

DESCRIPTION

METHOD FOR CLEANING OPTICAL DEVICE, DEVICE
EXPOSURE APPARATUS AND EXPOSURE METHOD, METHOD
5 FOR MANUFACTURING DEVICE, AND DEVICE

TECHNICAL FIELD

The present invention relates to a cleaning method of optical element, exposure method and apparatus, device and
10 device manufacturing method. More particularly, the present invention relates to a cleaning method suitable for cleaning optical elements irradiated by ultraviolet light with a wavelength not exceeding 200nm, an exposure method and apparatus using the ultraviolet light as illumination light
15 for exposure, and a device and device manufacturing method by using the exposure method and apparatus.

BACKGROUND ART

Conventionally, in the lithographic process to
20 manufacture devices such as semiconductors and liquid crystal displays, various types of exposure apparatus have been used to transfer a circuit pattern formed on a mask or reticle (to be generally referred to as a "reticle" hereinafter) onto a substrate such as a wafer or a glass plate. In recent years,
25 however, a reduction projection exposure apparatus based on a step-and-repeat method (often referred to simply as a stepper) which transfers the pattern onto a substrate through a projection optical system and a scanning type projection

exposure apparatus based on a step-and-scan method (often referred to as a scanning stepper) have become the mainstream.

With these exposure apparatus, as the required resolution becomes higher, the wavelength of the exposure
5 light becomes shorter, and an exposure apparatus that uses ArF excimer laser light as illumination light, which wavelength is approximately 193nm, is currently being developed.

With vacuum ultraviolet (VUV) light which has a
10 wavelength not exceeding 200nm, when there is air (oxygen) along the optical path most of the energy is absorbed, thus the energy required for exposure does not reach the substrate surface. So, in the current ArF excimer laser exposure apparatus, to effectively transfer (expose) the mask pattern
15 onto the substrate, the gas within the optical system along most of the optical path is replaced with a gas which index of refraction is close to 1, such as nitrogen (N_2) gas. Also, excimer laser light narrow-banded to a wavelength which absorption of oxygen is low, is used as the illumination light
20 for exposure to effectively transfer the pattern onto the substrate.

In a projection exposure apparatus, in order to transfer accurately the pattern of the reticle onto the substrate, optical elements such as mirrors and lenses are used. These
25 optical elements are housed in housings and barrels (housing of a projection optical system), and outgas from these housings and impurity within the environment interior of the optical system cause water and organic contaminants to adhere by a

small amount to the optical elements, which cannot be avoided. The contaminants have a high absorbency to ArF laser excimer light, so with an ArF laser excimer exposure apparatus the transmittance of the optical system decreases because of the
5 contaminants adhered on the surface of the optical elements and thus the image quality of the optical system deteriorates. This resulted in a deterioration of the pattern transferred onto the substrate and in the yield decrease of microdevices such as integrated circuits at times.

10 It is acknowledged that by irradiating ultraviolet light having a wavelength that does not exceed 200nm like an ArF excimer laser beam onto an optical element with contaminants adhered on the surface, the energy of the ultraviolet light breaks down the organic contaminant structure and cleans the
15 optical element. In the current excimer laser exposure apparatus, prior to the actual exposure, the exposure light is usually irradiated onto the optical elements so as to perform self-cleaning and remove the contaminants from the surface of the optical elements.

20 With the cleaning method described above, of breaking the contaminant structure by the energy of the ultraviolet light, however, the cleaning efficiency was not sufficient, and to improve the sufficiency the optical element had to be irradiated by the exposure light for many hours. This caused
25 an unnecessary decrease in operation efficiency, and even damaged the glass material. The decrease in operation efficiency, as a matter of course is a factor leading to a cost-up in manufacturing microdevices like integrated

circuits.

The present invention has been made in consideration of the situation above, and has as its first object to provide a cleaning method that sufficiently cleans the optical
5 elements within a short period of time.

It is the second object of the present invention to provide an exposure method and apparatus that can improve the yield and productivity of microdevices.

It is the third object of the present invention to
10 provide a microdevice on which a fine pattern is formed with high precision, and the device manufacturing method for improving the productivity of such a device.

DISCLOSURE OF INVENTION

15 According to the first aspect of the present invention, there is provided a cleaning method of an optical element housed in a housing filled with a first gas containing oxygen, wherein the housing is irradiated with ultraviolet light for a predetermined period of time, the ultraviolet light having
20 a wavelength which is absorbed by oxygen.

With this method, ultraviolet light having a wavelength, which is absorbed by oxygen, is irradiated on the interior of the housing for a predetermined period of time. The oxygen contained in the first gas (gas containing oxygen) within the
25 housing absorbs the energy of the ultraviolet light, generating ozone by the photochemical reaction, and the oxidation of ozone rinses the optical elements so that the contaminants on the surface of the optical elements are removed.

Thus the optical elements are effectively cleaned. By this cleaning, it becomes possible to clean the optical elements in a shorter period of time compared with the conventional method, thus the time of illuminating the ultraviolet light can be reduced, resulting in reducing the damage to the glass material.

In this case, the ultraviolet light can be directly irradiated on the optical elements within the housing, but it can also be irradiated on the gas interior of the housing. With the former case, the structure of the organic contaminants can be broken down by the energy of the ultraviolet light, creating a cleaning effect on the optical elements, thus, a more effective cleaning can be expected. With the latter case, the damage to the glass material can be further reduced.

According to the cleaning method of an optical element in the present invention, on irradiating the ultraviolet light, the first gas within the housing can be replaced with a second gas which has a higher concentration of oxygen compared to the first gas. In such a case, the ultraviolet light is irradiated in a state where there is a sufficient amount of oxygen within the housing, and the amount of ozone generated by the photochemical reaction increases which in turn, improves the effectiveness of cleaning the optical elements by the oxidation of ozone.

Also, in the cleaning method of an optical element in the present invention, the first gas within the housing can be replaced with a third gas, which contains oxygen and ozone, upon irradiating ultraviolet light. In such a case, the

ultraviolet light is irradiated on the interior of the housing in a state where oxygen and ozone are in the housing. And by the oxidation of ozone generated by photochemical reaction and of ozone originally in the housing, the optical elements
5 can be cleaned more effectively than before.

With the cleaning method of an optical element in the present invention, the ultraviolet light can have a wavelength of approximately 193.23nm. With such a wavelength, the amount of energy of the ultraviolet light absorbed by oxygen is
10 greater than that of the adjacent wavelengths, therefore, the probability of ozone being generated by photochemical reaction is reasonably high.

According to the second aspect of the present invention, there is provided a first exposure apparatus which transfers
15 a mask pattern onto a substrate(W) through an optical system, the exposure apparatus comprising: a light source unit(12) capable of emitting first light and second light, the first light having an exposure wavelength and the second light having a wavelength which absorption by oxygen is greater than that
20 of the first light; an optical system for illumination (BMU, 14) which irradiates light emitted from the light source unit onto the mask; a projection optical system (PL) which projects light exiting from the mask onto the substrate; a controller (20) which sets the first light from the light source unit
25 to be irradiated onto the mask via the optical system for illumination upon exposure of transferring the mask pattern onto the substrate, and upon cleaning at least a part of the optical system for illumination and the projection optical

system sets the second light from the light source unit to be incident on the optical system for illumination.

The term "optical system for illumination", is used here meaning an optical system for illumination in a broad sense, and is a concept which includes a light transmitting system such as a beam matching unit.

With this exposure apparatus, upon cleaning at least a part of the optical system for illumination and projection optical system, the controller sets the second light from the light source unit to be incident on the optical system for illumination. Then, the second light from the light source unit is irradiated on the optical system for illumination and projection optical system via the optical system for illumination, generating ozone by photochemical reaction within the optical system for illumination and projection optical system. And the oxidation of the ozone generated effectively cleans the optical system for illumination and projection optical system, or at least a part of them (the optical elements). Accordingly, it becomes possible to clean the optical system within a shorter period of time compared with conventional methods, reducing the irradiating time itself of the second light for cleaning, which reduces the damage of glass material and can maintain a favorable image forming characteristics.

When the cleaning is completed, and upon exposure of transferring the mask pattern onto the substrate, the controller sets the first light, which has the exposure wavelength and is emitted from the light source unit, to be

irradiated onto the mask via the optical system for illumination. The first light from the light source is irradiated onto the mask, and the mask pattern is transferred onto the substrate through the projection optical system.

5 Consequently, exposure is performed via an optical system which image forming characteristics are maintained favorably by using light which exposure wavelength absorbs only a small amount of oxygen, therefore the mask pattern can be precisely transferred onto the substrate. This improves the yield and

10 productivity when producing microdevices.

In this case, upon the cleaning, when the second light is emitted, the controller (20) can purge a cleaning gas which contains at least one of oxygen and ozone along an optical path where an element subject to cleaning is arranged. When

15 the cleaning gas, which contains oxygen, is purged, the second light is emitted in a state where the gas, which contains oxygen, is purged along the optical path where the element subject to cleaning is arranged. The oxygen in the cleaning gas generates ozone by photochemical reaction, and the oxidation

20 of the ozone generated effectively cleans the optical system for illumination and projection optical system or at least a part of them (the optical elements) within a short time. Also, when a cleaning gas, which contains ozone, is purged, the second light is emitted in a state where the gas which

25 contains ozone, is purged along the optical path where the element subject to cleaning is arranged. Thus, the oxidation of the ozone generated effectively cleans the optical system for illumination and projection optical system or at least

a part of them (the optical elements) within a short time.

With the first exposure apparatus according to the present invention, the cleaning gas can be a gas, which sufficiently contains oxygen, or it can be a gas, which
5 contains both oxygen and ozone. In the former case, the second light is emitted in a state where the gas, which contains a sufficient amount of oxygen, is purged along the optical path where the element subject to cleaning is arranged. By the photochemical reaction of the oxygen contained in the gas,
10 more ozone is generated resulting in a shorter cleaning time of the optical system for illumination and projection optical system or at least a part of them (the optical elements) due to the oxidation of ozone. In the latter case, the second light is emitted in a state where the gas, which contains oxygen
15 and ozone, is purged along the optical path where the element subject to cleaning is arranged. By the photochemical reaction of the oxygen contained in the gas, ozone is generated. And along with the ozone contained in the gas, the cleaning time of the optical system for illumination and projection
20 optical system or at least a part of them (the optical elements) can be further reduced due to the oxidation of ozone.

In the first exposure apparatus according to the present invention, upon exposure, prior to emitting the first light, the controller (20) can purge a gas which index of refraction
25 is close to 1 into the optical system, such as a nitrogen gas (N_2). In such a case, as the first light, vacuum ultraviolet (VUV) light having a wavelength not exceeding 200nm can be used, since the energy of the ultraviolet light is not absorbed

by oxygen and the light intensity on the substrate surface is sufficient. The image forming characteristics of the optical system is also maintained in a preferable state on exposure, which results in an accurate transfer of the mask pattern, thus improving the yield and productivity when producing microdevices.

With the first exposure apparatus according to the present invention, the light source unit can be made of various structures. For example, the light source unit can have a first light source which emits the first light and a second light source which emits the second light; and in this case the controller can selectively choose one of the first light from the first light source and the second light from the second light source to guide to the optical system for illumination.

Alternatively, the light source unit (12) can be a single light source (12a) and have a switching mechanism (18) which changes a wavelength of light emitted from the light source; and in this case, the controller can switch the wavelength of light emitted from the light source via the switching mechanism on exposure and on cleaning.

The switching mechanism, in this case, can be structured of a driving mechanism, which drives a portion of a narrow-banding module; the narrow-banding module narrowing a width of the wavelength of light emitted from the light source.

Also, the narrow-banding module can be made so it can change the width of the wavelength of light emitted from the light source; and in this case, the controller can change the

width of the wavelength of light which is narrowed by the narrow-banding module to a width which include an absorption range by oxygen via the driving mechanism on cleaning.

With the first exposure apparatus according to the present invention, the second light can be an ArF excimer laser beam which has a wavelength of approximately 193.23nm. The amount of energy of the laser beam absorbed by oxygen in this wavelength is greater than that of the adjacent wavelengths, therefore, the probability of ozone being generated by photochemical reaction is reasonably high, resulting in further reducing the time required for cleaning the optical elements.

In the first exposure apparatus according to the present invention, the exposure apparatus can further comprise an adjustment unit which can adjust an intensity of light emitted from the light source unit (12) and is arranged along a part of an optical path, the optical path from the light source unit to the mask; and the controller can control the adjustment unit so as to make an intensity of the second light stronger compared to an intensity of the first light.

In such a case, the intensity of the second light (peak power) which is irradiated on the optical system upon cleaning becomes stronger than the intensity of the first light upon exposure, therefore, the cleaning of the optical elements can be performed efficiently, further reducing the time required for cleaning.

According to the third aspect of the present invention, there is provided a second exposure apparatus which transfers

a mask pattern onto a substrate (W) through an optical system, the exposure apparatus comprising: a light source unit (12) which can emit at least light of a predetermined wavelength width, including an exposure wavelength; an optical system
5 for illumination (BMU, 14) which irradiates the light from the light source unit onto the mask; a projection optical system (PL) which projects light exiting from the mask onto the substrate; an adjustment unit which can adjust an intensity of light emitted from the light source unit, and is arranged
10 along a part of an optical path, the optical path from the light source unit to the mask; and a controller (20) which controls the adjustment unit so as to make the intensity of the light emitted from the light source unit stronger upon cleaning at least a part of the optical system for illumination
15 and the projection optical system, compared with when the mask pattern is transferred onto the substrate by exposure.

The term "optical system for illumination", is used here meaning an illumination optical system in a broad sense, and is a concept which includes a light transmitting system such
20 as a beam matching unit.

With this exposure apparatus, upon cleaning at least a part of the optical system for illumination and projection optical system, the controller controls the adjustment unit which is arranged along a part of the optical path of the light
25 emitted from the light source unit to the mask arrangement surface (surface where the mask is arranged) so as to make the intensity of the light emitted from the light source stronger compared with when exposure is performed. The light

emitted from the light source unit in which the intensity is increased (the wavelength can be the same as of the exposure wavelength), is irradiated on the optical system for illumination and on the projection optical system via the optical system for illumination. This generates ozone by the photochemical reaction of oxygen in the interior of the optical system for illumination and the projection optical system. And due to the oxidation of ozone, the optical system for illumination and projection optical system or at least a part of them (the optical elements) can be effectively cleaned. In this case, since the light intensity of the light emitted on cleaning is stronger than that of exposure, the amount of ozone generated is increased, proving the cleaning to be more effective. Accordingly, the optical elements can be sufficiently cleaned within a shorter period of time compared to conventional methods, reducing the irradiating time itself of the light for cleaning, which reduces the damage of glass material and can maintain a favorable image forming characteristics.

When the cleaning is completed, and upon exposure of transferring the mask pattern onto the substrate, the controller controls the adjustment unit so as to set the light intensity at a predetermined level which is weaker than that of the light on cleaning. The light from the light source, which has the exposure wavelength, is then irradiated onto the mask, and the mask pattern is transferred onto the substrate through the projection optical system. On exposure, the generation of ozone by photochemical reaction can be

suppressed at a low level, therefore, the absorption of the exposure light by ozone is low, and thus exposure can be performed with the exposure light having a sufficiently high transmittance. As a consequence, the mask pattern can be transferred onto the substrate with high precision, improving both the yield and productivity on manufacturing microdevices.

With the second exposure apparatus, the adjustment unit can be made of various structures. For example, the adjustment unit can be arranged so that it can be inserted and withdrawn from a part of the optical path, and the adjustment unit can include a beam splitter which splits a light beam passing through the optical path and can have at least one optical delay element to guide one of a split beam through a delay optical path and back to the optical path; and the controller can insert the beam splitter into the optical path upon exposure and withdraw the beam splitter from the optical path upon cleaning. In such a case, when optical cleaning is performed, the controller withdraws the beam splitter from the optical path (the optical path of the light emitted from the light source unit to the mask arrangement surface), so the light from the light source unit is guided directly to the cleaning portion. Therefore, the light intensity is sufficient enough for cleaning, whereas on exposure, the controller inserts the beam splitter into the optical path. The light beam from the light source, is thus split by the beam splitter which structures the optical delay element, and between the split beams an optical path length

difference (optical path difference) is created which has the length of the delay optical path. The optical path length of the delay optical path, is in general, set so as to exceed the coherence length of the light source, therefore, reduces speckles and coherency caused on the irradiating surface (mask surface and substrate surface). Accordingly, the illumination uniformity of the image plane (substrate surface) is improved to a sufficient level thus improving the line width uniformity, making an exposure with high precision possible.

According to the fourth aspect of the present invention, there is provided a first exposure method which transfers a mask pattern onto a substrate (W) through an optical system, the exposure method comprising the steps of: a first step of irradiating ultraviolet light that has a wavelength which absorption by oxygen is greater than that of an exposure wavelength on the optical system, the optical system having a sufficient amount of oxygen in at least a part of its interior; a second step of replacing a gas of the optical system in at least a part of its interior which contains oxygen to a gas which has an index of refraction close to 1; and a third step of transferring a mask pattern onto a substrate through an optical system by irradiating ultraviolet light which has the exposure wavelength.

According to this method, in the first step, ultraviolet light having a wavelength which absorption by oxygen is greater than that of an exposure wavelength, is irradiated on the optical system for a predetermined period of time in a state

where there is a sufficient amount of oxygen in at least a part of its interior. This generates ozone by the photochemical reaction of oxygen in at least a part of its interior, and due to the oxidation of ozone the optical system
5 (optical elements within the optical system) are effectively cleaned. Next, in the second step, the gas of the optical system in at least a part of its interior, which contains oxygen, is replaced to a gas which has an index of refraction close to 1. And when the gas is replaced, in the third step, the
10 mask pattern is transferred onto the substrate through the optical system by irradiating ultraviolet light, which has an exposure wavelength. Thus, according to the present invention, when cleaning of the optical system is necessary, the wavelength of the exposure light is changed to a wavelength
15 which absorption by oxygen is large. The optical elements within the optical system are, then, cleaned in a state where there is a sufficient amount of oxygen in the optical path. After the optical cleaning is completed, the wavelength of the exposure light and the concentration of oxygen are resumed
20 to the original state, and transfer of the mask pattern (exposure) is performed. By these procedures, deterioration of the pattern image transferred onto the substrate can be prevented, resulting in an improvement in yield when producing microdevices such as integrated circuits, and can
25 consequently reduce the manufacturing cost.

The process in the first step can be performed in a state where there is a sufficient amount of oxygen along the overall optical path within the optical system. Alternatively, the

process can be performed at an area along the optical path where cleaning is necessary in the case there is enough oxygen, for example, near the substrate where it is farthest from the light source and difficult to perform cleaning. It is also
5 effective to perform the process of the first step, in other words, cleaning: just after the making of the exposure apparatus; after a long shutdown of operations; when changing exposure or illumination conditions; and when deterioration of image forming characteristics due to the contaminants on
10 the surface of the optical elements is predictable.

In the first exposure method according to the present invention, the intensity of the ultraviolet light irradiated in the first step can be stronger than that of the ultraviolet light in the third step. In such a case, stronger ultraviolet
15 light increases the effectiveness of optical cleaning.

According to the fifth aspect of the present invention, there is provided a second exposure method which transfers a mask pattern onto a substrate through an optical system, the exposure method comprising the steps of: a first step of
20 irradiating second light for a predetermined period of time, the second light having stronger intensity compared to that of first light emitted on exposure; a second step of replacing a gas of the optical system in at least a part of its interior which contains oxygen to a gas which has an index of refraction
25 close to 1; and a third step of transferring a mask pattern onto a substrate through an optical system by irradiating the first light which has an exposure wavelength.

With this method, in the first step, second light (the

wavelength can be either the same or different from the exposure wavelength) which intensity is stronger than that of first light emitted on exposure (exposure light) is irradiated on the optical system for a predetermined period of time. Ozone is generated in the optical system by the photochemical reaction of oxygen, and due to the oxidation of ozone the optical system (optical elements) is effectively cleaned. In this case, since the light intensity of the light for cleaning is stronger than that of exposure, the amount of ozone generated increases, thus causing a greater cleaning effect. Accordingly, it becomes possible to clean the optical system within a shorter period of time compared with conventional methods, reducing the irradiating time itself of the second light for cleaning, which reduces the damage of glass material and can maintain a favorable image forming characteristics. Next, in the second step, the gas of the optical system in at least a part of its interior, which contains oxygen, is replaced to a gas which has an index of refraction close to 1. And when the replacement is completed, in the third process, the first light that has the predetermined light intensity which is weaker than that of cleaning and the exposure wavelength, is irradiated onto the mask, and the mask pattern is transferred onto the substrate via the optical system. Thus, according to the present invention, when cleaning of the optical system is required, the intensity of exposure light is set to a stronger intensity, so as to effectively clean the optical elements in the optical system. After the cleaning is completed, the intensity of the

exposure light (and the wavelength) and the concentration of oxygen are resumed to the original state, and transfer of the mask pattern (exposure) is performed. On exposure, the generation of ozone by photochemical reaction can be suppressed at a low level, therefore, the absorption of the exposure light by ozone is low, and thus exposure can be performed with the exposure light having a sufficiently high transmittance. As a consequence, the mask pattern can be transferred onto the substrate with high precision, improving both the yield and productivity on manufacturing microdevices.

Also, in the lithographic process, patterns can be formed on substrates with high precision by using the exposure method in the present invention, and microdevices of a higher integration can be manufactured with a high yield, improving the productivity. Similarly, in the lithographic process, patterns can be formed on substrates with high precision by using the exposure apparatus in the present invention, and the yield of and productivity on manufacturing microdevices can both be improved. Accordingly, a microdevice of a higher integration can be manufactured with a high yield, improving the productivity. Therefore, according to still another aspect of the present invention, there is provided a device manufacturing method using the exposure method and exposure apparatus of the present invention, and a device manufactured by the device manufacturing method.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view showing the configuration of the exposure apparatus of an embodiment of the present invention;

Fig. 2 is a view showing a structure of a light source unit in Fig. 1;

Fig. 3 is a view showing a modified structure of a light source unit in Fig.1;

Fig. 4 is a view showing a structure of a beam matching unit BMU in Fig.1;

Fig. 5 is a line graph showing the light intensity distribution of light having a wavelength around 193.3nm passing through a dry air environment.

Fig. 6 is a view to describe the case when a gas mixture of dry air and ozone is supplied to an optical system of the exposure apparatus in Fig. 1.

Fig. 7 is a flow chart for explaining an embodiment of a device manufacturing method according to the present invention; and

Fig. 8 is a flow chart showing processing in step 404 in Fig. 7.

Best Mode for Carrying out the Invention

The first embodiment of the present invention will be described below with reference to Fig. 1 to 6. Fig. 1 schematically shows the general structure of the exposure apparatus 10 of an embodiment. The exposure apparatus 10 is a scanning type exposure apparatus for manufacturing semiconductor devices that employs the step-and-scan method,

and transfers a pattern of a reticle R as a mask onto a plurality of shot areas on a wafer W as a substrate.

The exposure apparatus 10, comprises a light source unit 12, illumination optical system 14, a reticle stage RST to hold a reticle R as a mask, a projection optical system PL, a wafer stage WST to hold a wafer as a substrate, and a control system for these components.

As the light source unit 12, an ArF excimer laser unit is used. The light source 12, in practice, is installed on the surface of the floor or in a different room (for example in a service room in which the degree of cleanliness is lower than that of a super clean room where the main body of the exposure apparatus is installed, or in a utility space provided beneath the floor). In Fig. 1, however, for the sake of convenience, the light source unit 12 is shown above the illumination optical system 14. The light source unit 12 is connected via a beam matching unit BMU, which is a light transmitting system and structured of a housing and optical elements (e.g. a plurality of deflection mirrors) arranged in the housing, to the illumination optical system 14.

The concrete structure of the beam matching unit BMU will be described later.

In this embodiment the beam matching unit BMU and the illumination optical system 14 structure an optical system for illumination in which the light source unit 12 irradiates the reticle R.

The light source unit 12 comprises: a laser resonator 12a; a beam splitter 12b which has a transmittance of 97% and

is arranged along the optical path of the laser beam emitted from the laser resonator 12a; a beam monitor mechanism 12c arranged on the optical path of the reflection beam of the beam splitter 12b; a high voltage power supply 12d (not shown in Fig.1, refer to Fig. 2 and Fig. 2); and the like.

Fig. 2 shows an example of the structure of the light source unit 12. As shown in Fig. 2, each component described above which structures the light source (such as 12a, 12b, 12c and 12d) are housed in a housing 13.

As shown in Fig.2, the laser resonator 12a comprises: an excimer laser tube (laser chamber) 202 which includes a discharge electrode; a total reflection mirror (rear mirror) 201 arranged at the rear of the eximer laser tube 202 (on the left hand side in Fig. 2); a low reflection mirror (front mirror) 205 arranged in front of the eximer laser tube 202 (on the right hand side in Fig. 2); a fixed Fabry-Perot etalon 203 arranged sequentially in between the excimer laser tube 202 and the low reflection mirror 205 and a angularly movable Fabry-Perot etalon 204.

In this case, the rear mirror 201 and the front mirror 205 configure the resonator, which increases the coherency.

The Fabry-Perot etalon (hereinafter referred to as etalon) 203 and the etalon 204 configure the narrow-banding module. More particularly, the etalon 203 and the etalon 204 are two quartz plates arranged in parallel to face each other in a predetermined interval, and operate as a band pass filter. Of the etalon 203 and the etalon 204, the etalon 203 is for rough adjustment, and the etalon 204 is for fine adjustment.

The etalon 203 and etalon 204 narrows and outputs the spectral line width (bandwidth) of the laser beam LB emitted from the laser resonator 12a to around $1/100 - 1/300$ of the natural bandwidth. By adjusting the tilt of the etalon 204, the
5 wavelength of the laser beam LB (oscillation wavelength) emitted from the laser resonator 12a can be shifted within a predetermined range.

Alternatively, the laser resonator 12a can be structured as in Fig. 3. With the laser resonator 12a in Fig. 3, the etalon
10 203 for rough adjustment is omitted, and instead of the rear mirror 201 a reflection type diffraction grating (grating) 206 which is angular movable can be arranged as a wavelength selective element. In this case, the resonator is configured of the grating 206 and the front mirror 205. And the
15 narrow-banding module is configured of the grating 206 and the etalon 204. In the case of the laser resonator 12a in Fig. 3, the grating 206 is used for rough adjustment, and the etalon 204 is used for fine adjustment. Either angle of the grating 206 and the etalon 204 can be changed, when changing the
20 wavelength of the laser beam LB (oscillation wavelength) emitted from the laser resonator 12a within a predetermined range.

Alternatively, the narrow-banding module can be structured of combining a prism and a diffraction grating
25 (grating).

The beam monitor mechanism 12c, in this embodiment, is configured of a diffuser, an etalon element, a line sensor and an energy monitor (not shown in Figs.). The detection

signal of the beam monitor mechanism 12c is sent to a controller 20. The light, which passes through the diffuser, diffracts at the etalon element, and forms a fringe pattern. The fringe pattern corresponds to the central wavelength of the incident light and the spectral half bandwidth (wavelength width), and the imaging signal of the fringe pattern is output to the controller 20 from the line sensor. The controller 20 performs a predetermined process to the imaging signal of the fringe pattern, and obtains the information of the optical properties of the incident light on the beam monitor mechanism 12c. Also, the controller 20 detects the energy power of the laser beam LB, in accordance with the output of the energy monitor.

In the light source unit 12, a driving mechanism 18 is also arranged (refer to Figs. 2 and 3). The driving mechanism 18 drives the spectral devices structuring the laser resonator 12a, such as the etalon 204 (in Fig. 2), the grating 206 and the etalon 204 (in Fig. 3) and gratings and prisms.

The driving mechanism 18 is controlled by the controller 20 based on the information of the optical properties of the incident light on the beam monitor mechanism 12c (the detecting results of the beam monitor 12c), and the central wavelength and the spectral half bandwidth (wavelength width) is controlled to be within the predetermined range. In this case, the central wavelength is continuously adjusted within the predetermined range, for example, within the range of 192.9 nm to 193.6 nm. That is, in this embodiment, the driving mechanism 18 configures a switching mechanism to adjust the

wavelength of the laser beam (ArF excimer laser beam) emitted from the laser resonator 12.

Also, the controller 20 controls the power supply voltage of the high-voltage power supply 12d by feedback control so that the value of the energy per pulse of the light source unit 12 is controlled so as to correspond to a target value of energy per pulse. This is performed, based on the energy power detected from the output value from the energy monitor structuring the beam monitor mechanism 12c upon ordinary exposure.

On the side of the illumination optical system 14 of the beam splitter 12b arranged in the housing 13 of the light source unit 12, a shutter 12f is arranged to cut off the laser beam in accordance with information from the controller 20.

Fig. 4 shows a configuration of the beam matching unit BMU. The main function of the beam matching unit BMU, is to match the position of the optical path of the narrowed laser beam (hereinafter, appropriately referred to as "ultraviolet pulse light" or "ArF excimer laser beam") LB incident from the laser light source 12 with the illumination optical system 14. In short, the incident position and incident angle of the ultraviolet pulse light LB is adjusted to an optimum so that the light is always incident on a predetermined position with respect to an optical axis of the illumination optical system 14.

The beam matching unit BMU in Fig. 4, is structured of a first optical delay element 52 and a second optical delay element 54, sequentially arranged on the optical path of the

ultraviolet pulse light LB.

The first optical delay element 52, is arranged in a predetermined angle in respect to a plane perpendicular to an optical axis of the optical path of the ultraviolet pulse light LB. It is configured of: a half mirror 56 as a beam splitter, which partially passes the ultraviolet pulse light LB, and the remaining beam reflected and split; and three mirrors 58, 60 and 62 arranged on the optical path of the reflecting beam of the half mirror 56 that structure a delay optical path 64 which is triangular and delays the reflecting beam for a predetermined period of time. As the half mirror 56, a mirror that has a reflectance of around 33% to 50% is used. Also, the optical length of the delay optical path 64 is, for example, two times of a coherence length d , i.e. $2d$. The coherence length d is determined by the wavelength distribution of light within a spatial resolution at a position near the light source unit 12 conjugate with the pattern surface of the reticle R being the irradiated surface. Accordingly, the reflected light reflected by the half mirror 56, sequentially proceeds to mirror 58, mirror 60 and mirror 62 and then returns to the half mirror 56 the time corresponding to the difference of the $2d$ and the optical path (hereinafter referred to as "delay time T " for convenience) later than the light passing through the half mirror 56. The light returning to the half mirror 56, is split into the passing beam and the reflected light again, and the reflected light proceeds along the same optical path as the passing beam (primitive ray) to the second optical delay element 54. In this case, the light

proceeds around the delay optical path infinite times, therefore, in principle the light emerges from the half mirror 56 infinite times. Due to the reflectance of the half mirror and mirrors, however, the light amount emerging is almost null
5 on the third or fourth round.

The first optical delay element 52, as described above, gives the light split by the half mirror 56 a delay time T , therefore deflection can be excluded from the series of waves split, reducing the coherency. In this case, the primitive
10 ray is the first beam passing through the half mirror 56.

The second optical delay element 54, has a structure similar to the first optical delay element 52, and is configured of: a half mirror 66 as a beam splitter arranged along the optical path of the ultraviolet pulse light LB
15 emitted from the first optical delay element 52; and three mirrors 70, 72 and 74 arranged so as to form a delay optical path 68 which is a triangular shape. In this case, the mirror 66 is arranged so that the normal direction of the surface of the mirror 66 and the normal direction of the surface of
20 the half mirror 56 are perpendicular to each other. Accordingly, the plane formed by the delay optical path 64 described earlier and the plane formed by the delay optical path 68 is perpendicular. And the optical path length of the delay optical path 68 is three times as long as that of the
25 delay optical path 64, i.e. $6d$.

Accordingly, the reflected light reflected by the half mirror 66, sequentially proceeds to mirror 70, mirror 72 and mirror 74 and then returns to the half mirror 66 the time

corresponding to the difference of the 6d and the optical path, i.e. 3T later than the light passing through the half mirror 66. The light returning to the half mirror 66, is split into the passing beam and the reflected light again, and the reflected light proceeds along the same optical path as the passing beam to a beam shaping optical system in the illumination optical system 14, which will be described later. In this case, as with the case described earlier, deflection can be excluded from the series of waves split, reducing the coherency. In this case, the primitive ray is the first beam passing through the half mirror 66.

In the beam matching unit BMU having the structure described above, the angle of deviation of the half mirror 56 and half mirror 66 is controlled by the controller 20 via an autocollimator which is not shown in Figs. By this control, the ultraviolet pulse light LB is adjusted so that it is always incident on a predetermined position with respect to an optical axis of the illumination optical system 14, the incident position and incident angle of the ultraviolet pulse light LB being adjusted to an optimum. That is, matching of the optical axis is performed. Along with the angle of deviation of the half mirror 56 and half mirror 66, the controller 20 controls the angle of deviation of the mirror 70, 72 and 74 via the autocollimator, which is not shown in Figs.

Details of optical delay elements (optical delay circuits) are disclosed in Japan Patent Laid Open No. 10-117434 and the corresponding U.S. Patent Application No. (Serial No.) 09/300660 (Application date, April 27, 1999),

and as long as national laws in designated states or elected states, to which this international application is applied, permit, the above cited disclosures are fully incorporated by reference herein.

5 Furthermore, in this embodiment, as shown in Fig. 4 by the arrows C, C', D and D' the half mirror 56 and half mirror 66 are structured so as to be insertable/detachable (arrangeable) along the optical path of the ultraviolet pulse light LB respectively, by a sliding mechanism not shown in
10 Figs. The controller 20 controls the sliding mechanism, as will be described later on. Naturally, in the case the half mirror 56 and half mirror 66 is withdrawn to the position shown in Fig. 4 by the imaginary line, the laser beam (ultraviolet pulse light) LB emitted from the light source unit 12 is
15 directly incident on the illumination optical system 14.

Referring back to Fig. 1, the illumination optical system 14, as is disclosed in detail in Japan Patent Laid Open No. 04-196513 and the corresponding U.S. Patent No. 5,473,410, is configured of components such as: a beam shaping optical
20 system (structured of a cylinder lens and a beam expander) arranged in a predetermined relationship within a housing, a rough energy adjuster, a fly-eye lens that form a secondary light source optical system; a condenser lens; a reticle blind; and a image forming lens, and the like (not shown in Figs.).
25 As long as national laws in designated states or elected states, to which this international application is applied, permit, the disclosures of the Japan Patent Laid Open and U.S. Patent cited above are fully incorporated by reference herein.

The illumination optical system 14, illuminates the rectangular (or arcuated) illumination area on the reticle R with illumination light for exposure having an illumination distribution almost uniform. In the illumination optical system 14, in between the secondary light source optical system and image forming lens system, a beam splitter 14a that has a transmittance of around 97% is arranged. Along the optical path of the reflected light, an incident light measurement device 22 referred to as an integrator sensor made of a photoelectric conversion element, is arranged. The photoelectric conversion signal of the incident light measurement device 22 is sent to the controller 20. The output of the incident light measurement device 22 is calibrated in advance with respect to a base illuminometer. Also, in respect to the output of the incident light measurement device 22, the output of the energy monitor described previously is calibrated, and the conversion coefficient (or the conversion function) of the both output values are obtained in advance, and the conversion coefficient is stored in the main controller 20.

On the reticle stage RST, the reticle R is fixed, for example by electrostatic suction. The reticle stage RST, is drivable in a predetermined scanning direction (Y axis direction in this case) in a designated scanning velocity via a reticle driving portion 24, which includes a linear motor provided on a reticle base not shown in Figs. The reticle stage RST, is also finely drivable in an X axis direction which is perpendicular to the Y axis direction, and in the rotatable

direction around a Z axis (θ direction) which is perpendicular to the XY plane.

The position of the reticle stage RST, is detected at all times by a reticle laser interferometer (hereinafter referred to as "reticle interferometer") 25 by a resolution of around 0.5 to 1nm. The information obtained by the reticle interferometer 25 is sent to the main controller 20, and the main controller 20 controls the reticle stage RST in accordance with the positional information (or the velocity information) through the reticle driving portion 24.

The projection optical system PL is arranged below the reticle stage RST as shown in Fig. 1, and the optical axis direction AX, is the Z direction. The projection optical system, in this case, is a double telecentric reduction optical system, and within the barrel a plurality of lens element arranged in a predetermined relationship which structures a refraction optical system is used. The projection magnification of the projection optical system PL, is for example, 1/5 (or 1/4). Therefore, when the illumination area of the reticle R is irradiated by the illumination light of the illumination optical system 14, the light passes through the reticle R and via the projection system, forming a reduced image (inverted image) of a circuit pattern fabricated on the illumination area of the reticle R on the wafer coated with photo resist, onto an exposure area conjugate with the illumination area.

The wafer stage WST, is arranged below the projection system PL, and is driven within an XY two-dimensional plane

on a wafer base (not shown in Figs.) by a driving unit 26 which includes a linear motor or a magnetic levitation type planar motor, and the like. On the upper surface of the wafer stage WST, a wafer W as a substrate is fixed through a wafer holder
5 (not shown in Figs.) for example, by electrostatic suction.

Also, on the upper surface of the wafer stage WST, a movable mirror 28 is provided. A wafer laser interferometer (hereinafter referred to as "wafer interferometer") 30 irradiates a measurement beam onto the mirror 28 so as to detect
10 the position of the wafer stage WST within the XY plane at all times, by, for example, a resolution of around 0.5 to 1nm. The positional information (or the velocity information) collected by the wafer interferometer 30 is sent to the controller 20, and the controller 20 controls the wafer stage
15 WST through the driving unit 26 in accordance with the information.

Furthermore, on the upper surface of the wafer stage WST, an exiting light measurement device 32 is fixed, which is made of a photoelectric conversion element. The exiting
20 light measurement device 32 is set so that the light receiving surface is almost the same level as the surface of the wafer W. The photoelectric conversion signal of the exiting light measurement device 32 is sent to the controller 20.

The output of the exiting light measurement device 32
25 is calibrated in advance with respect to the output of the incident light measurement device 22, and the conversion coefficient (or the conversion function) of the both output values are obtained in advance, and the conversion coefficient

is stored in the main controller 20.

Furthermore, with the exposure apparatus 10 in this embodiment, each optical system, that is, the beam matching unit BMU, illumination optical system 14, and the projection optical system PL respectively are connected with an intake pipe system and an exhaust pipe system.

More particularly, the structure of the intake pipe system includes a first, second and third intake pipe, i.e. 34A, 34B and 34C. One end of the first, second and third intake pipes are respectively connected to (the housing of) the beam matching unit, (the housing of) the illumination optical system 14, and (the barrel of) the projection optical system. The other end of the intake pipe 34A, 34B and 34C are divided into two ends, one end connected to a gas tank not shown in Figs. (containing nitrogen gas N_2 (with an oxygen concentration of less than 1%)) and the other end connected to an air tank which contains dry air also not shown in Figs.

Along each divided end of the first intake pipe 34A, a first solenoid valve 38A and a second solenoid valve 38B are respectively arranged, so as to open/close the flow of the pipe (gas passage). Identically, along the divided ends of the second intake pipe 34B, a third solenoid valve 38C and a fourth solenoid valve 38D are respectively arranged, so as to open/close the flow of the pipe (gas passage). Again, along the divided ends of the third intake pipe 34C, a fifth solenoid valve 38E and a sixth solenoid valve 38F are respectively arranged, so as to open/close the flow of the pipe (gas passage).

The first to sixth solenoid valves 38A to 38F are opened/closed by the controller 20 (which will be described later on).

The exhaust pipe system comprises a first, second, and
5 a third exhaust pipe 40A, 40B, and 40C. One end of the first
second and third exhaust pipe 40A, 40B and 40C are respectively
connected to (the housing of) the beam matching unit, (the
housing of) the illumination optical system 14, and (the barrel
of) the projection optical system. It also comprises a main
10 exhaust pipe 42, to where the other end of the 40A, 40B, and
40C are respectively connected.

Along the first, second, and third exhaust pipe, a first,
second, and third oxygen sensor 44A, 44B, and 44C are
respectively arranged in order to detect the oxygen
15 concentration of the gas flowing in the exhaust pipe (gas
passage). The detecting results of these three oxygen sensors
44A, 44B, and 44C are sent to the controller 20.

The controller 20 is structured with a microcomputer
(or a workstation) as a core, and controls the operation of
20 the respective components described earlier in the exposure
apparatus 10, as well as the opening/closing of the first to
sixth solenoid valves 38A to 38F. The controller 20 also can
perform calculation operations. It can calculate, for
example, the transmittance of the optical system from the light
25 source unit 12 to the position of the beam splitter 14a
(hereinafter appropriately referred to as "a first
transmittance") based on the output of the incident light
measurement device 22 and the output of the energy monitor

which structures the beam monitor mechanism 12c. Also the controller 20 can calculate the transmittance of the optical system from the position of the beam splitter 14a to the wafer surface (hereinafter appropriately referred to as "a second transmittance") based on the output of the incident light measurement device 22 and the output of the exiting light measurement device 32.

Next, the self-cleaning operation of the optical system (beam matching unit BMU, illumination optical system 14, projection optical system PL) in the exposure apparatus 10 structured as above, will be described. To be more accurate, the self-cleaning operation of the optical elements (such as lenses, beam splitters) configuring the optical system will be described mainly through the operation of the controller 20.

As a premise, the first to sixth solenoid valves 38A to 38F are closed, however, nitrogen gas having a high concentration of oxygen (a first gas) under 1% still remains within the interior of the exhaust pipe system and the optical system.

On starting the self-cleaning, the controller 20 opens the second, fourth, and sixth solenoid valves, 38B, 38D, and 38F. By this operation, the dry air (a second gas) stored in the gas tank (not shown in Figs.) starts to flow into the beam matching unit BMU, the illumination optical system 14, and the projection optical system PL through the intake pipes 34A, 34B, and 34C.

Next, the controller 20 starts sending the trigger pulse

to the high voltage power supply 12d; consequently the laser resonator 12a starts to emit the laser beam LB. At this stage, the shutter 12f is still in a closed state.

With the emitting of the laser beam LB, the laser beam
5 (ultraviolet pulse light) LB is incident on the beam monitor mechanism 12c via the beam splitter 12b. The beam monitor mechanism 12c, then sends the imaging signal of the fringe pattern and information on the pulse energy value to the controller 20.

10 The controller 20, then adjusts the angle of the etalon 204 (or the grating 206) which configure the laser resonator 12a through the driving mechanism 18, according to the information from the beam monitor mechanism 12c so as to change the wavelength of the laser beam to approximately 193.23nm.
15 Thus the wavelength of the laser beam LB emitted from the laser resonator 12a is changed to 193.23nm.

The reason why the wavelength of the ArF excimer laser beam is adjusted to 193.23nm is now described. Fig. 5 is a chart showing the light intensity distribution in the case
20 of an ArF excimer laser beam having a wavelength around 193.23nm passing through a dry air environment. In Fig. 5, the horizontal axis shows the wavelength (nm), and the vertical axis shows the light intensity (energy intensity) of the laser beam. In other words, Fig. 5 practically shows the absorbing
25 spectrum of oxygen of the ArF excimer laser beam.

As is obvious from Fig. 5, only a small difference in wavelength greatly changes absorption of oxygen around the wavelength of 193nm. By looking at the light intensity

distribution, the light intensity seems to be the weakest around the wavelength of 193.02nm, and the absorption amount of oxygen seems to be the greatest. In the wavelength range of 192.9nm to 193.6nm, however, the broad (prior to narrow banding) light intensity distribution from the ArF excimer laser light source tends to be stronger around the center, and the light intensity is originally weak around the wavelength of 193.02nm. So, even if the wavelength of the ArF excimer laser beam is adjusted to this wavelength, the energy absorption amount by oxygen will not increase so much. On the other hand, as for the wavelength around 193.23nm, originally the light intensity is strong, and in addition the light intensity of the ArF excimer laser beam passing through the dry air environment is weaker compared to the wavelength in sequence. Consequently, this wavelength is presumably a wavelength in which the energy absorption amount by oxygen is the greatest, in the adjustable range. Therefore, in this embodiment, by adjusting the wavelength of the ArF excimer laser beam to 193.23nm, the oxygen allows maximum absorption of the optical energy of the ArF excimer laser beam. A maximum level of ozone O_3 is thus, generated by photochemical reaction and the optical elements can be effectively cleaned by the oxidation of ozone.

In parallel with adjusting the wavelength as described above, the controller 20 withdraws the half mirrors 56 and 66, that structure the beam matching unit BMU. The half mirrors are driven off the optical path of the laser beam LB as shown in Fig. 4 with the imaginary lines, in the directions

of the arrows C and D via the sliding mechanism not shown in Figs. The withdrawal is performed, so that in the optical cleaning process which will be described next, the laser beam LB (second light) emitted from the light source unit 12 and having a wavelength of 193.23nm is directly incident on the illumination optical system 14, without passing through the first optical delay element 52 and the second optical delay element 54 (each optical element). The reason the laser beam needs to be directly incident, is because if the beam passes through the first optical delay element 52 and the second optical delay element 54, the intensity of the beam irradiating the illumination optical system 14 weakens. This consequently decreases the amount of ozone generated by the photochemical reaction, which in turn reduces the cleaning effect caused by the oxidation of ozone. That is, the peak power of the laser beam need to be maintained extremely high, so as to perform effective cleaning of the optical elements, and shorten the necessary cleaning time.

As soon as the withdrawal of the half mirrors 56 and 66 is completed, the controller 20 opens the shutter 12f, which is arranged within the light source unit 12. Then the laser beam LB is emitted from the light source unit 12, and the laser beam LB irradiates the gas interior of the beam matching unit BMU, illumination optical system 14 and projection optical system PL, and each optical elements configuring the beam matching unit and optical systems. Self-cleaning is thus started, by the irradiating ArF excimer laser beam (the second light) which has a wavelength of 193.23nm. The first gas,

within the optical system, is almost completely replaced with dry air, just before, or right after the self-cleaning has started.

Right after the self cleaning has started, the
5 controller 20 monitors the output of the interferometer 30
and drives the wafer stage WST via the driving unit 26 so as
to position the exiting light measurement device 32 directly
under the projection optical system PL. The controller 20
simultaneously gathers the output of the incident light
10 measurement device 22 and the output of the energy monitor
structuring the beam monitor mechanism. Then, it calculates
the first and second transmittance, and drives the wafer stage
so that the exiting light measurement device 32 is withdrawn
from under the projection optical system PL. The process of
15 determining the position of the exiting light measurement
device 32 directly under the projection optical system,
measuring and calculating the transmittances, and withdrawing
the wafer stage WST from under the projection optical system
PL is repeated at a predetermined interval.

20 By continuing the irradiation of the laser beam LB from
the laser resonator 12a during the state described above, the
organic contaminants adhered on the surface of the optical
elements of the illumination optical system 14 and the
projection optical system PL are shattered by the laser energy.
25 The oxidation of ozone generated by the photochemical reaction
also cleans the contaminants off of the surface of the optical
elements of the beam matching unit BMU, illumination optical
system 14 and the projection optical system PL, thus improving

the transmittance of the optical system.

The controller 20, as mentioned earlier monitors the change in the first and second transmittance obtained at predetermined intervals. And when the change in each
5 transmittance does not exceed a permissive value, for example, almost zero, in other words, the change in the first and second transmittance by time have saturated, the controller 20 judges that the cleaning is completed. The controller 20 then closes the shutter 12f, and stops sending the trigger pulse to the
10 high voltage power supply 12d arranged in the light source unit 12.

In this embodiment, such cleaning operation of the optical elements is to be performed when the optical elements of the optical system are apt to be contaminated: such as right
15 after the making of the exposure apparatus; after long hours of stopping the operation of the exposure apparatus; and upon changing the exposure conditions or the illumination conditions (to be more specific, such as when changing the aperture stop plate of the illumination optical system 14,
20 changing the reticle, and changing the pupil aperture of the projection optical system PL). The downtime during the operation of the exposure apparatus can be reduced to a minimum and can perform effective cleaning of the optical elements, so the full performance of the exposure apparatus itself can
25 be maintained.

The exposure operation of the exposure apparatus 10 is briefly described next.

First, reticle loading and wafer loading are performed

under the control of controller 20, by the reticle loader and wafer loader not shown in Figs.

Prior to the reticle loading, the self-cleaning of the optical elements, as described above, is performed, and upon
5 completing the cleaning, the adjustment of the wavelength of the excimer laser beam and replacement of the gas within the optical system is performed as follows.

In short, when the controller 20 judges that the cleaning of the optical elements has been completed, it shuts the
10 shutter 12F in the light source unit 12. It then adjusts the wavelength of the laser beam LB emitted from the laser resonator 12a via the driving mechanism 18 to 193.30nm, which is the exposure wavelength, while monitoring the output of the beam monitor mechanism 12c. Thus, when the shutter 12f
15 is opened, the laser beam LB that has the exposure wavelength (first light) is emitted from the light source unit 12. However, at this stage, the shutter 12f remains closed.

When the shutter 12f is closed, the controller 20 simultaneously closes the second, fourth, and sixth solenoid
20 valves, 38B, 38D, and 38F, as well as open the first, third, and fifth solenoid valves, 38A, 38C, and 38E. By this operation, the from the gas tank not shown in Figs. a high concentration of nitrogen gas (the first gas) that has an oxygen concentration not exceeding 1% is supplied
25 respectively to the beam matching unit BMU, illumination optical system 14 and projection optical system PL via the first, second, and third intake pipe 34A, 34B and 34C. After a predetermined period of time, the dry air remaining within

the beam matching unit BMU, illumination optical system 14 and projection optical system PL is practically replaced with the nitrogen gas. In this case, the controller 20 judges that the replacement has been completed by the output of the first, 5 second, and third sensor 44A, 44B, and 44C, when the oxygen concentration output of all three sensors fall within 1%.

Furthermore, almost simultaneously with the shutter 12f closing, the controller 20 drives the half mirror 56 and 66 configuring the beam matching unit BMU via the sliding unit 10 not shown in Figs. The half mirrors 56 and 66 are driven in the directions shown in Fig. 4 by the arrows C' and D', and inserted into the optical path of the laser beam LB shown by a solid line. In this case, the adjustment of matching the optical axis and of the angle of deviation of the mirror 58, 15 60, and 62, previously described, are performed in advance. And the tilt of the half mirror 56, 66, and mirror 58, 60, 62, 70, 72, and 74 are to be respectively maintained in the adjusted state.

The controller 20 can also open the shutter 12f, if 20 necessary, and then close the shutter 12f after the adjustment of matching the optical axis and of the angle of deviation of the mirror 58, 60, 62, 70, 72, and 74 via the autocollimator not shown in Figs.

In either case, when the shutter 12f is opened, the laser 25 beam LB having the exposure wavelength (the first light) emitted from the light source unit 12 proceeds via the first optical delay element 52 and the second optical delay element 54 which structures the beam matching unit BMU. It then

proceeds into the illumination optical system 14, consequently reducing the coherence on the irradiating surface, such as the pattern surface of the reticle R.

When the wavelength adjustment of the laser beam LB, replacement of the interior gas of the optical system, and the insertion of the half mirror 56 and 66 into the optical path are all completed, the controller 20 then prepares for reticle alignment and baseline measurement based on predetermined procedures. The reticle alignment and baseline measurement uses a reticle microscope, a reference mark plate on the wafer stage WST, and an alignment detection system which are not shown in Figs. In this case, the controller 20 performs the reticle alignment by opening the shutter 12f, and using the light with the exposure wavelength. The details of preparations for the reticle alignment and the baseline measurement, are disclosed in detail in, for example, Japan Patent Laid Open No. 04-324923, and the corresponding U.S. Patent No. 5,243,195. As long as the national laws in designated states or elected states, to which this international application is applied, permit, the disclosures cited above are fully incorporated by reference herein.

In the case the reticle alignment is performed with light having a wavelength other than the exposure wavelength, it can be performed in parallel with adjustment of the laser beam wavelength, or with the interior gas replacement of the optical system.

Then, the controller 20 performs alignment measurement such as EGA (enhanced global alignment) that is disclosed in

detail, for example, in Japan Patent Laid Open No. 61-44429, and the corresponding U.S. Patent No. 4,780,617, by using the alignment detection system not shown in Figs. As long as the national laws in designated states or elected states, to which
5 this international application is applied, permit, the disclosures cited above are fully incorporated by reference herein.

After completing the alignment measurements, exposure based on the step and scan method is performed as follows.

10 On exposure, the controller 20, first of all, moves the wafer stage WST so that the XY position of the wafer W is located on the starting position of scanning exposure in the initial shot area (first shot). The controller 20 also moves the reticle stage RST, so that the XY position of the reticle R
15 is located on the starting position of scanning exposure. The controller 20 performs scanning exposure by synchronously moving the reticle R and wafer W via the reticle driving portion 24 and the driving unit 26 in a speed velocity with respect to the projection magnification of the projection optical
20 system PL, in opposite directions along the Y axis. The light amount during the scanning exposure is controlled in accordance with the output of the incident light measurement device 22 and the output of the energy monitor. For example, it can be controlled by adjusting the pulse energy of the laser
25 beam emitted from the laser resonator 12a, or by adjusting the oscillation frequency of the laser resonator 12a.

After the transfer of a reticle pattern in a shot area is completed as described above, the wafer stage WST performs

a stepping movement which covers one shot area, and the scanning exposure of the next shot area begins. The stepping movement and scanning exposure are, repeated sequentially, and thus the necessary numbers of patterns are transferred
5 onto the shot areas of the wafer.

On exposing each shot area on the wafer W, the optical elements of the optical system are cleaned in advance and in the state that the optical properties can be exhibited to the maximum. Therefore, the deterioration of patterns
10 transferred onto the wafer that is caused by the deterioration of the image forming performance of the optical system upon scanning exposure can be suppressed. Also, on scanning exposure, the first optical delay element 52 and the second optical delay element 54 which structures the beam matching
15 unit BMU reduce the coherence on the irradiating surface. The interference fringes and speckles, which occur on the pattern surface of the reticle R and the conjugating exposure surface of the wafer W, thus, can be effectively suppressed, consequently improving the controllability of the pattern
20 line width.

As is obvious with the description so far, in this embodiment, an adjustment unit is structured by: the first and second optical delay element 52 and 54; and the sliding mechanism which inserts/detaches the beam splitter 56 and 66
25 configuring the first and second optical delay elements into/from the optical path of the laser beam LB. The adjustment unit is arranged along a portion of the optical path from the light source unit 12 to the arrangement surface

of the reticle R and the exiting light intensity can be adjusted by this unit.

From the descriptions above, with the exposure apparatus 10, self-cleaning operation is performed in the optical system (beam matching unit BMU, illumination optical system 14 and projection optical system PL). To be more precise, the self-cleaning operation of the optical elements within the housing structuring the optical systems is performed by the laser beam which has a wavelength adjusted so that the energy absorbed by oxygen is at the maximum. Upon the self-cleaning, dry air that has a high concentration of oxygen is purged into the optical system so that there is a sufficient amount of oxygen along the optical path. The laser beam then breaks down the organic structure of the contaminants, and ozone generated by the photochemical reaction is oxidized and effectively cleans the contaminants adhered on the optical elements within a short period of time. When this cleaning is performed, the half mirrors 56 and 66 are withdrawn from the optical path, so that the light intensity used for cleaning is stronger than that of the light used for exposure, to result in a more effective cleaning. Accordingly, by the improvement of work efficiency, the production cost of microdevices such as integrated circuits can be cut as well as reduce the damage of glass material caused by irradiating a high-energy beam (ArF excimer laser beam).

Furthermore, the optical elements of the optical system can perform self-cleaning in advance (or just before) of exposure, so that the transmittance of the optical system is

at the optimum upon exposure, and the pattern transferred onto the wafer can be kept from being deteriorated.

In addition, on exposure the beam splitter 56 and 66 are inserted into the optical path of the laser beam so that
5 optical delay can be performed by the first optical delay element 52 and the second optical delay element 54. This sufficiently reduces the coherence on the irradiating surface, thus effectively suppressing fine interference fringes and speckles on the wafer surface (image plane), and improving
10 the controllability (such as line width uniformity) of the pattern line width transferred onto the wafer. In this case, since the laser beam proceeds through the first and second optical delay elements 52 and 54, the light intensity of the exposure light irradiated on exposure weakens. This
15 suppresses the photochemical reaction of generating ozone from the small amount of oxygen (within 1%) concentrated in the nitrogen within the interior of the housing, which in turn can suppress the absorption of exposure light by ozone. Consequently, the decrease in transmittance of the exposure
20 light can be prevented.

According to this embodiment, therefore, the yield of microdevices such as integrated circuits can be improved, and also from this aspect the manufacturing cost can be reduced.

With the exposure apparatus 10 in this embodiment,
25 cleaning only a part of the optical element, that is, cleaning only one or two of the beam matching unit BMU, illumination optical system 14, and projection optical system PL can be easily performed.

For example, in order to clean only the optical elements in the projection optical system which is the furthest from the laser resonator 12a, and is the most difficult to clean, the first solenoid valve 38A and the third solenoid valve 38C
5 can be kept open (in this case, the second solenoid valve 38B and the fourth solenoid valve 38D are both closed), the fifth valve 38E closed, and the sixth valve 38F open. With this operation, the beam matching unit arranged on the upstream of the optical path and the illumination optical system 14
10 are in a state where nitrogen gas is flowing into the interior. And, in the projection optical system there is enough oxygen supplied to effectively clean the optical elements arranged in the projection optical system PL, while suppressing the energy absorption of the laser beam by oxygen.

15 In the embodiment described above, cleaning of the optical elements is performed in a state where the nitrogen gas (the first gas) within the optical system is replaced with the dry air (an example of the second gas having a sufficient amount of oxygen). The present invention, however, is not
20 limited to this.

For example, as shown in Fig. 6, instead of supplying dry air through the first, second, and third intake pipe 34A, 34B and 34C, a configuration supplying a mixture of dry gas and ozone O_3 (an example of a third gas containing oxygen and
25 ozone) can be substituted. In this case, the nitrogen gas within the beam matching unit BMU, the housing of the optical system for illumination, and the barrel (a type of housing) of the projection optical system PL is replaced with the

mixture of dry gas and ozone, and then the ArF excimer laser beam (vacuum ultraviolet light) with a wavelength of 193.23nm is irradiated on each housing. By irradiating the ArF excimer laser beam, the energy of the beam then breaks down the organic
5 structure of the contaminants adhered on the surface of the optical elements. The ozone generated by the photochemical reaction of oxygen, along with the ozone mixed in the gas within the system, further cleans the optical elements effectively by oxidation.

10 Also, in the embodiment described earlier, the cleaning of the optical elements in the optical system is performed with the nitrogen gas within the beam matching unit BMU, the housing of the optical system for illumination, and the barrel (a type of housing) of the projection optical system PL
15 replaced by the dry gas. The present invention, however, is not limited to this, and the cleaning can be performed without replacing the gas. That is, the nitrogen gas can be supplied to each housing, and the wavelength of the laser beam emitted from the laser light source 12 can be changed to 193.23 and
20 it can be irradiated on each housing for a predetermined period of time for self-cleaning of the optical elements. In this case, as well, the nitrogen within the housing contains a small amount of oxygen (not exceeding 1%), therefore, the oxygen absorbs the laser beam (the energy) and by photochemical
25 reaction, ozone is generated, and by oxidation of ozone the contaminants on the surface of the optical elements are removed. Changing the wavelength of the laser beam is more effective, compared to conventional cleaning where the wavelength of the

laser beam is not changed, accordingly, the time required for sufficient cleaning can be reduced. The damage of glass material due to long irradiation hours can also be reduced, due to the reduction.

5 In the case described above where the gas is not replaced, similar to the embodiment, if the intensity of the laser beam irradiating the illumination optical system 14 is stronger than that of exposure, changing the wavelength of the laser beam emitted from the light source unit 12 may not be required.

10 Because in such a case, the nitrogen within the housing contains a small amount of oxygen (not exceeding 1%), therefore, the oxygen absorbs the laser beam (the energy) and by photochemical reaction, ozone is generated, and by oxidation of ozone the contaminants on the surface of the optical

15 elements are removed. Enhancing the intensity of the laser beam is more effective, compared to self-cleaning where the intensity of the laser beam is the same as on exposure. Also, in this case, since the intensity of the exposure light is weaker compared to the light used for cleaning, it suppresses

20 the small amount of oxygen (not exceeding 1%) contained in the nitrogen from photochemical reaction, thus suppressing the exposure light from being absorbed by ozone generated by the photochemical reaction. This prevents the transmittance of the exposure light from decreasing.

25 In the embodiment described above, on cleaning the optical elements of the illumination optical system 14, projection optical system PL, the ultraviolet light is irradiated on the optical elements within the housing of the

optical system for a predetermined period of time. However, the present invention is not limited to this. That is, similar to cleaning the optical elements of the beam matching unit BMU as is previously described, the ultraviolet light can be
5 irradiated onto the gas interior of the housing. In the case where there is a sufficient amount of oxygen in the interior of the housing, by irradiating the gas within the housing the oxygen in the gas generates ozone by photochemical reaction, the optical elements can be cleaned by oxidation.

10 Furthermore, in the embodiment, the controller 20 switches the wavelength of the light emitted from a single light source unit 12 via the driving mechanism 18 between the wavelength of the first light (ultraviolet pulse light with a wavelength of 193.30nm) and the wavelength of the second
15 light (ultraviolet pulse light with a wavelength of 193.23nm) which energy absorption by oxygen is greater than the first light. However, the present invention is not limited to this, and a first light source emitting the light with the exposure wavelength and a second light source emitting the light with
20 greater energy absorption by oxygen can be arranged. The controller 20 can selectively choose either light to guide to the optical system for illumination (BMU, 14). In this case, the controller 20 can selectively choose the first or second light source unit or a shutter arranged on the light source
25 unit to operate the on/off. Alternatively, a switching unit can be arranged on the optical path between each light source and the illumination optical system 14, so that the optical path can be appropriately switched.

And, in the embodiment described above, the switching of the wavelength of the first light (ultraviolet pulse light with a wavelength of 193.30nm) and the wavelength of the second light (ultraviolet pulse light with a wavelength of 193.23nm) which energy absorption by oxygen is greater than the first light is performed by switching the wavelength of the light emitted from the light source unit 12, that is, wavelength shifting. The present invention, however, is not limited to this. For example, in the case of using the laser resonator 12a shown in Fig. 2, the controller 20 can drive the etalon 204 which performs fine adjustment and configures the narrow-banding module, via the driving mechanism 18 so that the etalon 204 is insertable/removable from the optical path as shown by the arrows A and A'. In this case, by removing the etalon 204 from the optical path, the wavelength width can be changed into a wavelength width that includes the range where energy is absorbed by oxygen. Thus, the switching operation to the second light which energy absorption by oxygen is greater than the first light can be achieved.

Alternatively, in the case of using the laser resonator 12a shown in Fig. 3, other than the etalon 204 that is used for exposure, an etalon 207 can be arranged as shown in Fig. 3 by the dotted line for the purpose of optical cleaning. The controller 20 can exchange the etalon 204 and 207 as shown in Fig. 3 by the arrows B and B', inserting the etalon 204 on exposure and the etalon 207 on cleaning. In this case, the etalon 207 can be made of a material that extracts the range of wavelength including the range that absorbs energy by oxygen.

In this manner, the wavelength width of the exiting light from the light source (excimer laser chamber 202) can be changed, achieving the switching of the first light to the second light.

Also, in the embodiment previously described, the first
5 optical delay element 52 and the second optical delay element 54 which have a delay optical path of a triangular shape are arranged in the beam matching unit BMU, however, the present invention is not limited to this. The optical delay elements can have an optical path of a square shape, and in such a case,
10 the optical delay path can be arranged of a reflection optical element such as four prisms, instead of four mirrors.

With the exposure apparatus in the embodiment, on optical cleaning, the exposure apparatus can perform either a wavelength shift which switches the wavelength of the light
15 emitted, change the wavelength width of the emitted light, or change the intensity of the emitted light, or perform a combination of these operations.

In the embodiment described above, the present invention is applied to a scanning type exposure apparatus (a scanning
20 stepper) for manufacturing semiconductor devices based on the step-and-scan method, which uses an ArF excimer laser unit as a light source. The present invention, however, is not limited to this. For example, the present invention can be suitably applied to a projection exposure apparatus (a
25 stepper) based on the step-and-repeat method, which uses an ArF excimer laser unit as a light source. Or, it can be suitably applied to an ArF excimer laser stepper for liquid crystal displays or an ArF excimer laser scanning stepper.

Also, in the case of F_2 laser beam which belongs to the same vacuum ultraviolet light region as of the ArF excimer laser beam, a similar case can be assumed of the energy amount absorbed by oxygen being different depending on wavelength.

5 The present invention, therefore, can be applicable to an exposure apparatus using the F_2 laser as the light source. With this exposure apparatus, the interior of the optical system, the air in between the optical system for illumination and the projection optical system, and the air in between the
10 projection optical system and the substrate are replaced with helium gas. So upon cleaning the optical elements, a wavelength of a large energy absorption by oxygen around the 157nm range is to be chosen and set, and the helium gas interior of each optical system is to be replaced with a gas containing
15 oxygen (including a gas containing oxygen and ozone). Self-cleaning is thus, similarly performed, producing the same kind of effects as the embodiment described above.

In the embodiment above, nitrogen is used for the gas supplied to the optical path. Alternatively, other inactive
20 gas, rare gas such as helium, neon, argon, krypton, xenon, and radon can be used, or a mixture of more than two types of gases can be used.

Furthermore, all optical elements are not limited to lenses of a refraction system. The elements can be structured
25 of a reflection element (a mirror) being a reflection system, or of a reflection optical element and a refraction optic element configuring a reflection/refraction system. The projection optical system used is also not limited to the

reduction system; it may be a one-to-one magnifying system or an enlarged magnifying system.

As the reflection/refraction type projection optical system described above, a reflection/refraction system having
5 a beam splitter and concave mirror as reflection optical elements, which is disclosed in, for example, Japan Patent Laid Open No.08-171054 and the corresponding U.S. Patent No. 5,668,672, and Japan Patent Laid Open No. 10-20195, and the corresponding U.S. Patent No. 5,835,275, can be used. In
10 addition, a reflection/refraction system having a concave mirror and the like as reflection optical elements without using any beam splitter, which is disclosed in, for example, Japan Patent Laid Open No. 08-334695 and the corresponding U.S. Patent No. 5,689,377, and Japan Patent Laid Open No.
15 10-3039, and the corresponding U.S. Patent Application No. 873,605 (application date: June 12, 1997), can be used. As long as the national laws in designated states or elected states, to which this international application is applied, permit, the disclosures cited above are fully incorporated
20 for reference herein.

Also, a reflection/refraction system disclosed in U.S. Patent Nos. 5,031,976, 5,488,229, and 5,717,518 can be used. In these disclosures, a plurality of refraction optic elements and two mirrors (a main mirror which is a concave mirror, and
25 a sub-mirror which is a rear mirror having a reflecting surface formed on a surface of a refraction element or plane-parallel plate which is located on the opposite side of the incident surface) are arranged coaxially, and an intermediate image

of a reticle pattern formed by the plurality of refraction
optic elements is re-formed on a wafer by the main mirror and
sub-mirror. In this reflection/refraction system, the main
mirror and sub-mirror are arranged following the plurality
5 of refraction optic elements, and illumination light passes
through a portion of the main mirror to be sequentially
reflected by the sub-mirror and main mirror, and reaches the
wafer through a portion of the sub-mirror. As long as the
national laws in designated states or elected states, to which
10 this international application is applied, permit, the
disclosures of the U.S. Patents cited above are fully
incorporated for reference herein.

Furthermore, as the reflection/refraction type
projection optical system, a reduction system may be used,
15 which has, for example, a circular image field, and is double
telecentric on the object surface side and the image surface
side, which has a projection magnification of $1/4$ or $1/5$. A
scanning exposure apparatus having the reflection/refraction
type projection optical system may be of a type in which an
20 illumination area for illumination light is determined so that
it is almost centered on the optical axis of the projection
optical system within its field of view, the illumination area
extending along a direction perpendicular to the scanning
direction of a reticle or wafer, and the shape of the slit
25 being rectangular. With a scanning exposure apparatus having
such a reflection/refraction type projection optical system,
a fine pattern almost equal to 100nm L/S pattern can be
transferred onto a wafer with high precision, by using, for

example an F_2 laser beam having a wavelength of 157nm as exposure illumination light.

Also, instead of using an excimer laser beam, a harmonic of a fixed laser such as a YAG laser can be used, which has
5 an oscillation spectrum for example, in one of the wavelength of 284nm, 193nm, and 157nm. A harmonic, which is obtained by amplifying a single-wavelength laser beam in the infrared or visible range being emitted by a DFB semiconductor laser or fiber laser with a fiber amplifier doped with erbium (or both
10 erbium and ytterbium), and converting the wavelength into ultraviolet light using a nonlinear optical crystal, may also be used.

For example, if the oscillation wavelength of a single-wavelength laser is set within the range of 1.51 to
15 1.59 μm , an eighth-harmonics which generation wavelength falls within the range of 189 to 199 nm or a tenth-harmonics which generation wavelength falls within the range of 151 to 159 nm is output. If the oscillation wavelength is set in the range of 1.544 to 1.553 μm , in particular, an eighth-harmonics
20 which generation wavelength falls within the range of 193 to 194 nm, that is, ultraviolet light having almost the same wavelength as that of an ArF excimer laser beam, can be obtained. If the oscillation wavelength is set within the range of 1.57 to 1.58 μm , a tenth-harmonics which generation wavelength
25 falls within the range of 157 to 158 nm, that is, ultraviolet light having almost the same wavelength as that of an F_2 laser beam, can be obtained.

Also, if the oscillation wavelength is set within the

range of 1.03 to 1.12 μm , a seventh-harmonics which generation wavelength falls within the range of 147 to 160 nm is output. If the oscillation wavelength is set within the range of 1.099 to 1.106 μm , in particular, a seventh-harmonics which generation wavelength falls within the range of 157 to 158 μm , that is, ultraviolet light having almost the same wavelength as that of an F_2 laser beam, can be obtained. And, as a single-wavelength oscillation laser, for example, an ytterbium-doped fiber laser can be used.

10 As the exposure light source, a Kr_2 laser (krypton dimer laser) having a wavelength of 146 nm), an Ar_2 (argon dimer) laser having a wavelength of 126 nm can be used. A harmonics generator such as a YAG laser or a semiconductor laser, which generates light in the vacuum ultraviolet light region, can
15 also be used as a light source.

 The exposure apparatus of this embodiment can be made by incorporating an optical system for illumination configured of a plurality of lenses, and a projection optical system into a main body of the exposure apparatus, and by
20 performing optical adjustment. The reticle stage and wafer stage made of many mechanical components are also incorporated into the main body. Then, the wiring and piping are connected, and finally, overall adjustment (such as electrical adjustment, operation check) is performed. The making of the
25 exposure apparatus, is preferably performed in a clean room in which conditions such as temperature, degree of cleanliness are controlled.

 In addition, a semiconductor device is manufactured

through the steps of: conducting function and performance design of the device; manufacturing a reticle on based on the design step; manufacturing wafers from a silicon material; transferring the reticle pattern onto the wafer by the use
 5 of the exposure apparatus of the embodiment above; assembling the device (including a dicing process, a bonding step, and a packaging process); and inspection.

Following are the details of the device manufacturing method.

10 <<Device Manufacturing Method>>

A device manufacturing method using the above exposure apparatus and method in a lithographic process will be described in detail next.

Fig. 7 is a flow chart showing an example of
 15 manufacturing a device (a semiconductor chip such as an IC or LSI, a liquid crystal panel, a CCD, a thin magnetic head, a micromachine, or the like). As shown in Fig. 7, in step 401 (design step), function/performance is designed for a device (e.g., circuit design for a semiconductor device) and a pattern
 20 to implement the function is designed. In step 402 (mask manufacturing step), a mask on which the designed circuit pattern is formed is manufactured. In step 403 (wafer manufacturing step), a wafer is manufacturing by using a silicon material or the like.

25 In step 404 (wafer processing step), an actual circuit and the like are formed on the wafer by lithography or the like using the mask and wafer prepared in steps 401 to 403, as will be described later. In step 405 (device assembly step),

a device is assembled by using the wafer processed in step 404. Step 405 includes processes such as dicing, bonding, and packaging (chip encapsulation).

Finally, in step 406 (inspection step), tests such as
5 a test on the operation of the device manufactured in step 405, and durability test are performed. After these steps, the device is completed and shipped out.

Fig. 8 is a flow chart showing a detailed example of step 404 described above in manufacturing the semiconductor
10 device. Referring to Fig. 8, in step 411 (oxidation step), the surface of the wafer is oxidized. In step 412 (CVD step), an insulating film is formed on the wafer surface. In step 413 (electrode formation step), an electrode is formed on the wafer by vapor deposition. In step 214 (ion implantation
15 step), ions are implanted into the wafer. Steps 411 to 414 described above constitute a pre-process for the respective steps in the wafer process and are selectively executed in accordance with the processing required in the respective steps.

20 When the above pre-process is completed in the respective steps in the wafer process, a post-process is executed as follows. In this post-process, first, in step 415 (resist formation step), the wafer is coated with a photosensitive agent. Next, as in step 416, the circuit
25 pattern on the mask is transcribed onto the wafer by the above exposure apparatus and method. Then, in step 417 (developing step), the exposed wafer is developed. In step 418 (etching step), an exposed member on a portion other than a portion

where the resist is left is removed by etching. Finally, in step 419 (resist removing step), the unnecessary resist after the etching is removed.

By repeatedly performing these pre-process and
5 post-process, multiple circuit patterns are formed on the wafer.

As described above, by using the device manufacturing method of this embodiment, since the exposure apparatus and exposure method described above are used in the exposure
10 process (step 416), it becomes possible to perform exposure with the optimum transmittance in the projection optical system. Then, the deterioration of the pattern transferred onto the wafer can be prevented, as well as sufficiently reduce the coherence on the irradiating surface so as to improve the
15 controllability of the pattern line width (for example, line width uniformity) of the pattern transferred onto the wafer. Consequently, the exposure accuracy including the overlay accuracy can be improved, thus making it possible to manufacture high-integrated microdevices which have a high
20 productivity (high yield).

The present invention is not limited to the embodiment described above, and each embodiment can be modified in other specific forms depending on requirements.

25 **INDUSTRIAL APPLICABILITY**

As has been described above, the cleaning method of the optical elements according to the present invention is suited to sufficiently clean the optical elements within a short

period of time. The exposure method and exposure apparatus according to the present invention is suitable in forming a fine pattern on a substrate such as a wafer in a lithographic process for manufacturing a microdevice such as an integrated
5 circuit. In addition, the device manufacturing method according to the present invention is suitable for manufacturing a device, which has a fine pattern.