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(54) **Catadioptric optical system and projection exposure apparatus equipped with the same**

Katadioptrisches optisches System und Projektionsbelichtungsvorrichtung mit einem solchen System

Système optique catadioptrique et dispositif d'exposition par projection muni d'un tel système

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- **OWEN G ET AL: "A CATADIOPTRIC REDUCTION CAMERA FOR DEEP UV MICROLITHOGRAPHY" MICROELECTRONIC ENGINEERING,NL,ELSEVIER PUBLISHERS BV., AMSTERDAM, vol. 11, no. 1 / 04, 1 April 1990 (1990-04-01), pages 219-222, XP000134590 ISSN: 0167-9317**
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EP 1 069 448 B1

Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a catadioptric optical system and a projection exposure apparatus equipped with the catadioptric optical system suitable when manufacturing in a photolithography process, for example, a semiconductor device or a liquid crystal display device. In particular, the invention relates to a catadioptric optical system suitable for a scanning type projection exposure apparatus.

Related Background Art

[0002] In a photolithography process for manufacturing semiconductor devices and the like, there is used a projection exposure apparatus by which a pattern image formed on a photomask or reticle (collectively referred to as "reticle" hereinafter) is projected and exposed onto a wafer, a glass plate, etc. coated with a photoresist or the like via a projection optical system. As the integration of the semiconductor devices and the like is improved, there has been a demand for a higher resolution of the projection optical system used in the projection exposure apparatus. In order to satisfy such a demand, there have been occurred necessities for shortening the wavelength of illumination light and increasing the numerical aperture (hereinafter referred to as "NA") of the projection optical system. In particular, regarding the exposure wavelength, replacing g-line (λ=436 nm), i-line (λ=356 nm) and, further, KrF excimer laser light (λ = 248 nm) are currently used. In the future, ArF excimer laser light (λ = 193 nm) and F_2 laser light (λ=157 nm) will probably be used.

[0003] However, as the wavelength of the illumination light becomes shorter, a fewer kinds of glass materials can be practically used due to light absorption. As a result, when the projection optical system is constructed by a refraction system alone, that is, only by optical elements not including a reflecting mirror with refractive power (a concave or convex mirror), chromatic aberration cannot be corrected. Additionally, because the optical performance required of the projection optical system is extremely high, various kinds of aberrations should preferably be corrected to a level of almost no aberration. Eighteen or more lens elements are required for correcting various aberrations to a desired optical performance by a refraction type projection optical system constituted of lens elements (see, for example, Japanese Unexamined Patent Publication Hei No. 5-173065), and it is difficult to suppress light absorption and avoid manufacturing costs' increase. Moreover, when extreme ultraviolet light with a wavelength of 200 nm or less is used, the optical performance may be affected by, for example, light absorption in glass material and on an anti-reflection film on the lens surface.

[0004] Further, although the oscillation bandwidth of laser light sources with an oscillation wavelength of 200 nm or less has been considerably narrowed, the bandwidth has still a certain wavelength width. Thus, to project and expose a pattern maintaining good contrast, correction of chromatic aberration of the order of pm (pico meter) is required. The optical system disclosed in the above-mentioned Japanese Unexamined Patent Publication Hei No. 5-173065 is a refraction type lens system made from a single kind of glass material, and its chromatic aberration is too large to be used with a light source having a wavelength width.

[0005] On the other hand, a reflection type optical system utilizing power (refractive power) of a concave mirror and the like does not effect chromatic aberration and, with respect to Petzval sum, creates a contribution with an opposite sign to a lens element. As a result, a so-called catadioptric optical system (hereinafter referred to as "catadioptric optical system"), which combines a catoptric optical system and a dioptric optical system together, can correct chromatic aberration as well as other various aberrations to a level of almost no aberration without increasing the number of lenses. Thus, a catadioptric optical system is an optical system having at least one lens element and at least one reflecting mirror with refractive power.

[0006] However, when a concave mirror is incorporated on the optical axis of a projection optical system of a projection exposure apparatus, light from the reticle side incident on the concave mirror is reflected toward the reticle. Addressing this problem, techniques to separate the optical path of light incident on a concave mirror from the optical path of light reflected by the concave mirror and also to direct the reflected light from the concave mirror to the wafer direction, i.e., various techniques to implement a projection optical system by a catadioptric optical system, have been extensively proposed.

[0007] However, when using a beam splitter as is used in the optical system disclosed in Japanese Unexamined Patent Publication Hei No. 5-281469, it is difficult to secure large-sized glass material for manufacturing the optical system. In addition, in the case of the optical system disclosed in Japanese Unexamined Patent Application Hei No. 5-51718, an optical path folding mirror (folding mirror) or a beam splitter is required, a plurality of lens barrels are required for manufacturing the optical system, resulting in such problems as difficulties in manufacture or in adjusting optical elements. A light beam impinges obliquely onto a plane reflecting mirror (folding mirror) for changing the optical path direction incorporated in a catadioptric optical system as necessary. Accordingly, extremely high surface accuracy of the mirror is required, resulting thus in the difficulty of the manufacture of the mirror. Further, the mirror is easily affected by vibration.

[0008] Meanwhile, when an optical path separating method disclosed in U.S. Patent No. 5,717,518 is used, optical elements constituting a optical system can all be disposed along a single optical axis. As a result, the optical system can be manufactured with high accuracy following an optical element adjustment method conventionally used in the projection optical system manufacture. However, the system requires a central light-shielding portion to shield light beam propagating along the optical axis, resulting in the contrast deterioration of a pattern of a certain frequency.

[0009] Additionally, because it is difficult to provide an anti-reflection film with sufficient optical performance in the extreme ultraviolet wavelength region, it is also required that the number of optical elements constituting an optical system be reduced as much as possible.

[0010] As can be seen from the above, it is preferable that, to expose a pattern having a linewidth of 0.18 μm or less, an optical system in which a good chromatic aberration correction capability is realized even when using a light source with a wavelength of 200 nm or less such as ArF or F_2 laser, no central light-shielding is used, a high numerical aperture of NA 0.6 or more can be secured, and the number of refractive and reflecting components is reduced as much as possible be provided.

[0011] EP 0 779 528A relates to an optical projection reduction system comprising a first mirror pair, a field mirror pair receiving light from the first mirror pair, and a third mirror pair receiving light from the field mirror pair, whereby an intermediate image is re-imaged to a final image at an image plane.

SUMMARY OF THE INVENTION

[0012] The present invention has been made in view of the above problems, and the object of the invention is to provide a catadioptric optical system in which chromatic aberration is well corrected in the extreme ultraviolet wavelength region, in particular, even in the wavelength region of 200 nm or less, and a NA (0.6 or more) necessary for high resolution is secured, and the number of refractive and reflecting components is reduced as much as possible; a projection exposure apparatus equipped with the optical system.

[0013] The present invention provides a catadioptric optical system as set out in claim 1.

[0014] The invention also provides a projection exposure apparatus as set out in claim 9.

[0015] Preferred features are set out in the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 is a view schematically illustrating the configuration of a projection exposure apparatus equipped with a catadioptric projection optical system to which. the present Invention is applied.

[0017] FIG. 2 is a view illustrating a lens configuration of a catadioptric optical system in accordance with a first embodiment of the present invention.

[0018] FIG. 3 is a view showing transverse aberrations of the catadioptric optical system in accordance with the first embodiment,

[0019] FIG. 4 is a view illustrating a lens configuration of a catadioptric optical system in accordance with a second embodiment of the present invention.

[0020] FIG. 5 is a view showing transverse aberrations of the oatadioptric optical system in accordance with the second embodiment.

[0021] FIG. 6 is a view illustrating a lens configuration of a catadioptric optical system in accordance with a third embodiment of the present invention.

[0022] FIG. 7 is a view showing transverse aberrations of the catadioptric optical system in accordance with the third embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0023] In the following, the catadioptric optical system in accordance with an embodiment of the present invention will be described with reference to the accompanying drawings. The system is a catadioptric optical system provided with a first catadioptric type imaging optical system G1 for forming an intermediate image I1 of a first surface 3 and with a second refraction type imaging optical system G2 for telecentrically forming the final image of the first surface 3 onto a second surface 9 (wafer surface, i.e., the final image plane) based on light from the intermediate image. The first optical system G1 has a lens group including at least one positive lens element, a first reflecting surface M1 which reflects light passed through the lens group and is substantially collimated, and a second reflecting surface M2 for directing light reflected by the first reflecting surface M1 to the second imaging optical system G2; and at least one of the first and second reflecting surfaces is a concave reflecting surface. Further, the second imaging optical system G2 has aperture diaphragm AS, all of the optical elements of the catadioptric optical system are disposed on a single linear optical axis AX, the first surface 3 and the second surface 9 are plane surfaces which are substantially mutually parallel; and an exit pupil of the catadioptric optical system is substantially circular.

[0024] A structurally reasonable catadioptric optical system is achieved by making the effective projected area an annular shape and by preventing mutual interference of optical elements through appropriately positioning the first and second reflecting surfaces M1 and M2.

[0025] Further, in the present invention, the following condition is preferably satisfied:

$$(1) \qquad 0.04<|fM1|/L<0.4$$

wherein fM1 is a focal length of the concave reflecting surface of the first or second reflecting surface, and L is a distance along the optical axis AX from the first surface 3 to the second surface 9. The condition (1) defines an appropriate power range of the concave reflecting surface.

[0026] Positive Petzval sum created by refractive lenses is corrected by negative Petzval sum created by the concave mirror. When the power is over the upper limit value of the condition (1), the positive Petzval sum created by refractive lenses cannot be sufficiently corrected, and the flatness of the image deteriorates. In contrast, when the power is below the lower limit value of the condition (1), the Petzval sum is overcorrected, and the flatness of the image deteriorates similarly

[0027] Further, in the present invention, the following condition is preferably satisfied:

$$(2) \qquad 0.6<|\beta M1|<20$$

wherein βM1 represents a magnification of the concave reflecting surface of the first or second reflecting surface. The condition (2) defines an appropriate magnification range of the concave reflecting mirror. When the magnification is over the upper limit value of the condition (2) or is below the lower limit value of the condition (2), symmetricity of the first imaging system G1 is seriously affected, large coma aberration being produced, and causes the image deterioration.

[0028] Further, in the present invention, the following condition is preferably satisfied:

$$(3) \qquad 0.3<|\beta 1|<1.8$$

wherein β1 is a magnification of the first imaging optical system G1. The condition (3) defines an appropriate magnification range of the first imaging optical system G1. When the magnification is over the upper limit value of the condition (3) or is below the lower limit value of the condition (3), power balance collapses, causing distortion aberration (distortion) and coma aberration. and the imaging performance deteriorates.

[0029] Further, in the present invention, it is preferable that, the first imaging optical system G1 has a light beam which intersects at least three times a plane P1 perpendicular to the optical axis AX. Light from the first surface 3, after being refracted by the lens group L1, passes through the plane P1 (the first time) to the reflecting surface M1, and, after being reflected by the surface, passes through again the plane P1 (the second time) to the reflecting surface M2. Further, the light, after being reflected by the reflecting surface M2, passes through again the plane P1 (the third time) and forms the intermediate image I1. In addition, by having made the effective projected area an annular shape, the light and the optical elements such as the reflecting surfaces M1 and M2 can be positioned so as not to physically interfere with each other.

[0030] Further, as mentioned above, the catadioptric optical system is telecentric on the second surface 9 side (wafer surface side), but it is preferable that the optical system be additionally telecentric on the first surface 3 side (reticle surface side).

[0031] In the following, embodiments of the present invention will be described with reference to the attached drawings. FIG. 1 is a drawing schematically illustrating the overall configuration of a projection exposure apparatus equipped with a projection optical system in accordance with any embodiment of the present invention optical systems. Note that, in FIG. 1, a Z-axis is set parallel to the optical axis AX of the projection optical system 8 constituting the projection exposure optical system, an X-axis is set parallel to the plane of the drawing of FIG.1. and a Y-axis is set perpendicular to the plane of the drawing, both of X- and Y- axes being in a plane perpendicular to the optical axis AX. Further, a reticle 3, as a projection original plate, on which a predetermined circuit pattern is formed is disposed on the object plane of the projection optical system 8, and a wafer 9, as a substrate, coated with a photoresist is disposed on the image plane of the projection optical system 8.

[0032] Light emitted from light source 1, via the illumination optical system 2, uniformly illuminates the reticle on which the predetermined pattern is formed. One or more folding mirrors for changing the optical path direction are disposed, as required, on the optical path from the light source 1 to the illumination optical system 2.

[0033] Note further that the illumination optical system 2 comprises optical systems such as an optical integrator constituted of, for example, a flyeye lens or an internal reflection type integrator for forming a plane light source having a predetermined size and shape; a variable field stop (reticle blind) for defining the size and shape of an illumination area on the reticle 3; and a field stop imaging optical system for projecting the image of this field stop on the reticle. Also note that. as an optical system from the light source 1 to the field stop, the illumination optical system disclosed in U.S. Patent No. 5,345,292 may be applied.

[0034] The reticle 3 is, via reticle holder 4, held on reticle stage 5 parallel to the XY plane. On the reticle 3 is formed a pattern to be transferred, and the overall pattern area is illuminated with light from the illumination optical system 2. The reticle stage 5 is so configured that the stage is two-dimensionally movable along a reticle plane (i.e., the XY plane) by the effect of a drive system, not shown, and that the coordinate position of the stage is measured by interferometer 7 using reticle moving mirror 6 and is position-controlled.

[0035] Light from the pattern formed on the reticle 3 forms, via the projection optical system 8, a mask pattern image onto the wafer which is a photosensitive substrate. The projection optical system 8 has a variable aperture diaphragm AS (see FIG. 2) near its pupil and is substantially telecentric on both of the reticle 3 and wafer 9 sides.

[0036] The wafer 9 is, via a wafer holder 10, held on a wafer stage 11 parallel to the XY plane. Onto a substantially similar exposure area to the illuminated area on the reticle 3 is thus formed the pattern image.

[0037] The wafer stage 11 is so configured that the stage is two-dimensionally movable along a wafer plane (i.e., the XY plane) by the effect of a drive system, not shown, and that the coordinate position of the stage is measured by interferometer 13 using wafer moving mirror 12 and thus the wafer stage is position-controlled.

[0038] As described above. the field view area on the mask 3 (illumination area) and the projection area (exposure area) on the wafer 9 both defined by the projection optical system 8 are rectangle-shaped areas having a short-side along the X-axis. Aligning the mask 3 and the wafer 9 is thus performed by using the drive systems and the interferometers (7, 13), and the wafer 9 is positioned onto the image plane of the projection optical system by the use of an autofocus/autoleveling system, not shown. Further, by synchronously moving (scanning) the mask stage 5 and the wafer stage 11, and accordingly, the mask 3 and the wafer 9, along the short-side direction of the rectangle-shaped exposure and illumination areas, i.e., along the X-direction. the mask pattern is scanningly exposed onto an area on the wafer 9 of which width is equal to the long-side length of the exposure area and of which length is equal to the scanning (moving) length of the wafer 9.

[0039] Note that over the overall optical path between the light source 1 and the wafer 9 is formed an inert gas atmosphere such as nitrogen or helium gas into which the exposure light is little absorbed.

(First Embodiment)

[0040] FIG. 2 is a drawing illustrating a lens configuration of a catadioptric optical system in accordance with a first embodiment of the present invention. The system is a catadioptric optical system comprising a first catadioptric type imaging optical system G1 for forming an intermediate image Il of a reticle (first surface) 3 and a second refraction type imaging optical system G2 for telecentrically forming the final image of the reticle surface 3 onto a wafer (second surface) 9 based on light from the intermediate image I1.

[0041] The first imaging optical system G1 has a lens group L1 including at least one positive lens element, a first reflecting surface M1 which reflects light passed through the lens group L1, and a second reflecting surface M2 for directing light reflected by the first reflecting surface M1 to the second imaging optical system G2, at least one of the first and second reflecting surfaces being a concave reflecting surface, and the second imaging optical system G2 having an aperture diaphragm AS. Further, all of the optical elements of the catadioptric optical system are disposed on a single linear optical axis AX, the reticle surface 3 and the wafer surface 9 are plane surfaces which are substantially mutually parallel; and an exit pupil of the catadioptric optical system is substantially circular.

[0042] In Table 1 are listed values of items of the projection optical system in accordance with the first embodiment. In Table 1, numerals in the leftmost column represent the order of lens surfaces from the reticle 3 (first object plane) side, r is the radius of curvature of the lens surface, d is the lens surface interval from the lens surface to the next lens surface, β is the overall magnification of the catadioptric optical system, NA is the numerical aperture on the wafer side (the second surface side), and λ is the standard wavelength. Note that the refractive indexes of the glass used in the first embodiment equal to those in the second embodiment.

[0043] Further, ASP in the lens data represents an aspherical surface. In each embodiment, an aspherical surface can be expressed by the following mathematical formula:

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