

# OPTICAL ARRANGEMENT OF AUTOFOCUS ELEMENTS FOR USE WITH IMMERSION LITHOGRAPHY

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## BACKGROUND OF THE INVENTION

This invention relates to an optical arrangement of autofocus elements for use with immersion lithography.

10 In semiconductor lithography systems in use today, automatic focusing and leveling (AF/AL) is typically accomplished by passing a low angle of incidence optical beam onto the surface of a silicon wafer and detecting its properties after subsequent reflection from the wafer surface. The wafer height is determined by optical and electrical processing of the reflected light beam. This beam passes under the last element of the projection lens. The source and receiver optics are typically mounted to a stable part of the system, close to the projection optics mounting  
15 position.

In immersion lithography, a liquid such as water fills the space between the last surface of the projection lens and the wafer. At the edge of the water, typically at the edge of the lens or supported structure near the edge of the lens, the liquid-air boundary is not well defined and changing rapidly. It is not possible to transmit an  
20 AF/AL beam through this interface without substantial disruption and subsequent loss of signal, and hence performance.

It is therefore a general object of this invention to provide a way to introduce AF/AL beams into the liquid layer without such disruption so as to preserve the optical accuracy and stability required.

25 More specifically, it is an object of this invention to provide an apparatus and a method for allowing AF/AL light beams to be used as in conventional lithography without the disrupting influence of the liquid immersion boundary at the edge of the lens.

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## SUMMARY OF THE INVENTION

Autofocus units according to this invention are for an immersion lithography apparatus which may be described generally as comprising not only a reticle stage arranged to retain a reticle, a working stage arranged to retain a workpiece with a

target surface and an optical system including an illumination source and an optical element such as a lens positioned opposite and above the workpiece for having an image pattern of the reticle projected on the workpiece by radiation from said illumination source, but also a fluid-supplying device for providing a fluid into the space defined between the optical element and the workpiece such that the fluid contacts both the optical element and the target surface of the workpiece. The optical element positioned opposite to the workpiece may be treated as a component of the autofocus unit itself which may be characterized as further comprising an autofocus light source serving to project a light beam obliquely at a specified angle such that this light beam passes through the fluid and is reflected by the target surface of the workpiece at a specified reflection position which is below the optical element, and a receiver for receiving and analyzing the light beam reflected by the target surface. Correction lenses may preferably be disposed on the optical path of the light beam projected from the autofocus light source for correcting propagation of the light beam.

As an alternative embodiment, the optical element opposite the workpiece may be cut on its two mutually opposite sides and optically transparent wedge-shaped elements may be placed under these cuts such that the light beam from the autofocus light source will pass through them as it is passed through the fluid to be reflected on the target surface of the workpiece and to reach the receiver without passing through the optical element at all. In order to cope with the potential problem of bubbles that may be formed due to the gap between the wedge element and the optical element, the gap may be filled with a suitable material, made sufficiently narrow such as less than 2.0mm such that capillary forces will keep the gap filled with the fluid, or provided with means for supplying a small suction to cause the fluid to move up through the gap or to supply the fluid such that that the gap can be kept filled. The boundary surface through which the light beam from the autofocus light source is refracted into the fluid from the interior of the wedge element need not be parallel to the target surface of the workpiece but may be appropriately sloped, depending on the indices of refraction of the materials that affect the design of the unit.

## BRIEF DESCRIPTION OF THE DRAWING

The invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a schematic cross-sectional view of an immersion lithography apparatus that incorporates the present invention;

Fig. 2 is a process flow diagram illustrating an exemplary process by which semiconductor devices are fabricated using the apparatus shown in Fig. 1 according to the present invention;

Fig. 3 is a flowchart of the wafer processing step shown in Fig. 2 in the case of fabricating semiconductor devices according to the present invention;

Fig. 4 is a schematic side cross-sectional view of an autofocus unit embodying this invention;

Fig. 5 is a schematic side cross-sectional view of another autofocus unit embodying this invention;

Fig. 6 is an enlarged view of a circled portion VI of Fig. 5.

Figs. 7, 8 and 9 are schematic side cross-sectional views of portions of other autofocus unit embodying this invention according to different embodiment of the invention.

Throughout herein, items and components that are equivalent or similar are sometimes indicated by the same numeral in different figures and may not necessarily be explained in a repetitious manner.

## DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Fig. 1 shows the general structure of an immersion lithography apparatus 100 which may incorporate the optical arrangement of autofocus elements embodying this invention.

As shown in Fig. 1, the immersion lithography apparatus 100 comprises an illuminator optical unit 1 including a light source such as a KrF excimer laser unit, an optical integrator (or homogenizer) and a lens and serving to emit pulsed ultraviolet light IL with wavelength 248nm to be made incidence to a pattern on a reticle R. The pattern on the reticle R is projected on a wafer W coated with a photoresist at a specified magnification (such as 1/4 or 1/5) through a telecentric light projection unit PL. The pulsed light IL may alternatively be ArF excimer laser light with wavelength 193nm, F<sub>2</sub> laser light with wavelength 157nm or the i-line of a mercury lamp with

wavelength 365nm. In what follows, the coordinate system with X-, Y- and Z-axes as shown in Fig. 1 is referenced to explain the directions in describing the structure and functions of the lithography apparatus 100. For the convenience of disclosure and description, the light projection unit PL is illustrated in Fig. 1 only by way of its last-  
5 stage optical element (such as a lens) 4 disposed opposite to the wafer W and a cylindrical housing 3 containing all others of its components.

The reticle R is supported on a reticle stage RST incorporating a mechanism for moving the reticle R by some amount in the X-direction, the Y-direction and the rotary direction around the Z-axis. The two-dimensional position and orientation of  
10 the reticle R on the reticle stage RST are detected by a laser interferometer (not shown) in real time and the positioning of the reticle R is effected by a main control unit 14 on the basis of the detection thus made.

The wafer W is set on a wafer holder (not shown) on a Z-stage 9 for controlling the focusing position (along the Z-axis) and the sloping angle of the wafer  
15 W. The Z-stage 9 is affixed to an XY-stage 10 adapted to move in the XY-plane substantially parallel to the image-forming surface of the light projection unit PL. The XY-stage 10 is set on a base 11. Thus, the Z-stage 9 serves to match the wafer surface with the image surface of the light projection unit PL by adjusting the focusing position (along the Z-axis) and the sloping angle of the wafer W by the auto-focusing  
20 and auto-leveling method, and the XY-stage 10 serves to adjust the position of the wafer W in the X-direction and the Y-direction.

The two-dimensional position and orientation of the Z-stage 9 (and hence also of the wafer W) are monitored in real time by another laser interferometer 13 with reference to a mobile mirror 12 affixed to the Z-stage 9. Control data based on the  
25 results of this monitoring are transmitted from the main control unit 14 to a stage-driving unit 15 adapted to control the motions of the Z-stage 9 and the XY-stage 10 according to the received control data. At the time of an exposure, the projection light is made to sequentially move from one to another of different exposure positions on the wafer W according to the pattern on the reticle R in a step-and-repeat routine.

30 The lithography apparatus 100 being described with reference to Fig. 1 is an immersion lithography apparatus and is hence adapted to have a liquid (or the "immersion liquid") 7 of a specified kind such as water filling the space between the

surface of the wafer W and the lower surface of the last-stage optical element 4 of the light projection unit PL at least while the pattern image of the reticle R is being copied on the wafer W.

5 The last-stage optical element 4 of the light projection unit PL is affixed to the cylindrical housing 3. In an optional embodiment, the last-stage optical element 4 may be made removable for cleaning or maintenance.

10 The liquid 7 is supplied from a liquid supply unit 5 that may comprise a tank, a pressure pump and a temperature regulator (not individually shown) to the space above the wafer W under a temperature-regulated condition and is collected by a liquid recovery unit 6. The temperature of the liquid 7 is regulated to be approximately the same as the temperature inside the chamber in which the lithography apparatus 100 itself is disposed. Numeral 21 indicates source nozzles through which the liquid 7 is supplied from the supply unit 5. Numeral 23 indicates recovery nozzles through which the liquid 7 is collected into the recovery unit 6. It is 15 to be reminded, however, that the structure described above with reference to Fig. 1 is not intended to limit the scope of the immersion lithography apparatus to which the liquid-removing methods and devices of the present invention are applicable. In other words, autofocus units of the present invention may be incorporated into immersion lithography apparatus of many different kinds. In particular, it is to be reminded that 20 the numbers and arrangements of the source and recovery nozzles 21 and 23 around the light projection unit PL may be designed in a variety of ways for establishing a smooth flow and quick recovery of the immersion liquid 7.

Fig. 4 shows an autofocus unit 50 (not shown in Fig. 1) according to this invention which may be incorporated into an immersion lithography system such as 25 shown at 100 in Fig. 1 but the invention is not intended to be limited by the specific type of the system into which it is incorporated. In this example, the last-stage optical element 4 of the light projection unit PL is a hemispherically shaped projection lens with its planar surface facing downward opposite to the upper surface (the "target surface") of the wafer W a space left in between. An autofocus light source 51 is 30 arranged such that its AF/AL light beam 54, emitted obliquely with respect to the target surface of the wafer W, passes through a lower peripheral part of this lens 4 and then is refracted into the immersion liquid 7 so as to be reflected by the target surface of the wafer W at a specified reflection position 55. A receiver 52 for receiving and

analyzing the reflected AF/AL light beam 54 is appropriately positioned on the opposite side of the light projection unit PL. Numerals 53 each indicate a what may be referred to as a correction lens disposed on the path of the AF/AL light beam 54 for correcting light propagation. Since the interface between the lens 4 and the liquid 7 is well defined and essentially free of bubbles, the light beams are unimpeded and can provide good signals to maintain high accuracy. In Fig. 4, broken lines indicate the exposure light cone, or the boundary of the exposure region.

Fig. 5 shows another autofocus unit 60 according to another embodiment of the invention. Its components that are similar to those described above with reference to Fig. 5 are indicated by the same numerals. The unit 60 shown in Fig. 5 is characterized as having the lower surface of the last-stage optical element 4 of the light projection unit PL cut in two places facing respectively the autofocus light source 51 and the receiver 52. The cut surfaces may be preferably flat, as shown in Fig. 5, and the last-stage optical element 4 is still functionally and essentially a hemispherical lens. Optically transparent parts, referred to as wedge elements 61 and 62, are placed on both sides of the lens 4 under these cut surfaces, the element 61 being on the side of the autofocus light source 51 and the element 62 being on the side of the receiver 52. The cuts and the wedge elements 61 and 62 are so designed that the AF/AL light beam 54 from the autofocus light source 51 will pass through the wedge element 61 and refracted into the immersion liquid 7 without passing through the lens 4 and, after being reflected by the target surface of the wafer W at the reflection position 55, will be refracted into the wedge element 62 and received by the receiver 52 again without passing through the lens 4. This embodiment is advantageous because the wedge elements can be made of a different material from the lens element 4 such as optical glass.

The lower interface between the wedge elements 61 and 62 and the lens 4 is important from the points of view of correct optical performance and generation of bubbles in the immersion liquid 7. With reference to Fig. 6, which shows more in detail the portion of the wedge element 61 in a close proximity of the lens 4, the gap D therebetween is a potential source of air bubbles, which may be entrained under the lens 4, adversely affecting its optical performance.

One of the solutions to this problem is to fill the gap with a suitable material or to press the wedge element 61 into contact with the lens 4 such that the gap D

becomes effectively zero and therefore does not perturb the liquid interface. Another solution is to keep D approximately equal to or less than 2.0mm such that capillary forces cause the liquid 7 to fill the gap and keep it filled even while the wafer W is moved under the lens 4. A third solution is to supply a small suction to cause the liquid 7 to move up inside the gap D and to prevent air from moving downward, as shown in Fig. 7 wherein numeral 70 indicates an air pump for providing the suction. Fig. 8 shows still another solution whereby a source 72 of the liquid 7 is supplied above the opening of the gap D to keep the gap D filled with the liquid 7.

The invention has been described above with reference to only a limited number of arrangements but they are not intended to limit the scope of the invention. Many modifications and variations are possible within the scope of the invention. The shaped of the wedge elements 61 and 62, for example need not be as described above with reference to Fig. 6. Depending, for example, upon the desired angle of incidence of the AF/AL light beam 54 relative to the indices of refraction of the immersion liquid 7 and the material of the wedge element 61, it may be advantageous, as shown in Fig. 9, to provide the wedge element 61 with a sloped surface portion 64 such that the AF/AL light beam 54 passing through the wedge element 61 will be refracted into the immersion liquid 7 not necessarily through a horizontal boundary surface as shown in Fig. 6 but through this appropriately sloped surface portion 64. This will provide flexibility in the design of the arrangement embodying this invention.

Fig. 2 is referenced next to describe a process for fabricating a semiconductor device by using an immersion lithography apparatus incorporating a liquid jet and recovery system embodying this invention. In step 301 the device's function and performance characteristics are designed. Next, in step 302, a mask (reticle) having a pattern is designed according to the previous designing step, and in a parallel step 303, a wafer is made from a silicon material. The mask pattern designed in step 302 is exposed onto the wafer from step 303 in step 304 by a photolithography system such as the systems described above. In step 305 the semiconductor device is assembled (including the dicing process, bonding process and packaging process), then finally the device is inspected in step 306.

Fig. 3 illustrates a detailed flowchart example of the above-mentioned step 304 in the case of fabricating semiconductor devices. In step 311 (oxidation step), the wafer surface is oxidized. In step 312 (CVD step), an insulation film is formed on the

wafer surface. In step 313 (electrode formation step), electrodes are formed on the wafer by vapor deposition. In step 314 (ion implantation step), ions are implanted in the wafer. The aforementioned steps 311-314 form the preprocessing steps for wafers during wafer processing, and selection is made at each step according to processing requirements.

At each stage of wafer processing, when the above-mentioned preprocessing steps have been completed, the following post-processing steps are implemented. During post-processing, initially, in step 315 (photoresist formation step), photoresist is applied to a wafer. Next, in step 316, (exposure step), the above-mentioned exposure device is used to transfer the circuit pattern of a mask (reticle) to a wafer. Then, in step 317 (developing step), the exposed wafer is developed, and in step 318 (etching step), parts other than residual photoresist (exposed material surface) are removed by etching. In step 319 (photoresist removal step), unnecessary photoresist remaining after etching is removed. Multiple circuit patterns are formed by repetition of these preprocessing and post-processing steps.

While a lithography system of this invention has been described in terms of several preferred embodiments, there are alterations, permutations, and various substitute equivalents which fall within the scope of this invention. It should also be noted that there are many alternative ways of implementing the methods and apparatuses of the present invention. It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, and various substitute equivalents as fall within the true spirit and scope of the present invention.

WHAT IS CLAIMED IS:

1. An apparatus comprising:  
a workpiece having a first surface;  
5 an optical element positioned adjacent the first surface of the workpiece and configured to project an image onto the first surface, there being a gap spaced between the first surface of the workpiece and the optical element, the gap being substantially filled with an immersion fluid; and  
an autofocus system including:  
10 an autofocus light source configured to emit a light beam through the immersion fluid onto the first surface of the workpiece; and  
a receiver configured to receive the light beam reflected off the first surface of the workpiece.
- 15 2. The apparatus of claim 1 further comprising a transparent element, positioned between the autofocus light source and the immersion fluid, the transparent element being configured to cause the light beam to pass through the interface between the transparent element and the immersion fluid.
- 20 3. The apparatus of claim 2 wherein the transparent element is configured to control the refraction of the light beam at the interface between the transparent element and the immersion fluid.
- 25 4. The apparatus of claim 3 wherein the refraction of the light beam at the interface ranges from 0 to 90 degrees.
5. The apparatus of claim 2 wherein the transparent element is made of a material selected from the group consisting of glass, plastic, calcium fluoride and fused silica.
- 30 6. The apparatus of claim 2 wherein the transparent element is the optical element.

7. The apparatus of claim 2 wherein the transparent element is positioned adjacent the optical element.

8. The apparatus of claim 2 wherein the transparent element is of a shape  
5 selected from the group consisting of rectangles, squares, ovals, wedges and spheres.

9. The apparatus of claim 7 wherein liquid is provided between the transparent element and the optical element.

10. The apparatus of claim 7 wherein a vacuum is provided in the space  
10 between the transparent element and the optical element.

11. The apparatus of claim 7 further comprising a suction-providing device  
for causing the immersion fluid to move up through the space between the transparent  
15 element and the optical element so that outside air is prevented from moving into the space.

12. The apparatus of claim 7 further comprising a fluid-supplying device  
configured to provide fluid in the space between the transparent element and the  
20 optical element.

13. A method in immersion lithography, said method comprising the steps  
of:

providing a workpiece having a first surface;  
25 positioning an optical element adjacent the first surface of the workpiece, ;  
projecting an image through the optical element onto the first surface, there  
being a gap spaced between the first surface of the workpiece and the optical element;  
filling the gap substantially with an immersion fluid;  
passing an autofocus light beam from an autofocus light source through the  
30 immersion fluid onto the first surface of the workpiece; and  
receiving the light beam reflected off the first surface of the workpiece with a  
receiver.

14. The method of claim 13 further comprising the step of positioning a transparent element between the autofocus light source and the immersion fluid, the transparent element being configured to cause the light beam to pass through the interface between the transparent element and the immersion fluid.

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15. The method of claim 14 wherein the transparent element is configured to control the refraction of the light beam at the interface between the transparent element and the immersion fluid.

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16. The method of claim 15 wherein the refraction of the light beam at the interface ranges from 0 to 90 degrees.

17. The method of claim 14 wherein the transparent element is made of a material selected from the group consisting of glass, plastic, calcium fluoride and fused silica.

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18. The method of claim 14 wherein the transparent element is the optical element.

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19. The method of claim 14 wherein the transparent element is positioned adjacent the optical element.

20. The method of claim 14 wherein the transparent element is of a shape selected from the group consisting of rectangles, squares, ovals, wedges and spheres.

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21. The method of claim 19 further comprising the step of providing liquid between the transparent element and the optical element.

22. The method of claim 19 further comprising the step of providing a vacuum in the space between the transparent element and the optical element.

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23. The method of claim 19 further comprising the step of providing a suction-providing device for causing the immersion fluid to move up through the

space between the transparent element and the optical element so that outside air is prevented from moving into the space.

24. The method of claim 19 further comprising the step of providing a  
5 fluid-supplying device configured to provide fluid in the space between the transparent element and the optical element.

25. An immersion lithography apparatus comprising:  
a reticle stage arranged to retain a reticle;  
10 a working stage arranged to retain a workpiece with a first surface;  
an optical system including an illumination source and an optical element, said optical element being positioned adjacent the first surface of the workpiece and configured to project an image onto the first surface, there being a gap spaced between the first surface of the workpiece and the optical element, the gap being substantially  
15 filled with an immersion fluid; and  
an autofocus system including an autofocus light source configured to emit a light beam through the immersion fluid onto the first surface of the workpiece and a receiver configured to received the light beam reflected off the first surface of the workpiece.

20 26. The apparatus of claim 25 further comprising a transparent element, positioned between the autofocus light source and the immersion fluid, the transparent element being configured to cause the light beam to pass through the interface between the transparent element and the immersion fluid.

25 27. The apparatus of claim 26 wherein the transparent element is configured to control the refraction of the light beam at the interface between the transparent element and the immersion fluid.

30 28. The apparatus of claim 27 wherein the refraction of the light beam at the interface ranges from 0 to 90 degrees.

29. The apparatus of claim 26 wherein the transparent element is made of a material selected from the group consisting of glass, plastic, calcium fluoride and fused silica.

5 30. The apparatus of claim 26 wherein the transparent element is the optical element.

31. The apparatus of claim 26 wherein the transparent element is positioned adjacent the optical element.

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32. The apparatus of claim 26 wherein the transparent element is of a shape selected from the group consisting of rectangles, squares, ovals, wedges and spheres.

33. The apparatus of claim 31 wherein liquid is provided between the  
15 transparent element and the optical element.

34. The apparatus of claim 31 wherein a vacuum is provided in the space between the transparent element and the optical element.

20 35. The apparatus of claim 31 further comprising a suction-providing device for causing the immersion fluid to move up through the space between the transparent element and the optical element so that outside air is prevented from moving into the space.

25 36. The apparatus of claim 31 further comprising a fluid-supplying device configured to provide fluid in the space between the transparent element and the optical element.

30 37. An object manufactured with the immersion lithography apparatus of claim 25.

38. A wafer on which an image has been formed by the immersion lithography apparatus of claim 25.

39. A method for making an object using a lithography process, wherein the lithography process utilizes the immersion lithography apparatus of claim 25.

40. A method for patterning a wafer using a lithography process, wherein the lithography process utilizes the immersion lithography system of claim 25.