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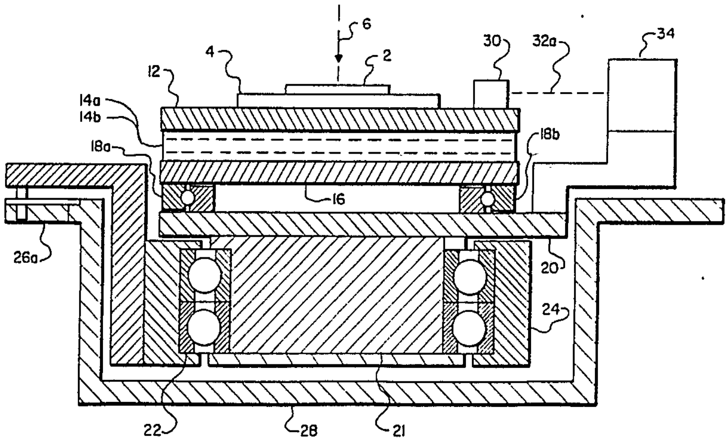

(57) Abstract

A positioning stage (8) which achieves high-speed step-and-repeat alignment of a semiconductor wafer (2) to a mask with a full six degrees of freedom. A precision planar translational stage is mounted on a rotating stage (20) to allow a single-laser interferometric system to be utilized to make precise measurements of translational (X and Y) and rotational (Θ) positions. The entire X-Y-Θ stage system can also be moved vertically in a Z direction, or tilted with respect to the X-Y plane, by independently adjustable flexible mounts (26a, 26b, 26c). The center of rotation of the rotational stage (20) is on the beam axis (6), so that registration of the wafer (2) to a mask is simplified. Because the mass of the rotating stage (20) is not moved during high-speed X and Y-positioning steps, fast response is possible. In lithography applications, one rotational correction at the beginning of the writing procedure suffices for all the chips on the wafer, if all the rows and columns of chips are perfectly straight. Besides its usefulness in litography with a flood ion beam, the invention is also useful in direct-write electron- or ion-beam lithography systems with focused beams, to obviate the need for high-speed electronic scan rotation.

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X-Y-θ-Z POSITIONING STAGE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention pertains to apparatus for positioning an object precisely with at least four and as many as six degrees of freedom, and in particular to a positioning stage for use in masked ion-beam lithography.

2. Description of the Related Art

The design and production of very large scale integrated (VLSI) circuitry components requires an assortment of costly apparatus and sophisticated processing techniques. Lithography is the process bringing together the many techniques for selectively removing or adding material to the semiconductor wafers from which the circuit chips are ultimately fabricated. One of the most promising techniques in this area of technology is masked ion-beam lithography, in which a collimated beam of ions passes through a mask onto a semiconductor wafer covered with photoresistive material. The advantage of using ion-beam lithography is that it allows extremely high pattern resolution. The massive ions have a relatively short mean free path in the photoresist material, and the secondary electrons produced in collisions have relatively low energy and also do not travel very far. Because there is some ion scattering when the ions travel through the mask, the mask and wafer must be positioned very closely to each other (approximately 25 micrometers) to achieve high-resolution exposures.

Once the mask is fixed in location, alignment of the wafer to the mask requires precise motions with at least four and as many as six degrees of freedom. The movements need to be accomplished very rapidly, and the wafer needs to be held rigidly in place once it is precisely located.

U.S. Patent Number 4,528,490 to Hansen, assigned to Hughes Aircraft Company, the assignee of the present invention, discloses a two-axis drive for a positioning stage. The drive includes, for each stage, a drive bar frictionally engaged against a drive capstan and held in place by a floating pressure roller so that the pressure roller can swing as the drive bar swings.

U.S. Patent Number 4,532,426 to Reeds, assigned to Hughes Aircraft Company, discloses a wafer height correction system for a focused beam system. The base plate of the wafer support is flexibly mounted with respect to the floor of the target chamber. Metal diaphragms flex by operation of one or more motors to adjust the position of the wafer support with respect to the focal point of the column.

Typical positioning apparatuses used for wafer lithography incorporate a rotating stage on top of a translational stage. Translational motion of the wafer in a plane and rotation of the wafer about an axis normal to that plane are allowed. The plane of translational motion is commonly referred to as the X-Y plane, and the angle of rotation in the X-Y plane as Θ. With this sort of arrangement, the mass of the rotating element must be moved in changing the X and Y positions of the wafer. The added inertia of the rotating stage reduces the speed of response that is obtainable. In addition, with this sort of arrangement, as the X and Y positions are varied, the center of rotation for θ moves relative to the system axis. In registering the lithography mask to the wafer, if the center of rotation does not lie on the system beam axis, then each chip on the wafer will require a different algorithm to use the mask-mask alignment sensing measurements to compute the necessary rotational corrections to align the mask and the wafer. Also, in conventional positioning systems the wafer is not fixed relative to the interferometer mirrors used in determining the position of the wafer. This makes the procedure of measuring the X-Y position of the wafer more complicated than it would be if the position of the wafer were fixed relative to the interferometer mirrors.

In conventional direct-write systems using a focused electron or ion beam to create the patterns on a chip, the center of rotation for the positioning stage does not coincide with the beam axis. The pattern to be written on the chip is programmed in X-Y coordinates on a computer which controls the scanning of the beam. Any rotational misalignment that is compensated for by rotating the wafer creates an X-Y shift of each chip that varies with the position of the chip on the wafer. The X-Y coordinates must now be transformed for each chip to take account of the rotation.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide apparatus for the precise positioning of an object in three dimensions, including three translational degrees of freedom and three angular degrees of freedom.

It is another object of the present invention to provide a positioning stage for masked ion-beam lithography, which allows translational movement of a semiconductor wafer in three mutually perpendicular directions, as well as rotational movement about three mutually perpendicular axes of rotation.

It is yet another object of the present invention to provide a positioning apparatus that avoids the necessity for high-speed electronic scan rotation in electron- and ion-beam direct-write systems.

It is still another object of the present invention to provide a positioning apparatus for use in wafer lithography in which the center of rotation for the rotating stage does not move relative to the beam axis.

Another object of the present invention is to provide a positioning stage for wafer lithography in which the mass of a rotating stage does not have to be moved during high-speed translational positioning steps, so that faster response is achieved.

One more object of the present invention is to provide a precision lithography positioning stage in which the object to be positioned is fixed relative to interferometer mirrors used for measuring the object's position.

Finally, it is an object of the present invention to provide a lithography positioning stage in which rotation of a semiconductor wafer can be done about the beam axis, independent of the wafer's position in a plane, so that the process of registering the wafer to the mask is simplified.

The invention provides means of achieving high-speed step-and-repeat alignment of a semiconductor wafer to a mask with a full six degrees of freedom. The apparatus disclosed consists of a precision planar translational stage mounted on a rotating stage in a manner that allows a single-laser interferometric system to be utilized to make precise measurements of translational (X and Y) and rotational (Θ) positions. The entire X-Y-Θ stage system can also be moved vertically in a Z direction, or tilted slightly with respect to the X-Y plane, by independent Z drives, so that a full six degrees of freedom in positioning a sample with high precision can be achieved. Because the mass of the rotating stage is not moved during high-speed X- and Y-positioning steps, fast response is possible. The center of rotation for Θ is on the beam axis and does not move relative to it. In lithography applications, a semiconductor wafer can be rotated about the beam axis independent of the X and Y positions, and registration of the wafer to the mask is simplified. One rotational correction at the beginning of the writing procedure suffices for all the chips on the wafer, if all the rows and columns of chips are perfectly straight. In general, however, very small corrections in position may be necessary for each chip exposure.

The invention fills the need for a rigidly coupled, fast-responding positioning apparatus that can be conveniently used in VLSI circuit chip lithography and related work. The disclosed apparatus allows the precise positioning of a semiconductor wafer in as many degrees of freedom as possible, in order to facilitate the alignment of a lithography mask to the wafer. In contrast to the prior art, the center of rotation of the rotational stage is on the beam axis, and does not require the mass of the rotating stage to be moved during translational positioning movements. The position of the wafer is fixed with respect to the interferometer mirrors used in measuring its position. Besides its usefulness in lithography with a flood ion beam, the invention is also useful in direct-write electron- or ion-beam lithography systems with focused beams, to obviate the need for high-speed electronic scan rotation.

An appreciation of other aims and objects of the invention and a more complete understanding of it may be achieved by studying the description of the preferred embodiment and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is sectional view of the apparatus of the present invention.

Fig. 2 is a schematic block diagram of the electronic control arrangement for the positioning stage.

FIG. 3 is a modified plan view of the X-Y-Θ-Z positioning stage used in the invention. Some component parts have been relocated to aid in understanding operation of the stage.

FIG. 4 is a perspective view of the present invention.

FIG. 5 is a perspective view of the present invention rotated through an angle of approximately 90° with respect to the view shown in FIG. 4.

FIG. 6 is a sectional view of showing one of the Z-positioning drives as well as part of the Θ rotation bearings.

FIG. 7 is a sectional view, with parts broken away, showing the capstan engagement with the drive bar, and the pressure roller mounting.

FIG. 8 is a sectional view, with parts broken away, of the Y drive bar attachment to the X-Y stage plate.

FIG. 9a is a perspective view of the Θ drive bar.

FIG. 9b is another perspective view of the Θ drive bar showing how its flexure allows the angle Θ to change.

FIG. 10 is a plan view of a half-angle coupling arrangement that connects one of the beamsplitters to the Θ stage platform.

DESCRIPTION OF A PREFERRED EMBODIMENT

FIG. 1 illustrates a semiconductor wafer 2 mounted conventionally on a mounting block 4 with a collimated ion beam impinging on it along a beam axis 6. The apparatus shown is in a vacuum. The wafer must be accurately positioned and regularly repositioned for treatment by the ion beam. Therefore, the positioning stage 8 of the present invention carries the wafer 2, and (referring to FIG. 2) electronic control means 10 is connected to drive the positioning stage 8 and position it with respect to the ion beam. The electronic control means 10 is preferably in the form of a computer having a program to establish the desired position of the wafer 2.

In the sectional view of FIG. 1, some of the details of the positioning stage 8 can be seen. An X-Y stage plate 12 which is the top portion of stage 8 is mounted on first and second X translation linear bearings 14a,14b. A typical linear bearing consists of a line of balls mounted in a retainer which maintains the spacing between the balls, and positioned between two "V"-shaped notches in which the ball surfaces roll during rectilinear motion. The first and second linear bearings 14a,14b are spaced apart and aligned in the X direction. Bearings 14a,14b in turn are mounted on an intermediate plate 16 that is mounted and rides on first and second Y translation linear bearings 18a,18b. The entire X-Y stage, comprising X-Y stage plate 12, X translation bearings 14a,14b, intermediate stage plate 16, and Y translation bearings 18a,18b, is mounted on a θ rotation stage platform 20. Platform 20 is mounted on the end of a rotor drum 21 set inside rotation bearings 22, which in turn are set inside a stator 24. Bearings 22 are a duplexed pair of nonseparable ball bearings which are preloaded to maintain an interference fit for the balls. Three vertically adjustable flexible mounts 26a,26b,26c (only one is shown in FIG. 1) are secured to a base 28 to support stator 24. An X position mirror 30 is mounted on the X-Y stage plate 12 to reflect the beam 32a from an X interferometer 34, which is used to sense the position of the wafer 2 along the X translational axis.

Intermediate stage plate 16 is constrained to move into and out of the page (the Y direction) in FIG. 1 in a linear direction with respect to θ stage platform 20. Stage plate 16 moves on first and second spaced Y translation linear bearings 18a,18b. The pair of spaced X translation bearings 14a,14b constrain the X-Y stage plate 12 to move left or right (the X direction) in FIG. 1 with respect to the intermediate stage plate 16. The X translation bearings 14a,14b are arranged so that the X-Y stage plate 12 moves along an axis parallel to the direction of the bearings 14a,14b, which are substantially parallel to each other and to the surface of X-Y stage plate 12. Wafer 2 is positioned on mounting block 4 on stage plate 12 and is substantially normal to the ion beam axis 6. Similarly, the Y translation linear bearings 18a,18b are arranged so that the intermediate stage plate 16 moves along an axis parallel to the direction of the bearings' alignment. The bearings are substantially parallel to each other and to the top surface of intermediate stage plate 16.

The X-Y stage plate 12, the intermediate stage plate 16, and the Θ stage platform 20 are each driven by separate drive mechanisms which are very similar. The drive mechanism for the intermediate stage plate 16 is shown in more detail in FIG. 7 as representative of all three drive mechanisms. A Y-drive motor 36 is mounted on a flange 38 which is secured to the bottom of base 28. A collar 40 extends upward from flange 38 and contains strong and heavy antifriction bearings 42. A Y drive capstan 44 with a Y drive pinion gear 46 mounted on it is driven by Y drive motor 36 and is supported by bearings 42. A seal 43 is positioned around the capstan within flange 38 so that the Y drive motor 36 may be in the nonvacuum space. There is a vacuum above the base 28. The seal 43 may be a Ferro-Fluidic seal.

A Y drive rack gear 48 on a Y drive bar 50 is engaged with pinion gear 46 on Y drive capstan 44. Y drive pressure rollers 52,53 engage the side of the Y drive bar 50 opposite Y drive capstan 44 to apply a normal force which keeps Y drive rack gear 48 meshed with Y drive pinion gear 46. The mounting of both Y drive pressure rollers 52,53 is the same. As seen in FIG. 7, Y drive pressure roller 52 is in the form of a needle type antifriction bearing mounted on a pin 54. Pin 54 is mounted on a Y drive yoke 56, and may be barrel shaped to permit tilting of pressure roller 52. Y drive yoke 56 is in turn mounted on antifriction bearings 58 which embrace the outer surface of collar 40. An annular cap 60 keeps bearings 42 and 58 in place. The axis of rotation of Y drive yoke 56 coincides with the axis of rotation of Y drive capstan 44, so that the pressure rollers 52,53 can swing around the capstan. The yoke structure is preloaded to maintain pressure on Y drive bar 50 to hold Y drive rack gear 48 in engagement with Y drive pinion gear 46 on Y drive capstan 44, independent of the direction of Y drive bar 50 around the axis of the capstan. With this construction, the direction of motion of the intermediate stage plate 16 on its Y translation bearings 18 need not be exactly parallel to the direction of motion of the Y drive bar 50 as driven by Y drive capstan 44.

Y drive motor 36 is connected to be appropriately driven to move the intermediate stage plate 16 into and out of the plane of FIG. 1. The direction of Y drive bar 50 has complete angular freedomin a plane normal to the Y drive capstan 44 and pin 54, which are substantially parallel to each other. In a similar way, an X drive motor 61 has an X drive capstan 62 with an X drive pinion gear 64 mounted on it. Pinion gear 64 engages a rack gear 66 on one side of the X drive bar 68. A pair of X drive pressure rollers 70,71 keep the gears meshed under pressure.

The attachment of the other end of the Y drive bar 50 to the intermediate stage plate 16 is illustrated in FIG. 8. A pin 74 is secured to and extends downward from the bottom of an insert 76, which is secured in an opening in intermediate stage plate 16. Bearings 78 embrace pin 74 and are constrained within a yoke 80, which is secured to the end of Y drive bar 50. The bearings 78 are a heavily preloaded duplex pair to eliminate backlash and provide a stiff connection. It is thus seen that Y drive bar 50 does not apply torques to intermediate stage plate 16. Y drive bar 50 has angular freedom of movement in a plane normal to the axis of Y drive capstan 44, because the drive end adjacent capstan 44 has such freedom and the yoke end under insert 76 has such freedom. It is particularly important to have the angular freedom for the drive bar 50, because its capstan end is referenced to the base 28 while its yoke end is referenced to the intermediate stage plate 16. Stage plate 16 has freedom of motion in the directions defined by the translation bearings 18a,18b and the rotation bearings 22.

Again in a way similar to that for the Y drive arrangement, a θ drive motor 83 has a θ drive capstan 88 with a θ drive pinion gear 86 mounted on it. Pinion gear 86 engages a rack gear 84 on one side of the θ drive bar 81. A pair of θ drive pressure rollers 87,89 which are mounted on an θ drive rotatable yoke keep the gears meshed under pressure.

The attachment of X drive bar 68 to stage plate 12 is similar to the attachment of Y drive bar 50 to intermediate plate 16 as described above and illustrated in FIG. 8. The attachment of the θ drive bar 81 to θ stage platform 20 is different from that for the X and Y drives, however. The θ drive bar is as shown in FIGS. 9a and 9b. Because the range of rotation in the angle θ is only a few degrees, the θ drive bar 81 has a narrowed section 82. The narrowed part allows it to flex slightly, as shown in FIG. 9b, as the θ stage platform 20 is rotated. The width of the θ drive bar 81 narrows from 3/4 of an inch to about 1/10 of an inch; the narrowed portion 82 has a length of about one and a half inches. The thickness of the drive bar 81 is about half an inch. The end of drive bar 81 has two holes 82a,82b through which bolts fasten it to the θ stage 20 platform 50.

Referring now to FIG. 3, which is a plan view of the X-Y-θ-Z positioning stage 8, details are seen of how the stage 8 is driven and how the position of the wafer 2 is measured. X drive bar 68 with rack gear 66 on one side couples the X-Y stage plate 12 via meshing pinion gear 64 on X drive capstan 62 to X drive motor 61. Similarly, Y drive bar 50 with rack gear 48 on one side couples intermediate stage plate 16 via meshing pinion gear 46 on Y drive capstan 44 (shown in FIG.

4) to Y drive motor 36 (shown in FIG. 3). The Θ drive bar 81 couples Θ stage platform 20 to Θ drive motor 83 (shown in FIG. 3) in a way similar to that for the X and Y drive couplings, through rack gear 84 meshed with pinion gear 86 on capstan 88. Three vertically adjustable flexible mounts 26a,26b,26c support the stator 24.

A Y interferometer 90 and Y receiver 104, an X interferometer 34 and X receiver 102, and a first beamsplitter 92 are all mounted on rotational stage platform 20. A second beamsplitter 94 is mounted separately and coupled to rotate through half the angle that the rotating stage does. The interferometer 90 is used in conjunction with a Y position mirror 96 mounted on the X-Y stage plate 12 to determine the Y position of the wafer being worked on. The X interferometer 34 is used in concert with the beamsplitters 92,94 and X position mirror 30 to determine the X position of the semiconductor wafer. A Θ interferometer 98 mounted on base 28 is used cooperatively with the second beamsplitter 94 and a retroreflector 100 mounted on platform 20 to determine the Θ angular position of the wafer. Laser receivers 102, 104, and 106 ultimately detect the three beams 32a,32b,32c derived from laser 108, also mounted on base 28, and sensed respectively by X interferometer 34, Y interferometer 90, and Θ interferometer 98. The semiconductor wafer 2 to be worked on is mounted on mounting block 4 on top of the X-Y stage plate 12, which must be adjusted to be perpendicular to the ion beam axis 6.

Referring now to FIG. 4, laser beam 32d must remain perpendicular to the face of beamsplitter 92 as the platform 20 rotates in Θ. Beamsplitter 94 is mechanically coupled to the Θ stage platform 20 so that it rotates through only half the angle through which the Θ stage platform 20 rotates. This is necessary because a beam reflected from a mirror rotates through twice the angle through which the mirror rotates. The mirrors 30 and 96 are used to reflect the X and Y interferometer beams, respectively. One possible arrangement for the half-angle mechanical coupling between the beamsplitter 94 and the Θ stage platform 20 is shown in FIG. 10.

In FIG. 10, the beamsplitter 94 is mounted on a rotation bearing 110 and is rigidly coupled to a first linkage arm 112 which is pivotally attached to one end of a second linkage arm 114. The distance from the center of the beamsplitter to the pivotal connection with the second linkage arm 114 is L_5. The second linkage arm 114 has a slot into which a first pivot pin 116 mounted on base 28 fits. A third arm 118 is pivotally connected to the other end of the second linkage arm 114 and to one end of a fourth linkage arm 120. The third arm 118 has a hole in it so that it can be pivotally mounted on a second pivot pin 122 which is rigidly attached to base 28. The distance from the pivot pin 122 to the pivotal connection point of the third linkage arm 118 with the fourth linkage arm 120 is L_2. The pivotal connection point of the second linkage arm 114 with third linkage arm 118 is equidistant from the two stationary pivot pins 116 and 122. The other end of fourth linkage arm 120 is pivotally attached to the Θ stage platform 20 at a distance L_1 from the center of the stage. The ratio L_1L_4/L_2L_5 is chosen to equal 1/2, so that the beamsplitter 94 rotates through 20 only half the angle through which the Θ stage platform rotates.

The X interferometer 34, Y interferometer 90, retroreflector 100, and laser receivers 102,104 are all mounted on the Θ stage platform 20. The Θ interferometer 98, laser receiver 106, and laser 108 are mounted on the base 28. The X and Y interferometers can both be Hewlett-

Packard Model 10706 interferometers, while the θ interferometer can be a Hewlett-Packard Model 10702A. Retroreflector 100 can be a Hewlett-Packard Model 10703A, and beamsplitters 92,94 can both be Hewlett-Packard Models 10701A. Laser receivers 102,104, and 106 can all be Hewlett-Packard Models 10780A, and laser 108 can be a Hewlett-Packard Model 5501.

The output beam from laser 108 is incident on first beamsplitter 94. Part of the incident beam is transmitted to θ interferometer 98 and the remainder is reflected to impinge on beamsplitter 92, which similarly divides the incident beam into a part reflected at right angles to X interferometer 34 and a residual transmitted beam which strikes Y interferometer 90.

The X, Y, and θ interferometers all work in essentially the same manner, except that the retroreflector 100 used with the θ interferometer 98 corresponds in its function roughly to the X position mirror 30 or the Y position mirror 96. The reason for using a corner cube reflector is that any beam reasonably close to normal incidence is reflected back parallel to itself, although with a slight lateral shift whose magnitude depends on the angular deviation from normality.

The beam leaving the laser at a nominal wavelength of 632.8 nm is actually composed of two differently polarized beams which differ by 20 MHz in frequency as a result of so-called Zeeman splitting of a transition line. the splitting of the line is effected by a magnetic field which permeates the active medium of the laser. Each interferometer comprises a polarizing beamsplitter in combination with an attached quarter-wave plate. Of the two differently polarized beams incident on the interferometer, only one traverses an optical path that includes reflection from the mirror or retroreflector. The motion of the reflecting element is converted, via the Doppler effect, into a frequency shift of the polarized beam reflected from it. The frequencies of the two differently polarized beams are fed to a difference counter. The number of counts in the difference is effectively a velocity multiplied by a time interval. The distance of travel of the reflector thus yields the distance of travel of the particular part of the stage to which it is attached. With the use of a phase lock oscillator at a frequency of ten times the Zeeman frequency shift, it is possible to resolve a change in position as small as 79 Angstroms for the position of the X or Y mirrors.

FIG. 5 gives a view of the apparatus of the present invention that is shifted some 90° with respect to the view given by FIG. 4. Two of the three flexible mounts 26a,26b,26c are shown. FIG. 6 is a partial sectional view showing some of the details of the flexible mount 26a as well as part of the rotation bearing 60. The flexible mount 26a comprises a flexible circular metal diaphragm 124a with a center hub 126a drilled and tapped to receive a mounting screw 128a which attaches the flexible 26a to the intermediate platform 24. Peripheral mounting screws 130a,131a connect the flexible mount 26a to the base 28. A cam 132a, coupled through reduction gearing 134a to a motor 136a raises or lowers the center hub 126a according to which part of its rotation cycle is reached. An encoder 137a senses the position of cam 132a and transmits positional information to computer electronic control 10. The spring constant associated with one of the flexible mounts 26 is typically 50,000 pounds per inch, so that the hub 126 will undergo a deflection of roughly 0.010 inch for an applied force of 500 pounds. The drive motors 136a,136b,136c can be a Pittman model GM 9413-2. The encoders 137a,137b,137c can all be a Teledyne Gurley rotary encoder model 8211. Since there are three flexible mounts 26a,26b,26c which are coupled to independent Z drive motors 136a,136b,136c, the tilt of the X-Y stage plate 20 with respect to the horizontal plane can be changed in addition to changing the Z position.

From studying the various figures it can be appreciated that in using the positioning apparatus of the present invention, rotation of the semiconductor wafer always occurs about the same axis, which coincides with the center of the beam cross section, independent of the X or Y positions of the stage. It should be noted also that the support points for the vertically adjustable flexible mounts are located as nearly as possible in the planes of the X and Y drives, in order that reaction forces resulting from X and Y accelerations will have minimal impact on Z.

The present invention has been described in detail with reference to a particular preferred embodiment, but persons possessing ordinary skill in the art to which this invention pertains will appreciate that various modifications may be made without departing from the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. An apparatus for positioning a semiconductor wafer with respect to the axis of an incident beam, comprising:

a first plate for supporting said wafer;

means for positioning said wafer at a predetermined position on said first plate;

means for moving said first plate in a first direction in the plane of the plate;

a second plate supporting said first plate;

means for moving said second plate in a second direction in said plane; and

means for supportively rotating the assembly comprising said first and second plates about said beam axis.

2. The apparatus of Claim 1, further comprising:

means for tilting said rotating means and for translating said rotating means in a direction perpendicular to said plane to thereby tilt and translate said first plate.

3. The apparatus of Claim 2, further comprising:

measuring means for measuring the position of said first plate and its angular orientation, said measuring means providing controls for the moving means for the first and second plates and for the rotating means to position said first plate at a predetermined position.

4. An apparatus for positioning a semiconductor wafer with respect to the axis of an incident beam, comprising:

a base;

a translational stage adapted to move in a plane;

a rotational stage supporting said translational stage and adapted to rotate about an internal axis;

first drive means mounted on said base for controlling the position of said translational stage in a first direction;

first coupling means connecting said translational stage to said first drive means;

second drive means mounted on said base for controlling the position of said translational stage in a second direction which is perpendicular to said first direction;

second coupling means for connecting said translational stage to said second drive means;

rotational drive means mounted on said base for controlling the angular orientation of said rotational stage with respect to rotation about said beam axis; and

rotational coupling means connecting said rotational stage to said rotational drive means.

5. The apparatus of Claim 4, in which said translational stage comprises:

a first set of bearings mounted on said rotational stage;

an intermediate stage plate connected to and riding on said first set of bearings, constrained to move on said first set of bearings in said second direction;

a second set of bearings mounted on said intermediate stage plate; and

a translational stage plate riding on said second set of bearings, constrained to move on said second set of bearings in said first direction.

6. The apparatus of Claim 5 further comprising mirrors mounted on said translational stage plate, and measuring means for measuring the positions of said mirrors, said measuring means controlling said first, second, and rotational drive motors, respectively, to position said wafer at a predetermined position.

7. The apparatus of Claim 5, in which said first and second sets of bearings comprise respective sets of linear bearings aligned in the respective directions of movement over said bearings.

8. The apparatus of Claim 4, in which said rotational stage comprises:

a rotor;

a stator; and

rotation bearings connecting said stator and said rotor, allowing said rotor to rotate about said beam axis.

9. The apparatus of Claim 8, in which said rotation bearings are a duplexed pair of nonseparable angular contact ball bearings which are preloaded to maintain an interference fit for the balls.

10. The apparatus of Claim 8, in which said rotor comprises a drum mounted inside said rotation bearings with a rotational stage platform at one end of said drum, overlying said bearings.

11. The apparatus of Claim 4, further comprising:

vertical adjustment means mounted on said base, for adjusting the vertical position and the angle of tilt of the assembly comprising said translational and rotational stages, said vertical adjustment means supporting said assembly.

12. The apparatus of Claim 11, in which said vertical adjustment means comprises:

a plurality of flexible mounts which support said rotational stage, each flexible mount independently allowing vertical motion of said stage by flexure of a flexible part of said mount; and

a plurality of vertical drive means attached to said base, for flexing said flexible parts of said mounts.

13. The apparatus of Claim 12, in which each said flexible mount comprises:

a flexible diaphragm;

a center hub on said diaphragm, supporting a portion of said rotational stage;

an outer mounting flange extending around the periphery of said diaphragm;

first mounting means mounting said flange to said base; and

second mounting means mounting said center hub to said stator.

14. The apparatus of Claim 13, in which each vertical drive means comprises:

a drive motor having an output shaft;

a set of reduction gears driven by said shaft; and

a cam driven by said gears, the cam contacting said center hub to move it vertically when the cam is rotated.

15. The apparatus of Claim 4, in which said rotational drive means comprises a rotational drive motor, and said

rotational coupling means comprises:

a rotational drive bar secured to said rotor, having rack gear teeth on a first long side which engage a pinion gear on a rotational drive capstan driven by said rotational drive motor, and having a narrowed section which allows transverse flexing; and

two rotational drive bar pressure rollers rotatably mounted on said base, bearing forcefully on a second long side of said drive bar opposite said first long side, and disposed to either side of the point of contact of said pinion gear with said rack gear teeth.

16. The apparatus of Claim 4, in which said first driving means comprises an first drive motor and said second driving means comprises a second drive motor, and in which:

said first coupling means comprises:

an first drive bar pivotally mounted on said translational stage plate, having rack gear teeth on a first long side which engage a pinion gear on an first drive capstan driven by said first drive motor; and

two first drive bar pressure rollers rotatably mounted on said base, bearing forcefully on a second long side of said second drive bar opposite said first long side, and disposed to either side of the position of said first drive capstan; and

said second coupling means comprises:

a second drive bar pivotally mounted on said intermediate stage plate, having rack gear teeth on a first long side which engage a pinion gear on a second drive capstan driven by said second drive motor; and

two second drive bar pressure rollers rotatably mounted on said base, bearing forcefully on a second long side of said second drive bar opposite said first long side, and disposed to either side of the position of said second drive capstan.

17. The apparatus of Claim 4, further comprising:
a laser mounted on said base;
a first interferometer mounted on said rotor;
a second interferometer mounted on said rotor;
a rotational interferometer mounted on said base;
first and second beamsplitters, said first beamsplitter being rotatably mounted to divide a beam from said laser into a first part along a first path to said rotational interferometer and a second part along a second path to said second beamsplitter, and said second beamsplitter being mounted to further divide said second part of said laser beam into a third part along a third path to said first interferometer and a fourth part along a fourth path to said second interferometer;
half-angle coupling means for causing said first beamsplitter to rotate through half the angle through which said rotor rotates;
a retroreflector mounted on said rotor, disposed behind said rotational interferometer on a side opposite the beam entrance side of said interferometer;
a first laser mirror mounted on said translational stage plate facing said first interferometer;
a second laser mirror mounted on said translational stage plate facing said second interferometer.
a first laser receiver mounted to receive that part of said laser beam which passes through said first interferometer after reflection from said first laser mirror;
a second laser receiver mounted to receive that part

of said laser beam which passes through said second interferometer after reflection from said second laser mirror; and

a third laser receiver mounted on said base to receive that part of said laser beam which passes through said rotational interferometer after reflection from said retroreflector.

18. The apparatus of Claim 17 wherein said first, second, and rotational interferometers control said first, second, and rotational drive motors, respectively, to position said wafer at a predetermined position.

19. The apparatus of Claim 16 wherein said half-angle coupling means comprises:

a first linkage arm, one end of which is rigidly coupled to said first beamsplitter;

a first pin mounted on said base;

a second linkage arm, one end of which is pivotally attached to the other end of said first linkage arm, and which has a slot through it to accept said first pin;

a second pin mounted on said base;

a third linkage arm pivotally attached to the other end of said second linkage arm and having a hole through it in which said second pin fits; and

a fourth linkage arm pivotally connected at one end to the other end of said third linkage arm, and pivotally connected at its other end to said rotor;

wherein the dimensions of the four linkage arms and their points of connection and the positions of said slot and said hole are chosen so that the first beamsplitter rotates through only half the angle through which the rotor does.

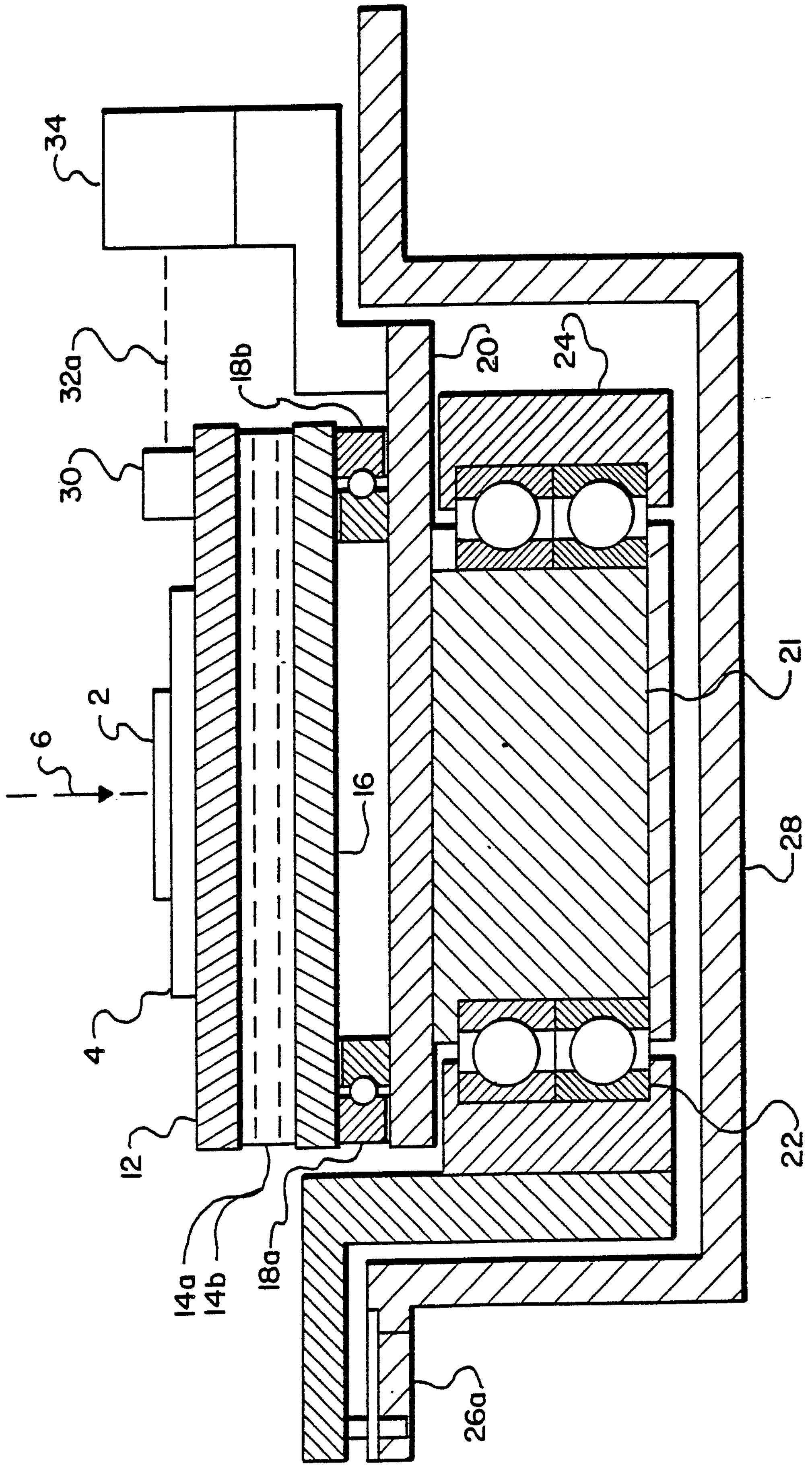
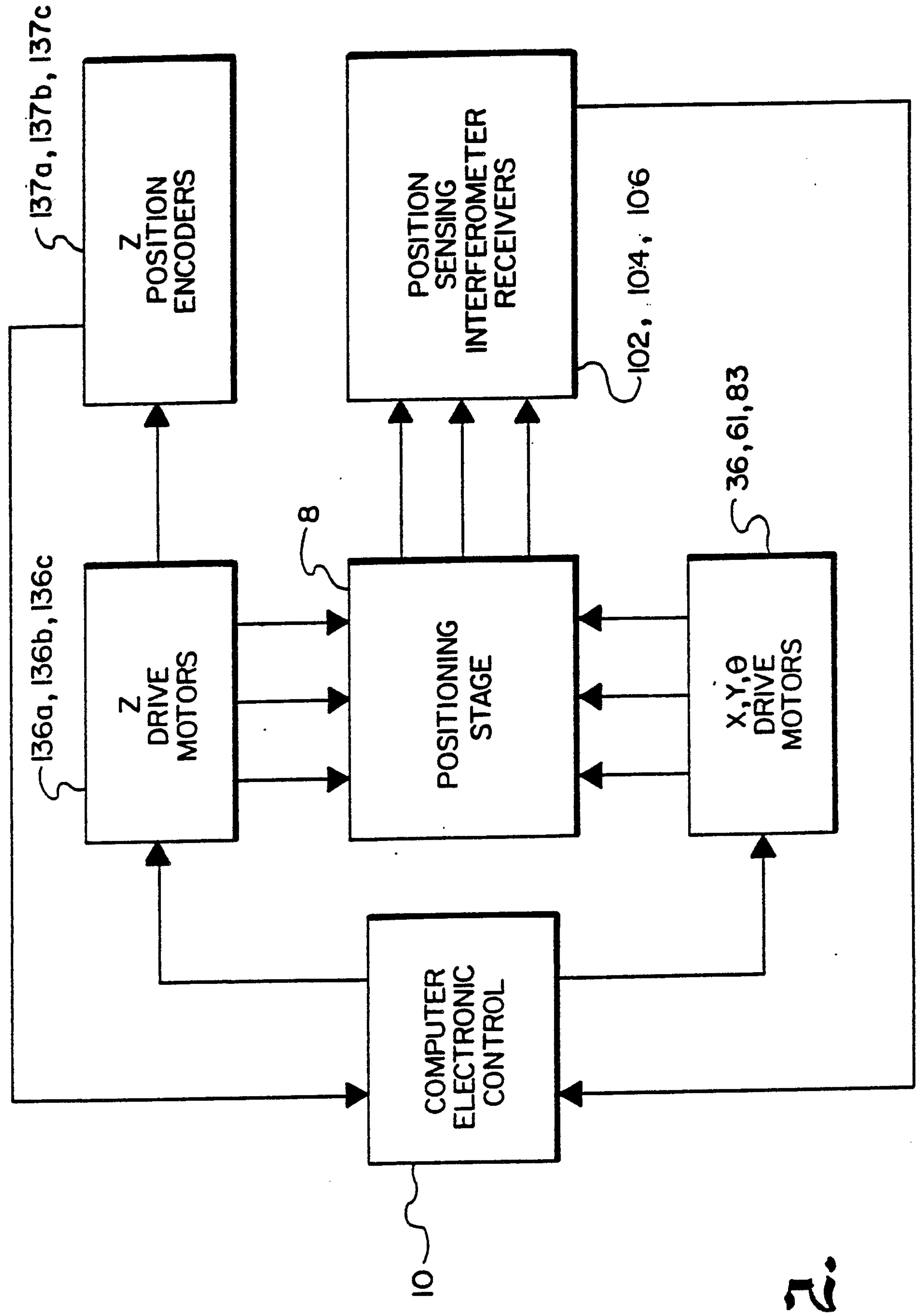


Fig.1.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POSITION SENSING INTERFEROMETER RECEIVERS
102, 104, 106
Z DRIVE MOTORS
136a, 136b, 136c
8
POSITIONING STAGE
X, Y, θ DRIVE MOTORS
36, 61, 83
COMPUTER ELECTRONIC CONTROL
10

Fig. 2.

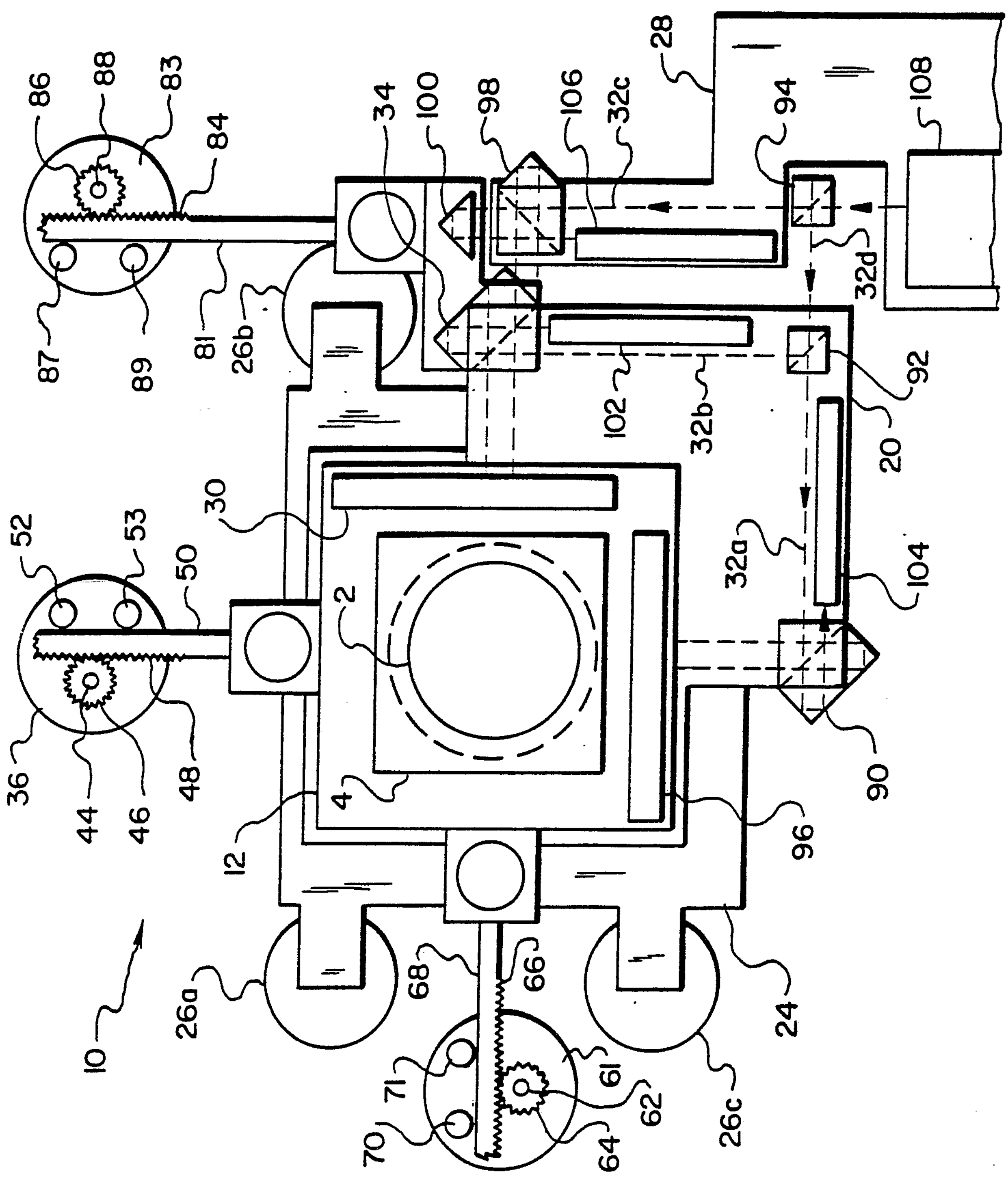
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Fig. 3.

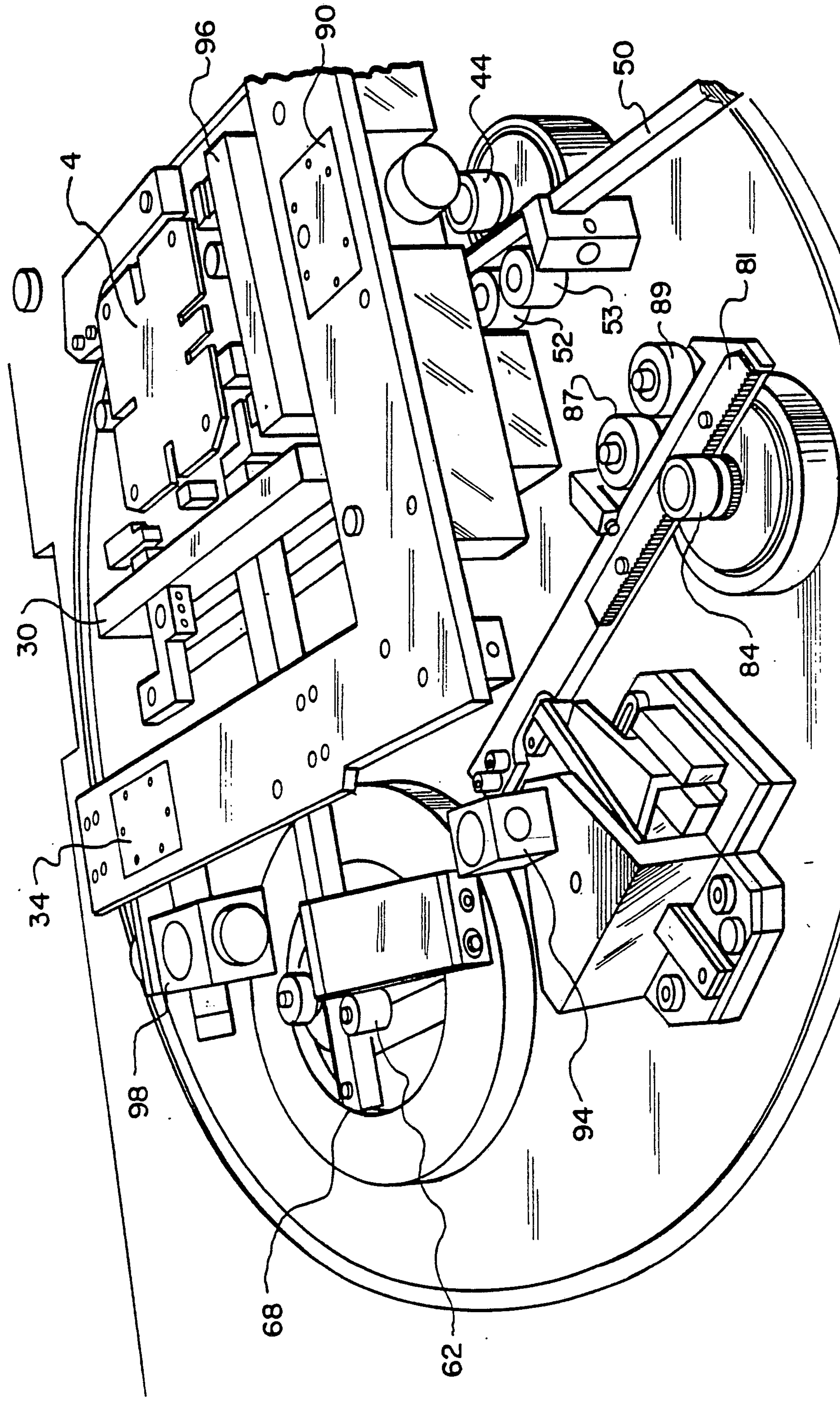


Fig.4.

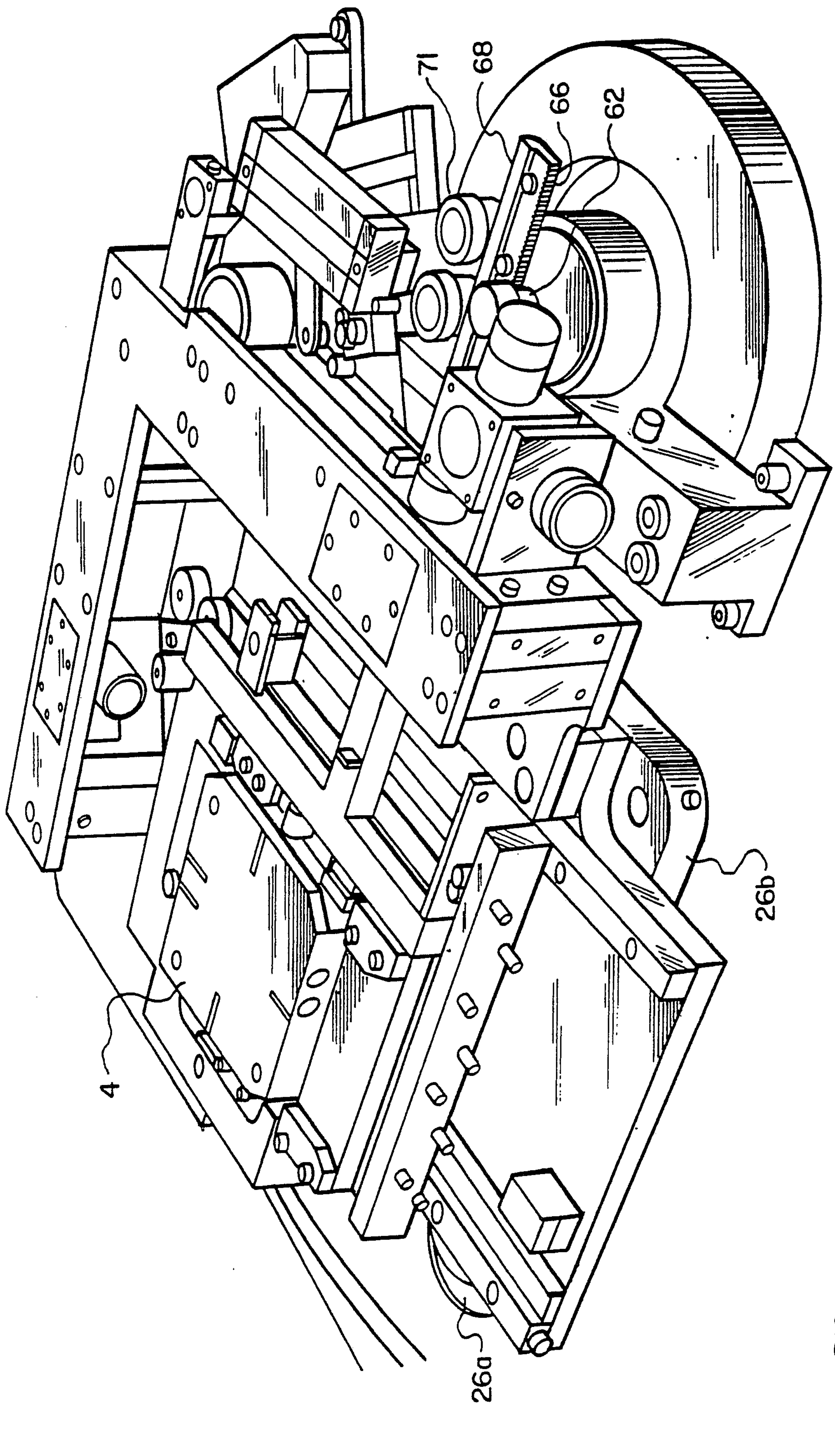
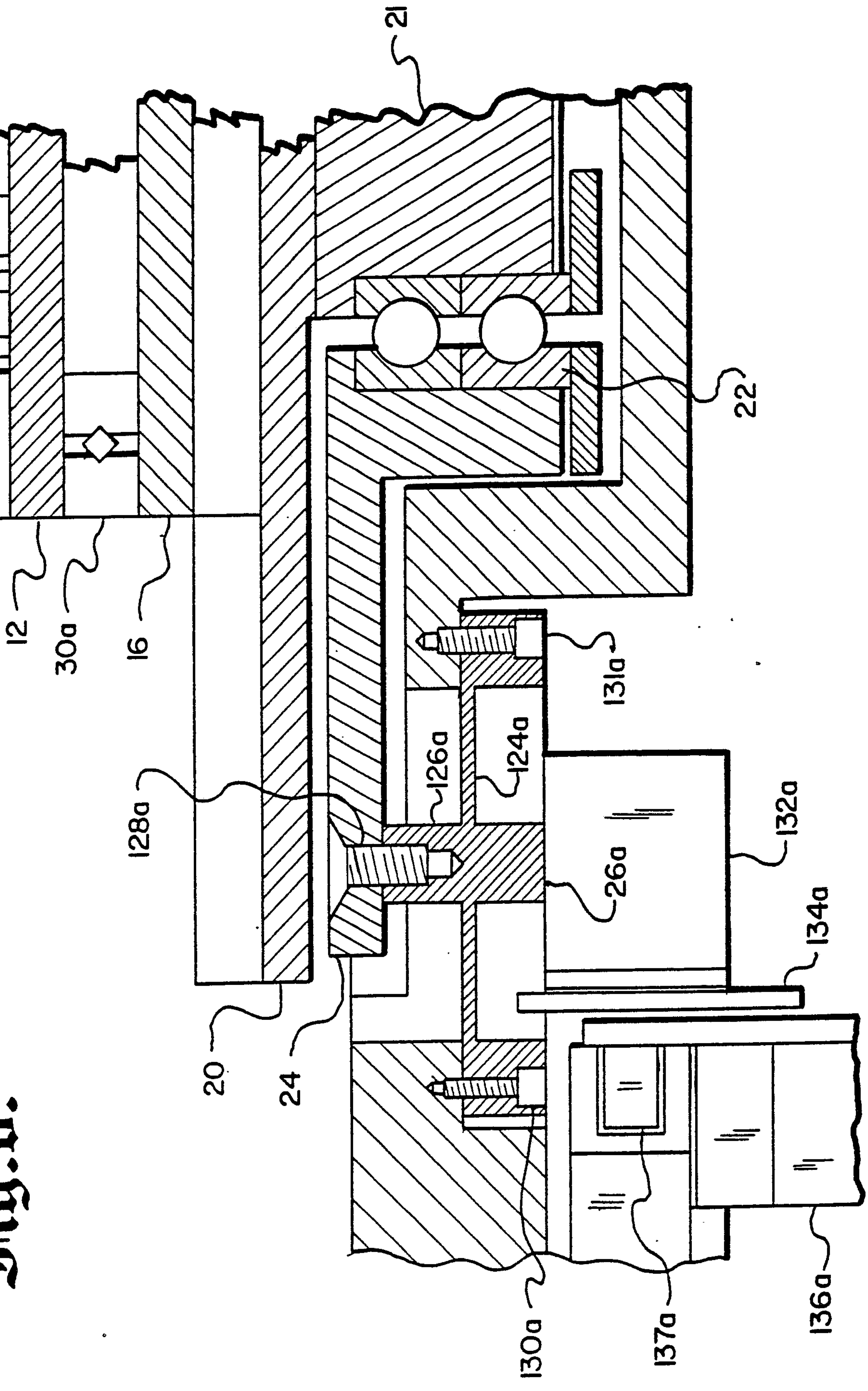


Fig.5.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137a
136a

Fig. 6.

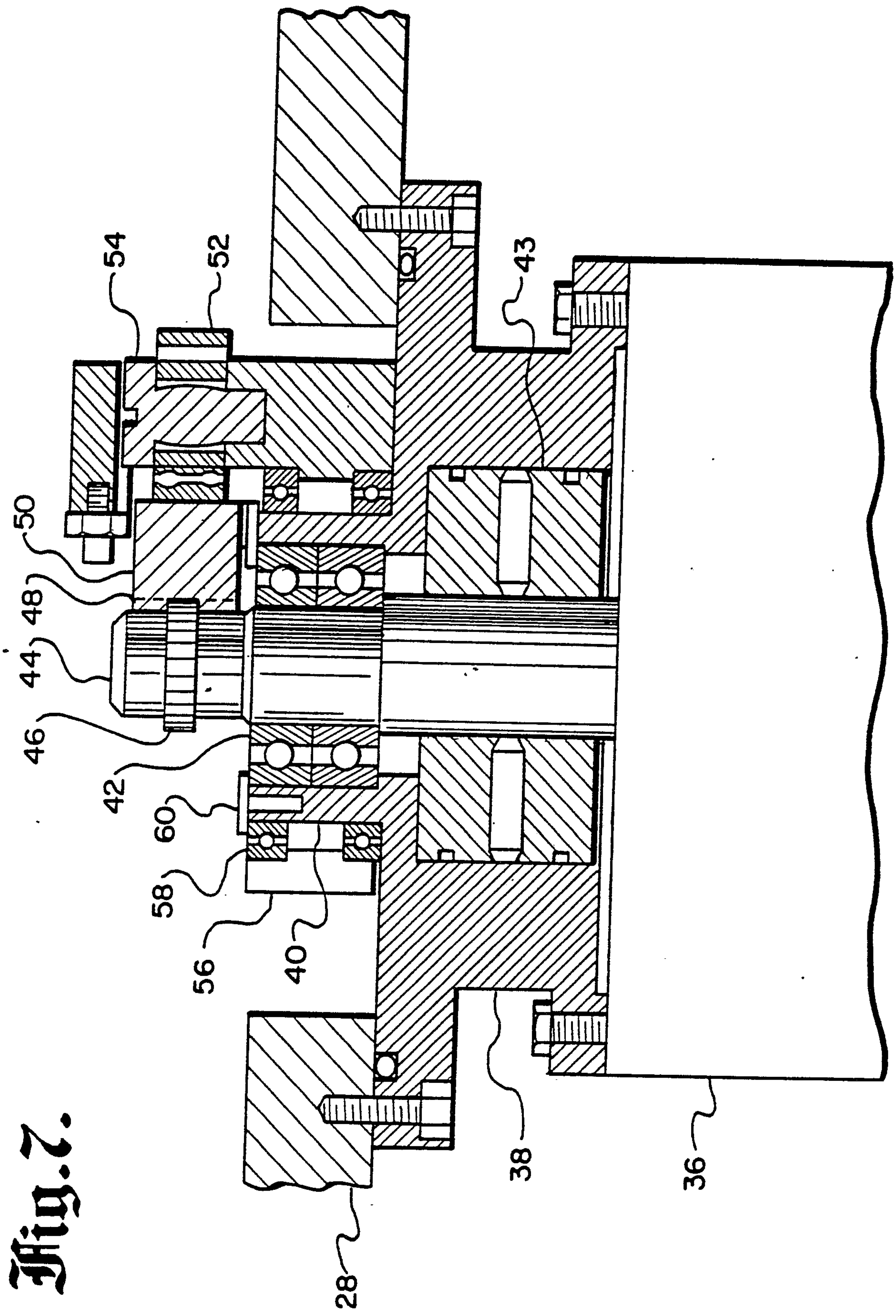


Fig.7.

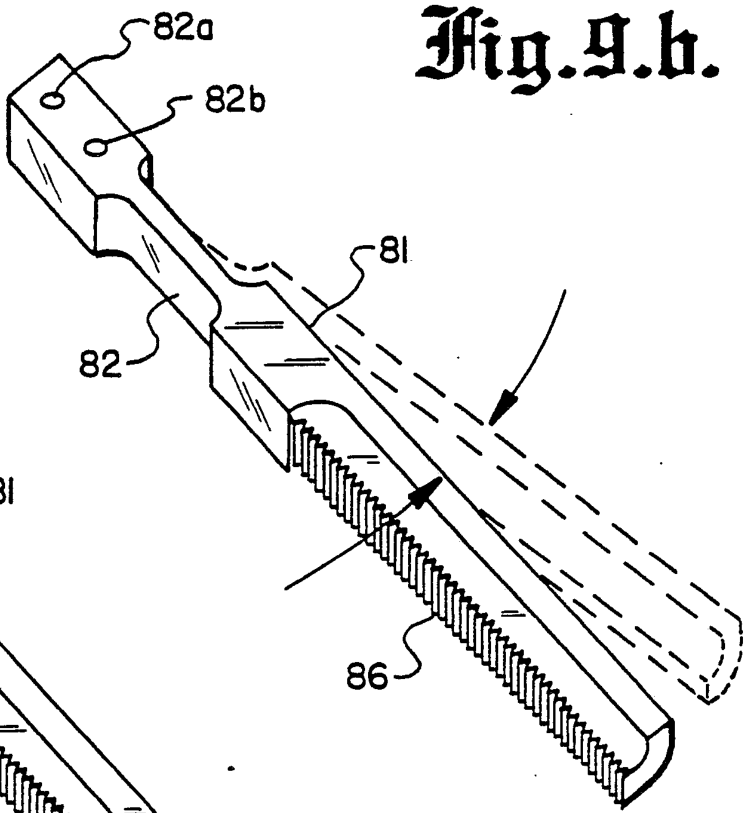


Fig.9.b.

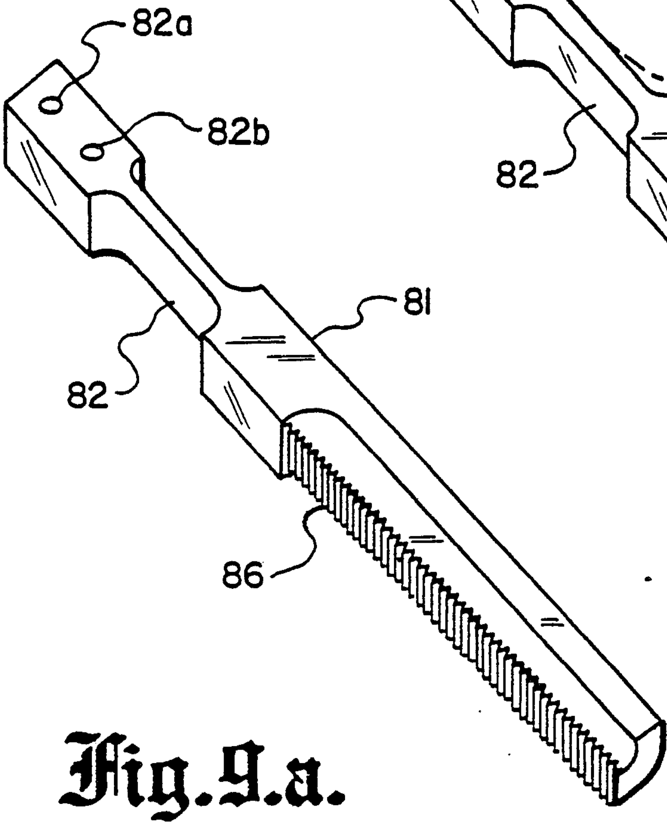


Fig.9.a.

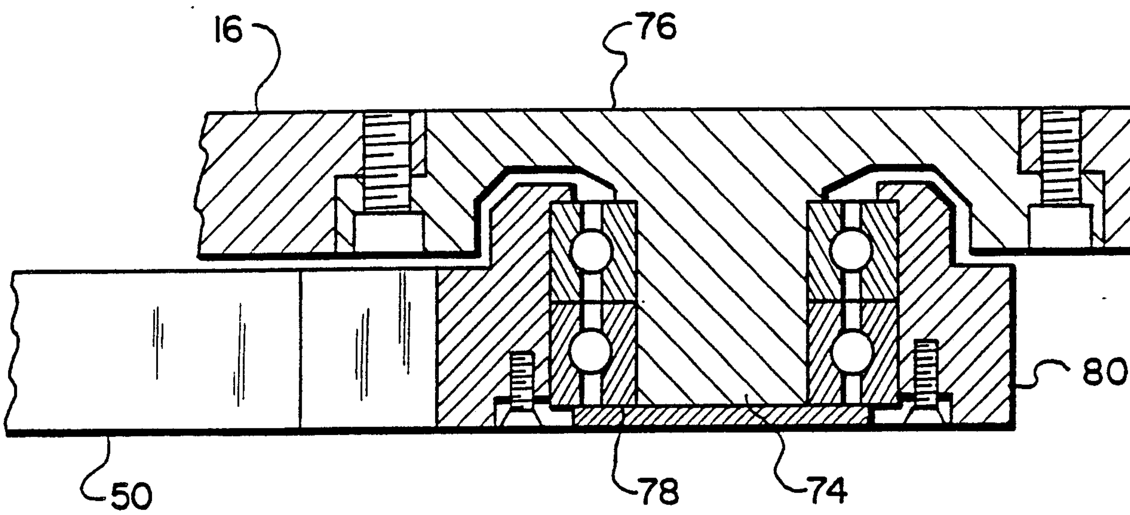
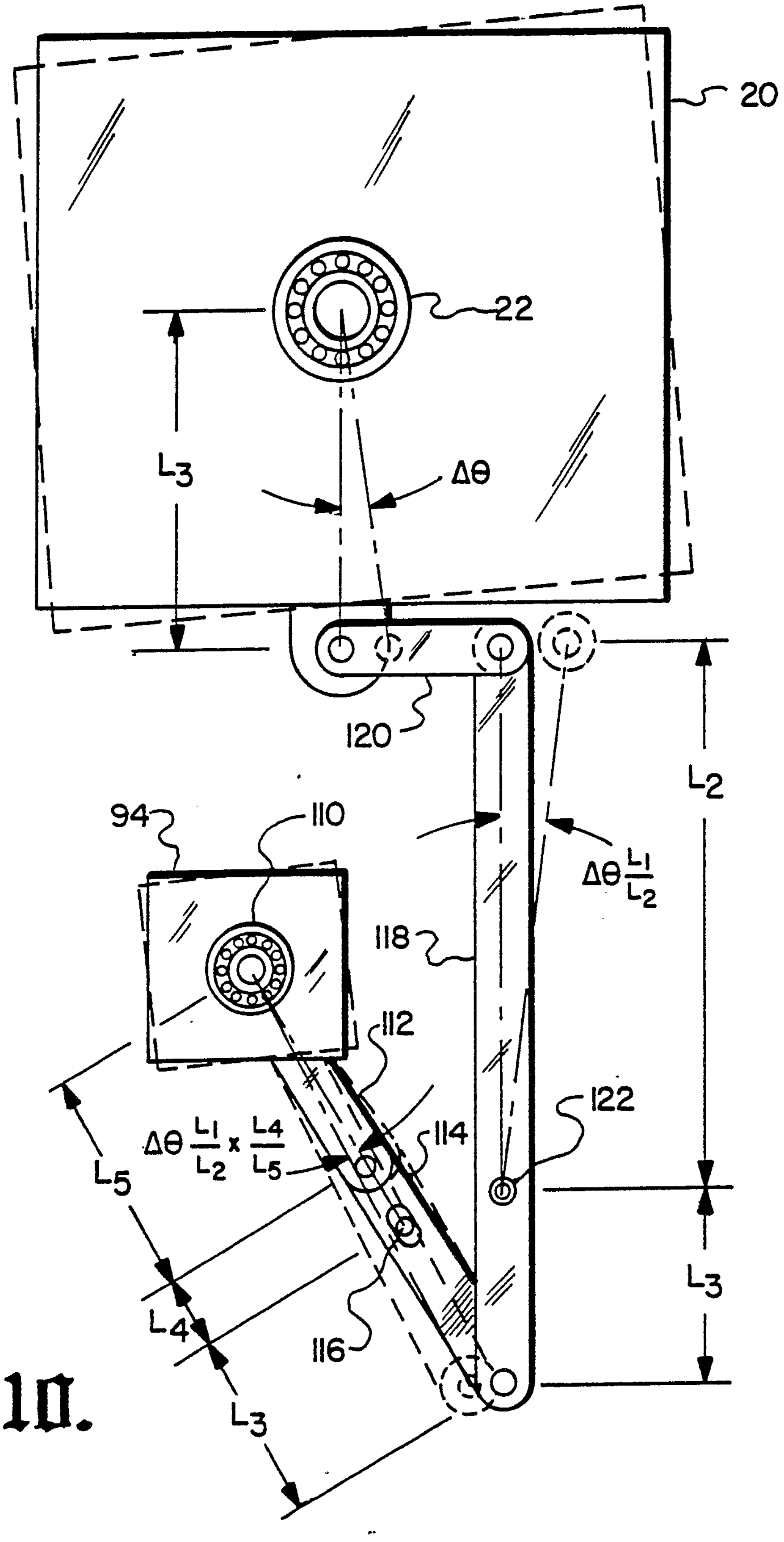


Fig.8.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22
L3
Δθ
120
L2
94
110
Δθ L1/L2
118
112
122
Δθ L1/L2 x L4/L5
114
L5
L3
L4
116
L3

Fig.10.

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 87/02954

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: H 01 J 37/20

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	H 01 J 37/00; G 03 B 41/00; G 03 F 7/00; 9/00; H 01 L 21/00; H 05 K 13/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	US, A, 4170418 (AIUCHI et al.) 9 October 1979 see column 3, line 64; figure 1 --	1,4,8,10
X	Technical Digest, no. 21, January 1971 Western Electric R.H. Keen et al.: "Photosensitive system for orienting a translucent substrate", pages 17-19, see page 18; figure 1 --	1,4
X	US, A, 3838274 (DOUBEK, Jr et al.) 24 September 1974 see column 4, lines 52-58; figure 1 --	1,4
X	US, A, 4203064 (SUZUKI et al.) 13 May 1980 see abstract; figure 1 --	1,4
X	FR, A, 1602768 (IBM) 5 March 1971 see page 6, lines 35-45; figure 1 --	1,4
		./.

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"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.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
21st March 1988	27 APR 1988
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	P.C.G. VAN DER PUTTEN

Form PCT/ISA/210 (second sheet) (January 1985)

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

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A	US, A, 4528490 (HANSEN) 9 July 1985 see abstract; figures 2-5 cited in the application	1,4
A	US, A, 4218136 (S. KONORIYA et al.) 19 August 1980 see column 2, lines 45-61; figure 1	1,4
A	EP, A, 0091234 (EATON) 12 October 1983 see page 9, lines 9-21; figure 1	1,4
A	Fujitsu Scientific & Technical Journal, vol. 15, no. 4, December 1979 (Tokyo, JP) T. Uchiyama et al.: "A precision auto mask aligner", pages 77-94, see pages 81-83; figures 2,5	1,4
A	EP, A, 0027570 (OPTIMETRIX) 29 April 1981	
A	US, A, 4585337 (E.H. PHILLIPS) 29 April 1986	

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 8702954 SA 20025

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 19/04/88
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		JP-A- 61216430	26-09-86

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82