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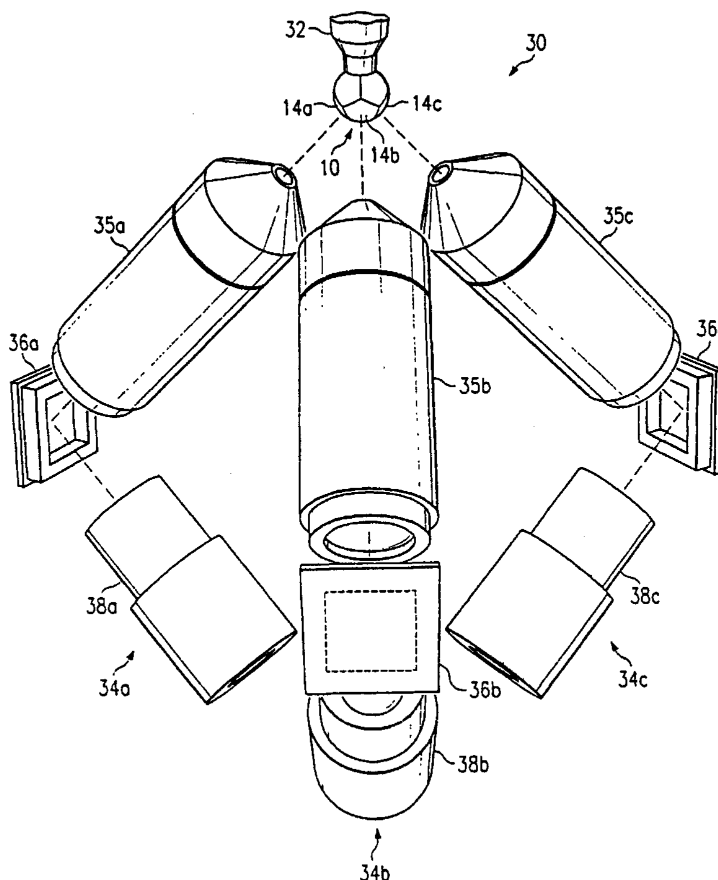
(54) Title: SYSTEM AND METHOD FOR PERFORMING LITHOGRAPHY ON A SUBSTRATE

(57) Abstract

Disclosed is a method, system (30), and lense system for performing lithography on a substrate (10). The system (30) includes a unique lense system for nonplanar substrates. The lense system includes a first lense section (35b) for receiving a pattern and producing a concave image of the pattern. The concave image can the be received by a second lense section (35a, 35c) for producing a nonplanar image of the pattern. The system also includes two light sources (34a, 34c) and a digital imaging device (34b) for projecting and exposing the pattern through the lense section (35b) and onto the substrate (10). Light from the first light source (34a) is used for exposing the pattern while light from second light source (34c) is used for receiving an alignment image. An image sensor (34b), using the light from the second light source (34c), detects an alignment image from the substrate. The alignment image is used to accommodate the projection of the pattern onto the substrate (10) so that the pattern is properly aligned to the substrate (10).



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SYSTEM AND METHOD FOR PERFORMING LITHOGRAPHY ON A SUBSTRATE

Background of the Invention

The invention relates generally to photo lithography, and more particularly, to a system for performing lithography on two and three dimensional substrates such as a spherical shaped substrate.

5 Conventional integrated circuits, or "chips," are formed from two dimensional or flat surface semiconductor wafers. The semiconductor wafer is first manufactured in a semiconductor material manufacturing facility and is then provided to a fabrication facility. At the latter facility, several layers are processed onto the semiconductor wafer surface using various design concepts, such as VLSI design. Although the processed chip includes several 10 layers fabricated thereon, the chip still remains relatively flat.

U.S. Patent No. 5,955,776, which is hereby incorporated by reference, describes a three dimensional, spherical-shaped substrate for receiving various circuits. Of the many process disclosed in the above-referenced application, several are related to imaging a circuit design onto the three dimensional substrate. Often, the circuit design to be imaged may be two dimensional 15 in nature.

There are numerous problems associated with imaging a two-dimensional circuit design onto a three-dimensional substrate, such as a spherical shaped substrate. For example, converting two-dimensional computer aided designs (CAD) of a circuit into a mask for projecting onto a three-dimensional surface requires separation of the circuit into unit segments that can 20 be positioned on the mask and then projected onto the device. Thus, when designing two-dimensional integrated circuits (IC) using CAD tools, there must be a way to segment the design into sections that can be positioned on a mask and projected onto a three-dimensional surface. Also, it is very difficult to expose all surfaces of a three-dimensional substrate.

One partial solution is shown in U.S. Patent Ser. No. 09/351,203. This application 25 teaches a system for designing a flat mask to be imaged onto a spherical substrate. The system uses a mask and several angled mirrors for reflecting a pattern from the mask onto various portions of the substrate. However, this solution has poor light efficiency due to the mask and the angled mirrors.

Another partial solution is shown in U.S. Patent 5,691,541. This patent teaches a maskless, reticle-free lithography system. However, this solution is for static systems, limited to two-dimensional substrates, and does not dynamically provide fine pattern alignment.

These and other conventional solutions do not provide the accuracy and light intensity often required for performing lithography on a three dimensional substrate. Therefore, what is still needed is a system and method for projecting a two-dimensional circuit design onto a three dimensional substrate.

Summary

A technological advance is achieved by a method, system, and lense system for performing lithography on a substrate. In one embodiment, the method captures the substrate and divides it into a number of regions. The substrate is first rough-aligned, and then a fine-alignment offset is determined. A pattern is then projected onto a first region of the substrate, adjusted by the first fine-alignment offset.

In some embodiments, the method then re-captures the substrate and fine-aligns a second pattern. The second pattern is then projected onto a second region of the substrate.

In some embodiments, the fine-alignment is performed by receiving an image of the roughly aligned substrate and comparing a predetermined mark on the image with the first pattern. This comparison can thereby determine the fine-alignment offset.

In some embodiments, the pattern is digitally stored in a computer memory device so that fine-aligning can be accomplished by moving the pattern in memory.

In one embodiment, the system for performing lithography on a substrate includes a lense section having one or more lenses, two light sources, and a device for projecting and exposing the pattern through the lense section and onto the substrate. Light from the first light source is used for exposing the pattern while light from second light source is used for providing an alignment image. An image sensor receives the alignment image from the substrate and uses it to properly align the pattern to the substrate.

In some embodiments, the system includes a beam splitter for separately directing the first and second lights. The beam splitter can separately direct the second light coming from the second light source and the alignment image coming from the substrate.

In another embodiment, the system utilizes a single source of light. A device such as a digital imaging device converts the light into a pattern, projects the pattern through the lense section, and exposes the pattern onto the substrate. A beam splitter is positioned between the digital imaging device and the substrate for separately directing an image of the substrate to an image sensor. As a result, the substrate image is used to accommodate the projection of the pattern onto the substrate so that the pattern is properly aligned to the substrate.

In some embodiments, the system includes a computer for receiving the alignment image from the image sensor and modifying the pattern used by the device to align the pattern with the substrate. The pattern may be digital so that the computer modifies the digital pattern by moving the pattern in memory.

In some embodiments, the system utilizes a reservoir for containing a transparent fluid through which the light may travel before reaching the substrate. One or more lenses of the lense section may be located in the reservoir of transparent fluid and/or may be part of the reservoir. In addition, a second reservoir may be used to contain the substrate.

In some embodiments, the system may use multiple lense sections and light sources. These embodiments may simultaneously expose different regions of the substrate, or may sequentially expose the substrate after it moves from one holder to another.

In one embodiment, a unique lense system can be used for nonplanar substrates. The lense system includes a first lense section for receiving a pattern and producing a concave image of the pattern. The concave image can then be received by a second lense section for producing a nonplanar image of the pattern. The nonplanar image coincides with the nonplanar substrate.

Brief Description of the Drawings

Fig. 1 is a three dimensional illustration of a substrate for receiving a photolithography operation.

Fig. 2 is a two dimensional illustration of the substrate of Fig. 1.

Fig. 3 is a flow chart for one embodiment of a method for performing lithography on a substrate such as the substrate of Fig. 1.

Figs. 4 and 5 are side views of a system for performing photolithography according to the method of Fig. 3.

Fig. 6 is a schematic drawing of a conventional lense system.

Figs. 7a-7b are drawings of an improved lense system according to one embodiment of the present invention.

Figs 7c-7d are drawings of different physical implementations of the lense system of Figs. 7a-7b.

Figs. 8a-8b are schematic diagrams of imaging systems for performing lithography according to the method of Fig. 3.

Figs. 9 and 11 are schematic diagrams of a computer system for facilitating the imaging systems of Figs. 8a-8b.

Fig. 10 includes illustrations of a pattern and alignment image used by the computer systems of Figs. 9 and 11.

Description of the Embodiments

The present invention provides a system and method for performing lithography on different shaped substrates. It is understood that the following disclosure provides many different embodiments, or examples, for implementing different features of this invention. Specific examples of lenses, components, substrates, and system configurations are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to limit the invention from that described in the claims.

The following disclosure is separated, for the sake of clarity, into three discussions: 1) an exemplary substrate; 2) an exemplary method; and 3) exemplary systems. Each of the discussions focuses on one or more components for implementing different embodiments of the invention. To further simplify the following disclosure, many examples are continued through each of the discussions.

1. An Exemplary Substrate

Referring now to Fig. 1, the reference numeral 10 refers, in general, to a three dimensional substrate on which an image or pattern will be imposed. For the sake of example, the substrate 10 may be a spherical shaped semiconductor device according to presently incorporated U.S. Patent No. 5,955,776, although other two and three dimensional devices will also benefit from the present invention. In the present embodiment, it is desired to perform lithographic operations on an outer surface 12 of the sphere.

The sphere 10 has a radius "R" from a center point "O". The surface 12 is divided into six circles, three of which (circles C1, C2, C3) are illustrated. Each of the circles intersects four other circles at exactly one point per circle. For example, circle C1 intersects the circle C2 at a point P12, and intersects the circle C3 at a point P13. In the present example, the center point O is located at the origin of an X,Y,Z axis, and the circle C1 radially extends around the X axis.

In addition, six great circles can be drawn on the surface 12. Each great circle connects two opposite intersection points. A great circle GC1 is illustrated, and passes through the point P12 and an opposite point (not shown).

Referring also to Fig. 2, a two-dimensional representation of the sphere 10 is viewed along the X axis of Fig. 1. The circle C1 is centered in this representation, and four great circles GC1, GC2, GC3, GC4 that intersect the circle C1 are illustrated. The smallest area defined by the intersection of the four great circles GC1, GC2, GC3, GC4 represents a region 14. It can be readily determined that six different regions are now defined, each identical in size and shape with the region 14. The six regions completely cover the surface 12. It is understood that in other embodiments, the regions may not completely cover the surface.

In the present embodiment, the six regions are not physically inscribed on the surface 12, but instead represent system-designated regions to be discussed below. The surface 12 may includes one or more physical alignment marks, such as an alignment mark 16, to locate and align the six regions. In some embodiments, the alignment mark 16 can be arbitrarily made on the surface 12 during a first etching process. From then on, all other lithographic and etching processes can align to the mark 16, thereby designating the six regions.

2. An Exemplary Method

Referring to Fig. 3, a method 20 may be used to perform a lithographic operation on the sphere 10. At step 22, a rough alignment procedure positions the sphere 10 so that the alignment mark 16 is near a predetermined location. The rough alignment can be done in many different ways, such as using a camera (not shown) to identify the mark 16 and using a holding device to capture the sphere 10.

At step 24, a fine alignment procedure is performed. The fine alignment procedure can operate in various ways. For one, the sphere 10 and/or a pattern source can be physically moved

in small increments until the two are aligned. In a maskless lithography system as described below, the pattern can be electrically altered to align with the sphere 10.

At step 26, several regions (e.g., region 14) of the sphere 10 are exposed with an appropriate pattern. At step 28 the sphere is moved so that at step 29, the remaining regions of the sphere 10 can be exposed. As a result, all of the regions receive an appropriate pattern and the entire outer surface 12 of the sphere 10 is exposed. It is understood, however, that in some embodiments, only portions of the outer surface need to be exposed. In these latter embodiments, step 26 discussed above may be sufficient to expose all the desired portions.

3. Exemplary Systems

Referring now to Fig. 4, one or more steps of the method 20 (Fig. 3) can be performed by a photolithography system 30. The system 30 includes a holding device 32 for securing the sphere 10 in a predetermined position. For the sake of example, one type of holding device is a positive pressure catcher as disclosed in U.S. Ser. No. 09/162,616, which is hereby incorporated by reference. The catcher 32 may be able to position the sphere 10 as required in step 22 of Fig. 3 so that the alignment mark 16 (not shown) is near a predetermined location.

Located proximate to the sphere 10 are three imaging systems 34a, 34b, 34c. The imaging systems are each directed to three different regions of the sphere 10. For the sake of example, the imaging systems 34a, 34b, 34c are directed towards regions 14a, 14b, 14c, respectively. In the present embodiment, each of the regions 14a, 14b, 14c are similar to the region 14 of Fig. 2.

The imaging systems 34a, 34b, 34c include three lense systems 35a, 35b, 35c, which are visually aligned with three digital light processing ("DLP") mirror devices 36a, 36b, 36c, respectively, such as is produced by Texas Instruments of Dallas, TX. Three projection systems 38a, 38b, 38c are also aligned with the three mirror devices 36a, 36b, 36c, respectively. In another embodiment, a light emitting diode ("LED") display can be used instead of the mirror devices. The use of LED displays and mirror devices for photolithographic operations is discussed in greater detail in U.S. Patent Ser. No. 09/348,369, which is herein incorporated by reference.

By using the LED displays or mirror devices, the fine alignment step 24 (Fig. 2) can thereby be accomplished through digital adjustment. That is, the pattern in the mirror devices

36 can be adjusted to compensate for the rough alignment of step 22, thereby securing a fine alignment. Discussed in greater detail below, the adjustment can be made, for example, by aligning to the alignment mark 16 on the sphere 10.

Once aligned, light can be projected from the three projection systems 38a, 38b, 38c, onto the three mirror devices 36a, 36b, 36c, respectively, which thereby produce three separate patterns (one each). The three patterns are then projected through each of the lense systems 35a, 35b, 35c to expose the patterns on the regions 14a, 14b, 14c, respectively. The imaging systems 34a, 34b, 34c adjust the patterns so that they are finely focused and aligned to their respective region.

Once the first three patterns have been exposed on the sphere 10, the sphere may move to a new position. Referring simultaneously to Figs. 4 and 5, for the sake of example, the sphere 10 drops, as shown in Fig. 4, to be received by a second catcher 50 in Fig. 5. The alignment of the sphere 10 in Fig. 5 is almost exactly the same as it was in Fig. 4, so the rough alignment procedure may be skipped, in some embodiments.

Referring specifically to Fig. 5, the photolithography system 30 includes three additional imaging systems 54a, 54b, 54c to project and expose the second group of patterns onto regions 56a, 56b, 56c, respectively. The same configurations and procedures described above with reference to Fig. 4 can be used with respect to Fig. 5.

Referring now to Fig. 6, a prior art lense 60 can be used to focus a pattern of light rays 62 towards a flat substrate 64, such as a semiconductor wafer. However, such a lense actually distorts the pattern as it appears on the substrate 64. In actuality, the pattern produced focuses into a concave image, as described by intermediate image 66.

Since the sphere 10 has a convex surface 12, the distortion from the prior art lense 60 would even be more prevalent. Therefore, it is desired to reduce this distortion as much as possible.

Referring to Figs. 7a, 7b, 7c, and 7d, some embodiments of the present invention use a unique lense system that focuses the pattern to coincide with the substrate. In one embodiment, the lense system 35 (Fig. 4) can be logically divided into three separate sections 71, 72, 73. As is shown in the figure, the lense system 35 is located very close to the sphere 10, as compared to its proximity to the mirror device 36.

Fig. 7a also shows a plurality of light rays 74 that are ray traced from the mirror device 36 to the substrate 10. Fig. 7b shows the same sections 71, 72, 73 of lenses, without the light rays 74 being illustrated, in order to clarify the lense layout for each section. Fig. 7c shows the same sections 71, 72, 73 of lenses, configured in a mechanical fixture 74 for typical production operations.

Fig. 7d shows an alternate embodiment where the lenses 71-73 and/or the sphere 10 are suspended in a transparent liquid 75a. In this embodiment, the catchers 38 an 50 are not needed during exposure. Instead, the sphere 10 can be placed in a transparent container 76, which also includes a transparent liquid 75b. The transparency of the container 76 and the liquids 75 is specifically chosen to accommodate the optical affects for the lithographic operation. In addition, the liquid 75a may be contained in a reservoir 77 having a plurality of transparent portions 77a, 77b, as needed. In some embodiments, the transparent portions may actually be one of the individual lenses from lense groups 71-73. By having some or all of the lenses 71-73 and/or the sphere 10 suspended in liquid, the effects of movement and vibration are significantly reduced.

Referring to Figs. 7a-7d together, the first section 71 provides a first group of lenses L1, L2, L3, L4; the second section 72 provides a second group of lenses L5, L6, L7; and the third section 73 provides a third group lenses L8, L9, L10, L11. The first section 71 produces a concave-inverted image of the pattern to be exposed, similar to the intermediate image 66 of Fig. 6. The second section 72 receives the concave-inverted image from the first section 71 and produces a convex-inverted image that is formed from relatively-parallel light rays. The third section 73 receives the convex-inverted image from the second section 72 and projects the pattern onto the surface of the sphere 10. Although the third section 73 tries to distort the image of the pattern in a concave manner, the final image on the sphere 10 is still slightly convex.

As a result, since the surface 12 of the sphere 10 is also slightly convex, very little distortion, if any, appears on the sphere. The lenses 71-73 are also chosen to accommodate a spherical shaped substrate. If the substrate is of another shape (e.g., oblong or angular), then different shaped lenses can be used to coincide with the surfaces of the substrate. It is noted

that the lense system 35 only has a few constituent lens elements, a large numerical aperture, and an excellent spherical image surface across an entire field of view.

Referring now to Fig. 8a, in one embodiment, each of the six imaging systems 34a, 34b, 34c (Fig. 4) and 54a, 54b, 54c (Fig. 5) are similarly constructed. For the sake of simplicity, only
5 the imaging system 34a will be discussed in greater detail.

The imaging system 34a includes the projection systems 38a and an alignment system 78a. The projection system 38a includes a G-line light source 80 that projects light off a flat, stationary mirror 82 and towards the mirror device 36. The mirror device 36 is operable to selectively direct the G-line light through the lense system 35a and onto the sphere 10. The G-
10 line light is of a type that, when exposed on photoresist (on the substrate 10), causes the photoresist to develop.

Before the imaging system 34a exposes the pattern onto the sphere 10, however, the alignment system 78a is used to align the pattern with the sphere. The alignment system 78a includes a red light source 84, a beam splitter 86, a lense system 88, and a detector 90. The red
15 light source 84 projects a red light through the beam splitter 86 and towards the mirror device 36. The mirror device 36 is operable to selectively direct the red light through the lense system 35a and onto the sphere 10. The red light does not affect photo resist, so that it can be projected onto the sphere 10 without any permanent affects.

The mirror device 36 also directs a reflection of the red light back towards the beam
20 splitter 86. The beam splitter 86 is designed to have the desired angular affect on the red-light so that the reflection is directed towards the lense system 88 and the detector 90. This reflection can be used as an alignment image by the detector 90, so that fine alignment procedures can be performed, as discussed below.

Referring now to Fig. 8b, in another embodiment, the beam splitter 86 can be positioned
25 directly between the mirror device 36 and the lense system 35. In this embodiment, a portion of the light is directed toward the sphere 10, while the remaining portion is directed towards the detector 90.

Also in this embodiment, a CCD camera 92 is used as the detector for image alignment. In addition, a moveable staging system 93 is used to position the sphere 10. The system 93
30 includes a mechanical stage 93a that is rotatable about two axis by two motors 93b, 93c. This

embodiment supports immediate and continual alignment of the pattern on the mirror device 36 with the sphere 10.

Referring now to Fig. 9, in some embodiments, the detector 90 is one of six detectors, one for each of the six imaging systems 34a, 34b, 34c (Fig. 4) and 54a, 54b, 54c (Fig. 5). However, only three mirror devices 36a, 36b, 36c are used, being shared between the operation discussed in Fig. 4 and the operation discussed in Fig. 5. The detectors 90 are connected to an image converter 94, which is further connected to a computer 96. Likewise, the mirror devices 36a, 36b, 36c, are connected to drivers 98a, 98b, 98c, respectively, which are further connected to the computer 96.

Referring to Fig. 10, in the present embodiment, the computer 96 includes memory for storing a pattern 100 to be projected onto the sphere 10. The pattern 100 may include an item 16' for aligning to the sphere 10. The computer 96 receives an alignment image 102 from one or more the detectors 90. The alignment image 102 may include the alignment mark 16 (Fig. 2). The computer compares the desired location of the item 16' (e.g., X_1, Y_1, Θ_1) with the location of the alignment mark 16 (e.g., X_2, Y_2, Θ_2) to determine an alignment offset (e.g., X_1-X_2, Y_1-Y_2, Θ_1-Θ_2). The computer then "moves" the pattern 100 stored in memory to accommodate the difference between the alignment images and the expected alignment. This movement can be accomplished by changing an address space for the pattern 100 stored in memory. The moved pattern 100 is then provided to the mirror devices 36a, 36b, 36c through the drivers 98a, 98b, 98c, respectively. As a result, the aligned patterns can be exposed onto the sphere 10.

Referring now to Fig. 11, instead of detectors, one or more CCD cameras 104a, 104b are used to receive the alignment image from the sphere 10. The CCD camera 104a simultaneously catches all the alignment images for the first group of regions being exposed (e.g., regions 14a, 14b, 14c of Fig. 4). Likewise, the CCD camera 104b simultaneously catches all the alignment images for the second group of regions being exposed (e.g., regions 56a, 56b, 56c of Fig. 5). The ability to simultaneously catch multiple images can be accomplished by simultaneously directing the alignment images from multiple alignment systems (e.g., alignment system 78a of Fig. 8a) towards a single camera.

Referring again to Fig. 10, once the alignment images from the CCD cameras 104a, 104b are captured, they are combined into the alignment image 102 and the pattern 100 is aligned as discussed above.

Although illustrative embodiments of the invention have been shown and described, 5 other modifications, changes, and substitutions are intended in the foregoing disclosure. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

What is claimed is:

1. A method for performing lithography on a three-dimensional substrate, the method comprising the steps of:

capturing the substrate;

5 dividing the substrate into a number of regions;

performing a rough alignment on the substrate;

determining a first fine-alignment offset;

fine-aligning a first pattern according to the first offset;

projecting the first pattern onto a first region of the substrate.

10

2. The method of claim 1 further comprising the steps of:

re-capturing the substrate;

determining a second fine-alignment offset;

fine-aligning a second pattern according to the second offset;

15 projecting the second pattern onto a second region of the substrate.

3. The method of claim 1 wherein the step of determining a first fine-alignment offset includes the steps of:

receiving an image of the roughly aligned substrate; and

20 comparing a predetermined mark on the image with the first pattern to determine the first fine-alignment offset.

4. The method of claim 1 further comprising the step of:

digitally storing the pattern in a memory device so that the step of fine-aligning can be

25 accomplished by moving the pattern in the memory device.

5. A system for performing lithography on a substrate, the system comprising:
a lense section having one or more lenses;
a first light source for making a first light capable of exposing the substrate;
a device for converting the first light into a first pattern, projecting the first pattern
5 through the lense section, and exposing the first pattern onto the substrate;
a second light source for making a second light, the second light not being capable of exposing the substrate; and
an image sensor for using the second light to detect an alignment image from the substrate;
10 whereby the alignment image is used to accommodate the projection of the first pattern onto the substrate so that the first pattern is properly aligned to the substrate.

6. The system of claim 5 wherein the substrate is relatively flat.

15 7. The system of claim 5 further comprising:
a computer for receiving the alignment image from the image sensor and modifying the pattern used by the device to align the pattern with the substrate.

8. The system of claim 7 wherein the pattern is digital, the device is a digital
20 imaging device for displaying digital patterns, and the computer includes memory for storing the digital pattern.

9. The system of claim 8 wherein the computer modifies the digital pattern by moving the pattern in memory.

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10. The system of claim 5 further comprising:
a beam splitter for separately directing the first and second lights.

30

11. The system of claim 5 further comprising:

a reservoir for containing a transparent fluid through which the first and second light travel before reaching the substrate.

5 12. The system of claim 12 wherein at least one lense of the lense section is located in the reservoir of transparent fluid.

13. The system of claim 12 wherein at least one lense of the lense section is part of the reservoir.

10

14. The system of claim 5 further comprising:

a first reservoir for containing a first transparent fluid and at least one lense of the lense section; and

a second reservoir for containing a second transparent fluid and the substrate.

15

15. The system of claim 5 further comprising:

a second lense section having one or more lenses;

a third light source for making a third light; and

a second device for converting the third light into a second pattern, projecting the second

20 pattern through the second lense section, and exposing the second pattern onto the substrate;

whereby the first and second patterns are simultaneously exposed onto different regions of the substrate.

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16. The system of claim 5 further comprising:

a first apparatus for holding the substrate while the first pattern is projected onto a first region of the substrate;

a second apparatus for receiving and holding the substrate after the first pattern is projected onto the substrate;

a second lense section having one or more lenses;

a third light source for making a third light; and

a second device for converting the third light into a second pattern, projecting the second pattern through the second lense section, and exposing the second pattern onto the substrate;

whereby the second pattern is projected onto a second region of the substrate while being held by the second apparatus.

17. A system for performing lithography on a substrate, the system comprising:

a lense section having one or more lenses;

a light source for making a light;

a device for converting the light into a pattern, projecting the pattern through the lense section, and exposing the pattern onto the substrate;

a beam splitter for separately directing a portion of the light to an image sensor; and

the image sensor for detecting an alignment image from the substrate;

whereby the alignment image is used to accommodate the projection of the pattern onto the substrate so that the pattern is properly aligned to the substrate.

18. The system of claim 17 wherein the pattern is digital, the device is a digital imaging device for displaying digital patterns, and the system further comprises:

a computer for storing the digital pattern, receiving the alignment image from the image sensor, and modifying the stored digital pattern used by the digital imaging device to align the pattern with the substrate.

19. A lense system for use in performing photolithography on a nonplanar substrate, comprising:

a first lense section for receiving a pattern and producing a concave image of the pattern;

a second lense section for receiving the concave image and producing a nonplanar image
5 of the pattern;

wherein the nonplanar image relatively conforms to the nonplanar substrate.

20. The lense system of claim 19 wherein the nonplanar substrate is spherical in shape, and the second lense section includes a convex lense so that the nonplanar image is convex.

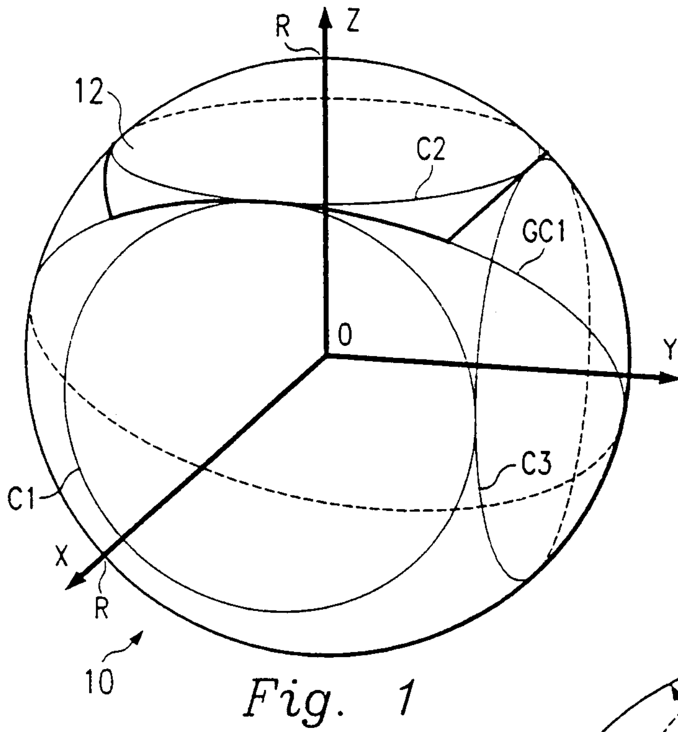

Fig. 1

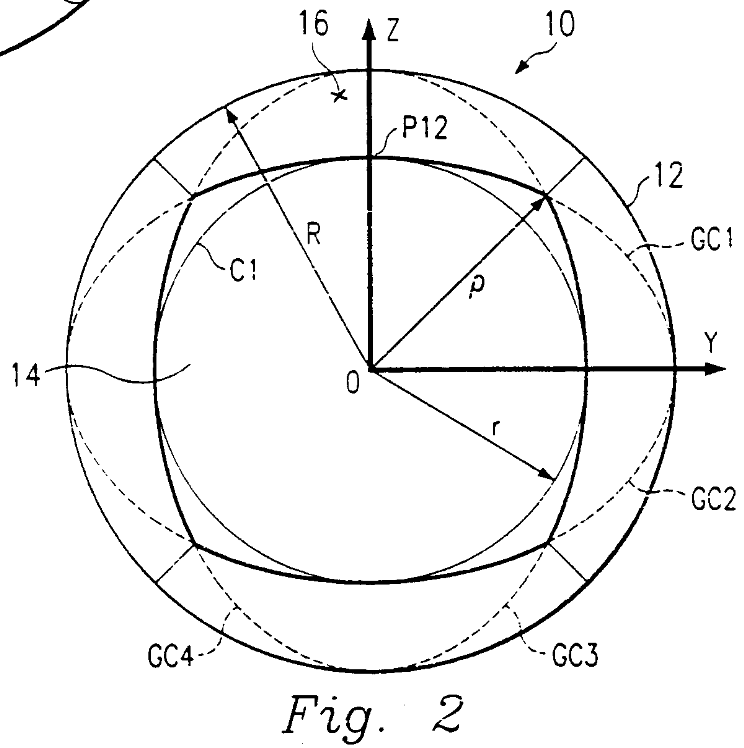

Fig. 2

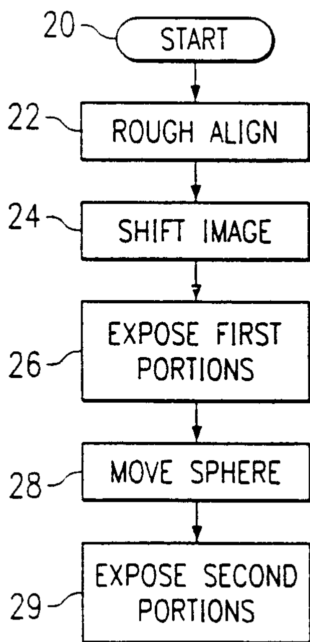

Fig. 3

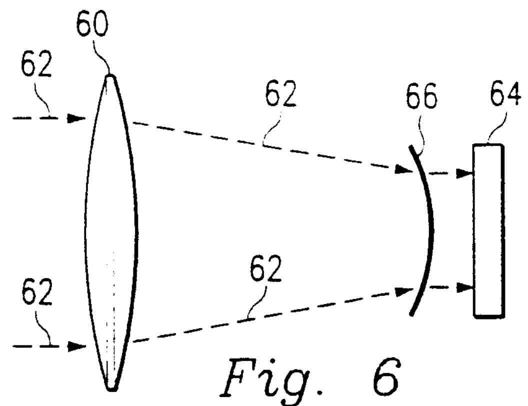

Fig. 6

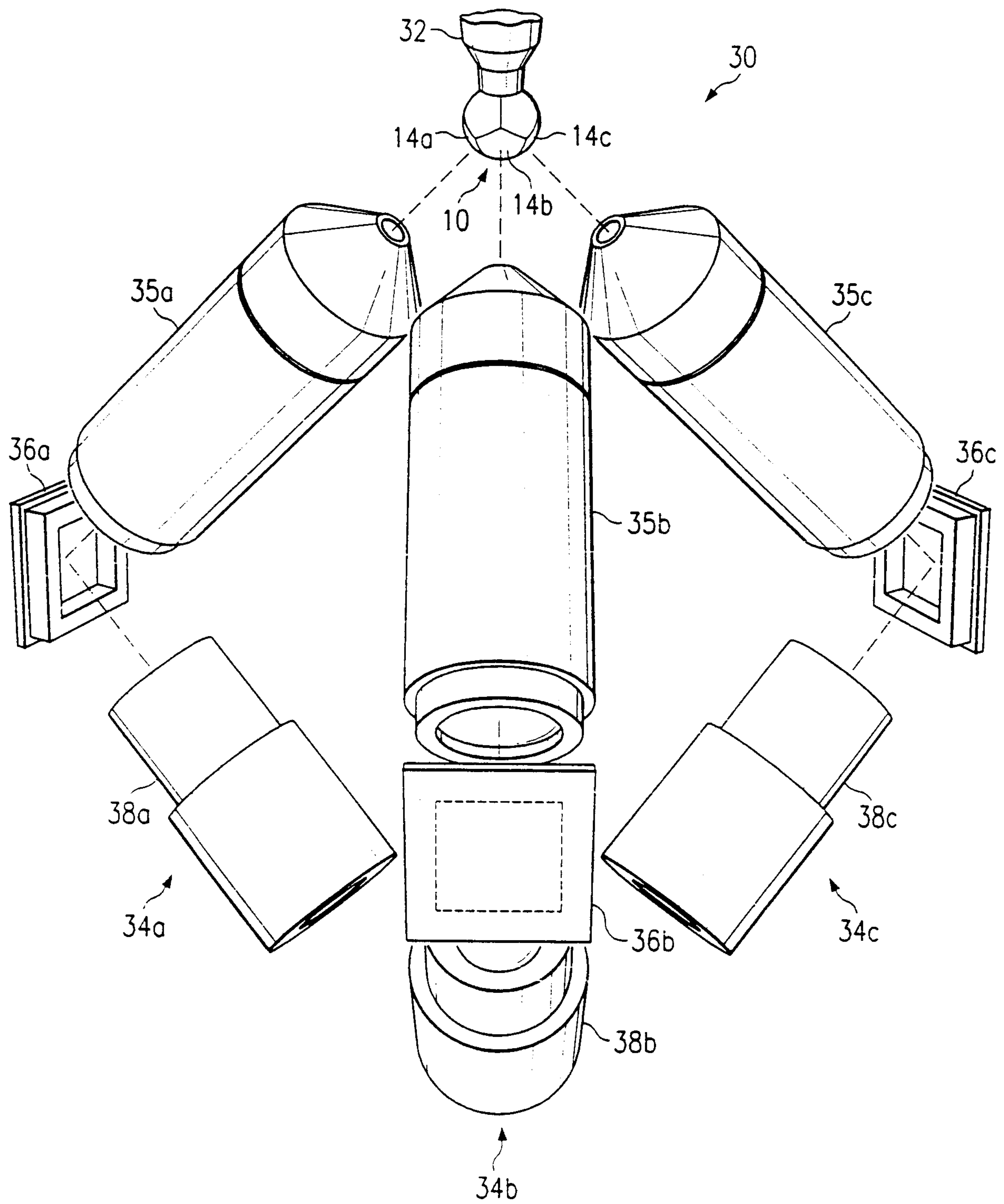

Fig. 4

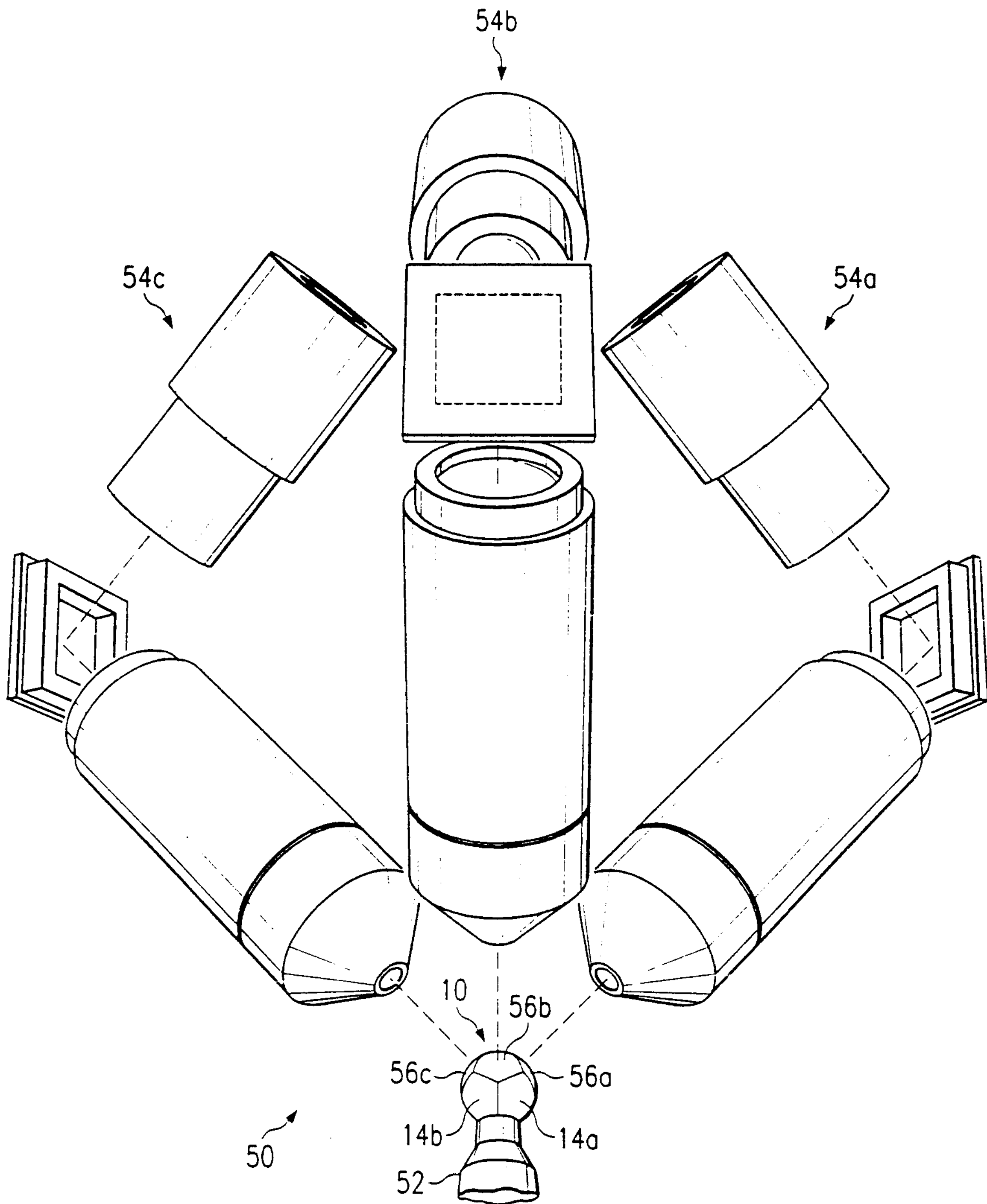

Fig. 5

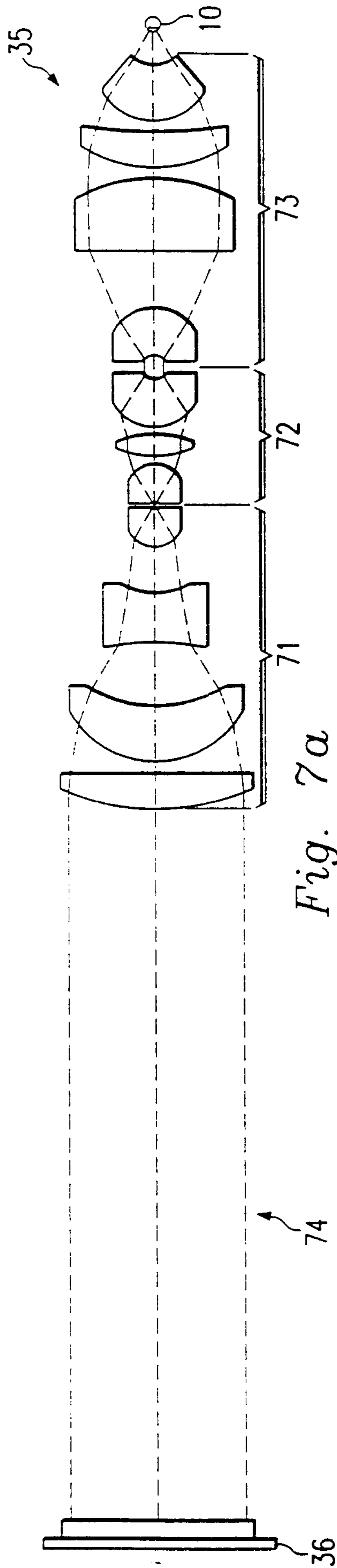

Fig. 7a

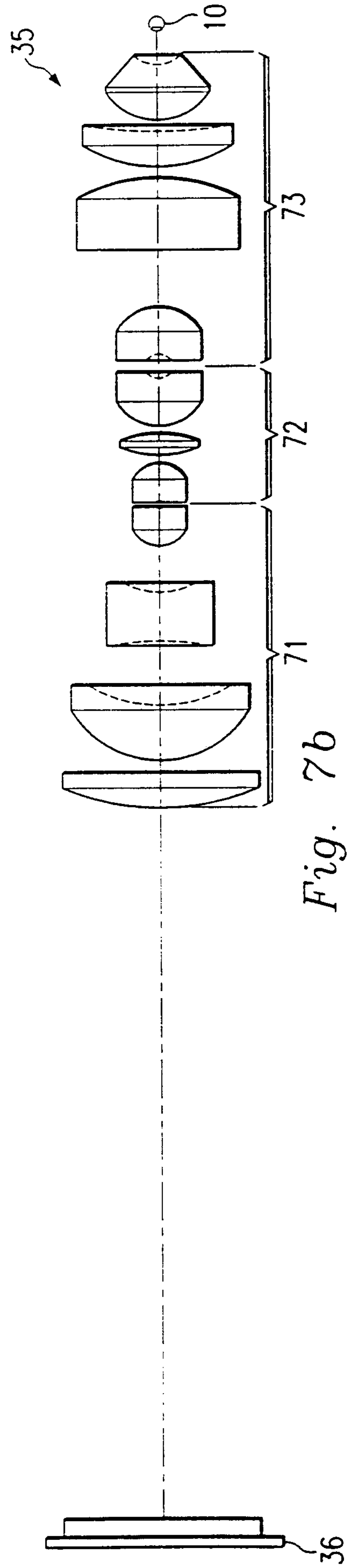

Fig. 7b

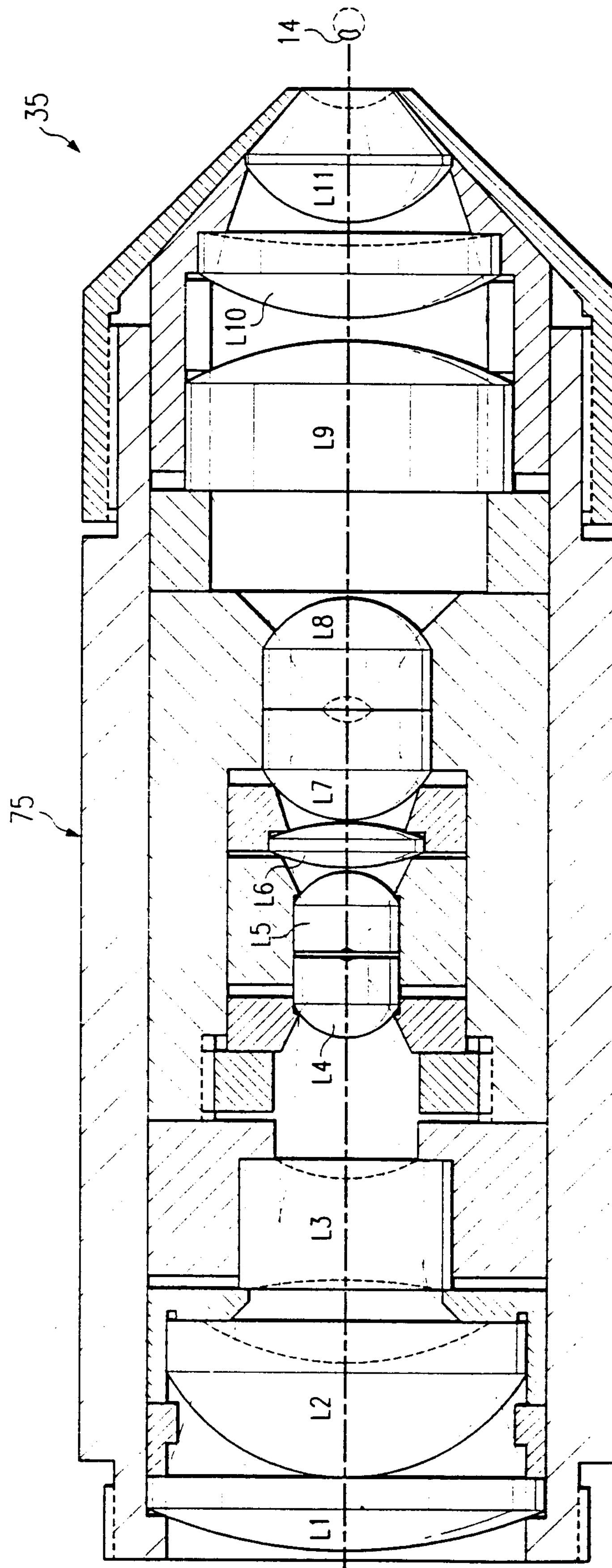

Fig. 7c

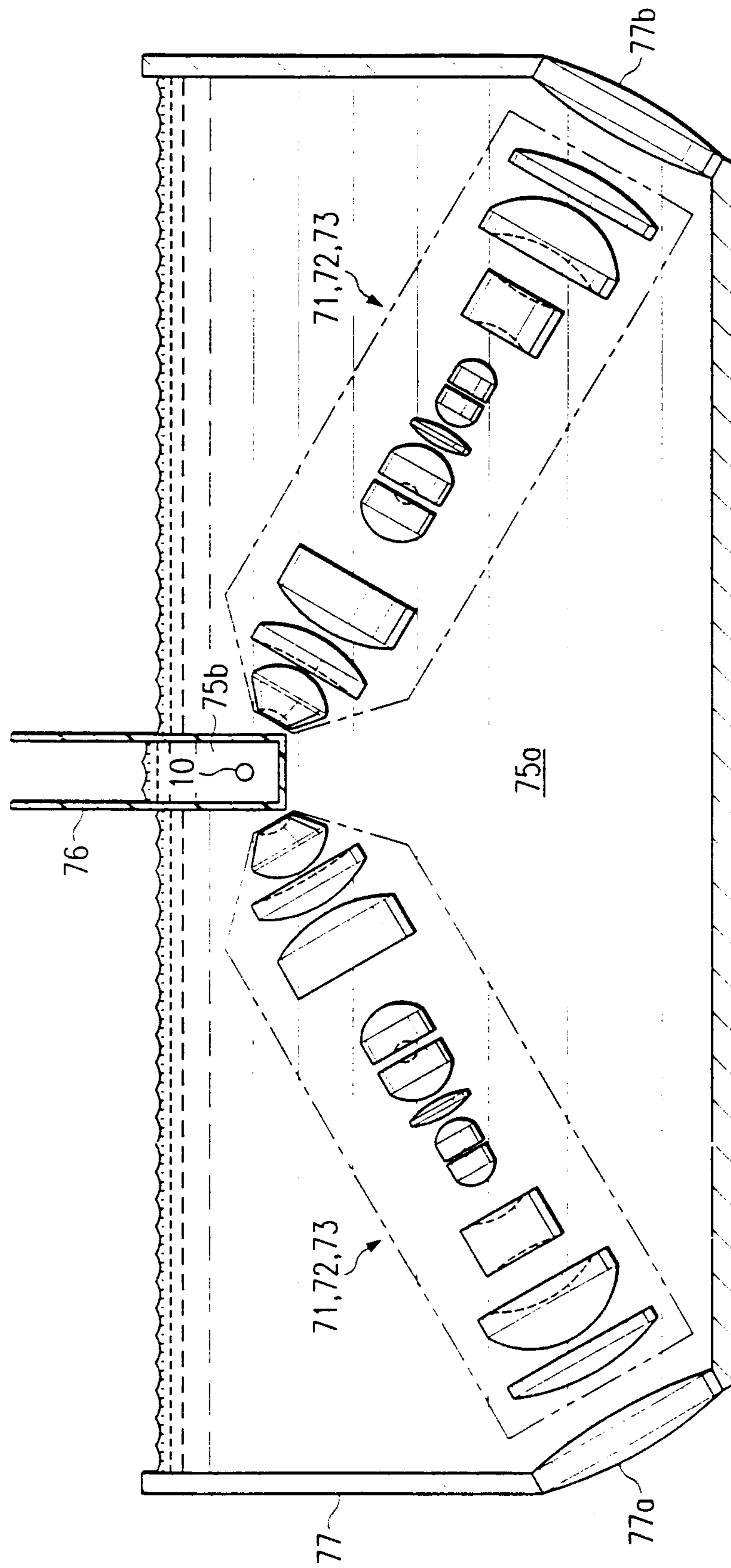

Fig. 7d

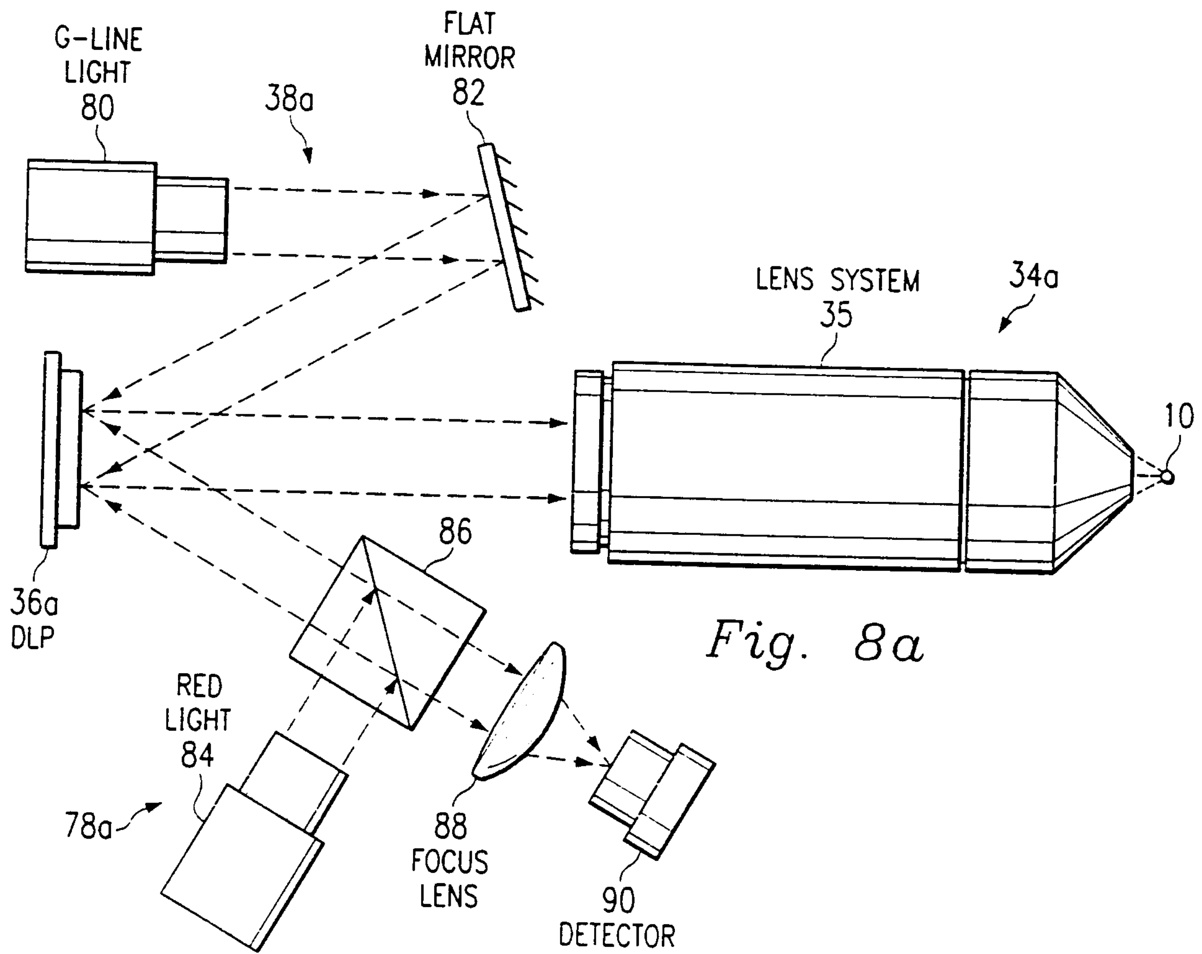

Fig. 8a

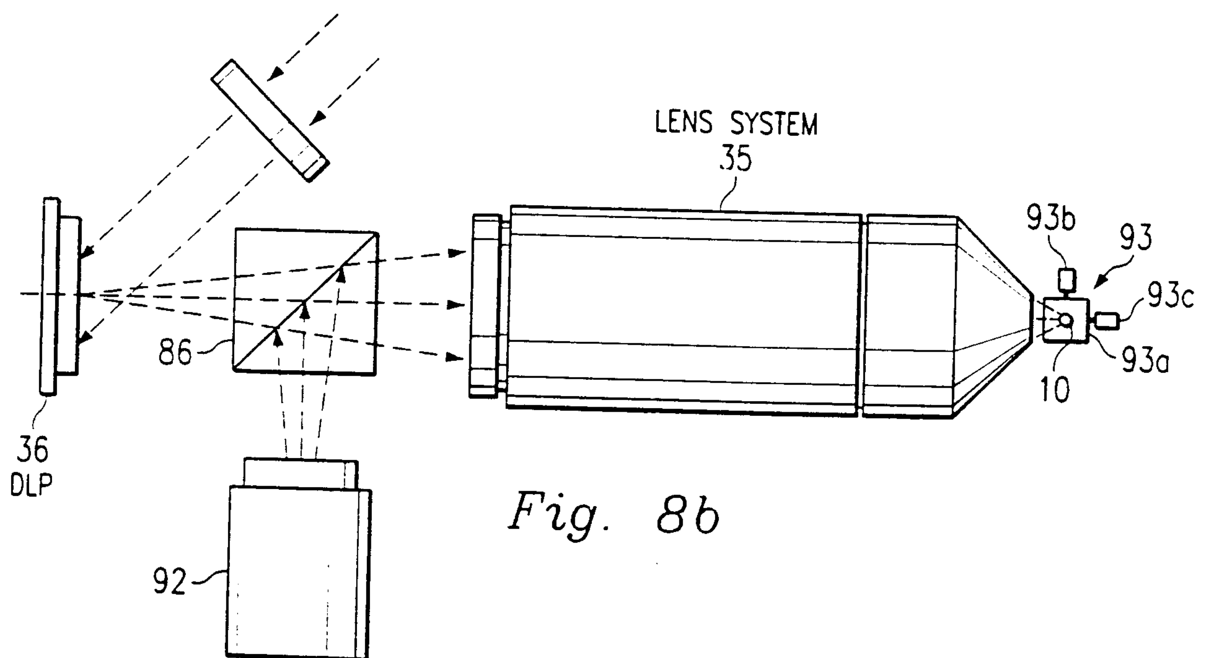

Fig. 8b

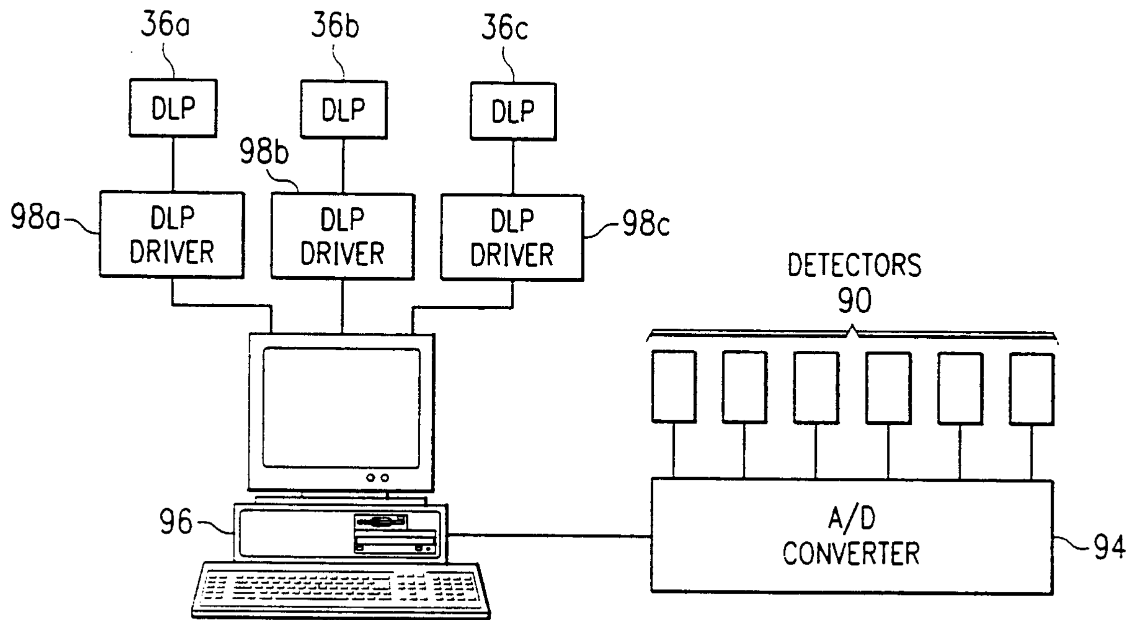

Fig. 9

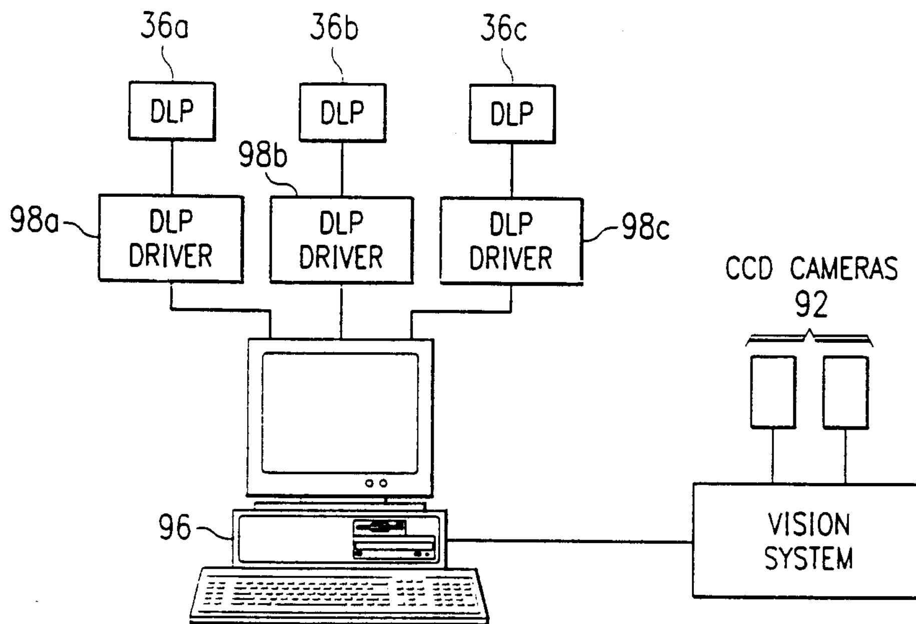

Fig. 11

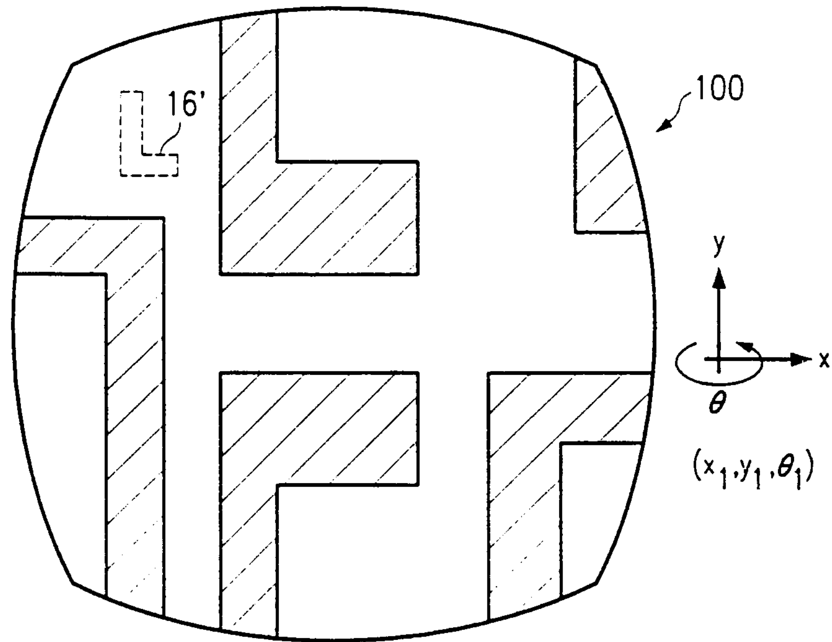

Fig. 10a

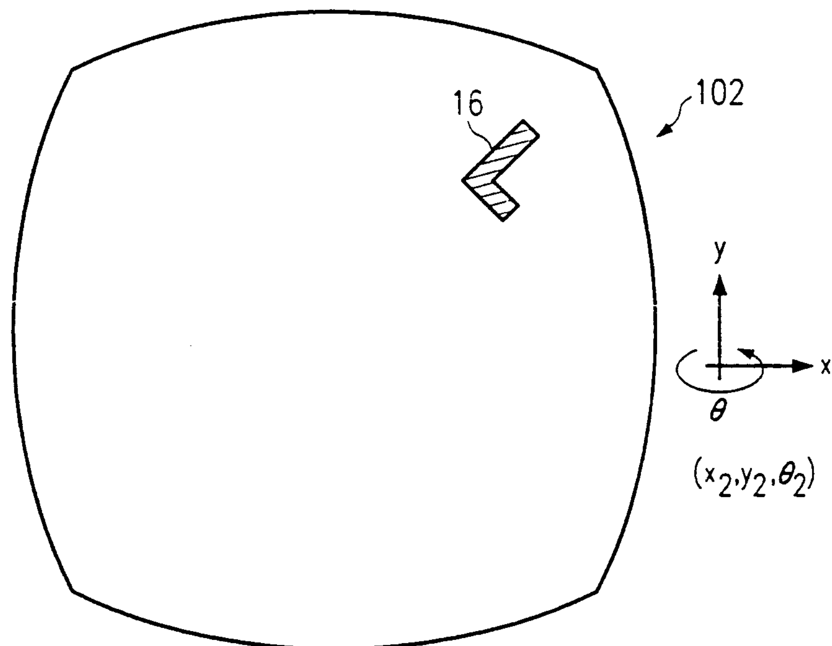

Fig. 10b

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/10193

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : G03F 9/00; G03B 27/42
US CL : 355/30; 430/22
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 355/30; 355/47; 430/22; 430/30

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPAT, Derwent

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, P	US 6,042,976 A (CHIANG et al.) 28 March 2000, col. 3, lines 40-50, col. 4, line 15-col. 5, line 30.	1-4
Y	US 5,879,843 A (UENO) 9 March 1999, col. 3, line 35-col. 5, line 25.	1-4
Y	US 5,866,281 A (GUCKEL et al.) 2 February 1999, col. 4, line 15-col. 8, line 20.	1-4
Y, E	US 6,061,118 A (TAKEDA) 9 May 2000, col. 2, lines 5-30.	1, 6, 19, 20
Y, P	US 5,955,776 A (ISHIKAWA) 21 September 1999, col. 2, line 20-col. 3, line 5	1, 6, 19, 20
Y	US 5,431,127 A (STEVENS et al.) 11 July 1995, col. 2, line 25-col. 3, line 30.	1, 6, 19, 20
Y	US 5,082,755 A (LIU) 21 January 1992, col. 3, lines 10-45.	5-20
Y	US 5,870,176 A (SWEATT et al.) 9 February 1999, col. 2, lines 1-12	5-20
Y	US 5,877,843 A (TAKAGI et al.) 2 March 1999, col. 4, line 1-col. 7, line 15.	5-20
Y	US 5,812,242 A (TOKUDA) 22 September 1998, col. 2, lines 20-65	5-20
Y	US 5,801,813 A (MORIMOTO et al.) 1 September 1998, col. 2, line 50-col. 3, line 25.	5-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

Date of mailing of the international search report
11 AUG 2000

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