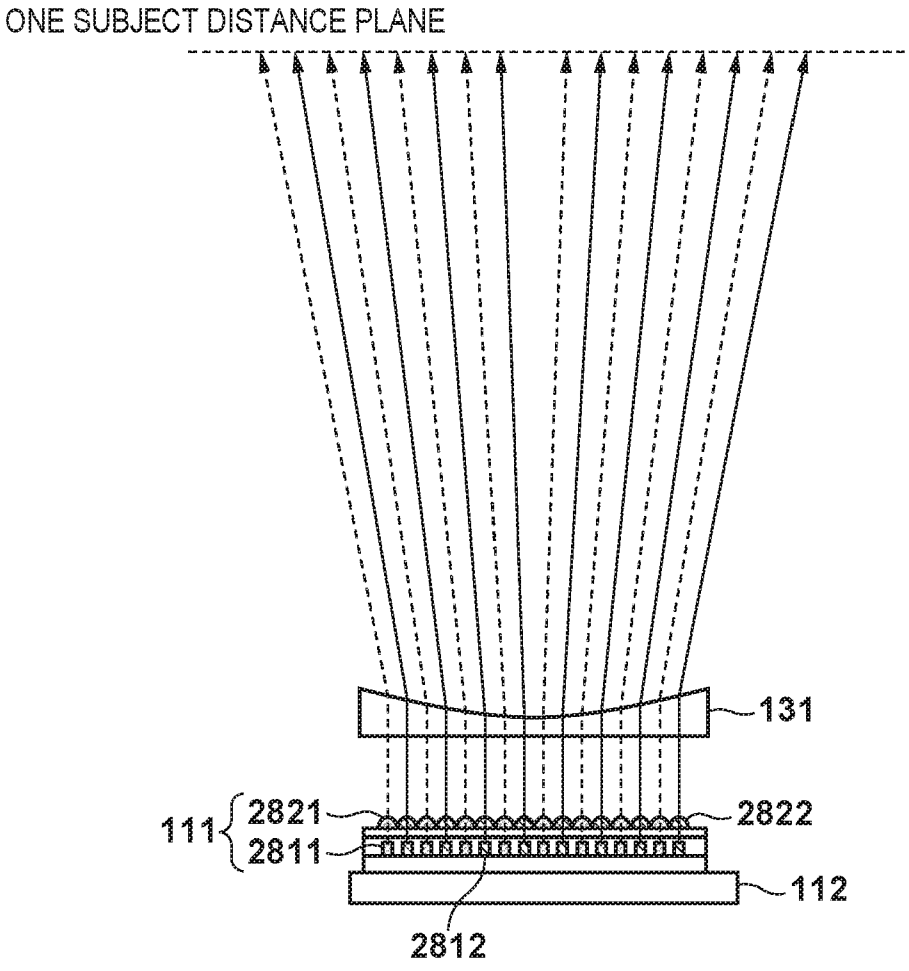


FIG. 20

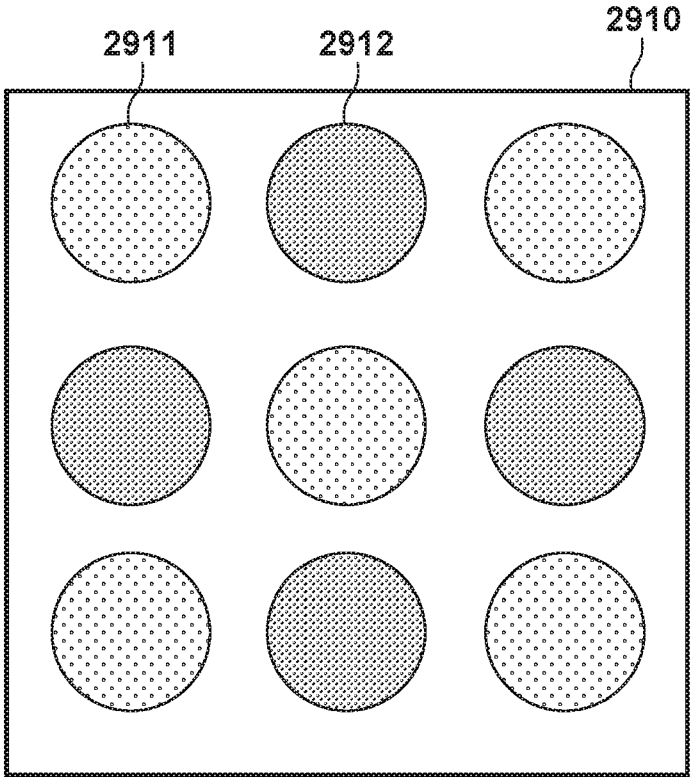


FIG. 21

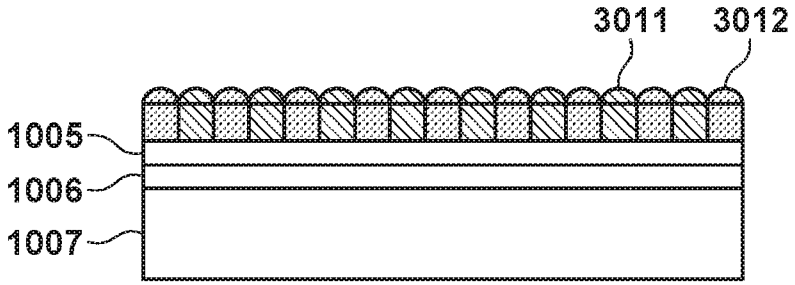
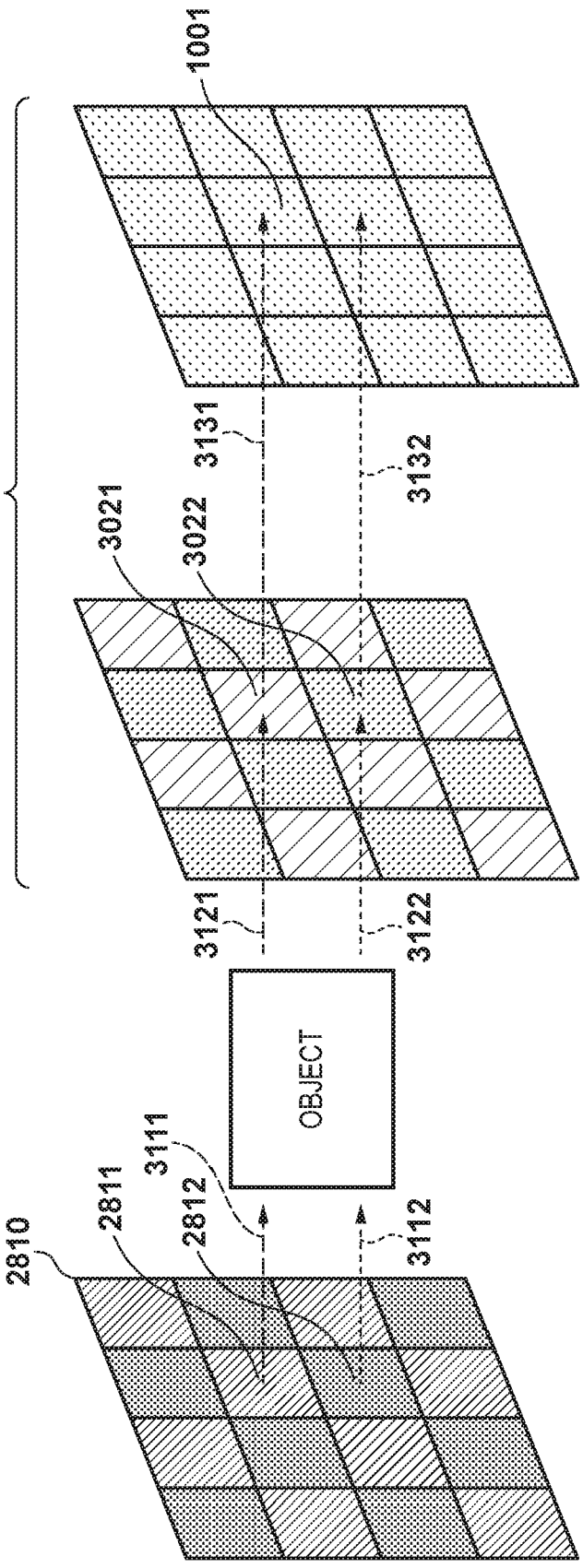


FIG. 22


1001
121
3131
3132
3021
3022
3121
3122
OBJECT
3111
2811
2812
2810
3112

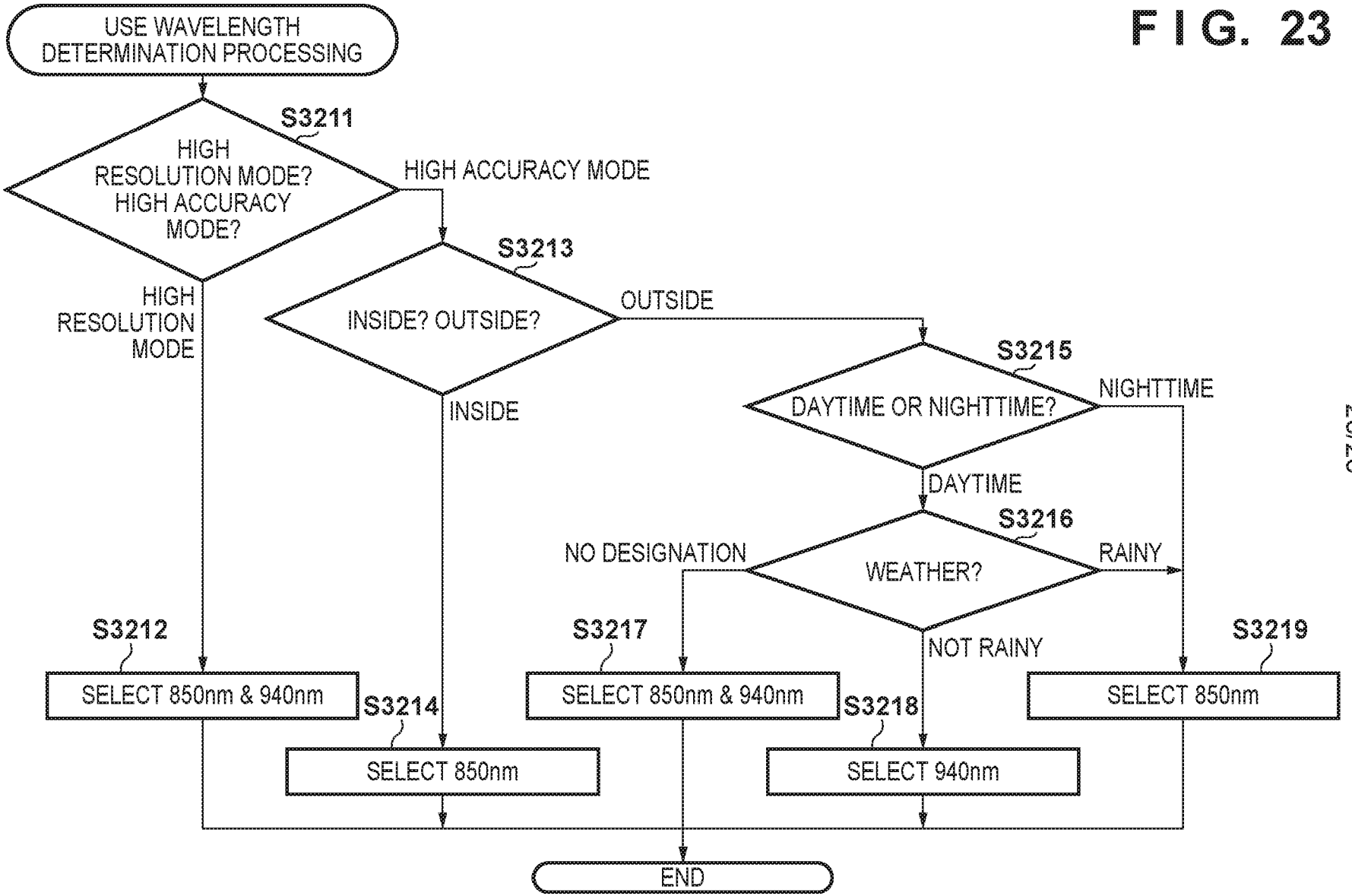

USE WAVELENGTH DETERMINATION PROCESSING
S3211
HIGH RESOLUTION MODE? HIGH ACCURACY MODE?
HIGH ACCURACY MODE
HIGH RESOLUTION MODE
S3213
INSIDE? OUTSIDE?
OUTSIDE
INSIDE
S3215
DAYTIME OR NIGHTTIME?
NIGHTTIME
DAYTIME
S3216
WEATHER?
NO DESIGNATION
RAINY
NOT RAINY
S3212
SELECT 850nm & 940nm
S3214
SELECT 850nm
S3217
SELECT 850nm & 940nm
S3218
SELECT 940nm
S3219
SELECT 850nm
END

FIG. 23

DESCRIPTION

TITLE OF INVENTION

RANGE FINDING APPARATUS

TECHNICAL FIELD

[0001] The present invention relates to a range finding apparatus.

BACKGROUND ART

[0002] There are known ToF (Time-of-Flight) range-finding methods for measuring a distance to an object that has reflected light, by measuring a time difference between a time when light was emitted and a time when reflected light was detected. Particularly when ToF range finding is performed outside, it is important to suppress the influence from ambient light.

[0003] PTL1 discloses a configuration for suppressing the influence from ambient light by controlling combinations of a wavelength of light emitted by a light-emission diode and a passband of a bandpass filter of a light-receiving device in accordance with a temperature.

CITATION LIST

PATENT LITERATURE

[0004]

PTL1: Japanese Patent Laid-Open No. 2019-78748

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0005] However, in PTL1, there is a need to provide two pairs of light-emitting units and/or two pairs of filters, or to use a light-emission diode whose light-

emitting wavelength changes in accordance with a temperature, resulting in a complicated configuration and a larger size. For this reason, the configuration disclosed in PTL1 is disadvantageous in terms of cost, and is inappropriate for usage for which the configuration is incorporated in a small-sized electronic device. Furthermore, in actuality, one wavelength is used for range finding, and thus, for example, when there is light of a wavelength that is close to the wavelength of ambient light, the influence from ambient light cannot be suppressed.

[0006] The present invention provides, as its one aspect, a range finding apparatus that mitigates at least one of such issues and can efficiently perform range finding that uses light of different wavelengths.

SOLUTION TO PROBLEM

[0007] A range finding apparatus according to one mode of the present invention includes: a light source unit capable of concurrently emitting light of a first wavelength and light of a second wavelength that is longer than the first wavelength, a light-receiving part that includes a pixel array in which pixels are two-dimensionally arranged, and that detects incident of light on the pixels, and measuring means for detecting a time period from when range finding is started until when incident of light on the pixels is detected, and computing distance information based on the detected time period. Here, a first pixel configured to receive light of the first wavelength and a second pixel configured to receive light of the second wavelength are two-dimensionally arranged in the pixel array.

ADVANTAGEOUS EFFECTS OF INVENTION

[0008] According to the present invention, it is possible to provide a range finding apparatus that can efficiently perform range finding that uses light of

different wavelengths.

BRIEF DESCRIPTION OF DRAWINGS

[0009] FIG. 1 is a block diagram showing an exemplary functional configuration of a range finding apparatus 100 that uses a light-receiving device according to an embodiment of the present invention.

FIG. 2A is a diagram showing a configuration example of a light source unit 111.

FIG. 2B is a diagram showing a configuration example of the light source unit 111.

FIG. 2C is a diagram showing a configuration example of the light source unit 111.

FIG. 3A is a diagram showing an example of a light-projection pattern of the light source unit 111.

FIG. 3B is a diagram showing an example of a light-projection pattern of the light source unit 111.

FIG. 4 is an exploded perspective view schematically showing a mounting example of the measurement unit 120.

FIG. 5A is a diagram related to a configuration example the light-receiving part 121.

FIG. 5B is a diagram related to a configuration example the light-receiving part 121.

FIG. 6A is a diagram showing an example of the spectroscopic characteristics of an optical bandpass filter that is provided in a pixel 511.

FIG. 6B is a diagram showing an example of the spectroscopic characteristics of an optical bandpass filter that is provided in a pixel 511.

FIG. 7 is a vertical cross-sectional view showing a configuration example of the light receiving element of a pixel 511.

FIG. 8A is a diagram showing an example of potential distribution on a cross-section in FIG. 7.

FIG. 8B is a diagram showing an example of potential distribution on a cross-section in FIG. 7.

FIG. 8C is a diagram showing an example of potential distribution on a cross-section in FIG. 7.

FIG. 9 is a circuit diagram showing a configuration example of a pixel 511.

FIG. 10 is a block diagram showing a configuration example of a TDC array unit 122.

FIG. 11 is a circuit diagram showing a configuration example of a high resolution TDC 1501.

FIG. 12 is a diagram related to operations of the high resolution TDC 1501.

FIG. 13 is a timing chart related to a range-finding operation.

FIG. 14 is a timing chart obtained by enlarging a portion of FIG. 13.

FIG. 15 is a diagram schematically showing an exemplary circuit configuration of a second oscillator 1512 of a low resolution TDC 1502.

FIG. 16 is a block diagram showing an exemplary functional configuration of a first oscillation adjusting circuit 1541 and a second oscillation adjusting circuit 1542.

FIG. 17 is a flowchart related to an example of a range-finding operation according to an embodiment of the present invention.

FIG. 18A is a diagram showing an example of a histogram of range-finding results.

FIG. 18B is a diagram showing an example of a histogram of range-finding results.

FIG. 18C is a diagram showing an example of a histogram of range-finding results.

FIG. 18D is a diagram showing an example of a histogram of range-finding results.

FIG. 18E is a diagram showing an example of a histogram of range-finding results.

FIG. 19A is a diagram showing a configuration example of a light source unit 111 according to a second embodiment.

FIG. 19B is a diagram showing a configuration example of the light source unit 111 according to the second embodiment.

FIG. 19C is a diagram showing a configuration example of the light source unit 111 according to the second embodiment.

FIG. 20 is a diagram showing an example of a light-projection pattern of the light source unit 111 according to the second embodiment.

FIG. 21 is a diagram showing a configuration example of a light-receiving part 121 according to the second embodiment.

FIG. 22 is a diagram schematically showing range finding according to the second embodiment.

FIG. 23 is a flowchart related to wavelength determination processing according to the second embodiment.

DESCRIPTION OF EMBODIMENTS

[0010] Hereinafter, the present invention will be described in detail based on exemplary embodiments thereof with reference to the attached drawings. Note that the following embodiments are not intended to limit the scope of the claimed invention. A plurality of features are described in the embodiments, but all of the features are not necessarily essential to the present invention, and some features may be combined as appropriate. Furthermore, in the attached drawings, the same reference numerals are given to the same or similar

configurations, and a redundant description thereof is omitted.

[0011] Note that, in the present specification, the characteristics of light receiving elements being the same indicates that the physical configurations and bias voltages of the light receiving elements are not made different in a proactive manner. Therefore, there can be a difference in characteristics due to inevitable factors such as manufacturing variation.

First Embodiment

[0012] FIG. 1 is a block diagram showing an exemplary functional configuration of a range finding apparatus that uses a light-receiving device according to the present invention. A range finding apparatus 100 includes a light-projection unit 110, a measurement unit 120, a light-receiving lens 132, and an overall control unit 140. The light-projection unit 110 includes a light source unit 111 in which light-emitting elements are arranged in a two-dimensional array, a light-source-unit drive unit 112, a light source control unit 113, and a light-projection lens 131. The measurement unit 120 includes a light-receiving part 121, a TDC (Time-to-Digital Convertor) array unit 122, a signal processing unit 123, and a measurement control unit 124. Note that, in the present specification, a combination of the light-receiving lens 132 and the light-receiving part 121 may be referred to as a "light-receiving unit 133".

[0013] The overall control unit 140 controls the overall operations of the range finding apparatus 100. The overall control unit 140 includes a CPU, a ROM, and RAM, for example, and controls the constituent elements of the range finding apparatus 100 by loading a program stored in the ROM to the RAM, and the CPU executing the program. At least a portion of the overall control unit 140 may be realized by a dedicated hardware circuit.

[0014] By causing a plurality of light-emitting elements 211 (FIG. 2B) arranged

in the light source unit 111 to emit light for a short time, pulsed light (pulse light) is emitted via the light-projection lens 131. Pulse light beams emitted from the individual light-emitting elements illuminate different spaces, respectively. A portion of the pulse light emitted from the light source unit 111 is reflected by a subject, and is incident on the light-receiving part 121 via the light-receiving lens 132. In the present embodiment, a configuration is adopted in which the light-emitting elements 211 that emit light and specific pixels among a plurality of pixels arranged in the light-receiving part 121 optically correspond to each other. Here, a pixel optically corresponding to a certain light-emitting element 211 is a pixel that is in a positional relation therewith such that a largest portion of reflected light of light emitted from the light-emitting element 211 is detected in the pixel.

[0015] A time period from when the light source unit 111 emits light until when reflected light of the light is incident on the light-receiving part 121 is measured as a ToF (Time-of-Flight) by the TDC array unit 122. Note that, in order to reduce the influence that noise components such as ambient light and a dark count or noise of the TDC array unit 122 have on a measurement result, a ToF (Time-of-Flight) is measured a plurality of times.

[0016] The signal processing unit 123 generates a histogram of measurement results obtained by the TDC array unit 122 performing measurement a plurality of times, and removes noise components based on the histogram. The signal processing unit 123 then computes a distance L of a subject by substituting a ToF (Time-of-Flight) obtained by averaging the measurement results from which the noise components have been removed, into Expression (1) below, for example.

$$L[m] = ToF[sec]*c[m/sec]/2 \quad \ldots (1)$$

Note that "c" indicates the speed of light. In this manner, the signal processing unit 123 computes distance information for each pixel.

Light-Projection Unit 110

[0017] A configuration example of the light-projection unit 110 will be described with reference to FIGS. 2A to 2C. FIG. 2A is a side view showing a configuration example of a collimator lens array 220 that constitutes the light source unit 111, and FIG. 2B is a side view showing a configuration example of a light source array 210 that constitutes the light source unit 111.

[0018] The light source array 210 has a configuration in which the light-emitting elements 211, which are vertical cavity surface emitting lasers (VCSELs), for example, are arranged in a two-dimensional array. On and off of the light source array 210 is controlled by the light source control unit 113. The light source control unit 113 can control on and off of in units of light-emitting elements 211.

[0019] Note that elements other than VCSELs such as edge surface emitting laser elements or light-emitting diodes (LEDs) may also be used as the light-emitting elements 211. When edge surface emitting laser elements are used as the light-emitting elements 211, a laser bar on which elements are one-dimensionally arranged on a board, or a laser bar stack having a two-dimensional array configuration in which laser bars are stacked can be used as the light source array 210. In addition, when LEDs are used as the light-emitting elements 211, it is possible to use the light source array 210 in which LEDs are arranged in a two-dimensional array on a board.

[0020] Note that, although there is no particular limitation, if the emission wavelength of the light-emitting elements 211 is a wavelength of near-infrared band, it is possible to suppress the influence of ambient light. VCSELs can be manufactured using a material used in an edge surface emitting laser or a surface emitting laser, by performing a semiconductor process. When a configuration for discharging a laser beam having a wavelength of near-infrared band is

adopted, a GaAs-based semiconductor material can be used. In this case, a dielectric multilayer film that forms a distributed Bragg reflection (DBR) reflection mirror constituting a VCSEL can be configured by alternately layering, in a periodical manner, two thin films made of materials having different refractive indexes (GaAs/AlGaAs). The wavelength of light emitted by the VCSEL can be changed by adjusting the element combination of a compound semiconductor, or the composition.

[0021] An electrode for injecting a current and hall into an active layer is provided in each of the VCSELs that make up a VCSEL array. By controlling the timing for injecting a current and hall into the active layer, any pulse light and modulated light can be discharged. The light source control unit 113 can individually drive the light-emitting elements 211, and can drive the light source array 210 in units of rows, columns, or rectangular regions.

[0022] In addition, the collimator lens array 220 has a configuration in which a plurality of collimator lenses 221 are arranged in a two-dimensional array such that each collimator lens 221 corresponds to one light-emitting element 211. A light beam emitted by the light-emitting element 211 is converted into a parallel light beam by the corresponding collimator lens 221.

[0023] FIG. 2C is a vertical cross-sectional view of an arrangement example of the light-source-unit drive unit 112, the light source unit 111, and the light-projection lens 131. The light-projection lens 131 is an optical system for adjusting a light-projection range of parallel light emitted from the light source unit 111 (the light source array 210). In FIG. 2C, the light-projection lens 131 is a concave lens, but may be a convex lens or an aspherical lens, or may be an optical system constituted by a plurality of lenses.

[0024] In the present embodiment, as an example, the light-projection lens 131 is configured such that light is emitted in a range of ± 45 degrees from the light-

projection unit 110. Note that, the light-projection lens 131 may be omitted by controlling a direction in which light is emitted, using the collimator lenses 221.

[0025] FIG. 3A shows an example of a light-projection pattern formed by the light-projection unit 110 that uses the light source array 210 in which VCSEL elements are arranged in 3 rows × 3 columns. Reference numeral 310 indicates a plance that directly faces the light-projection unit 110 and that is positioned at a predetermined distance. Nine light-projection areas 311 represent, on the plane 310, regions whose diameter is about the full width at half maximum (FWHM) of intensity distribution of light from the individual VCSEL elements.

[0026] A slight divergence angle is added, by the light-projection lens 131, to parallel light obtained as a result of the collimator lenses 221 converting light emitted from VCSELs, and thus a limited region is formed on an irradiation plane (the plane 310). If the positional relation between the collimator lens array 220 and the light source array 210 is constant, the light-projection areas 311 are formed on the plane 310 so as to respectively correspond to the light-emitting elements 211 that make up the light source array 210.

[0027] The light-projection unit 110 according to the present embodiment includes the light-source-unit drive unit 112 that can move the light source unit 111 on the same plane. By the light-source-unit drive unit 112 moving the position of the light source unit 111, it is possible to change the relative positional relation between the light-emitting elements 211 and the collimator lenses 221 or the light-projection lens 131. A method for the light-source-unit drive unit 112 to drive the light source unit 111 is not particularly limited, but it is possible to use a mechanism that uses electromagnetic induction or piezoelectric elements, such as a mechanism that is used for driving image capturing elements in order to correct hand shaking.

[0028] When the light-source-unit drive unit 112 moves the light source unit 111

on a plane parallel to the board of the light source unit 111 (a plane perpendicular to the optical axis of the light-projection lens 131), for example, it is possible to move the light-projection areas 311 on the plane 310 substantially in parallel. By causing the light source unit 111 emit light a plurality of times while moving the light source unit 111 on a plane parallel to the board of the light source unit 111, for example, the space resolution of light-projection areas can be increased in a pseudo manner.

[0029] FIG. 3B shows a space resolution of light-projection areas 411 on a plane 410 when the light source unit 111 is turned on four times in a constant cycle while moving the light source unit 111 that includes the light source array 210 similar to that in FIG. 3A, so as to rotate in a circle once on a plane parallel to the board of the light source unit 111. A space resolution that is four-times higher than the space resolution in a case shown in FIG. 3A where the light source unit 111 is not moved is obtained.

[0030] Therefore, performing distance measurement in a state where relative positions between the light source unit 111 and the light-projection lens 131 differs, it is possible to increase the density of distance measurement points. It is possible to increase the space resolution of the light-projection area 411 without separating a light flux, and thus the measurable distance is not shortened, and the distance accuracy does not decrease due to a decrease in the intensity of reflected light.

[0031] Note that the relative positions between the light source unit 111 and the light-projection lens 131 may be changed by moving the light-projection lens 131 on a plane parallel to the board of the light source unit 111. Note that, if the light-projection lens 131 includes a plurality of lenses, the entire light-projection lens 131 may be moved, or only some lenses may be moved.

[0032] Furthermore, a configuration may also be adopted in which the light

source unit 111 can be moved in a direction perpendicular to the board of the light source array 210 (optical axis direction of the light-projection lens 131) by the light-source-unit drive unit 112. Accordingly, it is possible to control the light divergence angle and the light projecting angle.

[0033] The light source control unit 113 controls light emission of the light source unit 111 (the light source array 210) in accordance with a light-receiving timing or the light-receiving resolution of the light-receiving unit 133.

Measurement Unit 120

[0034] Next, a configuration of the measurement unit 120 will be described. FIG. 4 is an exploded perspective view schematically showing a mounting example of the measurement unit 120. FIG. 4 shows the light-receiving part 121, the TDC array unit 122, the signal processing unit 123, and the measurement control unit 124. The light-receiving part 121 and the TDC array unit 122 constitute a light-receiving device.

[0035] The measurement unit 120 has a configuration in which a light receiving element board 510 that includes the light-receiving part 121 in which the pixels 511 are arranged in a two-dimensional array, and a logic board 520 that includes the TDC array unit 122, the signal processing unit 123, and the measurement control unit 124 are stacked. The light receiving element board 510 and the logic board 520 are electrically connected to each other through inter-board connection 530. FIG. 4 shows the light receiving element board 510 and the logic board 520 in a state of being spaced from each other to facilitate description.

[0036] Note that functional blocks mounted on the boards are not limited to the illustrated example. A configuration may also be adopted in which three or more boards are stacked, or all of the functional blocks may be mounted on one board. The inter-board connection 530 is configured as Cu-Cu connection, for example,

and one or more inter-board connections 530 may be disposed for each row of the pixels 511, or one inter-board connection 530 may be disposed for each pixel 511.

[0037] The light-receiving part 121 includes a pixel array in which the pixels 511 are arranged in a two-dimensional array. In the present embodiment, the light receiving elements of the pixels 511 are avalanche photodiodes (APD) or SPAD elements. In addition, as shown in FIG. 5A, pixels H (first pixels) having a first sensitivity and pixels L (second pixels) having a second sensitivity that is lower than the first sensitivity are alternately arranged in the row direction and the column direction. By arranging the pixels H and the pixels L adjacent to one another, offset correction of a pixel H that is based on a measurement result of a pixel L is enabled. In the present specification, the pixels H may also be referred to as "high-sensitivity pixels H", and the pixels L may also be referred to as "low-sensitivity pixels L".

[0038] FIG. 5B is a vertical cross-sectional view showing a structure example of pixels H and pixels L. Here, a resonance wavelength is denoted by λc, a refractive index of a high-refractive-index layer 901 is denoted by nH, and a refractive index of a low-refractive-index layer 902 is denoted by nL (<nH). Optical resonators 911 to 914 are multilayered film interference mirrors that (each) include a high-refractive-index layer 901 having a film thickness $dH=0.25\lambda c/nH$ and a low-refractive-index layer 902 having a film thickness $dL=0.25\lambda c/nL$. A configuration is adopted in which a low-refractive-index layer 902 having a film thickness dE1 (to dE4) = m1 (to m4) × 0. $5\lambda c/nL$ (m1 to m4 are natural numbers) is sandwiched by high-refractive-index layers 901 from the two sides.

[0039] Each pixel L has a configuration in which a second optical bandpass filter is provided on top of a dimming layer 903 that is constituted by a thin tungsten film having a film thickness of 30 nm and that has transmissivity of about 45%.

The second optical bandpass filter has a configuration in which the optical resonators 911 to 914 are layered, sandwiching the low-refractive-index layer 902 having the film thickness dL. The second optical bandpass filter has spectroscopic characteristics shown in FIG. 6A, and is an example of an optical component that is added to a light receiving element.

[0040] Each pixel H has a configuration in which a multilayered film interference mirror 915, a film thickness adjusting layer 905 constituted by a low-refractive-index layer and having the film thickness dE4, and a first optical bandpass filter are provided on top of a transmissivity layer 904 that is constituted by a low-refractive-index layer having a film thickness of 30 nm and that has a transmissivity of about 100%. The first optical bandpass filter is an example of an optical component that is added to a light receiving element, and has spectroscopic characteristics shown in FIG. 6B.

[0041] The first optical bandpass filter has a configuration in which the optical resonators 911 to 913 are layered, sandwiching the low-refractive-index layer 902 having the film thickness dL. The passbands of the first optical bandpass filter and second band have basically the same central wavelength, and, in FIGS. 6A and 6B, $\lambda cL = \lambda cH$. The central wavelength can be the peak wavelength of light emitted by the light source unit 111. On the other hand, a full width at half maximum WL of the spectroscopic characteristics of the second optical bandpass filter is narrower than a full width at half maximum WH of the spectroscopic characteristics of the first optical bandpass filter.

[0042] The full width at half maximum WL is set narrower than the full width at half maximum WH, since it is envisioned that short distance range finding is mainly performed in the high-sensitivity pixels H while a long distance range finding is mainly performed in the low-sensitivity pixels L. In the low-sensitivity pixels L, the full width at half maximum WL is narrowed so as to be

able to handle a long ToF, and noise light is kept from being measured before reflected light arrives.

[0043] In addition, the pixels L are configured to have a lower sensitivity than the pixels H as a result of being provided with the dimming layer 903. The dimming layer 903 is an example of an optical component for reducing the sensitivity of a pixel. Note that, in place of the dimming layer 903, another optical component such as masks that have different opening amounts may be used such that the pixels H and the pixels L have different sensitivities.

[0044] By providing, to each pixel L, a mask having an opening amount smaller than that of a mask provided in each pixel H, the light-receiving region of the light receiving element of the pixel L can be made narrower than the light-receiving region of the light receiving element of the pixel H, for example. It is not necessary to provide a mask to the pixel H, and, in this case, it suffices for a mask having an aperture ratio that is smaller than 100% to be provided to the pixel L. The mask can be formed of any material that can form a light shielding film.

[0045] In the present embodiment, instead of setting different configurations of light receiving elements themselves or different voltages that are applied thereto, an optical component that is added to a light receiving element is used to set different sensitivities of pixels. For this reason, the pixel H and the pixel L can have a common configuration of a light receiving element or a common voltage can be applied to the pixel H and the pixel L. Therefore, it is easy to manufacture the light receiving element array, and, in addition, it is possible to suppress variation in characteristics of light receiving elements.

[0046] FIG. 7 is a cross-sectional view that includes a semiconductor layer of a light receiving element that is common to the pixels H and the pixels L. Reference numeral 1005 indicates a semiconductor layer of the light receiving element board 510, reference numeral 1006 indicates a wiring layer of the light

receiving element board 510, and reference numeral 1007 indicates a wiring layer of the logic board 520. The light receiving element board 510 and the wiring layer of the logic board 520 are joined so as to face each other. The semiconductor layer 1005 of the light receiving element board 510 includes a light-receiving region (photoelectric conversion region) 1001, and an avalanche region 1002 for generating an avalanche current in accordance with a signal charge generated through photoelectric conversion.

[0047] In addition, a light shielding wall 1003 is provided between adjacent pixels in order to prevent light that has been obliquely incident on the light-receiving region 1001 of a pixel, from reaching the light-receiving region 1001 of an adjacent pixel. The light shielding wall 1003 is made of metal, and an insulator region 1004 is provided between the light shielding wall 1003 and the light-receiving region 1001.

[0048] FIG. 8A is a diagram showing potential distribution of a semiconductor region in the cross-section a-a' in FIG. 7. FIG. 8B is a diagram showing potential distribution in the cross-section b-b' in FIG. 7. FIG. 8C is a diagram showing potential distribution of the cross-section c-c' in FIG. 7.

[0049] Light that has been incident on the semiconductor layer 1005 of the light receiving element board 510 is subject to photoelectric conversion in the light-receiving region 1001, and an electron and a positive hole are generated. A positive hole carrying a positive electric charge is discharged via an anode electrode Vbd. As shown in FIGS. 8A, 8B, and 8C, an electron carrying a negative electric charge is transferred as a signal charge to the avalanche region 1002 due to an electric field that has been set such that the potential decreases toward the avalanche region 1002.

[0050] The signal charge that has arrived at the avalanche region 1002 causes avalanche breakdown, due to the strong electric field of the avalanche region

1002, and generates an avalanche current. This phenomenon occurs not only due to signal light (reflected light of light emitted by the light source unit 111) but also incidence of ambient light that is noise light, and generates noise components. In addition, a carrier is generated not only by incident light, but also generated thermally. An avalanche current caused by a thermally generated carrier is called a "dark count", and becomes a noise component.

[0051] FIG. 9 is an equivalent circuit diagram of a pixel 511. The pixel 511 includes an SPAD element 1401, a load transistor 1402, an inverter 1403, a pixel select switch 1404, and a pixel output line 1405. The SPAD element 1401 corresponds to a region obtained by combining the light-receiving region 1001 and the avalanche region 1002 in FIG. 7.

[0052] When the pixel select switch 1404 is switched on by a control signal supplied from the outside, an output signal of the inverter 1403 is output to the pixel output line 1405 as a pixel output signal.

When no avalanche current is flowing, the voltage of the anode electrode Vbd is set such that a reverse bias that is larger than or equal to a breakdown voltage is applied to the SPAD element 1401. At this time, there is no current flowing through the load transistor 1402, and thus the voltage of a cathode potential Vc is close to a power supply voltage Vdd, and a pixel output signal thereof is "0".

[0053] When an avalanche current is generated in the SPAD element 1401 due to arrival of a photon, the cathode potential Vc drops, and output of the inverter 1403 is reversed. That is to say, the pixel output signal changes from "0" to "1".

[0054] When the cathode potential Vc drops, a reverse bias that is applied to the SPAD element 1401 drops, and when the reverse bias falls to a breakdown voltage or lower, generation of an avalanche current stops.

Thereafter, as a result of a positive hole current flowing from the power

supply voltage Vdd via the load transistor 1402, the cathode potential Vc rises, output of the inverter 1403 (pixel output) returns from "1" to "0", and the state returns to the state before the arrival of the photon. A signal output from the pixels 511 in this manner is input to the TDC array unit 122 via a relay buffer (not illustrated).

TDC Array Unit 122

[0055] The TDC array unit 122 measures, as a ToF, a time period from a time when the light source unit 111 emits light until a time when the output signal of the pixel 511 changes from "0" to "1".

FIG. 10 is a diagram schematically showing a configuration example of the TDC array unit 122. In the TDC array unit 122, a high resolution TDC 1501 having a first measurement resolution is provided to half of the pixels that make up each pixel row of the pixel array, and a low resolution TDC 1502 having a second measurement resolution is provided to the other half, and thereby ToFs are measured in units of pixels. The second measurement resolution is lower than the first measurement resolution. In addition, a synchronous clock is supplied from the overall control unit 140, for example.

[0056] Here, an output signal of a high-sensitivity pixel H is driven by the relay buffer so as to be input to the high resolution TDC 1501, and an output signal of a low-sensitivity pixel L is driven by the relay buffer so as to be input to the low resolution TDC 1502. Specifically, regarding the high-sensitivity pixel H, a time period is measured with a higher measurement resolution than that of the low-sensitivity pixel L. In FIG. 10, an odd-numbered pixel output is output of a pixel H, and even-numbered pixel output is output of a pixel L. In order to substantially equalize delay times in relay buffers, the high resolution TDCs 1501 and the low resolution TDCs 1502 are alternately arranged.

[0057] Each high resolution TDC 1501 includes a first oscillator 1511, a first oscillation count circuit 1521, and a first synchronous clock count circuit 1531. The low resolution TDC 1502 includes a second oscillator 1512, a second oscillation count circuit 1522, and a second synchronous clock count circuit 1532. The first oscillation count circuit 1521 and the second oscillation count circuit 1522 are second counters that count changes in output values of the corresponding oscillators. The first synchronous clock count circuit 1531 and the second synchronous clock count circuit 1532 are first counters that count synchronous clocks.

[0058] Regarding output values of the TDCs, counting results of the synchronous clock count circuits occupy higher bits, internal signals of the oscillators occupy lower bits, and counting results of the oscillation count circuits occupy intermediate bits. That is to say, a configuration is adopted in which the synchronous clock count circuits perform rough measurement, internal signals of the oscillators are used for minute measurement, and the oscillation count circuits perform intermediate measurement. Note that each measurement bit may include a redundant bit.

[0059] FIG. 11 is a diagram schematically showing a configuration example of the first oscillator 1511 of the high resolution TDC 1501. The first oscillator 1511 includes an oscillation start/stop signal generation circuit 1640, buffers 1611 to 1617, an inverter 1618, an oscillation switch 1630, and delay-adjusting current sources 1620. In addition, the buffers 1611 to 1617 and the inverter 1618, which are delay elements, are alternately connected to the oscillation switches 1630 in series in a ring shape. The delay-adjusting current sources 1620 are respectively provided to the buffers 1611 to 1617 and the inverter 1618, and adjust the delay times of the corresponding buffers and inverter in accordance with an adjusting voltage.

[0060] FIG. 12 shows changes in output signals of the buffers 1611 to 1617 and the inverter 1618 and an internal signal of the oscillator, at the time of resetting, and after each delay time t_{buff} corresponding to one buffer stage has elapsed from when the oscillation switch 1630 was switched on. WI11 output to WI18 output respectively represent output signals of the buffers 1611 to 1617 and the inverter 1618.

[0061] At the time of resetting, the output values of the buffers 1611 to 1617 are "0" and the output value of the inverter 1618 is "1". After a delay time t_{buff} corresponding to one buffer stage has elapsed from when the oscillation switch 1630 was switched on, the output values of the buffers 1612 to 1617 and the inverter 1618 that are input/output consistent do not change. On the other hand, the output value of the buffer 1611 that is not input/output consistent changes from "0" to "1" (the signal proceeds by one stage).

[0062] When t_{buff} further elapses (after $2 \times t_{buff}$), the output values of the buffer 1611 and 1613 to 1617 and the inverter 1618 that are input/output consistent do not change. On the other hand, the output value of the buffer 1612 that is not input/output consistent changes from "0" to "1" (the signal further proceeds by one stage).

[0063] In this manner, each time a delay time t_{buff} corresponding to one buffer stage elapses, the output value of one of the buffers 1611 to 1617 and the inverter 1618 that is not input/output consistent changes from "0" to "1" in order. Then, after $8 \times t_{buff}$ elapses from when the oscillation switch 1630 was switched on, the output values of all of the buffers and inverter change to "1" (one signal cycle complete). When $8 \times t_{buff}$ further elapses (after $16 \times t_{buff}$ elapses), the output values of all of the buffers and inverter change to "0" (two signal cycles complete), the state returns to the original state.

[0064] Thereafter, output changes in a similar manner in a cycle of $16 \times t_{buff}$.

In this manner, the time resolution of the high resolution TDC 1501 equals to t_{buff}. In addition, the time resolution t_{buff} is adjusted to 2^{-7} (1/128) × the cycle of a synchronous clock by a later-described first oscillation adjusting circuit 1541.

[0065] In addition, oscillator output, that is, output of the inverter 1618 is input to the first oscillation count circuit 1521. The first oscillation count circuit 1521 measures a time period with the time resolution of 16 × t_{buff}, by counting a rising edge of the oscillator output.

[0066] FIG. 13 is a timing chart to the end of measurement of a time period from when light is emitted until when reflected light is detected by the SPAD element 1401. The timing chart shows changes in the cathode potential Vc of the SPAD element 1401, a pixel output signal, a synchronous clock, a count value of the synchronous clock count circuit, output of the oscillator start/stop signal generation circuit, oscillator output, and a count value of the oscillation count circuit.

[0067] The cathode potential Vc of the SPAD element 1401 is an analog voltage, and an upper portion of the timing chart in the figure indicates a higher voltage. The synchronous clock, the output of the oscillator start/stop signal generation circuit, and the oscillator output are digital signals, and upper portions of the timing charts in the figure indicate that the signals are on, and lower portions indicate that they are off. The count values of the synchronous clock count circuit and the oscillator count circuit are digital values, and are expressed in decimal numbers.

[0068] FIG. 14 is a diagram showing, in an enlarged manner, the output of the oscillator start/stop signal generation circuit, the oscillator output, and the count value of the oscillator count circuit, from time 1803 until time 1805 in FIG. 13, and the oscillator internal signal. The oscillator internal signal takes a digital value, and is expressed in a decimal number.

[0069] An operation of measuring, with the high resolution TDC 1501, a time period from time 1801 when the light source unit 111 emits light until time 1803 when a photon is incident on the SPAD element 1401 of a pixel and the pixel output signal changes from 0 to 1 will be described with reference to FIGS. 13 and 14.

[0070] The light source control unit 113 drives the light source unit 111 such that the light-emitting elements 211 emit light at time 1801 that is synchronized with a rise of a synchronous clock supplied via the overall control unit 140. When an instruction to start measurement is given from the overall control unit 140 at time 1801 when the light-emitting element 211 emits light, the first synchronous clock count circuit 1531 starts counting a rising edge of a synchronous clock.

[0071] When reflected light of the light emitted at time 1801 is incident on a pixel at time 1803, the cathode potential Vc of the SPAD element 1401 drops, and the pixel output signal changes from "0" to "1". When the pixel output signal changes to "1", the output of the oscillation start/stop signal generation circuit 1640 changes from "0" to "1", and the oscillation switch 1630 is switched on.

[0072] When the oscillation switch 1630 is switched on, an oscillation operation is started, and a signal loop is started inside the oscillator as shown in FIG. 12. Every time $16 \times t_{buff}$ elapses from when the oscillation switch 1630 was switched on and two signal cycles are complete in the oscillator, a rising edge emerges on the oscillator output, and the first oscillation count circuit 1521 measures the number of the rising edges. In addition, at time 1803, the first synchronous clock count circuit 1531 stops counting, and holds the count value.

[0073] At time 1803 when the first oscillator 1511 was switched on, and from time 1803, a first timing when the synchronous clock rises is time 1805. As the synchronous clock rises at time 1805, the output value of the oscillation start/stop signal generation circuit 1640 changes to "0", and the oscillation switch 1630 is

switched off. At the timing when the oscillation switch 1630 changes to "0", oscillation of the first oscillator 1511 ends, and an oscillation circuit internal signal is held as is. In addition, since oscillation ends, the first oscillation count circuit 1521 also stops counting.

[0074] A count result D_{Gclk} of the synchronous clock count circuit is a value obtained by measuring a time period from time 1801 until time 1802 in units of $2^7 \times t_{buff}$. In addition, a count result D_{ROclk} of the oscillator count circuit is a value obtained by measuring a time period from time 1803 until time 1804 in units of $2^4 \times t_{buff}$. Furthermore, an oscillator internal signal D_{ROin} takes a value obtained by measuring a time period from time 1804 until time 1805 in units of t_{buff}. The high resolution TDC 1501 performs the following processing on these values, and outputs the resultants to the signal processing unit 123, thereby completing one measurement operation.

[0075] The count result D_{ROclk} of the oscillator count circuit and the oscillator internal signal D_{ROin} are added in accordance with Expression 2 below.

$$D_{RO} = 2^4 \times D_{ROclk} + D_{ROin} \quad \ldots (2)$$

[0076] D_{RO} obtained using Expression 2 is a value obtained by measuring a time period from time 1803 until time 1805 in units of t_{buff}. In addition, a time period from time 1802 until time 1805 equals to one cycle of the synchronous clock, and thus is $2^7 \times t_{buff}$. For this reason, by subtracting D_{RO} from one cycle of the synchronous clock, the time period from time 1802 until time 1803 is obtained. When the time period from time 1802 until time 1803 is added to D_{Gclk}, namely a time period from time 1801 until time 1802, a value D_{ToF} indicating the time period from time 1801 until time 1803 measured in units of t_{buff} is obtained (Expression 3).

$$D_{ToF} = 2^7 \times D_{Gclk} + (2^7 - D_{RO}) = 2^7 \times D_{Gclk} + (2^7 - 24 \times D_{ROclk} - D_{ROin}) \quad \ldots (3)$$

[0077] FIG. 15 is a diagram schematically showing an exemplary circuit

configuration of the second oscillator 1512 of the low resolution TDC 1502. In the second oscillator 1512, buffers 2011 to 2013 and an inverter 2014 are alternately connected to oscillation switches 2030 in series in a ring shape. In addition, delay-adjusting current sources 2020 are respectively provided to the buffers 2011 to 2013 and the inverter 2014, and adjust the delay times of the corresponding buffers and inverter in accordance with an adjusting voltage.

[0078] Compared with the high resolution TDC 1501, the number of buffers and the number of oscillation switches are smaller, and are three instead of seven. On the other hand, a delay time t_{buff} of the buffers 2011 to 2013 and the inverter 2014 are adjusted to $2 \times t_{buff}$ of the high resolution TDC 1501 by a second oscillation adjusting circuit 1542.

[0079] Accordingly, the count cycle of the second oscillation count circuit 1522 equals to the count cycle of the first oscillation count circuit 1521. Therefore, the number of output bits of the second oscillation count circuit 1522 equals to the number of output bits of the first oscillation count circuit 1521. On the other hand, the number of bits of the oscillator internal signal of the second oscillator 1512 can be made smaller than that of the first oscillator 1511 by one bit.

[0080] As described above, it is envisioned that the low-sensitivity pixels L are mainly used for long distance range-finding. In the case of a long distance, the influence that the ToF measurement resolution has on the accuracy of a range-finding result for a short distance is greater than that for a long distance. For this reason, the ToF measurement resolution with which the low resolution TDC 1502 measures ToFs of the low-sensitivity pixels L is lower than that of the high resolution TDC 1501, giving priority to reducing the circuit scale and the power consumption.

[0081] A delay time t_{buff} varies due to a factor such as a manufacturing error of a transistor that is caused by a manufacturing process, a change in a voltage that is

applied to a TDC circuit, and a temperature. For this reason, the first oscillation adjusting circuit 1541 and the second oscillation adjusting circuit 1542 are provided for every eight TDCs.

[0082] FIG. 16 is a block diagram showing an exemplary functional configuration of the first oscillation adjusting circuit 1541 and the second oscillation adjusting circuit 1542. The first oscillation adjusting circuit 1541 and the second oscillation adjusting circuit 1542 have the same configuration, and thus the first oscillation adjusting circuit 1541 will be described below. The first oscillation adjusting circuit 1541 includes a dummy oscillator 2101, $1/2^3$ (1/8) frequency divider 2102, and a phase comparator 2103.

[0083] The dummy oscillator 2101 is an oscillator having the same configuration as the oscillator of a TDC that is connected thereto. Therefore, the dummy oscillator 2101 of the first oscillation adjusting circuit 1541 has the same configuration as the first oscillator 1511. The dummy oscillator 2101 of the second oscillation adjusting circuit 1542 has the same configuration as the second oscillator 1512.

[0084] Output of the dummy oscillator 2101 is input to the $1/2^3$ frequency divider 2102. The $1/2^3$ frequency divider 2102 outputs a clock signal obtained by changing the frequency of an input clock signal to $1/2^3$. A synchronous clock and output of the $1/2^3$ frequency divider 2102 are input to the phase comparator 2103. The phase comparator 2103 compares the frequency of the synchronous clock and the frequency of the clock signal output by the $1/2^3$ frequency divider 2102 with each other.

[0085] Then, the phase comparator 2103 increases an output voltage if the frequency of the synchronous clock signal is higher, and decreases the output voltage if the frequency of the synchronous clock is lower. Output of the phase comparator 2103 is input as an adjusting voltage to the delay-adjusting current

source 1620 of the first oscillator 1511, and delay is adjusted such that the oscillation frequency of the first oscillator 1511 is 2^3 times as high as the synchronous clock. The same applies to the second oscillation adjusting circuit 1542.

[0086] In this manner, an oscillation frequency of the oscillator is determined using a synchronous clock frequency as a reference. For this reason, by generating a synchronous clock signal using an external IC that can output a fixed frequency irrespective of a change in the process/voltage/temperature, it is possible to suppress variation in the oscillation frequency of the oscillator due to a change in the process/voltage/temperature.

[0087] By inputting a clock signal of 160 MHz as a synchronous clock signal, for example, oscillation frequencies for both the high resolution TDC 1501 and the low resolution TDC 1502 are eight times the synchronous clock frequency, namely 1.28 GHz. A delay time t_{buff} for one buffer stage that is the time resolution of a TDC is 48.8 ps for the high resolution TDC 1501, and 97.7 ps for the low resolution TDC 1502.

Range Finding Sequence

[0088] FIG. 17 is a flowchart related to an example of a range-finding operation according to the present embodiment.

In step S2201, the overall control unit 140 resets a histogram circuit and a measurement counter i of the signal processing unit 123. Also, the overall control unit 140 changes connection of the relay buffer (not illustrated) such that output of pixels 511 optically corresponding to light-emitting elements 211 that emit light in step S2202 is input to the TDC array unit 122.

[0089] In step S2202, the overall control unit 140 causes some of the light-emitting elements 211 that constitute the light source array 210 of the light source

unit 111 to emit light. At the same time, the overall control unit 140 instructs the TDC array unit 122 to start measurement.

[0090] The high resolution TDCs 1501 and the low resolution TDCs 1502 of the TDC array unit 122 output measurement results to the signal processing unit 123, when a change in output of the corresponding pixels 511 from "0" to "1" is detected. When a time corresponding to a predetermined maximum range-finding range has elapsed from when light was emitted, step S2204 is executed.

[0091] In step S2204, the signal processing unit 123 adds the measurement results obtained in step S2203 to the histograms of the respective pixels. The signal processing unit 123 does not add a measurement result to a histogram with respect to a pixel for which no measurement result has been obtained.

[0092] In step S2205, the signal processing unit 123 adds 1 to the value of a number-of-measurements counter i.

In step S2206, the signal processing unit 123 determines whether or not the value of the number-of-measurements counter i is larger than the present number of times N_{total}. The signal processing unit 123 executes step S2207 if it is determined that the value of the number-of-measurements counter i is larger than the preset number of times N_{total}, and executes 2202 if it is not determined that the value of the number-of-measurements counter i is larger than the preset number of times N_{total}.

[0093] In step S2207, the signal processing unit 123 removes counting results considered to be noise components, based on the histograms of the individual pixels, and executes step S2208.

In step S2208, the signal processing unit 123 averages measurement results that remained without being removed in step S2207, regarding the histograms of individual pixels, outputs the average value as a measured ToF, and ends a range-finding sequence once.

Noise Light Suppressing Effects Achieved by Using Pixels Having Different Sensitivities

[0094] Here, noise component removal processing in step S2207 and averaging in step S2208 will be described, and, after that, noise light reducing effects achieved by using pixels H and the pixels L having different sensitivities will be described.

[0095] FIG. 18A is a diagram showing an example of a histogram of results of TDC measurement performed the number of times N_{total} in a high-sensitivity pixel H. The horizontal axis indicates TDC measurement result (time period), and the vertical axis indicates frequency/the number of times of measurement. Note that the bin width of the TDC measurement result is set for convenience.

[0096] Since measurement results included in a section 2302 include a frequency peak/a peak in the number of times of measurement, it is conceivable that the measurement results are correct measurement results of time periods from when light was emitted until light was received. On the other hand, since measurement results included in a section 2304 are distributed irregularly and sparsely, it is conceivable that noise light such as ambient light that randomly occurs or a noise component caused by a dark count is included. Therefore, the measurement results included in the section 2304 are removed, and the average 2303 of only the measurement results included in the section 2302 is used as a range-finding result.

[0097] Similarly to FIG. 18A, FIG. 18B is also a diagram showing an example of a histogram of results of TDC measurement performed the number of times N_{total} in a high-sensitivity pixel H. The subject in FIG. 18B is the same as that in FIG. 18A, but FIG. 18B shows an example of a histogram of TDC measurement results obtained in a situation where there is more ambient light than that for the

measurements shown in FIG. 18A. TDC measurement ended when performed the number of times N_{total} due to noise light included in the section 2304, and no TDC measurement result for reflected light from the subject has been obtained.

[0098] FIG. 18C is a diagram showing an example of a histogram of results of TDC measurement performed the number of times N_{total} in a low-sensitivity pixel L in the same environment as that in FIG. 18B. Since the low-sensitivity pixel L has a lower sensitivity than the high-sensitivity pixel H, the number of times TDC measurement is performed on noise light is smaller. As a result, the number of measurement results included in the section 2302 is larger, and similarly to FIG. 18A, the average value of measurement results included in the section 2302 can be computed as a range-finding result. In this manner, the low-sensitivity pixel L is more resistant in a situation where there is great ambient light noise than the high-sensitivity pixel H.

[0099] Note that, here, a situation that can occur in an environment where there is great noise light has been described. However, a similar problem can also occur when an object that is a range-finding target is far away. This is because, when there is an object that is far away, a time period from light emission until when reflected light returns (that is to say, a time period during which noise light is detected) is long.

[0100] In the present embodiment, by using the high-sensitivity pixels H and the low-sensitivity pixels L, stable range finding can be performed with the influence of noise light being suppressed, even when the amount of noise light is large or range finding is performed on a distant object. Furthermore, the configuration of light receiving elements (SPADs) (light receiving area and the thickness of light-receiving part), and a voltage that is applied to the light receiving elements are common to the high-sensitivity pixels H and the low-sensitivity pixels L. For this reason, variation between a range-finding result obtained in a high-sensitivity

pixel H and a range-finding result obtained in a low-sensitivity pixel L is small, and an accurate range-finding result is obtained.

HDR Driving Method

[0101] Next, HDR driving of a high-sensitivity pixel H and a low-sensitivity pixel L will be described with reference to FIGS. 18D and 18E. FIG. 18D shows an example of a histogram of measurement results for a high-sensitivity pixel H, and FIG. 18E shows an example of a histogram of measurement results for a low-sensitivity pixel L adjacent to the high-sensitivity pixel H in FIG. 18D.

[0102] The light-emitting period of the light-emitting element 211 corresponding to the high-sensitivity pixel H is denoted by 2602, and the light-emitting period of the light-emitting element 211 corresponding to the low-sensitivity pixel L is denoted by 2702. The light-emitting period 2702 is four times the light-emitting period 2602. For this reason, during the same time period, the number of times range-finding can be performed for the high-sensitivity pixel H is four times larger than the number of times range-finding can be performed for the low-sensitivity pixel L. It is highly likely that the number of range-finding results for the high-sensitivity pixel H that are averaged will be larger than for the low-sensitivity pixel L, and measurement for the pixel H having a favorable sensitivity is performed by the high resolution TDC 1501, and thus the range-finding accuracy in a space corresponding to the high-sensitivity pixel H is higher than the range-finding accuracy in a space corresponding to the low-sensitivity pixel L.

[0103] When an object that is a range-finding target is at a long distance, a ToF is long, and thus it is highly likely that noise light will be measured. The light-emitting elements 211 corresponding to the low-sensitivity pixels L that have a high noise light suppressing effect do not perform next light emission until reflected light is detected. On the other hand, the light-emitting elements 211

corresponding to the high-sensitivity pixels H that have a low noise light suppressing effect perform next light emission before reflected light is detected. Accordingly, it is possible to shorten a time period from when the TDC starts measurement until when reflected light is detected, and to suppress the probability of noise light being measured during the time period from when light is emitted until when reflected light arrives, and, even in an environment in which noise light is significant, accurate time-period measurement can be performed for the high-sensitivity pixels H.

[0104] The signal processing unit 123 applies offset correction that is based on measurement results obtained for the adjacent low-sensitivity pixel L, to measurement results obtained for the high-sensitivity pixel H. Offset correction is to add a value obtained by multiplying the light-emitting period (measurement period) 2602 of the high-sensitivity pixel H by a constant, to a measurement result 2611 for the high-sensitivity pixel H, based on a measurement result 2711 for the adjacent low-sensitivity pixel L.

[0105] Since the measurement result 2711 is obtained for the low-sensitivity pixel L adjacent to the high-sensitivity pixel H, it is highly likely that a time period until when reflected light of emitted light arrives in the high-sensitivity pixel H is close to the measurement result 2711. In the examples in FIGS. 18D and 18E, the measurement result 2711 for the low-sensitivity pixel L is higher than twice the light-emitting period 2602 for the high-sensitivity pixel H and is smaller than three times. For this reason, in offset correction, the signal processing unit 123 adds a time period that is twice the light-emitting period 2602, to the measurement result 2611 for the high-sensitivity pixel H.

[0106] Note that an offset correction amount may be determined based on measurement results obtained for two or more low-sensitivity pixels L adjacent to a high-sensitivity pixel H that is a correction target. The offset correction

amount may be determined based on measurement results obtained for four or two low-sensitivity pixels L adjacent to the high-sensitivity pixel H in the horizontal direction and/or the vertical direction, for example.

[0107] In addition, a configuration may also be adopted in which an image capturing unit that captures an image in the light-projection range of the light-projection unit 110 is provided, and low-sensitivity pixels L to be used for determining an offset correction amount is specified using a captured image. The signal processing unit 123 specifies, based on a captured image, one or more adjacent low-sensitivity pixels L in which range finding is considered to be being performed for the same subject as the high-sensitivity pixel H that is a correction target, for example. The signal processing unit 123 may then determine an offset correction amount (or a coefficient by which the light-emitting period of the high-sensitivity pixel H is to be multiplied) using measurement results obtained for the specified low-sensitivity pixels L.

[0108] According to the present embodiment, by using light receiving elements having different sensitivities, it is possible to realize a light-receiving device having a wide dynamic range. In addition, the sensitivities of the light receiving elements differ due to optical components added to the light receiving elements. For this reason, it is possible to use light receiving elements having the same configuration, and it is advantageous from viewpoint of ease of manufacturing and suppression of variation in characteristics. In addition, lower resolution of time measurement is set for the low-sensitivity pixels than high-sensitivity pixels, and thereby it is possible to efficiently reduce the circuit scale and power consumption while supressing a decrease in the range-finding accuracy.

Second Embodiment

[0109] Next, a second embodiment of the present invention will be described.

A range finding apparatus according to the present embodiment uses pulse light of a plurality of wavelengths to perform range finding. FIGS. 19A to 19C are diagrams showing a configuration example of the light-projection unit 110 according to the present embodiment, and constituent elements common to the first embodiment are given the same reference numerals as those in FIG. 2. FIG. 19A is a side view showing a configuration example of a collimator lens array 2820 that constitutes the light source unit 111, and FIG. 19B is a side view showing a configuration example of a light source array 2810 that constitutes the light source unit 111.

[0110] In the present embodiment, the light source array 2810 includes first light-emitting elements 2811 that emit light of a first wavelength, and second light-emitting elements 2812 that emit light of a second wavelength that is longer than the first wavelength. Therefore, the light source unit 111 can emit light of the first wavelength and light of the second wavelength concurrently. Note that one type of light-emitting elements that can switch the light emission wavelength between the first wavelength and the second wavelength may be used. In this case, the following description may be read assuming that a light-emitting element controlled to emit light of the first wavelength is regarded as a first light-emitting element, and a light-emitting element controlled to emit light of the second wavelength is regarded as a second light-emitting element. Here, the first wavelength and the second wavelength are central wavelengths of emitted light.

[0111] Here, both the first light-emitting elements 2811 and the second light-emitting elements 2812 are VCSELs, and are arranged two—dimensionally so as to be alternately aligned in the row direction and the column direction. In addition, a central wavelength $\lambda 1$ of each first light-emitting element 2811 is 850 nm, and a central wavelength $\lambda 2$ of each second light-emitting element 2812 is 940 nm. It should be noted that the central wavelengths $\lambda 1$ and $\lambda 2$ are merely

exemplary. In addition, three or more types of light-emitting elements having different light emission wavelengths may also be used.

[0112] As shown in FIG. 19A, in the collimator lens array 2820, first collimator lenses 2821 corresponding to the first light-emitting elements 2811 and second collimator lenses 2822 corresponding to the second light-emitting elements 2812 are two-dimensionally arranged. Therefore, the arrangement of the first collimator lenses 2821 and the second collimator lenses 2822 corresponds to the arrangement of the first light-emitting elements 2811 and the second light-emitting elements 2812 in the light source array 2810. The first collimator lenses 2821 and the second collimator lenses 2822 may have a shape and/or a material suitable for the wavelengths $\lambda 1$ and $\lambda 2$, respectively. In addition, the first collimator lenses 2821 and the second collimator lenses 2822 may be the same as long as there is no disadvantage in terms of performance.

[0113] FIG. 19C is a vertical cross-sectional view showing an arrangement example of the light-source-unit driving unit 112, the light source unit 111, and the light projecting lens 131. The configuration in the present embodiment is the same as the first embodiment except that there are two types of light-emitting elements and two types of collimator lenses.

[0114] Similarly to FIG. 3A, FIG. 20 is a diagram showing an example of a light-projection pattern that is formed by the light-projection unit 110 according to the present embodiment. A light-projection pattern formed by 3 rows × 3 columns of light-emitting elements of the light source array 2810, on a plane that directly faces a light emission plane of the light-projection unit 110 and that is positioned at a predetermined distance. 2910 is. Among nine light-projection areas, light-projection areas 2911 are light-projection areas formed by first light-emitting elements 2811, and light-projection areas 2912 are light-projection areas formed by second light-emitting elements 2812. The light-projection areas

represent, on the plane 2910, regions whose diameter is about the full width at half maximum (FWHM) of intensity distribution of light from the individual light-emitting elements.

[0115] FIG. 21 is a vertical cross-sectional view schematically showing a configuration example of the light-receiving part 121 of the range finding apparatus 100 according to the present embodiment. In the present embodiment, the light-receiving part 121 includes first pixels 3011 having a passband of the central wavelength λ1 and second pixels 3012 having a passband of the central wavelength λ2. The arrangement of the first pixels 3011 and the second pixels 3012 in the light-receiving part 121 corresponds to the arrangement of the first light-emitting elements 2811 and the second light-emitting elements 2812 in the light source array 2810. Therefore, in the present embodiment, the first pixels 3011 and the second pixels 3012 are two-dimensionally arranged so as to be alternately aligned in the row direction and the column direction.

[0116] As described with reference to FIG. 7, reference numeral 1005 indicates a semiconductor layer of the light receiving element board 510, reference numeral 1006 indicates a wiring layer of the light receiving element board 510, and reference numeral 1007 indicates a wiring layer of the logic board 520. The passbands of the first pixels 3011 and the second pixels 3012 can be realized by optical bandpass filters that use multilayered film interference mirrors such as those described with reference to FIG. 5B. Therefore, an optical bandpass filter in which the central wavelength of the passband is λ1 is provided in the first pixels 3011,and an optical bandpass filter in which the central wavelength of the passband is λ2 is provided in the second pixels 3012. Note that, in the present embodiment, the full widths at half maximum of the first optical bandpass filter and the second optical bandpass filter do not need to be made different in a proactive manner. In addition, the structures of both the first pixels 3011 and the

second pixels 3012 may be the same as the structure of a pixel H.

[0117] FIG. 22 is a diagram schematically showing range finding that uses light of two types of wavelengths, using the light source array 2810 and the light-receiving part 121 of the range finding apparatus 100 according to the present embodiment. For convenience, in FIG. 22, light from the light source array 2810 passes through an object and is incident on the light-receiving part 121. However, in actuality, light from the light source array 2810 is reflected by an object and is incident on the light-receiving part 121. In addition, illustration of the light projecting lens 131 and the light-receiving lens 132 is omitted.

[0118] A light flux 3111 of the central wavelength λ1 emitted by a first light-emitting element 2811 is reflected by an object, and partial reflection light 3121 passes through a first bandpass filter 3021, and is incident on the light-receiving region 1001 of the first pixel 3011 (FIG. 7). In addition, a light flux 3112 of the central wavelength λ2 emitted by a second light-emitting element 2812 is reflected by an object, and partial reflection light 3122 passes through a second bandpass filter 3022, and is incident on the light-receiving region 1001 of the second pixel 3012.

[0119] Next, description will be given on how the TDC array unit 122 uses output of the first pixels 3011 and the second pixels 3012, in a range finding operation that is performed by the range finding apparatus 100 according to the present embodiment that includes the light source unit 111 and the light-receiving part 121 having the above-described configuration.

[0120] First, the relative difference in characteristics due to the difference between the wavelengths λ1 (850 nm) and λ2 (940 nm) will be described. The length of penetration of light of 850 nm into Si is relatively short for far-red light, and it is highly likely that light of 850 nm will be subject to photoelectrical conversion in the light-receiving region 1001. That is to say, the light-receiving

sensitivity thereof is high.

[0121] On the other hand, the solar-spectrum of light of 940 nm is relatively small, and thus the probability that light of 940 nm is included in ambient light is low, and light of 940 nm is unlikely to be affected by noise light, and is suitable when the intensity of ambient light is high. On the other hand, a significant portion of light of 940 nm is absorbed in moisture, and thus, in an environment where the humidity is high such as when it is raining, the S/N ratio is likely to decrease.

[0122] Due to such a difference in characteristics, when the intensity of ambient light is low (for example, inside) or in an environment where the humidity is high such as when it is raining, an accurate range finding result is more easily obtained by performing range finding with light of $\lambda 1$ (850 nm) whose wavelength is short. On the other hand, when the intensity of ambient light is high (for example, when the weather is sunny), an accurate range finding result is easily obtained by performing range finding with light of $\lambda 2$ (940 nm) whose wavelength is long. Therefore, determination can be made such that, when a condition on which the influence of ambient light is considered to be great is met, range finding is performed using the second pixels 3012, and, if the condition is not met, range finding is performed using the first pixels 3011.

[0123] It should be noted that, when only one type of pixels is used, the space resolution of distance information decreases. For this reason, when the space resolution of distance information is prioritized over the range finding accuracy, range finding may be performed using both the first pixels 3011 and the second pixels 3012.

[0124] Information required for the above determination (inside/outside, ambient light intensity, humidity, weather, and the like) can be obtained from a device that uses the range finding apparatus. As a matter of fact, the range finding apparatus

may be provided with a sensor that detects such information, a communication circuit for obtaining such information from an external apparatus, or the like. In addition, such information may be detected from an image captured in an area that includes an area for performing range finding. In addition, a configuration may be adopted in which a captured image is transmitted to an external apparatus, and information is obtained from the external apparatus. Alternatively, a configuration may also be adopted in which positional information of the range finding apparatus is provided to an external apparatus, and such information is obtained. In addition, the user may input such information.

[0125] The overall control unit 140 can execute the flowchart shown in FIG. 23, for example. When a wavelength of light (type of pixels) that is used for measurement is determined, the overall control unit 140 notifies the measurement unit 120 of the determined wavelength. The measurement control unit 124 controls the TDC array unit 122 and the signal processing unit 123 so as to obtain distance information based on a measurement result obtained by the TDC array unit 122 with respect to pixels that are based on the notification, from among output of the first pixels 3011 and output of the second pixels 3012 of the light-receiving part 121.

[0126] Note that light emission control of the light source unit 111 and drive control of the light-source-unit drive unit 112 at the time of range finding are performed by the light source control unit 113 in accordance with predetermined settings, for example. In addition, operations performed by the TDC array unit 122 and operations performed by the signal processing unit 123 at the time of range finding have been described in the first embodiment.

[0127] Therefore, only an operation of determining a wavelength of light that is used for range finding will be described below. Note that this determination operation can be executed, for example, when range finding is started. A

wavelength that is to be used for range finding is determined when the range finding sequence described with reference to FIG. 17 is started, and the determined wavelength is not changed during a period during which the range finding sequence is performed once (measurement of the preset number of times N_{total}), for example. An operation of determining a wavelength of light may be executed at another timing.

[0128] In step S3211, the overall control unit 140 determines whether the operation mode set in the range finding apparatus 100 is a high resolution mode or a high accuracy mode. An operation mode can be set by the user, for example, and setting values are stored in the ROM of the overall control unit 140. Note that an operation mode may be set from an external apparatus such as an electronic device that includes the range finding apparatus 100. The high resolution mode is an operation mode in which the space resolution of range finding is prioritized, and the high accuracy mode is an operation mode in which the range finding accuracy is prioritized.

[0129] If the high resolution mode is set, the overall control unit 140 executes step S3212. In step S3212, the overall control unit 140 determines that two types of wavelengths, namely both the wavelength $\lambda 1$ (850 nm) and the wavelength $\lambda 2$ (940 nm) are to be used, and ends wavelength determination processing.

[0130] On the other hand, if the high accuracy mode is set, the overall control unit 140 executes step S3213. In step S3213, the overall control unit 140 determines whether the range finding environment is inside or outside. The overall control unit 140 can perform the determination based on a result of the signal processing unit 123 analyzing output of a sensor of the range finding apparatus 100 or an external apparatus that detects a type of ambient light or an image captured in the range finding environment, for example. Another method may be used for the determination.

[0131] The overall control unit 140 executes step S3214 if it is determined that the range finding environment is inside, and executes step S3215 if it is determined that the range finding environment is outside.

In step S3214, the overall control unit 140 determines that the wavelength λ1 (850 nm) with which measurement can be performed with a high sensitivity is to be used, and ends wavelength determination processing.

[0132] In step S3215, the overall control unit 140 determines whether the current time is daytime (morning or noon) or nighttime based on time and date obtained from an incorporated clock or an external apparatus, for example. The overall control unit 140 stores, in the ROM, rough times of sunrise and sunset for each week, such that determination can be made as to whether the current time is daytime or night time, based on obtained time and date, for example. If it is possible to obtain positional information of the range finding apparatus, positional information may be taken into consideration.

[0133] The overall control unit 140 executes step S3216 if it is determined that the current time is daytime, and executes step S3219 if it is determined that the current time is nighttime.

In step S3216, the overall control unit 140 determines the current weather is rainy or not rainy. Here, the user selects the current weather, but the overall control unit 140 may perform the determination by using output of a pneumatic sensor and/or a humidity sensor, or by obtaining information from an external apparatus.

[0134] If a weather is not selected by the user, or the overall control unit 140 cannot determine a weather, the overall control unit 140 executes step S3217. In step S3217, the overall control unit 140 determines that two types of wavelengths, namely both the wavelengths λ1 (850 nm) and λ2 (940 nm) are to be used, and ends wavelength determination processing. Note that, unlike a case of the high

resolution mode, the signal processing unit 123 is controlled such that results obtained by performing measurement using the two wavelengths are evaluated, and one determined as resulting in a higher range finding accuracy is selected.

[0135] If, in step S3216, the user designates a weather other than a rainy weather or the overall control unit 140 determines that the current weather is not rainy, the overall control unit 140 executes step S3218. In step S3218, the overall control unit 140 determines that λ2 (940 nm) that is tolerant to ambient light is to be used, and ends wavelength determination processing.

[0136] If, in step S3216, the user designates a rainy weather or the overall control unit 140 determines that the current weather is rainy, the overall control unit 140 executes step S3219. In step S3219, the overall control unit 140 determines that λ1 (850 nm) that is less likely to be absorbed in water than 940 nm is to be used, and ends wavelength determination processing.

[0137] Note that the determination condition in wavelength determination processing described herein is exemplary, and another determination condition may be used, or a plurality of conditions may be combined for determination. In addition, the determination condition may be changed in accordance with a light emission wavelength.

[0138] In addition, a case is also conceivable in which the range finding environment is both outside and inside, and the like, and thus a configuration may be adopted in which range finding is basically performed using both the wavelengths, and, based on evaluation of range finding results. a result of measurement that uses one wavelength is selected for each partial region of the range finding area. Evaluation of range finding results can be performed using a known method. As an example, one or more of a state where the peak frequency in a histogram is high, a state where the number of peaks of a certain value or higher is smaller than two, and a state where the full width at half maximum of a

frequency group that includes a peak frequency is narrow (the skirts of the peak is narrow) can be used as an index indicating that the range finding accuracy is high.

[0139] According to the present embodiment, range finding that uses light of a plurality of wavelengths can be performed using a pair of light source unit and light projecting lens and one light-receiving part, and that is advantageous for decreasing the size of the range finding apparatus and reducing the cost. In addition, range finding operations that use light of a plurality of wavelengths are performed in parallel, and one of the wavelengths that is determined as resulting in an accurate result is used, whereby it is possible to obtain an appropriate range finding result in accordance with a change in the situation. In addition, when the space resolution of range finding is necessary, it is possible to use all of the range finding results for which light of a plurality of wavelengths is used. In this case, the range finding accuracy can also be improved by correcting, as necessary, a result of range finding performed using a wavelength that is disadvantageous in terms of the S/N ratio, based on a result of range finding performed using another wavelength.

Variation

[0140] In the present embodiment, for ease of description and understanding, a configuration has been described in which all of the pixels of the light-receiving part 121 are high-sensitivity pixels H according to the first embodiment. However, similarly to the first embodiment, it is also possible to use high-sensitivity pixels H and low-sensitivity pixels L. Specifically, the light-receiving part 121 can be provided with high-sensitivity pixels H and low-sensitivity pixels L that have a first bandpass filter for transmitting light of the wavelength $\lambda 1$, and high-sensitivity pixels H and low-sensitivity pixels L that have a second bandpass filter for transmitting light of the wavelength $\lambda 2$. Also in this case, the full width

at half maximum of the bandpass filter provided to the low-sensitivity pixels L can be made narrower than the full width at half maximum of the bandpass filter provided to the high-sensitivity pixels H.

[0141] By providing high-sensitivity pixels H and low-sensitivity pixels L for each type of bandpass filter, the dynamic range of the light-receiving part 121 can be increased for each wavelength of light that is used for range finding. When pixels having different sensitivities are provided, the influence of noise light can be reduced further by performing light emission control in accordance with the above HDR driving method.

[0142] In addition, in accordance with a range finding environment, measurement may be performed for only one type of pixels out of high-sensitivity pixels H and low-sensitivity pixels L, or only range finding results obtained for one type of pixels out of the high-sensitivity pixel H and the low-sensitivity pixel L may be used. In an environment where the wavelength λ1 (850 nm) that is shorter of the two is used, for example, measurement may be performed for only the low-sensitivity pixels L, or a configuration may also be adopted in which measurement is performed for the high-sensitivity pixels H and the low-sensitivity pixels L, and only measurement results obtained for the low-sensitivity pixels L are used.

[0143] In addition, in an environment where λ2 (940 nm) is used, measurement may be performed for only the high-sensitivity pixels H, or a configuration may also be adopted in which measurement is performed for the high-sensitivity pixels H and the low-sensitivity pixels L, and only measurement results obtained for the high-sensitivity pixels H are used. When measurement is performed for only one of type of pixels out of the high-sensitivity pixels H and the low-sensitivity pixels L, the power consumption can be suppressed. In addition, by using range finding results obtained for pixels having a sensitivity that is more suitable for an

environment, the high measurement accuracy can be realized using an easy technique.

Other Embodiment

[0144] The above-described range finding apparatus can be mounted in any electronic device that includes processing means for executing predetermined processing using distance information. Examples of such an electronic device includes image capture apparatuses, computer devices (personal computers, tablet computers, media players, PDAs, etc.), mobile phones, smartphones, game machines, robots, drones, and vehicles. These are exemplary, and the range finding apparatus according to the present invention can also be mounted in other electronic devices.

[0145] The present invention can be realized by performing processing for supplying a program for realizing one or more functions of the above embodiments to a system or an apparatus via a network or a storage medium, and causing one or more processors in the computer of the system or the apparatus to read out and execute the program. The present invention can also be realized by a circuit (for example, an ASIC) for realizing one or more functions.

[0146] The present invention is not limited to the content of the above embodiments and various changes and modifications can be made within the spirit and scope of the present invention. Therefore, the following claims are attached in order to make the scope of the present invention publicly available.

[0147] This application claims priority from Japanese Patent Application No. 2021-74415 filed April 26, 2021, which is hereby incorporated by reference herein.

CLAIMS

1. A range finding apparatus characterized by comprising:

a light source unit capable of concurrently emitting light of a first wavelength and light of a second wavelength that is longer than the first wavelength;

a light-receiving part that includes a pixel array in which pixels are two-dimensionally arranged, and that detects incident of light on the pixels; and

measuring means for detecting time periods from when range finding is started until when incident of light on the pixels is detected, and computing distance information based on the detected time periods,

wherein a first pixel configured to receive light of the first wavelength and a second pixel configured to receive light of the second wavelength are two-dimensionally arranged in the pixel array.

2. The range finding apparatus according to claim 1, characterized further comprising:

determination means for determining whether the first pixel or the second pixel is to be used for computing the distance information,

wherein the measuring means computes the distance information based on time periods detected for the pixel determined by the determination means.

3. The range finding apparatus according to claim 2, characterized in that

the determination means determines the pixel to be used for computing the distance information, in accordance with an operation mode set for the range finding apparatus.

4. The range finding apparatus according to claim 3, characterized in that

the determination means determines that, when the range finding apparatus is set to a high resolution mode, the first pixel and the second pixel are to be used for computing the distance information.

5. The range finding apparatus according to claim 3 or 4, characterized in that

when the range finding apparatus is not set to a high resolution mode, the determination means determines that the second pixel is to be used for computing the distance information if a predetermined condition on which an influence of ambient light is considered to be great is met, and determines that the first pixel is to be used for computing the distance information if the condition is not met.

6. The range finding apparatus according to claim 5, characterized in that

the condition is that the range finding apparatus is outside and it is not raining.

7. The range finding apparatus according to claim 1 or 2, characterized in that

the measuring means computes the distance information based on a time period detected for the first pixel or time periods detected for the second pixel.

8. The range finding apparatus according to claim 7, characterized in that

the measuring means selects the time period detected for the first pixel or the time period detected for the second pixel, based on histogram of the time periods detected for the first pixel and histogram of the time periods detected for the second pixel, and uses the selected time periods for computing the distance information.

9. The range finding apparatus according to any one of claims 1 to 8, characterized in that

the light source unit includes a light source array in which a first light-emitting element that emits light of the first wavelength and a second light-emitting element that emits light of the second wavelength are two-dimensionally arranged.

10. The range finding apparatus according to claim 9, characterized in that

an arrangement of the first pixel and the second pixel in the pixel array corresponds to an arrangement of the first light-emitting element and the second light-emitting element in the light source array.

11. The range finding apparatus according to any one of claims 1 to 10, characterized in that

a first optical bandpass filter that transmits light of the first wavelength is provided in the first pixel, and a second optical bandpass filter that transmits light of the second wavelength is provided in the second pixel.

12. The range finding apparatus according to any one of claims 1 to 11, characterized in that

both the first pixel and the second pixel include high-sensitivity pixels having a first sensitivity and low-sensitivity pixels having a sensitivity that is lower than the first sensitivity.

13. An electronic device characterized by comprising:

the range finding apparatus according to any one of claims 1 to 12; and

processing means for executing predetermined processing using distance information that is obtained by the range finding apparatus.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/014825

A. CLASSIFICATION OF SUBJECT MATTER

G01S 7/4863(2020.01)i
FI: G01S7/4863

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)

G01S7/48-G01S7/51; G01S17/00-G01S17/95; G01C3/06-G01C3/08; G01B11/00-G01B11/30

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2019-78748 A (SONY SEMICONDUCTOR SOLUTIONS CORPORATION) 23 May 2019 (2019-05-23) paragraphs [0014]-[0067], [0110]-[0137], fig. 1-10, 22-25	1-8, 11-13
Y	paragraphs [0014]-[0067], [0110]-[0137], fig. 1-10, 22-25	9-10
Y	US 10983197 B1 (HESAI TECHNOLOGY CO., LTD.) 20 April 2021 (2021-04-20) column 9, lines 15-58, column 12, lines 17-35, fig. 2	9-10
A	JP 2019-47486 A (CANON KK) 22 March 2019 (2019-03-22) entire text, all drawings	1-13
A	US 2018/0160103 A1 (SAMSUNG ELECTRONICS CO., LTD.) 07 June 2018 (2018-06-07) entire text, all drawings	1-13
A	US 2020/0057151 A1 (SENSE PHOTONICS INC.) 20 February 2020 (2020-02-20) entire text, all drawings	1-13

☐ 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
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"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	Date of mailing of the international search report
02 June 2022	**21 June 2022**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/014825

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