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(54) LASER SYSTEM AND ELECTRONIC DEVICE MANUFACTURING METHOD

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(57) **ABSTRACT**

A laser system includes a first pulse laser apparatus configured to output a first pulse laser beam in a predetermined cycle, a second pulse laser apparatus configured to output a second pulse laser beam in the predetermined cycle, a first polygon mirror configured to reflect the first pulse laser beam and the second pulse laser beam, and a processor configured to control the first pulse laser apparatus, the second pulse laser apparatus, and the first polygon mirror such that the first pulse laser beam and the second pulse laser beam are output with a shift of ½ of the predetermined cycle between them and optical paths of the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror are oriented in a first direction and at least partially overlapped.

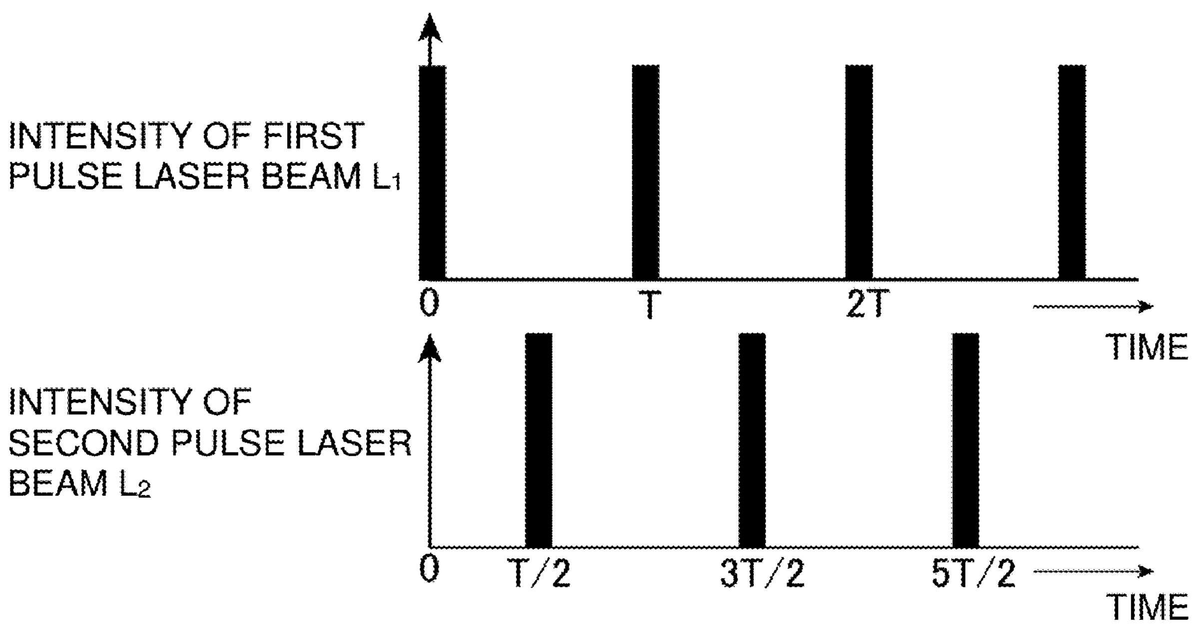


Fig. 1

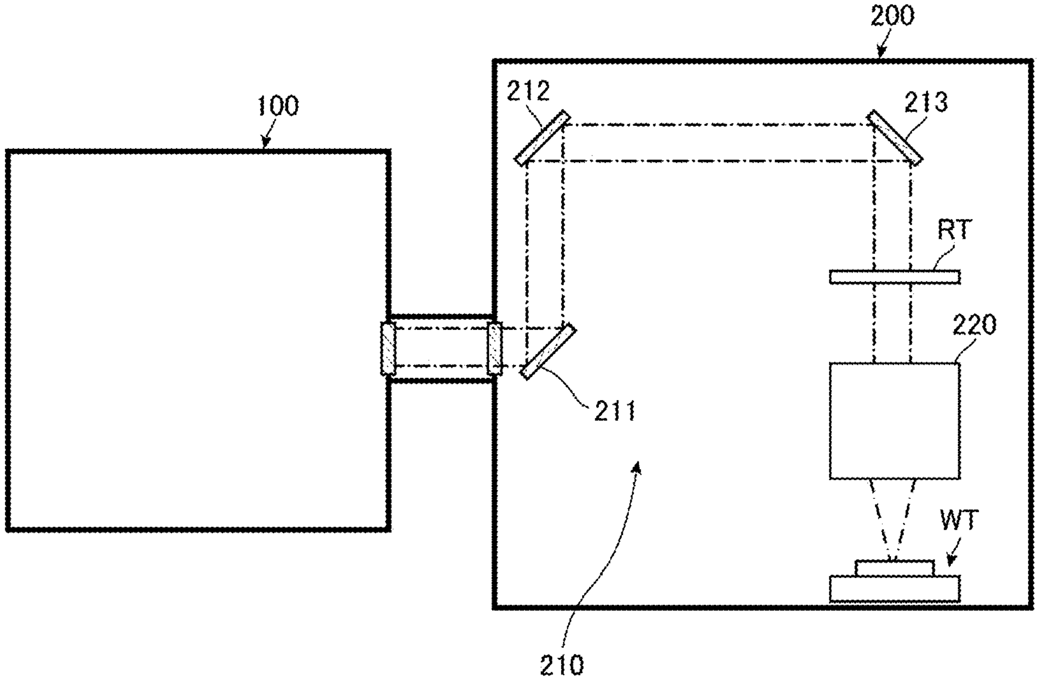


Fig. 2

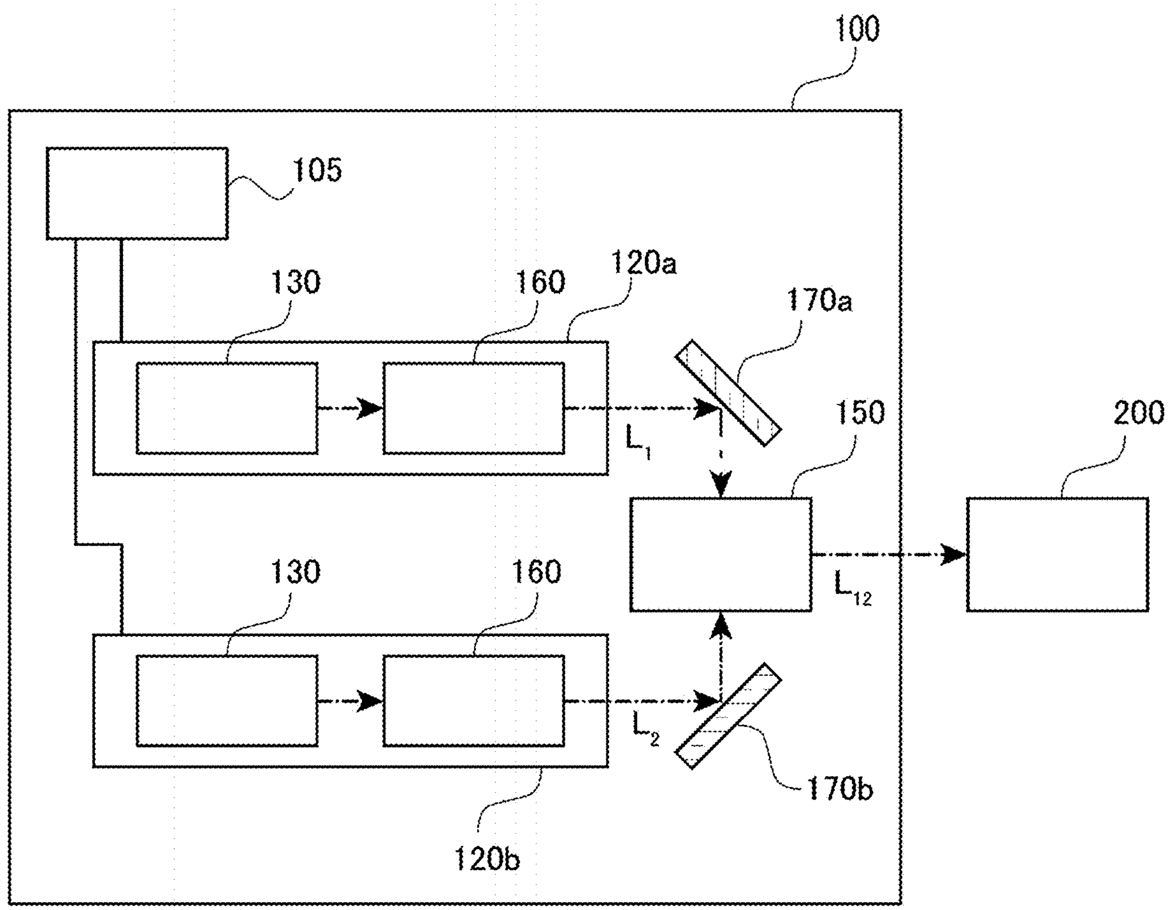
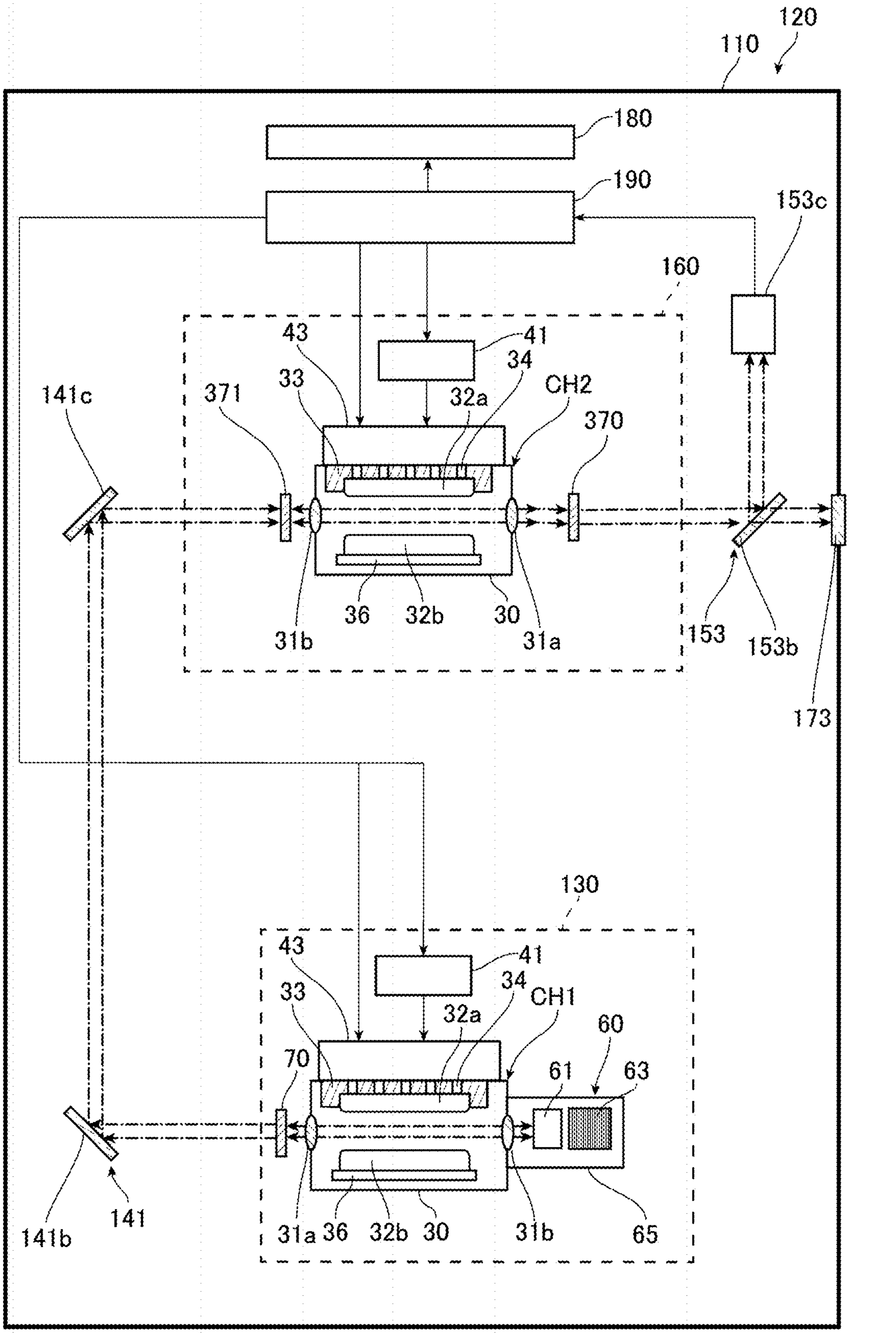
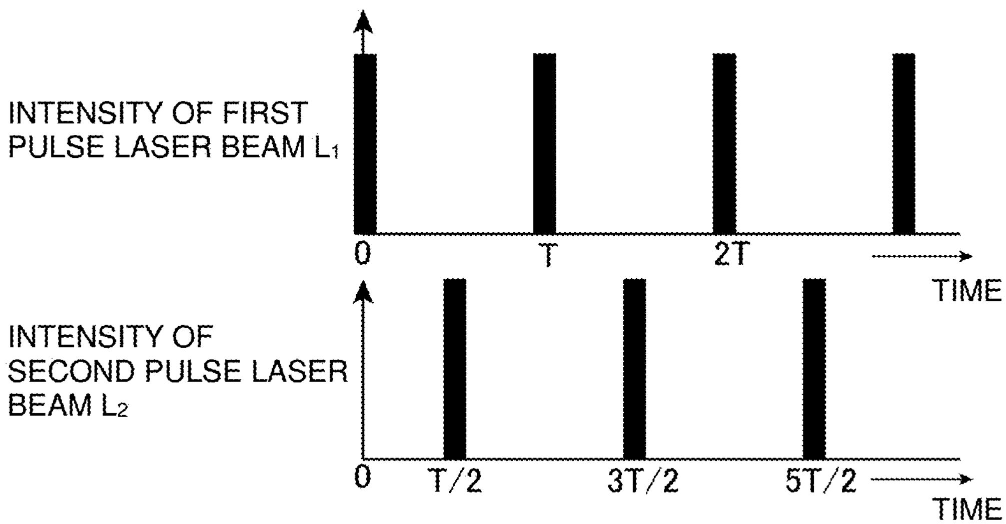


Fig. 3



120
110
180
190
153c
160
43
41
34
33
371
141c
32a
CH2
370
36
32b
30
31b
31a
153
153b
173
130
43
41
33
34
CH1
32a
60
70
61
63
141b
141
31a
36
32b
30
31b
65

Fig. 4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0
T
2T
TIME
INTENSITY OF SECOND PULSE LASER BEAM L_2
0
T/2
3T/2
5T/2
TIME

Fig. 5

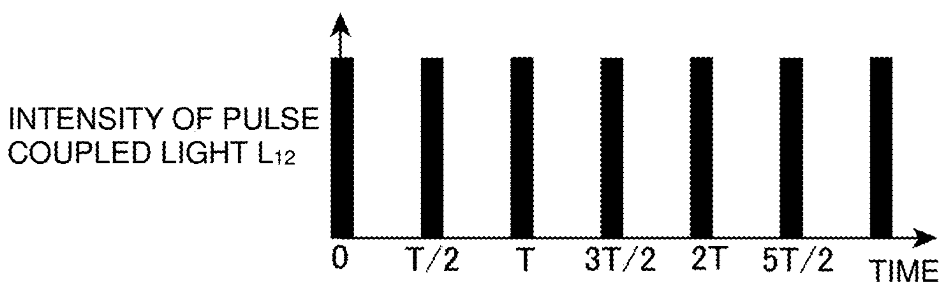

INTENSITY OF PULSE COUPLED LIGHT L_{12}
0
T/2
T
3T/2
2T
5T/2
TIME

Fig. 6

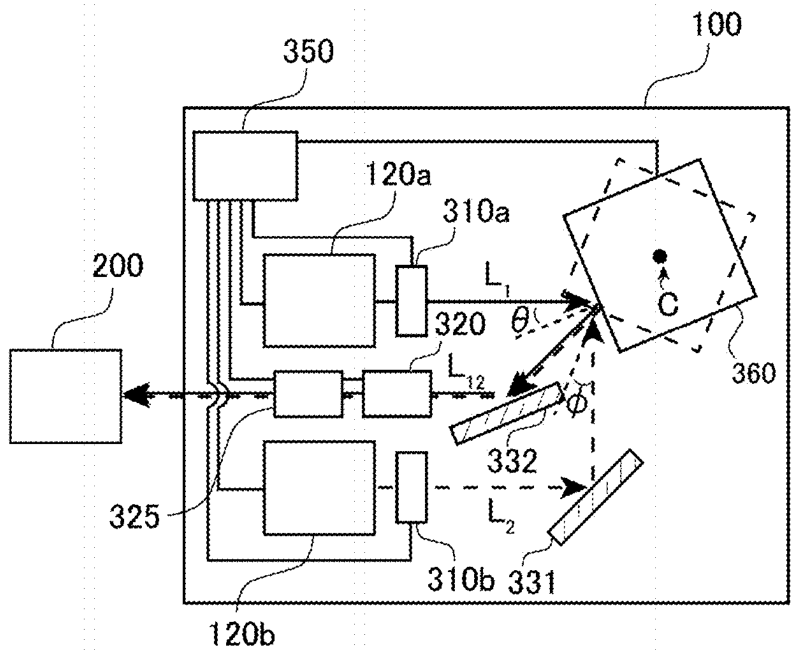

100
350
120a
310a
200
L1
C
θ
320
L12
360
Φ
332
325
L2
310b
331
120b

Fig. 7

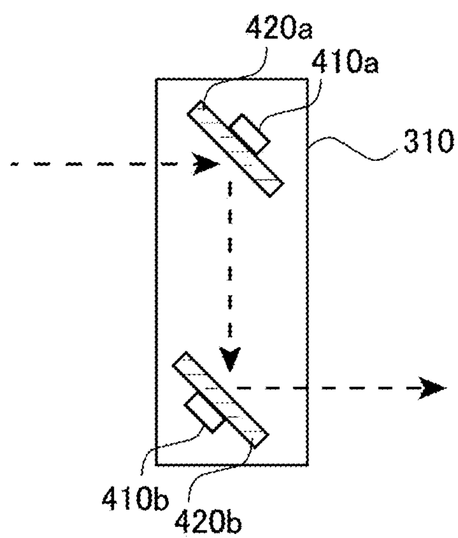

420a
410a
310
410b
420b

Fig. 8

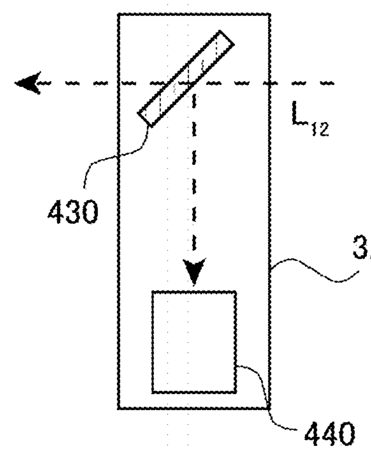

L12
430
320
440

Fig. 9

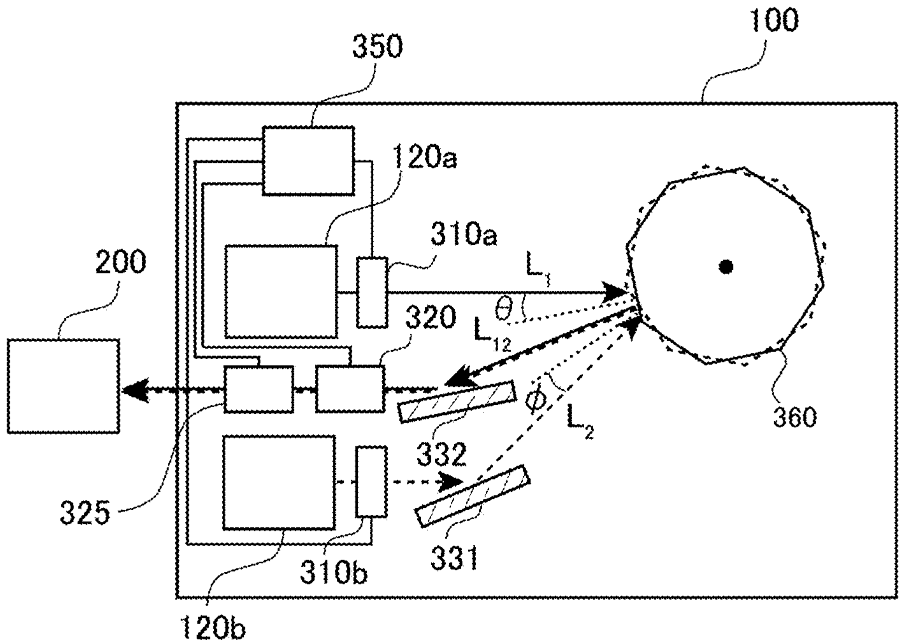

100
350
120a
310a
L1
θ
320
L12
200
ϕ
L2
360
332
325
331
310b
120b

Fig. 10

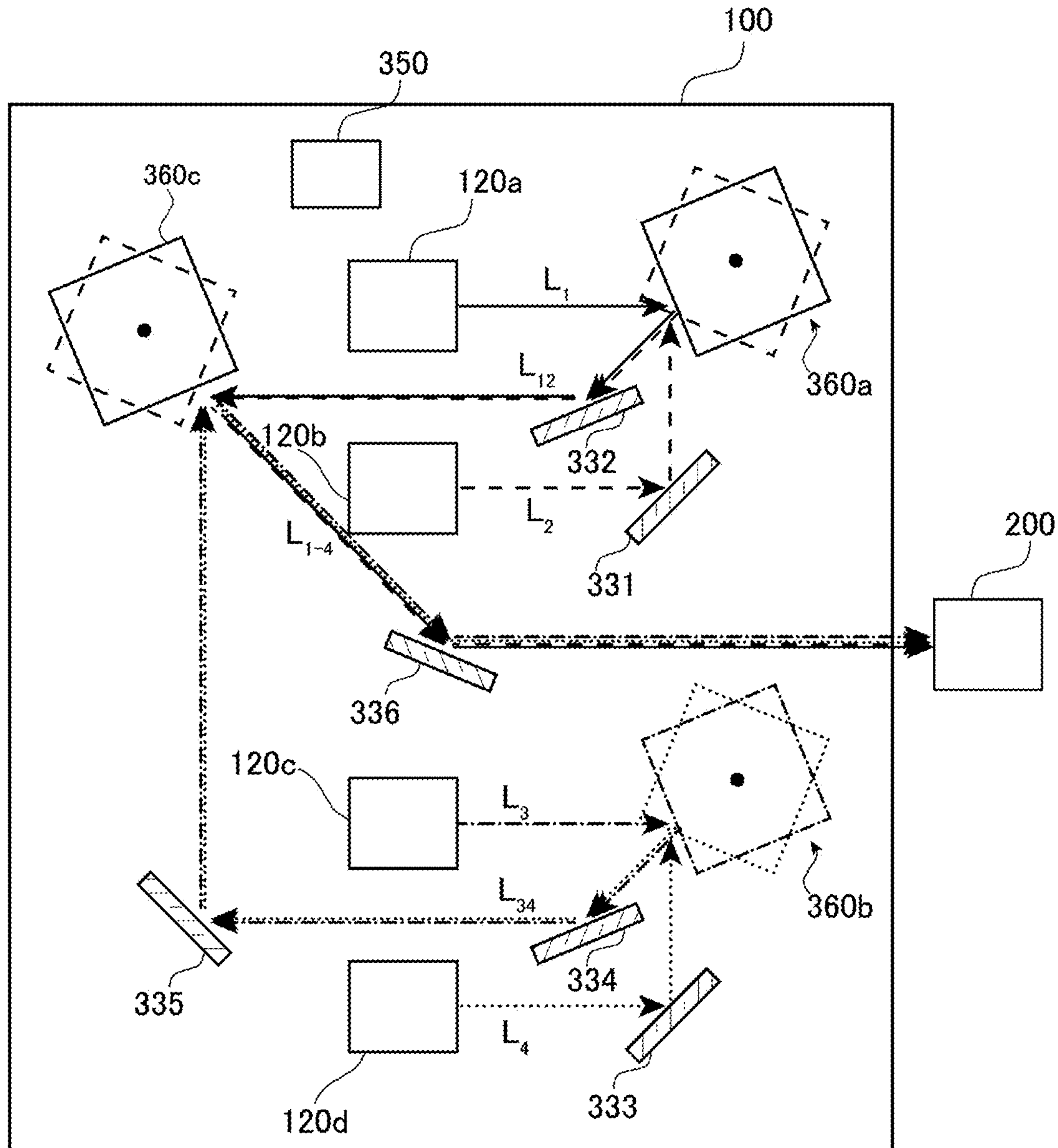

100
350
360c
120a
L1
360a
L12
120b
332
L2
L1-4
331
200
336
120c
L3
360b
L34
335
334
L4
333
120d

Fig. 11

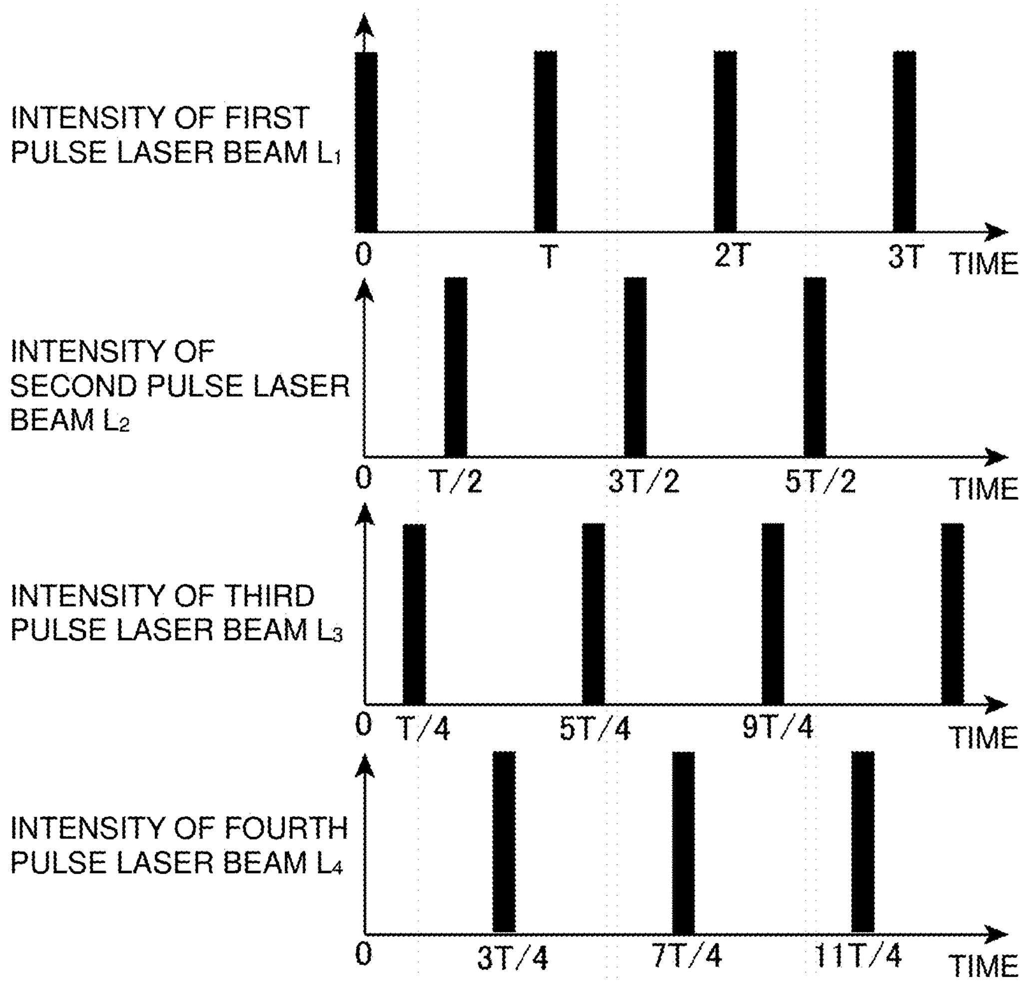

INTENSITY OF FIRST PULSE LASER BEAM L1
0
T
2T
3T
TIME
INTENSITY OF SECOND PULSE LASER BEAM L2
0
T/2
3T/2
5T/2
TIME
INTENSITY OF THIRD PULSE LASER BEAM L3
0
T/4
5T/4
9T/4
TIME
INTENSITY OF FOURTH PULSE LASER BEAM L4
0
3T/4
7T/4
11T/4
TIME

Fig. 12

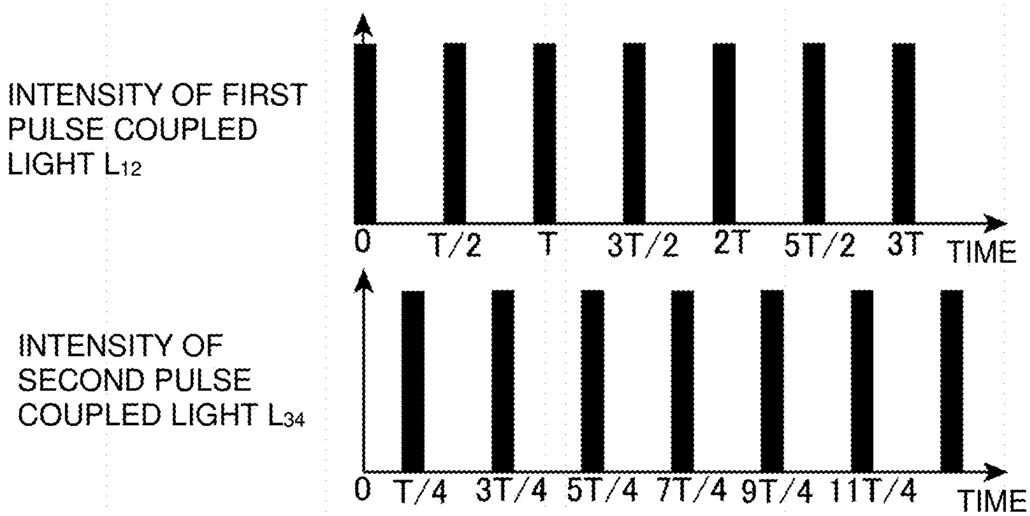

INTENSITY OF FIRST PULSE COUPLED LIGHT L_{12}
0
T/2
T
3T/2
2T
5T/2
3T
TIME
INTENSITY OF SECOND PULSE COUPLED LIGHT L_{34}
0
T/4
3T/4
5T/4
7T/4
9T/4
11T/4
TIME

Fig. 13

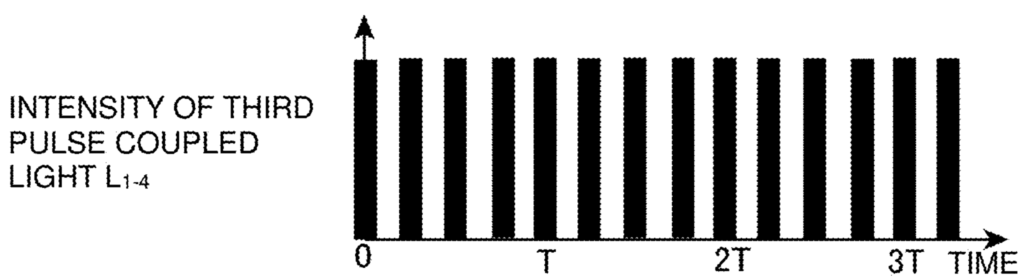
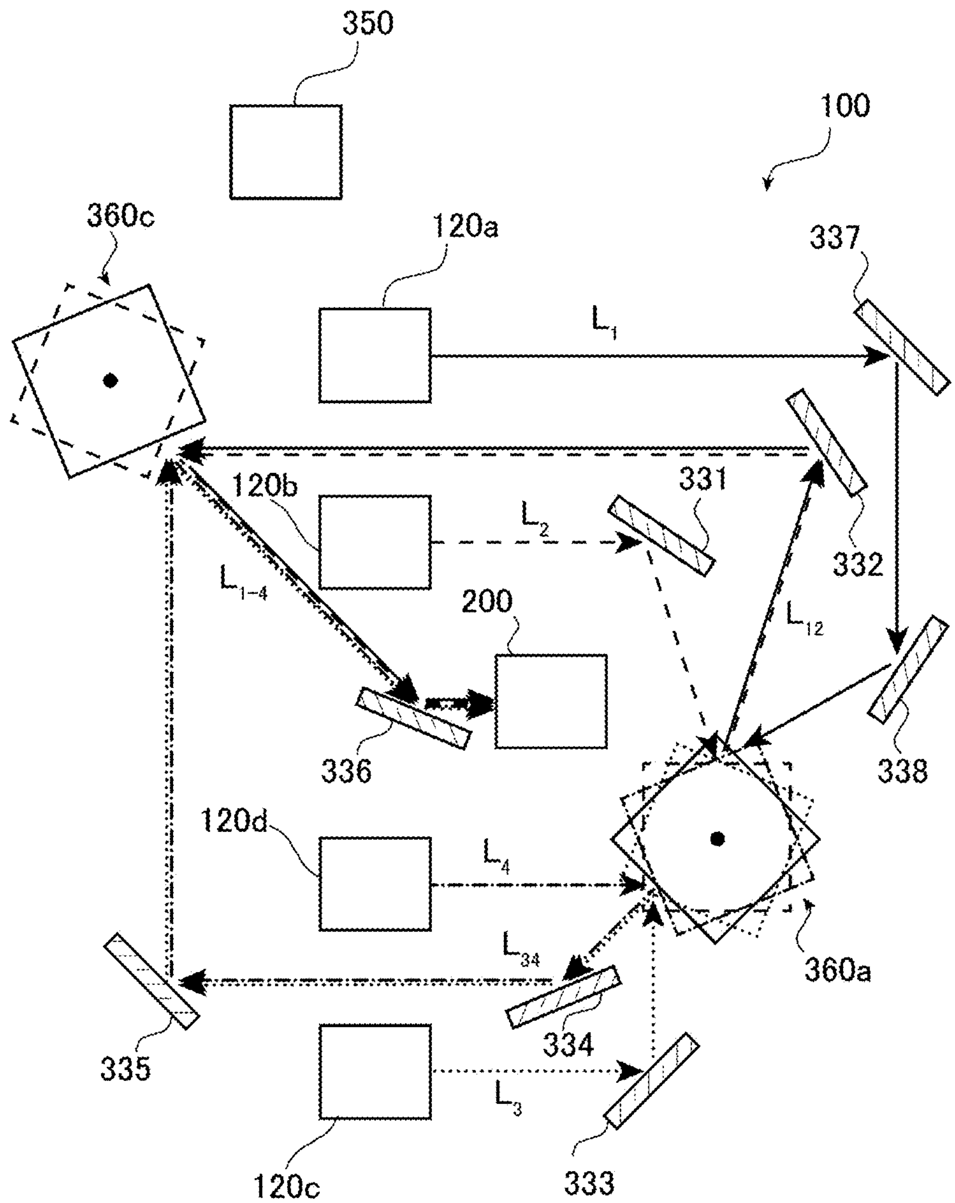

INTENSITY OF THIRD PULSE COUPLED LIGHT L_{1-4}
0
T
2T
3T
TIME

Fig. 14


350
100
360c
120a
337
L1
332
331
120b
L2
L1-4
L12
200
336
338
120d
L4
360a
L34
334
335
L3
120c
333

LASER SYSTEM AND ELECTRONIC DEVICE MANUFACTURING METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of Japanese Patent Application No. 2024-023270, filed on Feb. 19, 2024, the entire contents of which are hereby incorporated by reference.

BACKGROUND

1. Technical Field

[0002] The present disclosure relates to a laser system and an electronic device manufacturing method.

2. Related Art

[0003] Recently, in a semiconductor exposure apparatus, improvement in resolution has been desired for miniaturization and high integration of semiconductor integrated circuits. For this purpose, an exposure light source that outputs light having a shorter wavelength has been developed. For example, as a gas laser apparatus for exposure, a KrF excimer laser apparatus that outputs a laser beam having a wavelength of about 248 nm and an ArF excimer laser apparatus that outputs a laser beam having a wavelength of about 193 nm are used.

[0004] Spectral linewidths of spontaneous oscillation beams of the KrF excimer laser apparatus and the ArF excimer laser apparatus are as wide as from 350 pm to 400 pm. Therefore, when a projection lens is formed of a material that transmits ultraviolet light such as KrF and ArF laser beams, chromatic aberration may occur. As a result, the resolution may decrease. Thus, the spectral linewidth of the laser beam output from the gas laser apparatus needs to be narrowed to an extent that the chromatic aberration is ignorable. Therefore, in a laser resonator of the gas laser apparatus, a line narrowing module (LNM) including a line narrowing element (such as etalon or grating) may be provided in order to narrow the spectral linewidth. Hereinafter, a gas laser apparatus with a narrowed spectral linewidth is referred to as a line narrowing gas laser apparatus.

LIST OF DOCUMENTS

Patent Documents

[0005] Patent Document 1: U.S. Patent Application Publication No. 2023004091

[0006] Patent Document 2: Chinese Utility Model No. 219143208

[0007] Patent Document 3: U.S. Pat. No. 5,387,211

SUMMARY

[0008] A laser system according to one aspect of the present disclosure may include a first pulse laser apparatus, a second pulse laser apparatus, a first polygon mirror, and a processor. The first pulse laser apparatus may be configured to output a first pulse laser beam in a predetermined cycle. The second pulse laser apparatus may be configured to output a second pulse laser beam in the predetermined cycle. The first polygon mirror may be configured to reflect the first pulse laser beam and the second pulse laser beam. The processor may be configured to control the first pulse laser apparatus, the second pulse laser apparatus, and the first polygon mirror such that the first pulse laser beam and the second pulse laser beam are output with a shift of ½ of the predetermined cycle between the first pulse laser beam and the second pulse laser beam and optical paths of the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror are oriented in a first direction and at least partially overlapped.

[0009] Further, an electronic device manufacturing method according to one aspect of the present disclosure may include outputting a first pulse laser beam and a second pulse laser beam generated by a laser system to an exposure apparatus, and exposing a photosensitive substrate to the first pulse laser beam and the second pulse laser beam within the exposure apparatus to manufacture an electronic device. The laser system may include a first pulse laser apparatus configured to output the first pulse laser beam in a predetermined cycle, a second pulse laser apparatus configured to output the second pulse laser beam in the predetermined cycle, a first polygon mirror configured to reflect the first pulse laser beam and the second pulse laser beam, and a processor configured to control the first pulse laser apparatus, the second pulse laser apparatus, and the first polygon mirror such that the first pulse laser beam and the second pulse laser beam are output with a shift of ½ of the predetermined cycle between the first pulse laser beam and the second pulse laser beam and optical paths of the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror are oriented in a first direction and at least partially overlapped.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Some embodiments of the present disclosure will be described below, by way of example only, with reference to the accompanying drawings.

[0011] FIG. **1** is a schematic diagram illustrating a schematic configuration example of an entire electronic device manufacturing apparatus.

[0012] FIG. **2** is a schematic diagram illustrating a schematic configuration example of an entire laser system of a comparative example.

[0013] FIG. **3** is a schematic diagram illustrating a schematic configuration example of a pulse laser apparatus included in the laser system of the comparative example.

[0014] FIG. **4** is a timing chart illustrating a relation between an output timing of a first pulse laser beam and an output timing of a second pulse laser beam.

[0015] FIG. **5** is a timing chart illustrating an output timing of pulse coupled light obtained by combining the first pulse laser beam and the second pulse laser beam.

[0016] FIG. **6** is a schematic diagram illustrating a schematic configuration example of a laser system of Embodiment 1.

[0017] FIG. **7** is a schematic view illustrating a schematic configuration example of a beam steering device.

[0018] FIG. **8** is a schematic diagram illustrating a schematic configuration example of a beam measuring instrument.

[0019] FIG. **9** is a schematic diagram illustrating a schematic configuration example of a laser system in a modification of Embodiment 1.

[0020] FIG. **10** is a schematic diagram illustrating a schematic configuration example of a laser system of Embodiment 2.

[0021] FIG. **11** is a timing chart illustrating a relation among output timings of first to fourth pulse laser beams.

[0022] FIG. **12** is a timing chart illustrating a relation between output timings of pulse coupled light obtained by combining the first pulse laser beam and the second pulse laser beam and pulse coupled light obtained by combining the third pulse laser beam and the fourth pulse laser beam.

[0023] FIG. **13** is a timing chart illustrating an output timing of pulse coupled light obtained by combining the first to fourth pulse laser beams.

[0024] FIG. **14** is a schematic diagram illustrating a schematic configuration example of a laser system in a modification of Embodiment 2.

DESCRIPTION OF EMBODIMENTS

[0025] 1. Description of Electronic Device Manufacturing Apparatus Used in Electronic Device Exposure Process

[0026] 2. Description of Laser System of Comparative Example

[0027] 2.1 Configuration

[0028] 2.2 Operation

[0029] 2.3 Problem

[0030] 3. Description of Laser System of Embodiment 1

[0031] 3.1 Configuration

[0032] 3.2 Operation

[0033] 3.3 Effect and Advantage

[0034] 3.4 Modification

[0035] 4. Description of Laser System of Embodiment 2

[0036] 4.1 Configuration

[0037] 4.2 Operation

[0038] 4.3 Effect and Advantage

[0039] 4.4 Modification

[0040] Hereinafter, embodiments of the present disclosure will be described in detail with reference to the drawings. The embodiments described below show some examples of the present disclosure and do not limit contents of the present disclosure. In addition, all configurations and operations described in the embodiments are not necessarily essential as configurations and operations of the present disclosure. Here, the same components are denoted by the same reference signs, and any redundant description thereof is omitted.

1. Description of Electronic Device Manufacturing Apparatus Used in Electronic Device Exposure Process

[0041] FIG. **1** is a schematic diagram illustrating a schematic configuration example of an entire electronic device manufacturing apparatus used in an electronic device exposure process. As illustrated in FIG. **1**, the manufacturing apparatus used in the exposure process includes a laser system **100** and an exposure apparatus **200**. The exposure apparatus **200** includes an illumination optical system **210** including a plurality of mirrors **211**, **212**, and **213** and a projection optical system **220**. The illumination optical system **210** illuminates a reticle pattern of a reticle stage RT with a laser beam from the laser system **100**. The projection optical system **220** performs reduced projection of a laser beam transmitted through a reticle, and forms an image on an unillustrated workpiece disposed on a workpiece table WT. The workpiece is a photosensitive substrate such as a semiconductor wafer on which photoresist is applied. The exposure apparatus **200** synchronously translates the reticle stage RT and the workpiece table WT to expose the workpiece to a laser beam reflecting the reticle pattern. By transferring a device pattern onto the semiconductor wafer by the exposure process as described above, a semiconductor device that is an electronic device can be manufactured.

2. Description of Laser System of Comparative Example

2.1 Configuration

[0042] A laser system of a comparative example will be described. The comparative example of the present disclosure is an example recognized by the applicant as known only by the applicant, and is not a publicly known example admitted by the applicant.

[0043] FIG. **2** is a schematic diagram illustrating a schematic configuration example of the entire laser system **100** of the present example. The laser system **100** includes a first pulse laser apparatus **120*a*** and a second pulse laser apparatus **120*b***. The first pulse laser apparatus **120*a*** and the second pulse laser apparatus **120*b*** have the same configuration and include a laser oscillator **130** which is a master oscillator and an amplifier **160** which is a power oscillator. Further, the first pulse laser apparatus **120*a*** and the second pulse laser apparatus **120*b*** respectively output pulse laser beams L_1 and L_2 of a predetermined cycle.

[0044] The first pulse laser apparatus **120*a*** and the second pulse laser apparatus **120*b*** are, for example, ArF excimer laser apparatuses using a mixed gas including argon (Ar), fluorine (F_2), and neon (Ne). The ArF excimer laser apparatuses output a laser beam having a center wavelength of about 193.4 nm. The first pulse laser apparatus **120*a*** and the second pulse laser apparatus **120*b*** may be, for example, KrF excimer laser apparatuses using a mixed gas including krypton (Kr), F_2, and Ne. The KrF excimer laser apparatuses output a laser beam having a center wavelength of about 248.3 nm.

[0045] The laser system **100** further includes a beam combiner **150** that guides the first pulse laser beam L_1 and the second pulse laser beam L_2 to a same optical path, and reflective mirrors **170*a*** and **170*b*** that reflect the first pulse laser beam L_1 from the first pulse laser apparatus **120*a*** and the second pulse laser beam L_2 from the second pulse laser apparatus **120*b*** toward the beam combiner **150**.

[0046] The beam combiner **150** outputs the first pulse laser beam L_1 and the second pulse laser beam L_2, which have entered the beam combiner **150** via the reflective mirrors **170*a*** and **170*b***, on the same optical path. The beam combiner **150** may perform spatial beam coupling or polarized beam coupling of the first pulse laser beam L_1 and the second pulse laser beam L_2.

[0047] A processor **105** is a processing device including a storage device in which a control program is stored, and a central processing unit (CPU) which executes the control program. The processor **105** is specifically configured or programmed to execute various kinds of processing included in the present disclosure. The first and second pulse laser apparatuses **120*a*** and **120*b*** are controlled by the processor **105**, and the processor **105** causes the first and second pulse laser beams L_1 and L_2 to be shifted by ½ of the predetermined cycle and be output. Therefore, the first and second pulse laser beams L_1 and L_2 are alternately output. The optical paths of the first and second pulse laser beams L_1 and L_2 are overlapped by the beam combiner **150**, and a pulse laser beam is output from the laser system **100** at a repetition frequency twice as high as that of a single pulse laser apparatus.

[0048] In the present specification, a laser beam in a state where optical paths of pulse laser beams from a plurality of pulse laser apparatuses are at least partially overlapped such that the pulse laser beams travel in the same direction is referred to as pulse coupled light. Accordingly, the pulse laser beam formed of the first pulse laser beam L_1 and the second pulse laser beam L_2 output from the beam combiner **150** is pulse coupled light L_{12}.

[0049] Next, the configuration of a pulse laser apparatus **120** that represents the first pulse laser apparatus **120***a* and the second pulse laser apparatus **120***b* having the same configuration is illustrated in FIG. **3**. The pulse laser apparatus **120** mainly includes a housing **110**, and the laser oscillator **130** that is a master oscillator, an optical transmission unit **141**, the amplifier **160** that is a power oscillator, a detection unit **153**, a display unit **180**, and a processor **190** that are disposed in an internal space of the housing **110**.

[0050] The laser oscillator **130** mainly includes a chamber device CH**1**, a charger **41**, a pulse power module **43**, a line narrowing module **60**, and an output coupling mirror **70**.

[0051] FIG. **3** illustrates an internal configuration of the chamber device CH**1** viewed from a direction substantially perpendicular to a propagation direction of a laser beam. The chamber device CH**1** mainly includes a housing **30**, a pair of windows **31***a* and **31***b*, a pair of electrodes **32***a* and **32***b*, an insulating portion **33**, a feedthrough **34**, and an electrode holder portion **36**.

[0052] The housing **30** encloses a laser gas in the internal space. The internal space is a space where light is generated by excitation of a laser medium in the laser gas. This light is propagated to the windows **31***a* and **31***b*.

[0053] The window **31***a* is disposed on a front-side wall surface of the housing **30** in the propagation direction of the laser beam from the laser system **100** to the exposure apparatus **200**, and the window **31***b* is disposed on a rear-side wall surface of the housing **30** in the propagation direction. The windows **31***a* and **31***b* are made of, for example, a calcium fluoride substrate and surfaces of the windows **31***a* and **31***b* on an inner side and an outer side of the housing **30** are planar. The windows **31***a* and **31***b* are not limited to the calcium fluoride substrate as long as they can transmit the laser beam.

[0054] The electrodes **32***a* and **32***b* are disposed to face each other in the internal space of the housing **30**, and a longitudinal direction of the electrodes **32***a* and **32***b* is along the propagation direction of light generated by a high voltage applied between the electrode **32***a* and the electrode **32***b*. A discharge space between the electrode **32***a* and the electrode **32***b* in the housing **30** is sandwiched between the window **31***a* and the window **31***b*. The electrodes **32***a* and **32***b* are discharge electrodes for exciting the laser medium by glow discharge. In the present example, the electrode **32***a* is a cathode and the electrode **32***b* is an anode.

[0055] The electrode **32***a* is supported by the insulating portion **33**. The insulating portion **33** closes an opening formed in the housing **30**. The insulating portion **33** includes an insulator. In addition, the feedthrough **34** formed of a conductive member is disposed in the insulating portion **33**. The feedthrough **34** applies a voltage supplied from the pulse power module **43** to the electrode **32***a*. The electrode **32***b* is supported by the electrode holder portion **36** and is electrically connected to the electrode holder portion **36**.

[0056] The charger **41** is a DC power supply device that charges an unillustrated capacitor provided inside the pulse power module **43** with a predetermined voltage. The charger **41** is disposed outside the housing **30** and is connected to the pulse power module **43**. The pulse power module **43** includes an unillustrated switch controlled by the processor **190**. The pulse power module **43** is a voltage application circuit that, when the switch is turned from OFF to ON by the control, boosts the voltage applied from the charger **41** to generate a pulsed high voltage, and applies the high voltage to the electrodes **32***a* and **32***b*. When the high voltage is applied, discharge occurs between the electrode **32***a* and the electrode **32***b*. By energy of the discharge, the laser medium in the housing **30** is excited. When the excited laser gas shifts to a ground level, light is output, and the output light passes through the windows **31***a* and **31***b* and is output to the outside of the housing **30**. The windows **31***a* and **31***b* are inclined to form a Brewster's angle with respect to the propagation direction of the laser beam so as to suppress reflection of P-polarized light of the laser beam, and in the present example, are inclined with respect to a direction perpendicular to the propagation direction of the laser beam and a direction in which the electrodes **32***a* and **32***b* face each other. Therefore, the laser beam output from the chamber device CH**1** includes predetermined linearly-polarized light having a polarization direction perpendicular to the direction in which the electrodes **32***a* and **32***b* face each other, and the linearly-polarized light having a polarization direction different from the polarization direction of the predetermined linearly-polarized light is reduced from the laser beam.

[0057] The line narrowing module **60** includes a housing **65**, and a prism **61**, a grating **63**, and an unillustrated rotation stage that are disposed in an internal space of the housing **65**. An opening is formed in the housing **65**, and the housing **65** is connected to a rear side of the housing **30** through the opening.

[0058] The prism **61** widens a beam width of the light output from the window **31***b* and makes the light enter the grating **63**. Further, the prism **61** reduces a beam width of reflected light from the grating **63** and returns the light to the internal space of the housing **30** through the window **31***b*. The prism **61** is supported by the rotation stage and is rotated by the rotation stage. By rotation of the prism **61**, an incident angle of the light to the grating **63** is changed, and a wavelength of the light returning from the grating **63** to the housing **30** through the prism **61** can be selected. While FIG. **3** illustrates an example in which one prism **61** is disposed, two or more prisms may be disposed.

[0059] A surface of the grating **63** is formed of a material having a high reflectance, and many grooves are provided on the surface at predetermined intervals. The grating **63** is a dispersive optical element. A cross-sectional shape of each groove is, for example, a right-angled triangle. The light entering the grating **63** from the prism **61** is reflected by the grooves and is also diffracted in a direction corresponding to the wavelength of the light. The grating **63** is disposed in Littrow arrangement such that the incident angle of the light entering the grating **63** from the prism **61** coincides with a diffracting angle of diffracted light having a desired wavelength. Thus, the light of the desired wavelength is returned to the housing **30** through the prism **61**.

[0060] The output coupling mirror **70** transmits a part of the laser beam output from the window **31***a*, and reflects the other part back into the internal space of the housing **30** through the window **31***a*. The output coupling mirror **70** is fixed to an unillustrated holder, and is disposed in the internal space of the housing **110**.

[0061] The grating **63** and the output coupling mirror **70** provided across the housing **30** form a Fabry-Perot resonator, and the housing **30** is disposed on an optical path of the resonator.

[0062] The optical transmission unit **141** mainly includes high reflective mirrors **141***b* and **141***c*. The high reflective mirrors **141***b* and **141***c* are fixed to respective unillustrated holders in a state where respective inclination angles are adjusted, and are disposed in the internal space of the housing **110**. The high reflective mirrors **141***b* and **141***c* highly reflect the laser beam. The high reflective mirrors **141***b* and **141***c* are disposed on an optical path of the laser beam transmitted through the output coupling mirror **70**. The laser beam is reflected by the high reflective mirrors **141***b* and **141***c* and is propagated to a rear mirror **371** of the amplifier **160**. At least a part of the laser beam is transmitted through the rear mirror **371**.

[0063] The amplifier **160** amplifies energy of the laser beam output from the laser oscillator **130**. A basic configuration of the amplifier **160** is substantially the same as that of the laser oscillator **130**. Therefore, the configuration same as that of the laser oscillator **130** is denoted by the same sign, and detailed description is omitted unless specific description is needed. The electrodes **32***a* and **32***b* generate discharge for amplifying the laser beam from the laser oscillator **130**. The direction in which the electrodes **32***a* and **32***b* face each other is a direction perpendicular to the polarization direction of the linearly-polarized light in the laser beam from the laser oscillator **130**. The windows **31***a* and **31***b* are inclined with respect to the polarization direction of the predetermined linearly-polarized light such that the linearly-polarized light in the laser beam enters as the P-polarized light and the incident angle of the laser beam becomes the Brewster's angle. Therefore, a laser beam output from a chamber device CH**2** includes the predetermined linearly-polarized light, and the linearly-polarized light in the polarization direction different from the polarization direction of the predetermined linearly-polarized light is reduced from the laser beam.

[0064] The amplifier **160** differs from the laser oscillator **130** in that it does not include the line narrowing module **60** but includes the rear mirror **371**. The rear mirror **371** is provided between the high reflective mirror **141***c* and the window **31***b*. The rear mirror **371** transmits a part of the laser beam from the laser oscillator **130** toward the discharge space between the electrodes **32***a* and **32***b*, and reflects a part of the laser beam amplified in the chamber device CH**2** back to the discharge space of the chamber device CH**2**.

[0065] An output coupling mirror **370** is disposed on a side opposite to the rear mirror **371** with respect to the chamber device CH**2**. The output coupling mirror **370** reflects a part of the laser beam from the chamber device CH**2** and transmits the other part of the laser beam. Therefore, a partial reflective film having a predetermined reflectance is coated on a surface of the output coupling mirror **370** on the side of the chamber device CH2.

[0066] The detection unit **153** mainly includes a beam splitter **153***b* and a photosensor **153***c*.

[0067] The beam splitter **153***b* is disposed on an optical path of the laser beam transmitted through the output coupling mirror **370**. The beam splitter **153***b* transmits the laser beam transmitted through the output coupling mirror **370** toward an exit window **173** with a high transmittance, and reflects a part of the laser beam toward a light receiving surface of the photosensor **153***c*.

[0068] The photosensor **153***c* measures pulse energy of the laser beam incident on the light receiving surface of the photosensor **153***c*. The photosensor **153***c* is electrically connected to the processor **190**, and outputs a signal indicating the measured pulse energy to the processor **190**. The processor **190** controls a voltage to be applied to the electrodes **32***a* and **32***b* of the amplifier **160** based on the signal.

[0069] The exit window **173** is provided on the side opposite to the output coupling mirror **370** with respect to the beam splitter **153***b* of the detection unit **153**. The exit window **173** is provided on a wall of the housing **110**. The light transmitted through the beam splitter **153***b* is output from the exit window **173** to the exposure apparatus **200** outside the housing **110**. The laser beam is a pulse laser beam having a center wavelength of 193.4 nm, for example.

[0070] The display unit **180** is a monitor that displays a state of control by the processor **190** based on a signal from the processor **190**. The display unit **180** may be disposed outside the housing **110**.

[0071] The processor **190** of the present disclosure is a processing device having a configuration similar to that of the processor **105**. The processor **190** is specifically configured or programmed to perform various kinds of processing included in the present disclosure.

2.2 Operation

[0072] Next, the operation of the pulse laser apparatus **120** will be described.

[0073] When the pulse laser apparatus **120** outputs a laser beam, the processor **190** receives a signal indicating target energy Et and a light emission trigger signal from an unillustrated exposure processor of the exposure apparatus **200**, for example, via the processor **105**. The target energy Et has a target value for the energy of the laser beam used in the exposure process. The processor **190** sets a predetermined charging voltage to the charger **41** of the amplifier **160** such that energy E becomes the target energy Et, and turns ON the switch of the pulse power module **43** of the laser oscillator **130** in synchronization with the light emission trigger signal. Thus, the pulse power module **43** generates a pulsed high voltage from electric energy held in the charger **41**, and a high voltage is applied between the electrode **32***a* and the electrode **32***b* of the laser oscillator **130**. When the high voltage is applied, the discharge occurs between the electrode **32***a* and the electrode **32***b*, the laser medium contained in the laser gas between the electrode **32***a* and the electrode **32***b* is turned to an excited state, and light is discharged when the laser medium returns to a ground state. The discharged light resonates between the grating **63** and the output coupling mirror **70** of the laser oscillator **130** and is amplified every time it passes through the discharge space in the internal space of the housing **30**, and laser oscillation occurs. The laser beam includes the predetermined linearly-polarized light, and the linearly-polarized light in the polarization direction different from the polarization direction of the predetermined linearly-polarized light is reduced from the laser beam when the laser beam is transmitted through the windows **31***a* and **31***b*. A part of the laser beam is transmitted through the output coupling mirror **70** and is reflected by the high reflective mirrors **141***b* and **141***c*, and the laser beam is propagated into the amplifier **160**. The laser beam is transmitted through the rear mirror **371** and the windows **31***a* and **31***b* in the amplifier **160** and travels and propagates in the housing **30** of the amplifier **160**.

[0074] The processor **190** turns ON the switch of the pulse power module **43** of the amplifier **160** such that the discharge occurs when the laser beam from the laser oscillator **130** is propagated to the discharge space in the housing **30** of the amplifier **160**. That is, the processor **190** controls the pulse power module **43** such that a high voltage is applied to the electrodes **32***a* and **32***b* of the amplifier **160** after a lapse of predetermined delay time with respect to a timing at which the switch of the pulse power module **43** is turned ON.

[0075] As a result, the laser beam that enters the amplifier **160** is amplified in the amplifier **160**. In addition, the laser beam propagated to the internal space of the housing **30** is propagated to the output coupling mirror **370** through the window **31***a* as described above, and is reflected by the output coupling mirror **370**. The laser beam reflected by the output coupling mirror **370** is propagated through the window **31***a* to the internal space of the housing **30** and is output from the window **31***b*. The light output from the window **31***b* is reflected by the rear mirror **371** and is propagated through the window **31***b* to the internal space of the housing **30**. In this way, the laser beam of a predetermined wavelength reciprocates between the rear mirror **371** and the output coupling mirror **370**. The laser beam includes the predetermined linearly-polarized light, and the linearly-polarized light in the polarization direction different from the polarization direction of the predetermined linearly-polarized light is reduced from the laser beam when the laser beam is transmitted through the windows **31***a* and **31***b*. Further, the laser beam is amplified every time it passes through the discharge space inside the housing **30**.

[0076] A part of the laser beam from the chamber device CH2 of the amplifier **160** is transmitted through the output coupling mirror **370** and is propagated to the beam splitter **153***b*.

[0077] A part of the amplified laser beam propagated to the beam splitter **153***b* is transmitted through the beam splitter **153***b* and the exit window **173** and is propagated to the exposure apparatus **200**, and the other part is reflected by the beam splitter **153***b* and is propagated to the photosensor **153***c*.

[0078] The photosensor **153***c* measures the energy E of the received amplified laser beam. The photosensor **153***c* outputs a signal indicating measured energy E to the processor **190**. The processor **190** feedback-controls the charging voltage of the charger **41** such that a difference ΔE between the energy E and the target energy Et is within an allowable range. The laser beam having the difference ΔE within the allowable range is transmitted through the beam splitter **153***b* and the exit window **173** and is output.

[0079] Referring back to FIG. **2**, the operation of the laser system **100** of the comparative example will be further described. FIG. **4** is a timing chart illustrating a relation between an output timing of the first pulse laser beam L_1 of the first pulse laser apparatus **120***a* and an output timing of the second pulse laser beam L_2 of the second pulse laser apparatus **120***b* in the present example. A horizontal axis represents time, and a vertical axis represents intensity of the pulse laser beam. The same applies to other timing charts described below.

[0080] As described above, the first pulse laser apparatus **120***a* and the second pulse laser apparatus **120***b* respectively output the first and second pulse laser beams L_1 and L_2 of the predetermined cycle, and the first and second pulse laser beams L_1 and L_2 are shifted by ½ of the predetermined cycle from each other. Assuming that T is the predetermined cycle in which the first and second pulse laser beams L_1 and L_2 are output, phases are shifted from each other by a half cycle T/2. The processor **105** controls the first and second pulse laser apparatuses **120***a* and **120***b* to alternately output the respective first and second pulse laser beams L_1 and L_2 as described above.

[0081] The first pulse laser beam L_1 output from the first pulse laser apparatus **120***a* is reflected by the reflective mirror **170***a* and enters the beam combiner **150**. The second pulse laser beam L_2 output from the second pulse laser apparatus **120***b* is reflected by the reflective mirror **170***b* and enters the beam combiner **150**. The beam combiner **150** outputs the first pulse laser beam L_1 and the second pulse laser beam L_2 on the same optical path.

[0082] FIG. **5** is a timing chart illustrating an output timing of the pulse coupled light L_{12} output from the beam combiner **150**. The first pulse laser beam L_1 output from the first pulse laser apparatus **120***a* and the second pulse laser beam L_2 output from the second pulse laser apparatus **120***b* are alternately output from the beam combiner **150**. That is, the beam combiner **150** outputs the pulse coupled light L_{12} which is a train of pulse laser beams in the cycle T/2.

[0083] Thus, the pulse coupled light L_{12} is output from the laser system **100** at a repetition frequency twice as high as that of a single pulse laser apparatus.

2.3 Problem

[0084] With increase in throughput of the exposure apparatus **200**, a demand for higher output is increasing for the laser system **100** as a light source. However, when the beam combiner **150** is a spatial beam coupling system, a coupled beam size or beam divergence may become large. In a case of not changing design of the exposure apparatus, an event like not being able to use a part of the beam may occur when the beam size or the beam divergence becomes large. Therefore, there is a need to suppress the beam size or the size of the beam divergence so as not to change the design of the exposure apparatus. In addition, even in a case of newly designing the exposure apparatus, there is a need to suppress the beam size or the size of the beam divergence so as to suppress enlargement of the exposure apparatus and to further facilitate the design and manufacture of the exposure apparatus.

[0085] In addition, when the beam combiner **150** is a polarized beam coupling system, two different kinds of polarized light are provided to the exposure apparatus, and it may be inappropriate for exposure.

[0086] The following embodiments illustrate a laser system in which a plurality of pulse laser beams output from a plurality of pulse laser apparatuses can be laser beams suitable for exposure.

3. Description of Laser System of Embodiment 1

[0087] The laser system **100** of Embodiment 1 will be described. Any components same as those described above are denoted by same signs, and any redundant description thereof is omitted unless specific description is needed.

3.1 Configuration

[0088] FIG. **6** is a schematic diagram illustrating a schematic configuration example of the laser system **100** of Embodiment 1. As illustrated in FIG. **6**, the laser system **100** of the present embodiment mainly differs from the laser system **100** of the comparative example in that it includes a first polygon mirror **360** configured to reflect the first pulse laser beam L_1 and the second pulse laser beam L_2, and a processor **350** configured to control an output timing of the first pulse laser beam L_1, an output timing of the second pulse laser beam L_2, and a rotation angle of the first polygon mirror **360** so as to reflect the first pulse laser beam L_1 and the second pulse laser beam L_2 in a same first direction. The first and second pulse laser apparatuses **120***a* and **120***b* respectively output the first and second pulse laser beams L_1 and L_2 of a same frequency in the same manner as in the comparative example.

[0089] Note that the first pulse laser apparatus **120***a* and the second pulse laser apparatus **120***b* may be formed of the laser oscillator **130** which is a master oscillator and the amplifier **160** which is a power oscillator as in the comparative example, or may be formed only of the laser oscillator **130** without being provided with the amplifier **160**.

[0090] The laser system **100** of the present embodiment includes the processor **350** instead of the processor **105**. The processor **350** is a processing device similar to the processor **105**. The processor **350** is specifically configured or programmed to execute various kinds of processing included in the present embodiment. Further, the processor **350** is electrically connected to the processors **190** included in the first and second pulse laser apparatuses **120***a* and **120***b* and an unillustrated exposure processor of the exposure apparatus **200**, and transmits and receives various kinds of signals to/from the respective processors.

[0091] The first polygon mirror **360** includes N reflective mirrors for which an angle formed by the mirrors adjacent to each other is fixed. N is a natural number of three or larger. In the present embodiment, an example in which N is four is illustrated. The first polygon mirror **360** is connected to an unillustrated drive unit and is rotated at a substantially constant speed with a center axis C as a rotation axis. When a repetition frequency of the first pulse laser beam L_1 output from the first pulse laser apparatus **120***a* and the second pulse laser beam L_2 output from the second pulse laser apparatus **120***b* is X [Hz], a rotation number per unit time of the first polygon mirror **360** is preferably X/N [rps]. In the present embodiment, since N is four, the rotation number per unit time of the first polygon mirror **360** is X/4 [rps]. However, the rotation number per unit time of the first polygon mirror **360** including N reflective mirrors is not limited to X/N [rps], and may be 2X/N [rps], for example. The drive unit of the first polygon mirror **360** is electrically connected to the processor **350**, and a rotation speed of the first polygon mirror **360** is controlled by the processor **350**.

[0092] An incident angle θ of the first pulse laser beam L_1 coming from the first pulse laser apparatus **120***a* on the first polygon mirror **360** and an incident angle ϕ of the second pulse laser beam L_2 coming from the second pulse laser apparatus **120***b* on the first polygon mirror **360** are preferably the same angle. In a case where the incident angles θ and ϕ are the same angle, the incident angle is preferably 360/4N° when the first polygon mirror **360** includes N reflective mirrors. In the present embodiment, since N is four, the incident angle satisfies $\theta=\phi=22.5°$.

[0093] Each reflective mirror of the first polygon mirror **360** is formed of, for example, a multilayer film. In this case, each reflective mirror is formed so as to reflect the first and second pulse laser beams L_1 and L_2 from the first and second pulse laser apparatuses **120***a* and **120***b* at a high reflectance when they are incident at a predetermined incident angle. Therefore, in the present example, it is preferable that each reflective mirror have the highest reflectance at the incident angle of 22.5°.

[0094] The first pulse laser beam L_1 and the second pulse laser beam L_2 reflected by the first polygon mirror **360** are propagated in the same first direction. Further, optical paths of the first pulse laser beam L_1 and the second pulse laser beam L_2 reflected by the first polygon mirror **360** are at least partially overlapped. Therefore, the pulse coupled light L_{12} is provided from the first polygon mirror **360**.

[0095] The laser system **100** of the present embodiment further includes beam steering devices **310***a* and **310***b* provided in the optical paths of the first and second pulse laser beams L_1 and L_2 that are output from the first pulse laser apparatus **120***a* and the second pulse laser apparatus **120***b* and enter the first polygon mirror **360**, and configured to adjust the optical paths of the first and second pulse laser beams L_1 and L_2. That is, the beam steering devices **310***a* and **310***b* are provided upstream of the first polygon mirror **360**.

[0096] Since the beam steering devices **310***a* and **310***b* have the same configuration, the beam steering devices **310***a* and **310***b* will be described as a beam steering device **310**. FIG. **7** is a schematic diagram illustrating a schematic configuration example of the beam steering device **310**. The beam steering device **310** includes reflective mirrors **420***a* and **420***b* and actuators **410***a* and **410***b* that change directions of the reflective mirrors **420***a* and **420***b*, respectively. The actuators **410***a* and **410***b* are electrically connected to the processor **350**, and at least one of a position and an angle is controlled by the processor **350** to adjust the optical paths of the first and second pulse laser beams L_1 and L_2 output from the beam steering device **310**.

[0097] Note that the beam steering device **310** may be provided between one of the first pulse laser apparatus **120***a* and the second pulse laser apparatus **120***b* and the first polygon mirror **360**, and may not be provided on the optical path of the other thereof. In addition, when the first and second pulse laser beams L_1 and L_2 are output from the first and second pulse laser apparatuses **120***a* and **120***b* in appropriate directions, the laser system **100** may not include the beam steering device **310**.

[0098] In the present embodiment, the laser system **100** includes a mirror **331** configured to reflect the second pulse laser beam L_2, and the second pulse laser beam L_2 output from the second pulse laser apparatus **120***b* and made to pass through the beam steering device **310***b* is reflected by the mirror **331** and is incident on the first polygon mirror **360**.

[0099] Further, the laser system **100** of the present embodiment includes a beam measuring instrument **320** configured to measure at least one of a beam position and a pointing (direction) of the first and second pulse laser beams L_1 and L_2 reflected by the first polygon mirror **360**.

[0100] FIG. **8** is a schematic diagram illustrating a schematic configuration example of the beam measuring instrument **320**. The beam measuring instrument **320** includes a beam splitter **430** and a photosensor **440**. The beam splitter **430** reflects a part of the pulse coupled light L_{12} toward the photosensor **440** and transmits the other part. The photosensor **440** is electrically connected to the processor **350**. The photosensor **440** includes a light receiving surface for receiving light, measures at least one of the beam position and the pointing on the light receiving surface, and transmits a measurement result to the processor **350**. The beam measuring instrument **320** is preferably further capable of measuring pulse energy, power, a wavelength, a spectrum, and the like.

[0101] The processor **350** controls the beam steering devices **310***a* and **310***b* such that the optical path of the first pulse laser beam L_1 reflected by the first polygon mirror **360** and the optical path of the second pulse laser beam L_2 reflected by the first polygon mirror **360** approach each other based on the measurement result of the beam measuring instrument **320**. Further, the processor **350** controls the first pulse laser apparatus **120***a*, the second pulse laser apparatus **120***b*, the beam steering device **310***a*, the beam steering device **310***b*, and the first polygon mirror **360** based on the measurement results measured in the beam measuring instrument **320**, and adjusts the intensity and the optical path of the pulse coupled light L_{12} so as to obtain optimum beam power for the exposure apparatus **200**.

[0102] Note that the beam measuring instrument **320** may be provided outside the laser system **100**. In addition, the laser system **100** may not include the beam measuring instrument **320**.

[0103] In the present embodiment, the laser system **100** includes a mirror **332** configured to reflect the pulse coupled light L_{12}, and the pulse coupled light L_{12} from the first polygon mirror **360** is reflected by the mirror **332** and enters the beam measuring instrument **320**.

[0104] Further, in the present embodiment, a pulse stretcher **325** configured to temporally widen a pulse width of the first pulse laser beam L_1 and the second pulse laser beam L_2 is provided on an optical path through which the pulse coupled light L_{12} is propagated. That is, the pulse stretcher **325** is provided downstream of the first polygon mirror **360**. The pulse stretcher **325** includes, for example, a beam splitter that is disposed on the optical path of the pulse coupled light L_{12} and reflects and splits a part of the pulse coupled light L_{12}, and a plurality of reflective mirrors that reflect the split pulse coupled light L_{12} a plurality of times and delay the pulse coupled light L_{12} transmitted through the beam splitter. The delayed pulse coupled light L_{12} is returned on the same optical path as the optical path of the pulse coupled light L_{12} transmitted through the beam splitter.

[0105] The pulse stretcher **325** may be provided upstream of the first polygon mirror **360**, but is preferably provided downstream of the first polygon mirror **360**. When the pulse stretcher **325** is provided upstream of the first polygon mirror **360**, the first and second pulse laser beams L_1 and L_2 having the widened temporal pulse widths are reflected by the rotating first polygon mirror **360** causing a risk of that the optical paths of the reflected first and second pulse laser beams L_1 and L_2 are easily shifted. On the other hand, when the pulse stretcher **325** is provided downstream of the first polygon mirror **360**, the first and second pulse laser beams L_1 and L_2 before having the temporal pulse width widened are reflected by the first polygon mirror **360** such that the first pulse laser beam L_1 and the second pulse laser beam L_2 are easily reflected in the same direction. Note that the pulse stretcher **325** may not be provided.

[0106] In the present embodiment, as illustrated in FIG. **6**, an output direction of the first pulse laser beam L_1 output from the first pulse laser apparatus **120***a* and an output direction of the second pulse laser beam L_2 output from the second pulse laser apparatus **120***b* are opposite to an output direction of the pulse coupled light L_{12} formed of the first and second pulse laser beams L_1 and L_2 output from the laser system **100**. By outputting the first pulse laser beam L_1 and the second pulse laser beam L_2 in this way, it is possible to suppress the number of mirrors or the like that reflect the first pulse laser beam L_1 and the second pulse laser beam L_2, to improve efficiency of layout, and to make the laser system **100** smaller. However, the output direction of the first pulse laser beam L_1 output from the first pulse laser apparatus **120***a* and the output direction of the second pulse laser beam L_2 output from the second pulse laser apparatus **120***b* may not be opposite to the output direction of the pulse coupled light L_{12} output from the laser system **100**.

3.2 Operation

[0107] The processor **350** outputs the first and second pulse laser beams L_1 and L_2 from the first and second pulse laser apparatuses **120***a* and **120***b* in the same manner as in the comparative example. Therefore, the first and second pulse laser beams L_1 and L_2 are output with a shift of ½ of the predetermined cycle T between them, as illustrated in FIG. **4**. The first and second pulse laser beams L_1 and L_2 output from the first and second pulse laser apparatuses **120***a* and **120***b* have their optical paths adjusted by the beam steering devices **310***a* and **310***b*, enter the first polygon mirror **360**, and are reflected by a reflective surface of the first polygon mirror **360**.

[0108] Here, it is assumed that an angle formed by the first pulse laser beam L_1 incident on the first polygon mirror **360** and the second pulse laser beam L_2 incident on the first polygon mirror **360** is 90°. In FIG. **6**, a state of the first polygon mirror **360** at a timing at which the first pulse laser beam L_1 is incident thereon is indicated by a solid line, and a state of the first polygon mirror **360** at a timing at which the second pulse laser beam L_2 is incident thereon is indicated by a broken line. The two states of the first polygon mirror **360** are relatively rotated by 45°. In addition, in this case, when spatial absolute coordinates of a position where the first pulse laser beam L_1 is incident on the first polygon mirror **360** and spatial absolute coordinates of a position where the second pulse laser beam L_2 is incident on the first polygon mirror **360** coincide with each other, an optical path through which the first pulse laser beam L_1 reflected by the first polygon mirror **360** is propagated and an optical path through which the second pulse laser beam L_2 reflected by the first polygon mirror **360** is propagated are the same optical path. That is, optical axes coincide with each other.

Even when the first pulse laser beam L_1 and the second pulse laser beam L_2 are reflected by the same reflective surface, a reflecting position of the first pulse laser beam L_1 and a reflecting position of the second pulse laser beam L_2 on the reflective surface may be different from each other.

[0109] The processor **350** controls the output timing of the first pulse laser apparatus **120***a*, the output timing of the second pulse laser apparatus **120***b*, and the rotation angle of the first polygon mirror **360** such that the first and second pulse laser beams L_1 and L_2 reflected by the first polygon mirror **360** are reflected in the same first direction. As a result, as illustrated in FIG. **6**, the pulse laser beams become the pulse coupled light L_{12} and are propagated on the same optical path. Note that the optical paths of the first and second pulse laser beams L_1 and L_2 are only required to be oriented in the same first direction and at least partially overlapped, and the optical axes may not completely coincide with each other. However, it is preferable that the optical axis of the first pulse laser beam L_1 reflected by the first polygon mirror **360** coincide with the optical axis of the second pulse laser beam L_2. In addition, the same first direction may vary in a range of 0.1°.

[0110] In the present embodiment, the first polygon mirror **360** reflects the first and second pulse laser beams L_1 and L_2 in the first direction between the incoming first and second pulse laser beams L_1 and L_2. The pulse coupled light L_{12} that is the first and second pulse laser beams L_1 and L_2 reflected by the first polygon mirror **360** is propagated between the optical paths of the first and second pulse laser beams L_1 and L_2 incident on the first polygon mirror **360**, and is propagated between the first pulse laser apparatus **120***a* and the second pulse laser apparatus **120***b*.

[0111] The pulse coupled light L_{12} from the first polygon mirror **360** enters the beam measuring instrument **320** via the mirror **332**. The processor **350** controls the beam steering device **310** such that the beam position and the pointing of the pulse coupled light L_{12} are within a predetermined range based on the measurement result measured by the beam measuring instrument **320**. That is, the processor **350** controls the beam steering device **310** such that the optical paths of the first pulse laser beam L_1 and the second pulse laser beam L_2 reflected by the first polygon mirror **360** approach each other based on the measurement result of the beam measuring instrument **320**. The beam measuring instrument **320** may measure the pulse energy, the power, the wavelength, and the spectrum of each pulse laser light.

[0112] The pulse coupled light L_{12} transmitted through the beam measuring instrument **320** enters the pulse stretcher **325** to have the temporal pulse width widened, and is output from the pulse stretcher **325**.

[0113] In this way, the laser system **100** outputs the pulse coupled light L_{12} having a repetition frequency twice as high as that of the first and second pulse laser beams L_1 and L_2.

3.3 Effect and Advantage

[0114] The laser system **100** includes the first pulse laser apparatus **120***a* configured to output the first pulse laser beam L_1 in the predetermined cycle T, the second pulse laser apparatus **120***b* configured to output the second pulse laser beam L_2 in the predetermined cycle T, the first polygon mirror **360** configured to reflect the first pulse laser beam L_1 and the second pulse laser beam L_2, and the processor **350** configured to control the first pulse laser apparatus **120***a*, the second pulse laser apparatus **120***b*, and the first polygon mirror **360** such that the first pulse laser beam L_1 and the second pulse laser beam L_2 are output with a shift of ½ of the predetermined cycle T between them, and the optical paths of the first pulse laser beam L_1 and the second pulse laser beam L_2 reflected by the first polygon mirror **360** are oriented in the same first direction and at least partially overlapped.

[0115] The laser system **100** of the present embodiment can output the pulse coupled light L_{12} at the repetition frequency twice as high as that of a single pulse laser apparatus. In addition, an increase in the beam size and the beam divergence of the pulse coupled light L_{12} formed of the first and second pulse laser beams L_1 and L_2 can be suppressed. Further, the polarization direction of the pulse coupled light L_{12} can be fixed. Therefore, the laser system **100** of the present embodiment can output a laser beam appropriate for exposure. Further, since the first and second pulse laser beams L_1 and L_2 can be reflected at the same incident angle by the same polygon mirror and made into the pulse coupled light L_{12}, the energy and optical quality of the respective pulse laser beams of the pulse coupled light L_{12} can be brought close to each other. In addition, the optical path of the pulse coupled light L_{12} can be easily adjusted.

[0116] When the pulse coupled light L_{12} is not propagated in a space between the first pulse laser apparatus **120***a* and the second pulse laser apparatus **120***b* and intersects the optical path of the laser beam output from one of the pulse laser apparatuses **120**, an optical path pipe or the like that covers the optical path and brings surroundings of the laser beam into a predetermined atmosphere may intersect, and the configuration of the laser system **100** may become complicated. However, in the present embodiment, the first polygon mirror **360** reflects the first and second pulse laser beams L_1 and L_2 in the direction between the first and second pulse laser beams L_1 and L_2 incident on the first polygon mirror **360**, and the pulse coupled light L_{12} is propagated between the first pulse laser apparatus **120***a* and the second pulse laser apparatus **120***b*. Therefore, the pulse coupled light L_{12} does not intersect the optical paths of the first and second pulse laser beams L_1 and L_2 incident on the first polygon mirror **360**, and the configuration of the laser system **100** can be simplified.

3.4 Modification

[0117] Next, a modification of Embodiment 1 will be described. FIG. **9** is a schematic diagram illustrating a schematic configuration example of the laser system **100** of the present modification. The laser system **100** of the present modification differs from the laser system **100** of the embodiment in that the number of the reflective surfaces of the first polygon mirror **360** is different.

[0118] The number N of the reflective surfaces of the first polygon mirror **360** in the present modification is eight, and is larger than the number of the reflective surfaces of the first polygon mirror **360** in the embodiment. Therefore, the rotation number per unit time of the first polygon mirror **360** in the present modification can be smaller than the rotation number per unit time of the first polygon mirror **360** in the embodiment. For example, in the embodiment, since the number N of the reflective surfaces is four, when the repetition frequency of the first and second pulse laser beams L_1 and L_2 is X [Hz], the rotation number per unit time of the first polygon mirror **360** is X/4 [rps]. On the other hand, in the present modification, the rotation number per unit time of the first polygon mirror **360** can be X/8 [rps]. Since it is possible to further reduce the rotation number per unit time of the first polygon mirror **360** in this way, the control of the laser system **100** is facilitated. In addition, it is possible to reduce a change amount of an angle of the reflective surface while one pulse is being reflected by the reflective surface, and it is possible to suppress the shift of the optical paths of the first and second pulse laser beams L_1 and L_2 reflected by the first polygon mirror **360**.

[0119] Here, the incident angle θ of the first pulse laser beam L_1 coming from the first pulse laser apparatus **120***a* on the first polygon mirror **360** and the incident angle ¢ of the second pulse laser beam L_2 coming from the second pulse laser apparatus **120***b* on the first polygon mirror **360** are preferably equal to each other. In a case where the incident angles θ and ϕ are equal, the incident angle is preferably 360/4N° when the first polygon mirror **360** includes N reflective mirrors. In the present modification, since N is eight, the incident angle satisfies $\theta=\phi=11.25°$.

[0120] The number N of the reflective mirrors of the first polygon mirror **360** is not limited to four or eight, and may be a natural number of three or larger.

4. Description of Laser System of Embodiment 2

[0121] The laser system **100** of Embodiment 2 will be described. Any components same as those described above are denoted by same signs, and any redundant description thereof is omitted unless specific description is needed.

4.1 Configuration

[0122] FIG. **10** is a schematic diagram illustrating a schematic configuration example of the laser system **100** of Embodiment 2. The laser system **100** of the present embodiment mainly differs from Embodiment 1 in that it includes first to fourth pulse laser apparatuses **120***a* to **120***d* and generates third pulse coupled light L_{1-4} in three polygon mirrors of a first polygon mirror **360***a*, a second polygon mirror **360***b*, and a third polygon mirror **360***c*, while Embodiment 1 includes the two first and second pulse laser apparatuses **120***a* and **120***b* and generates the pulse coupled light L_{12} in one first polygon mirror **360**. In order to avoid complication of the drawing, electrical connection of the processor **350** is omitted in FIG. **10** and subsequent drawings.

[0123] The first polygon mirror **360***a* has a configuration similar to that of the first polygon mirror **360** of Embodiment 1, and similarly to Embodiment 1, reflects the first pulse laser beam L_1 and the second pulse laser beam L_2 in the first direction to generate first pulse coupled light L_{12} similar to the pulse coupled light L_{12} described in Embodiment 1.

[0124] The third and fourth pulse laser apparatuses **120***c* and **120***d* have a configuration similar to that of the first and second pulse laser apparatuses **120***a* and **120***b*, and output third and fourth pulse laser beams L_3 and L_4 in the predetermined cycle T. The third and fourth pulse laser beams L_3 and L_4 output from the third and fourth pulse laser apparatuses **120***c* and **120***d* are incident on the second polygon mirror **360***b*. In the present embodiment, the laser system **100** includes a mirror **333** configured to reflect the fourth pulse laser beam L_4, and the fourth pulse laser beam L_4 output from the fourth pulse laser apparatus **120***d* is reflected by the mirror **333** and is incident on the second polygon mirror **360***b*.

[0125] Note that a beam steering device configured to adjust an optical path may be provided, similarly to Embodiment 1, on at least one of optical paths from the first and second pulse laser apparatuses **120***a* and **120***b* to the first polygon mirror **360***a* and on at least one of optical paths from the third and fourth pulse laser apparatuses **120***c* and **120***d* to the second polygon mirror **360***b*.

[0126] The second polygon mirror **360***b* has a configuration similar to that of the first polygon mirror **360***a*, and reflects the third pulse laser beam L_3 and the fourth pulse laser beam L_4 in a second direction to generate the second pulse coupled light L_{34}.

[0127] The first pulse coupled light L_{12} from the first polygon mirror **360***a* and the second pulse coupled light L_{34} from the second polygon mirror **360***b* are incident on the third polygon mirror **360***c*. In the present embodiment, the first pulse coupled light L_{12} is reflected by the mirror **332** and is incident on the third polygon mirror **360***c*. Further, in the present embodiment, the laser system **100** includes mirrors **334** and **335** configured to reflect the second pulse coupled light L_{34}, and the second pulse coupled light L_{34} from the second polygon mirror **360***b* is reflected by the mirrors **334** and **335** and is incident on the third polygon mirror **360***c*.

[0128] The third polygon mirror **360***c* has a configuration similar to that of the first polygon mirror **360***a*, and reflects the first pulse coupled light L_{12} and the second pulse coupled light L_{34} in a third direction to generate the third pulse coupled light L_{1-4}. In the present embodiment, the laser system **100** includes a mirror **336** configured to reflect the third pulse coupled light L_{1-4}, and the third pulse coupled light L_{1-4} from the third polygon mirror **360***c* is reflected by the mirror **336** and is output from the laser system **100**. The beam measuring instrument **320** and the pulse stretcher **325** may be provided, similarly to Embodiment 1, on an optical path of the third pulse coupled light L_{1-4}.

[0129] The processor **350** of the present embodiment controls the first pulse laser apparatus **120***a*, the second pulse laser apparatus **120***b*, the third pulse laser apparatus **120***c*, the fourth pulse laser apparatus **120***d*, the first polygon mirror **360***a*, the second polygon mirror **360***b*, and the third polygon mirror **360***c* as described later.

4.2 Operation

[0130] In the present embodiment, the first polygon mirror **360***a* reflects the first and second pulse laser beams L_1 and L_2 in the first direction between the incoming first and second pulse laser beams L_1 and L_2. The pulse coupled light L_{12} that is the first and second pulse laser beams L_1 and L_2 reflected by the first polygon mirror **360***a* is propagated between the optical paths of the first and second pulse laser beams L_1 and L_2 incident on the first polygon mirror **360***a*, and is propagated between the first pulse laser apparatus **120***a* and the second pulse laser apparatus **120***b*. Further, the second polygon mirror **360***b* reflects the third and fourth pulse laser beams L_3 and L_4 in the second direction between the incoming third and fourth pulse laser beams L_3 and L_4. The pulse coupled light L_{34} that is the third and fourth pulse laser beams L_3 and L_4 reflected by the second polygon mirror **360***b* is propagated between the optical paths of the third and fourth pulse laser beams L_3 and L_4 incident on the second polygon mirror **360***b*, and is propagated between the third pulse laser apparatus **120***c* and the fourth pulse laser apparatus **120***d*. With such disposition, it is possible to suppress the number of mirrors, to improve efficiency of the layout, and to make the laser system **100** smaller.

[0131] FIG. **11** is a timing chart illustrating a relation among output timings of the first to fourth pulse laser beams L_1 to L_4. The output timings of the first and second pulse laser beams L_1 and L_2 output from the first and second pulse laser apparatuses **120***a* and **120***b* are similar to that in Embodiment 1.

[0132] The output timings of the third and fourth pulse laser beams L_3 and L_4 output from the third and fourth pulse laser apparatuses **120***c* and **120***d* are shifted by ¼ of the predetermined cycle T, that is, T/4 from the output timings of the first and second pulse laser beams L_1 and L_2. In the present embodiment, the output timing of the third pulse laser beam L_3 is delayed by ¼ of the predetermined cycle T from the output timing of the first pulse laser beam L_1, and is earlier by ¼ of the predetermined cycle T than the output timing of the second pulse laser beam L_2. Further, the output timing of the fourth pulse laser beam La is earlier by ¼ of the predetermined cycle T than the output timing of the first pulse laser beam L_1, and is delayed by ¼ of the predetermined cycle T from the output timing of the second pulse laser beam L_2.

[0133] The first pulse laser beam L_1 output from the first pulse laser apparatus **120***a* and the second pulse laser beam L_2 output from the second pulse laser apparatus **120***b* are respectively reflected by the first polygon mirror **360***a* and are output as the first pulse coupled light L_{12}. Similarly to Embodiment 1, the processor **350** controls the output timing of the first pulse laser apparatus **120***a*, the output timing of the second pulse laser apparatus **120***b*, and a rotation angle of the first polygon mirror **360***a*.

[0134] The third pulse laser beam L_3 output from the third pulse laser apparatus **120***c* and the fourth pulse laser beam LA output from the fourth pulse laser apparatus **120***d* are reflected by the second polygon mirror **360***b* and are output as the second pulse coupled light L_{34}. The processor **350** controls the output timing of the third pulse laser apparatus **120***c*, the output timing of the fourth pulse laser apparatus **120***d*, and a rotation angle of the second polygon mirror **360***b* such that at least a part of an optical path of the third pulse laser beam L_3 reflected by the second polygon mirror **360***b* and at least a part of an optical path of the fourth pulse laser beam L_4 reflected by the second polygon mirror **360***b* are overlapped and the third pulse laser beam L_3 and the fourth pulse laser beam L_4 are reflected in the same second direction.

[0135] FIG. **12** is a timing chart illustrating a relation between output timings of the first pulse coupled light L_{12} and the second pulse coupled light L_{34}. The first pulse coupled light L_{12} in the cycle T/2 is provided from the first polygon mirror **360***a*, and the second pulse coupled light L_{34} in the cycle T/2 is provided from the second polygon mirror **360***b*. Since the output timings of the third and fourth pulse laser beams L_3 and L_4 are shifted by ¼ of the predetermined cycle T from the output timings of the first and second pulse laser beams L_1 and L_2 as described above, the output timing of the first pulse coupled light L_{12} and the output timing of the second pulse coupled light L_{34} are shifted by ¼ of the predetermined cycle T. A rotation number per unit time of the third polygon mirror **360***c* is twice that of the first polygon mirror **360***a* and the second polygon mirror **360***b*, or the third polygon mirror **360***c* may have reflective surfaces twice as many as those of the first polygon mirror **360***a* and the second polygon mirror **360***b* as in the modification of Embodiment 1, and the rotation number per unit time of the third polygon mirror **360***c* may be the same as the rotation number per unit time of the first polygon mirror **360***a* and the second polygon mirror **360***b*.

[0136] The first pulse coupled light L_{12} and the second pulse coupled light L_{34} from the first and second polygon mirrors **360***a* and **360***b* are reflected by the third polygon mirror **360***c* and are output as the third pulse coupled light $L_{1\text{-}4}$.

[0137] FIG. **13** is a timing chart illustrating an output timing of the third pulse coupled light $L_{1\text{-}4}$. As described above, the output timings of the first to fourth pulse laser beams L_1 to La are shifted by ¼ of the predetermined cycle T. Therefore, a cycle of the third pulse coupled light $L_{1\text{-}4}$ is ¼ of the predetermined cycle T. Thus, from the third polygon mirror **360***c*, the third pulse coupled light $L_{1\text{-}4}$ in the cycle of T/4 is output.

[0138] Accordingly, the processor **350** of the present embodiment controls the first to fourth pulse laser apparatuses **120***a* to **120***d* and the first to third polygon mirrors **360***a* to **360***c* such that the optical paths of the first to fourth pulse laser beams L_1 to L_4 reflected by the third polygon mirror **360***c* are oriented in the same third direction and at least partially overlapped.

[0139] The beam measuring instrument **320** and the pulse stretcher **325** may be provided, similarly to Embodiment 1, on the optical path of the third pulse coupled light $L_{1\text{-}4}$.

4.3 Effect and Advantage

[0140] According to the laser system **100** of the present embodiment, the pulse laser beam can be output toward the exposure apparatus **200** at a repetition frequency four times as high as that of one pulse laser apparatus **120**.

4.4 Modification

[0141] FIG. **14** is a schematic diagram illustrating a schematic configuration example of the laser system **100** in a modification of Embodiment 2. In the description of the present modification, any components same as those of the laser system **100** described above are denoted by same signs, and any redundant description thereof is omitted unless specific description is needed. The laser system **100** of the present modification mainly differs from the laser system **100** of Embodiment 2 in that the first polygon mirror **360***a* serves also as the second polygon mirror **360***b*.

[0142] The first polygon mirror **360***a* has a configuration similar to that of the first polygon mirror **360** of Embodiment 1, and similarly to Embodiment 1, reflects the first pulse laser beam L_1 and the second pulse laser beam L_2 in the first direction to generate the first pulse coupled light L_{12} similar to the pulse coupled light L_{12} described in Embodiment 1. In the present modification, the laser system **100** includes a mirror **337** and a mirror **338** configured to reflect the first pulse laser beam L_1, and the first pulse laser beam L_1 output from the first pulse laser apparatus **120***a* is reflected by the mirrors **337** and **338** and is incident on the first polygon mirror **360***a*.

[0143] In addition, the first polygon mirror **360***a* reflects the third pulse laser beam L_3 and the fourth pulse laser beam L_4 in the second direction to generate the second pulse coupled light L_{34} similar to the second pulse coupled light L_{34} described in Embodiment 2.

[0144] The third polygon mirror **360***c* has a configuration similar to that of the first polygon mirror **360***a* of Embodiment 1, and similarly to Embodiment 1, reflects the first pulse coupled light L_{12} and the second pulse coupled light L_{34} in the third direction to generate the third pulse coupled light L_{1-4} similar to the third pulse coupled light L_{1-4} described in Embodiment 2. The rotation number per unit time of the third polygon mirror **360***c* is twice that of the first polygon mirror **360***a*.

[0145] A beam steering device configured to adjust an optical path may be provided, similarly to Embodiment 1, on at least one of the optical paths from the first and second pulse laser apparatuses **120***a* and **120***b* to the first polygon mirror **360***a* and on at least one of the optical paths from the third and fourth pulse laser apparatuses **120***c* and **120***d* to the first polygon mirror **360***a*.

[0146] Next, the operation of the modification will be described.

[0147] The output timings of the first to fourth pulse laser beams L_1 to La are the same as those of Embodiment 2. The relation between the output timings of the first pulse coupled light L_{12} and the second pulse coupled light L_{34} from the first polygon mirror **360***a* is the same as that of Embodiment 2.

[0148] The first pulse laser beam L_1 output from the first pulse laser apparatus **120***a* is reflected by the mirror **337** and the mirror **338** and is incident on the first polygon mirror **360***a*. At this time, the reflective surface on which the first and second pulse laser beams L_1 and L_2 are incident is a same first reflective surface. However, the rotation angle of the first polygon mirror **360***a* when the first pulse laser beam L_1 is incident on the first polygon mirror **360***a* is different from the rotation angle of the first polygon mirror **360***a* when the second pulse laser beam L_2 is incident on the first polygon mirror **360***a*.

[0149] The third and fourth pulse laser beams L_3 and L_4 output from the third and fourth pulse laser apparatuses **120***c* and **120***d* are incident on the first polygon mirror **360***a*. At this time, the reflective surface on which the third and fourth pulse laser beams L_3 and L_4 are incident is a same second reflective surface. Here, the second reflective surface is different from the first reflective surface. The rotation angle of the first polygon mirror **360***a* when the third pulse laser beam L_3 is incident on the first polygon mirror **360***a* differs from the rotation angle of the first polygon mirror **360***a* when the fourth pulse laser beam L_4 is incident on the first polygon mirror **360***a*.

[0150] The first polygon mirror **360***a* reflects the first pulse laser beam L_1 and the second pulse laser beam L_2 in the first direction to generate the first pulse coupled light L_{12}.

[0151] In addition, the first polygon mirror **360***a* reflects the third pulse laser beam L_3 and the fourth pulse laser beam L_4 in the second direction to generate the second pulse coupled light L_{34}.

[0152] The third polygon mirror **360***c* reflects the first pulse coupled light L_{12} and the second pulse coupled light L_{34} in the third direction to generate the third pulse coupled light L_{1-4}.

[0153] The processor **350** of the present modification controls the first to fourth pulse laser apparatuses **120***a* to **120***d* and the first and third polygon mirrors **360***a* and **360***c* such that the optical paths of the first to fourth pulse laser beams L_1 to L_4 reflected by the third polygon mirror **360***c* are oriented in the same third direction and at least partially overlapped.

[0154] The beam measuring instrument **320** and the pulse stretcher **325** may be provided, similarly to Embodiment 2, on the optical path of the third pulse coupled light L_{1-4}.

[0155] According to the configuration of the present modification, since one polygon mirror can be omitted as compared with the configuration of Embodiment 2, the configuration of the apparatus can be simplified.

[0156] The description above is intended to be illustrative and the present disclosure is not limited thereto. Therefore, it would be obvious to those skilled in the art that various modifications to the embodiments of the present disclosure would be possible without departing from the spirit and the scope of the appended claims. Further, it would be also obvious to those skilled in the art that embodiments of the present disclosure would be appropriately combined. The terms used throughout the present specification and the appended claims should be interpreted as non-limiting terms unless clearly described. For example, terms such as "comprise", "include", "have", and "contain" should not be interpreted to be exclusive of other structural elements. Further, indefinite articles "a/an" described in the present specification and the appended claims should be interpreted to mean "at least one" or "one or more". Further, "at least one of A, B, and C" should be interpreted to mean any of "A", "B", "C", "A+B", "A+C", "B+C", and "A+B+C" as well as to include combinations of any thereof and any other than "A", "B", and "C".

What is claimed is:

1. A laser system comprising:

a first pulse laser apparatus configured to output a first pulse laser beam in a predetermined cycle;

a second pulse laser apparatus configured to output a second pulse laser beam in the predetermined cycle;

a first polygon mirror configured to reflect the first pulse laser beam and the second pulse laser beam; and

a processor configured to control the first pulse laser apparatus, the second pulse laser apparatus, and the first polygon mirror such that the first pulse laser beam and the second pulse laser beam are output with a shift of ½ of the predetermined cycle between the first pulse laser beam and the second pulse laser beam and optical paths of the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror are oriented in a first direction and at least partially overlapped.

2. The laser system according to claim **1**, wherein

the first polygon mirror includes N reflective mirrors for which an angle formed by the mirrors adjacent to each other is fixed, and

a rotation number per unit time of the first polygon mirror is X/N [rps], when a frequency which is an inverse of the predetermined cycle is X [Hz].

3. The laser system according to claim **2**, wherein

an incident angle of the first pulse laser beam on the reflective mirror of the first polygon mirror and an incident angle of the second pulse laser beam on the reflective mirror of the first polygon mirror are 360/4N [°].

4. The laser system according to claim **2**, wherein

the N is equal to or larger than four and equal to or smaller than eight.

5. The laser system according to claim **1**, further comprising a beam steering device configured to adjust at least one of the optical paths of the first pulse laser beam and the second pulse laser beam incident on the first polygon mirror.

6. The laser system according to claim **5**, further comprising

a beam measuring instrument configured to measure at least one of a beam position and a pointing of the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror.

7. The laser system according to claim **6**, wherein

the processor controls the beam steering device such that the optical paths of the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror approach each other based on a measurement result of the beam measuring instrument.

8. The laser system according to claim **1**, wherein

the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror are propagated between an optical path of the first pulse laser beam incident on the first polygon mirror and an optical path of the second pulse laser beam incident on the first polygon mirror.

9. The laser system according to claim **1**, wherein

the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror are propagated between the first pulse laser apparatus and the second pulse laser apparatus.

10. The laser system according to claim **1**, wherein

an output direction of the first pulse laser beam output from the first pulse laser apparatus and an output direction of the second pulse laser beam output from the second pulse laser apparatus are opposite to an output direction of a pulse laser beam output from the laser system.

11. The laser system according to claim **1**, further comprising

a pulse stretcher configured to widen a pulse width of the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror.

12. The laser system according to claim **1**, further comprising:

a third pulse laser apparatus configured to output a third pulse laser beam in the predetermined cycle;

a fourth pulse laser apparatus configured to output a fourth pulse laser beam in the predetermined cycle;

a second polygon mirror configured to reflect the third pulse laser beam and the fourth pulse laser beam; and

a third polygon mirror configured to reflect the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror, and the third pulse laser beam and the fourth pulse laser beam reflected by the second polygon mirror, wherein

the processor controls the first pulse laser apparatus, the second pulse laser apparatus, the third pulse laser apparatus, the fourth pulse laser apparatus, the first polygon mirror, the second polygon mirror, and the third polygon mirror such that the third pulse laser beam and the fourth pulse laser beam are output with a shift of ½ of the predetermined cycle between the third pulse laser beam and the fourth pulse laser beam and also with a shift of ¼ of the predetermined cycle from the first pulse laser beam and the second pulse laser beam, optical paths of the third pulse laser beam and the fourth pulse laser beam reflected by the second polygon mirror are oriented in a second direction and at least partially overlapped, and optical paths of the first pulse laser beam, the second pulse laser beam, the third pulse laser beam, and the fourth pulse laser beam reflected by the third polygon mirror are oriented in a third direction and at least partially overlapped.

13. The laser system according to claim **12**, wherein

the first polygon mirror serves also as the second polygon mirror.

14. An electronic device manufacturing method comprising:

outputting a first pulse laser beam and a second pulse laser beam generated by a laser system to an exposure apparatus, the laser system including

a first pulse laser apparatus configured to output the first pulse laser beam in a predetermined cycle,

a second pulse laser apparatus configured to output the second pulse laser beam in the predetermined cycle,

a first polygon mirror configured to reflect the first pulse laser beam and the second pulse laser beam, and

a processor configured to control the first pulse laser apparatus, the second pulse laser apparatus, and the first polygon mirror such that the first pulse laser beam and the second pulse laser beam are output with a shift of ½ of the predetermined cycle between the first pulse laser beam and the second pulse laser beam and optical paths of the first pulse laser beam and the second pulse laser beam reflected by the first polygon mirror are oriented in a first direction and at least partially overlapped; and

exposing a photosensitive substrate to the first pulse laser beam and the second pulse laser beam within the exposure apparatus to manufacture an electronic device.

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