US012383984B2

(12) **United States Patent**
Okuma et al.

(10) **Patent No.: US 12,383,984 B2**
(45) **Date of Patent: Aug. 12, 2025**

(54) **LASER PROCESSING DEVICE**

(71) Applicant: **HAMAMATSU PHOTONICS K.K.**, Hamamatsu (JP)

(72) Inventors: **Junji Okuma**, Hamamatsu (JP); **Mitsuhiro Nagao**, Hamamatsu (JP); **Norihiro Fukuchi**, Hamamatsu (JP); **Yasunori Igasaki**, Hamamatsu (JP)

(73) Assignee: **HAMAMATSU PHOTONICS K.K.**, Hamamatsu (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/087,789**

(22) PCT Filed: **Mar. 28, 2017**

(86) PCT No.: **PCT/JP2017/012645**

§ 371 (c)(1),
(2) Date: **Sep. 24, 2018**

(87) PCT Pub. No.: **WO2017/170553**

PCT Pub. Date: **Oct. 5, 2017**

(65) **Prior Publication Data**

US 2020/0298345 A1 Sep. 24, 2020

(30) **Foreign Application Priority Data**

Apr. 1, 2016 (JP) 2016-074426

(51) **Int. Cl.**
B23K 26/53 (2014.01)
B23K 26/00 (2014.01)
(Continued)

(52) **U.S. Cl.**
CPC ***B23K 26/53*** (2015.10); ***B23K 26/00*** (2013.01); ***B23K 26/064*** (2015.10);
(Continued)

(58) **Field of Classification Search**
CPC B23K 26/0648; B23K 26/083; G02F 1/133553
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,577,429 B1 * 6/2003 Kurtz G02B 27/48 348/E9.026
7,209,279 B2 * 4/2007 Igasaki G03H 1/2205 359/290

(Continued)

FOREIGN PATENT DOCUMENTS

CN 101902012 A 12/2010
CN 102741011 A 10/2012

(Continued)

OTHER PUBLICATIONS

U.S. Appl. No. 13/575,376, filed Jan. 2011, Sakamoto; Takeshi.*

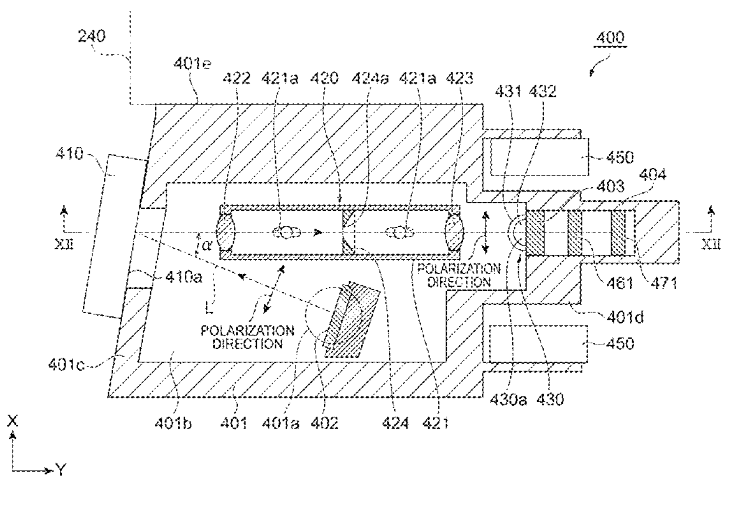
(Continued)

Primary Examiner — Steven W Crabb
Assistant Examiner — Fahmida Ferdousi
(74) *Attorney, Agent, or Firm* — Faegre Drinker Biddle & Reath LLP

(57) **ABSTRACT**

A laser processing device configured to emit laser light on an object to perform laser processing of the object, the laser processing device including: a laser output unit configured to output the laser light; a spatial light modulator configured to reflect the laser light output from the laser output unit while modulating the laser light in accordance with a phase pattern; and an objective lens configured to converge the laser light from the spatial light modulator toward the object, in which the spatial light modulator includes an entrance surface, a reflective surface, and a modulation layer configured to display the phase pattern to modulate the laser light, and a dielectric multilayer film having a high reflectance

(Continued)



region in a plurality of wavelength bands non-contiguous with each other is formed on the reflective surface.

2 Claims, 20 Drawing Sheets

(51) **Int. Cl.**

B23K 26/06	(2014.01)
B23K 26/064	(2014.01)
B23K 26/08	(2014.01)
B23K 103/00	(2006.01)
G02F 1/1335	(2006.01)

(52) **U.S. Cl.**
CPC ***B23K 26/0648*** (2013.01); ***B23K 26/083*** (2013.01); ***G02F 1/133553*** (2013.01); *B23K 2103/56* (2018.08)

(56) **References Cited**

U.S. PATENT DOCUMENTS

10,181,376	B2 *	1/2019	Birnbach	B23K 26/064 219/121.73
2003/0010763	A1 *	1/2003	Fukuchi	G02B 27/46 219/121.75
2010/0295836	A1 *	11/2010	Matsumoto	G09G 3/2092 345/211
2012/0327501	A1 *	12/2012	Sakamoto	B23K 26/53 359/290

FOREIGN PATENT DOCUMENTS

CN	103650264	A		3/2014
CN	203992813	U		12/2014
CN	104852269	A		8/2015
CN	105190382	A		12/2015
CN	105264411	A		1/2016
CN	207071747	U		3/2018
JP	3878758	B2	*	2/2007 .... G02F 1/135
JP	2007-264353	A		10/2007
JP	2011-152562	A		8/2011
JP	2012150510	A	*	8/2012
JP	2013-092688	A		5/2013
JP	2013-128088	A		6/2013
JP	5456510	B2		4/2014
KR	1020140084122			7/2014
WO	WO 2013/061960	A1		5/2013

OTHER PUBLICATIONS

Krueger et al., Spatial light modulator system for application as a dynamic diffractive element and in optical image processing, 2000 (Year: 2000).*
Screenshot of Abrisatechnologies.com (Year: 2015).*
JP-2012150510-A (Year: 2012).*
Wang et al., “Theoretical Analysis of Spectral Selective Transmission Coatings for Solar Energy PV System”, 2013 (Year: 2013).*
RP-Photonics, https://www.rp-photonics.com/gas_lasers.html, Mar. 25, 2016 (Year: 2016).*
Machine translation of JP-3878758-B2 (Year: 2007).*
Introduction to Polarization, edmundoptics.com (Year: 2015).*
Thorlabs, https://thorlabs.com/newgrouppage9.cfm?objectgroup_id=5840 (Year: 2015).*
Wang et al., “Theoretical Analysis of Spectral Selective Transmission Coatings for Solar Energy PV System”, (Year: 2013).*
https://www.rp.photonics.com/gas_lasers.html, (Year: 2016).*
International Preliminary Report on Patentability mailed Oct. 11, 2018 for PCT/JP2017/012645.
Qian Miaogen, “Material surface technology and application manual 4.2 Dielectric reflective film 1-7,” Beijing Machine Industry Publishing (China Machine Press), Nov. 30, 1998, p. 912 (including partial English-language translation).

* cited by examiner

Fig.1

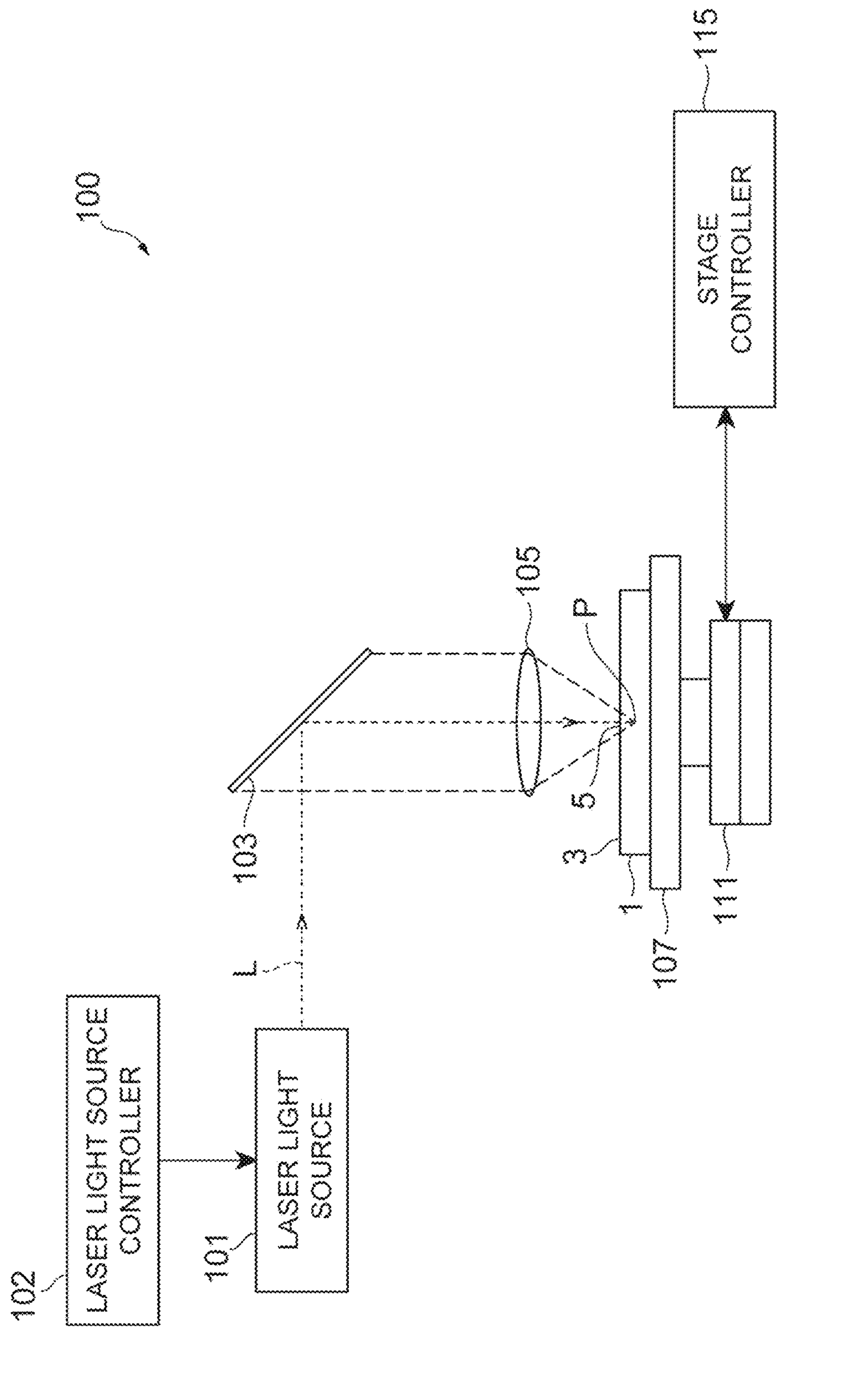

100
102
LASER LIGHT SOURCE CONTROLLER
101
LASER LIGHT SOURCE
L
103
105
P
5
3
1
107
111
STAGE CONTROLLER
115

Fig.2

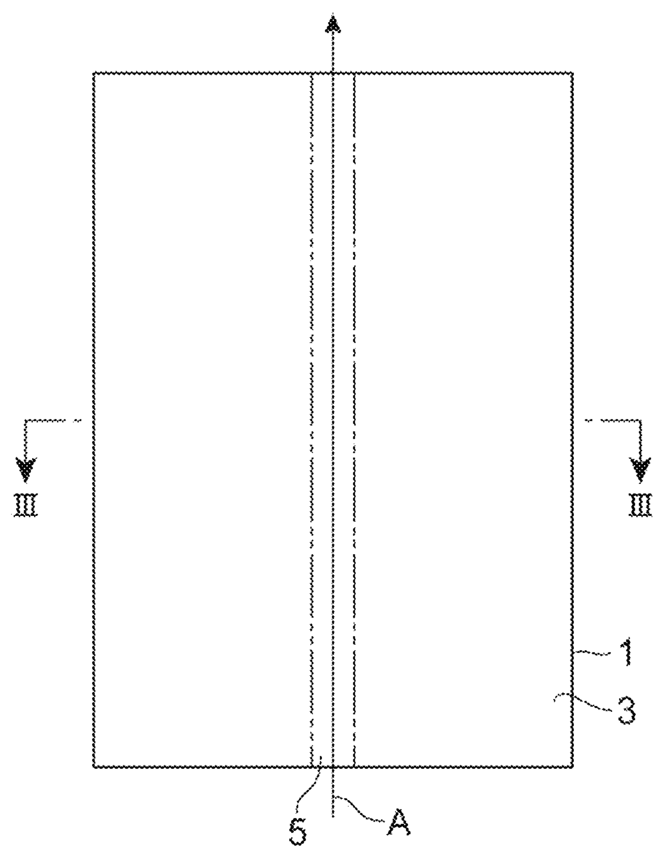


Fig.3

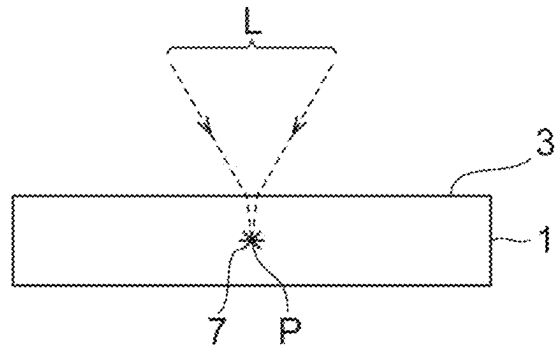


Fig.4

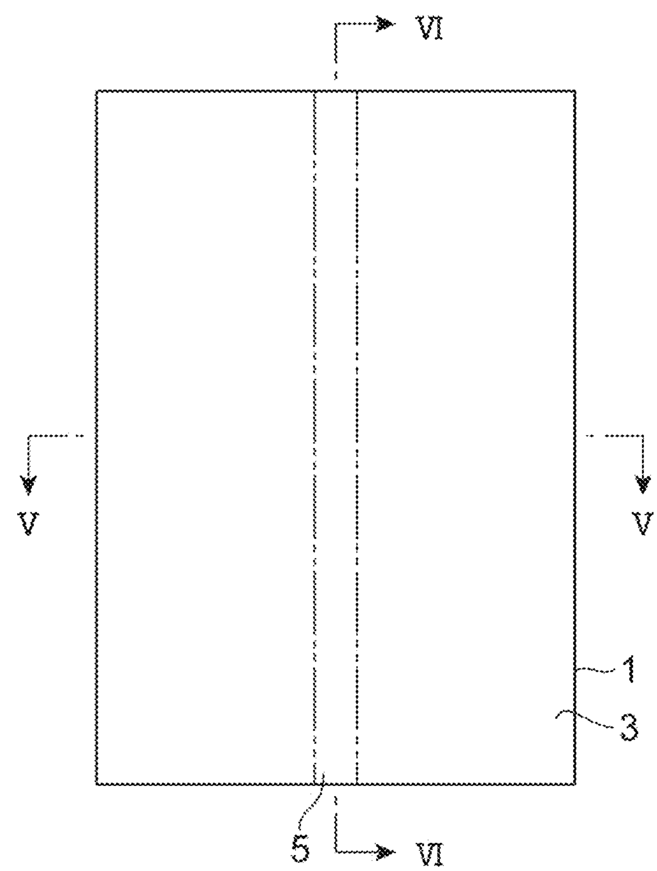


Fig.5

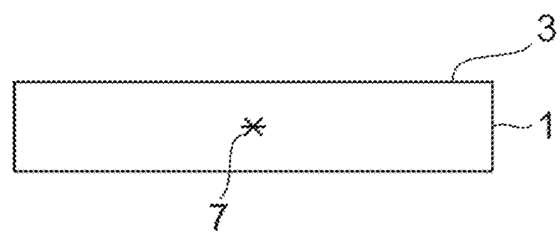


Fig.6

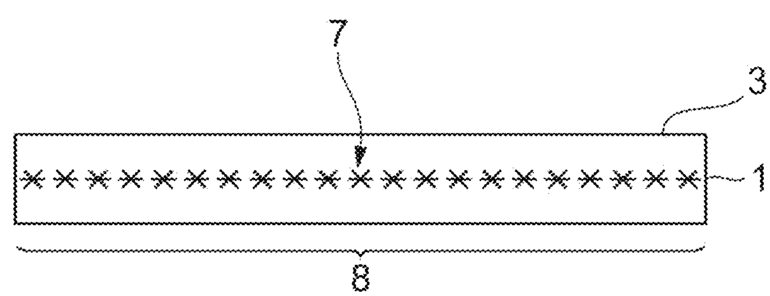


Fig.7

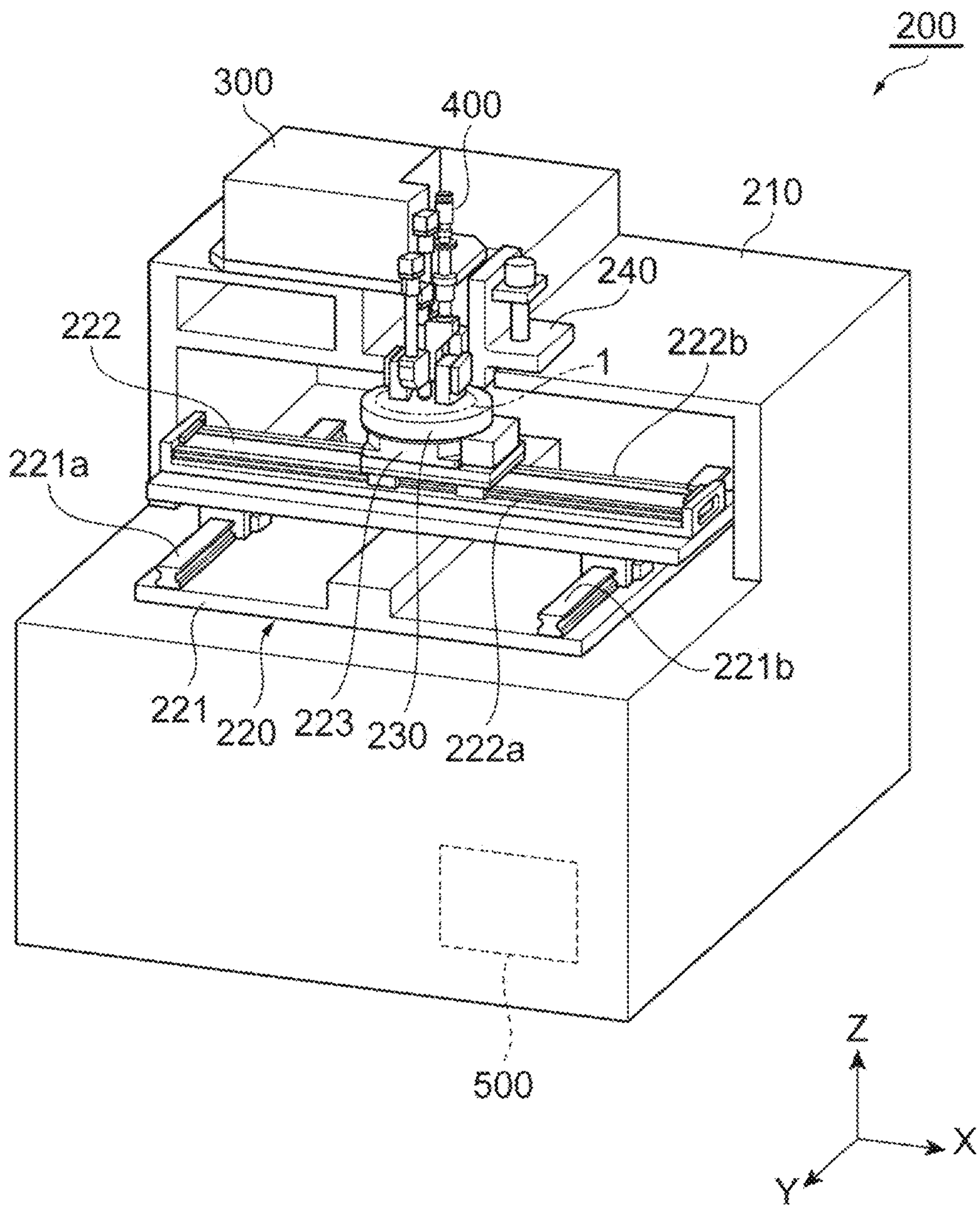

200
300
400
210
240
222
1
222b
221a
221b
221
220
223
230
222a
500
Z
X
Y

Fig.8

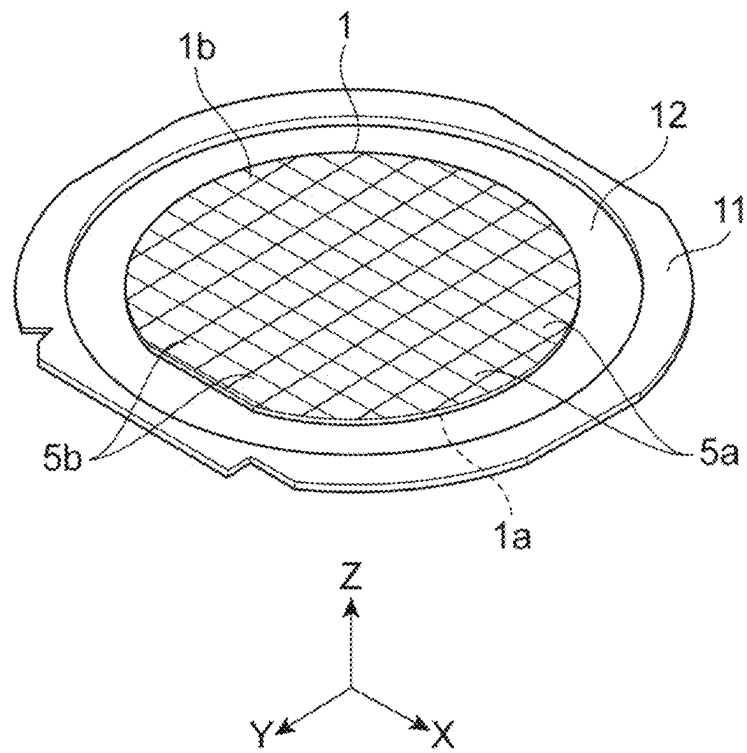
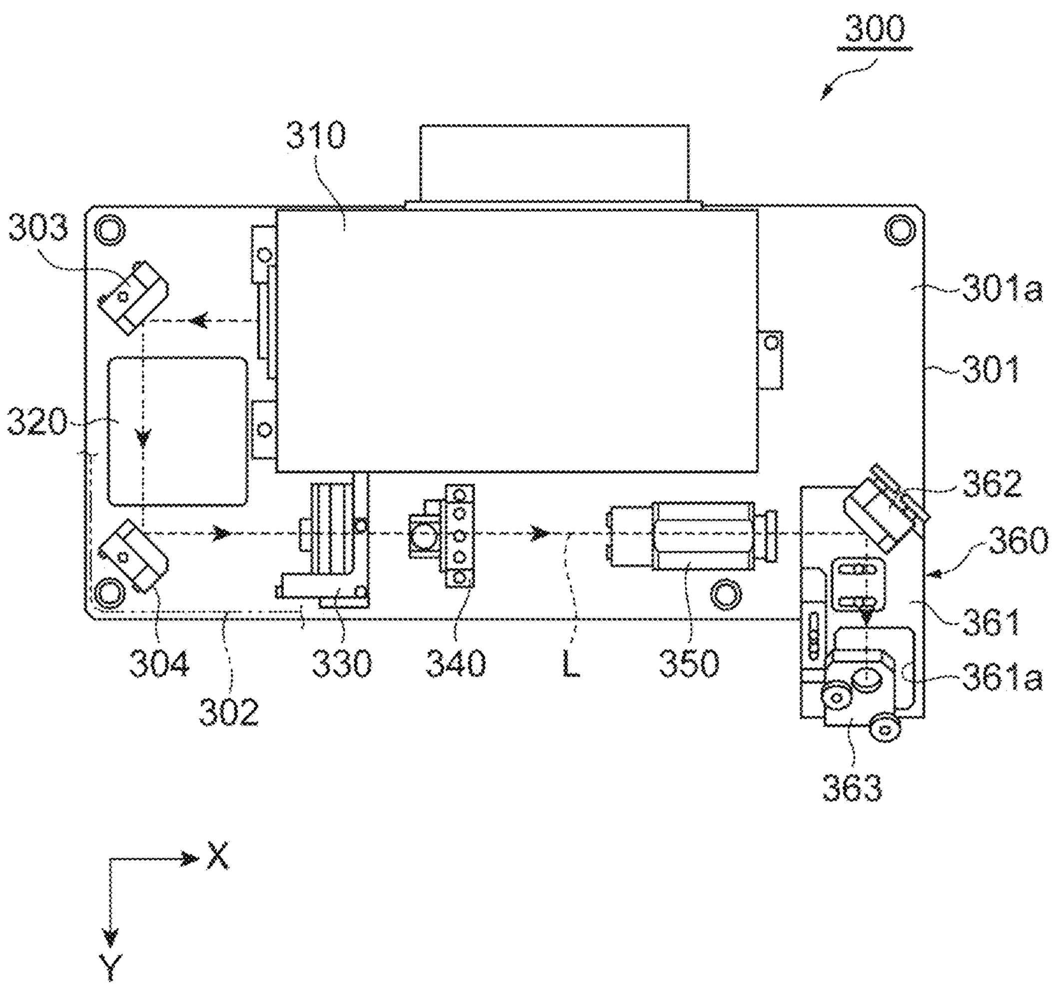


Fig.9


300
310
303
301a
301
320
362
360
361
361a
304
330
340
L
350
302
363
X
Y

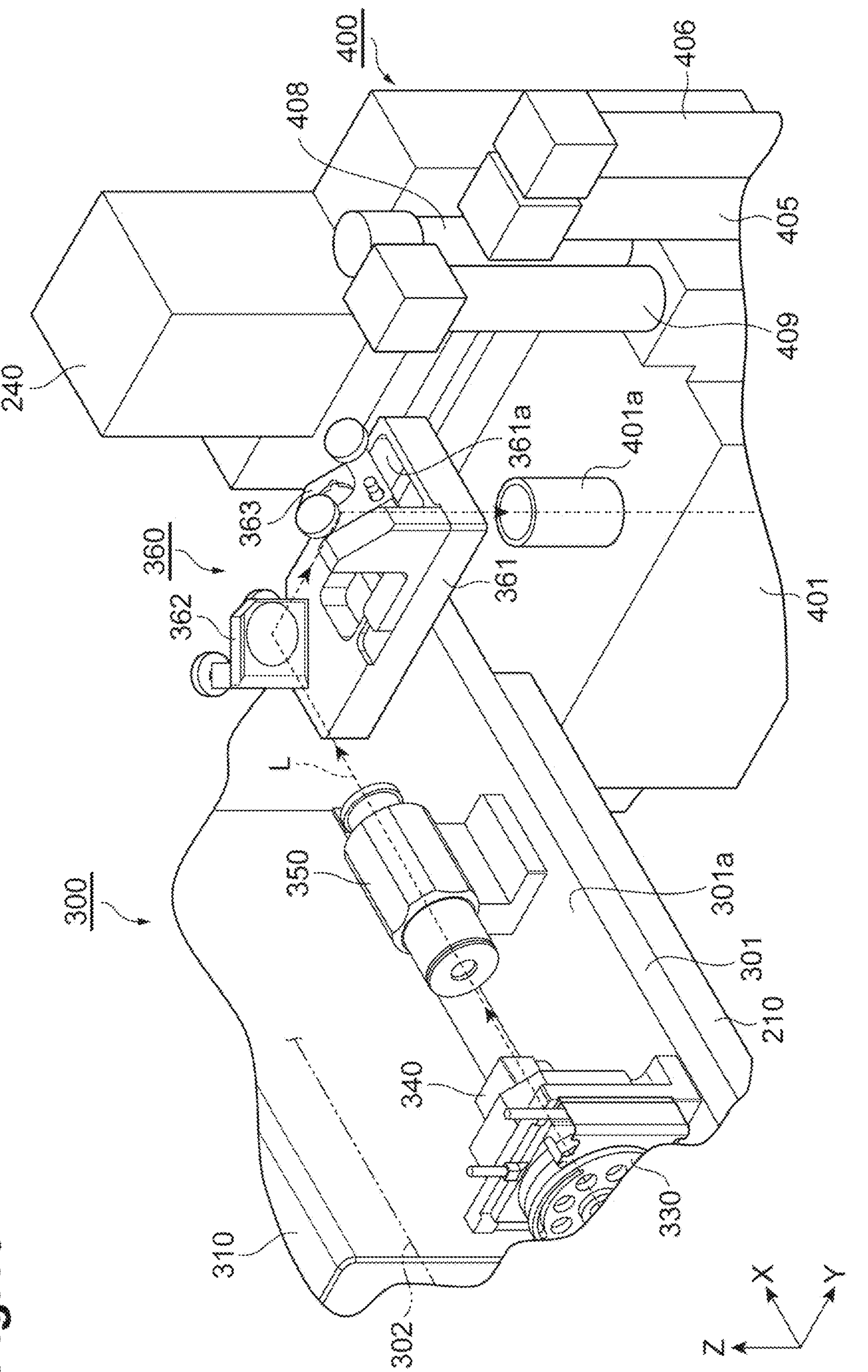

400
406
408
405
409
240
361a
401a
363
360
362
361
401
L
350
300
301a
301
210
340
330
310
302
X
Y
Z

Fig. 10

Fig.11

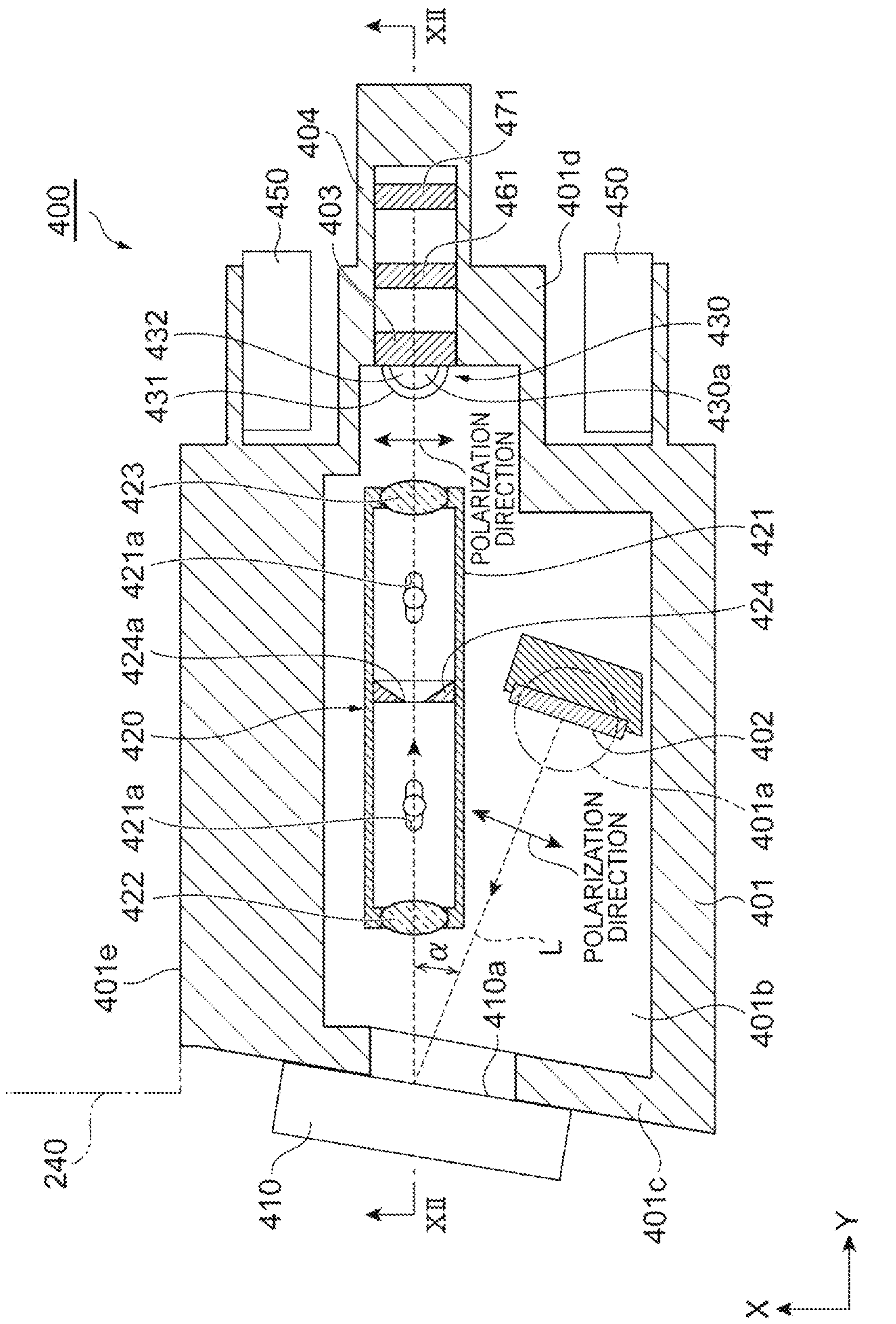

400
450
403
404
471
461
401d
450
431
432
430
430a
POLARIZATION DIRECTION
423
421a
424a
420
421a
422
421
424
402
401a
POLARIZATION DIRECTION
401
401b
401e
α
L
410a
240
410
401c
XII
XII
X
Y

Fig.12

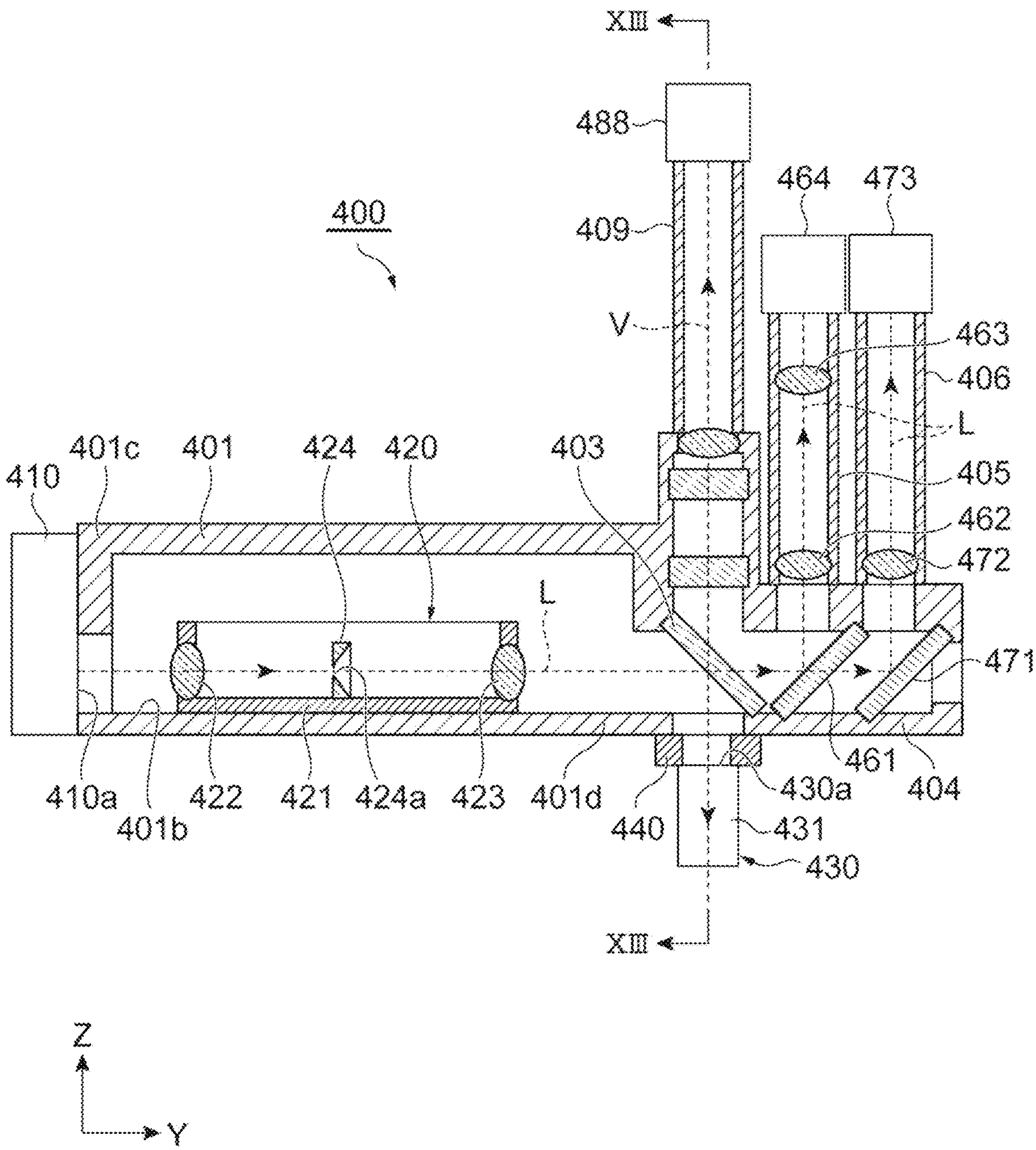

XIII
488
464
473
400
409
V
463
406
L
401c
401
424
420
403
405
410
462
472
L
471
461
404
410a
401b
422
421
424a
423
401d
440
430a
431
430
XIII
Z
Y

Fig.13

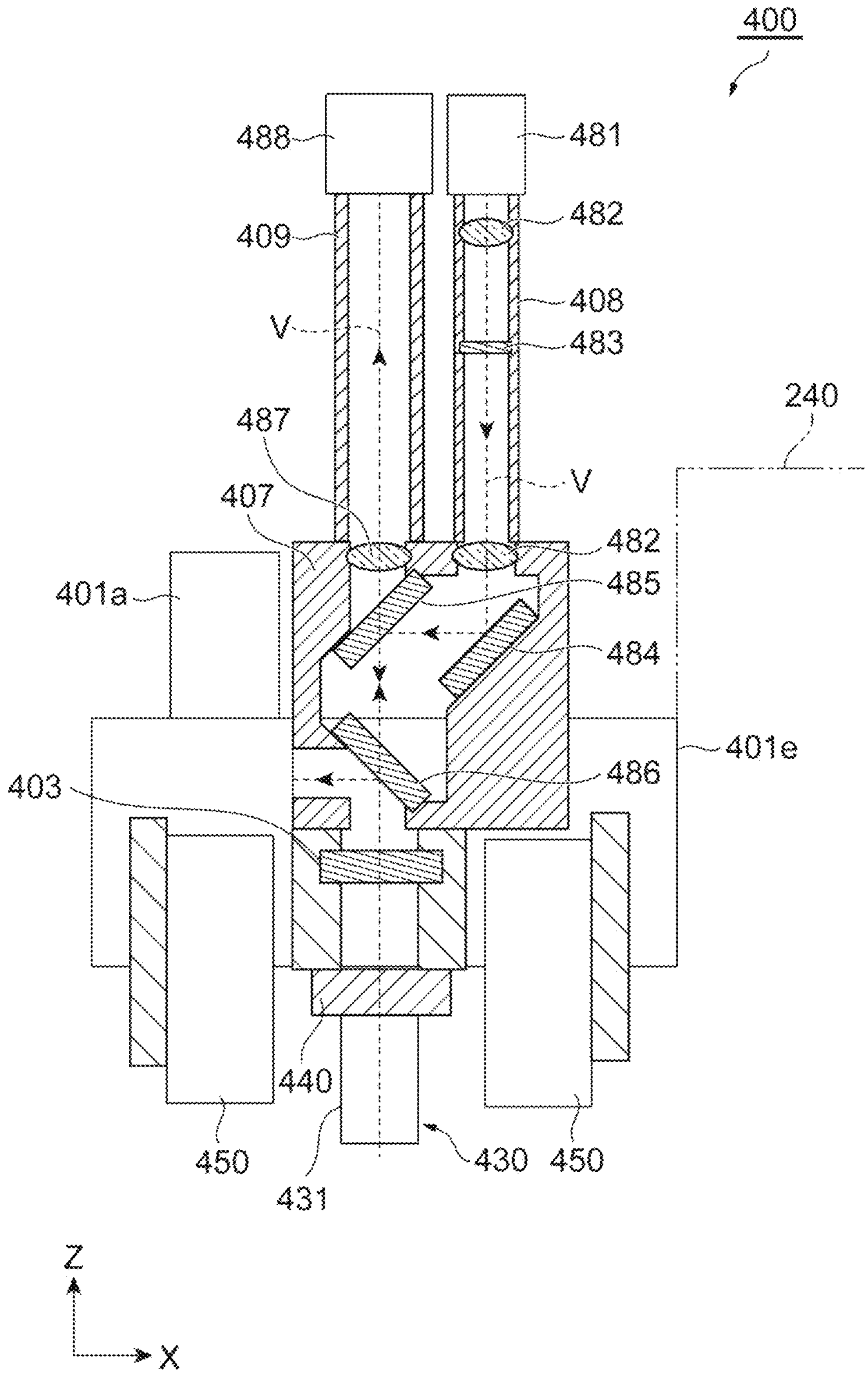

400
488
481
482
409
408
V
483
240
487
V
407
482
401a
485
484
401e
403
486
440
450
431
430
450
Z
X

Fig.14

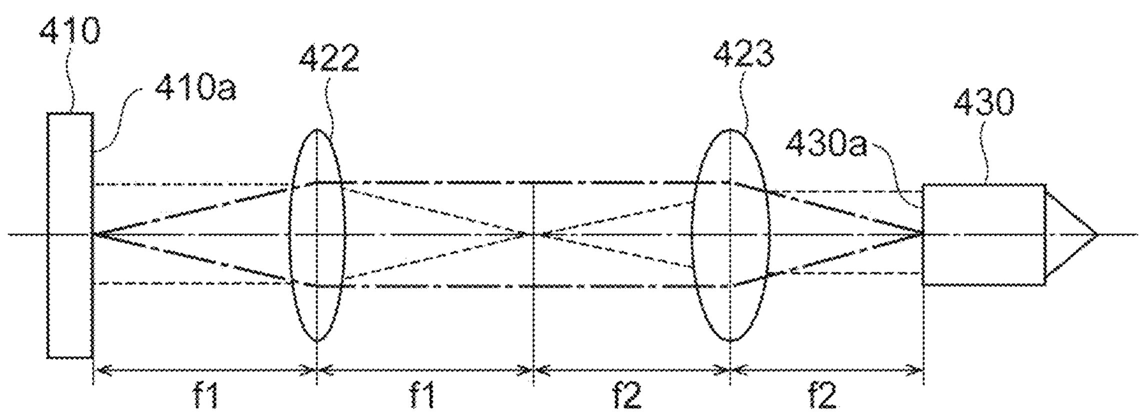


Fig.15

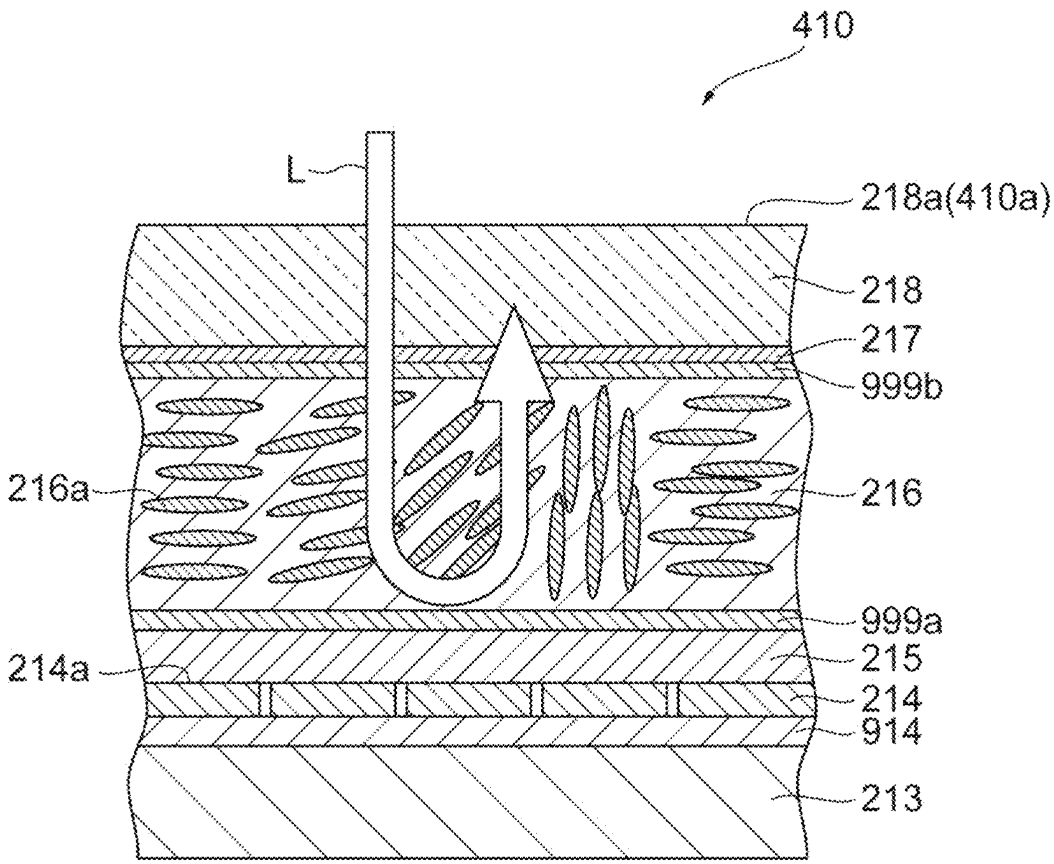
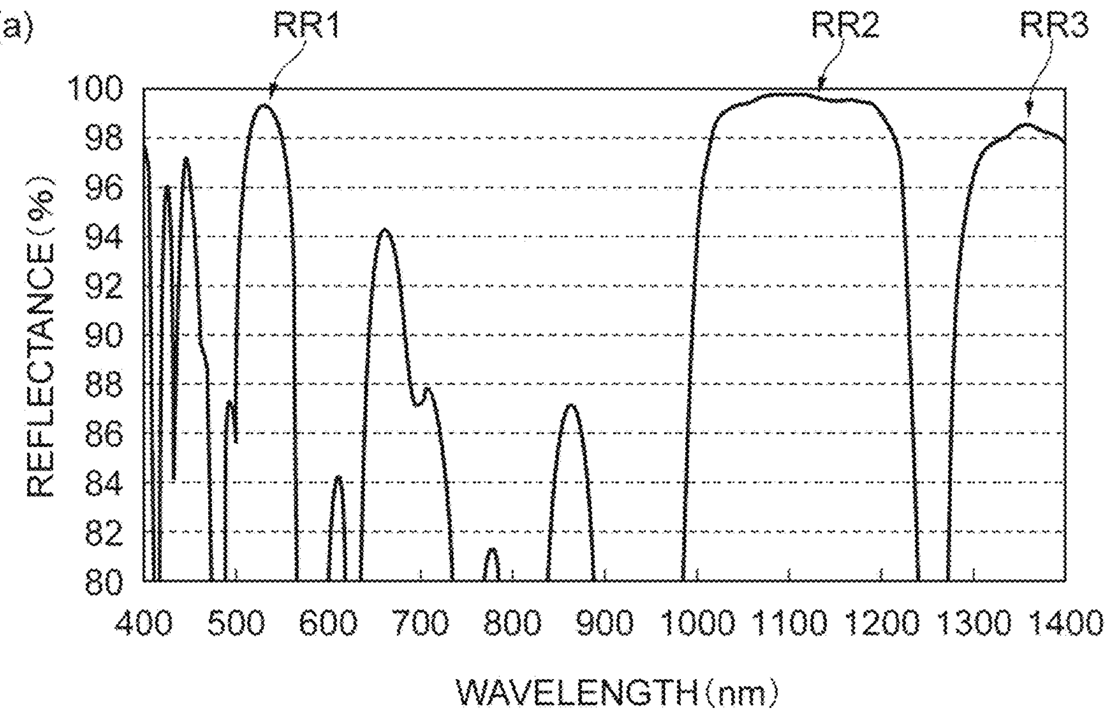


Fig.16

(a)


RR1
RR2
RR3
100
98
96
94
92
90
88
86
84
82
80
REFLECTANCE (%)
400 500 600 700 800 900 1000 1100 1200 1300 1400
WAVELENGTH (nm)

(b)

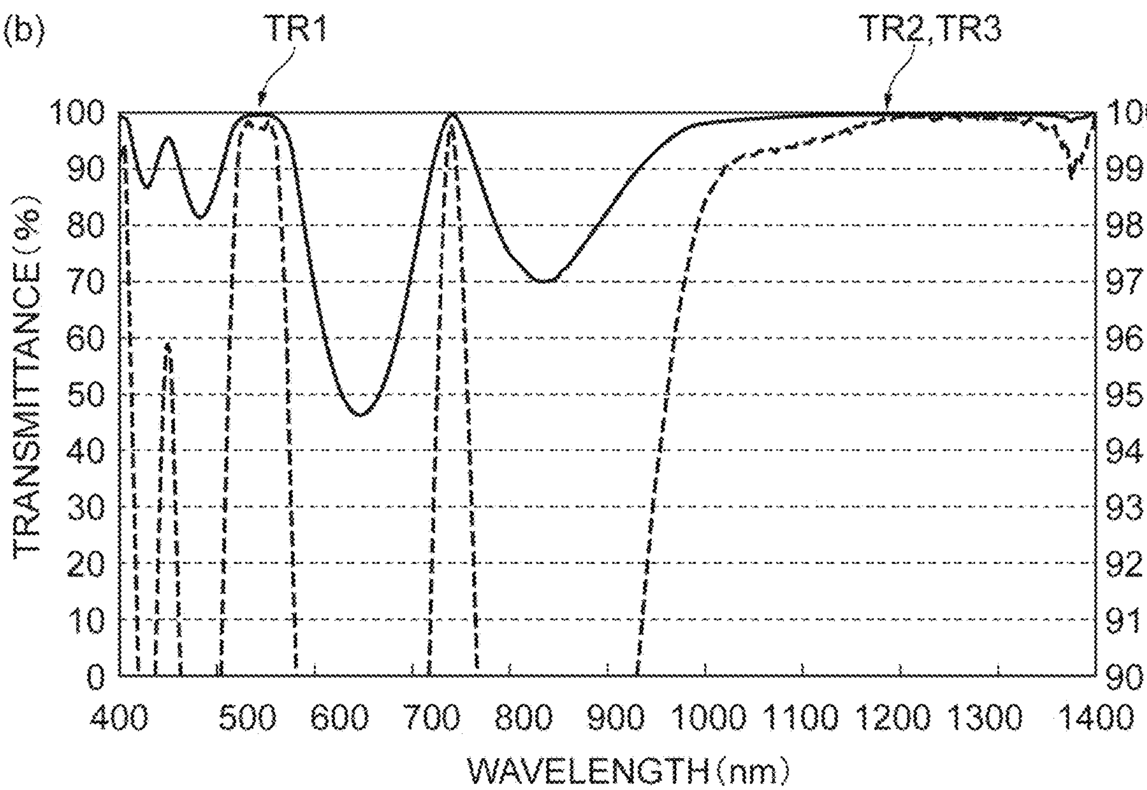
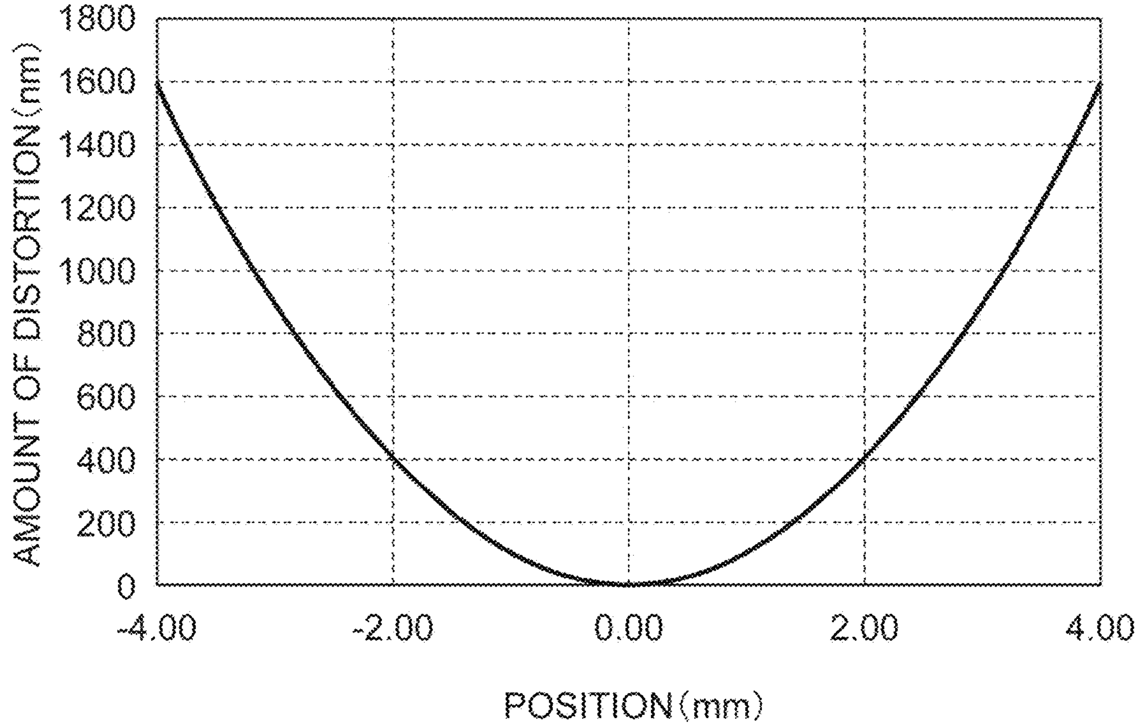

TR1
TR2,TR3
100
90
80
70
60
50
40
30
20
10
0
TRANSMITTANCE (%)
100
99
98
97
96
95
94
93
92
91
90
400 500 600 700 800 900 1000 1100 1200 1300 1400
WAVELENGTH (nm)

Fig.17

(a)


1800
1600
1400
1200
1000
800
600
400
200
0
AMOUNT OF DISTORTION (nm)
-4.00
-2.00
0.00
2.00
4.00
POSITION (mm)

(b)

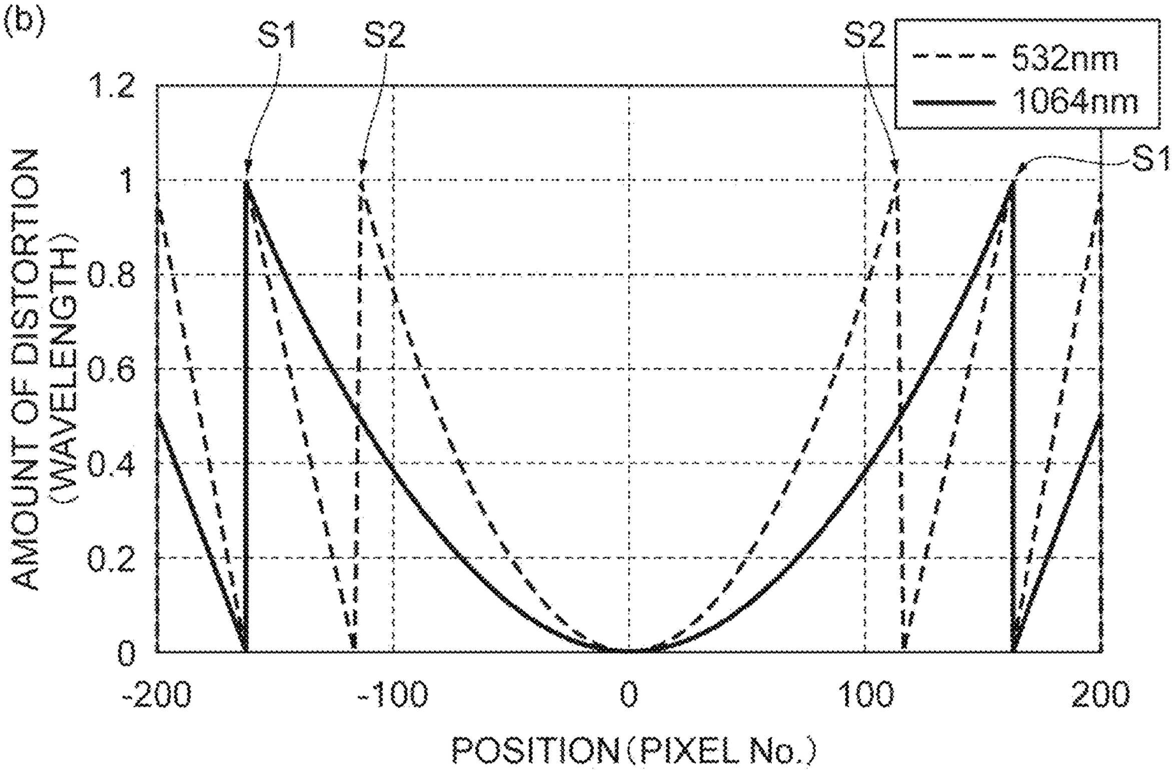
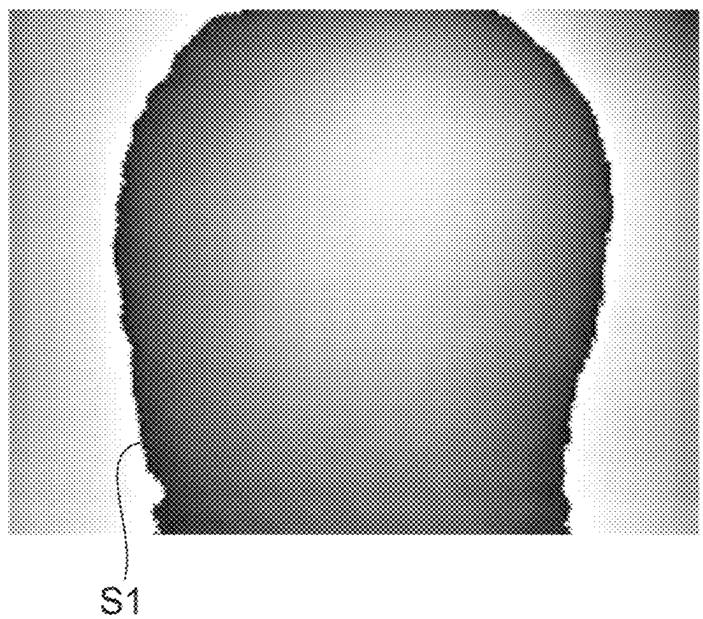

S1
S2
S2
S1
532nm
1064nm
1.2
1
0.8
0.6
0.4
0.2
0
AMOUNT OF DISTORTION (WAVELENGTH)
-200
-100
0
100
200
POSITION (PIXEL No.)

Fig.18

(a)



(b)

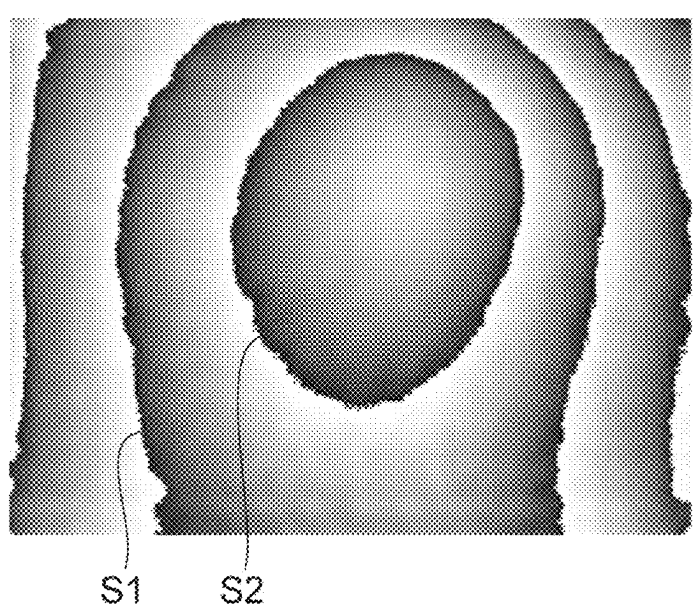
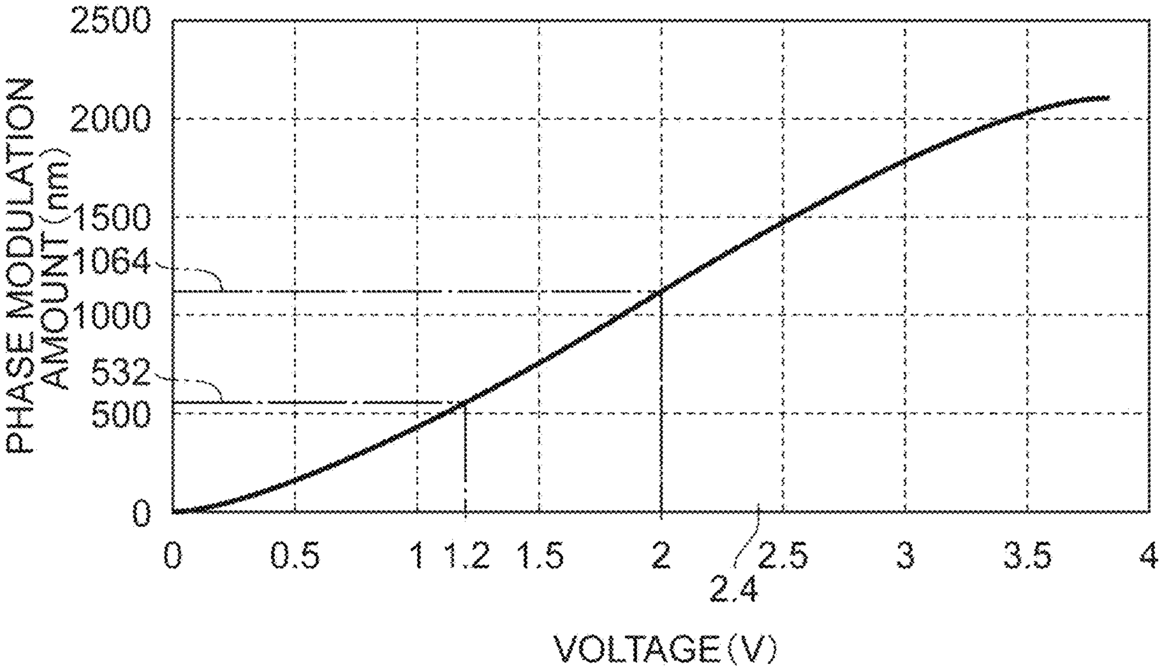


Fig.19

(a)


2500
2000
1500
1064
1000
532
500
0
PHASE MODULATION AMOUNT (nm)
0
0.5
1
1.2
1.5
2
2.5
3
3.5
4
2.4
VOLTAGE (V)

(b)

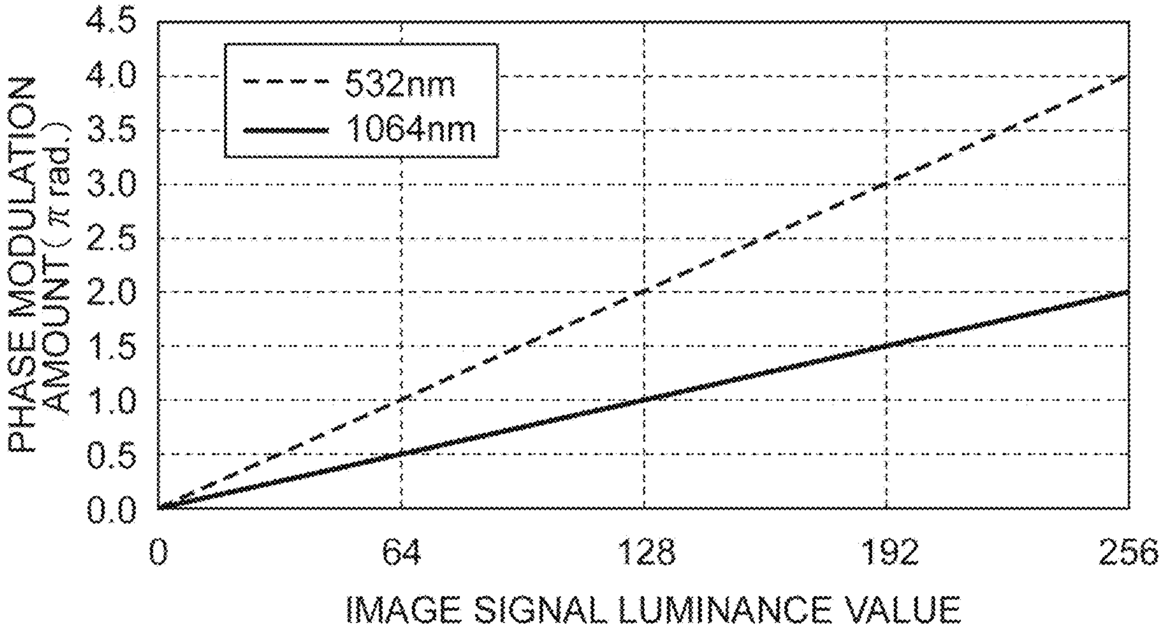
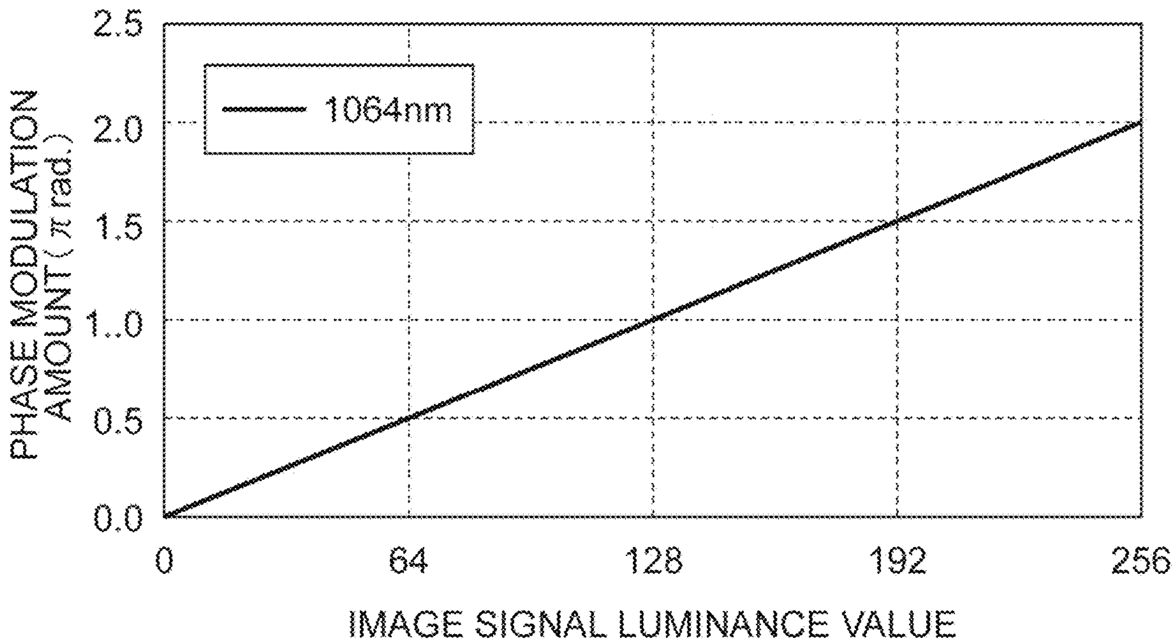

4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
PHASE MODULATION AMOUNT (π rad.)
532nm
1064nm
0
64
128
192
256
IMAGE SIGNAL LUMINANCE VALUE

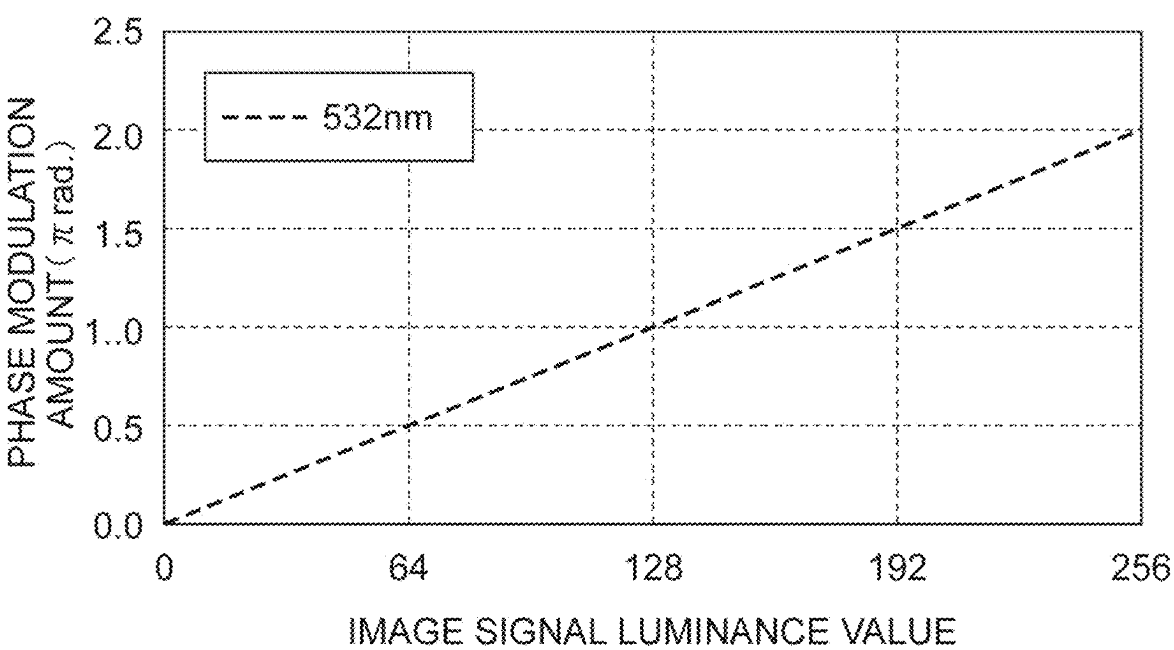
Fig.20

(a)



1064nm
PHASE MODULATION AMOUNT (π rad.)
2.5
2.0
1.5
1.0
0.5
0.0
0
64
128
192
256
IMAGE SIGNAL LUMINANCE VALUE

(b)



532nm
PHASE MODULATION AMOUNT (π rad.)
2.5
2.0
1.5
1.0
0.5
0.0
0
64
128
192
256
IMAGE SIGNAL LUMINANCE VALUE

LASER PROCESSING DEVICE

TECHNICAL FIELD

One aspect of the present invention relates to a laser processing device.

BACKGROUND ART

Patent Literature 1 describes a laser processing device including a holding mechanism configured to hold a workpiece and a laser irradiation mechanism configured to irradiates the workpiece held by the holding mechanism with laser light. In the laser irradiation mechanism of the laser processing device, components arranged on an optical path of the laser light from a laser oscillator to a converging lens are arranged in one housing, and the housing is secured to a wall portion erected on a base of the laser processing device.

CITATION LIST

Patent Literature

Patent Literature 1: Japanese Patent No. 5456510

SUMMARY OF INVENTION

Technical Problem

In the laser processing device as described above, a wavelength of the laser light suitable for processing may vary depending on specifications of the object to be processed, processing conditions, and the like.

An object of one aspect of the present invention is to provide a laser processing device adaptable to a plurality of wavelength bands.

Solution to Problem

A laser processing device according to one aspect of the present invention is a laser processing device configured to emit laser light on an object to perform laser processing of the object, the laser processing device including: a laser output unit configured to output the laser light; a spatial light modulator configured to reflect the laser light output from the laser output unit while modulating the laser light in accordance with a phase pattern; and an objective lens configured to converge the laser light from the spatial light modulator toward the object, in which the spatial light modulator includes an entrance surface at which the laser light enters, a reflective surface configured to reflect the laser light entering from the entrance surface toward the entrance surface, and a modulation layer arranged between the entrance surface and the reflective surface and configured to display the phase pattern to modulate the laser light, and a dielectric multilayer film having a high reflectance region in a plurality of wavelength bands non-contiguous with each other is formed on the reflective surface.

In the laser processing device, the laser light is modulated in accordance with the phase pattern of the spatial light modulator, and then is converged toward the object by the objective lens. The spatial light modulator includes the entrance surface at which the laser light enters, the reflective surface configured to reflect the laser light entering from the entrance surface, and the modulation layer arranged between the entrance surface and the reflective surface. When entering from the entrance surface and passing through the modulation layer, the laser light is modulated in accordance with the phase pattern. In addition, the laser light is modulated also when reflected by the reflective surface and then again passing through the modulation layer, and is emitted from the spatial light modulator. Here, on the reflective surface, the dielectric multilayer film is formed having the high reflectance region in the plurality of wavelength bands non-contiguous with each other. Therefore, with the spatial light modulator, it is possible to modulate the laser light while reducing loss on the reflective surface of the laser light of the plurality of wavelength bands. Accordingly, the laser processing device is adaptable to the plurality of wavelength bands.

A laser processing device according to one aspect of the present invention may further include a pattern holding unit configured to hold a distortion correction pattern as the phase pattern for correcting distortion given to a wavefront of the laser light depending on flatness of the reflective surface, in which the pattern holding unit holds the distortion correction pattern different for each of the wavelength bands. Generally, the reflective surface of the spatial light modulator has a predetermined flatness for each spatial light modulator. However, to correct the distortion given to the wavefront of the laser light depending on the flatness, a phase modulation amount is required different depending on the wavelength. Therefore, as in this case, if the distortion correction pattern is held different for each of the wavelength bands, the laser processing device is easily and reliably adaptable to the plurality of wavelength bands.

A laser processing device according to one aspect of the present invention may further include a table holding unit configured to hold a table in which a luminance value of an image signal for displaying the phase pattern on the modulation layer and a phase modulation amount of the phase pattern are associated with each other, in which the table holding unit holds the table different for each of the wavelength bands. Here, for the laser light of a certain wavelength, a table is prepared in which luminance values of, for example, 256 gradations of the image signal are assigned to (associated with) the phase modulation amounts for one wavelength (2π), whereby a phase modulation pattern suitable for the wavelength can be easily displayed on the modulation layer.

However, if the same table is used for laser light having a wavelength shorter than the wavelength, luminance values of smaller gradations are used for the phase modulation amounts for one wavelength, so that reproducibility drops of the wavefront after the modulation. To cope with this, in this case, the table is held different for each of the wavelength bands. For this reason, it is possible to use a table suitable for each wavelength band, and degradation of the reproducibility of the wavefront can be suppressed.

In the laser processing device according to one aspect of the present invention, an antireflective film having a high transmittance region in the plurality of wavelength bands may be formed on the entrance surface. In this case, the loss of the laser light can be further reduced, and the laser processing device is reliably adaptable to the plurality of wavelength bands.

In the laser processing device according to one aspect of the present invention, the plurality of wavelength bands may include a first wavelength band of greater than or equal to 500 nm and less than or equal to 550 nm, and a second wavelength band of greater than or equal to 1000 nm and less than or equal to 1150 nm. Alternatively, in the laser processing device according to one aspect of the present invention, the plurality of wavelength bands may include a third wavelength band of greater than or equal to 1300 nm and less than or equal to 1400 nm. In these cases, the laser processing device is adaptable to each wavelength band. Note that, the laser light of the first wavelength band is suitable for internal absorption type laser processing on a substrate made of sapphire, for example. In addition, the laser light of each of the second wavelength band and the third wavelength band is suitable for internal absorption type laser processing for a substrate made of silicon, for example.

Advantageous Effects of Invention

According to one aspect of the present invention, a laser processing device can be provided adaptable to a plurality of wavelength bands.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a schematic configuration diagram of a laser processing device used for forming a modified region.

FIG. **2** is a plan view of an object to be processed for which the modified region is formed.

FIG. **3** is a sectional view of the object to be processed taken along the line of FIG. **2**.

FIG. **4** is a plan view of the object to be processed after laser processing.

FIG. **5** is a sectional view of the object to be processed taken along the line V-V of FIG. **4**.

FIG. **6** is a sectional view of the object to be processed taken along the line VI-VI of FIG. **4**.

FIG. **7** is a perspective view of a laser processing device according to an embodiment.

FIG. **8** is a perspective view of an object to be processed attached to a support table of the laser processing device of FIG. **7**.

FIG. **9** is a sectional view of a laser output unit taken along the ZX plane of FIG. **7**.

FIG. **10** is a perspective view of a part of the laser output unit and a laser converging unit in the laser processing device of FIG. **7**.

FIG. **11** is a sectional view of the laser converging unit taken along the XY plane of FIG. **7**.

FIG. **12** is a sectional view of the laser converging unit taken along the line XII-XII of FIG. **11**.

FIG. **13** is a sectional view of the laser converging unit taken along the line XIII-XIII of FIG. **12**.

FIG. **14** is a diagram illustrating an optical arrangement relationship among a reflective spatial light modulator, a 4f lens unit, and a converging lens unit in the laser converging unit of FIG. **11**.

FIG. **15** is a partial sectional view of a reflective spatial light modulator in the laser processing device of FIG. **7**.

FIGS. **16**(*a*) and **16**(*b*) are a graph illustrating a reflectance characteristic of a reflective film illustrated in FIG. **15** and a graph illustrating a transmittance characteristic of an antireflective film provided on a front surface of a transparent substrate, respectively.

FIGS. **17**(*a*) and **17**(*b*) each are a graph illustrating distortion of a front surface of a pixel electrode illustrated in FIG. **15**.

FIGS. **18**(*a*) and **18**(*b*) each are a diagram illustrating a distortion correction pattern displayed on a liquid crystal layer illustrated in FIG. **15**.

FIGS. **19**(*a*) and **19**(*b*) each are a diagram illustrating a table in which a luminance value of an image signal and a phase modulation amount are associated with each other.

FIGS. **20**(*a*) and **20**(*b*) each are a diagram illustrating a table in which a luminance value of an image signal and a phase modulation amount are associated with each other.

DESCRIPTION OF EMBODIMENTS

In the following, one embodiment of one aspect of the present invention will be described in detail with reference to the drawings. In the drawings, the same elements or corresponding elements are denoted by the same reference numerals, and overlapping explanations may be omitted.

In a laser processing device according to the embodiment, laser light is converged at an object to be processed to form a modified region within the object to be processed along a line to cut. Therefore, formation of the modified region will be described at first with reference to FIGS. **1** to **6**.

As illustrated in FIG. **1**, a laser processing device **100** includes a laser light source **101** configured to cause laser light L to oscillate in a pulsating manner, a dichroic mirror **103** arranged so as to change a direction of the optical axis (optical path) of the laser light L by 90°, and a converging lens **105** configured to converge the laser light L. The laser processing device **100** further includes a support table **107** configured to support an object to be processed **1** that is an object to which the laser light L converged by the converging lens **105** is emitted, a stage **111** that is a moving mechanism configured to move the support table **107**, a laser light source controller **102** configured to control the laser light source **101** in order to adjust the output, pulse width, pulse waveform, and the like of the laser light L, and a stage controller **115** configured to control the movement of the stage **111**.

In the laser processing device **100**, the laser light L emitted from the laser light source **101** changes the direction of its optical axis by 90° with the dichroic mirror **103** and then is converged by the converging lens **105** within the object to be processed **1** mounted on the support table **107**. At the same time, the stage **111** is moved, so that the object to be processed **1** moves with respect to the laser light L along a line to cut **5**. Thus, a modified region along the line to cut **5** is formed in the object to be processed **1**. While the stage **111** is moved here for relatively moving the laser light L, the converging lens **105** may be moved instead or together therewith.

Employed as the object to be processed **1** is a planar member (for example, a substrate or a wafer), examples of which include semiconductor substrates formed of semiconductor materials and piezoelectric substrates formed of piezoelectric materials. As illustrated in FIG. **2**, in the object to be processed **1**, the line to cut **5** is set for cutting the object to be processed **1**. The line to cut **5** is a virtual line extending straight. In a case where a modified region is formed within the object to be processed **1**, the laser light L is relatively moved along the line to cut **5** (that is, in the direction of arrow A in FIG. **2**) while a converging point (converging position) P is set within the object to be processed **1** as illustrated in FIG. **3**. Thus, a modified region **7** is formed within the object to be processed **1** along the line to cut **5** as illustrated in FIGS. **4**, **5** and **6**, and the modified region **7** formed along the line to cut **5** becomes a cutting start region **8**. The line to cut **5** corresponds to an irradiation schedule line.

The converging point P is a position at which the laser light L is converged. The line to cut **5** may be curved instead of being straight, a three-dimensional one combining them, or one specified by coordinates. The line to cut **5** may be one actually drawn on a front surface **3** of the object to be processed **1** without being restricted to the virtual line. The modified region **7** may be formed either continuously or intermittently. The modified region **7** may be formed in either rows or dots, and only needs to be formed at least within the object to be processed **1**, on the front surface **3**, or on a back surface. A crack may be formed from the modified region **7** as a start point, and the crack and the modified region **7** may be exposed at an outer surface (the front surface **3**, the back surface, or an outer peripheral surface) of the object to be processed **1**. A laser light entrance surface in forming the modified region **7** is not limited to the front surface **3** of the object to be processed **1** but may be the back surface of the object to be processed **1**.

Incidentally, in a case where the modified region **7** is formed within the object to be processed **1**, the laser light L is transmitted through the object to be processed **1** and is particularly absorbed near the converging point P located within the object to be processed **1**. Thus, the modified region **7** is formed in the object to be processed **1** (that is, internal absorption type laser processing). In this case, the front surface **3** of the object to be processed **1** hardly absorbs the laser light L and thus does not melt. On the other hand, in a case where the modified region **7** is formed on the front surface **3** or the back surface of the object to be processed **1**, the laser light L is particularly absorbed near the converging point P located on the front surface **3** or the back surface, and removal portions such as holes and grooves are formed (surface absorption type laser processing) by being melted from the front surface **3** or the back surface and removed.

The modified region **7** is a region in which density, refractive index, mechanical strength and other physical characteristics are different from the surroundings. Examples of the modified region **7** include a molten processed region (meaning at least one of a region resolidified after having been once molten, a region in the molten state, and a region in the process of resolidifying from the molten state), a crack region, a dielectric breakdown region, a refractive index changed region, and a mixed region thereof. Other examples of the modified region **7** include a region where the density of the modified region **7** has changed compared to the density of an unmodified region in a material of the object to be processed **1**, and a region formed with a lattice defect. In a case where the material of the object to be processed **1** is single crystal silicon, the modified region **7** can also be said to be a high dislocation density region.

The molten processed region, refractive index changed region, region where the density of the modified region **7** has changed compared to the density of the unmodified region, and region formed with the lattice defect may further incorporate the crack (cracking or microcrack) therewithin or at an interface between the modified region **7** and the unmodified region. The incorporated crack may be formed over the whole surface of the modified region **7** or in only a portion or a plurality of portions thereof. The object to be processed **1** includes a substrate made of a crystalline material having a crystal structure. For example, the object to be processed **1** includes a substrate formed of at least one of gallium nitride (GaN), silicon (Si), silicon carbide (SiC), LiTaO3, and sapphire (Al2O3). In other words, the object to be processed **1** includes, for example, a gallium nitride substrate, a silicon substrate, a SiC substrate, a LiTaO3 substrate, or a sapphire substrate. The crystalline material may be either an anisotropic crystal or an isotropic crystal. In addition, the object to be processed **1** may include a substrate made of a non-crystalline material having a non-crystalline structure (amorphous structure), and may include a glass substrate, for example.

In the embodiment, the modified region **7** can be formed by forming a plurality of modified spots (processing marks) along the line to cut **5**. In this case, the plurality of modified spots gathers to be the modified region **7**. Each of the modified spots is a modified portion formed by a shot of one pulse of pulsed laser light (that is, laser irradiation of one pulse: laser shot). Examples of the modified spots include crack spots, molten processed spots, refractive index changed spots, and those in which at least one of them is mixed. As for the modified spots, their sizes and lengths of the crack occurring therefrom can be controlled as necessary in view of the required cutting accuracy, the required flatness of cut surfaces, the thickness, kind, and crystal orientation of the object to be processed **1**, and the like. In addition, in the embodiments, the modified spots can be formed as the modified region **7**, along the line to cut **5**.

[Laser Processing Device According to Embodiments]

Next, the laser processing device according to the embodiments will be described. In the following description, the directions orthogonal to each other in the horizontal plane are defined as the X-axis direction and the Y-axis direction, and the vertical direction is defined as the Z-axis direction.

[Overall Configuration of Laser Processing Device]

As illustrated in FIG. **7**, a laser processing device **200** includes a device frame **210**, a first moving mechanism (moving mechanism) **220**, a support table **230**, and a second moving mechanism **240**. Further, the laser processing device **200** includes a laser output unit **300**, a laser converging unit **400**, and a controller **500**.

The first moving mechanism **220** is attached to the device frame **210**. The first moving mechanism **220** includes a first rail unit **221**, a second rail unit **222**, and a movable base **223**. The first rail unit **221** is attached to the device frame **210**. The first rail unit **221** is provided with a pair of rails **221*a*** and **221*b*** extending along the Y-axis direction. The second rail unit **222** is attached to the pair of rails **221*a*** and **221*b*** of the first rail unit **221** so as to be movable along the Y-axis direction. The second rail unit **222** is provided with a pair of rails **222*a*** and **222*b*** extending along the X-axis direction. The movable base **223** is attached to the pair of rails **222*a*** and **222*b*** of the second rail unit **222** so as to be movable along the X-axis direction. The movable base **223** is rotatable about an axis parallel to the Z-axis direction as the center.

The support table **230** is attached to the movable base **223**. The support table **230** supports the object to be processed **1**. The object to be processed **1** includes a plurality of functional devices (a light receiving device such as a photodiode, a light emitting device such as a laser diode, a circuit device formed as a circuit, or the like) formed in a matrix shape on the front surface side of a substrate made of a semiconductor material such as silicon. When the object to be processed **1** is supported on the support table **230**, as illustrated in FIG. **8**, on a film **12** stretched over an annular frame **11**, for example, a front surface **1*a*** of the object to be processed **1** (a surface of the plurality of functional devices side) is pasted. The support table **230** holds the frame **11** with a clamp and suctions the film **12** with a vacuum chuck table, to support the object to be processed **1**. On the support table **230**, a plurality of lines to cut **5*a*** parallel to each other and a plurality of lines to cut **5*b*** parallel to each other are set in a grid pattern so as to pass between adjacent functional devices on the object to be processed **1**.

As illustrated in FIG. **7**, the support table **230** is moved along the Y-axis direction by operation of the second rail unit **222** in the first moving mechanism **220**. In addition, the support table **230** is moved along the X-axis direction by operation of the movable base **223** in the first moving mechanism **220**. Further, the support table **230** is rotated about the axis parallel to the Z-axis direction as the center by operation of the movable base **223** in the first moving mechanism **220**. As described above, the support table **230** is attached to the device frame **210** to be movable along the X-axis direction and the Y-axis direction, and to be rotatable about the axis parallel to the Z-axis direction as the center.

The laser output unit **300** is attached to the device frame **210**. The laser converging unit **400** is attached to the device frame **210** via the second moving mechanism **240**. The laser converging unit **400** is moved along the Z-axis direction by operation of the second moving mechanism **240**. As described above, the laser converging unit **400** is attached to the device frame **210** so as to be movable along the Z-axis direction with respect to the laser output unit **300**.

The controller **500** includes a Central Processing Unit (CPU), Read Only Memory (ROM), Random Access Memory (RAM), and the like. The controller **500** controls operation of each unit of the laser processing device **200**.

As an example, in the laser processing device **200**, a modified region is formed within the object to be processed **1** along each of the lines to cut **5***a* and **5***b* (see FIG. **8**) as follows.

First, the object to be processed **1** is supported on the support table **230** such that a back surface **1***b* (see FIG. **8**) of the object to be processed **1** becomes the laser light entrance surface, and each of the lines to cut **5***a* of the object to be processed **1** is aligned in a direction parallel to the X-axis direction. Subsequently, the laser converging unit **400** is moved by the second moving mechanism **240** such that the converging point of the laser light L is located at a position apart from the laser light entrance surface of the object to be processed **1** by a predetermined distance within the object to be processed **1**. Subsequently, while a constant distance is maintained between the laser light entrance surface of the object to be processed **1** and the converging point of the laser light L, the converging point of the laser light L is relatively moved along each line to cut **5***a*. Thus, the modified region is formed within the object to be processed **1** along each of the lines to cut **5***a*.

When the formation of the modified region along each of the lines to cut **5***a* is completed, the support table **230** is rotated by the first moving mechanism **220**, and each of the lines to cut **5***b* of the object to be processed **1** is aligned in the direction parallel to the X-axis direction. Subsequently, the laser converging unit **400** is moved by the second moving mechanism **240** such that the converging point of the laser light L is located at a position apart from the laser light entrance surface of the object to be processed **1** by a predetermined distance within the object to be processed **1**. Subsequently, while a constant distance is maintained between the laser light entrance surface of the object to be processed **1** and the converging point of the laser light L, the converging point of the laser light L is relatively moved along each line to cut **5***b*. Thus, the modified region is formed within the object to be processed **1** along each line to cut **5***b*.

As described above, in the laser processing device **200**, the direction parallel to the X-axis direction is a processing direction (scanning direction of the laser light L). Note that, the relative movement of the converging point of the laser light L along each line to cut **5***a* and the relative movement of the converging point of the laser light L along each line to cut **5***b* are performed by the movement of the support table **230** along the X-axis direction by the first moving mechanism **220**. In addition, the relative movement of the converging point of the laser light L between the lines to cut **5***a* and the relative movement of the converging point of the laser light L between the lines to cut **5***b* are performed by the movement of the support table **230** along the Y-axis direction by the first moving mechanism **220**.

As illustrated in FIG. **9**, the laser output unit **300** includes a mounting base **301**, a cover **302**, and a plurality of mirrors **303** and **304**. Further, the laser output unit **300** includes a laser oscillator **310**, a shutter **320**, a λ/2 wave plate unit **330**, a polarizing plate unit **340**, a beam expander **350**, and a mirror unit **360**.

The mounting base **301** supports the plurality of mirrors **303** and **304**, the laser oscillator **310**, the shutter **320**, the λ/2 wave plate unit **330**, the polarizing plate unit **340**, the beam expander **350**, and the mirror unit **360**. The plurality of mirrors **303** and **304**, the laser oscillator **310**, the shutter **320**, the λ/2 wave plate unit **330**, the polarizing plate unit **340**, the beam expander **350**, and the mirror unit **360** are attached to a main surface **301***a* of the mounting base **301**. The mounting base **301** is a planar member and is detachable with respect to the device frame **210** (see FIG. **7**). The laser output unit **300** is attached to the device frame **210** via the mounting base **301**. That is, the laser output unit **300** is detachable with respect to the device frame **210**.

The cover **302** covers the plurality of mirrors **303** and **304**, the laser oscillator **310**, the shutter **320**, the λ/2 wave plate unit **330**, the polarizing plate unit **340**, the beam expander **350**, and the mirror unit **360** on the main surface **301***a* of the mounting base **301**. The cover **302** is detachable with respect to the mounting base **301**.

The laser oscillator **310** oscillates linearly polarized laser light L in a pulsating manner along the X-axis direction. The wavelength of the laser light L emitted from the laser oscillator **310** is included in any of the wavelength bands of from 500 nm to 550 nm, from 1000 nm to 1150 nm, or from 1300 nm to 1400 nm. The laser light L in the wavelength band of from 500 nm to 550 nm is suitable for internal absorption type laser processing on a substrate made of sapphire, for example. The laser light L in each of the wavelength bands of from 1000 nm to 1150 nm and from 1300 nm to 1400 nm is suitable for internal absorption type laser processing for a substrate made of silicon, for example. The polarization direction of the laser light L emitted from the laser oscillator **310** is, for example, a direction parallel to the Y-axis direction. The laser light L emitted from the laser oscillator **310** is reflected by the mirror **303** and enters the shutter **320** along the Y-axis direction.

In the laser oscillator **310**, ON/OFF of the output of the laser light L is switched as follows. In a case where the laser oscillator **310** includes a solid state laser, ON/OFF of a Q switch (acousto-optic modulator (AOM), electro-optic modulator (EOM), or the like) provided in a resonator is switched, whereby ON/OFF of the output of the laser light L is switched at high speed. In a case where the laser oscillator **310** includes a fiber laser, ON/OFF of the output of a semiconductor laser constituting a seed laser and an amplifier (excitation) laser is switched, whereby ON/OFF of the output of the laser light L is switched at high speed. In a case where the laser oscillator **310** uses an external modulation device, ON/OFF of the external modulation device (AOM, EOM, or the like) provided outside the resonator is switched, whereby ON/OFF of the output of the laser light L is switched at high speed.

The shutter **320** opens and closes the optical path of the laser light L by a mechanical mechanism. Switching ON/OFF of the output of the laser light L from the laser output unit **300** is performed by switching ON/OFF of the output of the laser light L in the laser oscillator **310** as described above, and the shutter **320** is provided, whereby the laser light L is prevented from being unexpectedly emitted from the laser output unit **300**, for example. The laser light L having passed through the shutter **320** is reflected by the mirror **304** and sequentially enters the λ/2 wave plate unit **330** and the polarizing plate unit **340** along the X-axis direction.

The λ/2 wave plate unit **330** and the polarizing plate unit **340** function as the output adjusting unit configured to adjust the output (light intensity) of the laser light L. In addition, the λ/2 wave plate unit **330** and the polarizing plate unit **340** each function as the polarization direction adjusting unit configured to adjust the polarization direction of the laser light L. The laser light L having sequentially passed through the λ/2 wave plate unit **330** and the polarizing plate unit **340** enters the beam expander **350** along the X-axis direction.

The beam expander **350** collimates the laser light L while adjusting the diameter of the laser light L. The laser light L having passed through the beam expander **350** enters the mirror unit **360** along the X-axis direction.

The mirror unit **360** includes a support base **361** and a plurality of mirrors **362** and **363**. The support base **361** supports the plurality of mirrors **362** and **363**. The support base **361** is attached to the mounting base **301** so as to be position adjustable along the X-axis direction and the Y-axis direction. The mirror (first mirror) **362** reflects the laser light L having passed through the beam expander **350** in the Y-axis direction. The mirror **362** is attached to the support base **361** such that its reflective surface is angle adjustable around an axis parallel to the Z-axis, for example.

The mirror (second mirror) **363** reflects the laser light L reflected by the mirror **362** in the Z-axis direction. The mirror **363** is attached to the support base **361** such that its reflective surface is angle adjustable around an axis parallel to the X-axis, for example, and is position adjustable along the Y-axis direction. The laser light L reflected by the mirror **363** passes through an opening **361***a* formed in the support base **361** and enters the laser converging unit **400** (see FIG. **7**) along the Z-axis direction. That is, an emission direction of the laser light L by the laser output unit **300** coincides with a moving direction of the laser converging unit **400**. As described above, each of the mirrors **362** and **363** includes a mechanism configured to adjust the angle of the reflective surface.

In the mirror unit **360**, the position adjustment of the support base **361** with respect to the mounting base **301**, the position adjustment of the mirror **363** with respect to the support base **361**, and the angle adjustment of the reflective surface of each of the mirrors **362** and **363** are performed, whereby the position and angle of the optical axis of the laser light L emitted from the laser output unit **300** are aligned with respect to the laser converging unit **400**. That is, each of the plurality of mirrors **362** and **363** is a component configured to adjust the optical axis of the laser light L emitted from the laser output unit **300**.

As illustrated in FIG. **10**, the laser converging unit **400** includes a housing **401**. The housing **401** has a rectangular parallelepiped shape with the Y-axis direction as the longitudinal direction. The second moving mechanism **240** is attached to one side surface **401***e* of the housing **401** (see FIGS. **11** and **13**). A cylindrical light entrance unit **401***a* is provided in the housing **401** so as to face the opening **361***a* of the mirror unit **360** in the Z-axis direction. The light entrance unit **401***a* allows the laser light L emitted from the laser output unit **300** to enter the housing **401**. The mirror unit **360** and the light entrance unit **401***a* are separated from each other by a distance in which mutual contact does not occur when the laser converging unit **400** is moved along the Z-axis direction by the second moving mechanism **240**.

As illustrated in FIGS. **11** and **12**, the laser converging unit **400** includes a mirror **402** and a dichroic mirror **403**. Further, the laser converging unit **400** includes a reflective spatial light modulator **410**, a 4f lens unit **420**, a converging lens unit (objective lens) **430**, a drive mechanism **440**, and a pair of distance measuring sensors **450**.

The mirror **402** is attached to a bottom surface **401***b* of the housing **401** so as to face the light entrance unit **401***a* in the Z-axis direction. The mirror **402** reflects the laser light L entering the housing **401** via the light entrance unit **401***a* in a direction parallel to the XY plane. The laser light L collimated by the beam expander **350** of the laser output unit **300** enters the mirror **402** along the Z-axis direction. That is, the laser light L as parallel light enters the mirror **402** along the Z-axis direction. For that reason, even if the laser converging unit **400** is moved along the Z-axis direction by the second moving mechanism **240**, a constant state is maintained of the laser light L entering the mirror **402** along the Z-axis direction. The laser light L reflected by the mirror **402** enters the reflective spatial light modulator **410**.

The reflective spatial light modulator **410** is attached to an end **401***c* of the housing **401** in the Y-axis direction in a state where the reflective surface **410***a* faces the inside of the housing **401**. The reflective spatial light modulator **410** is, for example, a reflective liquid crystal (Liquid Crystal on Silicon (LCOS)) Spatial Light Modulator (SLM), and reflects the laser light L in the Y-axis direction while modulating the laser light L. The laser light L modulated and reflected by the reflective spatial light modulator **410** enters the 4f lens unit **420** along the Y-axis direction. Here, in a plane parallel to the XY plane, an angle α formed by an optical axis of the laser light L entering the reflective spatial light modulator **410** and an optical axis of the laser light L emitted from the reflective spatial light modulator **410**, is an acute angle (for example, from 10° to 60°). That is, the laser light L is reflected at an acute angle along the XY plane in the reflective spatial light modulator **410**. This is for suppressing an incident angle and a reflection angle of the laser light L to inhibit the degradation of diffraction efficiency, and for sufficiently exerting performance of the reflective spatial light modulator **410**. Note that, in the reflective spatial light modulator **410**, for example, the thickness of a light modulation layer in which a liquid crystal is used is extremely thin as several micrometers to several tens of micrometers, so that the reflective surface **410***a* can be regarded as substantially the same as a light entering and exiting surface of the light modulation layer.

The 4f lens unit **420** includes a holder **421**, a lens **422** on the reflective spatial light modulator **410** side, a lens **423** on the converging lens unit **430** side, and a slit member **424**. The holder **421** holds a pair of the lenses **422** and **423** and the slit member **424**. The holder **421** maintains a constant mutual positional relationship between the pair of lenses **422** and **423** and the slit member **424** in a direction along the optical axis of the laser light L. The pair of lenses **422** and **423** constitutes a double telecentric optical system in which the reflective surface **410***a* of the reflective spatial light modulator **410** and an entrance pupil plane (pupil plane) **430***a* of the converging lens unit **430** are in an imaging relationship.

Thus, an image of the laser light L on the reflective surface **410***a* of the reflective spatial light modulator **410** (an image of the laser light L modulated in the reflective spatial light modulator **410**) is transferred to (imaged on) the entrance pupil plane **430***a* of the converging lens unit **430**. A slit **424***a* is formed in the slit member **424**. The slit **424***a* is located between the lens **422** and the lens **423** and near a focal plane of the lens **422**. Unnecessary part of the laser light L modulated and reflected by the reflective spatial light modulator **410** is blocked by the slit member **424**. The laser light L having passed through the 4f lens unit **420** enters the dichroic mirror **403** along the Y-axis direction.

The dichroic mirror **403** reflects most (for example, from 95% to 99.5%) of the laser light L in the Z-axis direction and transmits part (for example, from 0.5% to 5%) of the laser light L along the Y-axis direction. Most of the laser light L is reflected at a right angle along the ZX plane in the dichroic mirror **403**. The laser light L reflected by the dichroic mirror **403** enters the converging lens unit **430** along the Z-axis direction.

The converging lens unit **430** is attached to an end **401***d* (an end on the opposite side from the end **401***c*) of the housing **401** in the Y-axis direction via the drive mechanism **440**. The converging lens unit **430** includes a holder **431** and a plurality of lenses **432**. The holder **431** holds the plurality of lenses **432**. The plurality of lenses **432** converges the laser light L at the object to be processed **1** (see FIG. **7**) supported by the support table **230**. The drive mechanism **440** moves the converging lens unit **430** along the Z-axis direction by driving force of a piezoelectric device.

The pair of distance measuring sensors **450** is attached to the end **401***d* of the housing **401** so as to be respectively located on both sides of the converging lens unit **430** in the X-axis direction. Each of the distance measuring sensors **450** emits light for distance measurement (for example, laser light) to the laser light entrance surface of the object to be processed **1** (see FIG. **7**) supported by the support table **230**, and detects the light for distance measurement reflected by the laser light entrance surface, thereby acquiring displacement data of the laser light entrance surface of the object to be processed **1**. Note that, for the distance measuring sensors **450**, sensors can be used of a triangulation method, a laser confocal method, a white confocal method, a spectral interference method, an astigmatism method, and the like.

In the laser processing device **200**, as described above, the direction parallel to the X-axis direction is the processing direction (scanning direction of the laser light L). For that reason, when the converging point of the laser light L is relatively moved along each of the lines to cut **5***a* and **5***b*, out of the pair of distance measuring sensors **450**, one of the distance measuring sensors **450** being relatively advanced with respect to the converging lens unit **430** acquires the displacement data of the laser light entrance surface of the object to be processed **1** along each of the lines to cut **5***a* and **5***b*. Then, the drive mechanism **440** moves the converging lens unit **430** along the Z-axis direction on the basis of the displacement data acquired by the distance measuring sensors **450** such that a constant distance is maintained between the laser light entrance surface of the object to be processed **1** and the converging point of the laser light L.

The laser converging unit **400** includes a beam splitter **461**, a pair of lenses **462** and **463**, and a profile acquisition camera (intensity distribution acquisition unit) **464**. The beam splitter **461** divides the laser light L transmitted through the dichroic mirror **403** into a reflection component and a transmission component. The laser light L reflected by the beam splitter **461** sequentially enters the pair of lenses **462** and **463**, and the profile acquisition camera **464** along the Z-axis direction. The pair of lenses **462** and **463** constitutes a double telecentric optical system in which the entrance pupil plane **430***a* of the converging lens unit **430** and an imaging surface of the profile acquisition camera **464** are in an imaging relationship. Thus, an image of the laser light L on the entrance pupil plane **430***a* of the converging lens unit **430** is transferred to (imaged on) the imaging surface of the profile acquisition camera **464**. As described above, the image of the laser light L on the entrance pupil plane **430***a* of the converging lens unit **430** is the image of the laser light L modulated in the reflective spatial light modulator **410**. Therefore, in the laser processing device **200**, an imaging result by the profile acquisition camera **464** is monitored, whereby an operation state of the reflective spatial light modulator **410** can be grasped.

Further, the laser converging unit **400** includes a beam splitter **471**, a lens **472**, and a camera **473** for monitoring an optical axis position of the laser light L. The beam splitter **471** divides the laser light L transmitted through the beam splitter **461** into a reflection component and a transmission component. The laser light L reflected by the beam splitter **471** sequentially enters the lens **472** and the camera **473** along the Z-axis direction. The lens **472** converges the entering laser light L on an imaging surface of the camera **473**. In the laser processing device **200**, while an imaging result by each of the cameras **464** and **473** is monitored, in the mirror unit **360**, the position adjustment of the support base **361** with respect to the mounting base **301**, the position adjustment of the mirror **363** with respect to the support base **361**, and the angle adjustment of the reflective surface of each of the mirrors **362** and **363** are performed (see FIGS. **9** and **10**), whereby a shift can be corrected of the optical axis of the laser light L entering the converging lens unit **430** (a positional shift of intensity distribution of the laser light with respect to the converging lens unit **430**, and an angular shift of the optical axis of the laser light L with respect to the converging lens unit **430**).

The plurality of beam splitters **461** and **471** is arranged in a cylindrical body **404** extending along the Y-axis direction from the end **401***d* of the housing **401**. The pair of lenses **462** and **463** is arranged in a cylindrical body **405** erected on the cylindrical body **404** along the Z-axis direction, and the profile acquisition camera **464** is arranged at an end of the cylindrical body **405**. The lens **472** is arranged in a cylindrical body **406** erected on the cylindrical body **404** along the Z-axis direction, and the camera **473** is arranged at an end of the cylindrical body **406**. The cylindrical body **405** and the cylindrical body **406** are arranged side by side in the Y-axis direction. Note that, the laser light L transmitted through the beam splitter **471** may be absorbed by a damper or the like provided at an end of the cylindrical body **404**, or may be used for an appropriate purpose.

As illustrated in FIGS. **12** and **13**, the laser converging unit **400** includes a visible light source **481**, a plurality of lenses **482**, a reticle **483**, a mirror **484**, a semitransparent mirror **485**, a beam splitter **486**, a lens **487**, and an observation camera **488**. The visible light source **481** emits visible light V along the Z-axis direction. The plurality of lenses **482** collimates the visible light V emitted from the visible light source **481**. The reticle **483** gives a scale line to the visible light V. The mirror **484** reflects the visible light V collimated by the plurality of lenses **482** in the X-axis direction. The semitransparent mirror **485** divides the visible light V reflected by the mirror **484** into a reflection component and a transmission component. The visible light V reflected by the semitransparent mirror **485** is sequentially transmitted through the beam splitter **486** and the dichroic mirror **403** along the Z-axis direction, and is emitted via the converging lens unit **430** to the object to be processed **1** supported by the support table **230** (See FIG. **7**).

The visible light V emitted to the object to be processed **1** is reflected by the laser light entrance surface of the object to be processed **1**, enters the dichroic mirror **403** via the converging lens unit **430**, and is transmitted through the dichroic mirror **403** along the Z-axis direction. The beam splitter **486** divides the visible light V transmitted through the dichroic mirror **403** into a reflection component and a transmission component. The visible light V transmitted through the beam splitter **486** is transmitted through the semitransparent mirror **485** and sequentially enters the lens **487** and the observation camera **488** along the Z-axis direction. The lens **487** converges the entering visible light V on an imaging surface of the observation camera **488**. In the laser processing device **200**, an imaging result by the observation camera **488** is observed, whereby a state of the object to be processed **1** can be grasped.

The mirror **484**, the semitransparent mirror **485**, and the beam splitter **486** are arranged in a holder **407** attached on the end **401***d* of the housing **401**. The plurality of lenses **482** and the reticle **483** are arranged in a cylindrical body **408** erected on the holder **407** along the Z-axis direction, and the visible light source **481** is arranged at an end of the cylindrical body **408**. The lens **487** is arranged in a cylindrical body **409** erected on the holder **407** along the Z-axis direction, and the observation camera **488** is arranged at an end of the cylindrical body **409**. The cylindrical body **408** and the cylindrical body **409** are arranged side by side in the X-axis direction. Note that, each of the visible light V transmitted through the semitransparent mirror **485** along the X-axis direction and the visible light V reflected in the X-axis direction by the beam splitter **486** may be absorbed by a damper or the like provided on a wall portion of the holder **407**, or may be used for an appropriate purpose.

In the laser processing device **200**, replacement of the laser output unit **300** is assumed. This is because the wavelength of the laser light L suitable for processing varies depending on the specifications of the object to be processed **1**, processing conditions, and the like. For that reason, a plurality of the laser output units **300** is prepared having respective wavelengths of emitting laser light L different from each other. Here, prepared are the laser output unit **300** in which the wavelength of the emitting laser light L is included in the wavelength band of from 500 nm to 550 nm, the laser output unit **300** in which the wavelength of the emitting laser light L is included in the wavelength band of from 1000 nm to 1150 nm, and the laser output unit **300** in which the wavelength of the emitting laser light L is included in the wavelength band of from 1300 nm to 1400 nm.

On the other hand, in the laser processing device **200**, replacement of the laser converging unit **400** is not assumed. This is because the laser converging unit **400** is adapted to multiple wavelengths (adapted to a plurality of wavelength bands non-contiguous with each other). Specifically, the mirror **402**, the reflective spatial light modulator **410**, the pair of lenses **422** and **423** of the 4f lens unit **420**, the dichroic mirror **403**, the lens **432** of the converging lens unit **430**, and the like are adapted to the multiple wavelengths.

Here, the laser converging unit **400** is adapted to the wavelength bands of from 500 nm to 550 nm, from 1000 nm to 1150 nm, and from 1300 nm to 1400 nm. This is implemented by designing the components of the laser converging unit **400** so as to satisfy desired optical performance, such as coating the components of the laser converging unit **400** with a predetermined dielectric multilayer film. Note that, in the laser output unit **300**, the λ/2 wave plate unit **330** includes a λ/2 wave plate, and the polarizing plate unit **340** includes a polarizing plate. The λ/2 wave plate and the polarizing plate are optical devices having high wavelength dependence. For that reason, the λ/2 wave plate unit **330** and the polarizing plate unit **340** are provided in the laser output unit **300** as different components for each wavelength band.

[Optical Path and Polarization Direction of Laser Light in Laser Processing Device]

In the laser processing device **200**, as illustrated in FIG. **11**, the polarization direction of the laser light L converged at the object to be processed **1** supported by the support table **230** is a direction parallel to the X-axis direction, and coincides with the processing direction (scanning direction of the laser light L). Here, in the reflective spatial light modulator **410**, the laser light L is reflected as P-polarized light. This is because in a case where a liquid crystal is used for the light modulation layer of the reflective spatial light modulator **410**, when the liquid crystal is oriented such that the liquid crystal molecules are inclined in a surface parallel to the plane including the optical axis of the laser light L entering and exiting the reflective spatial light modulator **410**, phase modulation is applied to the laser light L in a state where the rotation of the plane of polarization is inhibited (for example, see Japanese Patent No. 3878758).

On the other hand, in the dichroic mirror **403**, the laser light L is reflected as S-polarized light. This is because, for example, when the laser light L is reflected as the S-polarized light rather than when the laser light L is reflected as the P-polarized light, the number of coatings is reduced of the dielectric multilayer film for making the dichroic mirror **403** adapt to the multiple wavelengths, and designing of the dichroic mirror **403** becomes easier.

Therefore, in the laser converging unit **400**, the optical path from the mirror **402** via the reflective spatial light modulator **410** and the 4f lens unit **420** to the dichroic mirror **403** is set along the XY plane, and the optical path from the dichroic mirror **403** to the converging lens unit **430** is set along the Z-axis direction.

As illustrated in FIG. **9**, in the laser output unit **300**, the optical path of the laser light L is set along the X-axis direction or the Y-axis direction. Specifically, the optical path from the laser oscillator **310** to the mirror **303**, and the optical path from the mirror **304** via the λ/2 wave plate unit **330**, the polarizing plate unit **340**, and the beam expander **350** to the mirror unit **360** are set along the X-axis direction, and the optical path from the mirror **303** via the shutter **320** to the mirror **304**, and the optical path from the mirror **362** to the mirror **363** in the mirror unit **360** are set along the Y-axis direction.

Here, as illustrated in FIG. **11**, the laser light L having traveled to the laser converging unit **400** from the laser output unit **300** along the Z-axis direction is reflected by the mirror **402** in a direction parallel to the XY plane, and enters the reflective spatial light modulator **410**. At this time, in the plane parallel to the XY plane, an acute angle α is formed by the optical axis of the laser light L entering the reflective spatial light modulator **410** and the optical axis of the laser light L emitted from the reflective spatial light modulator **410**. On the other hand, as described above, in the laser output unit **300**, the optical path of the laser light L is set along the X-axis direction or the Y-axis direction.

Therefore, in the laser output unit **300**, it is necessary to cause the λ/2 wave plate unit **330** and the polarizing plate unit **340** to function not only as the output adjusting unit configured to adjust the output of the laser light L but also as the polarization direction adjusting unit configured to adjust the polarization direction of the laser light L.

[4f Lens Unit]

As described above, the pair of lenses **422** and **423** of the 4f lens unit **420** constitutes the double telecentric optical system in which the reflective surface **410***a* of the reflective spatial light modulator **410** and the entrance pupil plane **430***a* of the converging lens unit **430** are in the imaging relationship. Specifically, as illustrated in FIG. **14**, the distance of the optical path between the center of the lens **422** on the reflective spatial light modulator **410** side and the reflective surface **410***a* of the reflective spatial light modulator **410** is a first focal length f1 of the lens **422**, the distance of the optical path between the center of the lens **423** on the converging lens unit **430** side and the entrance pupil plane **430***a* of the converging lens unit **430** is a second focal length f2 of the lens **423**, and the distance of the optical path between the center of the lens **422** and the center of the lens **423** is a sum of the first focal length f1 and the second focal length f2 (that is, f1+f2). In the optical path from the reflective spatial light modulator **410** to the converging lens unit **430**, the optical path between the pair of lenses **422** and **423** is a straight line.

In the laser processing device **200**, from a viewpoint of increasing an effective diameter of the laser light L on the reflective surface **410***a* of the reflective spatial light modulator **410**, a magnification M of the double telecentric optical system satisfies $0.5<M<1$ (reduction system). As the effective diameter is increased of the laser light L on the reflective surface **410***a* of the reflective spatial light modulator **410**, the laser light L is modulated with a high-precision phase pattern. From a viewpoint of inhibiting the optical path from becoming longer of the laser light L from the reflective spatial light modulator **410** to the converging lens unit **430**, it is possible to set $0.6<M\leq 0.95$. Here, (the magnification M of the double telecentric optical system)=(the size of the image on the entrance pupil plane **430***a* of the converging lens unit **430**)/(the size of the object on the reflective surface **410***a* of the reflective spatial light modulator **410**). In the case of the laser processing device **200**, the magnification M of the double telecentric optical system, the first focal length f1 of the lens **422**, and the second focal length f2 of the lens **423** satisfy $M=f2/f1$.

From a viewpoint of reducing the effective diameter of the laser light L on the reflective surface **410***a* of the reflective spatial light modulator **410**, the magnification M of the double telecentric optical system may satisfy $1<M<2$ (enlargement system). As the effective diameter is reduced of the laser light L on the reflective surface **410***a* of the reflective spatial light modulator **410**, the magnification can be reduced of the beam expander **350** (see FIG. **9**), and in the plane parallel to the XY plane, the angle α (see FIG. **11**) is reduced formed by the optical axis of the laser light L entering the spatial light modulator **410** and the optical axis of the laser light L emitted from the reflective spatial light modulator **410**. From the viewpoint of inhibiting the optical path from becoming longer of the laser light L from the reflective spatial light modulator **410** to the converging lens unit **430**, it is possible to set $1.05\leq M\leq 1.7$.

[Reflective Spatial Light Modulator]

As illustrated in FIG. **15**, the reflective spatial light modulator **410** includes a silicon substrate **213**, a drive circuit layer **914**, a plurality of pixel electrodes **214**, a reflective film **215** such as a dielectric multilayer mirror, an alignment film **999***a*, a liquid crystal layer (modulation layer) **216**, an alignment film **999***b*, a transparent conductive film **217**, and a transparent substrate **218** such as a glass substrate, which are layered in this order.

The transparent substrate **218** includes a front surface **218***a*. As described above, the front surface **218***a* can be regarded as substantially constituting the reflective surface **410***a* of the reflective spatial light modulator **410**, but more specifically, the front surface **218***a* is an entrance surface at which the laser light L enters. That is, the transparent substrate **218** is made of a light transmitting material such as glass, for example, and transmits the laser light L entering from the front surface **218***a* of the reflective spatial light modulator **410** to the inside of the reflective spatial light modulator **410**. The transparent conductive film **217** is formed on a back surface of the transparent substrate **218**, and includes a conductive material (for example, ITO) which transmits therethrough the laser light L.

The plurality of pixel electrodes **214** is arranged in a matrix on the silicon substrate **213** along the transparent conductive film **217**. Each pixel electrode **214** is made of a metal material such as aluminum, for example, while its front surface **214***a* is processed flat and smooth. The front surface **214***a* reflects the laser light L entering from the front surface **218***a* of the transparent substrate **218** toward the front surface **218***a*. That is, the reflective spatial light modulator **410** includes the front surface **218***a* at which the laser light L enters, and the front surface **214***a* configured to reflect the laser light L entering from the front surface **218***a*, toward the front surface **218***a*. The plurality of pixel electrodes **214** are driven by an active matrix circuit provided in the drive circuit layer **914**.

The active matrix circuit is provided between the plurality of pixel electrodes **214** and the silicon substrate **213**, and controls an applied voltage to each of the pixel electrodes **214** in accordance with a light image to be output from the reflective spatial light modulator **410**. Such an active matrix circuit includes a first driver circuit configured to control the applied voltage for pixel rows arranged in the X-axis direction, and a second driver circuit configured to control the applied voltage for pixel rows arranged in the Y-axis direction, which are not illustrated, for example, and a predetermined voltage is applied to the pixel electrode **214** of a pixel specified by the driver circuits, by the controller **500**.

The alignment films **999***a*, **999***b* are arranged on both end surfaces of the liquid crystal layer **216**, respectively, so as to align a group of liquid crystal molecules in a fixed direction. The alignment films **999***a*, **999***b* are made of a polymer material such as polyimide, of which surfaces coming into contact with the liquid crystal layer **216** are subjected to rubbing, and the like.

The liquid crystal layer **216** is arranged between the plurality of pixel electrodes **214** and the transparent conductive film **217** and modulates the laser light L according to an electric field formed between each pixel electrode **214** and the transparent conductive film **217**. That is, when a voltage is applied to the pixel electrodes **214** by the active matrix circuit of the drive circuit layer **914**, an electric field is formed between the transparent conductive film **217** and the pixel electrodes **214**, and the alignment direction of liquid crystal molecules **216***a* changes according to a magnitude of the electric field formed in the liquid crystal layer **216**. When the laser light L enters the liquid crystal layer **216** through the transparent substrate **218** and the transparent conductive film **217**, the laser light L is modulated by the liquid crystal molecules **216***a* while passing through the liquid crystal layer **216**, and reflected by the reflective film **215**, and then modulated again by the liquid crystal layer **216**, and emitted.

At this time, the voltage applied to each of the pixel electrodes **214** is controlled by the controller **500**, and, in accordance with the voltage, a refractive index changes in a portion sandwiched between the transparent conductive film **217** and each of the pixel electrodes **214** in the liquid crystal layer **216** (the refractive index changes of the liquid crystal layer **216** at a position corresponding to each pixel). Due to the change in the refractive index, the phase of the laser light L can be changed for each pixel of the liquid crystal layer **216** in accordance with the voltage applied. That is, phase modulation corresponding to the hologram pattern can be applied by the liquid crystal layer **216** for each pixel.

In other words, a modulation pattern as the hologram pattern applying the modulation can be displayed on the liquid crystal layer **216** of the reflective spatial light modulator **410**. The wavefront is adjusted of the laser light L that enters and is transmitted through the modulation pattern, and shifts occur in phases of components of individual rays constituting the laser light L in a predetermined direction orthogonal to their traveling direction. Therefore, the laser light L can be modulated (for example, intensity, amplitude, phase, and polarization of the laser light L can be modulated) by appropriately setting the modulation pattern to be displayed in the reflective spatial light modulator **410**.

In other words, depending on the voltage applied to each pixel electrode **214**, a refractive index distribution is generated in the liquid crystal layer **216** along the arrangement direction of the pixel electrodes **214**, and a phase pattern that can apply phase modulation to the laser light L is displayed on the liquid crystal layer **216**. That is, the reflective spatial light modulator **410** includes the liquid crystal layer (modulation layer) **216** arranged between the front surface **218***a* and the front surface **214***a* and configured to display the phase pattern to modulate the laser light L.

Subsequently, the reflective spatial light modulator **410** will be described in more detail. The reflective spatial light modulator **410** is configured to be adaptable to the plurality of wavelength bands non-contiguous with each other (multi-wavelength adaptable) such as a first wavelength band of greater than or equal to 500 nm and less than or equal to 550 nm, a second wavelength band of greater than or equal to 1000 nm and less than or equal to 1150 nm, and a third wavelength band of greater than or equal to 1300 nm and less than or equal to 1400 nm. For that reason, on the front surface **214***a* of the pixel electrode **214**, the reflective film **215** is formed, and the reflective film **215** is a dielectric multilayer film having a high reflectance region in the plurality of wavelength bands. FIG. **16**(*a*) is a diagram illustrating an example of a reflectance characteristic of the reflective film **215**. As illustrated in FIG. **16**(*a*), here, the reflective film **215** has a high reflectance region RR**1** corresponding to the first wavelength band, a high reflectance region RR**2** corresponding to the second wavelength band, and a high reflectance region RR**3** corresponding to the third wavelength band.

Low reflectance regions are respectively formed between the high reflectance regions RR**1** to RR**3**. Thus, the high reflectance regions RR**1** to RR**3** are non-contiguous with each other in a high reflectance range. Here, the high reflectance region is a region where the reflectance is greater than or equal to 95%. Therefore, here, the low reflectance region is a region where the reflectance is less than 95%. Note that, as described above, the reflective film **215** has the plural high reflectance regions RR**1** to RR**3** non-contiguous with each other (in the high reflectance range), but it is also possible to make the high reflectance region RR**1** to the high reflectance region RR**3** contiguous in the high reflectance range. That is, as an example, the reflective film **215** can also be configured to have a high reflectance over the entire wavelength range from 500 nm that is the lower limit of the first wavelength band to 1400 nm that is the upper limit of the third wavelength band. However, in this case, the number of dielectric multilayer films increases, and the film thickness of the reflective film **215** increases. As a result, a large voltage is required to display a predetermined phase pattern in the liquid crystal layer **216**. Therefore, as described above, it is advantageous to set only the respective target wavelength bands (the first wavelength band to the third wavelength band) to the high reflectance, to suppress the increase in the film thickness of the dielectric multilayer film.

On the front surface **218***a* of the transparent substrate **218**, an antireflective film (not illustrated) is formed having a high transmittance region in the plurality of wavelength bands. FIG. **16**(*b*) is a diagram illustrating an example of a transmittance characteristic of the antireflective film. As illustrated in FIG. **16**(*b*), the antireflective film provided on the front surface **218***a* has a high transmittance region TR**1** corresponding to the first wavelength band, a high transmittance region TR**2** corresponding to the second wavelength band, and a high transmittance region TR**3** corresponding to the third wavelength band. Note that, in FIG. **16**(*b*), the solid line illustrates a transmittance range of 0% to 100% (vertical axis on the left side), and the broken line illustrates a transmittance range of 90% to 100% (vertical axis on the right side). In addition, the high transmittance region here is a region where the transmittance is approximately greater than or equal to 98%.

Here, the front surface **214***a* of the pixel electrode **214** has a predetermined flatness. That is, the front surface **214***a* may have a predetermined distortion. When the front surface **214***a* is distorted, distortion is also applied to the wavefront of the laser light L reflected by the front surface **214***a*. For this reason, the laser processing device **200** includes a distortion correction pattern that is a phase pattern for correcting distortion of the wavefront. FIG. **17**(*a*) is a graph illustrating an example of the distortion. In the example of FIG. **17**(*a*), a case is illustrated in which the distortion occurs over the front surface **214***a* of the plurality of pixel electrodes **214** depending on a warp of the silicon substrate **213**, for example.

FIG. **17**(*b*) is a graph in which an amount of distortion in FIG. **17**(*a*) is divided by the wavelength of the laser light L so as to obtain an amount of distortion converted into the wavelength. In addition, in FIG. **17**(*b*), the horizontal axis is converted into the pixel number (pixel position) of the pixel electrode **214**. As illustrated in FIG. **17**(*b*), for the amount of distortion converted into the wavelength, fold-backs S**1** and S**2** are formed at each one wavelength (2π). For this reason, in the case of being converted into the wavelength, the amount of distortion at each pixel varies between those of when the wavelength of the laser light L is 1064 nm (solid line) and when the wavelength of the laser light L is 532 nm (broken line), for example. That is, different phase modulation amounts (that is, distortion correction patterns) are required depending on the wavelength of the laser light L.

FIG. **18**(*a*) illustrates a distortion correction pattern for a wavelength of 1064 nm, and FIG. **18**(*b*) illustrates a distortion correction pattern for a wavelength of 532 nm. Note that, actually, FIGS. **18**(*a*) and **18**(*b*) each illustrate an image signal for displaying the distortion correction pattern on the liquid crystal layer **216**. In the image signal, the distribution of the luminance value corresponds to the distribution of the refractive index of the liquid crystal layer **216** via the voltage. Therefore, the image signal of each of FIGS. **18**(*a*) and **18**(*b*) is equivalent to the phase pattern (distortion correction pattern). As illustrated in FIGS. **18**(*a*) and **18**(*b*), the distortion correction pattern for the wavelength of 1064 nm includes a pattern corresponding to the fold-back S**1**, whereas the distortion correction pattern for the wavelength of 532 nm includes patterns respectively corresponding to the fold-backs S**1** and S**2** (the fold-back period is half).

As described above, the laser processing device **200** holds the distortion correction pattern different for each of the plurality of wavelength bands (that is, includes a pattern holding unit). The pattern holding unit may be configured in the controller **500** or in the reflective spatial light modulator **410**. Here, at least distortion correction patterns are held corresponding to three wavelength bands of the first wavelength band, the second wavelength band, and the third wavelength band. Each of the distortion correction patterns is a pattern obtained by converting a distortion correction amount into each wavelength, that is, a pattern in which the fold-backs S**1** and S**2** of the distortion correction amount (phase modulation amount) are formed at a period corresponding to the wavelength.

Here, the laser processing device **200** includes a table (hereinafter referred to as "Look-Up table (LUT)") in which the luminance value of the image signal for forming the phase pattern in the liquid crystal layer **216** and the phase modulation amount of the phase pattern are associated with each other. Subsequently, the LUT will be described. FIG. **19**(*a*) is a diagram illustrating an example of a relationship between the voltage applied to the liquid crystal layer **216** and the phase modulation amount (wavelength indication) applied to the laser light L by the liquid crystal layer **216**. FIG. **19**(*b*) is a diagram illustrating an example of the LUT. As illustrated in FIG. **19**(*a*), for example, to apply a phase modulation for one wavelength (1064 nm) to the laser light L having a wavelength of 1064 nm, it is sufficient that a voltage of approximately 2 V is applied to the liquid crystal layer **216**.

Therefore, as illustrated by the solid line in FIG. **19**(*b*), by assigning the voltages of 0 V to 2 V to the luminance value of 256 gradations of the image signal, the phase modulation amounts of 0 to a (for one wavelength) of the laser light L of 1064 nm and the luminance values of 256 gradations can be associated with each other. On the other hand, as illustrated in FIG. **19**(*a*), to apply a phase modulation for one wavelength (532 nm) to the laser light L having a wavelength of 532 nm, it is sufficient that a voltage smaller than 2 V (for example, about 1.2 V) is applied to the liquid crystal layer **216**. Note that, the phase modulation amount is not an absolute amount but a difference. For that reason, it is also possible to use a region of about 2.4 V to 3.5 V in the laser light of 532 nm, as the LUT, for example. Since the characteristics such as the response speed of the liquid crystal change in the voltage range to be used, it is possible to use the optimum voltage range depending on the application.

Therefore, as described above, if the voltages of 0 V to 2 V are assigned to the luminance values of 256 gradations of the image signal, as illustrated in FIG. **19**(*b*), for the laser light L of 532 nm, phase modulation amounts (for example, 4π) larger than 2π (one wavelength) are associated with the luminance values of 256 gradations. Therefore, for the phase modulation amounts for 2π (one wavelength) of the effective laser light L of 532 nm, luminance values are used of smaller gradations than 256 gradations (for example, 128 grayscales). For this reason, when the same LUT is used for the plural wavelengths, the reproducibility degrades of the wavefront after modulation of the laser light L having a relatively short wavelength among the plural wavelengths.

To cope with this, the laser processing device **200** holds the LUT different for each of the wavelength bands. As an example, the laser processing device **200** holds a LUT (see FIG. **20**(*a*)) in which the phase modulation amounts of 0 to 2π (for one wavelength) of the laser light L of 1064 nm and the luminance values of 256 gradations are associated with each other by assigning the voltages of 0 V to 2 V to the luminance values of 256 gradations of the image signal as described above, and a LUT (see FIG. **20**(*b*)) in which the phase modulation amounts of 0 to 2π (one wavelength) of the laser light L of 532 nm and the luminance values of 256 gradations are associated with each other by assigning voltages of 0 V to 1.2 V to the luminance values of 256 gradations of the image signal. The LUTs in FIGS. **20**(*a*) and **20**(*b*) can be expressed differently from each other by displaying the wavelength on the vertical axis.

As described above, the laser processing device **200** holds the LUT different for each of the wavelength bands (that is, includes a table holding unit). The table holding unit may be configured in the controller **500** or in the reflective spatial light modulator **410**. Here, at least LUTs are held corresponding to three wavelength bands of the first wavelength band, the second wavelength band, and the third wavelength band. In each LUT, for the shorter wavelength band, smaller phase modulation amounts converted into the wavelength are associated with the luminance values of certain gradations (here, 256 gradations).

As described above, in the laser processing device **200**, the laser light L is modulated in accordance with the phase pattern of the reflective spatial light modulator **410**, and then converged by the converging lens unit **430** toward the object to be processed **1**. The reflective spatial light modulator **410** includes the front surface **218***a* of the transparent substrate **218** at which the laser light L enters, the front surface **214***a* of the pixel electrode **214** configured to reflect the laser light L entering from the front surface **218***a*, and the liquid crystal layer **216** arranged between the front surface **218***a* and the front surface **214***a*.

When entering from the front surface **218***a* and passing through the liquid crystal layer **216**, the laser light L is modulated in accordance with the phase pattern. In addition, the laser light L is modulated also when being reflected by the front surface **214***a* and again passing through the liquid crystal layer **216**, and is emitted from the reflective spatial light modulator **410**. Here, on the front surface **214***a*, the reflective film **215** is formed that is a dielectric multilayer film having the high reflectance regions RR**1** to RR**3** in the plurality of wavelength bands non-contiguous with each other. Therefore, with the reflective spatial light modulator **410**, it is possible to modulate the laser light L while reducing the loss on the front surface **214***a* of the laser light L of the plurality of wavelength bands. Accordingly, the laser processing device **200** is adaptable to the plurality of wavelength bands.

The laser processing device **200** includes the pattern holding unit (for example, the controller **500**) configured to hold the distortion correction pattern as the phase pattern for correcting distortion given to the wavefront of the laser light L depending on the flatness of the front surface **214***a* of the pixel electrode **214**. The pattern holding unit holds the distortion correction pattern different for each of the wavelength bands. As described above, the front surface **214***a* of the pixel electrode **214** has a predetermined flatness for each reflective spatial light modulator **410**. However, to correct the distortion given to the wavefront of the laser light L depending on the flatness, the phase modulation amount is required different depending on the wavelength. Therefore, as described above, if the distortion correction pattern is held different for each of the wavelength bands, the laser processing device is easily and reliably adaptable to the plurality of wavelength bands.

The laser processing device **200** includes the table holding unit (for example, the controller **500**) configured to hold the LUT in which the luminance value of the image signal for displaying the phase pattern on the liquid crystal layer **216** and the phase modulation amount of the phase pattern are associated with each other. The table holding unit holds the LUT different for each of the wavelength bands. As described above, for the laser light L of a certain wavelength, the LUT is prepared in which the luminance values of, for example, 256 gradations of the image signal are assigned to (associated with) the phase modulation amounts for one wavelength (2π), whereby a phase modulation pattern suitable for the wavelength can be easily displayed on the liquid crystal layer **216**.

However, if the same LUT is used for the laser light L having a wavelength shorter than the wavelength, luminance values of smaller gradations are used for the phase modulation amounts for one wavelength, so that reproducibility drops of the wavefront after the modulation. To cope with this, the laser processing device **200** holds the LUT different for each of the wavelength bands. For this reason, it is possible to use a LUT suitable for each wavelength band, and degradation of the reproducibility of the wavefront can be suppressed.

Further, in the laser processing device **200**, on the front surface **218***a* of the transparent substrate **218**, the antireflective film is formed having the high transmittance regions TR**1** to TR**3** in the plurality of wavelength bands. For this reason, the loss of the laser light L can be further reduced, and the laser processing device is reliably adaptable to the plurality of wavelength bands.

The above is one embodiment of one aspect of the present invention. One aspect of the present invention is not limited to the above-described embodiment, but may be modified within a range not changing the gist of each claim, or may be applied to another.

For example, the above-described embodiment is not limited to one configured to form the modified region **7** within the object to be processed **1**, and may be one configured to perform another laser processing such as ablation. The above-described embodiment is not limited to a laser processing device used for laser processing of converging the laser light L within the object to be processed **1**, and may be a laser processing device used for laser processing of converging the laser light L at the front surface **1***a*, **3** or the back surface **1***b* of the object to be processed **1**.

In the above embodiment, the imaging optical system constituting the double telecentric optical system in which the reflective surface **410***a* of the reflective spatial light modulator **410** and the entrance pupil plane **430***a* of the converging lens unit **430** are in the imaging relationship is not limited to the pair of lenses **422** and **423**, and may be one including the first lens system (for example, a doublet, three or more lenses, or the like) on the reflective spatial light modulator **410** side, and the second lens system (for example, a doublet, three or more lenses, or the like) on the converging lens unit **430** side, or the like.

In the laser converging unit **400**, the dichroic mirror **403** is the mirror configured to reflect the laser light L having passed through the pair of lenses **422** and **423** toward the converging lens unit **430**; however, the mirror may be a total reflection mirror.

The converging lens unit **430** and the pair of distance measuring sensors **450** are attached to the end **401***d* of the housing **401** in the Y-axis direction; however, the converging lens unit **430** and the pair of distance measuring sensors **450** only need to be attached at a side closer to the end **401***d* from the center position of the housing **401** in the Y-axis direction. The reflective spatial light modulator **410** is attached to the end **401***c* of the housing **401** in the Y-axis direction; however, the reflective spatial light modulator **410** only need to be attached at a side closer to the end **401***c* from the center position of the housing **401** in the Y-axis direction. In addition, the distance measuring sensors **450** may be arranged only on one side of the converging lens unit **430** in the X-axis direction.

INDUSTRIAL APPLICABILITY

A laser processing device can be provided adaptable to a plurality of wavelength bands.

REFERENCE SIGNS LIST

1 object to be processed
100, **200** laser processing device
214*a* front surface (reflective surface)
215 reflective film (dielectric multilayer film)
216 liquid crystal layer (modulation layer)
218*a* front surface (entrance surface)
300 laser output unit
410 reflective spatial light modulator (spatial light modulator)
430 converging lens unit (objective lens)
500 controller (pattern holding unit, table holding unit)
L laser light.

The invention claimed is:

1. A laser processing device configured to emit laser light on an object to perform laser processing of the object, the laser processing device comprising:

a laser output unit configured to output the laser light;

a spatial light modulator configured to reflect the laser light output from the laser output unit while modulating the laser light in accordance with a phase pattern, wherein

the spatial light modulator includes an entrance surface at which the laser light enters, a reflective surface configured to reflect the laser light entering from the entrance surface toward the entrance surface, and a modulation layer arranged between the entrance surface and the reflective surface and configured to display the phase pattern to modulate the laser light,

a dielectric multilayer film having a high reflectance region in a plurality of wavelength bands non-contiguous with each other is formed on the reflective surface,

the plurality of wavelength bands includes a first wavelength band of greater than or equal to 500 nm and less than or equal to 550 nm, and a second wavelength band of greater than or equal to 1000 nm and less than or equal to 1150 nm,

an antireflective film having a high transmittance region in the plurality of wavelength bands is formed on the entrance surface, and the spatial light modulator reflects the laser light as P-polarized light;

an objective lens configured to converge the laser light from the spatial light modulator toward the object;

a dichroic mirror configured to reflect the laser light from the spatial light modulator toward the objective lens, wherein the dichroic mirror reflects the laser light as S-polarized light;

a pattern holding unit configured to hold, for each of the plurality of wavelength bands, a distortion correction pattern as the phase pattern for correcting distortion given to a wavefront of the laser light depending on flatness of the reflective surface, wherein the pattern holding unit holds the distortion correction pattern different for each of the plurality of wavelength bands; and

a table holding unit configured to hold, for each of the plurality of wavelength bands, a table in which luminance values of an image signal for displaying the phase pattern on the modulation layer and phase modulation amounts of the phase pattern are associated with each other, wherein

the laser processing device includes a device frame,

the laser output unit includes a laser oscillator configured to oscillate the laser light having the first wavelength band or the laser light having the second wavelength band,

the laser output unit includes a λ/2 wave plate unit, and a polarizing plate unit on which the laser light is incident,

the laser output unit includes a mounting base configured to support the laser oscillator, the λ/2 wave plate unit, and the polarizing plate unit,

the laser output unit is attached to the device frame via the mounting base, and is adapted to be detachable from the device frame with the mounting base,

the laser processing device has a laser converging unit including a housing, the spatial light modulator, the dichroic mirror, and the objective lens,

the spatial light modulator, the dichroic mirror, and the objective lens are fixed on the housing of the laser converging unit,

the laser processing device includes a moving mechanism configured to move the laser converging unit along a Z-axis direction,

the dichroic mirror and the objective lens are adapted to the first wavelength band and the second wavelength band by having a coating of the dielectric multilayer film,

the table holding unit holds the table different for each of the plurality of wavelength bands,

in the table corresponding to the first wavelength band, the phase modulation amounts associated with a specified range of the luminance values are smaller than the phase modulation amounts associated with the specified range of the luminance values in the table corresponding to the second wavelength band, and

a range of an applied voltage of the modulation layer which is assigned to the specified range of the luminance values in the first wavelength band is narrower than a range of the applied voltage of the modulation layer which is assigned to the specified range of the luminance values in the second wavelength band.

2. The laser processing device according to claim **1**, wherein

the plurality of wavelength bands includes a third wavelength band of greater than or equal to 1300 nm and less than or equal to 1400 nm, and

in the table corresponding to the third wavelength band, the phase modulation amounts associated with the specified range of the luminance values are larger than the phase modulation amounts associated with the specified range of the luminance values in the tables corresponding to the first and second wavelength bands.

* * * * *