US 20170266727A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2017/0266727 A1

(43) Pub. Date: Sep. 21, 2017

NISHINO et al.

(54) ADDITIVE MANUFACTURING APPARATUS AND ADDITIVE MANUFACTURING METHOD

(71) Applicant: **Kabushiki Kaisha Toshiba**, Minato-ku, Tokyo (JP)

(72) Inventors: **Tomoko NISHINO**, Yokohama (JP); **Naotada OKADA**, Yokohama (JP)

(73) Assignee: **Kabushiki Kaisha Toshiba**, Minato-ku, Tokyo (JP)

(21) Appl. No.: **15/505,448**

(22) PCT Filed: **Feb. 23, 2015**

(86) PCT No.: **PCT/JP2015/055080**

§ 371 (c)(1),
(2) Date: **Feb. 21, 2017**

(30) **Foreign Application Priority Data**

Sep. 16, 2014 (JP) 2014-187982

Publication Classification

(51) **Int. Cl.**

B22F 3/105	(2006.01)
G01B 11/24	(2006.01)
B33Y 30/00	(2006.01)
G01N 21/17	(2006.01)
B29C 67/00	(2006.01)
B33Y 10/00	(2006.01)

(52) **U.S. Cl.**

CPC *B22F 3/1055* (2013.01); *B29C 67/0077* (2013.01); *B29C 67/0088* (2013.01); *B33Y 10/00* (2014.12); *B33Y 30/00* (2014.12); *G01N 21/1702* (2013.01); *G01B 11/2441* (2013.01); *B29K 2105/251* (2013.01)

(57) **ABSTRACT**

An additive manufacturing apparatus according to one embodiment includes a manufacturing unit, an elastic wave generation unit, an elastic wave detection unit, and an inspection unit. The manufacturing unit sequentially stacks a layer formed by emitting a first energy beam to a material and solidifying the material. The elastic wave generation unit emits a second energy beam to a manufactured object including the layer and generates an elastic wave propagating in the manufactured object. The elastic wave detection unit detects the elastic wave. The inspection unit inspects the manufactured object on the basis of a detection result from the elastic wave detection unit.

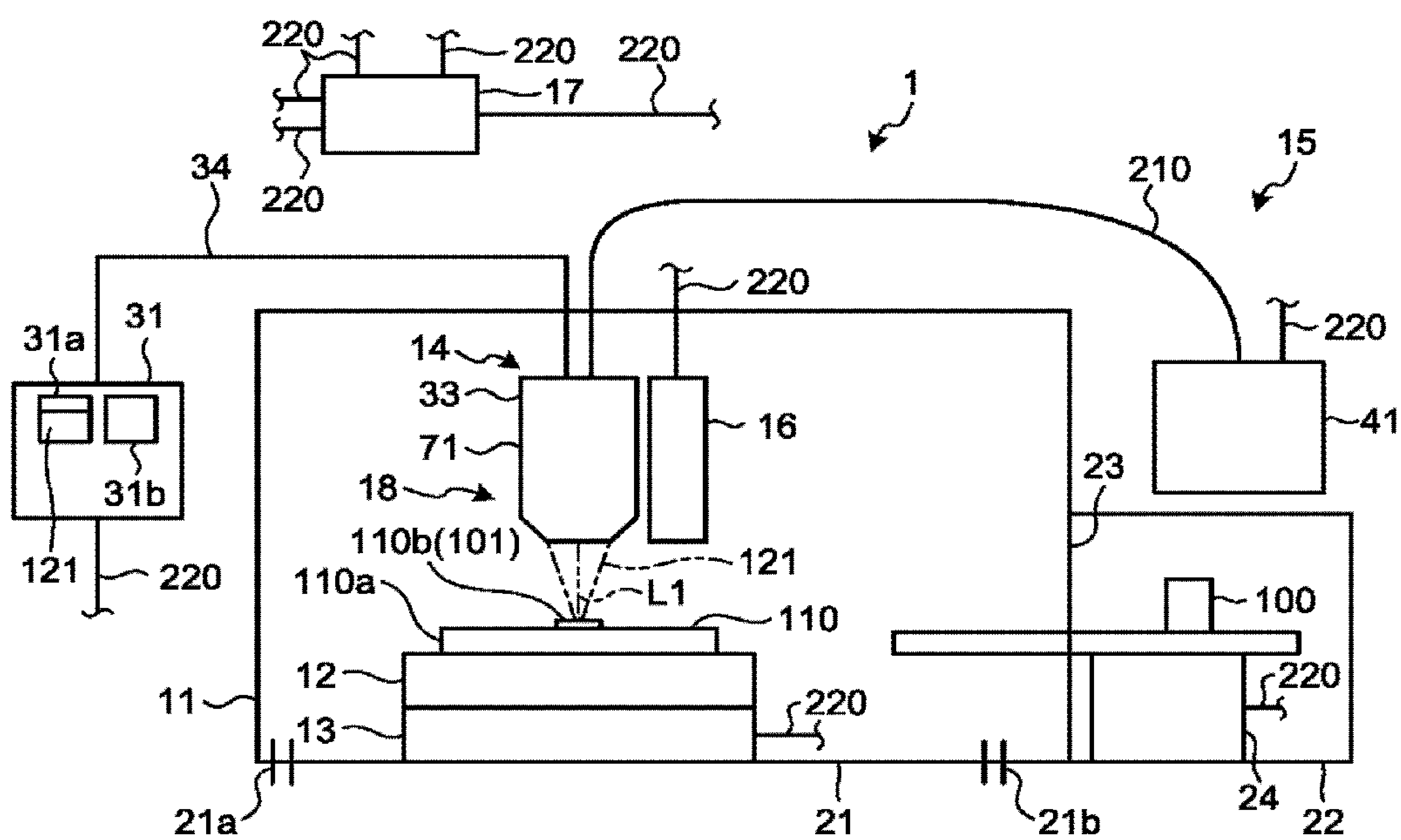


FIG.1

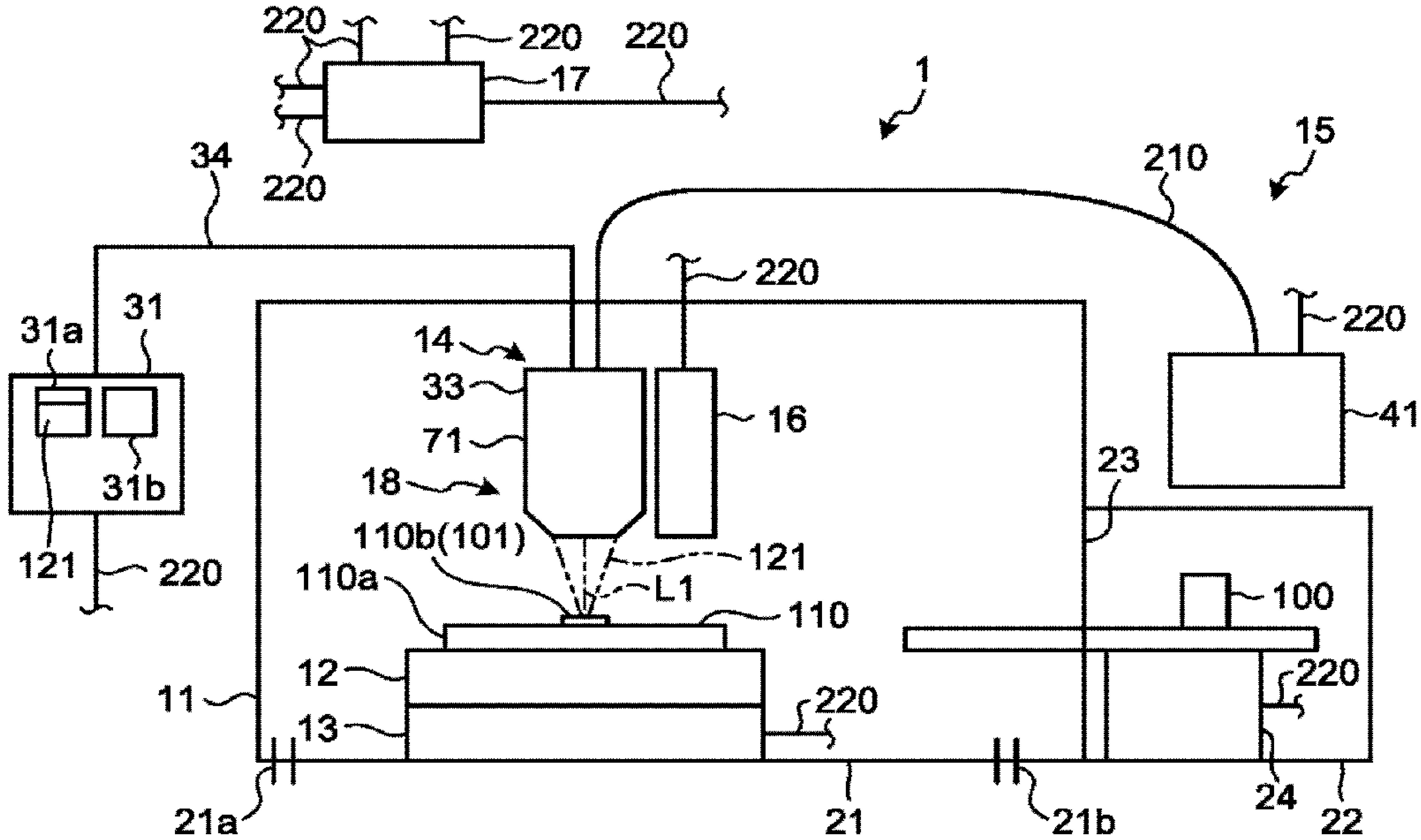

220
220
220
17
220
1
15
34
210
220
220
31a
31
14
33
16
41
71
18
23
31b
110b(101)
121
121
220
L1
100
110a
110
12
220
11
220
13
21a
21
21b
24
22

FIG.2

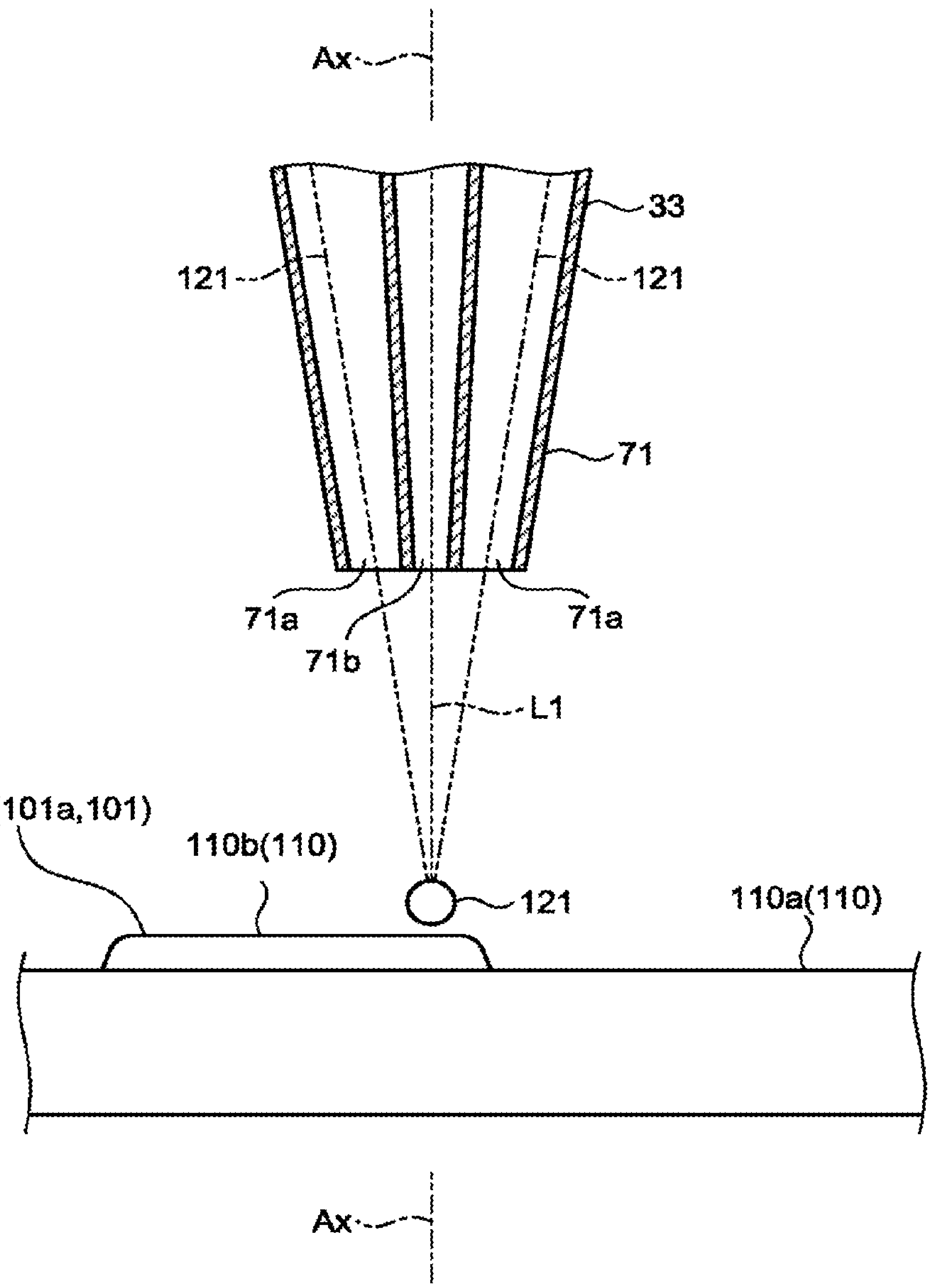

Ax
33
121
121
71
71a
71b
71a
L1
101b(101a,101)
110b(110)
121
110a(110)
Ax

FIG.3

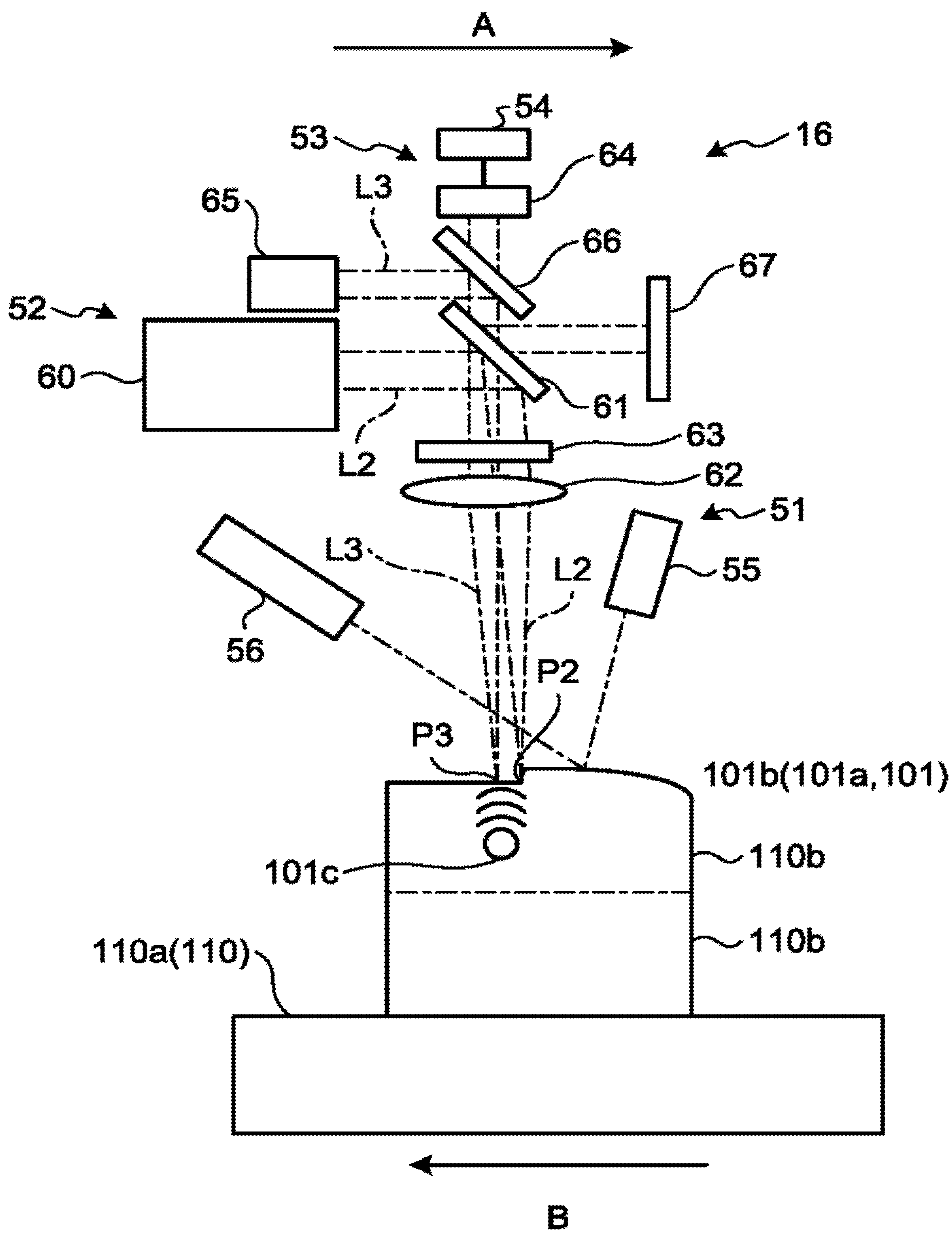

A
54
53
64
16
65
L3
66
67
52
60
61
L2
63
62
51
L3
L2
55
56
P2
P3
101b(101a,101)
101c
110b
110b
110a(110)
B

FIG.4

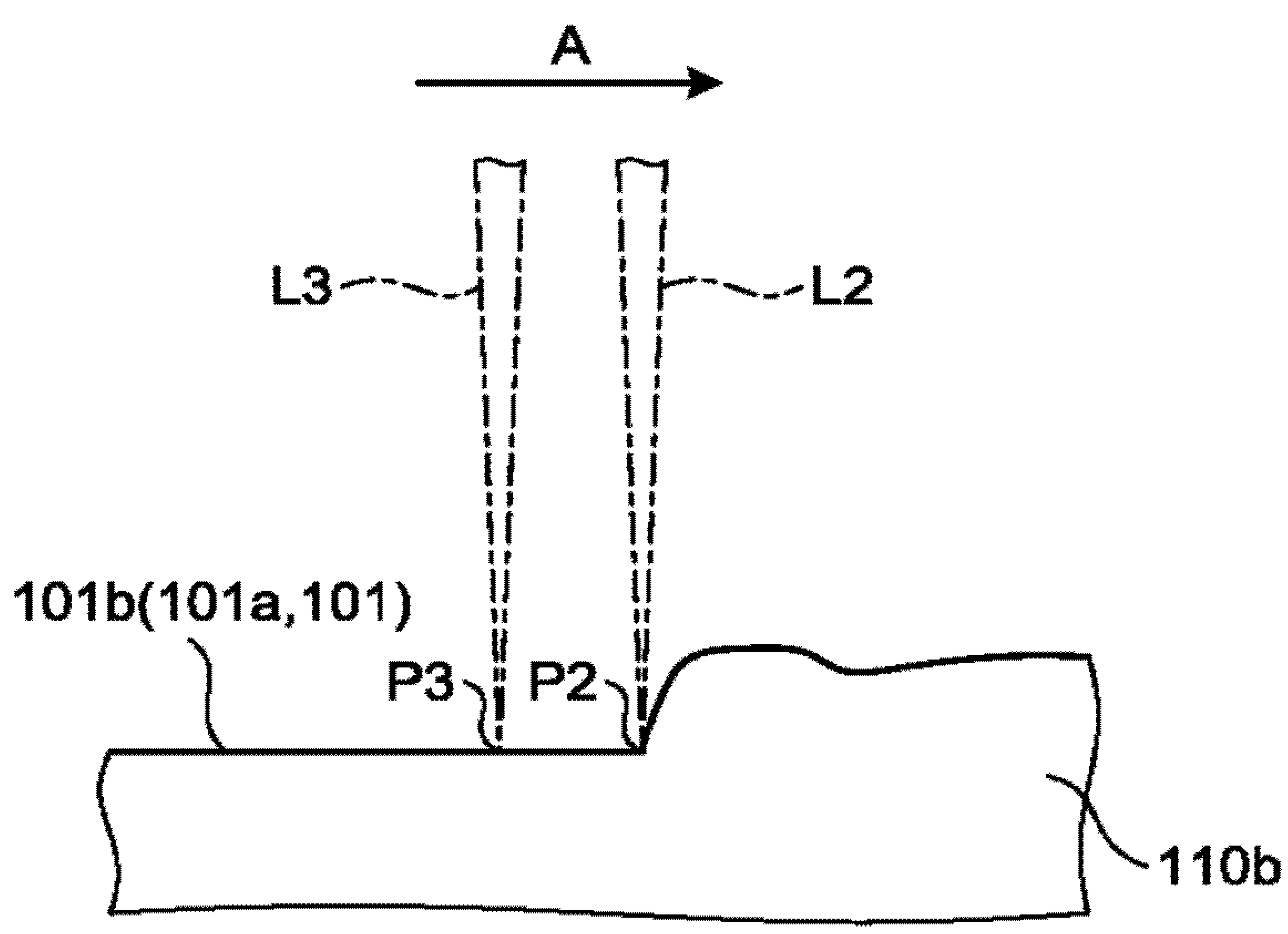


FIG.5

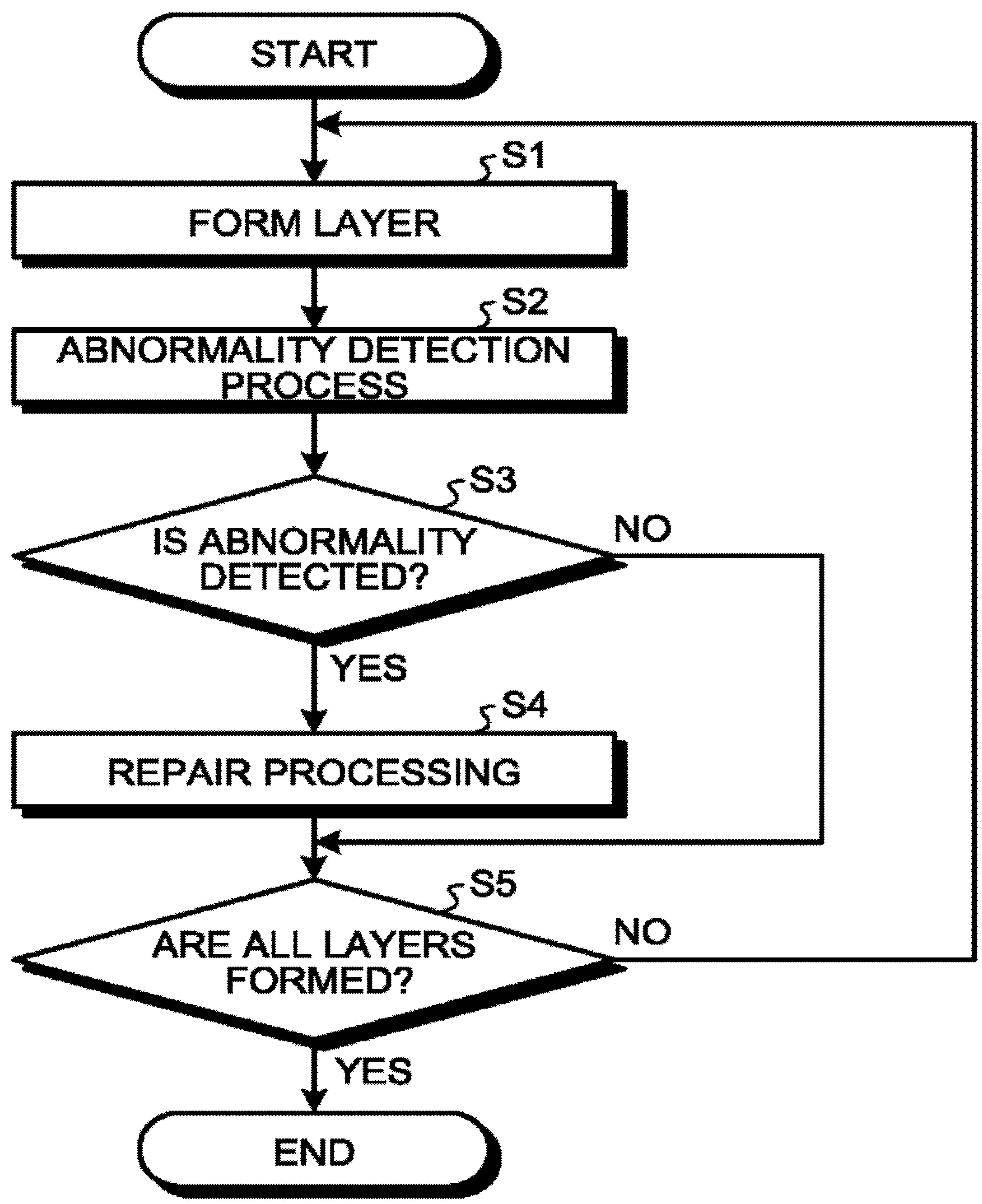

START
S1
FORM LAYER
S2
ABNORMALITY DETECTION PROCESS
S3
IS ABNORMALITY DETECTED?
NO
YES
S4
REPAIR PROCESSING
S5
ARE ALL LAYERS FORMED?
NO
YES
END

FIG.6

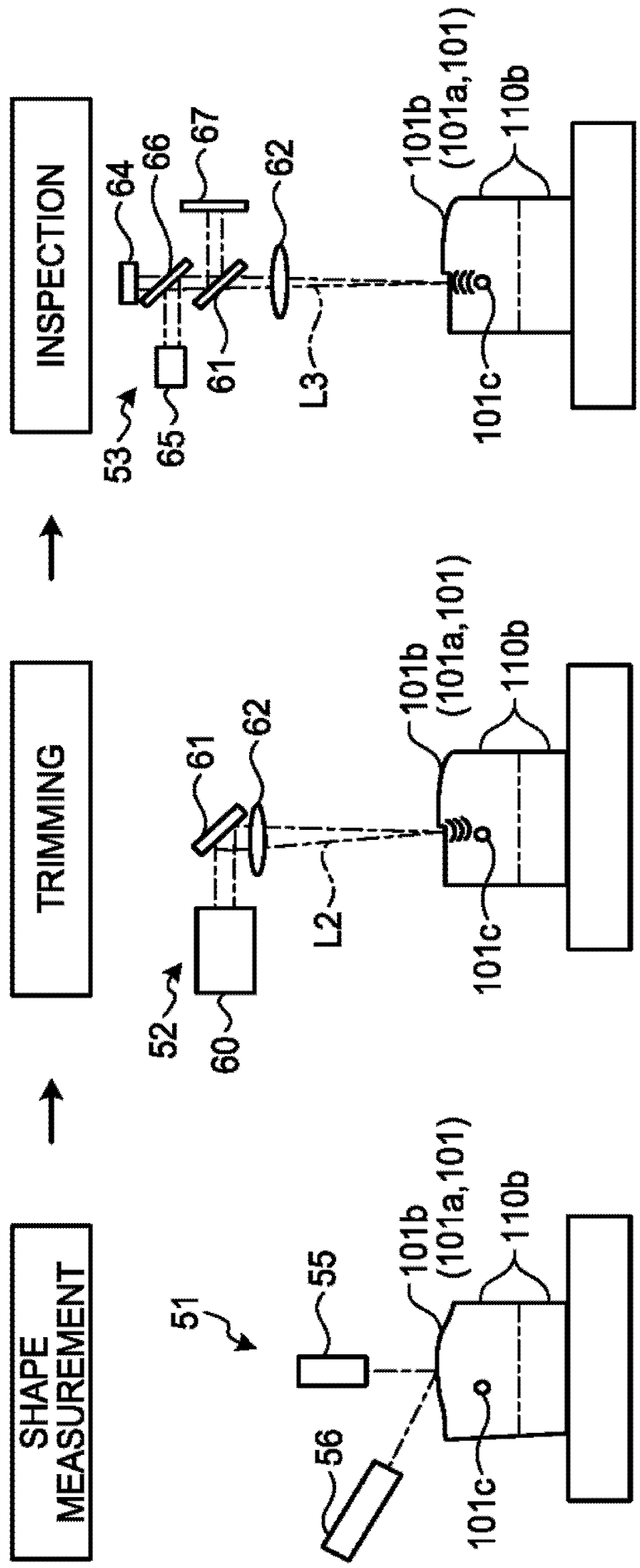

SHAPE MEASUREMENT
51
55
56
101b
(101a,101)
110b
101c
TRIMMING
52
60
61
62
L2
101b
(101a,101)
110b
101c
INSPECTION
53
64
65
66
67
61
62
L3
101b
(101a,101)
110b
101c

FIG.7

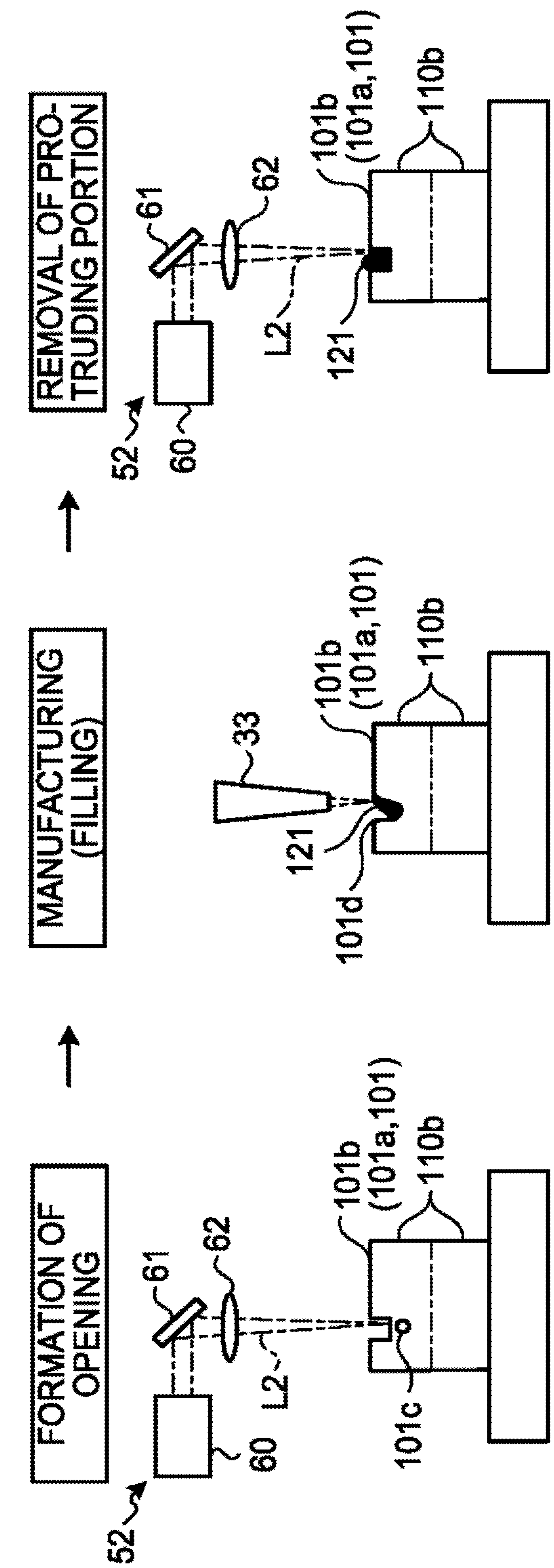
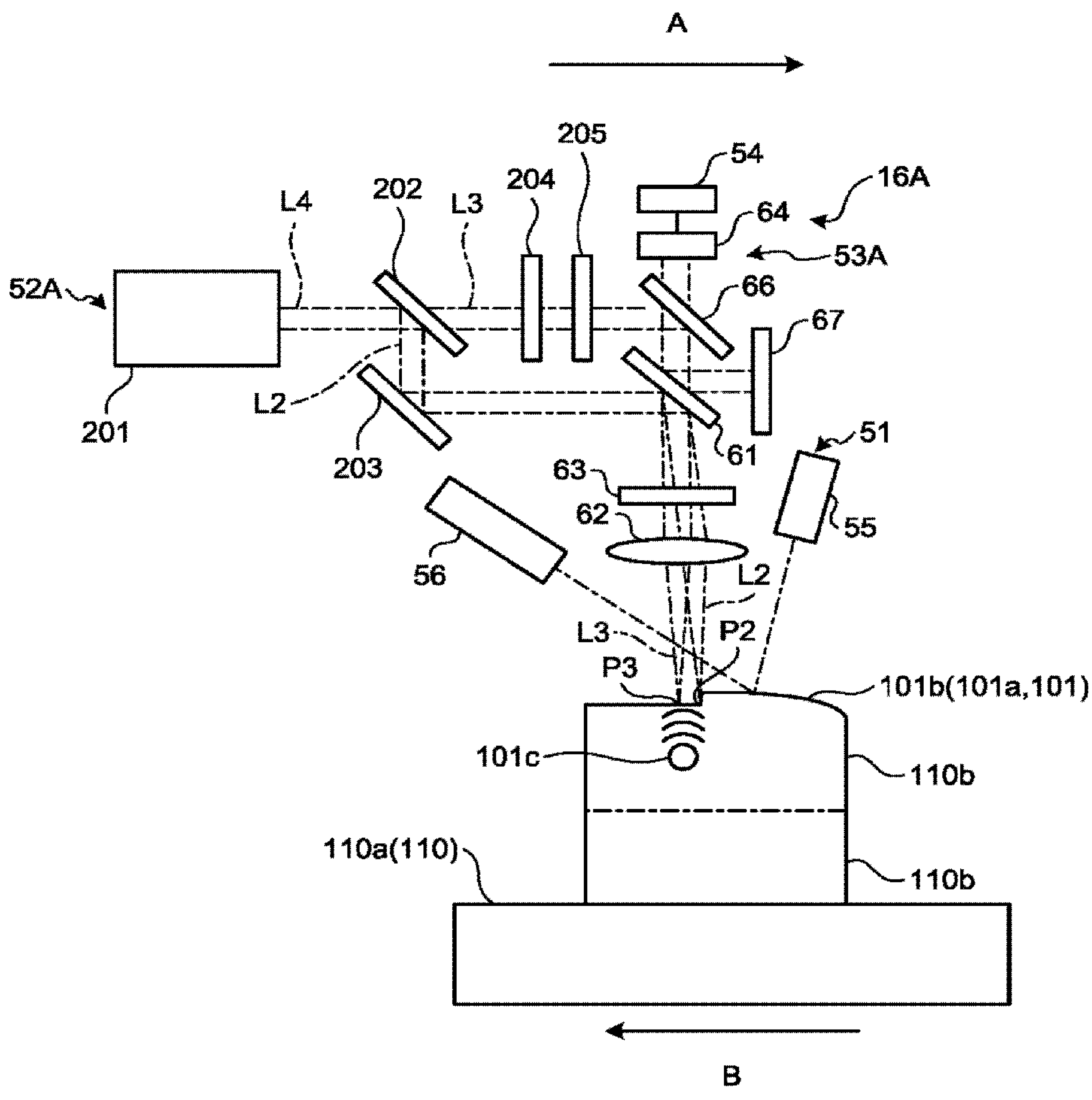

FORMATION OF OPENING
MANUFACTURING (FILLING)
REMOVAL OF PRO-TRUDING PORTION
52
60
61
62
L2
101b
(101a,101)
110b
101c
33
121
101d

FIG.8


A
205
54
204
202
L3
16A
L4
64
53A
52A
66
67
L2
201
61
51
203
63
62
55
56
L2
L3
P2
P3
101b(101a,101)
101c
110b
110a(110)
110b
B

ADDITIVE MANUFACTURING APPARATUS AND ADDITIVE MANUFACTURING METHOD

FIELD

[0001] Embodiments of the present invention relates to an additive manufacturing apparatus and an additive manufacturing method.

BACKGROUND

[0002] Conventionally, there has been known an additive manufacturing apparatus to form an additive manufactured object. The additive manufacturing apparatus forms a layer by melting a powder material by a laser beam, and forms the additive manufactured object having a three-dimensional shape by stacking the layers.

CITATION LIST

Patent Literature

[0003] Patent Literature 1: JP 2006-200030 A
[0004] Patent Literature 2: JP 2012-163406 A

SUMMARY OF THE INVENTION

Problem to be Solved by the Invention

[0005] A manufactured object which is manufactured by such an additive manufacturing apparatus may contain an abnormal area such as a bubble generated during manufacture. It is significant to obtain an additive manufacturing apparatus and an additive manufacturing method which allow detection of abnormality in such a manufactured object.

Means for Solving Problem

[0006] An additive manufacturing apparatus according to one embodiment includes a manufacturing unit, an elastic wave generation unit, an elastic wave detection unit, and an inspection unit. The manufacturing unit sequentially stacks a layer formed by emitting a first energy beam to a material and solidifying the material. The elastic wave generation unit emits a second energy beam to a manufactured object including the layer and generates an elastic wave propagating in the manufactured object. The elastic wave detection unit detects the elastic wave. The inspection unit inspects the manufactured object on the basis of a detection result from the elastic wave detection unit.

BRIEF DESCRIPTION OF DRAWINGS

[0007] FIG. **1** is an exemplary schematic view of an additive manufacturing apparatus according to a first embodiment.

[0008] FIG. **2** is an exemplary schematic cross-sectional view of part of a nozzle according to the first embodiment.

[0009] FIG. **3** is an exemplary schematic view of an inspection device according to the first embodiment.

[0010] FIG. **4** is an exemplary schematic view of irradiation positions of laser beams according to the first embodiment.

[0011] FIG. **5** is an exemplary flowchart of a procedure to form an additive manufactured object according to the first embodiment.

[0012] FIG. **6** is an exemplary explanatory view of an abnormality detection process for an additive manufactured object according to the first embodiment.

[0013] FIG. **7** is an exemplary explanatory view of repair processing for an additive manufactured object according to the first embodiment.

[0014] FIG. **8** is an exemplary schematic view of an inspection device according to a second embodiment.

DETAILED DESCRIPTION

[0015] Embodiments will be described below with reference to the drawings. Note that, in the following embodiments, similar elements are included. Therefore, in the following, those similar elements are denoted by common reference numerals/signs, and repeated description will be omitted.

First Embodiment

[0016] An additive manufacturing apparatus **1** according to the present embodiment, illustrated in FIG. **1**, forms an additive manufactured object according to a laser deposition method. The additive manufacturing apparatus **1** includes a treatment tank **11**, a stage **12**, a moving device **13**, a nozzle device **14**, an optical device **15**, an inspection device **16**, a control unit **17**, and the like. The additive manufacturing apparatus **1** feeds a material **121** (manufacturing material) through the nozzle device **14**, and emits a laser beam L**1** to the material **121** to form a layer **110***b* of the material **121** on an object **110** disposed on the stage **12**, so that the layers **110***b* are stacked to form an additive manufactured object **100**. Here, a manufactured object **101** includes at least one layer **110***b*. The manufactured object **101** represents an intermediate product provided in a manufacturing process of the additive manufactured object **100**, or the additive manufactured object **100** having been formed.

[0017] The object **110** is an object to which the material **121** is fed through the nozzle device **14**, and includes a base **110***a* and the layer **110***b*. A plurality of the layers **110***b* is stacked on an upper face of the base **110***a*. The material **121** includes a powdered metal material, a powdered resin material, or the like. Alternatively, the material **121** may be not the powdered material but a linear material. For manufacturing, at least one material **121** can be used.

[0018] In the treatment tank **11**, a main chamber **21** and a sub-chamber **22** are provided. The sub-chamber **22** is provided adjacent to the main chamber **21**. Between the main chamber **21** and the sub-chamber **22**, a door portion **23** is provided. When the door portion **23** is opened, the main chamber **21** and the sub-chamber **22** communicate with each other, and when the door portion **23** is closed, the main chamber **21** is air-tightly sealed.

[0019] In the main chamber **21**, an air inlet hole **21***a* and an air outlet hole **21***b* are provided. An inert gas such as nitrogen or argon is supplied into the main chamber **21** through the air inlet hole **21***a* by operation of an air supplying device (not illustrated). A gas in the main chamber **21** is exhausted from the main chamber **21** through the air outlet hole **21***b* by operation of an air exhausting device (not illustrated).

[0020] Furthermore, in the main chamber **21**, a transfer device (not illustrated) is provided. Furthermore, a conveying device **24** is provided from the main chamber **21** to the sub-chamber **22**. The transfer device transfers the additive manufactured object **100** treated in the main chamber **21** to the conveying device **24**. The conveying device **24** conveys the additive manufactured object **100** transferred from the transfer device, into the sub-chamber **22**. That is, the sub-chamber **22** stores therein the additive manufactured object **100** treated in the main chamber **21**. After the additive manufactured object **100** is stored in the sub-chamber **22**, the door portion **23** is closed, and the sub-chamber **22** and the main chamber **21** are isolated from each other.

[0021] In the main chamber **21**, the stage **12**, the moving device **13**, part of the nozzle device **14**, the inspection device **16**, and the like are provided.

[0022] The stage **12** supports the object **110**. The moving device **13** can move the stage **12** in orthogonal triaxial directions.

[0023] The nozzle device **14** feeds the powdered (or linear) material **121** to the object **110** positioned on the stage **12**. Furthermore, the nozzle device **14** has a nozzle **33** emitting the laser beam L**1** to the object **110** positioned on the stage **12**. Furthermore, the nozzle **33** emits the laser beam L**1** while feeding the material **121**. The nozzle device **14** emits the laser beam L1 to the material **121** to melt the material **121**, and forms the layer **110***b*. The nozzle device **14** repeatedly forms the layer **110***b*, and sequentially stacks the layers **110***b*. The nozzle device **14** constitutes a manufacturing unit **18** together with the optical device **15**. The laser beam L**1** is an example of a first energy beam. Note that, the energy beam preferably melts or sinters the material **121**, and may be, for example, an electron beam or an electromagnetic wave ranging from microwaves to ultraviolet.

[0024] The nozzle device **14** has a feeding device **31** (manufacturing material feeding device), the nozzle **33**, a feed tube **34**, and the like. The material is fed from the feeding device **31** to the nozzle **33**, through the feed tube **34**.

[0025] The feeding device **31** includes a tank **31***a* and a feed unit **31***b*. The tank **31***a* stores therein the powder material **121**. The feed unit **31***b* feeds a predetermined amount of the material **121** in the tank **31***a*, to the nozzle **33**. When the material **121** is the powdered material, the feed unit **31***b* feeds a carrier gas (gas) containing the material **121** to the nozzle **33**. The carrier gas is, for example, an inert gas such as nitrogen or argon.

[0026] The nozzle **33** has a casing **71**. The casing **71** is configured to have a vertically elongated tubular shape. As illustrated in FIG. **2**, in the casing **71**, a plurality of passages **71***a* and a single passage **71***b* are provided.

[0027] The passage **71***b* is positioned coaxially with an axis Ax of the casing **71**. That is, the passage **71***b* extends vertically. In the passage **71***b*, the laser beam L**1** is introduced from the optical device **15**. In the passage **71***b*, an optical system is provided which includes a conversion lens for converting the laser beam L**1** to parallel light, and a lens for focusing the laser beam L**1** converted to the parallel light. The laser beam L**1** is focused under the casing **71** by the lens. The laser beam L**1** has a focal point (convergence point) positioned on the axis Ax.

[0028] Each of the passages **71***a* is connected to the feeding device **31** through the feed tube **34**. When the material **121** is the powdered material, the material **121** is fed to each passage **71***a* from the feeding device **31**, together with the carrier gas. The passage **71***a* has a lower portion inclined with respect to the axis Ax of the casing **71** to be closer to the axis Ax toward the lower side.

[0029] When the material **121** is the powdered material, the nozzle **33** jets (injects) the material **121** below the casing **71** (passage **71***a*), from a lower end (an opening) of the passage **71***a*. Alternatively, when the material **121** is the linear material, the nozzle **33** extrudes (injects) the material **121** below the casing **71** (passage **71***a*), from the lower end (the opening) of the passage **71***a*. The jetted or extruded material **121** reaches the convergence point of the laser beam L1. The material **121** fed by the nozzle **33** is melted by the laser beam L1 to form a mass of the molten material **121**. Note that, the material **121** may be sintered by the laser beam L1.

[0030] As illustrated in FIG. **1**, the optical device **15** includes a laser emitter **41** and a cable **210**. The laser emitter **41** has an oscillator (not illustrated), and emits the laser beam L**1** by oscillation of the oscillator. The laser emitter **41** can change a power density of the laser beam L1 to be emitted. The laser emitter **41** is connected to the nozzle **33** through the cable **210**. The laser beam L1 emitted from the laser emitter **41** is guided to the nozzle **33**.

[0031] As illustrated in FIG. **3**, the inspection device **16** (apparatus) has a measurement unit **51**, a processing unit **52**, a laser interferometer **53**, and an inspection unit **54** (abnormality detection unit). The measurement unit **51** measures a shape of the manufactured object **101**. The processing unit **52** emits a laser beam L**2** to the manufactured object **101** to partially remove a surface **101***a* of the manufactured object **101**, and generates an elastic wave propagating in the manufactured object **101**, upon impact of emission of the laser beam L2. Furthermore, the processing unit **52** processes the surface **101***a* of the manufactured object **101** on the basis of a measurement result from the measurement unit **51**, and irregularities on the surface **101***a* of the manufactured object **101** can be reduced, that is, can be leveled. The laser interferometer **53** detects the elastic wave. The inspection unit **54** inspects the manufactured object **101** on the basis of a detection result of the elastic wave.

[0032] The measurement unit **51** has an illuminating device **55** (illuminating apparatus), a camera **56** (imaging unit), and an image processing device (not illustrated). The measurement unit **51** measures a shape of a surface of an object to be measured (layer **110***b* or manufactured object **101**), for example, using a light section method. In this measurement, the illuminating device **55** emits linear light to the surface of the object to be measured (layer **110***b* or manufactured object **101**). The camera **56** captures an image including the linear light. The image processing device measures irregularities in the surface shape on the basis of a position of the linear light (deviation from reference line). The measurement unit **51** transmits the measured shape (measurement result) to the control unit **17** (see FIG. **1**). Note that, the measurement unit **51** may measure the shape of the object to be measured using a method (e.g., interference method or the like) other than the light section method.

[0033] The processing unit **52** has a laser emitter **60** (light source), a beam splitter **61**, and a lens **62** (condensing lens).

[0034] The laser emitter **60** has the oscillator (not illustrated), and emits the laser beam L2 by oscillation of the oscillator. The laser beam L2 is, for example, a pulse laser beam. The laser emitter **60** emits the laser beam L2 having intensity large enough to vaporize a solidified material **121** of the manufactured object **101**. The laser beam L2 emitted from the laser emitter **60** is made incident to the beam splitter **61**.

[0035] The beam splitter **61** is positioned on a side of the laser emitter **60**, from which the laser beam L**2** is emitted. The beam splitter **61** reflects part of the incident laser beam L**2**. Note that, in FIG. **3** and the like, illustration of the laser beam L**2** emitted from the laser emitter **60** and passing through the beam splitter **61** is omitted. The laser beam L**2** reflected from the beam splitter **61** is made incident to the lens **62**.

[0036] The laser beam L**2** from the beam splitter **61** is focused by the lens **62**, and is emitted to the surface **101***a* of the manufactured object **101** (layer **110***b*). Specifically, the laser beam L**2** is emitted to, for example, an end face **101***b* of the manufactured object **101** in a stacking direction of the plurality of layers **110***b*. At this time, the laser beam L**2** is emitted to the end face **101***b* (surface **101***a*) of the manufactured object **101**, substantially along a normal direction (stacking direction of the layers **110***b*) of the end face **101***b* (surface **101***a*).

[0037] The processing unit **52** vaporizes part of the material of the manufactured object **101** and removes part of the manufactured object **101** with the laser beam L**2** emitted to the manufactured object **101** through the above-described optical system (first optical system). At this time, the processing unit **52** can change an amount of manufactured object **101** to be removed according to a measurement result from the measurement unit **51** to reduce the irregularities on the surface **101***a* (end face **101***b*), that is, to level the end face **101***b* (surface **101***a*). The processing unit **52** can change an amount of end face **101***b* (surface **101***a*) to be removed by, for example, changing the intensity of the laser beam L**2**. In this case, the intensity of the laser beam L**2** is set larger with increasing height of the surface **101***a*. The processing unit **52** processes the end face **101***b* to have a flat face parallel with a movement direction (direction orthogonal to the stacking direction) of the stage.

[0038] Furthermore, the processing unit **52** generates the elastic wave (density wave) in the manufactured object **101**, upon impact of irradiation of the end face **101***b* (surface **101***a*) with the laser beam L**2**. In the manufactured object **101**, the elastic wave radially propagates from a processing position processed by the laser beam L**2** on the end face **101***b* (surface **101***a*). The processing unit **52** is an example of an elastic wave generation unit and a removal unit. That is, the elastic wave generation unit serves as the processing unit **52** and the removal unit. In other words, the processing unit **52** serves as the elastic wave generation unit and the removal unit. Furthermore, the laser beam L**2** is an example of a second energy beam and a first laser beam.

[0039] Furthermore, an optical filter **63** is provided between the beam splitter **61** and the lens **62**. The optical filter **63** is configured to transmit the laser beam L**2** reflected from the beam splitter **61** to the lens **62**, and not to transmit the reflected light of the laser beam L**2** emitted from the lens **62** to the manufactured object **101** and reflected from the manufactured object **101**. Furthermore, an optical filter (not illustrated) can be provided on the opposite side of the beam splitter **61** relative to the laser emitter **60**. The optical filter does not transmit the laser beam L**2** emitted from the laser emitter **60** and passing through the beam splitter **61**.

[0040] The laser interferometer **53** has a laser emitter **65**, a beam splitter **66**, the beam splitter **61**, the lens **62**, a mirror **67**, and a detector **64**. The laser interferometer **53** detects the elastic wave propagating in the manufactured object **101**. The laser interferometer **53** is an example of an elastic wave detection unit.

[0041] The laser emitter **65** has the oscillator (not illustrated), and emits a laser beam L**3** oscillated by the oscillator. The laser beam L**3** is, for example, a continuous laser beam (CW laser beam) or a pulse laser beam. The laser beam L**3** emitted from the laser emitter **65** is made incident to the beam splitter **66**.

[0042] The beam splitter **66** is positioned on a side of the laser emitter **65**, from which the laser beam L**3** is emitted. The beam splitter **66** partially reflects the incident laser beam L**3**. The laser beam L**3** reflected from the beam splitter **61** is made incident to the lens **62**. Note that, in FIG. **3** and the like, the laser beam L**3** emitted from the laser emitter **65** and passing through the beam splitter **66** is not illustrated.

[0043] The laser beam L**3** from the beam splitter **66** is focused by the lens **62**, and is emitted to the end face **101***b* (surface **101***a*) of the manufactured object **101** (layer **110***b*). At this time, the laser beam L**3** is emitted to the end face **101***b* (surface **101***a*) of the manufactured object **101** substantially along a normal direction of the end face **101***b* (surface **101***a*). The laser beam L**3** emitted to the end face **101***b* is reflected from the end face **101***b*, and is made incident to the detector **64** as detected light through the lens **62**, the beam splitter **61**, and the beam splitter **66**. The end face **101***b* of the manufactured object **101** is oscillated by a reflected wave (elastic wave) of the elastic wave reflected in the manufactured object **101**. The laser interferometer **53** detects displacement of the end face **101***b* on the basis of reflected light from the end face **101***b*. Note that, the laser emitter **65** emits the laser beam L**3** having intensity at which the material **121** does not melt on the end face **101***b*.

[0044] While, part of the laser beam L**3** emitted from the laser emitter **65** and made incident to the beam splitter **61** through the beam splitter **66** is reflected from the beam splitter **61** and made incident to the mirror **67**.

[0045] The mirror **67** reflects the incident laser beam L**3**. Part of the laser beam L**3** reflected from the mirror **67** is made incident to the detector **64** as reference light through the beam splitter **61** and the beam splitter **66**.

[0046] The detector **64** is positioned on the opposite side of the beam splitter **66** relative to the beam splitter **61**. The detector **64** receives reflected light (detected light) of the laser beam L**3** reflected from the end face **101***b* of the manufactured object **101**, and reflected light (reference light) of the laser beam L**3** reflected from the mirror **67**. The detector **64** can detect displacement of the end face **101***b* (temporal change in height of the end face **101***b*) on the basis of interference between the detected light and the reference light. That is, the detector **64** detects the elastic wave (reflected wave) on the end face **101***b* of the manufactured object **101**.

[0047] The inspection unit **54** detects (determines) an abnormality **101***c* in the manufactured object **101** on the basis of a detection result from the detector **64**. Here, when a portion of the manufactured object **101** having no abnormality **101***c* therein is inspected, the elastic wave generated on the end face **101***b* reaches a bottom face of the manufactured object **101**, is reflected from the bottom face, and returns to the end face **101***b*. In contrast, when a portion of the manufactured object **101** having the abnormality **101***c* therein is inspected, the elastic wave generated on the end face **101***b* is reflected from the abnormality **101***c* and returns to the end face **101***b*. That is, an elapsed time is longer with increasing depth of the abnormality **101***c*, and the elapsed time is shorter with decreasing depth of the abnormality **101***c*. Therefore, the inspection unit **54** can detect the depth (position) of the abnormality **101***c* on the basis of the elapsed time from emission of the laser beam to detection of the displacement of the end face **101***b*, or on the basis of a parameter changing according to the elapsed time.

[0048] Furthermore, when the abnormality **101***c* is a void, the reflected wave has a smaller intensity with decreasing size of the abnormality **101***c* and with increasing density of the inspected portion, and the reflected wave has a larger intensity with increasing size of the abnormality **101***c* and with decreasing density of the inspected portion. Therefore, the inspection unit **54** can detect a size of the abnormality **101***c* or a density of an inspected portion, on the basis of the intensity (amplitude) of the reflected wave or the parameter changing according to the intensity of the reflected wave.

[0049] As described above, the inspection unit **54** can detect the presence or absence, the depth (position), the density, or the like of the abnormality **101***c* in the manufactured object **101**, on the basis of a detection result (elastic wave, elastic wave signal) from the detector **64**. Note that, the inspection unit **54** can detect a position of the abnormality **101***c* on a plane orthogonal to the stacking direction, on the basis of information obtained from the control unit **17** and representing an irradiation position of the laser beam L**3** from the laser emitter **65**. Furthermore, the inspection unit **54** has, for example, a control unit and a storage unit. The control unit has a central processing unit (CPU), a controller, or the like. The storage unit has a read only memory (ROM), a random access memory (RAM), and the like. The control unit can execute various calculation processing relating to the abnormality detection according to a loaded program (e.g., an operating system (OS), an application, or a web application).

[0050] Here, in the present embodiment, a single lens **62** focuses the laser beam L**2** and the laser beam L**3**, as illustrated in FIG. **3**. However, as illustrated in FIG. **4**, a focal position (converging position) of the laser beam L**2** focused by the lens **62** is different in location from a focal position (converging position) of the laser beam L**3** focused by the lens **62**. Specifically, in a relative movement direction of the laser beams L**2** and L**3**, that is, the relative movement direction of the inspection device **16** relative to the manufactured object **101** (direction indicated by an arrow A in FIG. **3**), an irradiation position P**3** of the laser beam L**3** is positioned in back (on the upstream side) of an irradiation position P**2** of the laser beam L**2**. Therefore, the laser beam L**3** is emitted to a position of the end face **101***b* which has the irregularities reduced or leveled by the laser beam L**2**, and displacement is then detected on the basis of the reflected wave (elastic wave) from the position. Thus, according to the present embodiment, displacement can be detected with high accuracy, compare with, for example, detection of the displacement based on a reflected wave (elastic wave) from a position which has irregularities not reduced by the laser beam L**2** and to which the laser beam L**3** is emitted. Note that, an arrow B in FIG. **3** represents the movement direction of the stage **12** (manufactured object **101**) moved by driving the moving device **13**.

[0051] Furthermore, in the present embodiment, the laser beam L**2** (first laser beam) and the laser beam L**3** (second laser beam) may have different wavelengths so that the laser beams do not interfere with each other. Specifically, for example, the wavelength of the laser beam L**2** may be shorter than the wavelength of the laser beam L**3**. Furthermore, the laser beam L**2** and the laser beam L**3** may be different in polarization direction (polarization plane) so that the laser beams do not interference with each other. Specifically, for example, one of the laser beam L**2** and the laser beam L**3** may be P polarized light, and the other thereof may be S polarized light.

[0052] Furthermore, when the laser beam L**2** has a smaller pulse width, the elastic wave has a higher frequency and resolution is increased, whereby detection of a smaller abnormality **101***c* is facilitated. However, when the laser beam L**2** has the smaller pulse width, that is, the elastic wave has a higher frequency, the elastic wave is more absorbed in the manufactured object **101** and detection of the elastic wave is made more difficult. Accordingly, the pulse width of the laser beam L**2** is set according to the size of the abnormality **101***c* to be detected. For example, for the abnormality **101***c* having a size not less than several micrometers, the pulse width of the laser beam L**2** can be set to 1 fs to 1 ns.

[0053] As an example, the control unit **17** has a central processing unit (CPU) and a storage unit. The storage unit has a read only memory (ROM), a random access memory (RAM), and the like. The control unit **17** is electrically connected to the moving device **13**, the optical device **15**, the conveying device **24**, the feeding device **31**, and the inspection device **16**, through a signal line **220**. The control unit **17** (CPU) controls the moving device **13**, the optical device **15**, the conveying device **24**, the feeding device **31**, and the inspection device **16**, according to a loaded program (e.g., an operating system (OS), an application, or a web application). The additive manufacturing apparatus **1** forms the additive manufactured object **100** on the basis of control (program) of the control unit **17**.

[0054] The control unit **17** controls the moving device **13** to move the stage **12** in the triaxial directions. The control unit **17** controls the conveying device **24** to convey the additive manufactured object **100** having been formed to the sub-chamber **22**. The control unit **17** controls the feeding device **31** to adjust feeding or non-feeding of the material **121** and an amount of the material **121** to be fed. The control unit **17** controls the laser emitter **41** to adjust the intensity (power density) of the laser beams L**1**, L**2**, and L**3** emitted from the laser emitters **41**, **60**, and **65**. Furthermore, the control unit **17** controls a moving device (not illustrated) to control the movement of the nozzle **33**. Furthermore, the control unit **17** controls a moving device (not illustrated) to control the movement of the inspection device **16**.

[0055] The storage unit of the control unit **17** stores therein data or the like representing a shape (reference shape) of the additive manufactured object **100** to be formed. This shape data includes data about the shape (reference shape) of each layer **110***b*.

[0056] The control unit **17** has a function of determining the shape of the layer **110***b* or the additive manufactured object **100**. The control unit **17** compares the shape of the layer **110***b* or the additive manufactured object **100** measured by the measurement unit **51** with the reference shape stored in the storage unit, and determines whether a portion without a predetermined shape is formed.

[0057] Furthermore, the control unit **17** has a function of trimming the shape of the layer **110***b* or the additive manufactured object **100** into a predetermined shape. The control unit **17** controls the laser emitter **60** of the processing unit **52** so that the laser beam L**2** has intensity strong enough to vaporize a portion (portion to be removed) of the layer **110***b* or the additive manufactured object **100** having a shape other than the predetermined shape. Next, the control unit **17** controls the processing unit **52** and the moving device **13** so that the laser beam L**2** is emitted to the portion. Therefore, the portion is vaporized.

[0058] Next, an example of a procedure of forming the additive manufactured object **100** by the additive manufacturing apparatus **1** (i.e., a method for producing the additive manufactured object **100**) will be described with reference to a flowchart of FIG. **5**.

[0059] First of all, the control unit **17** controls the moving device **13**, the nozzle device **14**, and the optical device **15** to form the layer **110***b* (S**1**). At S**1**, the material **121** is fed and the laser beam L**1** is emitted on the basis of the data (reference data) about the layer **110***b* stored in the storage unit. At this time, the control unit **17** controls the moving device **13**, the feeding device **31**, and the like to feed the material **121** from the nozzle **33** to a predetermined range, and controls the laser emitter **41** to melt the fed material **121** by the laser beam L**1**. Therefore, a predetermined amount of the molten material **121** is fed to a range in which the layer **110***b* is formed on the base **110***a*. At this time, in the present embodiment, the material **121** is fed so that the layer **110***b* to be formed has a height larger than the height in the data about the layer **110***b* stored in the storage unit. After the material **121** is jetted or extruded on the base **110***a* or the layer **110***b*, a mass of the material **121**, such as a layer or a thin film, is formed. At this time, the material **121** is cooled by the carrier gas carrying the material **121** or solidified by being cooled due to heat transfer to the mass of the material **121**, and then the layer **110***b* is formed. The control unit **17** may perform annealing. In the annealing, the control unit **17** controls the laser emitter **41** so that the laser beam L**1** is emitted to the layer **110***b* onto the base **110***a*. Therefore, after the material **121** in the layer **110***b* is melted again, the material **121** is solidified again. Note that, annealing may be performed outside the additive manufacturing apparatus **1**, using an annealing apparatus (not illustrated).

[0060] Next, the control unit **17** controls the inspection device **16** and the moving device **13** to inspect inside the manufactured object **101** (S**2**: abnormality detection process (inspection process)). As illustrated in FIG. **6**, at S**2**, shape measurement, trimming, and inspection are performed. First of all, the control unit **17** controls the measurement unit **51** and the moving device **13** to measure the shape (surface shape, three-dimensional shape) of the surface **101***a* of the layer **110***b* of the manufactured object **101**. The control unit **17** obtains measured shape data representing the shape of the layer **110***b* from the measurement unit **51**. Then, the control unit **17** controls the processing unit **52** and the moving device **13** to trim the end face **101***b* of the manufactured object **101** (surface **101***a*). At this time, the control unit **17** controls the processing unit **52** and the moving device **13** so that the height of the layer **110***b* is substantially the same as the height indicated in the data about the layer **110***b* stored in the storage unit (e.g., a certain height). At this time, the control unit **17** changes the amount of end face **101***b* to be removed according to a measured height of the end face **101***b* of the layer **110***b* (irregularities) so that the height of the end face **101***b* of the layer **110***b* (thickness of the layer **110***b*) is substantially constant. Specifically, the control unit **17** controls the processing unit **52** so that the laser beam L**2** has intensity according to the amount of end face **101***b* to be removed. Therefore, for example, a next layer **110***b* can be effectively formed flat, or accuracy in inspection of the elastic wave is effectively increased. Trimming is performed with emission of the laser beam L**2** by the processing unit **52**. Then, the laser interferometer **53** detects, using the laser beam L**3**, the elastic wave generated by emission of the laser beam L**2**, and the inspection unit **54** detects (determines) the presence or absence of an abnormality **101***c* in the manufactured object **101** on the basis of a detection result from the laser interferometer **53**. The detection of the presence or absence of the abnormality **101***c* is performed whenever the laser beam L**2** is emitted. In the present embodiment, detection of the presence or absence of the abnormality **101***c* is performed for whole area of the end face **101***b*. Furthermore, when comparison, which is performed between reference shape data about the layer **110***b* stored in the storage unit and the measured shape data as a measurement result from the measurement unit **51**, shows that the manufacturing is performed in a portion (area) where the manufacturing should not be performed, the control unit **17** removes the portion at the trimming. For example, when manufacturing is performed in a portion (area) where manufacturing should not be performed in a direction orthogonal to the stacking direction, the control unit **17** removes the portion.

[0061] S**2** may be performed whenever one layer **110***b* is formed, or may be performed whenever a plurality of layers **110***b* is formed. S**2** is performed after the layer **110***b* is formed. Note that, the shape measurement and the trimming may be performed whenever one layer **110***b* is formed, and detection of the elastic wave may be performed whenever a plurality of layers **110***b* is formed.

[0062] Then, as illustrated in FIG. **5**, when the inspection device **16** (the inspection unit **54**) detects an abnormality **101***c* in the manufactured object **101** ("Yes" at S**3**), the control unit **17** repairs (removes) the abnormality **101***c* (S**4**: repairing processing). When the abnormality **101***c* is a void, at S**4**, formation of an opening, manufacturing (filling), and removal of a protruding portion are performed, as illustrated in FIG. **7**. First of all, the control unit **17** controls the processing unit **52** and the moving device **13** to remove a portion of the manufactured object **101** between the end face **101***b* (surface **101***a*) and the abnormality **101***c*, that is, a portion of the manufactured object **101** on a side of the end face **101***b* relative to the abnormality **101***c*. Therefore, an opening **101***d* is formed in the manufactured object **101** to have the abnormality **101***c* at the bottom. Next, the control unit **17** controls the manufacturing unit **18** so that the opening **101***d* is filled with the material **121** and the material **121** is solidified. At this time, the manufacturing unit **18** performs manufacturing, for example, until the material **121** protrudes from the opening **101***d*. Then, the control unit **17** controls the processing unit **52** to remove at least part of the manufactured object **101** protruded from the opening **101***d*, that is, all or part of a portion of the manufactured object **101** protruding from the opening **101***d*. More specifically, the control unit **17** controls the laser emitter **60** of the processing unit **52** to vaporize the protruding portion (material **121**) protruded from the opening **101***d*. Since the protruding portion is removed as described above, a filled portion is further readily leveled. Note that, S**4** may be performed whenever a plurality of layers **110***b* is formed.

[0063] In contrast, when the inspection device **16** does not detect the abnormality **101***c* in the manufactured object **101** ("No" at S**3**), S**4** is not performed.

[0064] Next, as illustrated in FIG. **5**, when not all layers **110***b* are formed ("No" at S**5**), the processing returns to S**1**, and a new layer **110***b* is formed on the layer **110***b* having been formed. The control unit **17** repeatedly performs processing of S**1** to S**5** to stack the plurality of layers **110***b*. When all layer **110***b* are formed ("Yes" at S**5**), a series of processing is finished.

[0065] As described above, in the present embodiment, the manufacturing unit **18** sequentially stacks the layer **110***b* formed by emitting the laser beam L**1** (first energy beam) to the powdered (or linear) material **121** and solidifying the material **121**; the processing unit **52** (elastic wave generation unit) generates the elastic wave propagating in the manufactured object **101** including at least one layer **110***b*; the laser interferometer **53** detects the elastic wave; and the inspection unit **54** inspects the manufactured object **101** on the basis of a detection result from the laser interferometer **53**. Thus, the abnormality **101***c* in the manufactured object **101** can be detected.

[0066] Furthermore, in the present embodiment, the processing unit **52** emits the laser beam L**2** (second energy beam) to process the surface **101***a* of the manufactured object **101**. The processing unit **52** emits the laser beam **12** to the surface **101***a* to generate the elastic wave. That is, since the processing unit **52** functions as the elastic wave generation unit, the additive manufacturing apparatus **1** can have a simple configuration in comparison with a configuration in which the elastic wave generation unit is provided separately from the processing unit **52**.

[0067] Furthermore, in the present embodiment, the laser beam L**2** (first laser beam) and the laser beam L**3** (second laser beam) do not interfere with each other. Thus, the abnormality **101***c* in the manufactured object **101** can be detected with high accuracy.

[0068] Furthermore, in the present embodiment, a single lens **62** focuses the laser beam L**2** and the laser beam L**3**. Thus, the additive manufacturing apparatus **1** can have a simple configuration in comparison with a configuration in which the laser beam L**2** and the laser beam L**3** are focused by different lenses.

[0069] Furthermore, in the present embodiment, the processing unit **52** (removal unit) can partially remove the manufactured object **101**. When the inspection unit **54** detects the abnormality **101***c* in the manufactured object **101**, the processing unit **52** partially removes the manufactured object **101** from the surface **101***a* of the manufactured object **101** to the abnormality **101***c*, and then the manufacturing unit **18** fills the material **121** in the opening **101***d* of the manufactured object **101** formed after removal thereof by the processing unit **52**, so that the material **121** is solidified. Thus, the manufactured object **101** repaired after removing the abnormality **101***c* can be obtained.

Second Embodiment

[0070] An additive manufacturing apparatus **1**A according to the present embodiment includes a configuration similar to that of the additive manufacturing apparatus **1** according to the first embodiment. However, in the present embodiment, an inspection device **16**A is different from the inspection device **16** according to the first embodiment, as illustrated in FIG. **8**.

[0071] The inspection device **16**A has the measurement unit **51**, a processing unit **52**A, a laser interferometer **53**A, and the inspection unit **54**.

[0072] In the present embodiment, a laser emitter **201** (light source), the beam splitter **61**, the beam splitter **66**, a beam splitter **202**, the mirror **67**, a mirror **203**, the lens **62** (condensing lens), a wavelength converter **204**, a light intensity adjusting member **205**, and the detector **64** are provided as members constituting the processing unit **52**A and the laser interferometer **53**A. The processing unit **52**A has the laser emitter **201**, the beam splitters **61** and **202**, the mirror **203**, and the lens **62**. In contrast, the laser interferometer **53**A has the laser emitter **201**, the beam splitters **61**, **66**, and **202**, the lens **62**, the mirror **67**, the wavelength converter **204**, the light intensity adjusting member **205**, and the detector **64**. The processing unit **52**A is an example of the elastic wave generation unit and the removal unit.

[0073] The laser emitter **201** has the oscillator (not illustrated), and emits a laser beam L**4** oscillated by the oscillator. The laser beam L**4** is, for example a pulse laser beam. The laser beam L**4** is an example of a third laser beam.

[0074] The laser beam L**2** emitted from the laser emitter **201** is made incident to the beam splitter **202**, and is divided into the laser beam L**2** and the laser beam L**3** by the beam splitter **202**. The beam splitter **202** is an example of a dividing unit.

[0075] The laser beam L**2** is reflected from the mirror **203** and is made incident to the beam splitter **61**. The laser beam L**2** is partially reflected from the beam splitter **61**, is focused by the lens **62**, and is emitted to the end face **101***b* of the manufactured object **101**.

[0076] The laser beam L**3** is made incident to the wavelength converter **204** and the light intensity adjusting member **205** in sequence, is converted in wavelength by the wavelength converter **204**, and is reduced in light intensity by the light intensity adjusting member **205**. The laser beam L**3** emitted from the light intensity adjusting member **205** is made incident to the beam splitter **66**. The laser beam L**3** is partially reflected by the beam splitter **66**, and is made incident to the beam splitter **61**. The laser beam L**3** incident to the beam splitter **61** is divided into light incident to the lens **62** and light incident to the mirror **67**, similarly to the first embodiment. The laser beam L**3** incident to the lens **62** is focused by the lens **62**, and is emitted to the end face **101***b* of the manufactured object **101**. The laser beam L**3** emitted to the end face **101***b* of the manufactured object **101** is reflected from the end face **101***b*, and is made incident to the detector **64** through the lens **62**, the beam splitter **61**, and the beam splitter **66**. In contrast, the laser beam L**3** reflected from the mirror **67** is made incident to the detector **64** through the beam splitter **61** and the beam splitter **66**. Note that, the laser beam L**3** is adjusted by the light intensity adjusting member **205** in light intensity to have intensity small enough to prevent melting of the material **121** on the end face **101***b*.

[0077] Furthermore, also in the present embodiment, a single lens **62** focuses the laser beam L**2** and the laser beam L**3**, similarly to the first embodiment. Furthermore, the focal position (converging position) of the laser beam L**2** focused by the lens **62** is different in location from the focal position (converging position) of the laser beam L**3** focused by the lens **62**. Specifically, in a relative movement direction of the laser beams L**2** and L**3**, that is, a relative movement direction of the inspection device **16**A relative to the manufactured object **101** (e.g., direction indicated by an arrow A), an irradiation position P**3** of the laser beam L**3** is positioned in back (on the upstream side) of an irradiation position P**2** of the laser beam L**2**.

[0078] Furthermore, in the present embodiment, since the wavelength of the laser beam L**3** of the laser beam L**2** is converted by the wavelength converter **204**, the laser beam L**3** and the laser beam L**2** do not interference with each other even if the laser beam L**3** and the laser beam L**2** overlap each other.

[0079] As described above, in the present embodiment, a single laser emitter **201** emits the laser beam L**4** (third laser beam), and the beam splitter **202** (dividing unit) divides the laser beam L**4** emitted from the laser emitter **201** into the laser beam L**2** (first laser beam) and the laser beam L**3** (second laser beam). Thus, the number of laser emitters **201** can be reduced in comparison with a configuration in which laser emitters are provided for the laser beams L**2** and L**3** emitted from the laser emitter **201**.

[0080] Note that, each of the above-described embodiments may be configured, for example, so that the feeding device **31** supplies a plurality of materials **121** of different kinds to the nozzle **33** and the plurality of different materials **121** is selectively supplied from the nozzle **33** so as to adjust (change) the percentages of the materials **121**. Therefore, a gradient material (functional gradient material), in which the proportions of the materials **121** change (gradually reduce or gradually increase) according to the position (location) in the additive manufactured object **100**, can be manufactured. Specifically, for example, upon forming the layer **110***b*, the control unit **17** can control the feeding device **31** to have the proportions of the materials **121** set (stored) corresponding to each position of three-dimensional coordinates of the additive manufactured object **100**, so that the additive manufactured object **100** can be formed as the gradient material (functional gradient material) in which the proportions of the materials **121** are arbitrarily changed in a three-dimensional direction. An amount of change (rate of change) in percentage of the material **121** per unit length can be also variously set.

[0081] As described above, according to each of the above-described embodiments, the additive manufacturing apparatuses **1** and **1**A and the additive manufacturing method can be obtained by which the abnormality **101***c* in the manufactured object **101** can be detected, for example.

[0082] Certain embodiments have been described, but these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. The novel embodiments may be embodied in a variety of other forms, and furthermore, various omissions, substitutions and changes may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such embodiments or modifications as would fall within the scope and spirit of the inventions.

[0083] For example, the additive manufacturing apparatus may have a configuration (powder bed process) or the like, in which a step of feeding powder material by a material feed unit to form a material layer and a step of emitting the first energy beam such as laser beam to the material layer by an irradiation device to solidify a material are repeatedly performed to stack individualized layers (layers) for manufacturing. In this configuration, the material **121** protruded from the opening **101***d* may be removed as required. For example, when the material **121** protruded from the opening **101***d* has a height smaller than the height of the material layer, the material **121** may not be removed.

[0084] Furthermore, in each of the above-described embodiments, the elastic wave is generated in an ablation mode using the laser beam L**2** emitted from the processing unit **52**, but a configuration for emitting the laser beam may be provided separately from the processing unit **52** to generate the elastic wave in a thermal stress mode using the laser beam.

1. An additive manufacturing apparatus comprising:
- a manufacturing unit that sequentially stacks a layer formed by emitting a first energy beam to a material and solidifying the material;
- an elastic wave generation unit that emits a second energy beam to a manufactured object including the layer and generates an elastic wave propagating in the manufactured object;
- an elastic wave detection unit that detects the elastic wave; and
- an inspection unit that inspects the manufactured object on the basis of a detection result from the elastic wave detection unit.

2. The additive manufacturing apparatus according to claim **1**, wherein
- the elastic wave generation unit is served as a processing unit that processes a surface of the manufactured object by emitting the second energy beam.

3. The additive manufacturing apparatus according to claim **2**, further comprising
- a measurement unit that measures a shape of the layer, wherein
- the processing unit processes the surface on the basis of a measurement result from the measurement unit.

4. The additive manufacturing apparatus according to claim **2**, wherein
- the elastic wave detection unit detects the elastic wave in an area of the manufactured object having the surface processed by the processing unit.

5. The additive manufacturing apparatus according to claim **2**, wherein
- the second energy beam is a first laser beam,
- the elastic wave detection unit is a laser interferometer that emits a second laser beam to the surface and receives reflected light of the second laser beam reflected from the surface, and
- the first laser beam and the second laser beam do not interfere with each other.

6. The additive manufacturing apparatus according to claim **5**, further comprising
- a single lens that focuses the first laser beam and the second laser beam.

7. The additive manufacturing apparatus according to claim **5**, further comprising:
- a single laser emitter that emits a third laser beam; and
- a dividing unit that divides the third laser beam emitted from the laser emitter into the first laser beam and the second laser beam.

8. The additive manufacturing apparatus according to claim **1**, further comprising
- a removal unit that is capable of partially removing the manufactured object, wherein
- when the inspection unit detects abnormality in the manufactured object, the removal unit partially removes the

manufactured object from the surface of the manufactured object to the abnormality, and the manufacturing unit fills the material in an opening of the manufactured object formed after removal thereof by the removal unit and solidifies the material.

9. The additive manufacturing apparatus according to claim **8**, wherein

the removal unit removes at least part of the manufactured object protruded from the opening.

10. An additive manufacturing method comprising:

emitting a first energy beam to a material and solidifying the material to form a layer;

emitting a second energy beam to a manufactured object including the layer, and generating an elastic wave propagating in the manufactured object;

detecting the elastic wave; and

inspecting the manufactured object on the basis of a detection result about the elastic wave.

11. The additive manufacturing method according to claim **10**, further comprising:

processing a surface of the manufactured object by emitting the second energy beam; and

generating the elastic wave by processing the surface.

12. The additive manufacturing method according to claim **11**, further comprising:

measuring a shape of the layer; and

processing the surface on the basis of a result of the measurement.

13. The additive manufacturing method according to claim **11**, wherein

the detecting includes detecting the elastic wave in an area of the manufactured object in which the surface is processed.

14. The additive manufacturing method according to claim **11**, wherein

the second energy beam is a first laser beam,

the additive manufacturing method further comprises emitting the second laser beam to the surface and receiving reflected light of the second laser beam reflected from the surface to detect the elastic wave, and

the first laser beam and the second laser beam do not interfere with each other.

15. The additive manufacturing method according to claim **14**, further comprising:

emitting a third laser beam; and

dividing the third laser beam into the first laser beam and the second laser beam.

16. The additive manufacturing method according to claim **10**, further comprising

when abnormality in the manufactured object is detected, partially removing the manufactured object from the surface of the manufactured object to the abnormality, and filling the material in an opening of the manufactured object formed after removal thereof and solidifying the material.

17. The additive manufacturing method according to claim **16**, wherein

the partially removing includes removing at least part of the manufactured object protruded from the opening.

* * * * *