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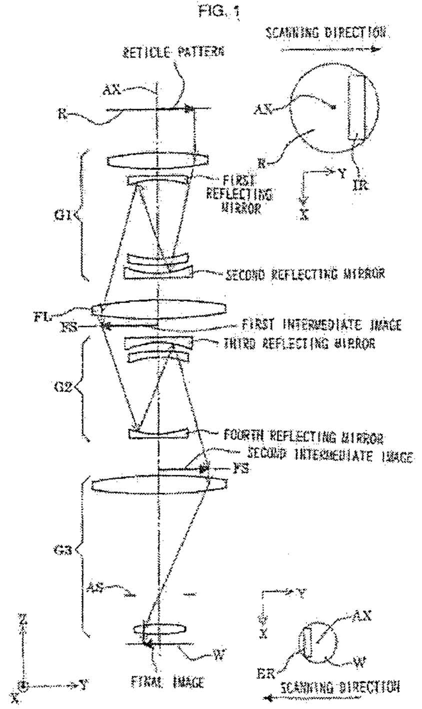
(54) ## CATADIOPTRIC SYSTEM AND EXPOSURE DEVICE HAVING THIS SYSTEM

(57) A catadioptric system includes: a first image forming optical system that includes at least two reflecting mirrors and forms a first intermediate image of a first plane with light originating from the first plane; a second image forming optical system that includes at least two reflecting mirrors and forms a second intermediate image of the first plane with light having traveled via the first image forming optical system; and a refractive type of third image forming optical system that forms a final image of the first plane onto a second plane with light having traveled via the second image forming optical system, and optical members constituting the first image forming optical system, the second image forming optical system and the third image forming optical system are all disposed along a single linear optical axis.

FIG. 1



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Description

[0001] The disclosures of the following priority applications are herein incorporated by reference: Japanese Patent Application No. 2000-322068 filed October 23, 2000; Japanese Patent Application No. 2001-003200 filed January 11, 2001; and Japanese Patent Application No. 2001-309516 filed October 5, 2001.

TECHNICAL FIELD

[0002] The present invention relates to a catadioptric system and an exposure apparatus having this catadioptric system and, more specifically, it relates to a high resolution catadioptric type projection optical system ideal in an application in an exposure apparatus which is employed when manufacturing semiconductor elements or the like through a photolithography process.

BACKGROUND ART

[0003] As further miniaturization is pursued with increasing vigor in the field of semiconductor production and semiconductor chip substrate production today, the projection optical system in an exposure apparatus that prints patterns needs to achieve higher resolution. The wavelength of the exposure light must be reduced and the NA (numerical aperture at the projection optical system) must be increased to raise the resolution. However, since light absorption becomes a factor that needs to be taken into consideration, only limited types of optical glass can be utilized in practical application in conjunction with exposure light with small wavelengths. For instance, if the wavelength is 180nm or less, only fluor can be utilized as glass material in practical application.

[0004] In such a situation, if the projection optical system is constituted by using refractive optical members (lenses, plane parallel plates, etc.) alone, it is impossible to correct any chromatic aberration with the refractive projection optical system. In other words, it is extremely difficult to constitute a projection optical system achieving the required resolution with refractive optical members alone. In response, attempts have been made to constitute a projection optical system with reflective optical members, i.e., reflecting mirrors, alone.

[0005] However, the reflective projection optical system achieved by using reflective optical members alone is bound to become large. In addition, aspherical reflecting surfaces must be formed. It is to be noted that it is extremely difficult to form a high precision aspherical reflecting surface in the actual manufacturing process. Accordingly, various so-called catadioptric reducing optical systems achieved by using refractive optical members constituted of both optical glass that can be used in conjunction with exposure light with small wavelengths and reflecting mirrors, have been proposed.

[0006] Among these catadioptric systems, there is a type of catadioptric system that forms an intermediate image only once by using a single concave reflecting mirror. In such a catadioptric system, the optical system portion for reciprocal paths, of which the concave reflecting mirror is a component, only includes negative lenses and does not have any refractive optical member with positive power. As a result, light enters the concave reflecting mirror as a wide light flux, which requires that the concave reflecting mirror have a large diameter.

[0007] In particular, when the optical system portion for reciprocal paths having the concave reflecting mirror adopts a completely symmetrical configuration, the onus of the aberration correction imposed on the refractive optical system portion at the succeeding stage is reduced by minimizing the occurrence of aberration at the optical system portion for reciprocal paths. However, a sufficient working distance cannot be readily assured in the vicinity of the first plane in the symmetrical optical system for reciprocal paths. In addition, a half prism must be used to branch the optical path.

[0008] Furthermore, if a concave reflecting mirror is used at a secondary image forming optical system provided to the rear of the position at which the intermediate image is formed, the light needs to enter the concave reflecting mirror as a wide light flux in order to assure the degree of brightness required by the optical system. As a result, it is difficult to miniaturize the concave reflecting mirror whose diameter tends to be necessarily large.

[0009] There is also a type of catadioptric system that forms an intermediate image only once by using a plurality of reflecting mirrors. In this type of catadioptric optical system, the number of lenses required to constitute the refractive optical system portion can be reduced. However, the following problems must be addressed with regard to such catadioptric systems.

[0010] In the catadioptric system having the optical system portion for reciprocal paths adopting the structure described above provided toward the second plane on the reduction side, other restrictions imposed with regard to the reduction factor make it impossible to assure a sufficiently long distance to the second plane (the wafer surface) over which the light travels after it is reflected at the reflecting mirror. For this reason, a large number of lenses cannot be inserted in this optical path and the level of brightness achieved at the optical system is bound to be limited. In addition, even if an optical system with a large numerical aperture is achieved, numerous refractive optical members must be provided in the optical path with a limited length, and thus, it is not possible to assure a sufficiently long distance between the wafer surface at the second plane and the surface of the lens toward the second plane, i.e., the so-called working distance WD cannot be set to a sufficiently long value.

[0011] Since the optical path has to be bent, the catadioptric system in the related art is bound to have a plurality of optical axes (an optical axis is a line extending through the center of the curvature of a refractive curved surface or a reflective curved surface constituting an optical system). As a result, a plurality of lens barrels must be included in the optical system configuration, which makes it extremely difficult to adjust the individual optical axes relative to one another and, ultimately, to achieve a high precision optical system. It is to be noted that a catadioptric system having all the optical members provided along a single linear optical axis may be achieved by using a pair of reflecting mirrors each having an opening (a light transmission portion) at the center. However, in this type of catadioptric system, the central light flux must be blocked, i.e., central shielding must be achieved, in order to block off unnecessary light which advances along the optical axis without being reflected at the reflecting mirrors. As a result, a problem arises in that the contrast becomes lowered in a specific frequency pattern due to the central shielding.

[0012] In addition, positions at which an effective field stop and an effective aperture stop should be installed can not be assured in the catadioptric systems in the related art. Also, as explained above, a sufficient working distance cannot be assured in the catadioptric systems in the related art. Furthermore concave reflecting mirrors tend to become large in the catadioptric systems in the related art, as described above, making it impossible to miniaturize the optical systems.

[0013] While the catadioptric system disclosed in EP1069448A1 achieves advantages in that a sufficient working distance is assured toward the second plane (on the wafer-side) and in that the system is configured along a single optical axis, it still has a problem in that a sufficiently long working distance cannot be assured toward the first plane (on the mask side) (the distance between the mask surface at the first plane and the surface of the lens closest to the first plane) . In addition, the catadioptric system disclosed in WO 01/51979A2 poses a problem in that the diameter of the reflecting mirror is too large and thus, a sufficiently large numerical aperture cannot be achieved. Likewise, the diameter of the reflecting mirror is too large and, as a result, a sufficiently large numerical aperture cannot be achieved in the catadioptric system disclosed in Japanese Laid-open Patent Publication No. 2001-228401.

DISCLOSURE OF THE INVENTION

[0014] An object of the present invention, which has been achieved by addressing the problems discussed above, is to provide a catadioptric system that facilitates adjustment and high precision production of the optical system and is capable of achieving a high resolution of 0.1μm or less by using light in a vacuum ultraviolet wavelength range of, for instance, 180nm or smaller.

[0015] Another object of the present invention is to provide a catadioptric system that assures positions at which an effective field stop and an effective aperture stop should be installed and is capable of achieving a high resolution of 0.1μm or less by using light in a vacuum ultraviolet wavelength range of, for instance, 180nm or smaller.

[0016] Yet another object of the present invention is to provide a catadioptric system that assures a sufficiently long working distance and is capable of achieving a high resolution of 0.1μm or less by using light in a vacuum ultraviolet wavelength range of, for instance, 180nm or smaller.

[0017] A further object of the present invention is to provide a catadioptric system that achieves miniaturization of the optical system by keeping down the size of concave reflecting mirrors and is also capable of achieving a high resolution of 0.1μm or less by using light in a vacuum ultraviolet wavelength range of, for instance, 180nm or smaller.

[0018] A still further object of the present invention is to provide a catadioptric system that assures a sufficiently long working distance on the first plane side, achieves a satisfactorily large numerical aperture by keeping down the diameter of reflecting mirrors and is capable of achieving a high resolution of 0.1μm or less by using light in a vacuum ultraviolet wavelength range of, for instance, 180nm or smaller.

[0019] A still further object of the present invention is to provide an exposure apparatus that utilizes the catadioptric system according to the present invention as a projection optical system and is capable of achieving good projection exposure with a high resolution of 0.1μm or less by using exposure light with a wavelength of, for instance, 180nm or smaller.

[0020] A still further project of the present invention is to provide a micro device manufacturing method through which a high precision micro device can be manufactured by executing good projection exposure with a high resolution of, for instance, 0.1μm or less with the exposure apparatus according to the present invention.

[0021] In order to attain the above objects, a catadioptric system according to the present invention comprises: a first image forming optical system that includes at least two reflecting mirrors and forms a first intermediate image of a first plane with light originating from the first plane; a second image forming optical system that includes at least two reflecting mirrors and forms a second intermediate image of the first plane with light having traveled via the first image forming optical system; and a refractive type of third image forming optical system that forms a final image of the first plane onto a second plane with light having traveled via the second image forming optical system, and optical members constituting the first image forming optical system, the second image forming optical system and the third image forming optical system are all disposed along a single linear optical axis.

[0022] In this catadioptric system, it is preferred that a field lens is provided in an optical path between the first image forming optical system and the second image forming optical system.

[0023] Also, it is preferred that the first image forming optical system includes the two reflecting mirrors and at least one lens element.

[0024] In these cases, it is preferred that a combined optical system comprising the first image forming optical system and the field lens achieves telecentricity toward the first plane and toward the second plane.

[0025] In each of the above catadioptric systems, it is preferred that the first image forming optical system includes at least one negative lens element provided in an optical path between the two reflecting mirrors.

[0026] Also, it is preferred that the second image forming optical system includes at least one negative lens element provided in an optical path between the two reflecting mirrors.

[0027] Another catadioptric system according to the present invention comprises a plurality of optical members that form two intermediate images of a first plane in an optical path between the first plane and a second plane and form a third intermediate image of the first plane onto the second plane as a final image, and the plurality of optical members are disposed along a single linear optical axis.

[0028] In this catadioptric system, it is preferred that the intermediate images are formed at positions off the optical axis.

[0029] Another catadioptric system according to the present invention comprises a plurality of reflecting mirrors disposed along a single linear optical axis, and an image over a rectangular area away from the optical axis on a first plane is formed onto a second plane.

[0030] In this catadioptric system, it is preferred that a field stop that defines an image area formed at the catadioptric system and an aperture stop that defines a numerical aperture of the catadioptric system, are further provided.

[0031] Another catadioptric system according to the present invention comprises: a first image forming optical system that includes at least a first reflecting mirror and a second reflecting mirror and forms a first intermediate image of a first plane with light originating from the first plane; a second image forming optical system that includes at least a third reflecting mirror and a fourth reflecting mirror and forms a second intermediate image of the first plane with light having traveled via the first image forming optical system; and a refractive type of third image forming optical system that forms a final image of the first plane onto a second plane with light having traveled via the second image forming optical system, and: optical members constituting the first image forming optical system, the second image forming optical system and the third image forming optical system are all disposed along a single linear optical axis; and at least one negative lens is provided immediately before each of two reflecting mirrors among the first reflecting mirror, the second reflecting mirror, the third reflecting mirror and the fourth reflecting mirrors on a reflecting surface side.

[0032] In this catadioptric system, it is preferred that: a magnification factor chromatic aberration is corrected by providing at least one negative lens immediately before each of the two reflecting mirrors on the reflecting surface side; and a magnification factor chromatic aberration coefficient LAT satisfies a condition expressed as $|LAT| < 5 \times 10^{-6}$. In this case or in the above catadioptric system, it is preferred that: an on-axis chromatic aberration is corrected by providing at least one negative lens immediately before each of the two reflecting mirrors on the reflecting surface side; and an on-axis chromatic aberration coefficient AX satisfies a condition expressed as $|AX| < 2 \times 10^{-4}$.

[0033] An exposure apparatus according to the present invention comprises: an illumination system that illuminates a mask; and a projection optical system that forms an image of a pattern formed at the mask onto a photosensitive substrate, and: the projection optical systems comprises a catadioptric system according to any one of claims 1 through 13; and the mask corresponds to the first plane in the catadioptric system and the photosensitive substrate corresponds to the second plane in the catadioptric system.

[0034] In this exposure apparatus, it is preferred that a drive system that causes the mask and the photosensitive substrate to move relative to the catadioptric system in order to scan the pattern of the mask to expose onto the photosensitive substrate, is further provided.

[0035] A micro device manufacturing method according to the present invention comprises: an exposure step in which the pattern of the mask is exposed onto the photosensitive substrate with the above exposure apparatus; and a development step in which the photosensitive substrate having undergone the exposure step is developed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036]

FIG. 1 illustrates the basic structure of a catadioptric system according to the present invention;

FIG. 2 schematically illustrates the overall structure of an exposure apparatus having the catadioptric system achieved in any of the embodiments of the present invention provided as a projection optical system;

FIG. 3 shows positional relationship between the rectangular exposure area (i.e., the effective exposure area) formed on the wafer and the reference optical axis;
FIG. 4 shows the lens configuration of the catadioptric system achieved in a first embodiment;
FIG. 5 shows the lateral aberration manifesting at the catadioptric system in the first embodiment;
FIG. 6 shows the lens configuration of the catadioptric system achieved in a second embodiment;
FIG. 7 shows the lateral aberration manifesting at the catadioptric system in the second embodiment;
FIG. 8 shows the lens configuration of the catadioptric system achieved in a third embodiment;
FIG. 9 shows the lateral aberration manifesting at the catadioptric system in the third embodiment;
FIG. 10 shows the lens configuration of the catadioptric system achieved in a fourth embodiment;
FIG. 11 shows the lateral aberration manifesting at the catadioptric system in the fourth embodiment;
FIG. 12 shows the lens configuration of the catadioptric system achieved in a fifth embodiment;
FIG. 13 shows the lateral aberration manifesting at the catadioptric system in the fifth embodiment;
FIG. 14 shows the lens configuration of the catadioptric system achieved in a sixth embodiment;
FIG. 15 shows that positional relationship between the arch-shaped effective exposure area formed on the wafer and the reference optical axis in the sixth embodiment;
FIG. 16 shows the lateral aberration manifesting at the catadioptric system in the sixth embodiment;
FIG. 17 shows the lens configuration of the catadioptric system achieved in a seventh embodiment;
FIG. 18 shows the lateral aberration manifesting at the catadioptric system in the seventh embodiment;
FIG. 19 shows the lateral aberration manifesting at the catadioptric system in the seventh embodiment;
FIG. 20 shows the lens configuration of the catadioptric system achieved in an eighth embodiment;
FIG. 21 shows the lateral aberration manifesting at the catadioptric system in the eighth embodiment;
FIG. 22 shows the lateral aberration manifesting at the catadioptric system in the eighth embodiment;
FIG. 23 shows the lens configuration of the catadioptric system achieved in a ninth embodiment;
FIG. 24 shows the lateral aberration manifesting at the catadioptric system in the ninth embodiment;
FIG. 25 shows the lateral aberration manifesting at the catadioptric system in the ninth embodiment;
FIG. 26 presents a flowchart of a method adopted to obtain a micro device constituted of a semiconductor device; and
FIG. 27 presents a flowchart of a method adopted to obtain a micro device constituted of a liquid crystal display element.

BEST MODE FOR CARRYING OUT THE INVENTION

[0037] FIG. 1 illustrates the basic structure adopted in a catadioptric system according to the present invention. It is to be noted that in FIG. 1, the catadioptric system according to the present invention is utilized as a projection optical system in an exposure apparatus that performs scanning exposure. As shown in FIG. 1, the catadioptric system according to the present invention includes a first image forming optical system G1 for forming a first intermediate image of the pattern at a reticle R constituting a projection original which is set at a first plane. It is to be noted that the first image forming optical system G1 includes at least two reflecting mirrors i.e., a first reflecting mirror and a second reflecting mirror.

[0038] Light having traveled through the first image forming optical system G1 then forms a second intermediate image of the pattern at the reticle R via a second image forming optical system G2 having at least two reflecting mirrors, i.e., a third reflecting mirror and a fourth reflecting mirror. The light having traveled through the second image forming optical system G2 forms a final image of the pattern at the reticle R onto a wafer W constituting a photosensitive substrate which is set at a second plane via a refractive third image forming optical system G3 having refractive optical members alone with no reflecting mirror. All the optical members constituting the first image forming optical system G1, the second image forming optical system G2 and the third image forming optical system G3 are disposed along a single linear optical axis AX.

[0039] In a more specific mode of the embodiment, a field lens FL is provided in the optical path between the first image forming optical system G1 and the second image forming optical system G2. The field lens FL has a function of matching and connecting the first image forming optical system G1 and the second image forming optical system G2 without actively contributing to the formation of the first intermediate image. In addition, the first image forming optical system G1 includes at least one lens element as well as the two reflecting mirrors. Thus, the combined optical system constituted of the first image forming optical system G1 and the field lens FL achieves telecentricity toward the reticle (toward the first plane) and toward the wafer (toward the second plane). It is to be noted that a field lens may also be provided as necessary in the optical path between the second image forming optical system G2 and the third image forming optical system G3.

[0040] In the specific mode of the embodiment, it is desirable to provide at least one negative lens element (L13 or L21) in the optical path between the two reflecting mirrors at, at least either the first image forming optical system G1

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