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Ohta et al.

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[54] PROJECTION EXPOSURE APPARATUS

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[73] Assignee: Canon Kabushiki Kaisha, Tokyo, Japan

[21] Appl. No.: 728,317

[22] Filed: Jul. 8, 1991

Related U.S. Application Data

[63] Continuation of Ser. No. 572,340, Aug. 24, 1990, abandoned, which is a continuation of Ser. No. 409,311, Sep. 19, 1989, abandoned.

[30] **Foreign Application Priority Data**

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Aug. 30, 1989 [JP] Japan 64-226204

[51] Int. Cl.[5] G01J 1/20

[52] U.S. Cl. 250/201.2; 355/53; 353/101

[58] Field of Search 355/30, 53; 353/101; 250/201.2, 548, 557; 354/406, 407, 408

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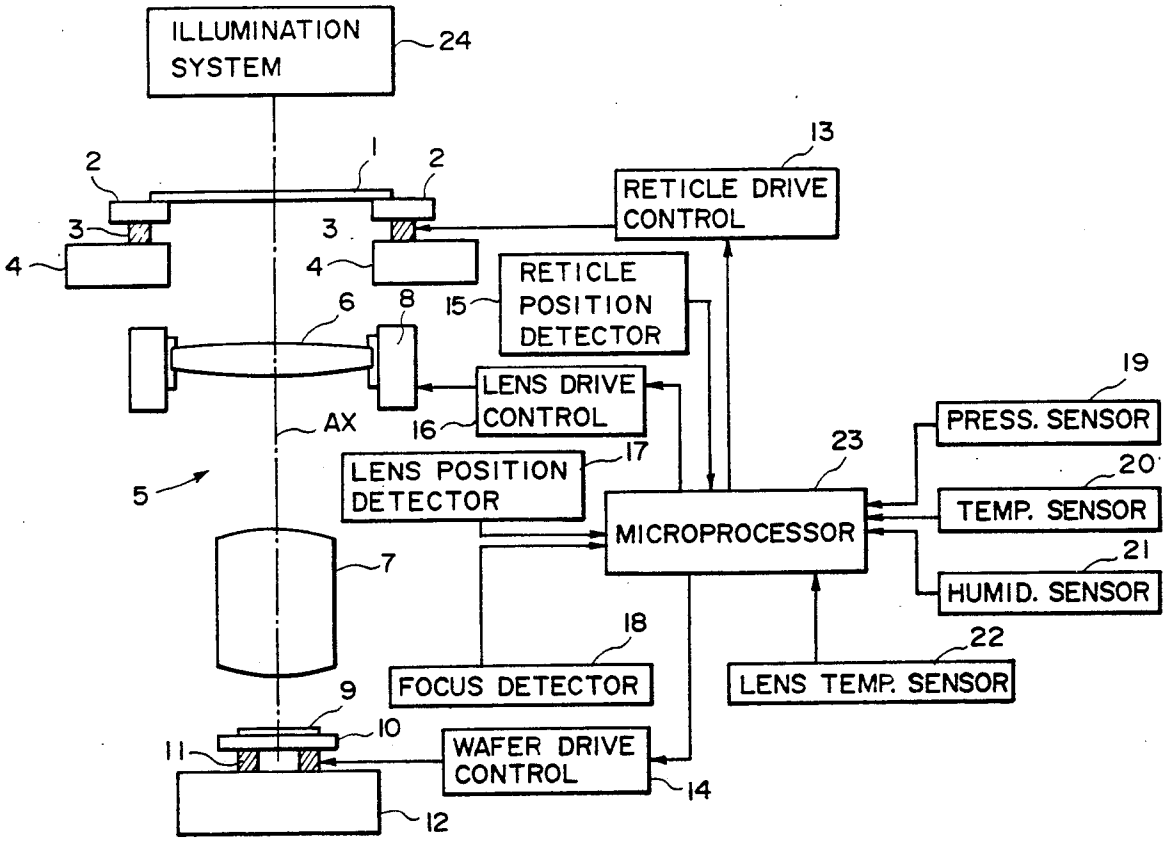
61-160934 7/1986 Japan .
62-32613 2/1987 Japan .
62-35620 2/1987 Japan .

Primary Examiner—David C. Nelms
Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

A projection exposure apparatus includes a projection optical system for projecting an image of a pattern of a first object to a second object, and an adjusting system for adjusting projection magnification and distortion of the projected image of the pattern, the adjusting system being operable to displace the first object and a lens element of the projection optical system in a direction of an optical axis of the projection optical system.

23 Claims, 4 Drawing Sheets



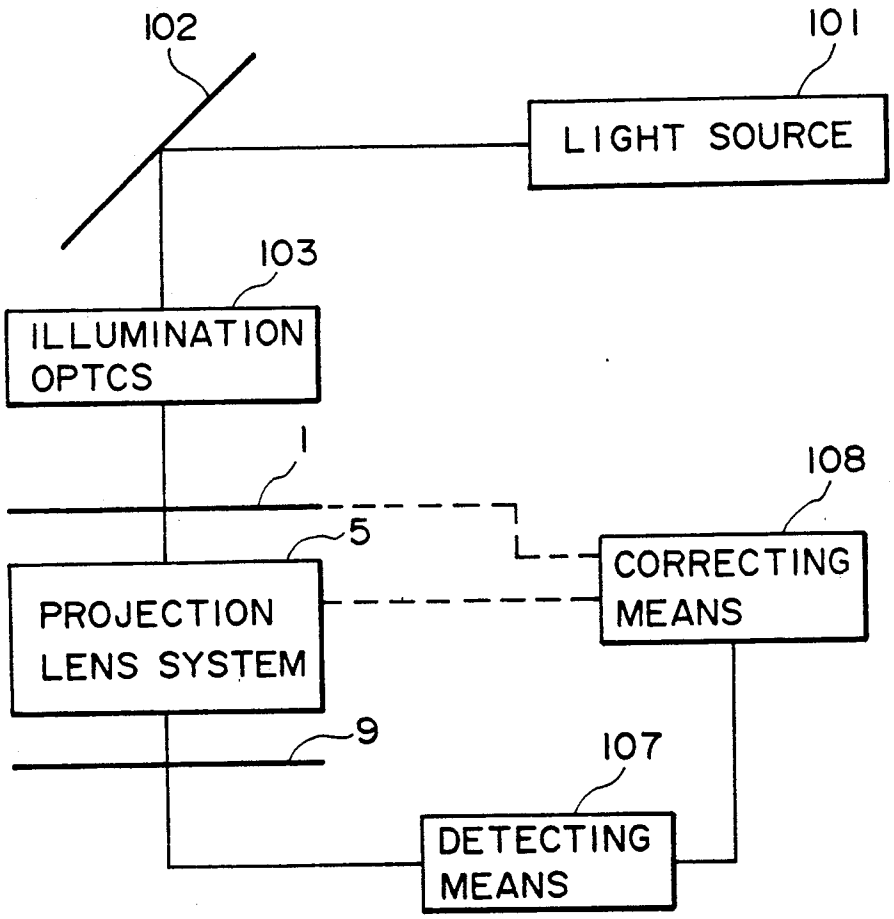
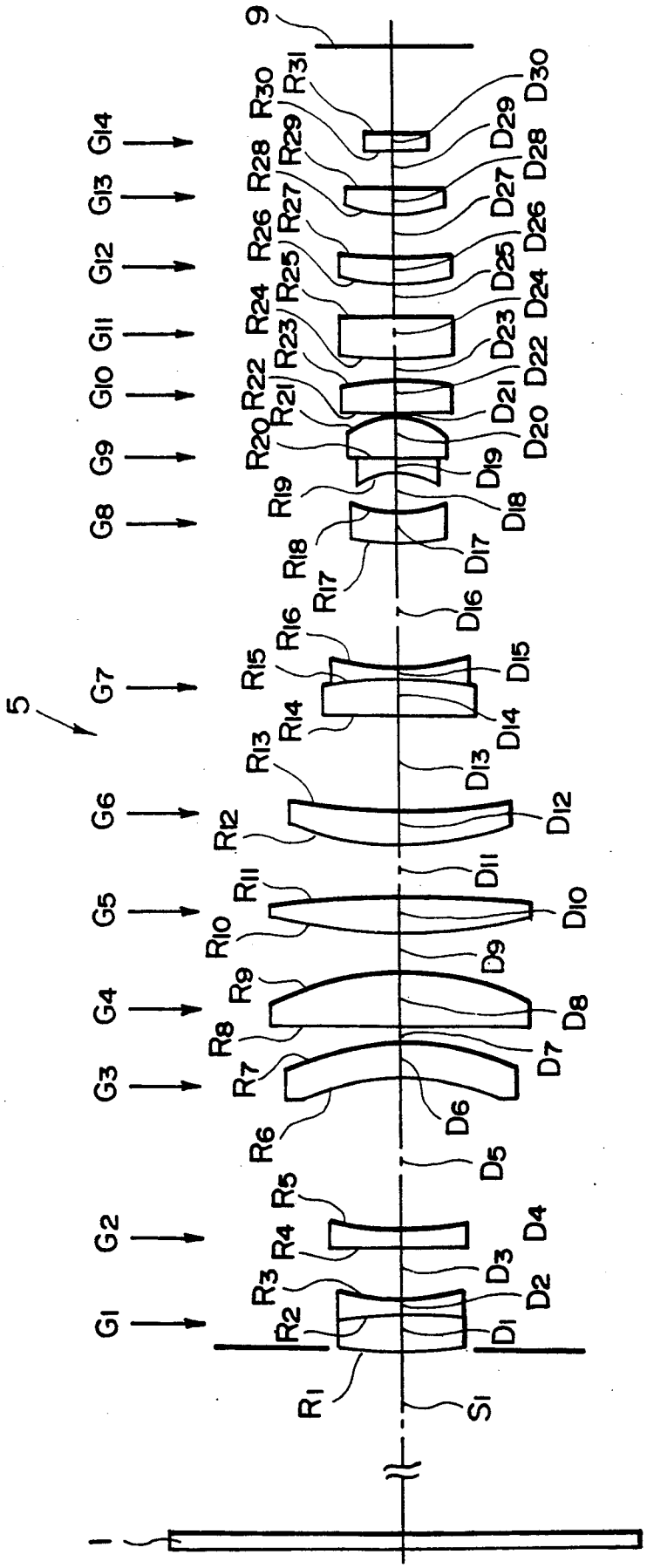

102
101
LIGHT SOURCE
103
ILLUMINATION OPTCS
1
108
5
CORRECTING MEANS
PROJECTION LENS SYSTEM
9
107
DETECTING MEANS

FIG. 1


5
G1
G2
G3
G4
G5
G6
G7
G8
G9
G10
G11
G12
G13
G14
R1
R2
R3
R4
R5
R6
R7
R8
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R10
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R12
R13
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D25
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D28
D29
D30
S1
9

FIG. 2

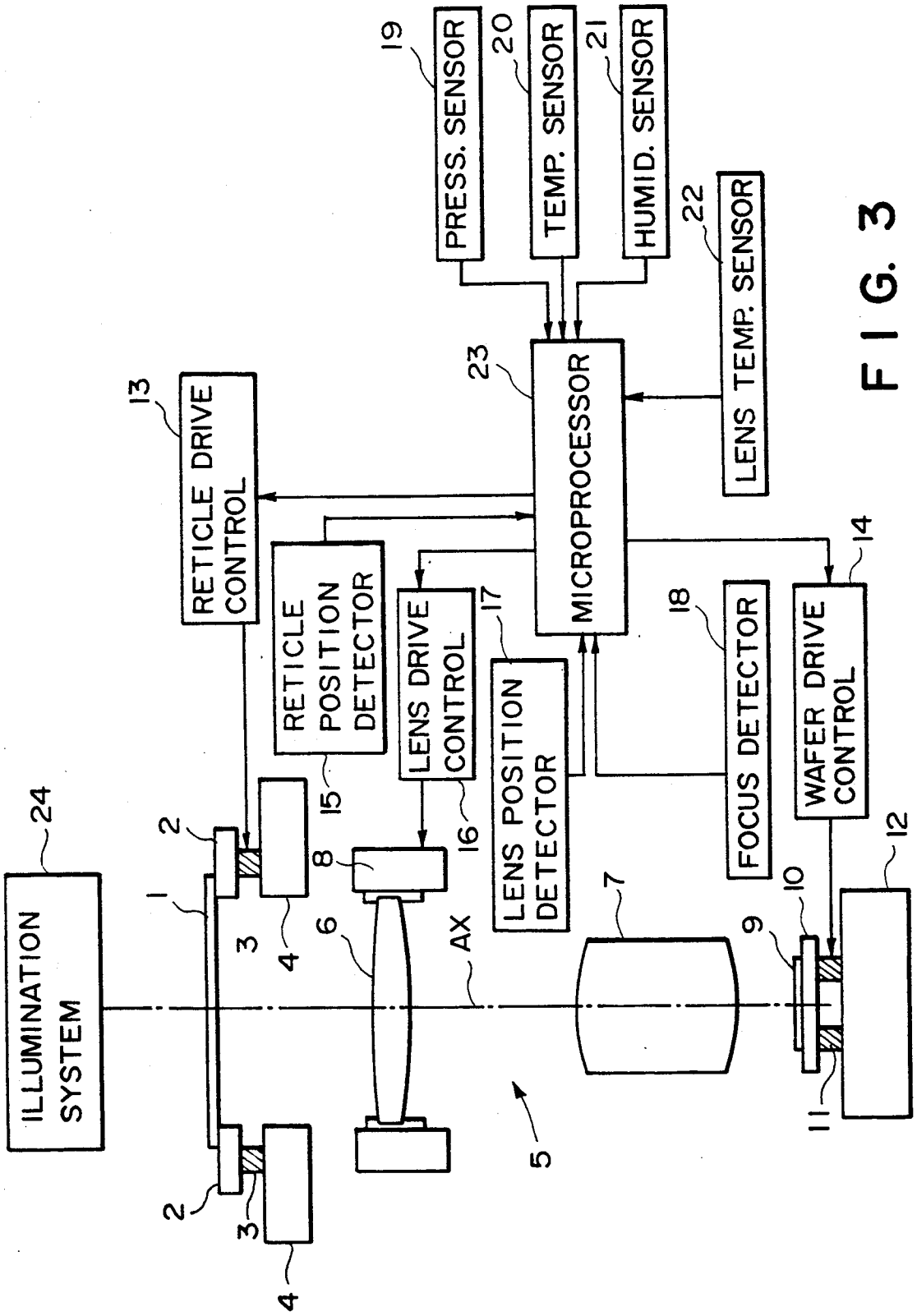
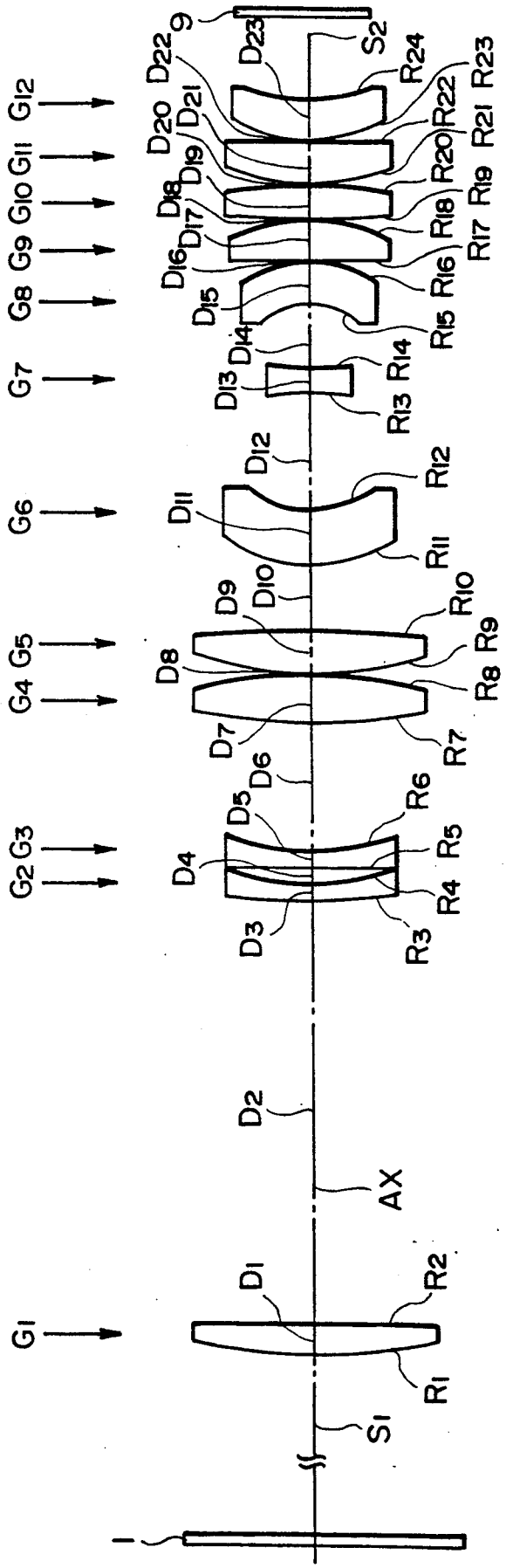

ILLUMINATION SYSTEM
24
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
AX
RETICLE DRIVE CONTROL
RETICLE POSITION DETECTOR
LENS DRIVE CONTROL
LENS POSITION DETECTOR
FOCUS DETECTOR
WAFER DRIVE CONTROL
MICROPROCESSOR
PRESS. SENSOR
TEMP. SENSOR
HUMID. SENSOR
LENS TEMP. SENSOR

FIG. 3


G1
G2
G3
G4
G5
G6
G7
G8
G9
G10
G11
G12
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
D14
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D16
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R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
R24
S1
S2
AX
9

FIG. 4

PROJECTION EXPOSURE APPARATUS

This application is a continuation of prior application, Ser. No. 07/572,340 filed Aug. 24, 1990, which application was a continuation of prior application, Ser. No. 07/409,311 filed Sept. 19, 1989, both now abandoned.

FIELD OF THE INVENTION AND RELATED ART

This invention relates to a projection exposure apparatus and, more particularly, to a projection exposure apparatus for use in the manufacture of semiconductor microcircuit devices, for projecting a circuit pattern of a reticle to a semiconductor wafer through a projection lens system.

In projection exposure apparatuses for manufacture of semiconductor chips such as integrated circuits, large scaled integrated circuits or otherwise, one important problem is enhancement of precision with regard to superposition of an image of a circuit pattern projected by a projection lens system on a semiconductor wafer, onto a circuit pattern having been formed on the wafer through a preceding process. As the factors which influence the superposing precision, there are error in the projection magnification of the projected image of the pattern and error with regard to the distortion of the projected image of the pattern, those problems being discussed in Japanese Laid-Open Patent Application Sho 62-35620. Those errors have to be sufficiently corrected before the image of the pattern is projected on the wafer for actual exposure.

SUMMARY OF THE INVENTION

It is accordingly an object of the present invention to provide a unique and improved projection exposure apparatus in which both the projection magnification error and the distortion error can be corrected satisfactorily.

In accordance with an aspect of the present invention, to achieve the above object, there is provided a projection exposure apparatus, comprising: a projection optical system for projecting an image of a pattern of a first object to a second object; and adjusting means for adjusting a projection magnification and distortion of the projected image of the pattern, said adjusting means being operable to displace the first object and one or more lens elements of said projection optical system in a direction of an optical axis of said projection optical system.

In accordance with one preferred form of the present invention, a projection exposure apparatus includes a projection optical system which is non-telecentric on the object side, but is telecentric on the image side and which is adapted to project an image of a pattern of a first object, placed on the object side, to a second object placed on the image side, and an adjusting means for displacing the first object in the direction of an optical axis of the projection optical system for adjustment of the projection magnification of the projected image of the pattern and also to displace at least one of the lens elements of the projection optical system, which is closest to or close to the first object, in the direction of the optical axis of the projection optical system for adjustment of distortion of the projected image of the pattern.

In accordance with another preferred form of the present invention, a projection exposure apparatus includes a projection optical system which is telecentric

both on the object side and on the image side and which is adapted to project an image of a pattern of a first object, placed on the object side, to a second object placed on the image side, and an adjusting means for displacing at least one of the lenses of the projection optical system, which is closest to or close to the first object, in a direction of an optical axis of the projection optical system for adjustment of the projection magnification of the projected image of the pattern and also to displace the first object in the direction of the optical axis of the projection optical system for adjustment of distortion of the image of the pattern.

These and other objects, features and advantages of the present invention will become more apparent upon consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram, schematically showing a projection exposure apparatus according to an embodiment of the present invention.

FIG. **2** is a section, showing the structure of a projection lens system of the projection exposure apparatus according to the FIG. **1** embodiment.

FIG. **3** is a schematic and diagrammatic view of a projection exposure apparatus according to another embodiment of the present invention.

FIG. **4** is a section, showing the structure of a projection lens system of the projection exposure apparatus according to the FIG. **3** embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** is a block diagram, showing one embodiment wherein the invention is applied to a projection exposure apparatus for manufacture of semiconductor devices.

Denoted in this Figure at **101** is a light source unit which comprises a super-high pressure Hg lamp, an elliptical mirror, an interference filter, a lens assembly and the like and which is adapted to emit light of g-line. Denoted at **102** is a reflection mirror for reflecting light from the light source unit **101** toward an illumination optical system **103**. The illumination optical system **103** receives the light from the reflection mirror **102** and illuminates a reticle **1** on which a fine electronic circuit pattern for IC, LSI or otherwise is formed. Denoted at **5** is a projection lens system for projecting, at a predetermined reducing magnification, an image of the circuit pattern of the reticle **1** to a wafer **9**. The projection lens system **5** is structured to be non-telecentric on the reticle **1** side, but to be telecentric on the wafer **9** side.

Denoted at **107** is a detecting means for detecting any magnification error and distortion of the projected image of the pattern of the reticle **1**. By way of example, a photoelectric converting means (not shown) such as a two-dimensional image pickup element is disposed at the position of the wafer **9** surface or at a position equivalent thereto. By this photoelectric converting means, the image of the pattern projected by the projection lens system **5** is photoelectrically converted into a video signal. The detecting means **107** receives the video signal and determines the position coordinate of each of a number of predetermined points of the projected image of the pattern, with respect to an X-Y coordinate system having been set on a plane (imaginary plane) which is orthogonal to an optical axis of the projection lens sys-

tem 5. Then, with regard to each point of the pattern image, the detecting means **107** calculates a deviation of the detected position coordinate of each point from a preset reference coordinate (reference grid, for example) of the X-Y coordinate system having been memorized into a memory of the detecting means **107**. On the basis of the thus obtained deviations, the detecting means **107** detects any error in the projection magnification of the projected image of the pattern as well as any distortion (which may result chiefly from symmetrical distortion aberration of the projection lens system **5**), and produces signals corresponding to the detected errors.

As an alternative, a pattern of a reticle may be actually printed on a wafer having a resist surface layer and, after development, any error in the projection magnification as well as distortion of the printed pattern may be measured by using a separate measuring device.

Denoted at **108** is a correcting means which is operable in response to the output signals from the detecting means **107** to change the distance (spacing) S_1 between the reticle **1** and the projection lens system **5** as well as one of the lens spacings of the lens elements constituting the projection lens system **5**.

In the present embodiment structured such as described above, the spacing S_1 as well as one of the spacings of the lenses of the projection optical system are adjusted, by which any error in the projection magnification of the image of the reticle pattern projected by the projection lens system as well as any distortion error of the projected image can be corrected satisfactorily, without causing deterioration of various aberrations due to displacement of the reticle and a lens or lenses.

The correcting means **108** of the present embodiment includes a reticle driving device (not shown) and a lens driving device (also not shown). The reticle driving device is operable to displace the reticle **1** in the direction of the optical axis of the projection lens system **5**. On the other hand, the lens driving device is operable to displace one or more lenses of the projection optical system **5**, closest to or close to the reticle **1**, in the direction of the optical axis of the projection optical system. These driving devices may be those of known type, such as disclosed in Japanese Laid-Open Patent Application Sho 62-32613 or Japanese Laid-Open Patent Application Sho 60-261137, and details of these driving devices are omitted here for simplicity.

Next, details of the lens structure of the projection optical system of the present embodiment will be explained.

FIG. **2** is a section of the projection lens system **5** used in the FIG. **1** apparatus.

Denoted in this Figure at **1** is a reticle on which an electronic circuit pattern is formed. Denoted at G_1 through G_{14} are lenses which constitute the projection lens system **5**; and denoted at **9** is a wafer which is placed at a best imaging plane of the projection lens system **5**. Character S_1 denotes the distance (on-axis air spacing) between the reticle **1** and the projection lens system **5**.

Numerical data of the projection lens system **5** of the present embodiment is set forth in Table 1.

In this numerical example, R_i (i=1-31) denotes the curvature radius (mm) of the i-th lens surface in an order from the object side (reticle **1** side); D_i(i=1-30) is the on-axis air spacing or on-axis lens thickness (mm) between the i-th surface and the (i+1)-th surface, in an order from the object side; N_i (i=1-17) denotes the refractive index of the i-th lens element in an order from the object side; and S_1 is the on-axis air spacing (mm) between the reticle **1** and the lens G_1.

TABLE 1

		S_i = 259.819	
G1	R_1 = 143.86	D_1 = 9.975	N_1 = 1.50415
	R_2 = −81.46	D_2 = 3.429	N_2 = 1.60250
	R_3 = 51.49	D_3 = 14.028	
G2	R_4 = 540.12	D_4 = 4.987	N_3 = 1.60250
	R_5 = 62.56	D_5 = 41.773	
G3	R_6 = −68.02	D_6 = 9.664	N_4 = 1.56226
	R_7 = −74.29	D_7 = 4.052	
G4	R_8 = 1355.17	D_8 = 15.587	N_5 = 1.50415
	R_9 = −73.55	D_9 = 10.287	
G5	R_{10} = 135.96	D_{10} = 10.599	N_6 = 1.53639
	R_{11} = −200.04	D_{11} = 13.093	
G6	R_{12} = 81.78	D_{12} = 9.352	N_7 = 1.56226
	R_{13} = 160.24	D_{13} = 24.004	
G7	R_{14} = −463.01	D_{14} = 9.664	N_8 = 1.53639
	R_{15} = −146.45	D_{15} = 2.805	N_9 = 1.60250
	R_{16} = 64.24	D_{16} = 34.915	
G8	R_{17} = 49.49	D_{17} = 8.417	N_{10} = 1.62753
	R_{18} = 30.04	D_{18} = 11.222	
G9	R_{19} = −16.99	D_{19} = 2.493	N_{11} = 1.60250
	R_{20} = 351.55	D_{20} = 11.534	N_{12} = 1.50415
	R_{21} = −22.57	D_{21} = 1.247	
G10	R_{22} = −654.15	D_{22} = 9.975	N_{13} = 1.50415
	R_{23} = −74.32	D_{23} = 4.751	
G11	R_{24} = 153.24	D_{24} = 11.534	N_{14} = 1.53639
	R_{25} = −275.84	D_{25} = 8.728	
G12	R_{26} = 50.46	D_{26} = 7.170	N_{15} = 1.56226
	R_{27} = 144.70	D_{27} = 10.911	
G13	R_{28} = 41.10	D_{28} = 7.274	N_{16} = 1.56226
	R_{29} = −387.53	D_{29} = 11.222	
G14	R_{30} = −95.33	D_{30} = 3.117	N_{17} = 1.62753
	R_{31} = −291.36		

Table 2 shows the amount of shift (ΔSD) (hereinafter "symmetrical distortion change ΔSD") of the image point at an image height of 10 mm on the image surface of the projection lens system, according to Table 1, resulting from a change in the symmetrical distortion aberration, as well as the amount of shift (Δβ) (hereinafter referred to as "projection magnification change Δβ") of that image point resulting from a change in the projection magnification, which occur when the on-axis spacing S_1 between the reticle **1** and the lens G_1 as well as the on-axis spacing D_3, D_5, D_7, D_9, D_{11}, D_{13}, D_{16}, D_{18}, D_{21}, D_{23}, D_{25}, D_{27} or D_{29} of adjacent lenses G_i and G_{i+1} (i=1-13) are changed individually, each by 1 mm. Also, in Table 2, there is shown the ratio $|\Delta SD/\Delta\beta|$ between these shifts. In Table 2, a sign "positive" is assigned to the shift of the image point which is in a direction away from the optical axis of the projection lens system, while a sign "negative" is assigned to the shift of the image point which is in a direction toward the optical axis of the projection lens system.

TABLE 2

	ΔSD (micron)	Δβ (micron)	ΔSD/Δβ
S_1	0.8	26	0.031
l_1	49.3	5	9.87
l_2	546.2	−138	3.96
l_3	515.3	−136	3.79
l_4	−6.9	7	0.98

TABLE 2-continued

	ΔSD (micron)	Δβ (micron)	ΔSD/Δβ
l_5	102.5	−148	0.69
l_6	145.5	−331	0.44
l_7	31.8	−58	0.55
l_8	40.3	12	3.36
l_9	15.4	55	0.28
l_{10}	6.3	−10	0.63
l_{11}	3.8	−53	0.07
l_{12}	5.4	−71	0.08
l_{13}	1.0	47	0.02

Based on Table 2, in the present embodiment, both the spacing S_1 and the spacing D_3 (with which aberration other than the symmetrical distortion is small) are adjusted for adjustment of the projection magnification and the symmetrical distortion.

When the change in the spacing S_1 is denoted by ΔS_1 and the change in the spacing D_3 is denoted by Δl_1, then from Table 2 the changes ΔSD and Δβ in the symmetrical distortion and the projection magnification can be expressed as follows:

$$\Delta SD = 0.8 \times \Delta S_1 + 49.3 \times \Delta D_3$$

$$\Delta\beta = 26 \times S_1 + 5 \times \Delta D_3 \quad (2)$$

Accordingly, once correction target values for the symmetrical distortion and the magnification projection are given, the changes ΔS_1 and ΔD_3 can be given by:

$$\Delta S_1 = -k(5 \times \Delta SD - 49.3 \times \Delta\beta)$$

$$\Delta D_3 = k(26 \times \Delta SD - 0.8 \times \Delta\beta) \quad (2)$$

wherein $k = (1277.8)^{-1}$

By using these values, it is now possible to satisfactorily correct both the projection magnification error and the symmetrical distortion error due to a change in pressure, temperature, humidity or otherwise.

The change in aberration of the projection lens system **5** which results from a change in the spacing S_1 (i.e. the distance between the reticle **1** and the projection lens system **5**), is small as compared with the change in paraxial value such as the projection magnification or focus position, for example, and the ratio between the change in the magnitude of aberration and the change in the paraxial value, that is

$$\frac{\text{(Change in Magnitude of Aberration)}}{\text{(Change in Paraxial Value)}}$$

is small. This is because the inclination of a light ray in the projection lens system **5** is large as compared with the inclination of a light ray between the object surface and the projection lens system and that, if the air spacing between lenses changes, there occurs a large difference in the height of incidence of the light ray at a refracting surface of the lens, thus causing a large aberration change. Accordingly, in the present embodiment wherein a projection lens system **5** which is telecentric only on the image side is used, the adjustment of distortion is made mainly by adjusting the spacings S_1 and D_3 through the movement of the lens G_1, while the adjustment of the projection magnification is made mainly by adjusting the spacing S_1 through the movement of the reticle **1**. In this manner, both the projection magnification error and the symmetrical distortion error in the projection exposure apparatus can be corrected.

While in the present embodiment the reticle **1** and the lens G_1 close to the reticle **1** are displaced for execution of adjustment of the projection magnification and the distortion, according to the type of projection lens system used, it is possible to structure the apparatus so that the reticle and a lens element, not close to the reticle, can be displaced. As a further alternative, a plurality of lens elements may be displaced.

FIG. **3** is a schematic and diagrammatic view of a projection exposure apparatus according to another embodiment of the present invention.

Denoted in FIG. **3** at **1** is a reticle on which a fine electronic circuit pattern is formed; at **2** is a reticle chuck for holding the reticle **1** by attraction; at **3** is a reticle driving device mounted to the reticle chuck **2**; at **4** is a reticle stage for supporting the reticle driving device **4**; at **5** is a reduction projection lens system which is telecentric both on the object side and on the image side; at **6** is lens (hereinafter referred to as a "field lens") of the projection lens system **5**, which lens is disposed close to the reticle **1**; at **7** is a lens system which is constituted by other lenses of the projection lens system **5**; at **8** is a lens driving device for displacing the field lens **7** in a direction of an optical axis AX of the projection lens system **5**; at **9** is a wafer which is coated with a radiation sensitive material such as resist, for example; at **10** is a wafer chuck for holding the wafer **9** by attraction; at **11** is a wafer driving device mounted to the wafer chuck **9**; and at **12** is a wafer stage for supporting the wafer driving device **11** and being movable in a plane perpendicular to the optical axis AX of the projection lens system **5**.

The reticle driving device **3** and the wafer driving device **11** each may comprise a piezoelectric device, for example. The reticle driving device **3** is operable to displace the reticle chuck **2** along the optical axis AX of the projection lens system **5** to thereby move the reticle **1** along the optical axis AX. The wafer driving device **11** is operable to displace the wafer chuck **10** along the optical axis AX of the projection lens system **5**, to thereby move the wafer **9** along the optical axis AX. On the other hand, the lens driving device **8** functions to move the field lens **6** along the optical axis AX of the projection lens system **5**, by using a pneumatic pressure. The lens driving device **8** may be of a known type such as disclosed in the aforementioned Japanese-Laid-Open Patent Application Sho 62-32613, and details of it are omitted here for simplicity.

The drive of the reticle chuck **2** by the reticle driving device **3** is executed in accordance with a signal from a reticle drive control system **13** and, here, the position of the reticle **1** in the direction of the optical axis AX can be detected by a reticle position detector **15**. Similarly, the drive of the field lens **8** by the lens driving device **8** is executed in accordance with a signal from a lens drive control system **16** and, here, the position of the field lens **8** in the direction of the optical axis AX can be detected by a lens position detector **17**. The reticle position detector **15** and the lens position detector **17** each may comprise any one of various position detectors, an example of which is an optical encoder. The drive of the wafer chuck **10** by the wafer driving device **11** is executed in accordance with a signal from a wafer drive control system **14** and, here, the position of the wafer **9** (the surface thereof) in the direction of the optical axis AX can be detected by a focus detector **18**. The focus detector **18** may comprise an air sensor or an optical sensor of a known type having been used convention-

ally in this type of projection exposure apparatus. The signals from the reticle position detector **15**, the lens position detector **17** and the focus detector **18** are supplied into a microprocessor **23**. On the other hand, in order to allow detection of any change in pressure, temperature and humidity around the projection lens system **5**, there are provided a pressure sensor **19**, a temperature sensor **20** and a humidity sensor **21**. Also, for detection of any change in temperature of the projection lens system **5** due to absorption of light, there is provided a lens temperature sensor **22**. Similarly, the signals from these sensors **19**, **20**, **21** and **22** are supplied into the microprocessor **23**. The reticle drive control system **13**, the lens drive control system **16** and the wafer drive control system **14** are all controlled by the microprocessor **23**.

Denoted at **24** is an illumination system for illuminating the circuit pattern of the reticle **1** with uniform illuminance. In this embodiment, the illumination system **24** includes a light source for exposure which comprises a KrF excimer laser that can emit a laser beam of a wavelength $\lambda=248.4$ nm. The laser beam from the illumination system **24** is directed through the reticle **1** and the projection lens system **5** to the wafer **9**, whereby an image of the circuit pattern of the reticle **1** is projected on the wafer **9**. In this embodiment, for projection exposure by use of a laser beam having a wavelength in a deep UV region, the lens elements constituting the projection lens system **5** are made of the same material of synthetic quartz (SiO_2) having a high transmission factor with respect to light of a wavelength $\lambda=248.4$ nm.

Details of the structure of the projection lens system **5** are such as illustrated in FIG. **4** which is a sectional view of the projection lens system **5**. As illustrated, the projection lens system **5** is constituted by twelve lens elements, denoted at G_1 through G_{12}, which are disposed between the reticle **1** and the wafer **9** and are arranged along the optical axis AX. One lens denoted at G_1 in FIG. **4** corresponds to the field lens **6** shown in FIG. **2**. Also, a lens group denoted at G_2 through G_{12} corresponds to the lens system **7** shown in FIG. **3**.

Numerical lens data of the projection lens system shown in FIG. **4** are set forth in Table 3. In Table 3, R_i ($i=1$–24) denotes the curvature radius (mm) of the i-th lens surface counted in an order from the object side (reticle **1** side); D_i ($i=1$–23) denotes the on-axis lens thickness or on-axis air spacing (mm) between the i-th lens surface and the (i+1)-th lens surface, counted in an order from the object side; and N_i ($i=1$–12) denotes the refractive index of the lens G_i ($i=1$–12). Further, S_1 denotes the on-axis air spacing (mm) between the circuit pattern bearing surface of the reticle **1** and the surface of the lens G_1, facing the reticle **1** side; and S_2 denotes the on-axis air spacing (mm) between the wafer **9** surface and the surface of the lens G_{12}, facing the wafer **9** side.

TABLE 3

		$S_1 = 100.0000$	
G1	$R_1 = 223.62115$	$D_1 = 15.00000$	$N_1 = 1.521130$
	$R_2 = -3002.34716$	$D_2 = 198.58486$	
G2	$R_3 = 447.09682$	$D_3 = 8.00000$	$N_2 = 1.521130$
	$R_4 = 120.41202$	$D_4 = 6.85000$	
G3	$R_5 = 1361.15326$	$D_5 = 8.00000$	$N_3 = 1.521130$
	$R_6 = 116.03892$	$D_6 = 60.00000$	
	$R_7 = 233.10252$	$D_7 = 24.00000$	$N_4 = 1.521130$

TABLE 3-continued

G4	$R_8 = -194.78245$	$D_8 = 1.00000$	
G5	$R_9 = 183.54325$	$D_9 = 20.00000$	$N_5 = 1.521130$
	$R_{10} = -539.45990$	$D_{10} = 30.00000$	
G6	$R_{11} = 68.35126$	$D_{11} = 27.00000$	$N_6 = 1.521130$
	$R_{12} = 49.48403$	$D_{12} = 55.00000$	
G7	$R_{13} = -74.38180$	$D_{13} = 12.00000$	$N_7 = 1.521130$
	$R_{14} = 121.20157$	$D_{14} = 30.00000$	
G8	$R_{15} = -36.94984$	$D_{15} = 20.00000$	$N_8 = 1.521130$
	$R_{16} = -53.05412$	$D_{16} = 1.00000$	
G9	$R_{17} = -664.38932$	$D_{17} = 18.00000$	$N_9 = 1.521130$
	$R_{18} = -89.10035$	$D_{18} = 1.00000$	
G10	$R_{19} = 358.30545$	$D_{19} = 16.50000$	$N_{10} = 1.521130$
	$R_{20} = -215.20590$	$D_{20} = 1.00000$	
G11	$R_{21} = 122.34875$	$D_{21} = 18.50000$	$N_{11} = 1.521130$
	$R_{22} = 608.00265$	$D_{22} = 1.00000$	
G12	$R_{23} = 68.11099$	$D_{23} = 20.00000$	$N_{12} = 1.521130$
	$R_{24} = 103.07287$	$S_2 = 73.14190$	

Table 4 shows the amount of shift (ΔSD) (hereinafter "symmetrical distortion change ΔSD") of the image point at an image height of 10 mm on the image surface of the projection lens system, according to Table 3, resulting from a change in the symmetrical distortion aberration, and the amount of shift ($\Delta\beta$) (hereinafter referred to as "projection magnification change $\Delta\beta$") of that image point resulting from a change in the projection magnification, which occur when the on-axis spacing S_1 between the reticle **1** and the lens G_1, the on-axis air spacing S_2 between the lens G_{12} and the wafer **9**, and the on-axis air spacing D_{2i} ($i=1$–11) between adjacent lenses G_i and G_{i+1} ($i=1$–11), are changed individually, each by 1 mm. Also, in Table 4, there is shown the ratio $|\Delta SD/\Delta\beta|$ between these shifts. In Table 4, a sign "positive" is assigned to the shift of the image point which is in a direction away from the optical axis of the projection lens system, and a sign "negative" is assigned to the shift of the image point which is in a direction toward the optical axis of the projection lens system.

TABLE 4

	ΔSD (micron)	$\Delta\beta$(micron)	$\lvert\Delta SD/\Delta\beta\rvert$
S_1	0.77	0	∞
D_2	1.08	−20	0.054
D_4	1.03	−15	0.068
D_6	4.40	20	0.22
D_8	−0.33	−10	0.033
D_{10}	−0.32	45	0.007
D_{12}	0.19	35	0.005
D_{14}	−0.24	−75	0.003
D_{16}	0.58	−90	0.006
D_{18}	−0.67	−10	0.067
D_{20}	−0.39	20	0.020
D_{22}	0.20	20	0.01
S_2	0	0	0

Based on Table 4, in the present embodiment both the spacings S_1 and D_2 (with which the change in aberration other than the symmetrical distortion aberration is small) are adjusted for adjustment of the projection magnification and the symmetrical distortion.

When the change in the spacing S_1 is denoted by ΔS_1 and the change in the spacing D_2 is denoted by ΔD_2, then from Table 4 the changes ΔSD and $\Delta\beta$ in the

symmetrical distortion and the projection magnification can be expressed such as follows:

$$\Delta SD = 0.77 \times \Delta S_1 + 1.08 \times \Delta D_2$$

$$\Delta\beta = -20 \times \Delta D_2 \quad (3)$$

Accordingly, the changes ΔD_2 and ΔS_1 can be given by:

$$\Delta S_1 = k_1(20 \times \Delta SD + 1.08 \times \Delta\beta)$$

$$\Delta D_2 = 1/20 \times \Delta\beta \quad (4)$$

wherein $k_1 = (15.4)^{-1}$

The change in aberration of the projection lens system **5** which results from a change in the spacing S_1 (i.e. the distance between the reticle **1** and the projection lens system **5**), is small as compared with the change in paraxial value such as the projection magnification or focus position, for example, and the ratio between the change in the magnitude of aberration and the change in the paraxial value, that is

$$\frac{\text{(Change in Magnitude of Aberration)}}{\text{(Change in Paraxial Value)}}$$

is small. This is because the inclination of a light ray in the projection lens system **5** is large as compared with the inclination of a light ray between the object surface and the projection lens system and that, if the air spacing between lenses changes, there occurs a large difference in the height of incidence of the light ray at a refracting surface of the lens, thus causing a large aberration change.

Accordingly, in the present embodiment which uses a projection lens system **5** that is telecentric both on the object side and on the image side, the adjustment of the projection magnification is made mainly by adjusting the spacings S_1 and D_2 through the movement of the lens G_1 (field lens **6**), while the adjustment of distortion is made mainly by adjusting the spacing S_1 through the movement of the reticle **1**. In this manner, both the projection magnification error and the symmetrical distortion error in the projection exposure apparatus can be corrected.

Referring back to FIG. **3**, description will be made of details of the manner of correcting the projection magnification error and the distortion error of a projected image of a pattern, in the projection exposure apparatus of the present embodiment.

The microprocessor **23** has a memory in which calculating equations for obtaining the projection magnification change $\Delta\beta$ and the distortion change ΔSD of the projection lens system **5** are programmed in advance. Each equation contains variables each corresponding to a change in pressure, temperature, humidity or a change in temperature of the projection lens system **5**, with respect to a preset reference value. Also, equation (4) discussed above is programmed in this memory, such that by substituting the values of $\Delta\beta$ and ΔSD into equation (4), it is possible to obtain the amount of movement of the field lens **6** and the amount of movement of the reticle **1**. It is to be noted that the equations for obtaining the values $\Delta\beta$ and ΔSD on the basis of the changes in pressure, temperature and in the temperature of the projection lens system, can be determined by experiments. On the other hand, the focus position of the pattern image formed by the projection lens system **5** changes depending upon the pressure, temperature and humidity around the projection lens system **5** as well as upon the temperature of the projection lens system **5**. Additionally, it is changeable depending upon the positions of the reticle **1** and the field lens **6**. Thus, in the present embodiment, on the basis of these variation factors, the calculating equations for obtaining the magnitude of the change in focus position of the projection lens system **5** are programmed in advance in the memory of the microprocessor **23** and, in accordance with the calculating equations, the focus position can be detected correctly.

The microprocessor **23** receives signals from the pressure sensor **19**, the temperature sensor **20**, the humidity sensor **21** and the lens temperature sensor **22**, corresponding to the pressure, the temperature, the humidity and the lens temperature, and determines the amount of movement of the reticle **1** and the amount of the movement of the field lens **6** in accordance with the predetermined conditioning equations such as described hereinbefore. On the other hand, signals from the reticle position detector **15** and the lens position detector **17**, corresponding to the positions of the reticle **1** and the field lens **6** (with respect to the direction of the optical axis AX), are applied to the microprocessor **23**. In response, the microprocessor **23** supplies, to the reticle drive control system **13**, a position signal of the reticle **1** and a signal corresponding to the amount of movement of the reticle **1** to be made, and also supplies, to the lens drive control system **16**, a position signal of the field lens **6** and a signal corresponding to the amount of movement of the field lens **6** to be made. Then, in response to the signals from the microprocessor **23**, the reticle drive control system **13** applies a suitable control signal to the reticle driving device **3** such that, by this reticle driving device **3**, the reticle **1** is moved in the direction of the optical axis AX by a suitable amount. Also, in response to the signals from the microprocessor **23**, the lens drive control system **16** applies a suitable control signal to the lens driving device **16** such that, by this lens driving device **16**, the field lens **6** is moved in the direction of the optical axis AX by a suitable amount. By this adjustment of the position of the reticle **1** and the field lens **6**, the projection magnification error and the distortion error of the pattern image due to the change in pressure, temperature or humidity around the projection lens system **5** or the temperature of the projection lens system **5**, can be corrected.

Further, on the basis of the signals from the reticle position detector **15**, the lens position detector **17**, the pressure sensor **19**, the temperature sensor **20**, the humidity sensor **21** and the lens temperature sensor **22**, the microprocessor **23** operates to detect the focus position of the pattern image formed by the projection lens system **5**, and controls the wafer drive control system **14** in accordance with the signal from the focus detector **18** corresponding to the position of the wafer **9** (the surface thereof), so that the wafer **9** can be correctly positioned at the focus position. The wafer drive control system **14** applies a suitable control signal to the wafer driving device **11**, such that, by this wafer driving system **11**, the wafer **9** is moved in the direction of the optical axis AX, whereby the wafer **9** can be positioned at the focus position of the pattern image.

With the operation described hereinbefore, the projection magnification of the pattern image can be corrected to a predetermined magnification and the distortion of the pattern image can be reduced to a predeter-

mined allowable range. By this, the pattern image can be correctly superposed on a pattern having been formed on the wafer **9** by the preceding process. Additionally, since the wafer **9** position can be made coincident with the focus position of the pattern image, a sharp pattern image can be projected on the wafer **9**.

While in the present embodiment, the movable field lens **6** for adjustment of the projection magnification of the pattern image is constituted by one lens element (G_1), it may be constituted by plural lens elements. Also, while in the present embodiment the output signals of the pressure sensor **19**, the temperature sensor **20**, the humidity sensor **21** and the lens temperature sensor **22** are used for detection of any change in the projection magnification and distortion of the pattern image, resulting from the changes in pressure, temperature, humidity and lens temperature, it is a possible alternative that the pattern image as projected through the projection lens system **5** is picked up by using an image pickup device and any change in the projection magnification and distortion of the pattern image is detected on the basis of the size and shape of the pattern image, as in the foregoing embodiment. If, on that occasion, the image pickup device is mounted to the wafer stage **12**, it is then possible to detect any change in the projection magnification or distortion of the pattern image at a desired moment and also, it is possible to avoid complicated structure of the exposure apparatus.

While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purposes of the improvements or the scope of the following claims.

What is claimed is:

1. A projection exposure apparatus, comprising:

a projection optical system for projecting an image of a pattern of a first object to a second object; and

adjusting means for adjusting projection magnification and distortion of the projected image of the pattern, said adjusting means being operable to displace the first object and a lens element of said projection optical system in a direction of an optical axis of said projection optical system.

2. An apparatus according to claim **1**, wherein said adjusting means includes first driving means for moving the first object and a second driving means for moving said lens element.

3. An apparatus according to claim **2**, wherein said lens element is one of the lens elements of said projection optical system which is close to the first object.

4. An apparatus according to claim **2**, further comprising:

a pressure sensor for detecting any change in pressure surrounding said apparatus; and

control means responsive to an output from said pressure sensor, for controlling said adjusting means.

5. An apparatus according to claim **4**, further comprising:

a first position sensor for detecting the position of said lens element;

a second position sensor for detecting the position of the first object;

wherein outputs of said first and second position sensors are applied to said control means and wherein, on the basis of the outputs of said first and second position sensors and of an output of said pressure sensor, said control means determines the amount of movement of each of the first object and said lens element to be made.

6. An apparatus according to claim **5**, further comprising:

a temperature sensor for detecting any change in temperature surrounding said apparatus; and

a humidity sensor for detecting any change in humidity surrounding said apparatus;

wherein outputs of said temperature sensor and said humidity sensor are applied to said control means and wherein, on the basis of the outputs of said temperature sensor and said humidity sensor, said control means determines the amount of movement of each of the first object and said lens element to be made.

7. An apparatus according to claim **5**, further comprising:

detecting means for detecting the position of the second object; and

a driving mechanism for moving the second object in a direction of an optical axis of said projection optical system;

wherein on the basis of signals from said pressure sensor and said detecting means, said control means controls said driving mechanism so as to position the second object at a focus position of said projection optical system.

8. An apparatus according to claim **1**, wherein said adjusting means displaces the first object and said lens element substantially without causing a change in aberration of said projection optical system, other than symmetrical distortion aberration.

9. An apparatus according to claim **2**, further comprising:

image detecting means for taking an image of the pattern and for detecting any change thereof; and

control means responsive to an output from said image detecting means, for controlling said adjusting means.

10. A projection exposure apparatus, comprising:

a projection optical system for projecting an image of a pattern of a first object on a second object; said projection optical system being nontelecentric on the first object side and being telecentric on the second object side; and

adjusting means for moving the first object in a direction of an optical axis of said projection optical system for adjustment of projection magnification of the image of the pattern, and for moving a lens element of said projection optical system which is close to the first object, in the direction of the optical axis of said projection optical system, for adjustment of distortion of the image of the pattern.

11. An apparatus according to claim **10**, wherein said adjusting means displaces the first object and said lens element substantially without causing a change in aberration of said projection optical system, other than symmetrical distortion aberration.

12. A projection exposure apparatus, comprising:

a projection optical system for projecting an image of a pattern of a first object on a second object, said projection optical system being telecentric both on the first object side and on the second object side; and

adjusting means for moving a lens of said projection optical system close to the first object in a direction of an optical axis of said projection optical system, for adjustment of projection magnification of the

image of the pattern, and for moving the first object in the direction of the optical axis of said projection optical system, for adjustment of distortion of the image of the pattern.

13. An apparatus according to claim **12**, wherein said adjusting means displaces the first object and said lens element substantially without causing a change in aberration of said projection optical system, other than symmetrical distortion aberration.

14. A projection exposure apparatus, comprising:

a projection optical system, having an optical axis and including a plurality of lenses, for projecting a pattern of a mask onto a wafer; and

an adjusting means for changing an interval, with respect to the direction of the optical axis, between the mask and one of said plurality of lenses of said projection optical system, which lens is close to the mask, to compensate for distortion of said projection optical system.

15. An apparatus according to claim **14**, wherein said projection optical system is telecentric on the mask side, and said adjusting means comprises means for displacing the mask in the direction of the optical axis to thereby compensate for the distortion.

16. An apparatus according to claim **14**, wherein said projection optical system is non-telecentric on the mask side, and said adjusting means comprises means for displacing said one lens in the direction of the optical axis to thereby compensate for the distortion.

17. An apparatus according to claim **14**, further comprising means for adjusting magnification of said projection optical system with respect to projection of the pattern.

18. An apparatus according to claim **15**, further comprising means for adjusting magnification of said projection optical system with respect to projection of the pattern.

19. An apparatus according to claim **16**, further comprising means for adjusting magnification of said projection optical system with respect to projection of the pattern.

20. In a semiconductor device manufacturing method including projecting an image of a circuit pattern of a mask onto a wafer through a projection optical system, the improvement comprising:

determining a change in distortion of the projection optical system; and

changing an interval between the mask and the projection optical system with respect to a direction of an optical axis of the projection optical system in accordance with the determination, so as to substantially correct any change in distortion.

21. In a semiconductor device manufacturing method including projecting an image of a circuit pattern of a mask onto a wafer through a projection lens system, the improvement comprising:

determining a change in each of distortion and magnification of the projection lens system; and

displacing, in accordance with the determination, the mask and a lens element of the projection lens system, which lens element is near the mask in a direction of an optical axis of the projection optical system, so as to substantially correct any changes in distortion and magnification.

22. In a semiconductor device manufacturing method including projecting an image of a circuit pattern of a mask onto a wafer through a projection optical system, the improvement comprising:

changing an interval between the mask and the projection optical system with respect to a direction of an optical axis of the projection optical system so as to substantially correct distortion of the projected image of the circuit pattern.

23. In a semiconductor device manufacturing method including projecting an image of a circuit pattern of a mask onto a wafer through a projection lens system, the improvement comprising:

displacing the mask and a lens of the projection lens system, which lens element is near the mask, so as to substantially correct any error in size and distortion of the projected image of the circuit pattern.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. 5,105,075

DATED April 14, 1992

INVENTOR(S) Masakatu Ohta, et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

ON THE TITLE PAGE

IN FOREIGN APPLICATION PRIORITY DATA

"Sep. 19, 1988 [JP] Japan ... 1-234096
Aug. 30, 1989 [JP] Japan ... 64-226204"
should read:
--Sep. 19, 1988 [JP] Japan ... 63-234096
Aug. 30, 1989 [JP] Japan ... 1-226204--.

IN U.S. PATENT DOCUMENTS

"4,825,247 10/1989 Kemi et al." should read --4,825,247 4/1989 Kemi, et al.--.

IN THE DISCLOSURE

COLUMN 5

Line 26, "$\Delta B=26xS_1+5x\Delta D_3$ (2)" should read --$\Delta B=26x\Delta S_1+5x\Delta D_3$ (1)--.

Signed and Sealed this

Twentieth Day of July, 1993

Attest:

Michael K. Kirk

MICHAEL K. KIRK

Attesting Officer

Acting Commissioner of Patents and Trademarks