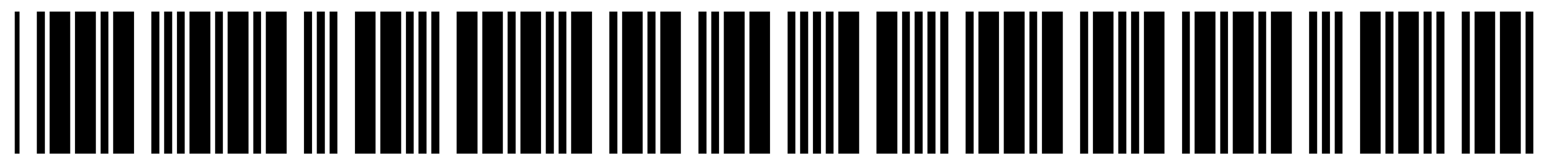


US00RE36799E

United States Patent [19]

Nishi

[11] E **Patent Number: Re. 36,799**

[45] **Reissued Date of Patent: Aug. 1, 2000**

[54] **PROJECTION OPTICAL APPARATUS USING PLURAL WAVELENGTHS OF LIGHT**

[75] Inventor: **Kenji Nishi**, Kawasaki, Japan

[73] Assignee: **Nikon Corporation**, Tokyo, Japan

[21] Appl. No.: **08/967,345**

[22] Filed: **Oct. 27, 1997**

Related U.S. Patent Documents

Reissue of:

[64] Patent No.: **5,138,176**
Issued: **Aug. 11, 1992**
Appl. No.: **07/711,625**
Filed: **Jun. 6, 1991**

U.S. Applications:

[63] Continuation of application No. 08/571,631, Dec. 13, 1995, abandoned, which is a continuation of application No. 08/288,767, Aug. 11, 1994, abandoned.

[30] **Foreign Application Priority Data**

Jun. 13, 1990 [JP] Japan 2-154287

[51] **Int. Cl.**[7] **G01B 11/00**

[52] **U.S. Cl.** **250/548**; 356/401

[58] **Field of Search** .... 250/548, 557, 250/237 R; 356/399, 400, 401; 355/53

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,251,160	2/1981	Bouwhuis et al.	356/401
4,269,505	5/1981	Mayer	355/62
4,437,758	3/1984	Suzuki	356/401
4,473,293	9/1984	Phillips	355/53
4,492,459	1/1985	Omata	355/43
4,725,737	2/1988	Nakota et al.	356/401
4,780,913	11/1988	Williams .	
4,795,244	1/1989	Uehara et al.	356/401
4,798,962	1/1989	Matsumoto et al.	356/401
4,856,905	8/1989	Nishi	356/401
4,880,310	11/1989	Nishi	356/401
5,004,348	4/1991	Magome	356/401
5,243,195	9/1993	Nishi	250/548

FOREIGN PATENT DOCUMENTS

63-283129	11/1988	Japan .
4-321214	11/1992	Japan .

Primary Examiner—Stephone Allen
Attorney, Agent, or Firm—Vorys, Sater, Semyour and Pease LLP

[57] **ABSTRACT**

A projection optical apparatus comprising a projection optical system for projectively focusing a pattern image of a mask under illumination by light of first wavelength onto a sensitive substrate, a stage holding the sensitive substrate, a fiducial plate disposed on the stage, a first mark detector for illuminating light of second wavelength different from the first wavelength, through a first mark area formed on the mask and the projection optical system, onto [the sensitive substrate or] a second mark area formed on the fiducial plate, then detecting optical information produced from the second mark area, a fourth mark area formed on [the sensitive substrate or] the fiducial plate and arranged in a predetermined positional relationship relative to the second mark area, a third mark area formed on the mask and arranged in a predetermined positional relationship relative to the first mark area, a second mark detector for illuminating the light of first wavelength onto the fourth mark area through the third mark area and the projection optical system, and then detecting optical information produced from the fourth mark area, under a condition that the first mark detector is detecting the optical information produced from the second mark area, and an error detector for detecting detection errors due to a distortion at respective positions in the view field of the projection optical system where the first mark area and the second mark area are present, based on the detected results by the first mark detector and the second mark detector.

22 Claims, 7 Drawing Sheets

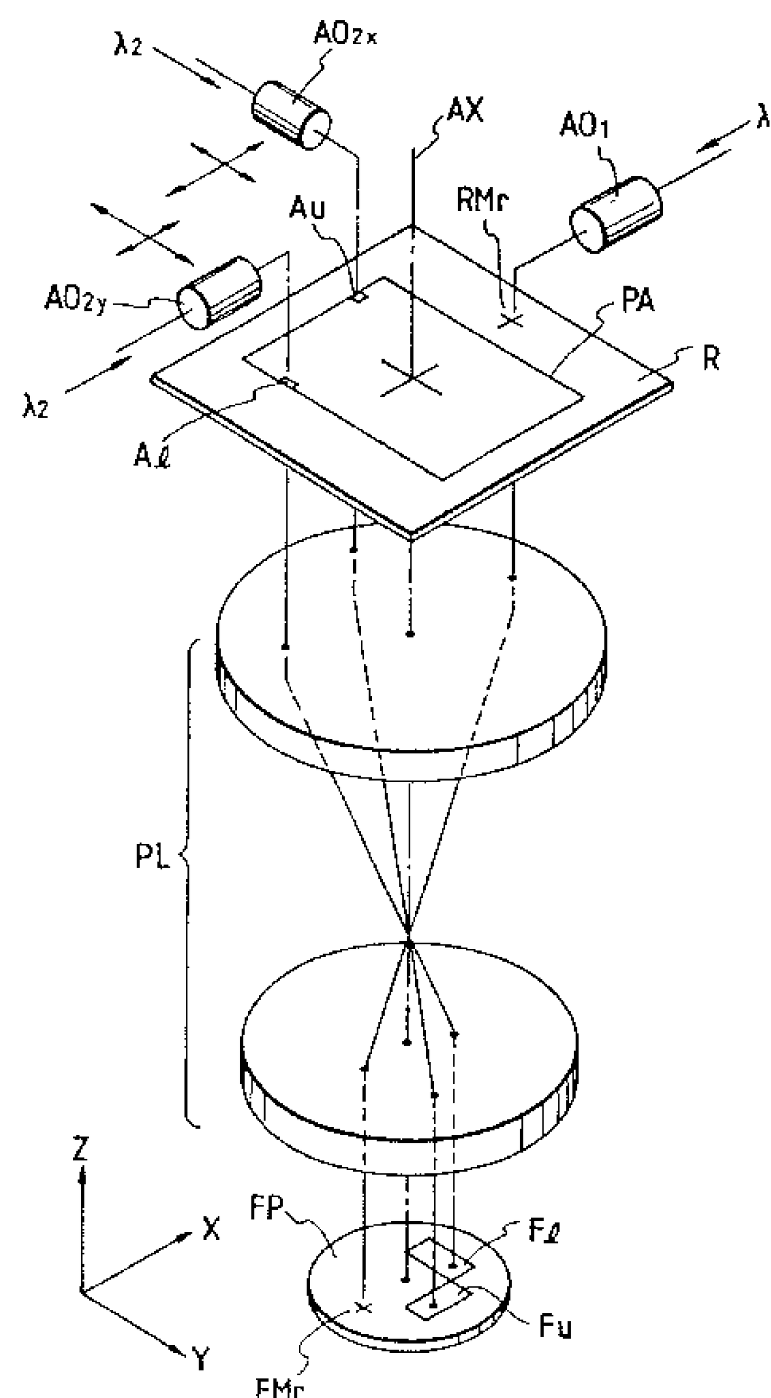


FIG. 1

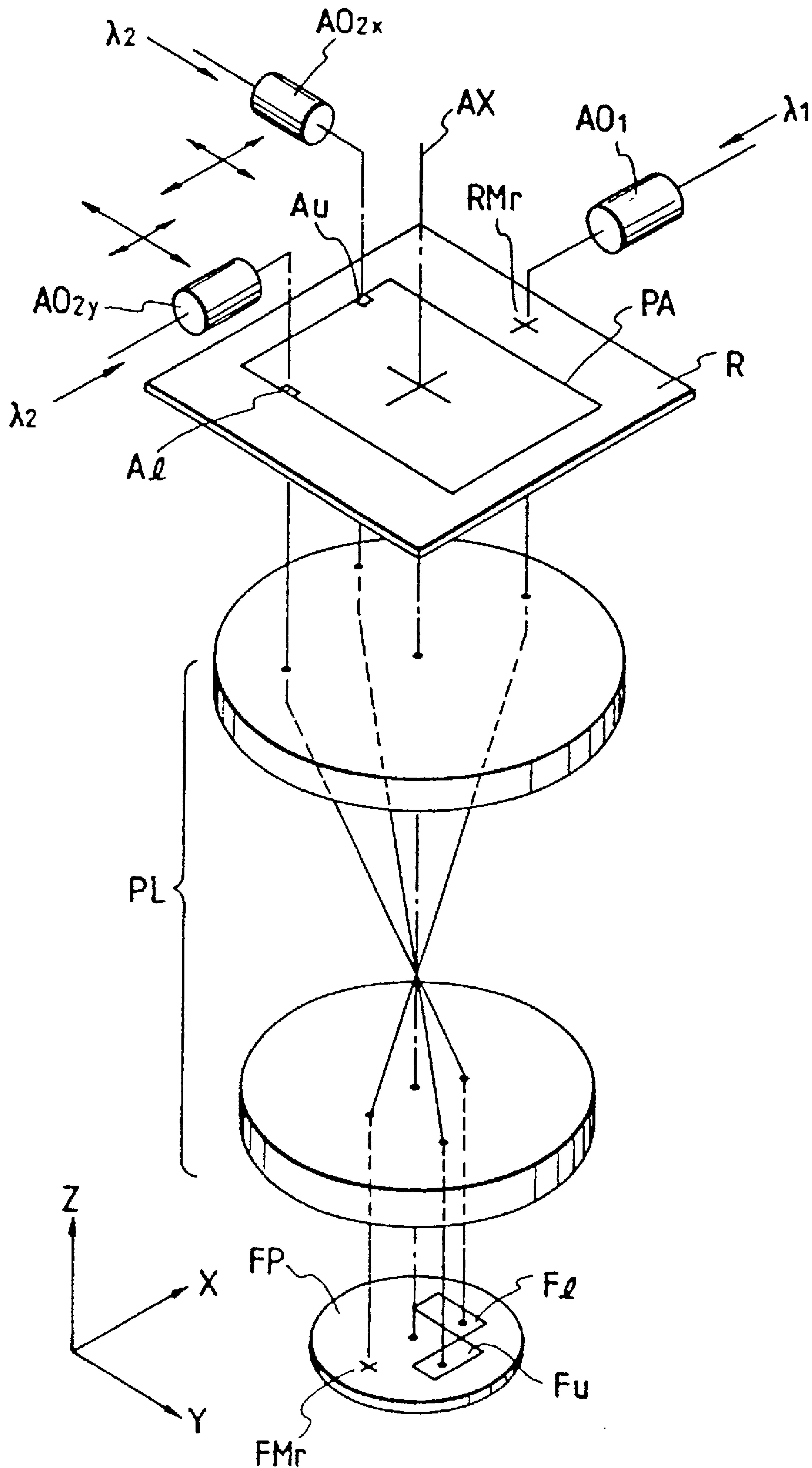


FIG. 2

FIG. 3

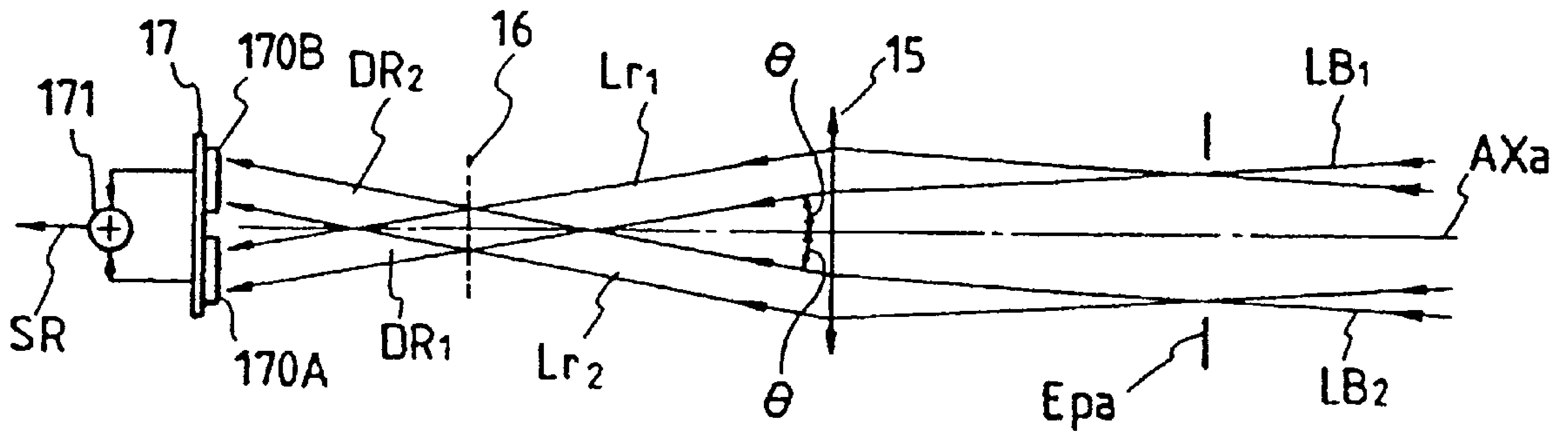


FIG. 5

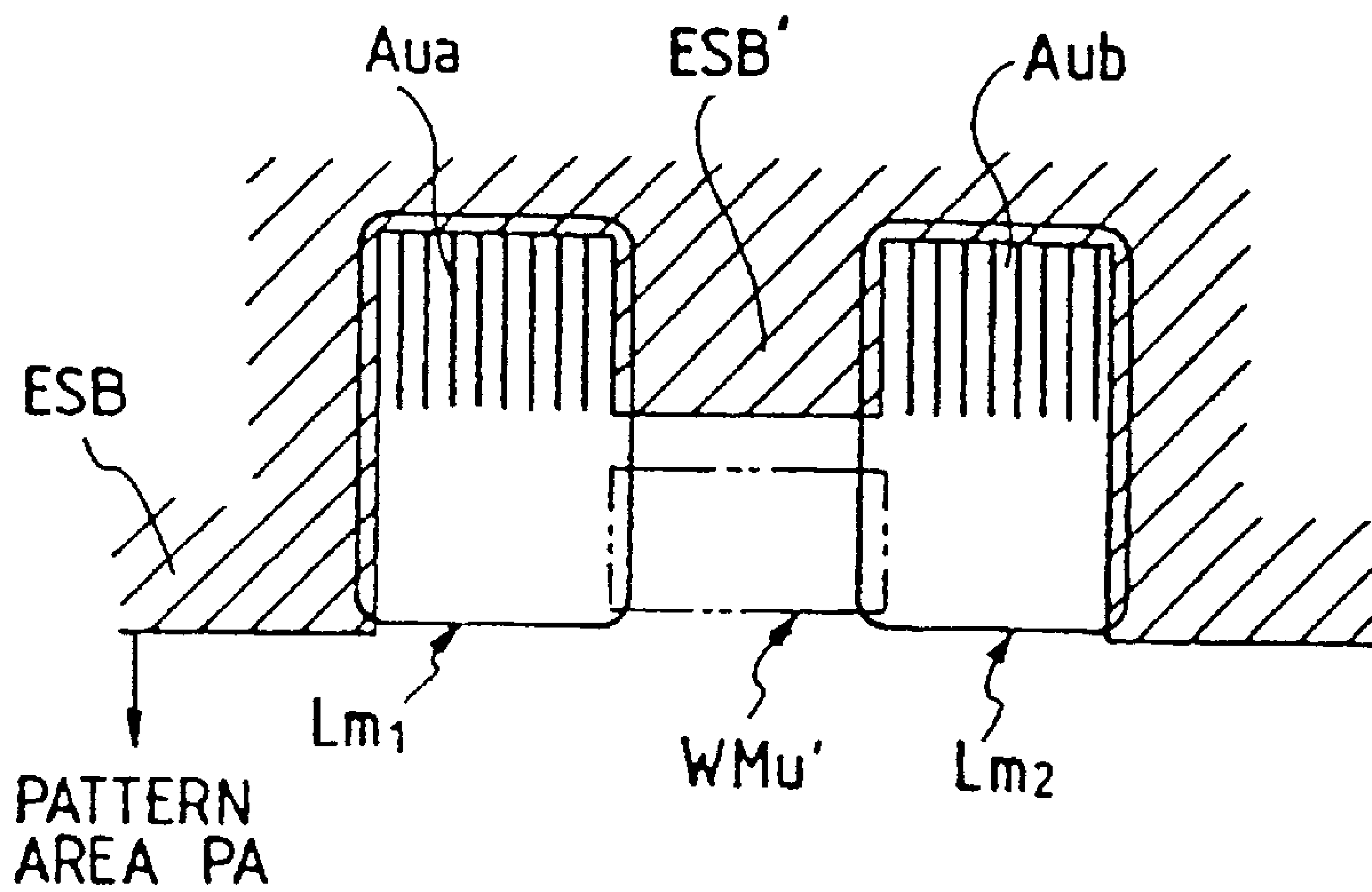


FIG. 6

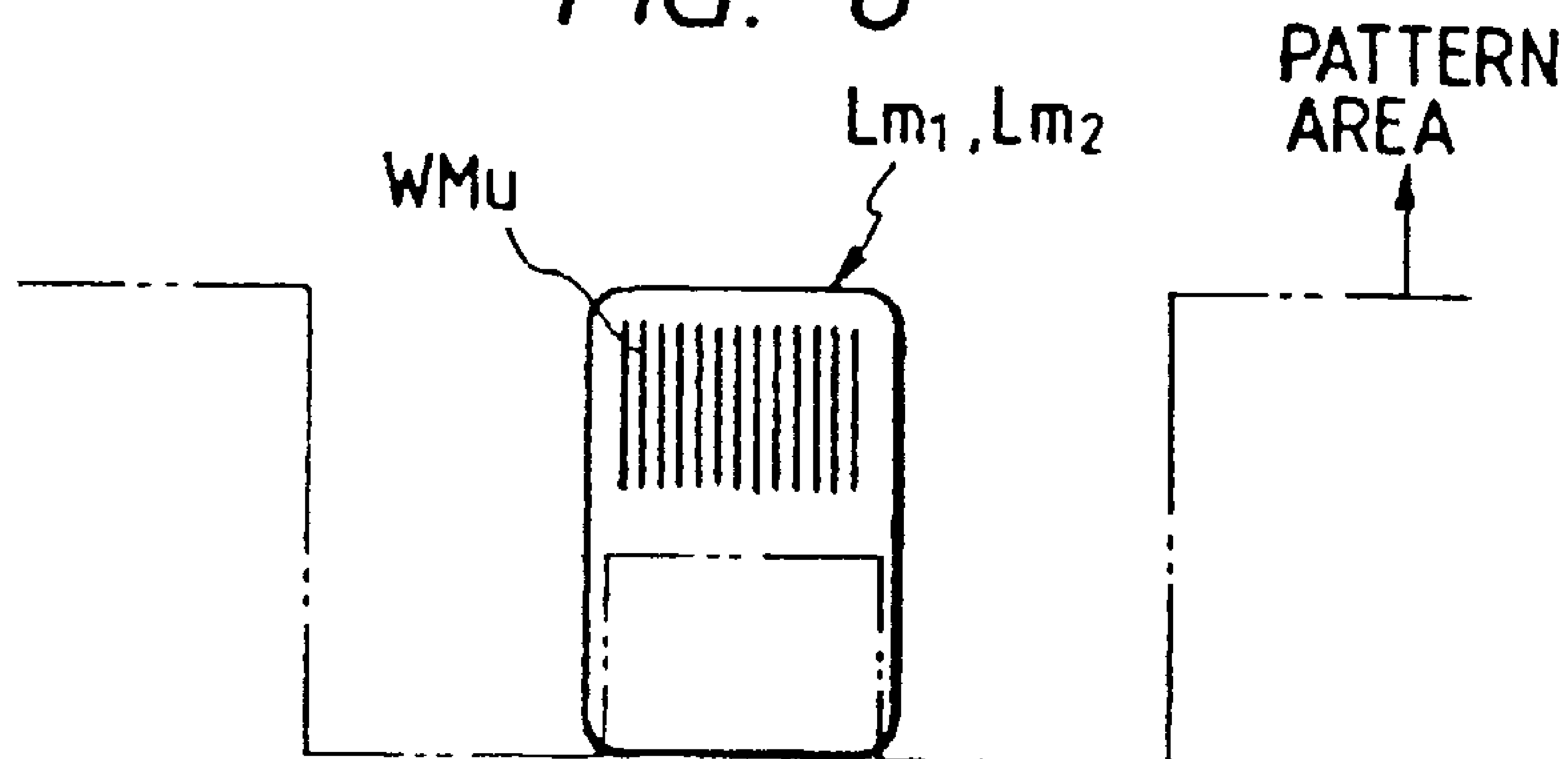


FIG. 4

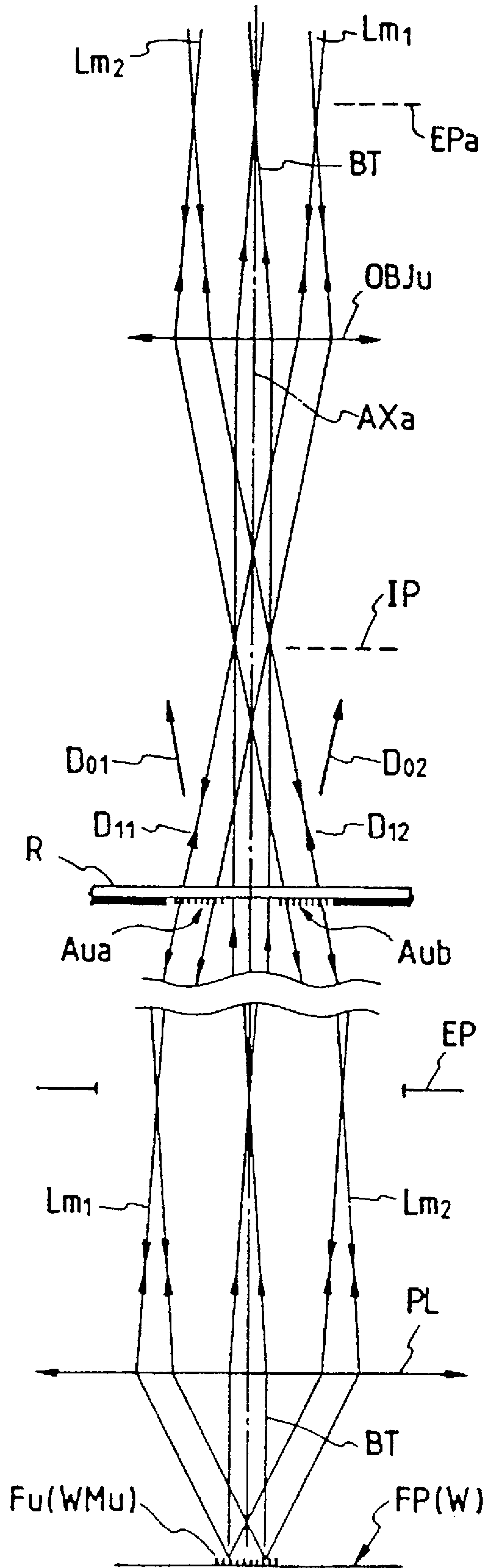


FIG. 7A

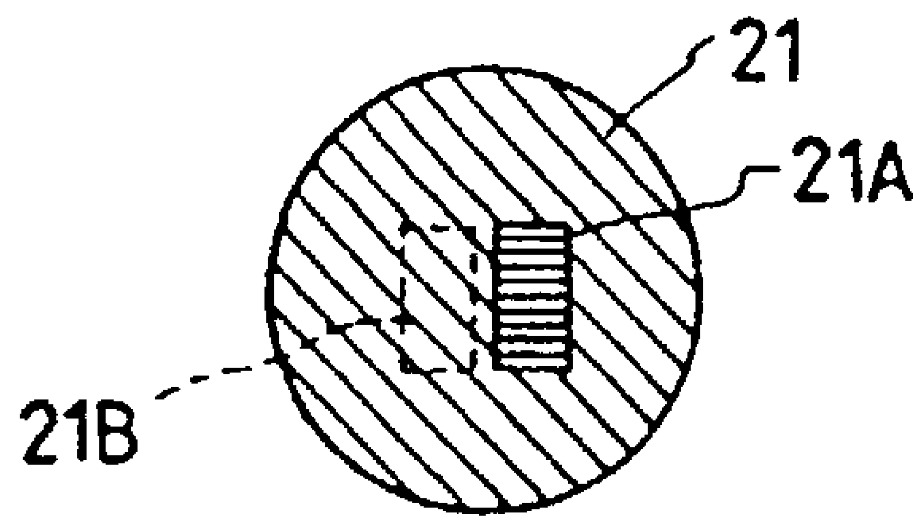


FIG. 7B

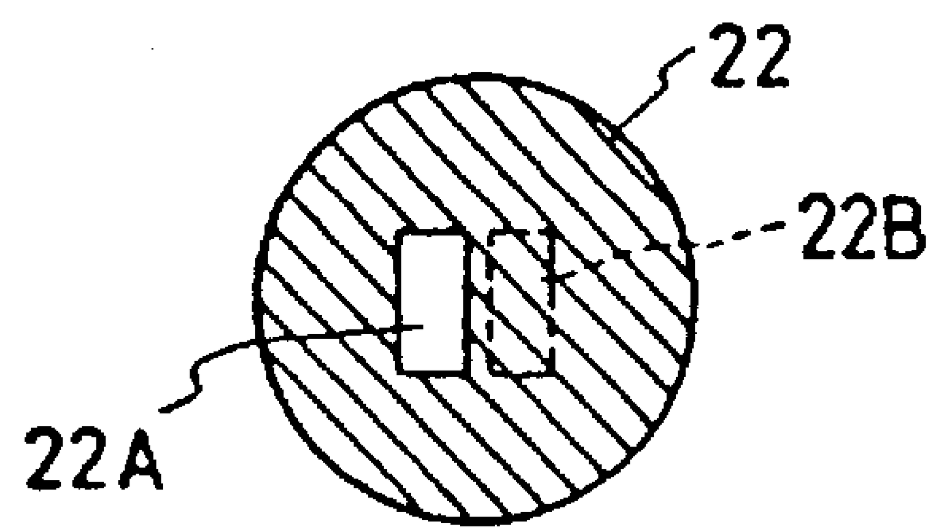


FIG. 8

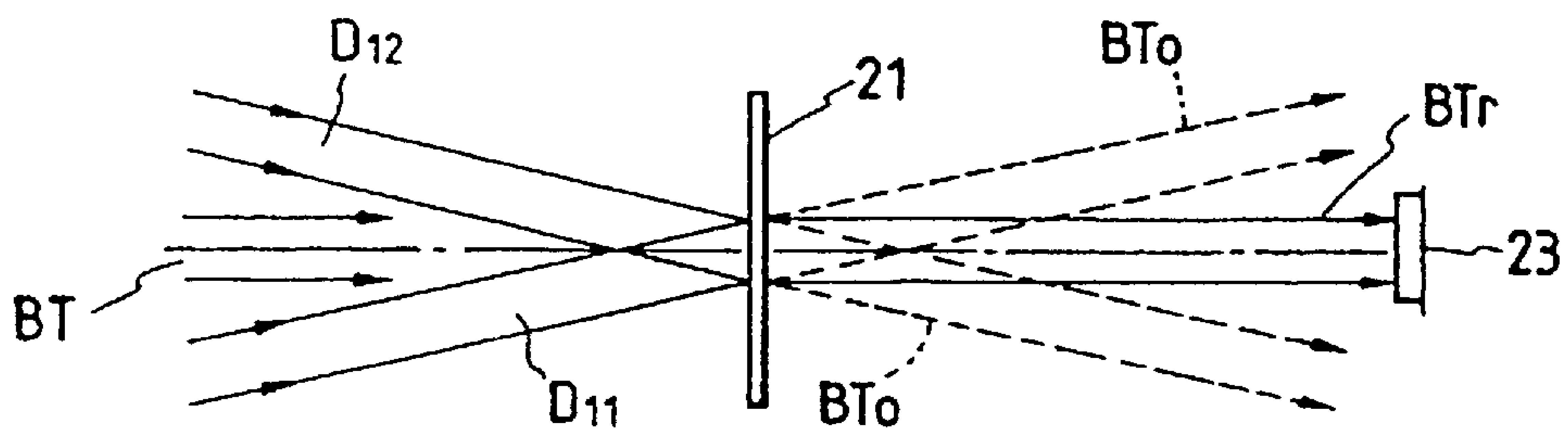


FIG. 9

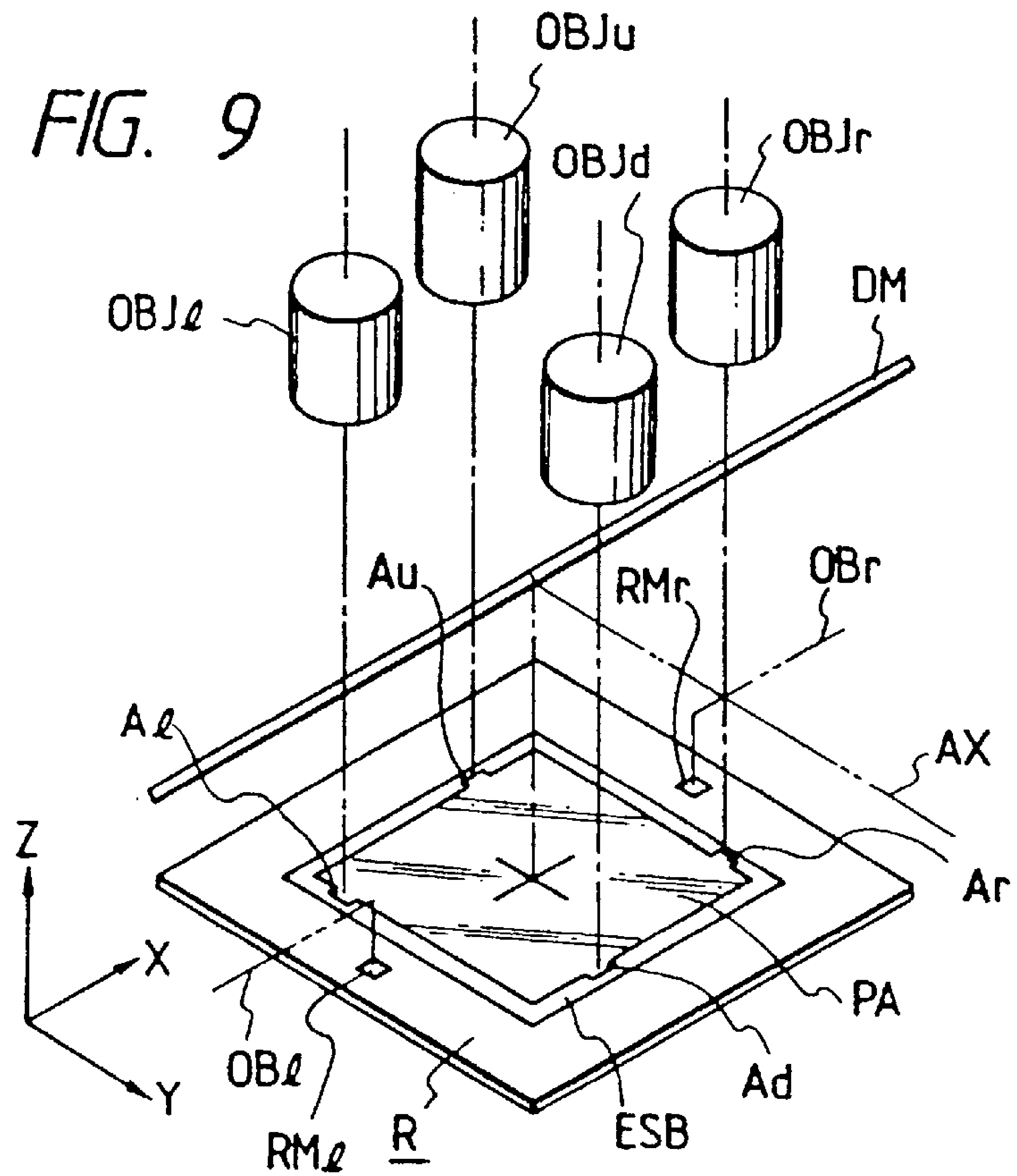


FIG. 10

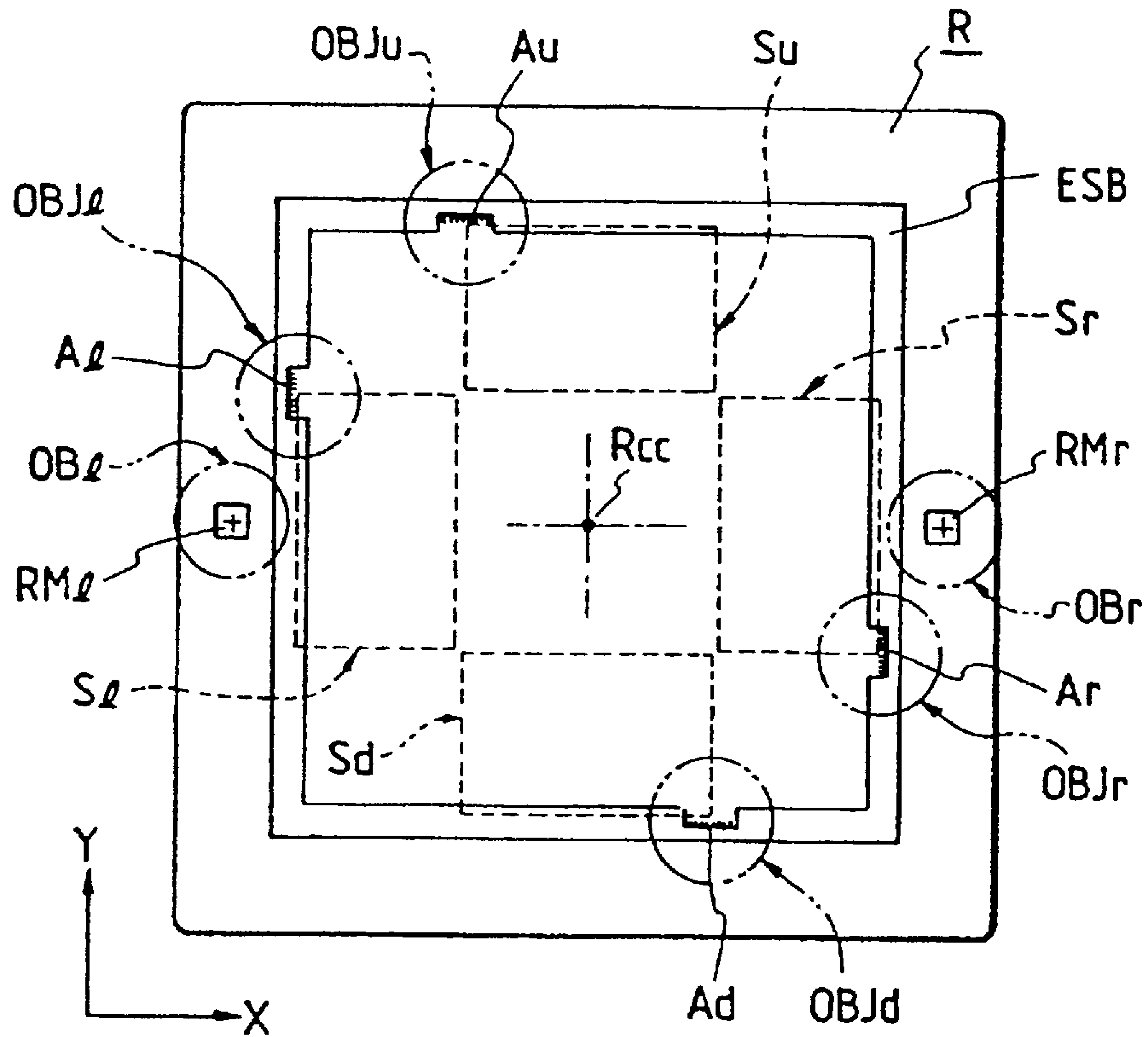
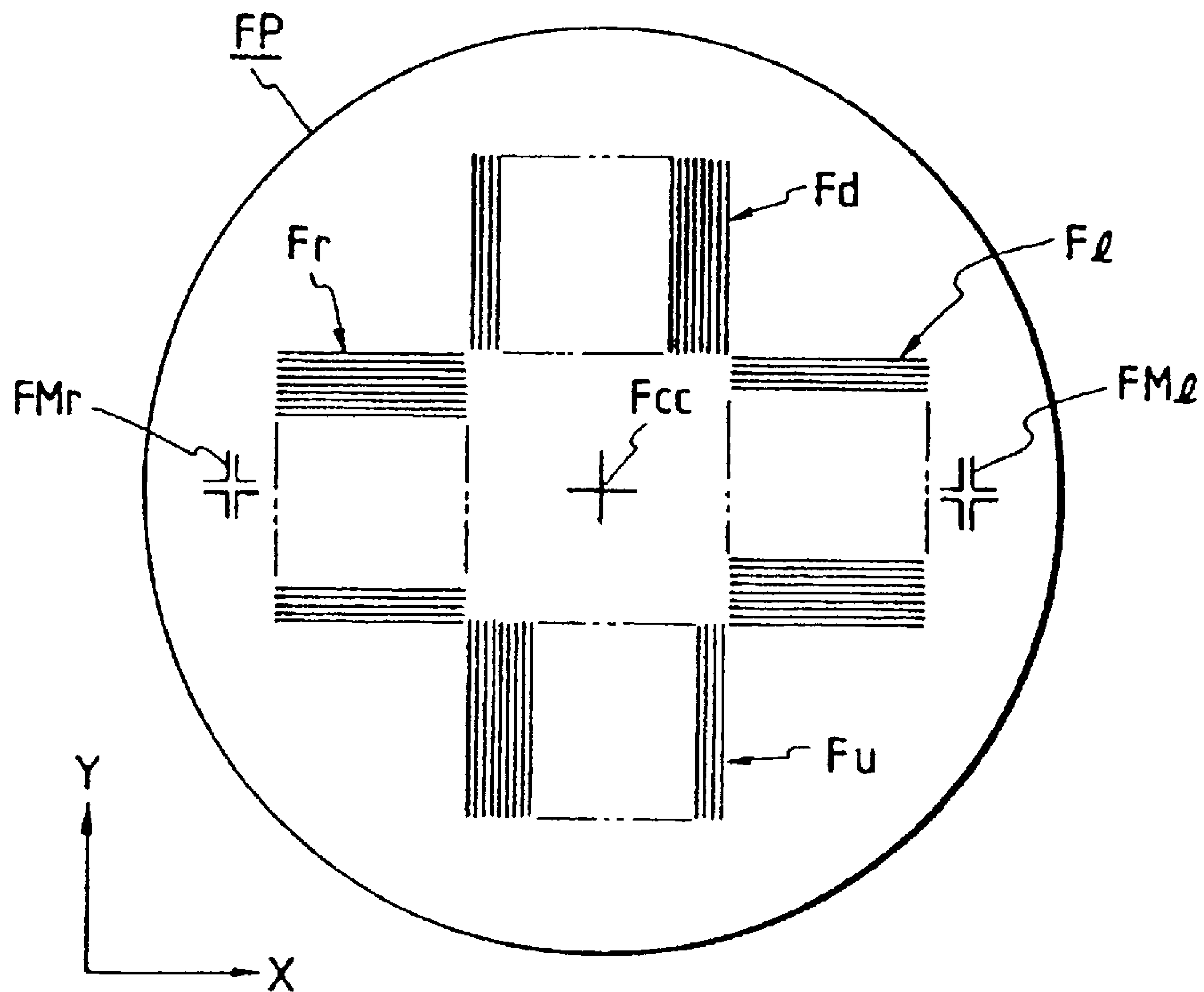


FIG. 11



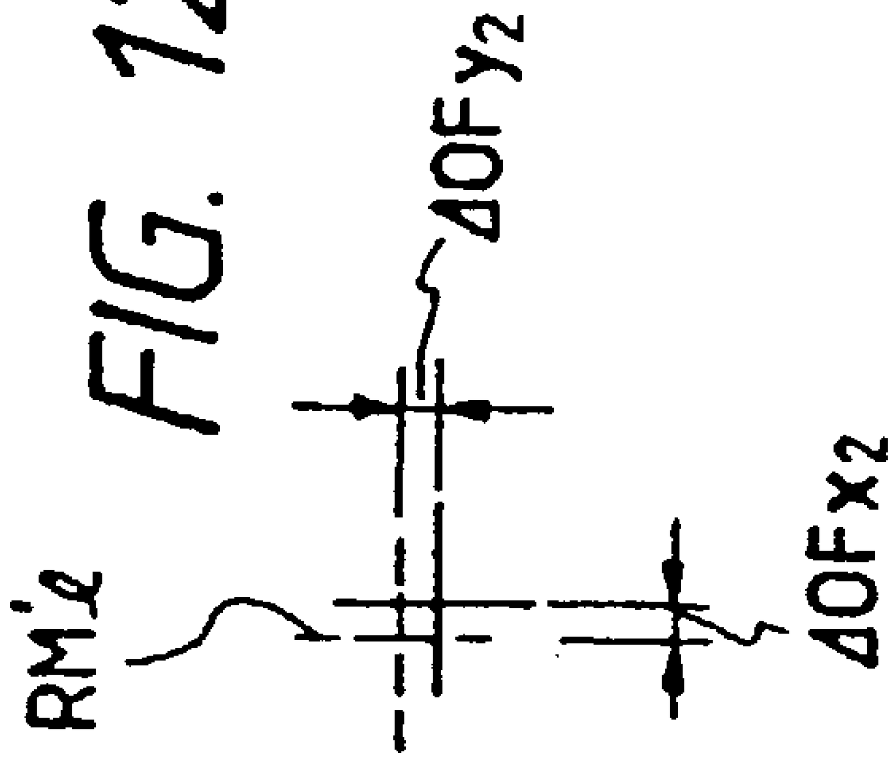


FIG. 12C

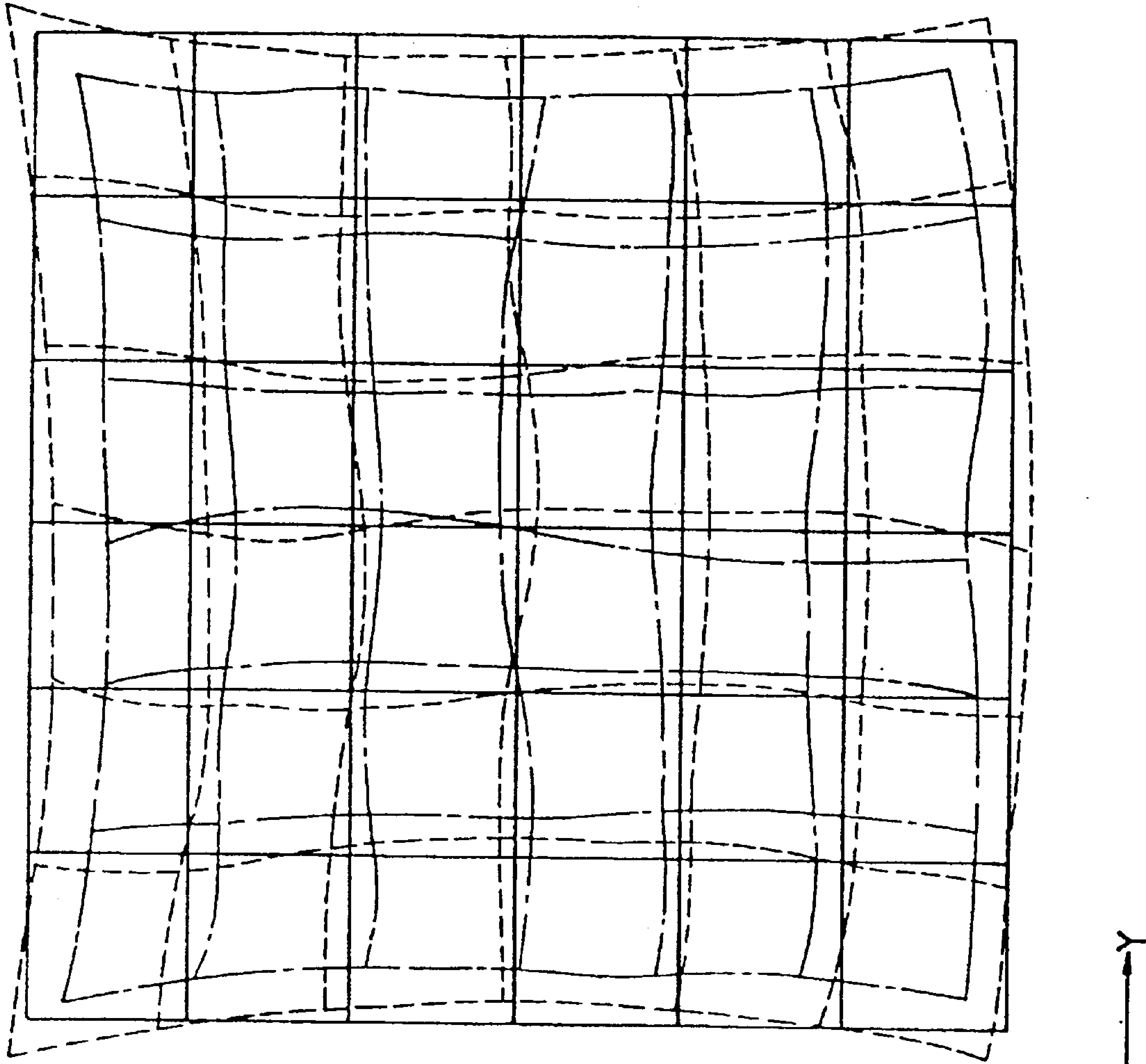


FIG. 12A

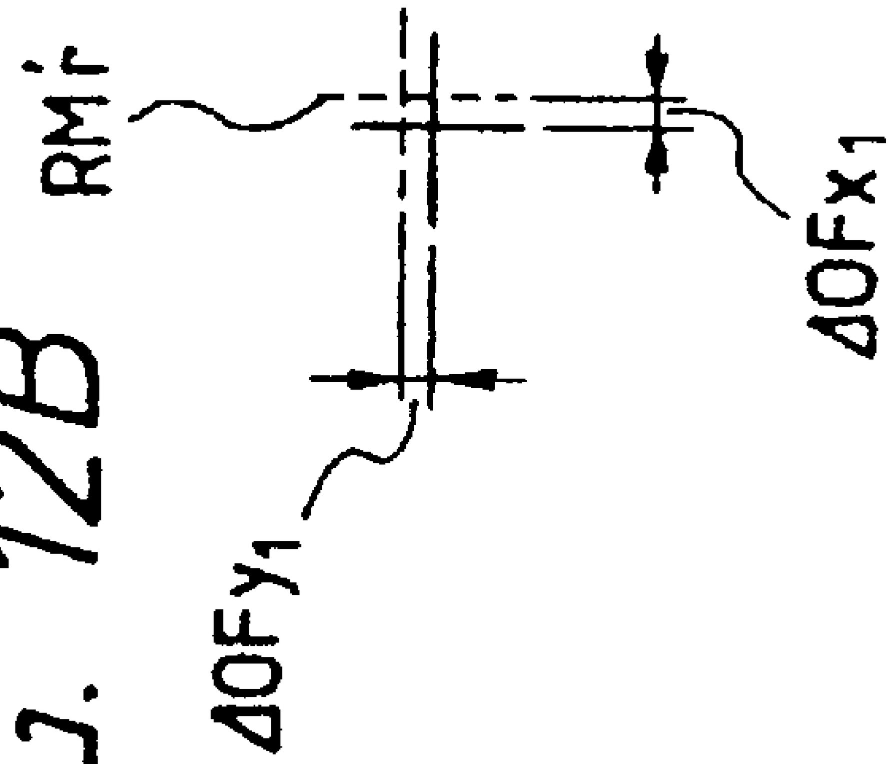


FIG. 12B

PROJECTION OPTICAL APPARATUS USING PLURAL WAVELENGTHS OF LIGHT

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This is a continuation of reissue application Ser. No. 08/571,631 filed Dec. 13, 1995, which is a continuation of reissue application Ser. No. 08/288,767 filed Aug. 11, 1994, both now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a projection exposure apparatus used in the lithography process for semiconductor devices, liquid display devices or the like, and more particularly to an alignment apparatus which can reduce an extent of alignment errors attributable to distortion caused by a projection system of the projection exposure apparatus.

2. Related Background Art

Recently, steppers mounting projection lenses of large numerical aperture thereon have been widely used as apparatus for printing a pattern of masks (reticles) on semiconductor wafers with resolution on the order of submicrons.

In such a stepper, a chip pattern (shot area) already formed on the wafer and a reticle pattern newly exposed in superposed relation must be aligned with each other at overall precision less than a fraction of the minimum line width. Of late, therefore, steppers mounting alignment apparatus (sensors) with an ability of higher precision thereon have been researched and developed for practical use.

In the future, it is believed that those steppers which will be primarily used in producing 4 Mbit D-RAMs and 16 Mbit D-RAMs will of necessity have a die-by-die exposure mode using the TTR (Through-The-Reticle) method in which a mark on the reticle and a mark in each shot area on the wafer are successively detected and aligned with each other, followed by printing.

While various techniques have so far been proposed to implement the TTR alignment method, most promising one is a different wavelength TTR alignment method in which the reticle mark and the wafer mark are simultaneously detected by using an illumination light different in wavelength from an exposure light. This type alignment method is advantageous in that because there will not occur a phenomenon for a resist layer on the wafer to strongly absorb the exposure light, the mark can be stably detected even for such wafers as having a resist impregnated with dyes or a multi-layered resist, and the resist in a mark area can be prevented from being exposed or sensitized upon illumination for alignment. Typical techniques (projection exposure apparatus) well known as to implement the different wavelength TTR alignment method are disclosed in U.S. Pat. Nos. 4,251,160, 4,269,505, 4,492,459 or 4,473,293.

In any of those typical projection exposure apparatus, however, an optical system for correcting chromatic aberration of the illumination light having the different wavelength for alignment is disposed between a reticle and a projection lens. Such a correction optical system serves to maintain the reticle mark and the wafer mark in focused relation to each other under the illumination light having the different wavelength, but has suffered from an intrinsic problem that stability is insufficient and precise reproducibility cannot be obtained in the alignment.

In the last several years, a method permitting the different wavelength TTR alignment without using such [an] *a* correction optical system with less stability and reproducibility has been proposed in U.S. Pat. No. 4,880,310 or Japanese Patent Laid Open No. 63-283129 (corresponding to U.S. application Ser. No. 192,784 filed on May 10, 1988). In an alignment system disclosed in the above reference, beams for illuminating the reticle mark and the wafer mark are simultaneously focused by a two-focusing element and an object lens on two planes, respectively. One plane is coincident with a pattern plane (mark plane) of the reticle, whereas the other [plate] *plane* is coincident with a wafer conjugate plane in a space away from the reticle pattern plane by a distance corresponding to the amount of axial (on-axis) chromatic aberration of the projection lens.

Adopting the above disclosed method eliminates the need of providing an optical element, other than the projection lens, in an optical path for alignment between the reticle and the wafer, and permits the TTR alignment as if the exposure light is used.

However, the latest projection lens is corrected in its various aberrations satisfactorily for only the exposure light, but exhibits both axial chromatic aberration and magnification chromatic aberration. Even if use of the two-focusing element succeeds in correcting the axial chromatic aberration, the magnification chromatic aberration cannot be always corrected satisfactorily, thereby requiring it to remove an alignment error (offset) attributable to the magnification chromatic aberration by some method. For this reason, a technique of coping with the magnification chromatic aberration (distortion) has been proposed in U.S. Pat. Nos. 4,780,913 and 4,856,905, by way of example. Of them, U.S. Pat. No. 4,780,913 discloses such a technique that a reference mark capable of exiting light rays at two wavelengths, i.e., the exposure light at one wavelength and the illumination light for alignment at a different wavelength, is provided on a wafer stage and moved on the image plane side of a projection lens to scan a retroprojected image of the reference mark on the reticle side for determining a position of the reticle mark, thereby preparing a distortion map in the view field of the projection lens beforehand. On the other hand, U.S. Pat. No. 4,856,905 discloses such a technique that the exposure light is introduced in the form of a beam to an illumination beam transmitting system (comprising a scanner mirror, two-focusing element, object lens, etc.) of a different wavelength TTR alignment system, allowing an illumination beam at the different wavelength and an illumination beam at the wavelength of the exposure light to be scanned simultaneously, whereby data of light information are photoelectrically detected from respective reference marks on the reticle mark and the wafer stage to determine a distortion at the alignment point based on differences in the amount of position deviation detected for each wavelength of the beam.

The aforementioned prior arts for coping with the magnification chromatic aberration are arranged so that both the illumination light for alignment and the illumination light for exposure pass through the same position in the view field of the projection lens. Specifically, in U.S. Pat. No. 4,780,913, two types of illumination light are required to be introduced to the rear side of the same reference mark through optical fibers or the like. In U.S. Pat. No. 4,856,905, the illumination light for exposure is required to be introduced to the different wavelength TTR alignment system.

That structure has suffered from problems as follows. An arrangement of the alignment optical system is complicated, which leads to a difficulty in manufacture that a severer level

is required in the performance of constituent optical elements (particularly, achromatism). In addition, it is difficult to make a match between various conditions of the optical system (such as a sigma value, number of aperture and tele-centricity) under the illumination light for exposure and various conditions of the optical system under the illumination light for alignment, thus rendering it hard to know a precise distortion error enough for practical use. Moreover, an actual exposure apparatus (stepper) of even ⅕ reduction type is designed so as to accommodate an exposure of a wide field (view field) on the order of 15×15 mm to 20×20 mm. But, exposure areas of reticle patterns employed by stepper users are versatile in size, and the position of the alignment mark in the projection field is naturally changed variously depending on the size. Because the distortion amount of the projection lens with respect to an ideal lattice under the illumination light for exposure is also changed depending on change in the alignment position, there has been another problem that the difference between distortion characteristics under the illumination light for alignment and the illumination light for exposure, which has been determined at only the alignment position is not enough for satisfactory correction, taking into account the fact that the reticle pattern must be superposed with the shot area over the entire wide field.

Further, the apparatus disclosed in the above cited U.S. Pat. No. 4,856,905 has a specific problem as follows. Where the illumination light for exposure and the illumination light for alignment are separated from each other depending on their ranges of wavelength by a dichroic mirror obliquely disposed above the reticle at an angle of 45°, if transmissivity (or reflectivity) of the dichroic mirror for the illumination light for alignment is set very high, the illumination light for exposure to be detected by the different wavelength TTR alignment system could not pass through (or be reflected by) the TTR alignment system in its large part, making is difficult to detect the mark. On the other hand, if wavelength characteristics of the dichroic mirror are selected to give some degree of transmissivity (or reflectivity) to the illumination light for exposure as well, the amount or intensity of light directing toward the reticle from an exposure light illuminating system during the exposure would now be reduced correspondingly.

SUMMARY OF THE INVENTION

The present invention has been achieved in view of the various problems as stated above, and has for its object to provide a projection optical apparatus equipped with a different wavelength TTR alignment system which can detect and correct an alignment offset attributable to, particularly, a distortion with high precision.

To achieve the above **[**problem**]** *object*, with the present invention, a fiducial mark (fourth mark area) to be detected under an illumination light for exposure (light of first wavelength characteristic) and a fiducial mark (second mark area) to be detected under an illumination light for alignment (a light of second wavelength characteristic) are arranged on a fiducial plate to be positionally separate from each other, the fiducial plate being fixed on a stage on which a sensitive plate such as a wafer is rested. Furthermore, a reticle mark (third mark area) to be detected under the illumination light for exposure and a reticle mark (first mark area) to be detected under the illumination light for alignment are disposed on a reticle (mask) respectively corresponding to the separate positions of the associated fiducial marks on the fiducial plate. A different wavelength TTR alignment system (first mark detection means) for detecting the reticle mark (first mark area) and the fiducial mark (second mark area) under the illumination light for alignment, and an exposure wavelength TTR alignment system (second mark detection means) for detecting the reticle mark (third mark area) and the fiducial mark (fourth mark area) under the illumination light for exposure are arranged as independent optical systems of each other and to be capable of detecting the corresponding marks simultaneously by both the TTR alignment systems.

FIG. **1** shows a schematic configuration of a stepper for explaining the principles of the present invention. A circuit pattern area PA on a reticle R is projected to one shot area on a wafer (not shown in FIG. **1**) by a projection lens PL which is tele-centric on both sides. Around the pattern area PA on the reticle R, there are provided marks Au, Al to be respectively detected by TTR alignment systems AO_{2x}, AO_{2y} each using an illumination light of different wavelength **[**(λ_{2x})**]** (λ_2). The mark Au to be detected by the alignment system AO_{2x} is used for alignment in the X direction, whereas the mark Al to be detected by the alignment system AO_{2y} is used for alignment in the Y direction. These marks Au and Al are formed midway one side extending in the X direction of the pattern area PA and another side extending in the Y direction thereof, respectively. The different wavelength TTR alignment systems AO_{2x}, AO_{2y} are each able to move an alignment position in the X and Y directions. Further, at a location outside the pattern area PA on the reticle R, but within the view field of the projection lens PL, there is formed a mark RMr to be detected by a TTR alignment system AO_1 using an illumination light of exposure wavelength λ_1. The position of the mark RMr is always fixedly located regardless of reticles having different sizes of the pattern area PA. Then, the exposure light for uniformly illuminating the pattern area PA during the exposure is set not to be shielded by a distal end portion of the. TTR alignment system AO_1. Accordingly, even in the case where a variety of reticles having different sizes of the pattern area PA are exchanged from one to another, the TTR alignment system AO_1 is not required to be moved and can be held fixed on the apparatus.

Meanwhile, below the projection lens PL, there is located a fiducial (reference mark) plate FP fixedly disposed on wafer stage. The surface of the fiducial plate FP is conjugate to the reticle R with respect to the projection lens PL under the exposure wavelength. A fiducial mark FMr to be detected at the same time as the mark RMr on the reticle R and fiducial marks Fu, Fl to be detected at the same time as the marks Au, Al on the reticle R, respectively, are formed on the surface of the fiducial plate FP by etching of a chromium layer, etc. The mark Fu corresponds to the mark Au and is formed in a wide area enough to cover any positions to which the mark Au is movable on the reticle R. This also equally applies to the mark Fl.

Then, in the configuration of FIG. **1**, when the fiducial plate FP is positioned such that the mark RMr (the third mark area) and the fiducial mark FMr (the fourth mark area) are simultaneously detected by the TTR alignment system AO_1, the mark Au (the first mark area) and the fiducial mark Fu (the second mark area) are simultaneously detected by the TTR alignment system AO_1, for example. Since the positional relationship between the fiducial marks FMr and Fu on the fiducial plate FP, as well as the positional relationship between the marks RMr and Au on the reticle R are precisely known in advance, a difference between the amount or alignment error detected by the different wavelength TTR alignment system AO_{2X} and the amount of alignment error detected by the exposure wavelength TTR

alignment system AO_1 represents an offset amount in the X direction attributable to chromatic aberration at the position of the mark Au.

By storing this offset amount, therefore, the error can be easily corrected when the reticle R and the wafer are later aligned with each other by using the TTR alignment system AO_{2X}.

In this way, with the different wavelength TTR alignment system and the exposure wavelength TTR alignment system being arranged independently of each other, but to carry out the simultaneous mark detecting operation, an influence of distortion can be corrected more strictly and reliably.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a configuration for explaining the principles of a stepper according to an embodiment of the present invention;

FIG. **2** is a view showing a detailed configuration of the stepper according to the embodiment of the present invention:

FIGS. **3** and **4** are views for explaining an optical system of a different wavelength TTR alignment system;

FIG. **5** is a plan view showing an arrangement of reticle grating marks;

FIG. **6** is a plan view showing an arrangement of a wafer grating marks;

FIG. **7**A is a plan view showing a fiducial grating for a reticle;

FIG. **7**B is a plan view showing a field iris for a wafer;

FIG. **8** is a view for explaining an optical system of the different wavelength TTR alignment system;

FIG. **9** is a perspective view showing a practical arrangement of the different wavelength TTR alignment system and an exposure wavelength TTR alignment system;

FIG. **10** is a plan view showing a practical pattern arrangement of the reticle;

FIG. **11** is a plan view showing a pattern arrangement on a fiducial mark plate; and

FIGS. **12**A to **12**C are views showing distortion characteristics at the wavelength of an exposure light and a different wavelength.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, a configuration of a stepper according to one preferred embodiment of the present invention will be described with reference to FIGS. **2** to **11**.

While this embodiment employs a different wavelength TTR alignment system of two-beam interference type using gratings, as disclosed in the above cited U.S. application Ser. No. 192,784, the present invention is also applicable to other types of alignment system (including an image detecting method or spot scanning method) exactly in the same manner.

In FIG. **2**, a dichroic mirror DM is obliquely disposed above a reticle R at an angle of 45° to bend an optical axis AX of a projection lens PL at a right angle or horizontally on the drawing. The dichroic mirror DM reflects an exposure light propagating along the optical axis AX from an illumination system for exposure (not shown) at a percentage greater than about 90% so that the reflected light is directed toward a pattern area PA on a reticle R. The reticle R is held on a reticle stage RS which is finely movable in the two dimensional directions (X, Y, θ directions), the reticle stage RS being positioned by a driver **1**. On the other hand, an XY stage ST for holding a wafer W and a fiducial plate FP thereon is disposed below the projection lens PL and movable in the X and Y directions by a motor **2**, the coordinate position of the stage ST being successively measured by a laser interferometer **3**. Positioning of the stage ST is performed by a stage driver circuit **4** which monitors the measured value of the interferometer **3** and drives the motor **2**. The stage driver circuit **4** controls the movement and positioning of the stage ST based, on a command from a main controller **5**. The main controller **5** also supervises control of the driver **1**.

While a different wavelength TTR alignment system of the this embodiment is constructed above the dichroic mirror DM in two to four eyes (representing the number of object lenses), FIG. **2** shows only one eye, i.e., the system corresponding to AO_{2X} in FIG. **1**.

A tele-centric object lens OBJu and a mirror M_1 are held by a holder **11** which is movable in the X and Y directions by the driver **10** together with the object lens and the mirror.

The object lens OBJu is arranged to be out of interference with the dichroic mirror DM and to have its optical axis vertical to the reticle R.

An illumination light for the different wavelength alignment is emitted in the form of a linearly polarized beam LB from a laser light source **12** such as a helium-neon or argon ion laser, and enters a two-beam forming frequency shifter unit **13**. In the unit **13**, there are disposed means for dividing the beam LB into two beams, two AOMs (acousto-optic modulators) **130**A, **130**B for respectively applying high-frequency modulations (frequency shifts) to the divided two beams, small lenses **131**A, **131**B for focusing the respective frequency shifted beams, and so on. The AOM **130**A is driven at frequency f_1 (for example, 80 MHz) and a 1st order diffracted beam LB_1 therefrom is taken out through the small lens **131**A, whereas the AOM **130**B is driven at frequency f_2 (for example, 80.03 MHz) and a 1st order diffracted beam LB_2 therefrom is taken out through the small lens **131**B. The two beams LB_1, LB_2 have their principal rays set parallel to the optical axis of the alignment system and symmetrical about the optical axis, and are each divided by a beam splitter **14** into two beams. A pair of divided beams L_{r1}, L_{r2} having passed through the beam splitter **14** are converted by condenser lens (inverse Fourier transform lens) **15** into fluxes of parallel light which cross each other in its focus plane on the rear or downstream side. A reference grating **16** is disposed in the rear focus plane so as to produce an interference fringe with the pitch depending on the crossing angle and wavelength of the two beams L_{r1}, L_{r2}. The interference fringe moves over the reference grating **16** in one direction at a speed depending on a frequency difference Δf (30 KHz) between the two beams L_{r1} and L_{r2}. On the reference grating **16**, there is provided a transmission type diffraction grating with the pitch being equal to the pitch of the interference fringe. Accordingly, the reference grating **16** produces an interference light DR_1 between a 0th order light of the beam L_{r1} and a 1st order light created from the beam L_{r2}, as well as an interference light DR_2 between a 0th order light of the beam L_{r2} and a 1st order light created from the beam L_{r1}, the amounts of the interference lights DR_1, DR_2 being detected by a photoelectric element **17**. Here, the intensity of the interference lights DR_1, DR_2 is changed sinusoidally at the frequency difference Δf (30 KHz), i.e., beat frequency, so that an output signal SR from the photoelectric element **17** becomes an AC signal of 30 KHz. This signal SR is used as a reference signal for phase comparison in the alignment process.

FIG. **3** is a view showing optical paths of the beams LB_1, LB_2 and behaviors thereof in detail from the lens **15** to the photoelectric element **17**. First, the two beams LB_1, LB_2 are respectively condensed by the action of the small lenses **131**A, **131**B in a plane EPa to become beam waists. The plane EPa is a Fourier plane in coincidence with a focus plane of the lens **15** on the front or upstream side, so that the beams L_{r1}, L_{r2} propagate from the lens **15** in the form of parallel light fluxes to cross each other on the reference grating **16**. Respective positions of the beams L_{r1}, L_{r2} in the plane EPa are set to be symmetrical about the optical axis AXa of the alignment system, and the distance of each beam position from the optical axis AXa determines an incident angle θ of the beams L_{r1}, L_{r2} with respect to the reference grating **16**.

Following the general analytical theory, a diffraction angle α of ±1st order diffracted lights with respect to a 0th order light, produced by a coherent beam of wavelength λ impinging upon a one-dimensional grating with a pitch Pg, is uniquely determined by $\sin \alpha=\lambda/Pg$. Therefore, by setting the pitch Pg of the reference grating **16** such that the diffraction angle α of the 1st order diffracted light becomes just 2θ with respect to the 0th order light of the beam L_{r1} (i.e., the interference light DR_1), the 1st order diffracted light of the beam L_{r1} produces coaxially with the 0th order light of the beam L_{r2} (i.e., the interference light DR_2).

At this time, the pitch of the interference fringe produced on the reference grating **16** is equal to the grating pitch Pg.

The photoelectric element **17** has light receiving surfaces **170**A, **170**B for separately receiving the two interference beams DR_1, DR_2. Respective photoelectric signals from the light receiving surfaces **170**A, **170**B are added to each other by an adder **171** in an analog manner and the resulting sum is outputted as the reference signal SR.

Returning again to the explanation of FIG. **2**, two beams L_{m1}, L_{m2} reflected by the beam splitter **14** are further reflected by another beam splitter **18** to enter the object lens OBJu through the mirror M_1. The object lens OBJu converts the two beams L_{m1}, L_{m2} into respective fluxes of parallel light which cross each other in a spatial plane IP. The plane IP is spaced from the reticle R by a distance corresponding to the amount ΔL of axial chromatic aberration in the direction of the optical axis AX, and is conjugate to the wafer W or the fiducial plate FP under the wavelength (λ_2) of the illumination beam LB for alignment. The two beams L_{m1}, L_{m2} having crossed each other in the plane IP are spaced from each other in a mark area Au on the reticle R and, after becoming beam waists in a pupil EP of the projection lens PL, they cross each other again on the fiducial plate FP (or the wafer W) in the form of parallel light fluxes.

FIG. **4** is a view of optical paths showing behavior of the beams L_{m1}, L_{m2}. The focus plane of the object lens OBJu on the front or upstream side is coincident with the plane EPa shown in FIG. **3**, so that the two beams L_{m1}, L_{m2} turn to beam waists in the plane EPa. The two beams L_{m1}, L_{m2} exiting from the object lens OBJu become fluxes of parallel light and cross each other in the plane IP, i.e., in the rear focal plane of the object lens OBJu. Thereafter, the beam L_{m1} illuminates a reticle grating mark Aua in the mark area Au on the reticle R and also passes through a transparent portion of the mark area Au, followed by entering the projection lens PL. Then, the beam L_{m1} becomes a flux of parallel light again which obliquely illuminates a grating in a mark area Fu on the fiducial plate FP (or the wafer W).

Likewise, the beam L_{m2} illuminates a reticle grating mark Aub in the mark area Au on the reticle R and also passes through a transparent portion of the mark area Au, following which the beam L_{m2} obliquely illuminates the grating in the mark area Fu on the fiducial plate FP (or the wafer W) in a direction symmetrical to the beam L_{m1}.

As shown in FIG. **4**, the two beams L_{m1}, L_{m2} become fluxes of converging light in a pupil space (comprising the optical path between the object lens OBJu and the small lenses **131**A, **131**B and the interior of the projection lens PL) with their principal rays being parallel to the optical axis AXa, and then become fluxes of parallel light in an image space (comprising the optical path between the object lens OBJu and the projection lens PL and the optical path between the projection lens PL and the fiducial plate FP or the wafer W) with their principal rays crossing each other in a focal plane (image plane) of the projection lens PL.

From the mark area Fu on the fiducial plate FP, an interference light BT is vertically produced in the upward direction. The interference light BT is resulted from interference between a 1st order diffracted light vertically produced from the mark Fu upon irradiation of the beam L_{m1} and a 1st order diffracted light vertically produced from the mark Fu upon irradiation of the beam L_{m2}, the interference light BT being a flux of parallel light in the image space. After converging into, a beam waist at the center of the pupil EP of the projection lens PL, the interference light BT reversely propagates along the optical axis Axa of the object lens OBJu while passing through a transparent portion (between the marks Aua and Aub) at the center of the mark area on the reticle R in the form of a parallel light flux. The interference light BT converges again into a beam waist at the center of the front focal plane of the object lens PL, that is, the plane EPa conjugate to the pupil EP of the projection lens PL, followed by returning toward a light receiving system while passing through the mirror M_1 and the beam splitter **18** in this order as shown in FIG. **2**. Structure of the mark area Au on the reticle R will now be explained with reference to FIGS. **5** and **6**. As shown in FIG. **5**, a light shielding band ESB of constant width is formed all around the circuit pattern area PA on the reticle R. At a part of the light shielding band ESB, there are arranged two grating marks Aua, Aub with a light shielding portion ESB' therebetween. The marks Aua and Aub have the same pitch, and their width in a direction perpendicular to the pitch direction is set about a half the total width of the transparent window. The width of the light shielding portion ESB' is also set about a half the total width of the transparent window. A grating mark WMu on the wafer W is located in a portion WMu' in the mark area under the wavelength for alignment. The two beams L_{m1}, L_{m2} respectively illuminate the grating marks Aua and Aub in a rectangular shape. Meanwhile, as shown in FIG. **6**, the beam L_{m1} having passed through the transparent portion adjacent to the mark Aua on the same side as the pattern area PA illuminates the wafer mark WMu, and the beam L_{m2} having passed through the transparent portion adjacent to the mark Aub on the same side as the pattern area PA also illuminates the wafer mark WMu. The interference light BT vertically produced from the mark WMu returns to the object lens OBJu after passing through the portion WMu' in the plane of the reticle R as shown in FIG. **6**.

When the beams L_{m1}, L_{m2} respectively illuminate the reticle grating marks Aua, Aub in FIG. **4**, higher order diffracted lights are also reflected along with 0th order lights D_{01},D_{02}. In this embodiment, the pitch of the mark Aua (Aub) is set so that assuming an incident angle of the beam L_{m1}(L_{m2}) upon the grating mark Aua (Aub) be θ', the diffraction angle of the 1st order diffracted light with respect

to the 0th order light $D_{01}(D_{02})$ becomes exactly 2θ'. With such setting, the grating mark Aua produces a 1st order diffracted light D_{11} (with the frequency shift f_1) propagating along the optical path of the beam L_{m1} exactly in a reversed direction, whereas the grating mark Aub produces a 1st order diffracted light D_{12} (with the frequency shift f_2) propagating along the optical path of the beam L_{m2} exactly in a reversed direction. Accordingly, along with the interference light BT, the 1st order diffracted beams D_{11}, D_{12} are also returned toward the light receiving system through the object lens OBJu. Referring to FIG. **2** again, the interference light BT and the 1st order diffracted lights D_{11}, D_{12} pass through the beam splitter **18** and enter a condensing lens system **19**. The lens system **19** is an inverse Fourier transform lens which converts all of the interference light BT and the 1st order diffracted lights D_{11}, D_{12} into fluxes of parallel light and causes them to cross each other in a focal plane (image conjugate plane) of the lens system **19**. The three beams having passed through the lens system **19** are each divided into two parts by a beam splitter **20**. Respective parts having passed through the beam splitter **20** reach a fiducial grating plate **21** for the reticle, whereas the reflected parts reach a field iris **22**. The fiducial grating plate **21** and the field iris **22** are both conjugate to the **[**plate**]** *plane* IP (i.e., the plane conjugate to the fiducial plate FP or the wafer W). Accordingly, at the fiducial grating plate **21**, the 1st order diffracted lights D_{11}, D_{12} cross each other to produce an interference fringe in the crossed area. The resulting interference fringe of course flows or drifts one-dimensionally at the beat frequency Δf (30 KHz). As shown in FIG. **7A**, therefore, a transmission type diffraction grating **21A** is provided on the fiducial grating plate **21** covered with a chromium layer, and an interference light BTr between two diffracted lights *is* coaxially produced from the grating **21A**. This behavior will now be described by referring to FIG. **8**. Because of meeting an image conjugate relation, the fiducial grating plate **21** is conjugate to the plane IP and the wafer mark WMu (or the surface of the fiducial plate FP) so that the interference light BT also impinges upon the fiducial grating plate **21** in addition to the 1st order diffracted lights D_{11}, D_{12}. However, since the wafer mark WMu and the reticle marks Aua, Aub are arranged in the X-Y plane to be shifted laterally, the interference light BT returns to a portion (light shielding portion) **21B** on the fiducial grating plate **21**, which portion is adjacent to the grating **21A** where the two 1st order diffracted lights D_{11}, D_{12} cross each other, as shown in FIG. **7A**.

Accordingly, by just setting the position and size of the grating **21A** on the fiducial grating plate **21** in match with the size of the mark Aua or Aub, the interference light BT from the wafer mark WMu can be shielded.

Respective 0th order lights BTo of the 1st order diffracted lights D_{11}, D_{12} illuminating the grating **21A** on the fiducial grating plate **21** propagate so as to deviate from a photoelectric element **23**, and only the interference light BTr between two 1st order diffracted lights vertically produced from the grating **21A** is received by the photoelectric element **23**. This technique is the same as the case of taking out the interference light BT from the wafer mark WMu as shown in FIG. **4**. In either case, the grating pitch of the wafer mark WMu or the grating **21A** is set exactly two times the pitch of the interference fringe produced thereon.

The intensity of the interference light BTr thus received by the photoelectric element **23** is changed sinusoidally at the beat frequency Δf (30 KHz). Therefore, an output signal Sm of the photoelectric element **23** becomes an AC signal which is linearly changed in a phase difference relative to the reference signal SR depending on the amount of displacement of the reticle marks Aua, Aub in the pitch direction on the basis of the reference grating **16**.

On the other hand, the interference light BT and the 1st order diffracted lights D_{11}, D_{12}, all reflected by the beam splitter **20** shown in FIG. **2**, reaches the field iris **22**. The iris **22** is formed with an opening **22A** which allows only the interference light BT to pass therethrough, as shown in FIG. **7B**, while the two 1st order diffracted lights D_{11}, D_{12} are shielded by a light shielding portion **22B**.

The interference light BT having passed through the iris **22** reaches a photoelectric element **26** through a mirror **24** and a condenser lens **25**. The photoelectric element **26** produces an output signal Sw depending on change in the intensity of the interference light BT. This output signal Sw also becomes an AC signal of which level is changed sinusoidally at the beat frequency Δf, the phase of the AC signal relative to the reference signal SR being changed in proportion to the amount of deviation of the mark WMu on the wafer W or the fiducial mark Fu on the fiducial plate FP from the reference grating **16**.

The reference signal SR and the output signals Sm, Sw are inputted to a phase difference measurement unit **27** which determines a phase difference ϕm of the output signal Sm relative to the reference signal SR, determines a phase difference ϕw of the output signal Sw relative to the reference signal SR, and further a difference therebetween $\Delta\phi=\phi m-\phi w$. In the case of this embodiment, since the diffraction grating pitch on the fiducial plate FP (or the wafer W) is two times the pitch of the interference fringe produced thereon, one period (±180°) of the phase difference Δϕ corresponds to ½ (±¼ pitch) of the diffraction grating pitch. Based on the phase difference Δϕ, the measurement unit **27** calculates position correction amounts (or position shift amounts) ΔX, ΔY of the water stage ST or the reticle stage RS, values of those amounts being delivered to the main controller **5**.

In the foregoing, the system from the driver **10** to the measurement unit **27**, including the object lens OBJu, corresponds to first mark detecting means in the present invention.

Meanwhile, in FIG. **2**, the mark RMr on the reticle R is detected by a TTR alignment system for exposure (corresponding to AO_1 in FIG. **1**) which comprises a mirror M_2, an object lens OBr, a beam splitter **30**, a lens system **31**, an illumination field iris **32**, a condenser lens **33**, a fiber **34**, a focusing lens **35**, a beam splitter **36**, and CCD image sensors **37A**, **37B**. The fiber **34** emits an illumination light at the exposure wavelength to uniformly irradiate the iris **32** through the condenser lens **33**. The illumination light having passed through an opening of the iris **32** enters the object lens OBr through the lens system **31** and the beam splitter **30**, following which it is bent by the mirror M_2 at a right angle to vertically illuminate a local area of the reticle R including the mark RMr downwards. The iris **32** is conjugate to the reticle R so that an opening image or the iris **32** is focused on the reticle R. The beam splitter **30** is located near a front focus plane or the tele-centric object lens OBr, i.e., a plane conjugate to the pupil EP of the projection lens FL, thereby reflecting a part of the light returned from the object lens OBr toward the focusing lens **35**. The CCD image sensors **37A**, **37B** have their light receiving surfaces which are conjugate to the reticle R through the object lens OBr and the focusing lens **35**, and also conjugate to the wafer W or the fiducial plate FP through the projection lens PL. Incidentally, an exit end of the fiber **34** is located to be

conjugate to the pupil EP of the projection lens PL for achievement of the Keller's illumination. In the case of this embodiment, the optical path between the object lens OBr and the beam splitter **30** exhibits an afocal system and, therefore, a deviation in the position of the mark RMr can be compensated for by arranging the object lens OBr and the mirror M_2 integrally with each other in such a manner as able to move together horizontally in FIG. **2**. But, in consideration of stability of the system, the mirror M_2 is here fixedly located at a position outside the pattern area PA having the maximum dimension possibly expected on the reticle R.

CCD image sensors **37**A, **37**B are arranged to have an angular spacing of 90° therebetween so that their horizontal scan lines coincide with the X and Y directions, respectively, for making position measurements of the crossshaped mark RMr in the X and Y directions separately. The reason is to avoid a difference in resolution as developed when using a single CCD image sensor to detect shifts of the mark image in both the horizontal and vertical directions, because a usual CCD image sensor **[**have**]** *has* different degrees of pixel resolution in the horizontal and vertical directions. An image processing unit **38** receives respective image signals (video signals) from the CCD image sensors **37**A, **37**B, detects a position shift amount of the mark RMr on the reticle R from the fiducial mark FMr on the fiducial plate FP, and then **[**deliver**]** *delivers* information of the position shift amount to the main controller **5**.

In addition to the above configuration, there are also provided a global mark detection system **40** of off-axis type for detecting a global aligment mark on the wafer W, a latent image in a resist layer or the respective fiducial marks on the fiducial plate FP, and a processing unit **42** for processing a signal from the system **40**. Furthermore, adjustment units **50**A, **50**B for adjusting or correcting various focusing characteristics of the projection lens PL are provided and supervised under control of the main controller **5**. The adjustment unit **50**A has a function of changing magnification, focus position, distortion, etc. of the projection lens PL by, for example, controlling pressure of a predetermined air chamber in the projection lens PL. The adjustment unit **50**B has a function of finely moving in the axial direction or tilting a lens element as one component of the projection lens PL (for example, a field lens on the reticle side).

The different wavelength TTR alignment system and the exposure light TTR alignment system are preferably arranged as schematically shown in FIG. **9**. As will be seen from FIG. **9**, reticle grating mark areas Au, Al, Ar, Ad, each being arranged as shown in FIG. **5**, are formed in the respective sides of the light shielding band ESB around the pattern area PA on the reticle R. The mark areas Au, Ad are used for alignment in the X direction plotted in FIG. **9**, whereas the mark areas Ar, Al are used for alignment in the Y direction.

Outside the light shielding band ESB, there is also provided a reticle mark RMl similar to the reticle mark RMr at a symmetrical position.

Therefore, object lenses OBr, OBl, of two exposure light TTR alignment systems are arranged to respectively detect the marks RMr, RMl below the dichroic mirror DM, and object lenses OBJu, OBJd, OBJr, OBJl of four different wavelength TTR alignment systems are arranged to respectively detect the mark areas Au, Ad, Ar, Al through the dichroic mirror DM.

When the reticle R and the wafer W are actually aligned with each other on a die-by-die basis by using the different wavelength TTR alignment systems, the four eyes are not always required to be used simultaneously, but three or two eyes may be used instead. This is relied on the fact that even in the case where any of corresponding marks (WMu, WMd, WMr, WMl) in one shot area on the wafer is defective, if one eye in the X direction and one eye in the Y direction at minimum properly output photoelectric signals, an alignment error (interruption of the sequence) can be avoided to the utmost by executing the alignment for the shot area of interest.

The mark arrangement on the reticle R as shown in FIG. **9** and the mark arrangement on the fiducial plate FP suitable for this embodiment will be next described with reference to FIGS. **10** and **11**.

FIG. **10** shows one preferred example of a pattern layout on the reticle R, in which the pattern area PA having the maximum dimension projectable by the projection lens PL is supposed. The cross-shaped reticle marks RMr, **[**RM**]** *RMl* are provided on a line passing the center Rcc of the pattern area PA on the reticle R and extending parallel to the X axis. These marks RMr, RMl are set substantially at the respective centers of the view fields of the object lenses OBr, OBl. In the reticle R shown in FIG. **10**, the four mark areas Au, Ad, Ar, Al are each located at a position farthest from the reticle center Rcc. Stated otherwise, rectangular areas Su, Sd, Sr, Sl indicated by broken lines in FIG. **10** respectively **[**stand for one**]** *are* examples of ranges where the optical axes (detection centers) of the object lenses OBJu, OBJd, OBJr, OBJl of the four different wavelength TTR alignment systems are movable. Then, in the case of FIG. **10**, the mark areas Au, Ad, Ar, Al are each provided at the outermost position of the movable range of the corresponding object lens.

FIG. **10** is illustrated by way of example and, depending on cases, the movable ranges Sr, Sl of the object lenses OBJr, OBJl may protrude into a region between the movable ranges Su, Sd of the object lenses OBJu, OBJd from the right and left.

FIG. **11** shows the mark arrangement on the fiducial plate FP with double cross-shaped fiducial marks FMr, FMl provided on the left and right sides of the center in the X direction. The center-to-center distance between the two fiducial marks FMr and FMl is set equal to a value resulted from multiplying the center-to-center distance between the two marks RMr and RMl on the reticle by the projection magnification (l/M). Accordingly, when the center Fcc of the fiducial plate FP is made coincident with the reticle center Rcc, the fiducial mark FMr and the reticle mark RMr are simultaneously observed by the object lens OBr of one exposure light TTR alignment system under a condition that the reticle mark RMr is positioned between the double lines of the fiducial mark FMr, and the fiducial mark **[**FM**]** *FMl* and the reticle mark RMl are simultaneously observed by the object lens OBl of the other exposure light TTR alignment system under a condition that the reticle mark RMl is positioned between the double lines of the fiducial mark FMl.

On the fiducial plate FP, there are also provided fiducial mark areas Fu, Fd, Fr, Fl in which diffraction gratings are engraved in positions and sizes respectively corresponding to the movable ranges Su, Sd, Sr, Sl on the reticle R when the center Fcc of the fiducial plate FP is made coincident with the reticle center Rcc. In the fiducial mark area Fu, for example, a group of grating lines engraved in the X direction with the constant pitch are formed similarly to the mark WMu on the wafer W and used for detecting a relative

position shift in the X direction from the mark area Au on the reticle R. This equally applies to the other fiducial mark areas Fd, Fr, Fl. Accordingly, even if the size of the pattern area PA (or the light shielding band ESB) is changed upon replacement of the reticle R with another one, it is possible to simultaneously detect an X-directional shift of the mark area Au from the fiducial mark Fu, an X-directional shift of the mark area Ad from the fiducial mark Fd, a Y-directional shift of the mark area Ar from the fiducial mark Fr, and a Y-directional shift of the mark area Al from the fiducial mark Fl by the four eyes (OBJu, OBJd, OBJr, OBJl) so long as the mark areas Au. Ad, Ar, Al on the reticle are present within the movable ranges Su, Sd, Sr, Sl, respectively.

In FIG. **11**, the two groups of plural grating lines making up the fiducial marks Fr and Fl on the left and right sides correspond to each other in one-to-one relation with respect to the Y direction, whereas the two groups of plural grating lines making up the fiducial marks Fu and Fd on the upper and lower sides correspond to each other in one-to-one relation with respect to the X direction. Further, the center-to-center spacing in the X direction between the mark area Au and Ad shown in FIG. **10** is accurately equal to integer times as much as the grating pitch of the fiducial marks Fu, Fd, whereas the center-to-center spacing in the Y direction between the mark area Ar and Al is accurately equal to integer times as much as the grating pitch of the fiducial marks Fr, Fl.

Operation of this embodiment, that is, base line measurement of the exposure light TTR alignment system and the different wavelength TTR alignment system in consideration of a distortion, will be described below. At first, an arbitrary reticle (such as shown in FIG. **10**, for example) is set on the reticle stage RS and the reticle alignment is performed by picking up images of the reticle marks RMr. RMl and the marks FMr, FMl on the fiducial plate FP by the CCD sensor elements **37**A, **37**B of the exposure light TTR alignment systems.

Then, the object lenses OBJu, OBJd, OBJr, OBJl (i.e., the holders **11**) of the four different wavelength alignment systems are set at positions respectively corresponding to the mark areas Au, Ad, Ar, Al, followed by checking shifts in illumination position of the two beams L_{m1}, L_{m2} in the X and Y directions and a tele-centric error of the two beams L_{m1}, L_{m2} by the use of the fiducial marks Fu, Fd, Fr, Fl on the fiducial plate FP. After completion of the checking, the four different wavelength alignment systems each determines amounts of relative position shifts between the reticle R and the fiducial plate FP at that position. In other words, the shift amounts in the X direction between the fiducial mark Fu (and Fd) and the reticle mark Au (and Ad), as well as the shift amounts in the Y direction between the fiducial mark Fr (and Fl) and the reticle mark Ar (and Al) are detected through the respective measurement units **27**.

Based on the detected shift amounts, the main controller **5** controls the driver **1** and the stage driver **4** for servo-driving the reticle stage RS or the wafer stage ST. Since the different wavelength alignment systems of this embodiment are each of the heterodyne type allowing successive measurement of the relative position shift amount even in a condition that the reticle mark and the fiducial mark remain at rest**[**. The**]**, *the* measurement units **27** continue successively outputting the information on the relative position shifts (such as in the X, Y and rotating directions). Therefore, the alignment between the reticle R and the fiducial plate FP is continued so that all the phase differences $\Delta\phi$ measured by the measurement units **27** of the four different wavelength alignment systems become zero (or a fixed value). During the above step of the different wavelength alignment, the image processing units **38** of the exposure light TTR alignment systems continue successively (at certain intervals of time) outputting the position shift amounts (ΔXr, ΔYr) in the X, Y directions between the reticle mark RMr and the fiducial mark FMr, as well as the position shift amounts (ΔXl, ΔYl) in the X, Y directions between the reticle mark RMl and the fiducial mark FMl. It is to be noted that in the case of a large distortion, the corresponding shift amount is added as an offset amount to a design value beforehand. Thus, the shift amounts (ΔXr, ΔYr), (ΔXl, ΔYl) determined by the exposure light TTR alignment systems correspond to averages of distortion differences at the alignment positions (i.e., the marks Au, Ad, Ar, Al) between the wavelength of the exposure light and the different wavelength therefrom. To put it in more detail, when the results of detecting two pairs of the reticle mark Au (the fiducial mark Fu) and the reticle mark Ad (the fiducial mark Fd) show that the phase differences $\Delta\phi$ therebetween are both zero, the shift amounts (ΔXr, ΔYr), (ΔXl, ΔYl) detected by the image processing units **38** are stored plural times, following which the stored results area averaged to determine overall alignment errors (in X, Y and θ directions) caused by a distortion difference between the reticle R and the fiducial plate FP. In the case of this embodiment, the reticle R and the fiducial plate FP are simultaneously aligned with each other by using four eyes of the different wavelength TTR alignment systems**[**, the**]**. *The* reticle R and the fiducial plate FP exhibit, as a consequence of the alignment, slight errors in the X, Y and θ directions depending on distortion characteristics of the projection lens PL at the different wavelength. These errors can be assumed as fixed offsets so long as the reticle marks Au, Ad, Ar, Al are not changed in their positions. Therefore, by detecting the shift amounts between the marks RMr, RMl and the fiducial marks FMr, FMl using the exposure light TTR alignment systems, the resulting shift amounts give offset amounts in the X, Y and θ directions which include the distortion amounts of the projection lens at the positions of the marks RMr, RMl under the exposure light.

Accordingly, when actually carrying out alignment of the shot area on the wafer W by the different wavelength TTR alignment systems thereafter, it is only required to control the reticle stage RS or the wafer stage ST so that the aligned position is shifted by the above offset amounts to reach the true alignment position. The offset amounts caused by the distortion difference in the X, Y and θ (rotating) directions are calculated in the main controller **5** based on information of the shift amounts from the image processing unit **38**, and stored until the reticle R will be realigned or replaced with another one.

As the distortion difference in the projection lens PL between the wavelength of the exposure light and the different wavelength therefrom may be changed upon the adjustment unit **50**B being actuated, it is desirable that immediately after actuating the adjustment unit **50**B to a large extent, the offset amounts are measured again by using the fiducial plate FP.

With this embodiment as stated above, since the mark areas Au, Ad, Ar, Al for the different wavelength TTR alignment are respectively provided on the four sides of the reticle R and the corresponding fiducial marks Fu, Fd, Fr, Fl on the fiducial plate FP are simultaneously detected, it is possible to precisely determine the overall alignment errors through TTR which are caused by an influence of distortions at the different wavelength. Further, with this embodiment, since the different wavelength TTR alignment systems and

the exposure light TTR alignment systems are simultaneously operated through the projection lens PL and the values measured by the interferometer **3** on the wafer stage ST are not used at all, errors due to fluctuating air in the atmosphere, which would raise a problem associated with the interferometer **3**, will not be involved so that the offset amounts can be measured with very high precision.

In addition, since this embodiment employs the different wavelength TTR alignment systems of heterodyne type having extremely high resolution, the highly accurate measurement is achieved. For example, assuming that the pitch of the diffraction gratings on the fiducial plate FP is on the order of 4 μm, the phase difference detectable range (±180°) is given ±1 μm. Also, assuming that the practical phase measurement resolution is ±2° in consideration of noises and so on, the position shift detecting resolution becomes as high as about ±0.01 μm.

Consequently, with such an arrangement that the reticle R and the fiducial plate FP are subjected to alignment servo control by using the different wavelength TTR alignment systems of heterodyne type, the highly stable positioning can be achieved.

While the projection lens PL of this embodiment has been explained as being tele-centric on both sides thereof, it may of course be tele-centric on either side only. In the case of a projection lens being tele-centric on both sides, the optical axis of the object lens of the exposure light TTR alignment system is vertical to the reticle surface and also coincident with the principal ray passing the pupil center of the projection lens PL. Therefore, if the mark patterns on the reticle are formed of reflective chromium layers, the light regularly reflected by the patterns are so strongly detected by the CCD image sensors that both the reticle mark RMr, RMl and the fiducial mark FMr, FMl may appear bright. In the case where the fiducial plate FP made of quartz glass or the like is entirely covered with a chromium layer and the fiducial marks FMr, FMl are formed by removing the chromium layer by etching or the like into desired patterns, it may happen that the fiducial marks FMr, FMl look black, but the whole of the surroundings become bright, thereby greatly lowering the contrast of the reticle marks RMr, RMl. In this case, an aperture iris (spatial filter) having a ring-shaped opening may be disposed in the illumination optical path of each exposure light TTR alignment system, e.g., in the pupil conjugate plane between the beam splitter **30** and the lens system **31** in FIG. **2**, for illuminating the reticle R in the dark field. With this arrangement, dark field images are focused on the CCD image sensors such that only respective edges of the reticle marks RMr, RMl and the fiducial marks FMr, FMl glint brightly. Moreover, the spatial filter disposed in the pupil conjugate plane may be formed of a liquid crystal, electrochromic (EC) or the like in which multiple ring-like openings arc patterned in concentric relation, allowing the illumination to be switched between the dark field and the light field. It is also possible to change the number of aperture for the illumination light.

A manner of improving superposition accuracy when using the apparatus as shown in FIG. **2**, in particular, a manner of improving the matching between different units of the apparatus, will be described below.

FIG. **12**A exaggeratedly represents distortion characteristics (broken lines) of the projection lens PL under the exposure wavelength and distortion characteristics (one-dot-chain lines) thereof under the different wavelength (i.e., the wavelength of the alignment light) on the basis of an ideal lattice (solid lines).

A distortion map like that can be drawn by, for example, making a trial print using a test reticle. Note that the distortion map under the different wavelength cannot be obtained by the trial printing, but can be obtained by using the method similar to the above stated embodiment in a combined manner.

At first, a test reticle having vernier marks for superposition measurement at respective ideal lattice points in the pattern area is prepared and aligned by the exposure light TTR alignment system. Then, a reticle blind in the exposure illumination system is fully opened and the test reticle is exposed onto a dummy wafer (such as a photosensitive resist layer, photo-chromic layer or bare silicon wafer coated with an opto-magnetic medium).

Next, the reticle blind is narrowed so as to illuminate only the vernier mark provided at the center of the test reticle. Following that, while stepping the wafer stage ST at the pitch of the ideal lattice points, an exposure is made in superposed relation to each latent image of the vernier mark on the test reticle having been exposed in advance on a step-by-step basis.

In this case, on assumptions that the stepping of the wafer stage ST is coincident with the division pitch of the ideal lattice, the distortion characteristics under the exposure wavelength on the basis of the ideal lattice can be determined by measuring the superposition accuracy between the latent image of each vernier mark exposed at the first time and the latent image of the same vernier mark printed at the second time in superposing relation. In the above measurement, the latent images of the vernier marks on the dummy wafer may be detected by the global mark detection system **40** of off-axis type shown in FIG. **2**, or by the exposure light TTR alignment system after properly modifying a shape of the vernier mark. Where the dummy wafer is formed of a usual photoresist layer, the measurement may be performed by the different wavelength TTR alignment system, etc. after once developing the dummy wafer to build resist images of the vernier marks.

Then, amounts of superposition errors are determined at each of the ideal lattice points in that way, and the resulting error amounts are statistically processed by the method of least squares for determining the respective offsets in the X, Y and θ directions. Based on those offsets, the shift amounts (ΔOF_{x1}, ΔOF_{y1}), (ΔOF_{x2}, ΔOF_{y2}) of the images RMr', RMl' of the reticle marks RMr, RMl under the exposure wavelength, indicated by broken lines in FIGS. **12**B and **12**C, from the ideal positions (solid lines) can be presumed as system offsets.

Consequently, when aligning the reticle marks RMr, RMl by the exposure light TTR alignment systems, it is possible to always make an exposure on the distortion map with the least errors from the ideal lattice, by taking into account the system offsets.

Further, since the difference in distortion between the exposure wavelength and the different wavelength can be determined following the above first embodiment, the reticle pattern can be exposed in superposed relation to each shot area on the wafer under a condition closest to the ideal lattice, by further taking into account (or compensating for) the distortion difference, even in the case of die-by-die alignment using the different wavelength TTR alignment systems. This implies that the matching between different units of plural steppers jointly constituting a single semiconductor manufacture line can be achieved on the order of the ideal lattice, and hence that the matching accuracy in the manufacture line can be improved.

Since the above embodiment is premised on using the stepper shown in FIG. **2**, the detection center of the exposure light TTR alignment system is fixedly positioned in the view field of the projection lens. Therefore, after determining and compensating for the system offsets (ΔOF_{x1}, ΔOF_{y1}), (ΔOF_{x2}, ΔOF_{y2}) during the reticle alignment beforehand so that the distortion map under the exposure wavelength becomes closest to the ideal lattice, as explained in connection with FIGS. **12**B and **12**C, distortion errors under the different wavelength may be determined at each alignment position using the different wavelength TTR alignment system.

According to the present invention, as described above, since a different wavelength TTR alignment system and an exposure light TTR alignment system are arranged to be separated from each other and to simultaneously detect a group of fiducial marks located on the image plane of a projection optical system, the distortion difference as developed in when using the different wavelength can be precisely measured. In other words, since the alignment light at the exposure wavelength and the alignment light at the different wavelength are detected by the respective TTR alignment systems exactly at the same timing through the projection optical system, the detected results commonly include measurement errors due to minute fluctuations in air flows, temperature distribution, etc. within the optical paths, thereby allowing those measurement errors to be canceled out. Another advantage is in that since the present invention does not rely on the method using a laser interferometer while running a wafer stage or the like, the results will not be affected by measurement accuracy (reproducibility) of the laser interferometer itself.

Further, according to the present invention, since a plurality of TTR alignment systems can be simultaneously operated using the group of fiducial marks, it is also possible to implement beam positioning, tele-centric checking and focus checking at the same time, which are necessary upon the an object lens of the TTR alignment system being moved, resulting in an advantage of increasing a throughput in setting of the TTR alignment system.

I claim:

1. A projection optical apparatus comprising:

a projection optical system for projectively focusing a pattern image of a mask under illumination by a light of first wavelength characteristic onto a sensitive substrate,

a stage for holding said sensitive substrate,

a fiducial plate disposed on said stage,

first mark detection means for illuminating a light of second wavelength characteristic different from said first wavelength characteristic, through a first mark area formed on said mask and said projection optical system, onto **[**said sensitive substrate or**]** a second mark area formed on said fiducial plate, and then detecting optical information produced from said second mark area,

a fourth mark area formed on **[**said sensitive substrate or**]** said fiducial plate and arranged in a predetermined positional relationship relative to said second mark area,

a third mark area formed on said mask and arranged in a predetermined positional relationship relative to said first mark area,

second mark detection means for illuminating said light of first wavelength characteristic onto said fourth mark area through said third mark area and said projection optical system, and then detecting optical information produced from said fourth mark area, under a condition that said first mark detection means is detecting the optical information produced from said second mark area, and

error detection means for detecting detection errors due to a distortion at respective positions in the view field of said projection optical system where said first mark area and said second mark area are present, based on the detected results by said first mark detection means and said second mark detection means.

2. A projection optical apparatus according to claim **1**, wherein:

said first mark detection means has a first object lens system movable depending on position change of said first mark area on said mask, and

[the**]** *a* uniform mark pattern is formed in said second mark area over a movable range of said first object lens system.

3. A projection optical apparatus comprising:

a projection optical system disposed between first and second planes such that said first and second planes are optically conjugate to each other under a first wavelength characteristic,

alignment mark means including first and third mark means disposed on said first plane with a predetermined positional relationship therebetween, and second and fourth mark means disposed on said second plane with a predetermined positional relationship therebetween;

first mark detection means for illuminating a light of second wavelength characteristic different from said first wavelength characteristic onto said second mark means through said first mark means and said projection optical system, and then detecting first optical information produced from said second mark means,

second mark detection means for illuminating said light of first wavelength characteristic onto said fourth mark means through said third mark means and said projection optical system, and then detecting second optical information produced from said fourth mark means, and

means for creating information of alignment errors developed between said first and second planes in the directions enough to define a plane, based on said first and second optical information.

4. A projection exposure apparatus for exposing a pattern area of a mask irradiated with first illumination light onto a substrate through a projection optical system, the apparatus comprising:

(a) a movable stare supporting the substrate and moving in a predetermined plane perpendicular to an optical axis of said projection optical system;

(b) a mask holder supporting the mask which has a mask mark formed at a peripheral position of the pattern area;

(c) a fiducial plate mounted on said movable stage and having first and second fiducial marks on its top face, the first fiducial mark being aligned through said projection optical system with the mask mark when said movable stage is located at a predetermined reference position with respect to the image field of said projection optical system;

(d) a first alignment system irradiating the mask mark and the first fiducial mark with the first illumination light and receiving a light from the mask mark and a light

from the first fiducial mark through said projection optical system, to detect a positional relationship between the mask mark and the first fiducial mark, when said movable stage is; located near the reference position; and

(*e*) *a second alignment system including a predetermined detecting reference, irradiating the second fiducial mark with second illumination light which has different wavelength from the first illumination light and receiving a light from the second fiducial mark through said projection optical system, to detect a positional relationship between the detecting reference and the second fiducial mark, when said movable stage is located near the reference position.*

5. A projection exposure apparatus for exposing a pattern area of a mask irradiated with first illumination light onto a substrate through a projection optical system, the apparatus comprising:

(*a*) *a movable stage supporting the substrate and moving in a plane perpendicular to an optical axis of said projection optical system;*

(*b*) *a fiducial plate fixedly mounted on a portion of said movable stage and having first and second fiducial patterns on its surface, said first and second fiducial patterns being arranged with predetermined positional relationship;*

(*c*) *a first alignment optical system detecting a light from said first fiducial pattern through said projection optical system and a peripheral portion of the pattern area of said mask and a light from a mask mark formed within the peripheral portion of said mask, when said mask mark and the first fiducial pattern are irradiated with a light of a same wavelength as the first illumination light;*

(*d*) *a controller driving and positioning said movable stage so that the first fiducial pattern is substantially aligned with the mask mark and simultaneously the second fiducial pattern is located at a predetermined position in the image field of said projection optical system; and*

(*e*) *a second alignment optical system detecting a light from the second fiducial pattern through said projection optical system, when the second fiducial pattern is irradiated with a light having different wavelength than the first illumination light;*

wherein said movable stage is stationary until said first and second alignment optical systems complete the light detecting operations.

6. A method for examining a variation of the base line distance between a center point of a reticle and a detecting center of an alignment system which detects positional deviation of a mark formed on a substrate for aligning the substrate through a projection optical system, the method comprising the steps of:

(*a*) *providing a fiducial plate within the image field of said projection optical system instead of the substrate, said fiducial plate having a first fiducial mark to be aligned with a reticle mark through said projection optical system and a second fiducial mark disposed at a predetermined positional relationship with respect to the first fiducial mark;*

(*b*) *positioning said fiducial plate at a reference position so that the first fiducial mark and the reticle mark are substantially aligned with each other through said projection optical system; and*

(*c*) *detecting the positional deviation between the detecting center of said alignment system and the second fiducial mark to determine the variation of said base line distance while said fiducial plate is stationary at the reference position.*

7. A method for aligning a substrate and a mask having a circuit pattern, and for exposing a an image of the circuit pattern onto the substrate through a projection optical system, the method comprising the steps of:

(*a*) *detecting a mask mark formed on the mask and a first fiducial mark disposed on a movable stage through said projection optical system with a first alignment system using a first wavelength of light and, substantially at the same time, detecting a second fiducial mark disposed on said movable stage through said projection optical system with a second alignment system using a different wavelength of light, when said movable stage is stationary at a baseline measurement position;*

(*b*) *determining a positional relationship between a detecting reference of said second alignment system and the circuit pattern of the mask in an image field of said projection optical system based on detection results obtained in step* (*a*);

(*c*) *detecting an alignment mark formed on the substrate, which is mounted on said movable stage, with said second alignment system;*

(*d*) *determining a positional relationship between the detecting reference of paid second alignment system and the alignment mark of the substrate in the image field of said projection optical system based on a detection result obtained in step* (*c*); *and*

(*e*) *positioning said movable stage to alit a shot area of the substrate and the image of the circuit pattern based on the positional relationships determined in steps* (*b*) *and* (*d*), *and exposing the shot area of the substrate.*

8. A method according to claim 7, wherein, in the step (*a*), *said first alignment system generates a first deviation signal representing a positional relationship of the mask mark and the first fiducial mark and, substantially at the game time, said second alignment system generates a second deviation signal representing a positional relationship of the detecting reference of said second alignment system and the second fiducial mark.*

9. A method according to claim 7, wherein the substrate has first and second X-direction alignment marks and first and second Y-direction alignment marks, and said second alignment system includes a first objective lens for detecting the first X-direction aliment mark, a second objective lens for detecting the first Y-direction alignment mark, a third objective lens for detecting the second X-direction alignment mark, and a fourth objective lens for detecting the second Y-direction alignment mark.

10. A method according to claim 9, wherein the step (*c*) *includes detecting at least one of said first and second X-direction alignment marks and at least one of said first and second Y-direction alignment marks, and the step* (*d*) *includes determining positional relationships between the detecting reference of said alignment system and each of said one X-direction alignment mark and said one Y-direction alignment mark.*

11. A method according to claim 7, wherein the steps (*a*) *and* (*b*) *are performed after operation of an adjustment unit which adjusts a magnification or a distortion characteristic of said projection optical system.*

12. A projection exposure apparatus comprising:

a projection optical system disposed between a mask and a substrate to project on the substrate an illumination light irradiating the mask;

a plate having fiducial marking formed thereon and disposed in an image field of said projection optical system;

a first alignment system irradiating a portion of said fiducial marking with a first alignment light different from said illumination light in wavelength to detect optical information produced from said fiducial marking through said projection optical system;

a second alignment system irradiating a portion of said fiducial marking with a second alignment light having substantially the same wavelength as said illumination light through said projection optical system to detect a positional relationship between said mask and said plate; and

an alignment controller connected to said first and second alignment systems to detect an offset amount of said first alignment system caused by said projection optical system.

13. An apparatus according to claim 12, wherein

said fiducial marking includes two mark patterns disposed at a predetermined positional relationship so that said two mark patterns are detected substantially at the same time by said first and second alignment systems, respectively.

14. An apparatus according to claim 12, wherein

said first alignment system includes a photodetector which receives, through a mark area on said mask, diffraction light produced from said fiducial marking and passing through said projection optical system.

15. An apparatus according to claim 12, further comprising:

an adjustment unit connected to said projection optical system to adjust an optical characteristic of said projection optical system,

wherein said alignment controller determines the offset amount of said first alignment system after an adjustment of said optical characteristic.

16. A projection exposure apparatus comprising:

a projection optical system disposed between a mask and a substrate to project on the substrate an illumination light irradiating the mask;

a first alignment system irradiating a first fiducial mark with a first alignment light different from said illumination light in wavelength to detect optical information produced from said first fiducial mark through said projection optical system;

a second alignment system irradiating a second fiducial mark with a second alignment light having substantially the same wavelength as said illumination light through said projection optical system to detect a positional relationship between said second fiducial mark and a mark on said mask; and

a plate disposed on a substrate side with respect to said projection optical system, said first and second fiducial marks being formed on said plate at a predetermined positional relationship so that said first and second alignment systems respectively detect said first and second fiducial marks substantially at the same time.

17. An apparatus according to claim 16, further comprising:

an alignment controller connected to said first and second alignment systems to determine a base line amount of said first alignment system.

18. A projection exposure method for protecting an illumination light irradiating a mask through a projection optical system on a substrate to transfer a pattern of said mask onto said substrate, comprising the steps of:

disposing a plate formed with a first fiducial mark and a second fiducial mark in an image field of said projection optical system;

detecting said first fiducial mark through said projection optical system by a first alignment system which uses a first beam different from said illumination light in wavelength;

detecting said second fiducial mark through said projection optical system by a second alignment system which uses a second beam having substantially the same wavelength as said illumination light; and

determining a base line amount of said first alignment system based on outputs of said first and second alignment systems.

19. A method according to claim 18, wherein

said step of detecting said first fiducial mark by said first alignment system and said step of detecting said second fiducial mark by said second alignment system are performed substantially at the same time.

20. A method according to claim 19, wherein

said plate is substantially at rest during said steps of detecting said first and second fiducial marks.

21. A method according to claim 18, wherein

said base line amount of said first alignment system is determined after an adjustment of an optical characteristic of said projection optical system or a position of said first alignment system.

22. A projection exposure method for protecting an illumination light irradiating a mask through a projection optical system on a substrate to transfer a pattern of said mask on said substrate, comprising the steps of:

disposing a plate formed with fiducial marking in an image field of said projection optical system;

detecting said fiducial marking through said projection optical system by a first alignment system which uses a first beam different from said illumination light in wavelength and by a second alignment system which uses a second beam having substantially the same wavelength as said illumination light, respectively; and

determining a base line amount of said first alignment system based on outputs of said first and second alignment systems.

* * * * *