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(54) **LIGHT SCANNING DEVICE AND IMAGE FORMING APPARATUS**

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(57) **ABSTRACT**

A light scanning device includes a mirror device that includes a movable mirror which swings about at least one axis, and a package that has at least two or more light transmission surfaces not constituting the same plane and accommodates the mirror device, in which out of the two or more light transmission surfaces of the package, one light transmission surface is a light receiving surface for receiving an incidence ray on the movable mirror from an outside, and the other light transmission surface is a light extraction surface for extracting light reflected by the movable mirror to the outside.

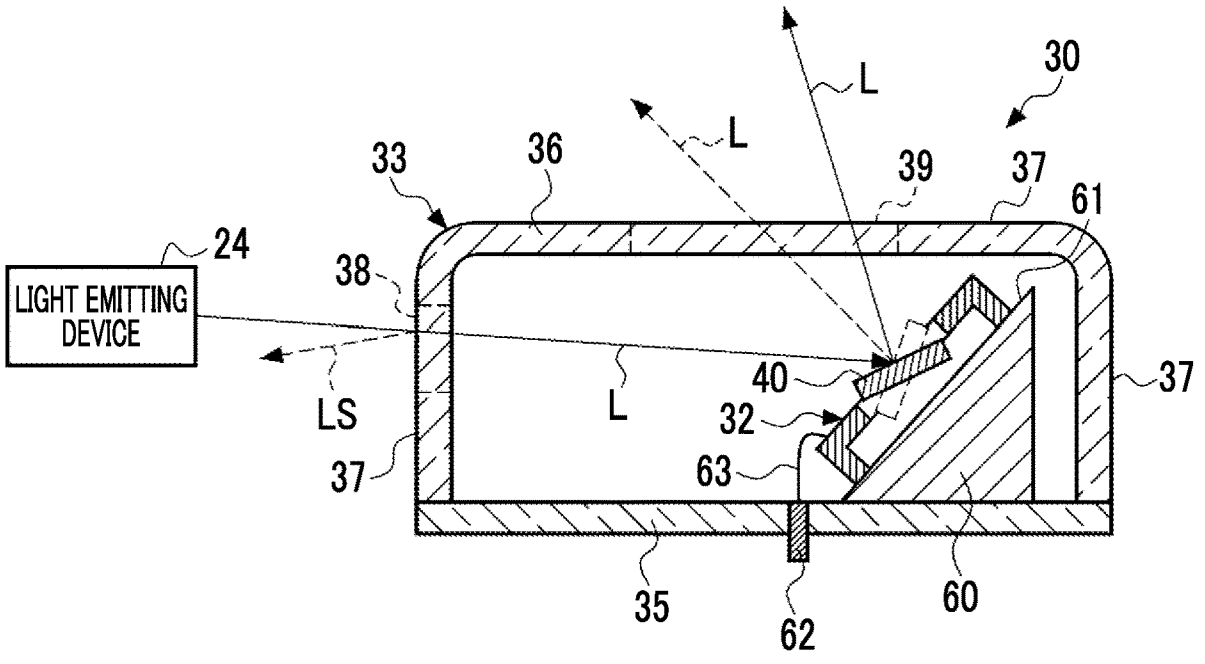


FIG. 1

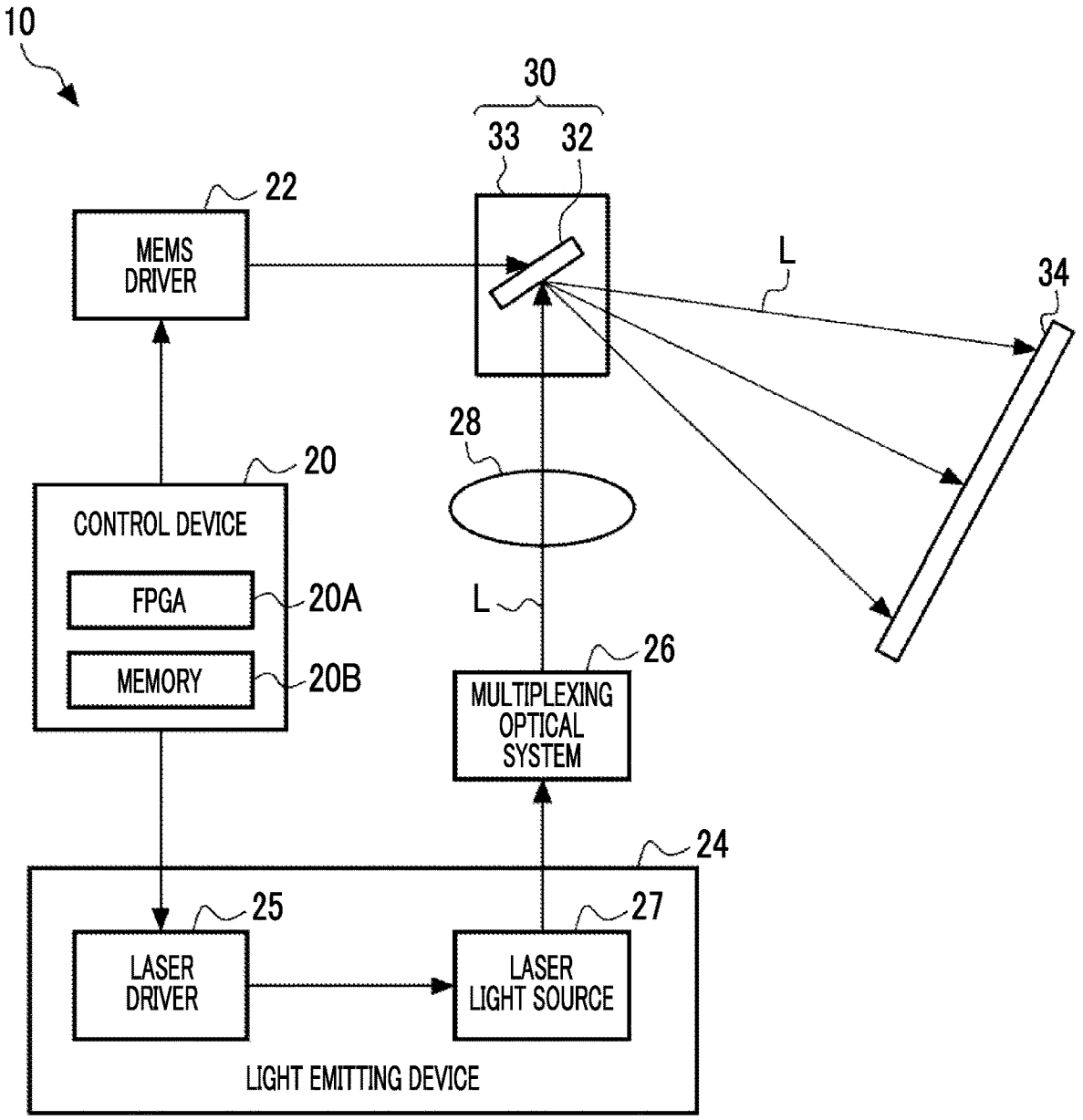

10
30
33
32
22
MEMS DRIVER
L
34
28
20
CONTROL DEVICE
FPGA
20A
MEMORY
20B
L
26
MULTIPLEXING OPTICAL SYSTEM
24
25
27
LASER DRIVER
LASER LIGHT SOURCE
LIGHT EMITTING DEVICE

FIG. 2

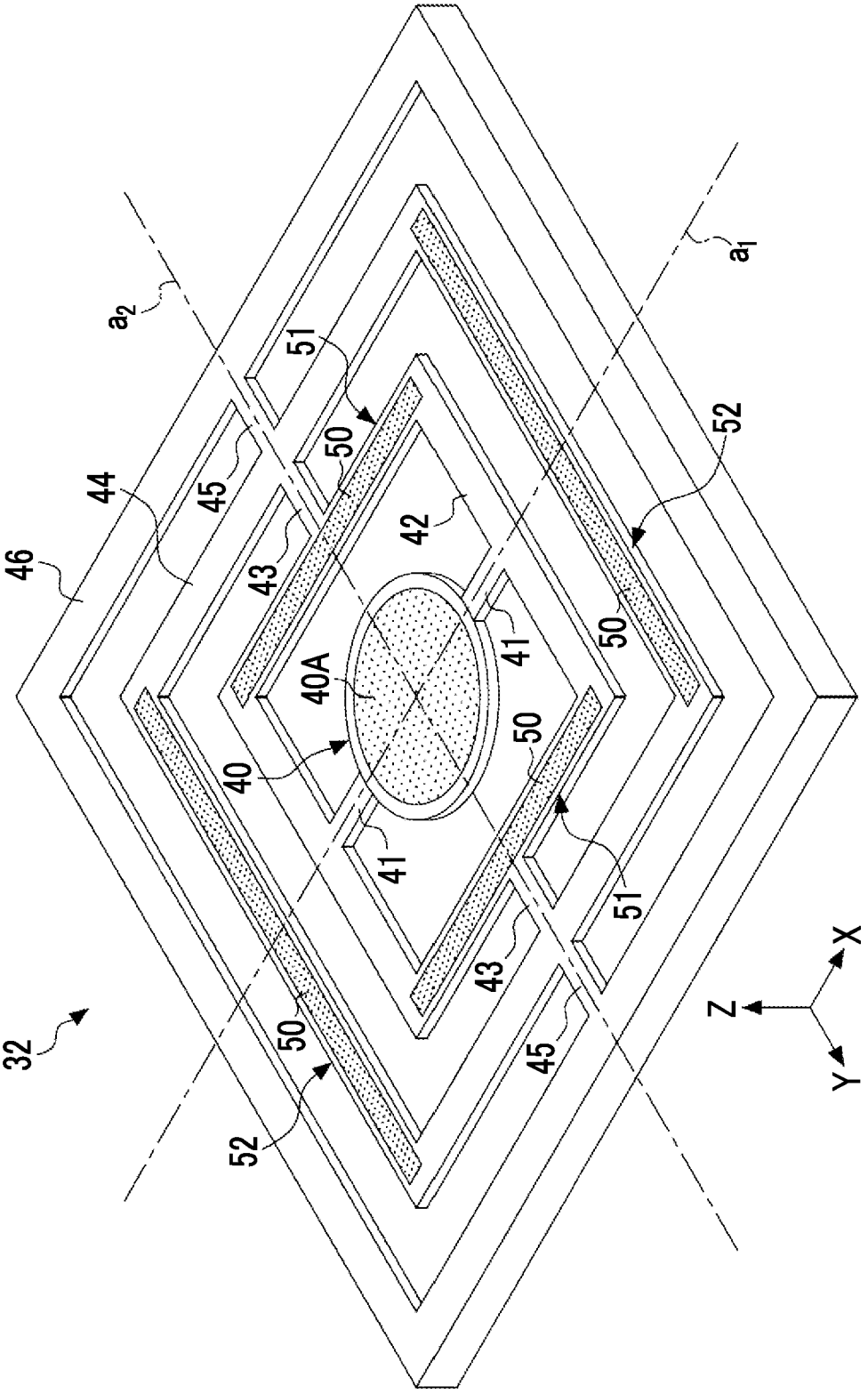


FIG. 3

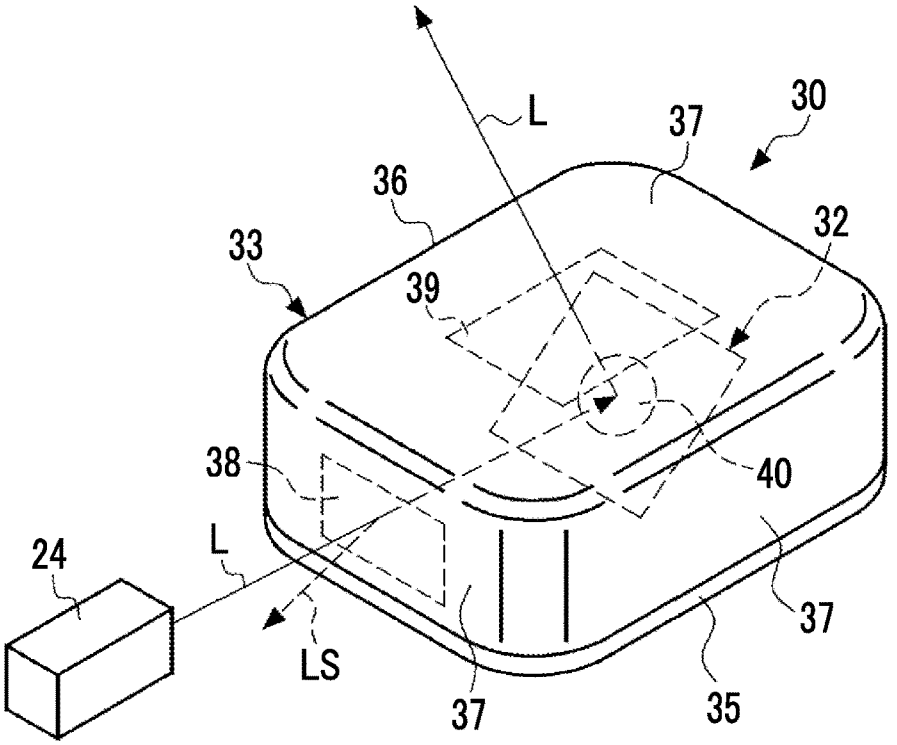

L
37
30
36
32
33
39
38
40
24
L
LS
37
37
35

FIG. 4

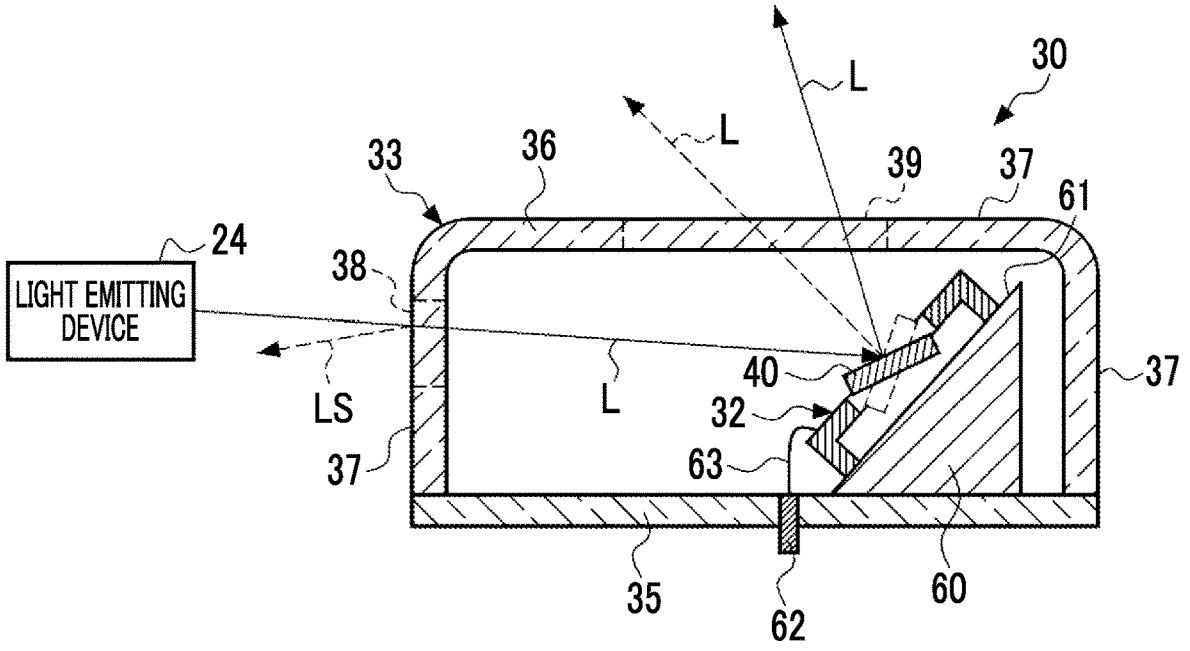

L
30
L
33
36
39
37
61
24
38
LIGHT EMITTING DEVICE
LS
L
40
37
32
37
63
35
62
60

FIG. 5

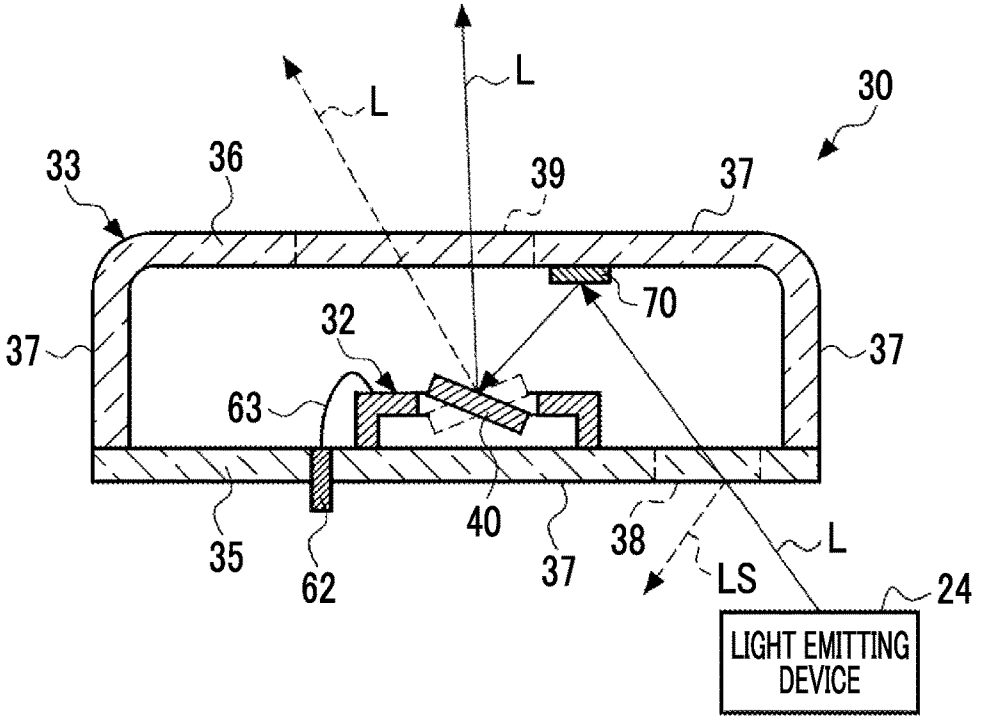

L
L
30
33
36
39
37
70
32
37
37
63
40
38
35
62
37
L
LS
24
LIGHT EMITTING DEVICE

FIG. 6

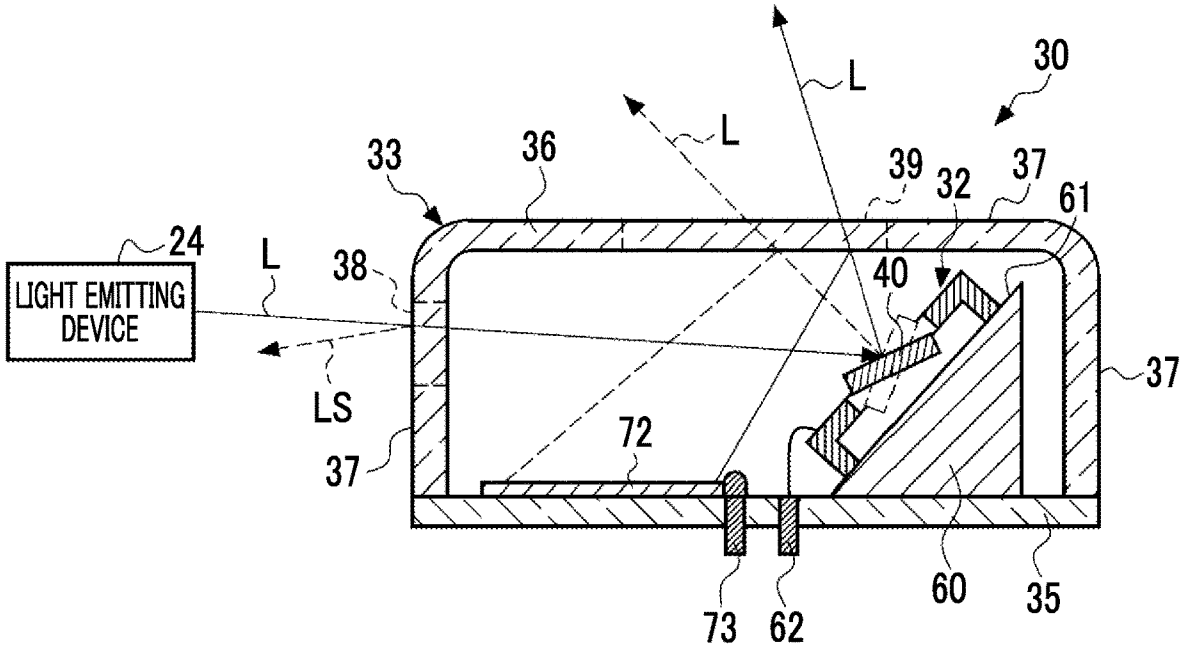

L
L
30
33
36
39
32
37
61
24
LIGHT EMITTING DEVICE
L
38
40
37
LS
72
37
60
35
73
62

FIG. 7

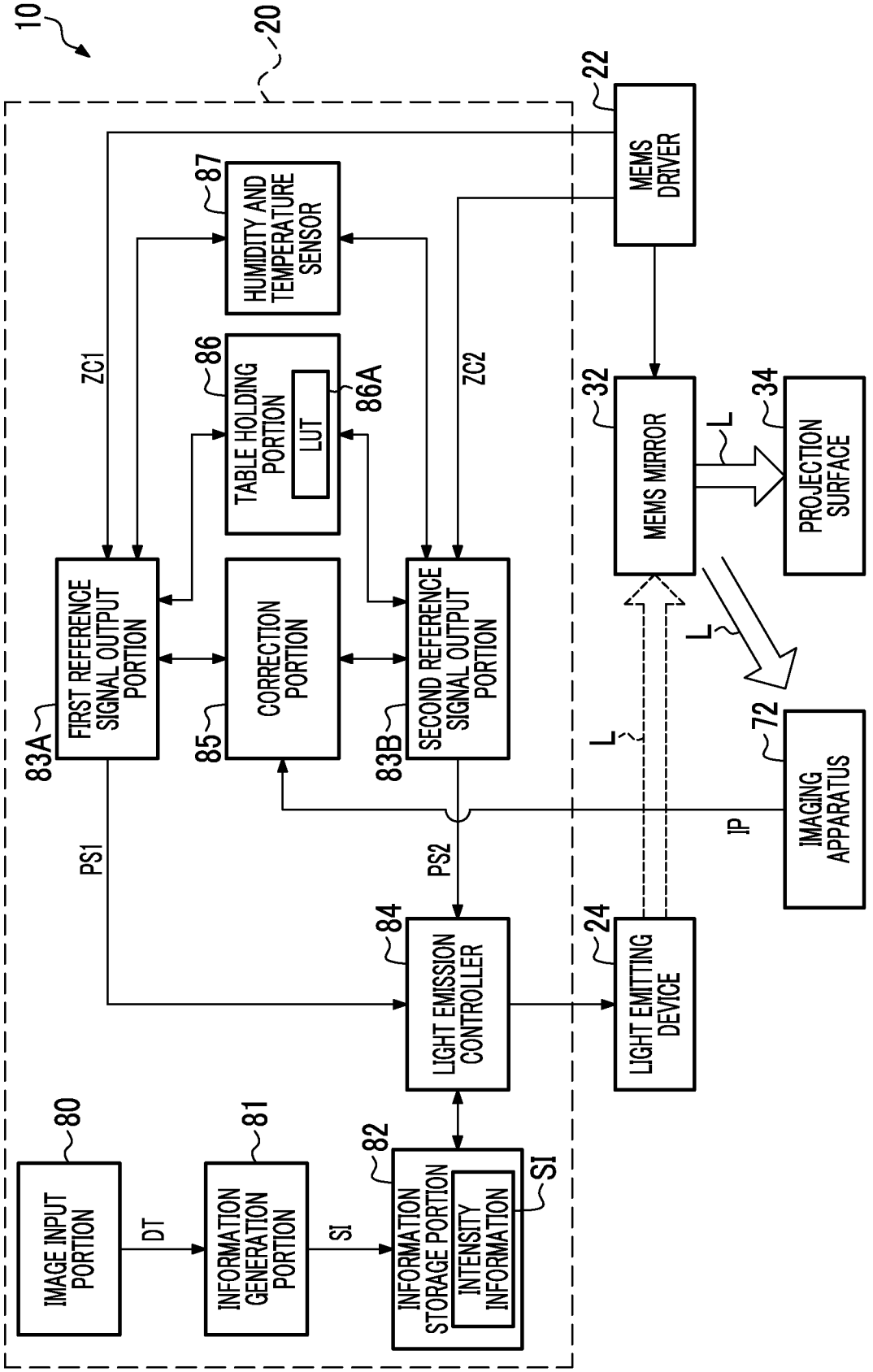

10
20
22
MEMS DRIVER
87
HUMIDITY AND TEMPERATURE SENSOR
86
TABLE HOLDING PORTION
LUT
86A
ZC1
ZC2
32
MEMS MIRROR
L
34
PROJECTION SURFACE
FIRST REFERENCE SIGNAL OUTPUT PORTION
CORRECTION PORTION
SECOND REFERENCE SIGNAL OUTPUT PORTION
83A
85
83B
L
72
IMAGING APPARATUS
IP
PS1
PS2
84
LIGHT EMISSION CONTROLLER
24
LIGHT EMITTING DEVICE
80
IMAGE INPUT PORTION
DT
81
INFORMATION GENERATION PORTION
SI
82
INFORMATION STORAGE PORTION
INTENSITY INFORMATION
SI

FIG. 8

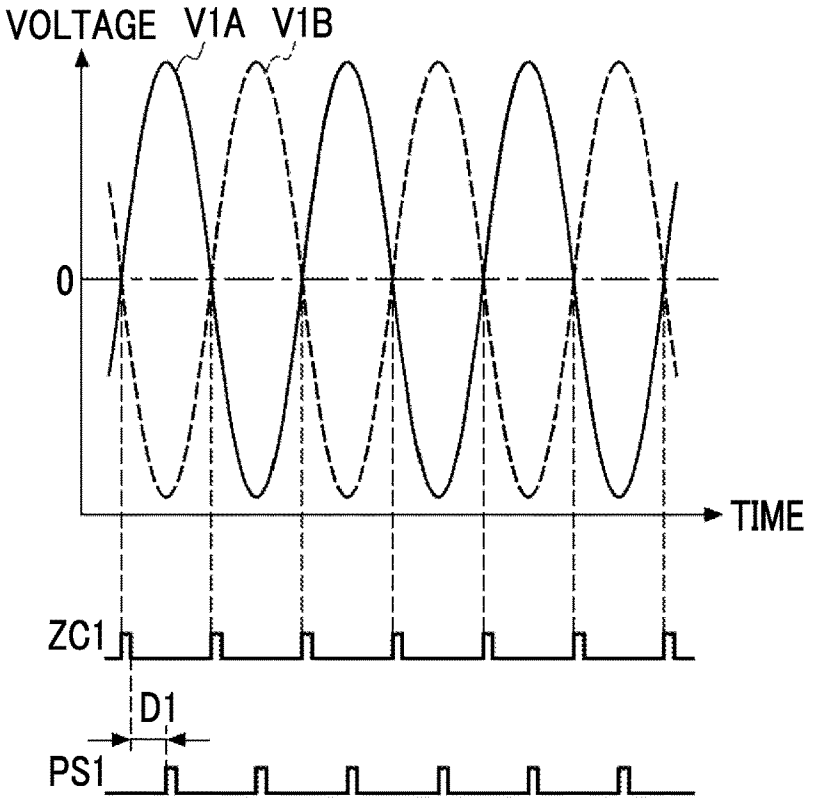

VOLTAGE
V1A
V1B
0
TIME
ZC1
D1
PS1

FIG. 9

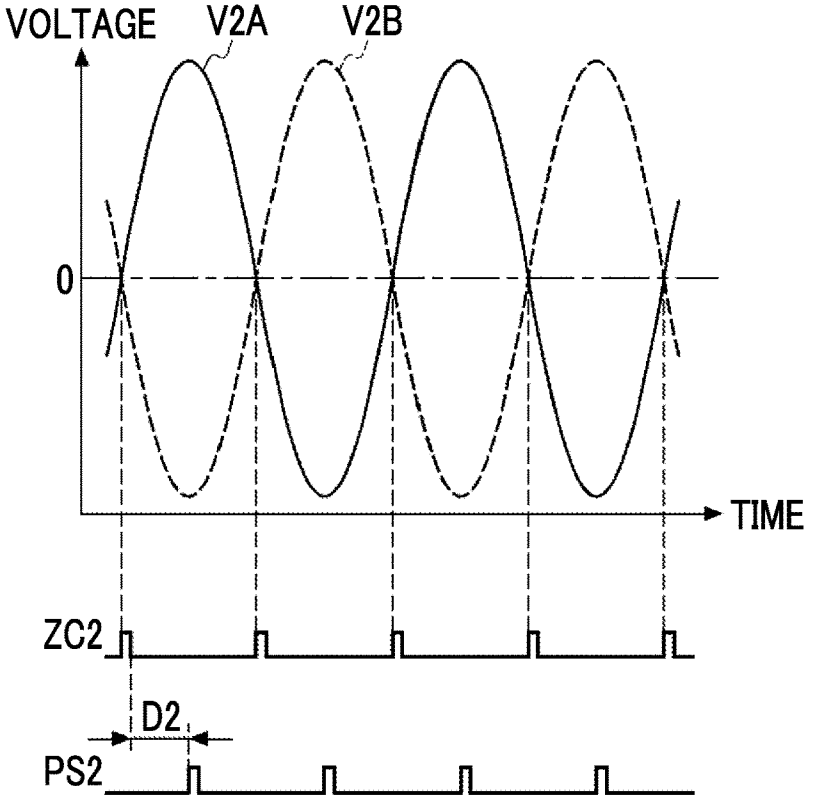

VOLTAGE
V2A
V2B
0
TIME
ZC2
D2
PS2

FIG. 10

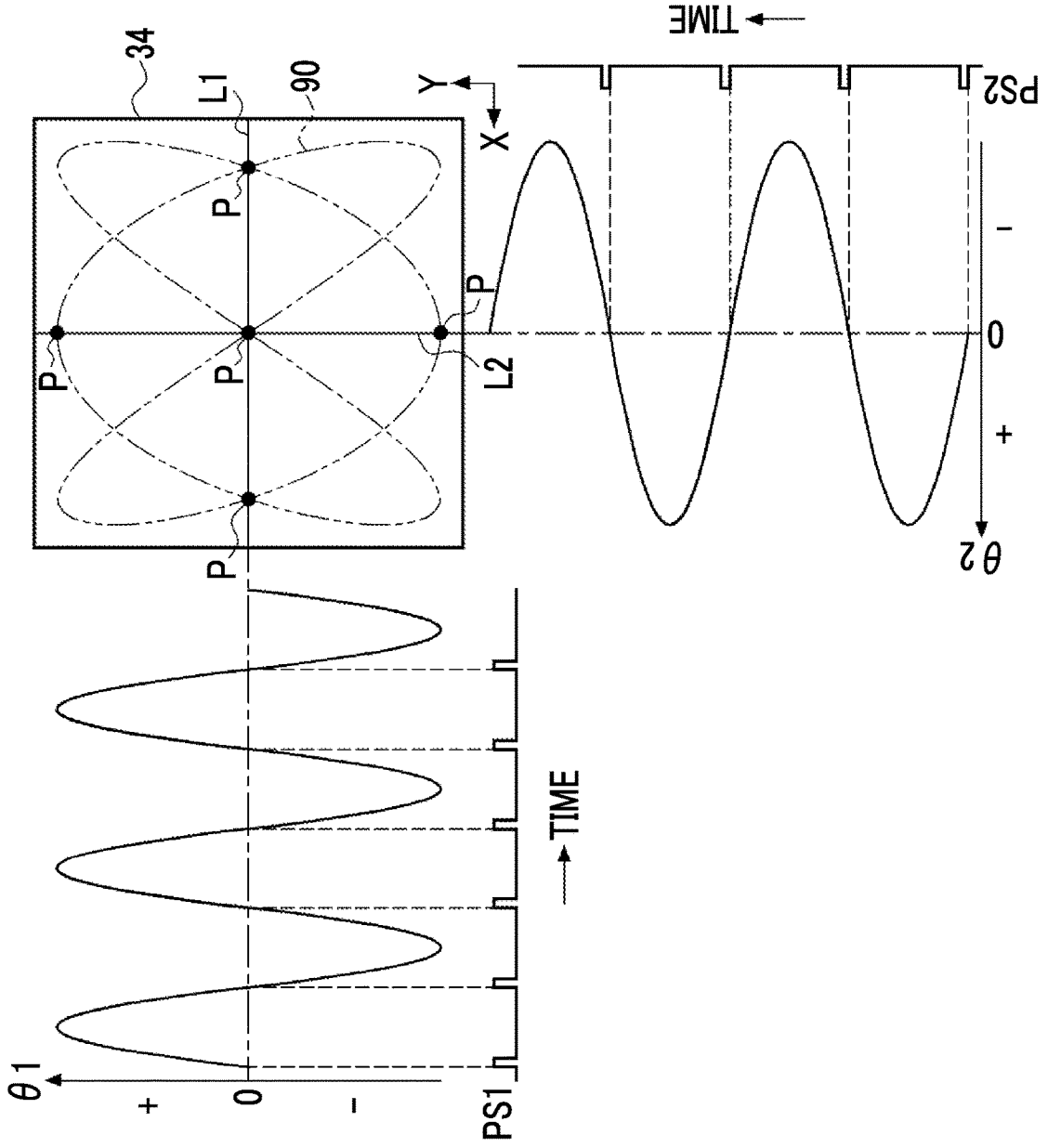


FIG. 11

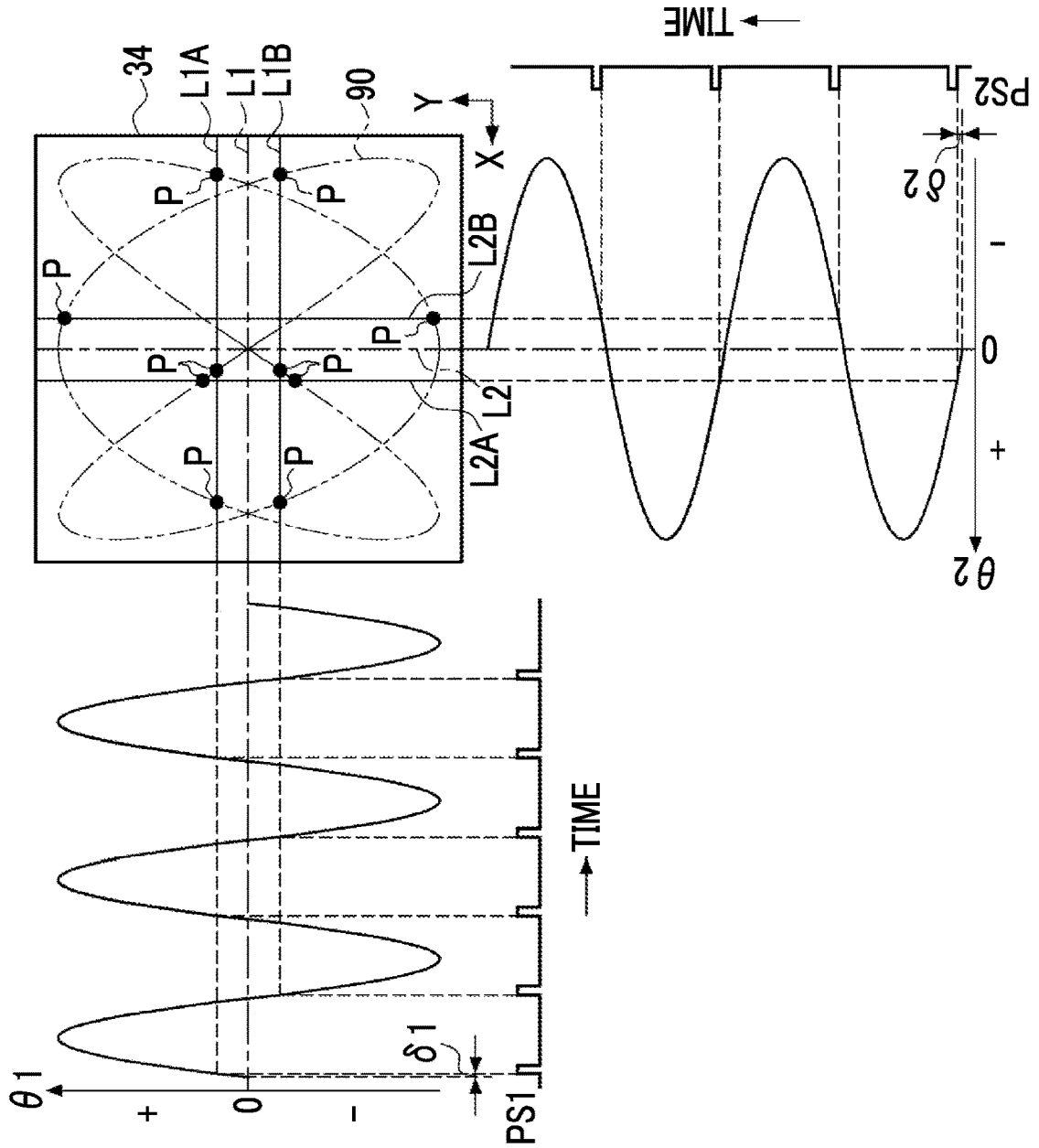


FIG. 12

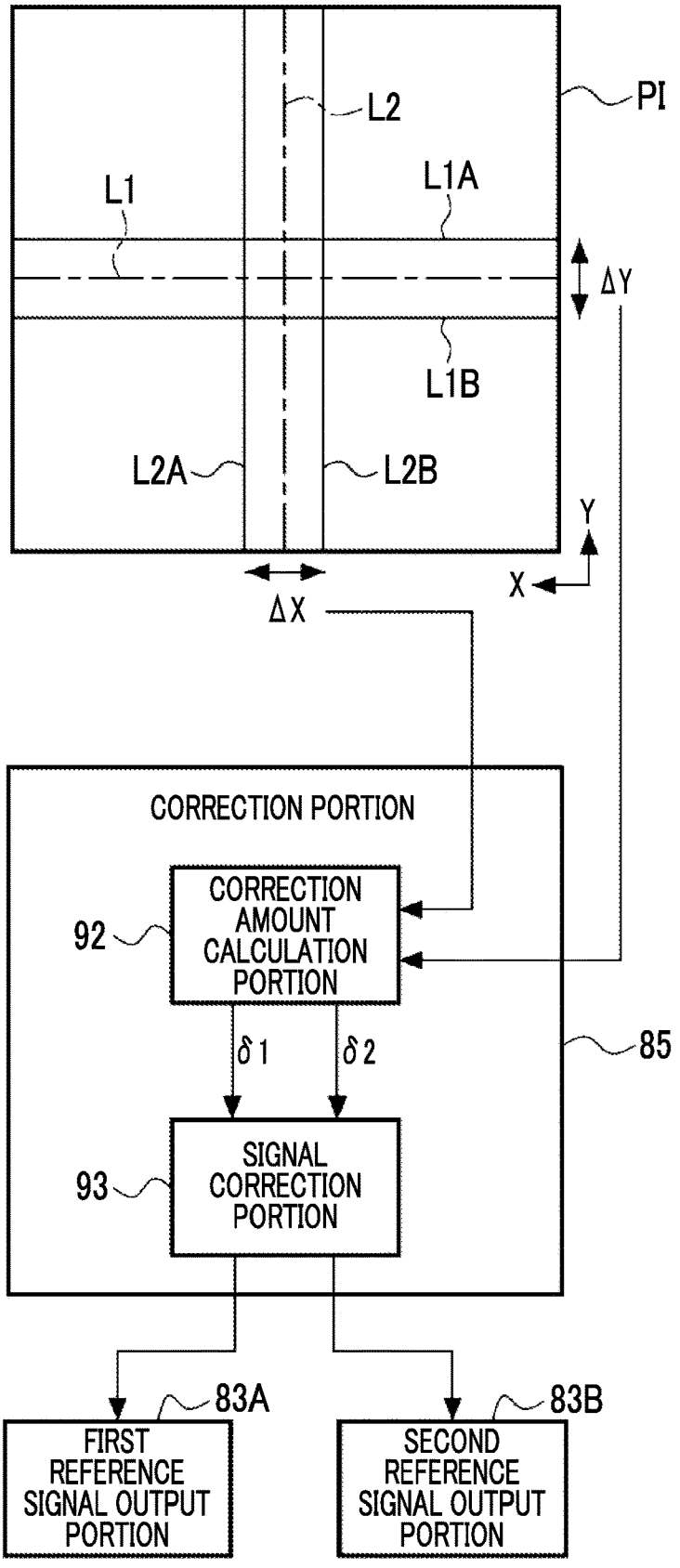

PI
L2
L1
L1A
ΔY
L1B
L2A
L2B
Y
X
ΔX
CORRECTION PORTION
92
CORRECTION AMOUNT CALCULATION PORTION
δ1
δ2
85
93
SIGNAL CORRECTION PORTION
83A
83B
FIRST REFERENCE SIGNAL OUTPUT PORTION
SECOND REFERENCE SIGNAL OUTPUT PORTION

FIG. 13A

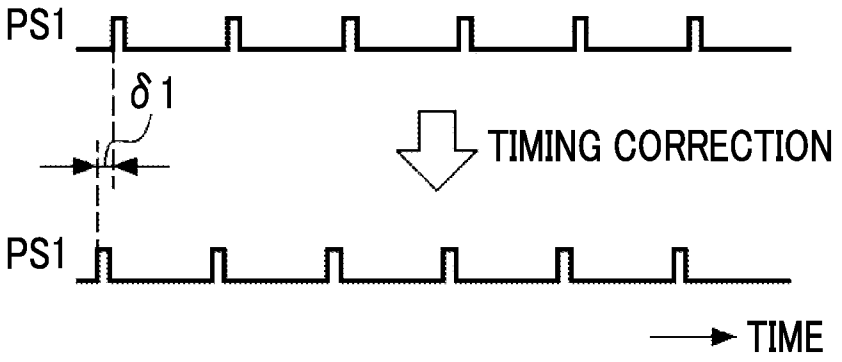
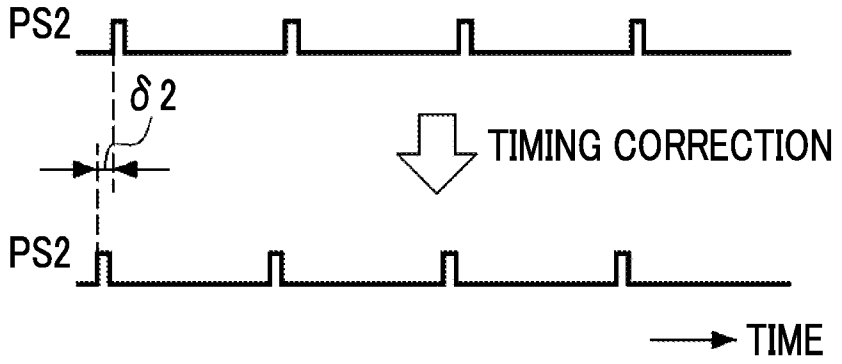


FIG. 13B



LIGHT SCANNING DEVICE AND IMAGE FORMING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority under 35 U.S.C. § 119 to Japanese Patent Application No. 2021-095861 filed on Jun. 8, 2021. The above application is hereby expressly incorporated by reference, in its entirety, into the present application.

BACKGROUND

1. Technical Field

[0002] The disclosed technology relates to a light scanning device and an image forming apparatus.

2. Description of the Related Art

[0003] An image forming apparatus that draws an image on a screen or the like by irradiating a mirror device configured with micro electro mechanical systems (MEMS) with light has been known. The mirror device includes a movable mirror that swings about at least one axis.

[0004] The mirror device is accommodated in a package in which a vacuum or a negative pressure is created in order to decrease air resistance of the swinging movable mirror. In this case, laser light is incident on the mirror device from an outside through a glass window provided in the package.

[0005] In a case where the mirror device is accommodated in the package, a part of the laser light incident on the glass window may be reflected on a surface of the glass window, and this reflected light may be incident on a drawing region of an image for the mirror device as stray light. In this case, in a case where the stray light is incident on the drawing region, an unnecessary bright point occurs in the image.

[0006] In S. Gu-Stoppel et al., Advanced Manufacturing, Electronics and Microsystem s: TechConnect Briefs 2016, P.87-90, <https://briefs.techconnect.org/wp-content/volumes/TCB2016v4/pdf/364.pdf5, guiding the reflected light outside the drawing region by incl ining the glass window is suggested because while providing an anti-reflection film on the surface of the glass window is considered in order to suppress the reflected light, it is difficult to completely suppress the reflected light with the anti-reflection film.

SUMMARY

[0007] However, in a case where the glass window is inclined as disclosed in S. Gu-Stoppel et al., Advanced Manufacturing, Electronics and Microsystems: TechConnect Briefs 2016, P.87-90, <https://briefs.techconnect.org/wp-content/volumes/TCB2016v4/pdf/364.pdf>, a problem arises in that a package size is increased because a thickness of the package is increased. In addition, a problem arises in that a manufacturing cost is increased because of the increase in package size.

[0008] An object of the disclosed technology is to provide a light scanning device and an image forming apparatus that can be provided in a small size at a decreased manufacturing cost without causing stray light to be incident on a drawing region.

[0009] In order to accomplish the above object, a light scanning device according to an aspect of the present disclosure is a light scanning device comprising a mirror device that includes a movable mirror which swings about at least one axis, and a package that has at least two or more light transmission surfaces not constituting the same plane and accommodates the mirror device, in which out of the two or more light transmission surfaces of the package, one light transmission surface is a light receiving surface for receiving an incidence ray on the movable mirror from an outside, and the other light transmission surface is a light extraction surface for extracting light reflected by the movable mirror to the outside.

[0010] It is preferable that a vacuum or a negative pressure is created inside the package.

[0011] It is preferable that a signal input terminal for receiving a driving signal for driving the movable mirror from the outside is provided in the package.

[0012] It is preferable that an optical element that guides light incident from the light receiving surface to the movable mirror by deflecting the light is provided inside the package.

[0013] It is preferable that the light receiving surface and the light extraction surface are configured with two light transmission surfaces that are not parallel.

[0014] It is preferable that an imaging apparatus and a signal output terminal for extracting an imaging signal output from the imaging apparatus to the outside are provided inside the package, and the light extraction surface guides a part of the light reflected by the movable mirror to the imaging apparatus by reflecting the part of the light.

[0015] An image forming apparatus according to another aspect of the present disclosure is an image forming apparatus comprising a light scanning device including a mirror device that includes a movable mirror which swings about at least one axis, and a package that has at least two or more light transmission surfaces not constituting the same plane and accommodates the mirror device, and a light emitting device that emits light, in which out of the two or more light transmission surfaces of the package, one light transmission surface is a light receiving surface for receiving an incidence ray on the movable mirror from an outside, and the other light transmission surface is a light extraction surface for extracting light reflected by the movable mirror to the outside, and the light emitted from the light emitting device is incident on the movable mirror through the light receiving surface.

[0016] According to the disclosed technology, a light scanning device and an image forming apparatus that can be provided in a small size at a decreased manufacturing cost without causing stray light to be incident on a drawing region can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Exemplary embodiments according to the technique of the present disclosure will be described in detail based on the following figures, wherein:

[0018] FIG. **1** is a schematic diagram illustrating an example of a configuration of an image forming apparatus,

[0019] FIG. **2** is a schematic perspective view illustrating an example of a configuration of a MEMS mirror,

[0020] FIG. **3** is a schematic perspective view illustrating an example of an exterior configuration of a light scanning device,

[0021] FIG. **4** is a schematic cross-sectional view illustrating an example of a cross-sectional structure of the light scanning device,

[0022] FIG. **5** is a schematic cross-sectional view illustrating an example of a cross-sectional structure of a light scanning device according to a second embodiment,

[0023] FIG. **6** is a schematic cross-sectional view illustrating an example of a cross-sectional structure of a light scanning device according to a third embodiment,

[0024] FIG. **7** is a block diagram illustrating an example of a functional configuration of a control device,

[0025] FIG. **8** is a diagram illustrating an example of a first driving signal, a first zero cross signal, and a first reference signal,

[0026] FIG. **9** is a diagram illustrating an example of a second driving signal, a second zero cross signal, and a second reference signal,

[0027] FIG. **10** is a diagram illustrating an example of a pattern drawn on a projection surface in a calibration mode,

[0028] FIG. **11** is a diagram illustrating an example of the pattern drawn on the projection surface in a case where a shift occurs between a swing of a mirror portion and timings of the first reference signal and the second reference signal,

[0029] FIG. **12** is a diagram illustrating an example of a functional configuration of a correction portion, and

[0030] FIGS. **13**A and **13**B are diagrams illustrating an example of timing correction performed by a signal correction portion: FIG. **13**A illustrates an example of correcting the timing of the first reference signal, and FIG. **13**B illustrates an example of correcting the timing of the second reference signal.

DETAILED DESCRIPTION

[0031] Hereinafter, embodiments according to the disclosed technology will be described in detail with reference to the drawings. As an example, in each of the following embodiments, a form of applying the disclosed technology to an image forming apparatus that forms an image on a projection surface by scanning laser light using a Lissajous method will be described.

First Embodiment

[0032] FIG. **1** illustrates an example of a configuration of an image forming apparatus **10** of the present embodiment. As illustrated in FIG. **1**, the image forming apparatus **10** of the present embodiment comprises a control device **20**, a MEMS driver **22**, a light emitting device **24**, a multiplexing optical system **26**, a collimator **28**, and a light scanning device **30**. The light scanning device **30** is configured with a MEMS mirror **32** and a package **33** that accommodates the MEMS mirror **32**. The MEMS mirror **32** is an example of a "mirror device" according to the embodiment of the disclosed technology.

[0033] The light emitting device **24** includes a laser driver **25** and a laser light source **27**. The laser driver **25** of the present embodiment drives the laser light source **27** based on an intensity modulation signal supplied from the control device **20** and causes laser light for forming an image to be output from the laser light source **27**. For example, the laser light source **27** outputs the laser light of three colors of red (R), green (G), and blue (B). The laser light is an example of "light" according to the embodiment of the disclosed technology.

[0034] The laser light output from the laser light source **27** is multiplexed by the multiplexing optical system **26**. Then, the MEMS mirror **32** in the package **33** is irradiated with the multiplexed laser light through the collimator **28**. The laser light condensed in the MEMS mirror **32** is reflected toward a projection surface **34** by the MEMS mirror **32**. For example, the projection surface **34** is a screen for projecting the image, or a retina of an eye of a person. That is, the image forming apparatus **10** of the present embodiment is used for a projector, augmented reality (AR) glasses, and the like.

[0035] In the present embodiment, the projection surface **34** is not limited to a surface of an actual object such as the screen and includes an imaginary plane in a space.

[0036] The MEMS driver **22** drives the MEMS mirror **32** under control of the control device **20**. In the MEMS mirror **32**, a mirror portion **40** (refer to FIG. **2**) that reflects laser light L swings about each of two axes orthogonal to each other as a central axis. In the present embodiment, the laser light L is scanned in a state of drawing a Lissajous curve on the projection surface **34** by the swing of the mirror portion **40** based on a driving signal. The Lissajous curve is a curve that is decided by a swing frequency about a first axis, a swing frequency about a second axis, and a phase difference therebetween. The mirror portion **40** is an example of a "movable mirror" according to the embodiment of the disclosed technology.

[0037] The control device **20** of the present embodiment includes a field programmable gate array (FPGA) **20**A and a memory **20**B. For example, the memory **20**B is a volatile memory and stores various information such as an image signal representing the image projected to the projection surface **34**. For example, the memory **20**B stores the image signal input from an outside of the image forming apparatus **10**.

[0038] FIG. **2** illustrates an example of a configuration of the MEMS mirror **32**. The MEMS mirror **32** includes the mirror portion **40**, a first support portion **41**, a first movable frame **42**, a second support portion **43**, a second movable frame **44**, a connecting portion **45**, and a fixed frame **46**.

[0039] The mirror portion **40** has a reflecting surface **40**A on which an incidence ray is reflected. For example, the reflecting surface **40**A is formed with a thin metal film of gold (Au), aluminum (Al), silver (Ag), or a silver alloy. For example, a shape of the reflecting surface **40**A is a circular shape.

[0040] The first support portion **41** is arranged outside the mirror portion **40** at each of positions that face with a second axis a_2 interposed therebetween. The first support portions **41** are connected to the mirror portion **40** on a first axis a_1 and support the mirror portion **40** in a swingable manner about the first axis a_1.

[0041] The first movable frame **42** is a rectangular frame surrounding the mirror portion **40** and is connected to the mirror portion **40** through the first support portions **41** on the first axis a_1. A piezoelectric element **50** is formed on the first movable frame **42** at each of positions that face with the first axis a_1 interposed therebetween. In such a manner, a pair of first actuators **51** are configured by forming two piezoelectric elements **50** on the first movable frame **42**.

[0042] The pair of first actuators **51** are arranged at positions that face with the first axis a_1 interposed therebetween. The first actuators **51** cause the mirror portion **40** to swing about the first axis a_1 by applying rotational torque about the first axis a_1 to the mirror portion **40**.

[0043] The second support portion **43** is arranged outside the first movable frame **42** at each of positions that face with

the first axis a_1 interposed therebetween. The second support portions **43** are connected to the first movable frame **42** on the second axis a_2 and support the first movable frame **42** and the mirror portion **40** in a swingable manner about the second axis a_2. In the present embodiment, the second support portions **43** are torsion bars that stretch along the second axis a_2.

[0044] The second movable frame **44** is a rectangular frame surrounding the first movable frame **42** and is connected to the first movable frame **42** through the second support portions **43** on the second axis a_2. The piezoelectric element **50** is formed on the second movable frame **44** at each of positions that face with the second axis a_2 interposed therebetween. In such a manner, a pair of second actuators **52** are configured by forming two piezoelectric elements **50** on the second movable frame **44**.

[0045] The pair of second actuators **52** are arranged at positions that face with the second axis a_2 interposed therebetween. The second actuators **52** cause the mirror portion **40** to swing about the second axis a_2 by applying rotational torque about the second axis a_2 to the mirror portion **40** and the first movable frame **42**.

[0046] The connecting portion **45** is arranged outside the second movable frame **44** at each of positions that face with the first axis a_1 interposed therebetween. The connecting portions **45** are connected to the second movable frame **44** on the second axis a_2.

[0047] The fixed frame **46** is a rectangular frame surrounding the second movable frame **44** and is connected to the second movable frame **44** through the connecting portions **45** on the second axis a_2.

[0048] In the present embodiment, the first axis a_1 and the second axis a_2 are orthogonal to each other. In the following description, a direction parallel to the first axis a_1 will be referred to as an X direction, a direction parallel to the second axis a_2 will be referred to as a Y direction, and a direction orthogonal to the first axis a_1 and the second axis a_2 will be referred to as a Z direction.

[0049] FIG. **3** illustrates an example of an exterior configuration of the light scanning device **30**. The package **33** has an almost rectangular parallelepiped shape. For example, the package **33** is configured with a substrate **35** having a flat plate shape and a lid member **36** having a box shape. For example, the substrate **35** and the lid member **36** are formed of glass having light transmittance. The package **33** is configured by joining the lid member **36** to the substrate **35**. The MEMS mirror **32** is accommodated inside the package **33**.

[0050] In addition, a vacuum or a negative pressure is created inside the package **33**. In such a manner, by creating a vacuum or a negative pressure inside the package **33**, an energy loss at a time of the swing of the mirror portion **40** is reduced, and a large deflection angle can be implemented with a low driving voltage. The negative pressure means that a pressure inside the package **33** is lower than a pressure (that is, atmospheric pressure) outside the package **33**.

[0051] The lid member **36** has four light transmission surfaces **37**. The four light transmission surfaces **37** are configured with one upper surface and three side surfaces. In the present embodiment, the light transmission surface **37** as one side surface among the four light transmission surfaces **37** functions as a "light receiving surface" for receiving the incidence ray on the mirror portion **40** from the outside. In addition, the light transmission surface **37** as one upper surface among the four light transmission surfaces **37** functions as a "light extraction surface" for extracting the light reflected by the mirror portion **40** to the outside. That is, in the present embodiment, the light receiving surface and the light extraction surface are configured with two light transmission surfaces **37** that are not parallel.

[0052] The laser light L emitted from the light emitting device **24** is transmitted through a light receiving region **38** on the light receiving surface and is incident into the package **33**. The laser light L incident into the package **33** is incident on the mirror portion **40** of the MEMS mirror **32**. The laser light L reflected by the mirror portion **40** is transmitted through a light extraction region **39** on the light extraction surface and is extracted outside the package **33**. The laser light L transmitted through the light extraction region **39** is incident on the projection surface **34** (refer to FIG. **1**).

[0053] FIG. **4** illustrates an example of a cross-sectional structure of the light scanning device **30**. As illustrated in FIG. **4**, the MEMS mirror **32** is fixed to the substrate **35** through a support member **60**. For example, the support member **60** has a triangular prism shape and has an inclined surface **61**. The MEMS mirror **32** is joined to the inclined surface **61**. That is, a surface of the mirror portion **40** is not parallel to any of the light receiving surface and the light extraction surface in a standstill state.

[0054] A signal input terminal **62** for receiving a driving signal for driving the mirror portion **40** from the outside is provided in the substrate **35**. For example, the signal input terminal **62** is electrically connected to the MEMS mirror **32** through a bonding wire **63**. The MEMS driver **22** (refer to FIG. **1**) inputs the driving signal into the MEMS mirror **32** through the signal input terminal **62**. For example, the signal input terminal **62** is individually provided in each of the pair of first actuators **51** and the pair of second actuators **52**. Driving signals having different frequencies are provided to the pair of first actuators **51** and the pair of second actuators **52**.

[0055] As illustrated in FIG. **3** and FIG. **4**, the laser light L emitted from the light emitting device **24** is partially reflected on the light receiving surface and becomes stray light LS. Since the light extraction surface is configured with the light transmission surface **37** that does not constitute the same plane with the light transmission surface **37** constituting the light receiving surface, the stray light LS is not incident on a drawing region (that is, the projection surface **34**).

[0056] In the light scanning device **30** of the present embodiment, inclining a glass window in order to guide the stray light LS outside the drawing region as in the related art is not necessary. Thus, a thickness of the package **33** is not increased, and a package size can be decreased. Thus, according to the disclosed technology, the light scanning device **30** that can be provided in a small size at a decreased manufacturing cost without causing the stray light to be incident on the drawing region is implemented.

[0057] In the embodiment, while the entire package **33** is formed of a light transmission material such as glass, the package **33** may be partially formed of a light shielding member. For example, a part other than the light receiving region **38** and the light extraction region **39** in the package **33** may be formed of a light shielding member.

Second Embodiment

[0058] Next, a second embodiment will be described. While the laser light is received into the package **33** from one side surface of the lid member **36** in the first embodiment, the laser light is received into the package **33** from the substrate **35** in the second embodiment.

[0059] FIG. **5** illustrates an example of a cross-sectional structure of the light scanning device **30** according to the second embodiment. The substrate **35** transmits light, and a surface of the substrate **35** is the light transmission surface **37**. In the embodiment, the light transmission surface **37** of the substrate **35** functions as the "light receiving surface" for receiving the incidence ray on the mirror portion **40** from the outside. The laser light L emitted from the light emitting device **24** is transmitted through the light receiving region **38** of the substrate **35** and is incident into the package **33**. The laser light L incident into the package **33** is incident on an inner surface side of the lid member **36**.

[0060] An optical element **70** is provided on the inner surface side of the lid member **36** at a position on which the laser light L is incident. The optical element **70** guides the laser light L incident from the light receiving region **38** to the mirror portion **40** of the MEMS mirror **32** by deflecting the laser light L. In the present embodiment, the optical element **70** is a reflecting film formed by sputtering or a vapor deposition method. The optical element **70** deflects the laser light L by specular reflection so that the laser light L is guided to the mirror portion **40**.

[0061] In the present embodiment, the MEMS mirror **32** is directly fixed to the substrate **35** without using the support member **60** (refer to FIG. **4**). That is, in the present embodiment, the MEMS mirror **32** is not inclined with respect to the substrate **35**. The laser light L reflected by the mirror portion **40** is transmitted through the light extraction region **39** on the upper surface of the lid member **36** and is extracted outside the package **33** in the same manner as in the above embodiment.

[0062] As described above, in the second embodiment, the laser light L is received from a rear surface side of the package **33**. Thus, the stray light LS caused by partial reflection of the laser light L on the light receiving surface is not incident on the drawing region. Accordingly, even in the second embodiment, since inclining the glass window in order to guide the stray light LS outside the drawing region as in the related art is not necessary, the light scanning device **30** that can be provided in a small size at a decreased manufacturing cost is implemented. In addition, since it is not necessary to incline the MEMS mirror **32** with respect to the substrate **35**, the thickness of the package **33** can be further decreased.

[0063] The optical element **70** is not limited to a reflecting film and may be an optical element such as a grating or a hologram. A grating or a hologram can emit the laser light L at an emission angle different from an incidence angle. Thus, using an optical element such as a grating or a hologram as the optical element **70** improves a degree of design freedom of a position and the like for arranging the optical element **70**.

Third Embodiment

[0064] Next, a third embodiment will be described. In the third embodiment, an imaging apparatus is provided inside the package **33**. The imaging apparatus is used for correcting a light emission timing of the laser light L by the light emitting device **24**.

[0065] FIG. **6** illustrates an example of a cross-sectional structure of the light scanning device **30** according to the third embodiment. In the present embodiment, an imaging apparatus **72** is attached to the substrate **35** inside the package **33**. The imaging apparatus **72** is provided on an optical path of the laser light L reflected on the light extraction region **39** out of the laser light L reflected by the mirror portion **40**. A signal output terminal **73** for extracting an imaging signal output from the imaging apparatus **72** to the outside is provided in the substrate **35**. Other configurations of the light scanning device **30** according to the present embodiment are the same as the configurations of the light scanning device **30** according to the first embodiment.

[0066] The imaging apparatus **72** generates a captured image IP by imaging the laser light L reflected on the light extraction region **39** and outputs the generated captured image IP to the control device **20** (refer to FIG. **1**). The imaging apparatus **72** is configured with an image sensor such as a charge coupled device (CCD) image sensor or a complementary metal oxide semiconductor (CMOS) image sensor. In addition, the imaging apparatus **72** may be configured with a position sensitive detector (PSD). The captured image IP is used for correcting timings of a first reference signal and a second reference signal, described later. The captured image IP is an example of "imaging information" according to the embodiment of the disclosed technology.

[0067] FIG. **7** illustrates an example of a functional configuration of the control device **20**. As illustrated in FIG. **7**, the control device **20** is configured with an image input portion **80**, an information generation portion **81**, an information storage portion **82**, a first reference signal output portion **83**A, a second reference signal output portion **83**B, a light emission controller **84**, a correction portion **85**, a table holding portion **86**, and a humidity and temperature sensor **87**. The image input portion **80**, the information generation portion **81**, the information storage portion **82**, the first reference signal output portion **83**A, the second reference signal output portion **83**B, the light emission controller **84**, the correction portion **85**, and the table holding portion **86** are functional portions implemented by causing the FPGA **20**A and the memory **20**B to operate in cooperation.

[0068] Image data DT that represents the image to be formed is input into the image input portion **80** from the outside. Hereinafter, the image corresponding to the image data DT input into the image input portion **80** may be referred to as an input image. As an example, in the present embodiment, the image data DT of colors represented by RGB signals is input into the image input portion **80**. The image data DT input into the image input portion **80** is output to the information generation portion **81**. The image data DT input into the image input portion **80** is not limited to the present embodiment and may be data corresponding to the image to be formed. For example, the image data DT may be binarized data that represents whether or not to output the laser light L. In addition, for example, the image data DT may be data that represents multiple values of an output amount.

[0069] The information generation portion **81** generates intensity information SI that represents a correspondence

relationship between a scanning position of the laser light L by the MEMS mirror **32** and a signal intensity of the input image. In a case where the input image is a color image, the signal intensity represents an intensity of each of the RGB signals. The information storage portion **82** stores the intensity information SI generated by the information generation portion **81**.

[0070] The MEMS driver **22** outputs first driving signals V**1**A and V**1**B illustrated in FIG. **8** as an example to the pair of first actuators **51** of the MEMS mirror **32**, and generates a first zero cross signal ZC**1** and outputs the first zero cross signal ZC**1** to the first reference signal output portion **83**A. The first driving signal V**1**A and the first driving signal V**1**B are sine waves having a phase difference of 180°.

[0071] The first zero cross signal ZC**1** is a pulsed signal that represents points at which the first driving signals V**1**A and V**1**B become zero. Signals output to the first reference signal output portion **83**A from the MEMS driver **22** are not limited to zero cross signals and may be signals having the same periods as the first driving signals V**1**A and V**1**B.

[0072] The MEMS driver **22** outputs second driving signals V**2**A and V**2**B illustrated in FIG. **9** as an example to the pair of second actuators **52** of the MEMS mirror **32**, and generates a second zero cross signal ZC**2** and outputs the second zero cross signal ZC**2** to the second reference signal output portion **83**B. The second driving signal V**2**A and the second driving signal V**2**B are sine waves having a phase difference of 180°.

[0073] The second zero cross signal ZC**2** is a pulsed signal that represents points at which the second driving signals V**2**A and V**2**B become zero. Signals output to the second reference signal output portion **83**B from the MEMS driver **22** are not limited to zero cross signals and may be signals having the same periods as the second driving signals V**2**A and V**2**B.

[0074] A frequency (hereinafter, referred to as a first driving frequency) of the first driving signals V**1**A and V**1**B and a frequency (hereinafter, referred to as a second driving frequency) of the second driving signals V**2**A and V**2**B have different frequency ratios. A frequency ratio of the first driving frequency and the second driving frequency is decided based on a shape of a Lissajous curve of light scanning performed by the MEMS mirror **32**.

[0075] The first reference signal output portion **83**A outputs a first reference signal PS**1** to the light emission controller **84** by estimating a point in time when a deflection angle (hereinafter, referred to as a first deflection angle) θ**1** of the mirror portion **40** about the first axis a_1 becomes equal to a first reference angle. In the present embodiment, the first reference angle is set to 0°. The first reference signal output portion **83**A generates the first reference signal PS**1** by estimating the point in time when the first deflection angle θ**1** becomes equal to the first reference angle, based on the first driving signals V**1**A and V**1**B.

[0076] Specifically, as illustrated in FIG. **8**, the first reference signal output portion **83**A outputs a signal obtained by delaying the first zero cross signal ZC**1** input from the MEMS driver **22** by a delay time period D**1** as the first reference signal PS**1**. In a case where the mirror portion **40** resonates about the first axis a_1, the delay time period D**1** is ideally a time period corresponding to **1**/**4** of a period of the first zero cross signal ZC**1**. However, a shift occurs due to an environmental condition (a temperature, a humidity, and the like). Thus, in the present embodiment, the first reference signal output portion **83**A acquires the delay time period D**1** based on a temperature and a humidity detected by the humidity and temperature sensor **87** and a look-up table (hereinafter, referred to as the LUT) **86**A held in the table holding portion **86**, and generates the first reference signal PS**1** based on the acquired delay time period D**1**.

[0077] The second reference signal output portion **83**B outputs a second reference signal PS**2** to the light emission controller **84** by estimating a point in time when a deflection angle (hereinafter, referred to as a second deflection angle) **02** of the mirror portion **40** about the second axis a_2 becomes equal to a second reference angle. In the present embodiment, the second reference angle is set to 0°. The second reference signal output portion **83**B generates the second reference signal PS**2** by estimating the point in time when the second deflection angle θ**2** becomes equal to the second reference angle, based on the second driving signals V**2**A and V**2**B.

[0078] Specifically, as illustrated in FIG. **9**, the second reference signal output portion **83**B outputs a signal obtained by delaying the second zero cross signal ZC**2** input from the MEMS driver **22** by a delay time period D**2** as the second reference signal PS**2**. In a case where the mirror portion **40** resonates about the second axis a_2, the delay time period D**2** is ideally a time period corresponding to **1**/**4** of a period of the second zero cross signal ZC**2**. However, a shift occurs due to an environmental condition (a temperature, a humidity, and the like). Thus, in the present embodiment, the second reference signal output portion **83**B acquires the delay time period D**2** based on the temperature and the humidity detected by the humidity and temperature sensor **87** and the LUT **86**A held in the table holding portion **86**, and generates the second reference signal PS**2** based on the acquired delay time period D**2**.

[0079] A relationship among the delay time period D**1**, the temperature, and the humidity and a relationship among the delay time period D**2**, the temperature, and the humidity are recorded in advance in the LUT **86**A. For example, these relationships are decided based on a past history.

[0080] The light emission controller **84** causes the light emitting device **24** to emit the laser light L based on the first reference signal PS**1** and the second reference signal PS**2**. In a drawing mode in which the image based on the image data DT is drawn on the projection surface **34**, the light emission controller **84** reads out the intensity information SI from the information storage portion **82** and causes the light emitting device **24** to emit the laser light L having an intensity decided based on the first reference signal PS**1** and the second reference signal PS**2** for each constant time period (for example, for each clock period).

[0081] In addition, in the present embodiment, a calibration mode for correcting the timings of the first reference signal PS**1** and the second reference signal PS**2** output by the first reference signal output portion **83**A and the second reference signal output portion **83**B, respectively, is performed. In the calibration mode, the light emission controller **84** causes the light emitting device **24** to emit the laser light L in accordance with the timing at which the first reference signal PS**1** is output from the first reference signal output portion **83**A, and the timing at which the second reference signal PS**2** is output from the second reference signal output portion **83**B. That is, in the calibration mode, the light emission controller **84** causes the light emitting device **24** to emit the laser light L at the point in time when

the first deflection angle θ**1** is estimated to become equal to the first reference angle (in the present embodiment, 0°), and the point in time when the second deflection angle θ**2** is estimated to become equal to the second reference angle (in the present embodiment, 0°).

[0082] In the calibration mode, the imaging apparatus **72** images the laser light L reflected on the light extraction region **39** out of the laser light L that is emitted from the light emitting device **24** and is reflected by the mirror portion **40**. The imaging apparatus **72** outputs the captured image IP generated by the imaging to the correction portion **85**. A pattern drawn on the projection surface **34** is imaged in the captured image IP.

[0083] The correction portion **85** corrects the timings of the first reference signal PS**1** and the second reference signal PS**2** output by the first reference signal output portion **83**A and the second reference signal output portion **83**B, respectively, based on a shift amount of the pattern captured in the captured image IP from a predetermined shape.

[0084] FIG. **10** illustrates an example of the pattern drawn on the projection surface **34** in the calibration mode. In the present example, the frequency ratio of the first driving frequency and the second driving frequency is set to 3:2 for simplification of description. In the present example, a Lissajous curve **90** is drawn on the projection surface **34** by the light scanning performed by the MEMS mirror **32**.

[0085] FIG. **10** illustrates a case where a shift does not occur between the swing of the mirror portion **40** and the timings of the first reference signal PS**1** and the second reference signal PS**2**. In such a manner, in a case where a shift does not occur, the light emitting device **24** emits the laser light L at the point in time of θ**1**=0 and the point in time of θ**2**=0. Thus, a first reference line L**1** and a second reference line L**2** on the projection surface **34** are irradiated with the laser light L. The first reference line L**1** is a straight line that passes through a center of the Lissajous curve **90** and is parallel to the X direction. The second reference line L**2** is a straight line that passes through the center of the Lissajous curve **90** and is parallel to the Y direction. Reference numeral P denotes a point (that is, a bright point) irradiated with the laser light L on the projection surface **34**.

[0086] In a case where the frequency ratio of the first driving frequency and the second driving frequency is set to make the Lissajous curve **90** more precise, the bright points P draw straight line patterns along the first reference line L**1** and the second reference line L**2**.

[0087] FIG. **11** illustrates a case where a shift occurs between the swing of the mirror portion **40** and the timings of the first reference signal PS**1** and the second reference signal PS**2**. In such a manner, in a case where a shift occurs, the light emitting device **24** emits the laser light L at points in time shifted from the point in time of θ**1**=0 and the point in time of θ**2**=0. Thus, positions shifted from the first reference line L**1** and the second reference line L**2** on the projection surface **34** are irradiated with the laser light L. In the present example, straight lines L**1**A and L**1**B shifted from the first reference line L**1** and straight lines L**2**A and L**2**B shifted from the second reference line L**2** are irradiated with the laser light L.

[0088] The straight line L**1**A is a line that is irradiated with the laser light L on an advancing path of Lissajous scanning. The straight line L**1**B is a line that is irradiated with the laser light L on a returning path of the Lissajous scanning. In addition, the straight line L**2**A is a line that is irradiated with the laser light L on the advancing path of the Lissajous scanning. The straight line L**2**B is a line that is irradiated with the laser light L on the returning path of the Lissajous scanning. The advancing path refers to a path along which the first deflection angle θ**1** is increased for the Y direction, and a path along which the second deflection angle θ**2** is increased for the X direction. The returning path refers to a path along which the first deflection angle θ**1** is decreased for the Y direction, and a path along which the second deflection angle θ**2** is decreased for the X direction.

[0089] In such a manner, in a case where a shift occurs between the swing of the mirror portion **40** and the timings of the first reference signal PS**1** and the second reference signal PS**2**, the first reference line L**1** is separated into the straight line L**1**A and the straight line LIB, and the second reference line L**2** is separated into the straight line L**2**A and the straight line L**2**B.

[0090] In a case where the frequency ratio of the first driving frequency and the second driving frequency is set to make the Lissajous curve **90** more precise, the bright points P draw straight line patterns along the straight line L**1**A, the straight line L**1**B, the straight line L**2**A, and the straight line L**2**B.

[0091] FIG. **12** illustrates an example of a functional configuration of the correction portion **85**. The correction portion **85** includes a correction amount calculation portion **92** and a signal correction portion **93**. The captured image IP is input into the correction portion **85** from the imaging apparatus **72**.

[0092] The correction amount calculation portion **92** derives a shift amount ΔY between the straight line L**1**A and the straight line L**1**B in the Y direction and a shift amount ΔX between the straight line L**2**A and the straight line L**2**B in the X direction based on the captured image IP. In addition, the correction amount calculation portion **92** derives a correction amount δ**1** of the timing of the first reference signal PS**1** for ΔX=0 and a correction amount δ**2** of the timing of the second reference signal PS**2** for ΔY=0 and outputs the derived correction amounts δ**1** and δ**2** to the signal correction portion **93**. For example, the correction amount calculation portion **92** derives the correction amounts δ**1** and δ**2** based on a relationship between the shift amount ΔX and the correction amount δ**1** and a relationship between the shift amount ΔY and the correction amount δ**2** stored in advance. Each of the relationship between the shift amount ΔX and the correction amount δ**1** and the relationship between the shift amount ΔY and the correction amount δ**2** is an almost proportional relationship.

[0093] The correction amount calculation portion **92** derives the shift amounts ΔX and ΔY based on the captured image IP obtained in a state where the timings of the first reference signal PS**1** and the second reference signal PS**2** are not corrected (that is, a state of δ**1**=0 and δ**2**=0), and derives the correction amounts δ**1** and δ**2** based on the derived shift amounts ΔX and ΔY.

[0094] The signal correction portion **93** corrects the timing of the first reference signal PS**1** output from the first reference signal output portion **83**A based on the correction amount δ**1** input from the correction amount calculation portion **92**, and corrects the timing of the second reference signal PS**2** output from the second reference signal output portion **83**B based on the correction amount δ**2** input from the correction amount calculation portion **92**.

[0095] FIGS. **13**A and **13**B illustrate an example of timing correction performed by the signal correction portion **93**. FIG. **13**A illustrates an example of correcting the timing of the first reference signal PS**1** based on the correction amount δ**1**. FIG. **13**B illustrates an example of correcting the timing of the second reference signal PS**2** based on the correction amount δ**2**. Correcting the timings of the first reference signal PS**1** and the second reference signal PS**2** results in ΔX=0 and ΔY=0. Accordingly, the straight line L**1**A matches the straight line L**1**B, and the straight line L**2**A matches the straight line L**2**B.

[0096] The signal correction portion **93** may be provided inside each of the first reference signal output portion **83**A and the second reference signal output portion **83**B. In this case, the first reference signal output portion **83**A corrects the timing of the first reference signal PS**1** based on the correction amount M input from the correction amount calculation portion **92**. Similarly, the second reference signal output portion **83**B corrects the timing of the second reference signal PS**2** based on the correction amount δ**2** input from the correction amount calculation portion **92**.

[0097] For example, the calibration mode is executed for a predetermined period when the image forming apparatus **10** is started. After the calibration mode is finished, the first reference signal output portion **83**A and the second reference signal output portion **83**B continue the timing correction based on the correction amounts δ**1** and δ**2** in the drawing mode. The calibration mode may be periodically executed during execution of the drawing mode.

[0098] As described above, the image forming apparatus **10** according to the present embodiment can suppress distortion of the image drawn on the projection surface **34** by correcting the timings of the first reference signal PS**1** and the second reference signal PS**2** based on the imaging information acquired by the imaging apparatus **72**.

[0099] In each of the embodiments, while the MEMS mirror **32** of two axes is used as the light scanning device, a MEMS mirror of one axis may be used as the light scanning device. Accordingly, the disclosed technology can also be applied to an image forming apparatus comprising a light scanning device of one axis in which a movable mirror swings about a first axis.

[0100] In the third embodiment, for example, the following various processors can be used as a hardware structure of a processing unit that executes various processing of the image input portion **80**, the information generation portion **81**, the information storage portion **82**, the first reference signal output portion **83**A, the second reference signal output portion **83**B, the light emission controller **84**, the correction portion **85**, and the table holding portion **86**. The various processors include, in addition to a central processing unit (CPU) that is a general-purpose processor functioning as various processing units by executing software (program), a programmable logic device (PLD) such as the FPGA that is a processor having a circuit configuration changeable after manufacturing, a dedicated electric circuit such as an application specific integrated circuit (ASIC) that is a processor having a circuit configuration dedicatedly designed to execute specific processing, and the like.

[0101] One processing unit may be configured with one of the various processors or may be configured with a combination of two or more processors of the same type or different types (for example, a combination of a plurality of FPGAs and/or a combination of a CPU and an FPGA). In addition, a plurality of processing units may be configured with one processor.

[0102] Examples of the plurality of processing units configured with one processor include, first, as represented by a computer such as a client and a server, a form in which one processor is configured with a combination of one or more CPUs and software, and the processor functions as the plurality of processing units. Second, as represented by a system on chip (SoC) or the like, a form of using a processor that implements functions of the entire system including the plurality of processing units by one integrated circuit (IC) chip is included. In such a manner, various processing units are configured using one or more of the various processors as a hardware structure.

[0103] Furthermore, more specifically, an electric circuit (circuitry) in which circuit elements such as semiconductor elements are combined can be used as the hardware structure of the various processors.

[0104] All documents, patent applications, and technical standards disclosed in the present specification are incorporated in the present specification by reference to the same extent as in a case where each of the documents, patent applications, technical standards are specifically and individually indicated to be incorporated by reference.

What is claimed is:

1. A light scanning device comprising:

a mirror device that includes a movable mirror which swings about at least one axis; and

a package that has at least two or more light transmission surfaces not constituting the same plane and accommodates the mirror device,

wherein out of the two or more light transmission surfaces of the package, one light transmission surface is a light receiving surface for receiving an incidence ray on the movable mirror from an outside, and the other light transmission surface is a light extraction surface for extracting light reflected by the movable mirror to the outside.

2. The light scanning device according to claim **1**,

wherein a vacuum or a negative pressure is created inside the package.

3. The light scanning device according to claim **1**,

wherein a signal input terminal for receiving a driving signal for driving the movable mirror from the outside is provided in the package.

4. The light scanning device according to claim **1**,

wherein an optical element that guides light incident from the light receiving surface to the movable mirror by deflecting the light is provided inside the package.

5. The light scanning device according to claim **1**,

wherein the light receiving surface and the light extraction surface are configured with two light transmission surfaces that are not parallel.

6. The light scanning device according to claim **1**,

wherein an imaging apparatus and a signal output terminal for extracting an imaging signal output from the imaging apparatus to the outside are provided inside the package, and

the light extraction surface guides a part of the light reflected by the movable mirror to the imaging apparatus by reflecting the part of the light.

7. An image forming apparatus comprising:

a light scanning device including a mirror device that includes a movable mirror which swings about at least one axis, and a package that has at least two or more light transmission surfaces not constituting the same plane and accommodates the mirror device; and

a light emitting device that emits light,

wherein out of the two or more light transmission surfaces of the package, one light transmission surface is a light receiving surface for receiving an incidence ray on the movable mirror from an outside, and the other light transmission surface is a light extraction surface for extracting light reflected by the movable mirror to the outside, and

the light emitted from the light emitting device is incident on the movable mirror through the light receiving surface.

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