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GB 1193297 A **EP 0511704 A** **WO 88/05205 A**
US 4572021 A

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(54) Abstract Title
Pattern-writing machine

(57) A pattern-writing machine comprises an electron beam column (11) for generating a deflectable electron beam, a displaceable stage (10) for supporting a substrate (13) to be scanned by the beam for writing a pattern on the substrate, and a displacing system for displacing the stage (10) and thereby the substrate (13) relative to the beam. The displacing system comprises three pairs of struts (15, 16, 17), which support the stage (11) and are individually variable in length, and drive means for varying the strut lengths to move the stage along each of three mutually orthogonal axes (X, Y, Z) and to pivot the stage about each of the three axes. The drive means can take the form of separately operable drives respectively associated with the struts and controlled by measuring systems detecting stage horizontal position, vertical position and attitude. The stage (15, 16, 17) are connected to the stage (10) and a fixed base (14) by universal joints (18, 19).

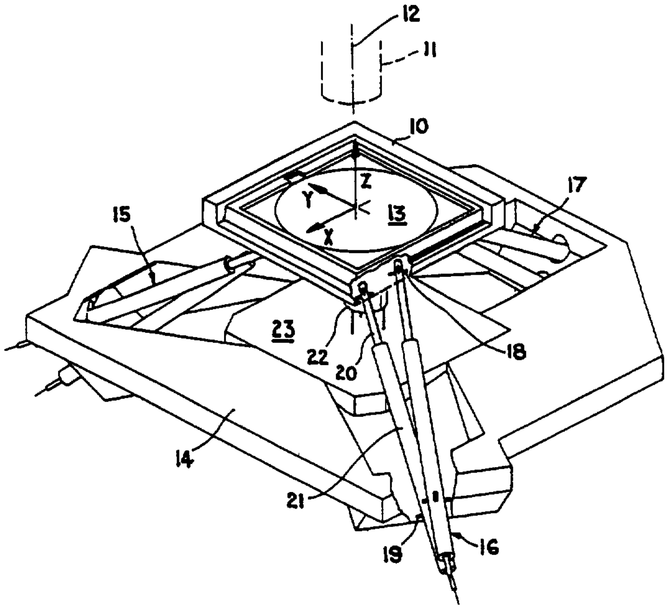

FIG.1

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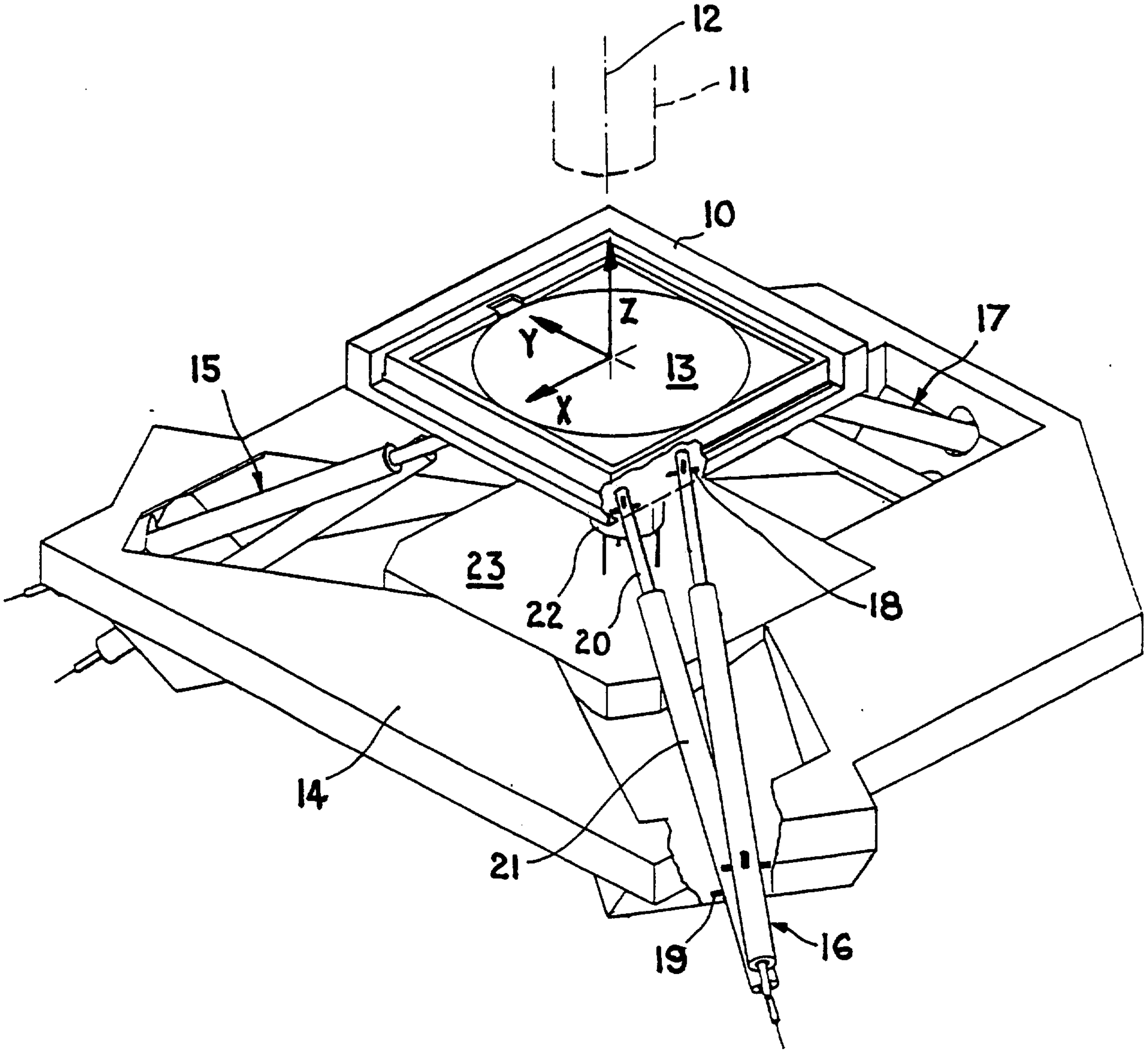

FIG.1

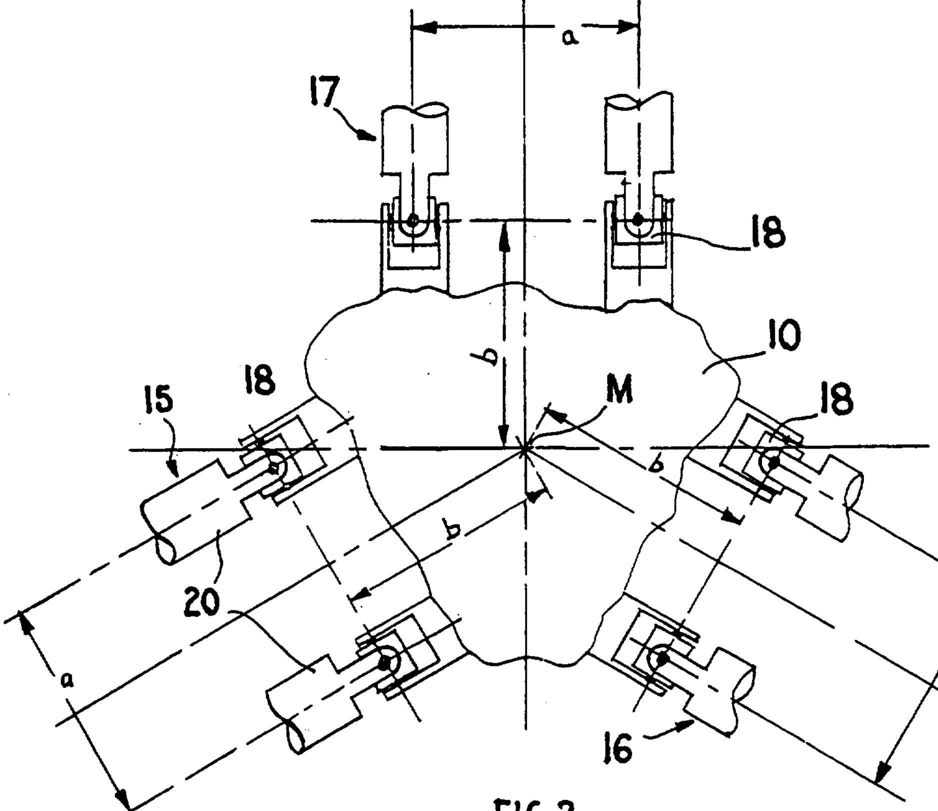

FIG.2

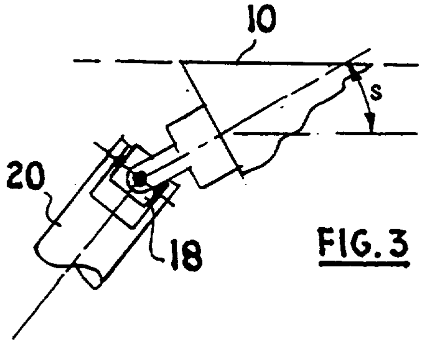

FIG.3

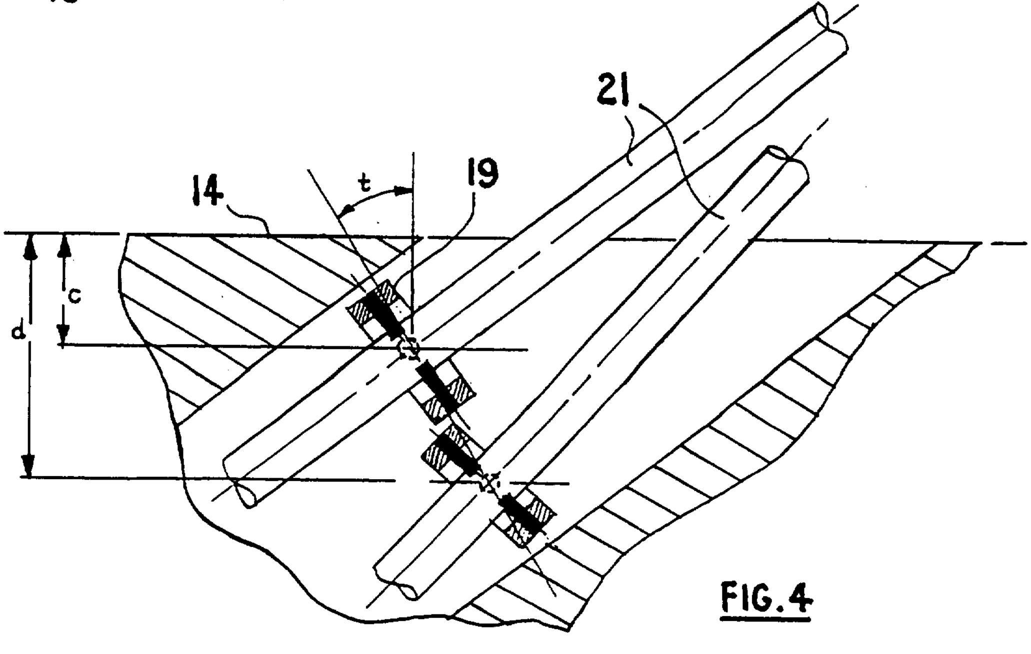

FIG.4

PATTERN-WRITING MACHINE

The present invention relates to a pattern-writing machine and has particular reference to substrate positioning in a machine for writing patterns by an electron beam.

In machines for pattern-writing by way of a deflectable electron beam, a substrate, such as a wafer or mask plate, on which an electronic circuit or other pattern is to be written is mounted horizontally on a stage and positioned so that it is intersected by the beam. The pattern is normally fractured into fields and the fields divided into sub-fields, which are written one at a time through corresponding scanning of the substrate by the beam.

In order to achieve the desired degree of accuracy in reproduction of the pattern the substrate must be positioned very accurately by precise movement of the stage along the X and Y axes and preferably also the Z axis. Current requirements for positioning accuracy are in the order of 20 nanometres in each of the X and Y axial directions and 1 micrometre in the Z axial direction and it is likely that even closer tolerances will be required in the future. This level of accuracy must be maintained over the entire substrate face presented to the beam. A future increase in the area of this face is also expected, such as from the present 22,500 square millimetres to 90,000 square millimetres or more.

For the purposes of positioning the substrate it is usual practice to carry out location measurements by way of a laser interferometer mensuration system, which can certainly provide accurate results, but which has to use, as target and reference points, something other than the beam and the substrate, in particular points adjacent to the beam and substrate. Because the measurement is indirect, errors can arise due to differential thermal expansion of the different materials involved, barometric pressure variations in different environments, differential deflections under load of separate components, and so forth.

In order to minimise these errors, which adversely influence the accuracy of the substrate position, it would be desirable for the beam or the substrate to be kept stationary in space. This is not possible, because if the beam is stationary the substrate cannot be moved with sufficient speed for economic and accurate pattern writing and if the substrate is stationary the beam cannot be deflected with sufficient accuracy over the required range. A combination of movements is required. Consequently the stage is moved to dispose individual areas, corresponding to the pattern fields, of the substrate top face one at a time and in desired sequence in a working zone of the beam, which is deflectable to scan each area. Since the pattern is written piece by piece in these areas, precise abutment of the pattern fields is critical and this imposes particular demands on the precision of stage movement. It is insufficient for accurate pattern writing if the areas corresponding to the fields abut solely in X and Y axial directions; they must also abut in the Z axial direction and angularly about the X, Y and Z axes. The stage positioning therefore should be precise with respect to all six degrees of freedom.

Known systems of stage movement can be divided into categories of two degrees of freedom and three degrees of freedom. Those in the first category, such as in Yosemite, Cambridge EBML, Philips, Leica VB6 and MEBES electron beam lithography machines, utilise ball and veeway guides with or without provision for adjustment and temperature change compensation or utilise air bearing guidance. Apart from complicated or sometimes absent measures for error correction, a major problem with these systems is compatibility of the stage drive with the high-vacuum environment in which the stage is located. The systems in the second category, such as that present in IBM machines, utilise a sliding carriage guided on an optical flat and provide angular movement by way of three pivoting capstan bars. These systems are compatible with a high-vacuum chamber, but do not allow for error correction in all degrees of freedom. Moreover, the sliding rather than rolling guidance of the carriage is a potential source of wear and particle generation.

It is therefore the object of the present invention to provide a pattern-writing machine in which a substrate, upon which a pattern is to be written by a deflectable electron beam, has enhanced freedom of movement and greater scope for error correction by comparison with the described prior art machines.

According to a first aspect of the invention there is provided a pattern-writing machine comprising an electron beam column for generating a deflectable electron beam, a displaceable stage for supporting a substrate to be scanned by the beam for the writing of a pattern thereon, and displacing means to displace the stage and thereby the substrate relative to the beam, characterised in that the displacing means comprises a plurality of struts supporting the stage and individually variable in length and drive means for varying the strut lengths to move the stage along each of three mutually orthogonal axes and to pivot the stage about each of the three axes.

Such a stage support and drive system allows the stage, and thus a substrate carried by the stage, six degrees of freedom, which optimises precise positioning of the substrate and enables easier correction of any detected positional errors. The stage support by struts eliminates sliding or rolling guidance of the stage in relation to guide surfaces and thus removes this source of wear. The stage also has improved stability, as it is fully supported in all settings and has no pronounced cantilever positions such as are inherent in ball and veeway guides.

Preferably, the machine comprises control means controlling the drive means to so move the stage along the three axes that individual areas of the stage and thereby of the substrate are disposed in a predetermined working zone of the beam in accordance with a predetermined sequence. The drive means can thus be controlled to move the substrate for field-by-field writing of a pattern. Control means can also be present to cause the stage and thereby the substrate to be maintained at a constant spacing from the lower end of the column. Consequently, whilst the substrate can be positioned by movement of the stage along the X and Y axes, movement of the stage along the Z axis can be kept as close to zero as possible with respect to an ideal height position. In addition, control means can be present to so pivot the stage about the three axes that the substrate can be constantly maintained in a plane normal to the column axis. Thus, motion about the X, Y and Z axes in relation to an ideal attitude can also be held as close to zero as possible. The control means for these different purposes can all be aspects of a single computer-based control.

For preference, the machine includes measuring means for measuring the vertical spacing of the stage from reference means and control means for controlling the drive means to move the stage along a vertical one of said axes in dependence on the measurement result. The machine can also include measuring means for measuring tilt of the substrate relative to reference means and control means controlling the drive means to pivot the stage about the orthogonal axes in dependence on the measurement result. Consequently, by movement along the Z axis and also about the X, Y and Z axes, corrections can be applied to the stage position to eliminate any detected positional error.

The measuring means can be disposed on the stage and the reference means above or below the stage. Equally, the locations of the measuring means and the reference means can be transposed. The reference means conveniently has the form of a single planar surface or of a plurality of planar surfaces in a common plane. The use of, for example, a single planar surface, which can function as a master optical flat co-operating with measuring means in the form of optical distance-sensing means, represents a particularly accurate method of position detection of the stage.

The machine can also include lens adjusting means for measuring a distance indicative of the spacing of the top surface of the substrate from a final lens of the column and adjusting the lens in dependence on the measurement result. This measurement arrangement for height position of the lens complements that for the height position of the stage and ensures accurate focussing of the beam on the substrate and consistent maintenance of the focus during displacement of the substrate for field scanning.

The displacing means preferably comprises three pairs of struts, wherein the struts of each pair are pivotably connected at lower ends thereof to a fixed base at connection points disposed one above the other and at upper ends thereof to the stage at connection points disposed one beside the other. This provides enhanced stability of the stage, especially if the struts are splayed so as to be more widely spaced at the base than at the stage. At the same time, the stage size can be kept light and small, so as to minimise its mass and consequently its inertia and magnetic disturbance. The connecting points can equally well be transposed, i.e. one beside the other at the base and one above the other at the stage. Stability and control can be further enhanced if the struts are connected to the base and stage by universal joints and if the strut pairs are equidistantly spaced apart, with the struts of each pair being spaced from each other by substantially the same amount as the struts of each other pair. The drive means can be in the form of individual drives, such as linear motors or threaded adjusting members driven by electric motors, arranged at the struts.

According to a further aspect of the invention there is provided a method of operating a machine of the first aspect of the invention, the method comprising the steps of deflecting the beam to scan a working zone and displacing the stage by way of the displacing means to dispose individual areas of the stage and thereby of the substrate in the zone in accordance with a predetermined sequence and to maintain a constant spacing of the substrate from a lower end of the column.

To complement such displacement of the stage along, in effect, the X, Y and Z axes, the method can also embrace the step of pivoting the stage about the three axes by the displacing means to maintain the substrate in a plane normal to the column axis.

Stage positioning and controlling can be enhanced by predetermining tolerances for vertical position and tilt of the stage and displacing the stage in dependence on detected deviation of its position and attitude from the predetermined tolerances.

An embodiment of the machine and example of the method of the invention will now be described in more detail with reference to the accompanying drawings, in which:

Fig. 1 is a schematic, partly broken-away perspective view of a stage, a fixed base and stage supporting and displacing struts in a pattern-writing machine embodying the invention;

Fig. 2 is a detail plan view, to an enlarged scale, showing the connection of the struts to the stage;

Fig. 3 is a detail side view, to an enlarged scale, showing the connection of one of the struts to the stage; and

Fig. 4 is a detail side view, to an enlarged scale, showing the connection of two of the struts to the base.

Referring now to the drawings there is shown part of an electron beam lithography machine for writing patterns, such as circuits, on a substrate. Such machines are in principle well-known and the drawings and following description are concerned only with the part of the machine to which the present invention relates.

The illustrated part of the machine comprises a displaceable stage 10 disposed under an electron beam column 11 having an axis 12. The column incorporates a series of lenses and in use directs a deflectable focussed electron beam towards the stage.

The stage 10 serves to carry a substrate which is indicated by 13 and temporarily mounted in a removable chuck on the stage. The stage is located in a vacuum chamber (not shown) and supported relative to a fixed base 14, also in the chamber, by displacing means in the form of three pairs of identical struts 15, 16 and 17. As shown in Fig. 2, the three pairs of struts are equidistantly spaced at intervals of 120° with respect to the centre M of the stage 10. The struts of each pair are connected to the stage 10 at connection points, in the form of upper universal joints 18, disposed one beside the other and to the base 14 at further connection points, in the form of lower universal joints 19, disposed one above the other. Each strut consists of an inner rod 20 guided in an outer casing 21. The universal joints 18 are coupled to the rods 20 and the universal joints 19 to the casings 21. The rods and casings can, however, be transposed.

Each strut is independently variable in length, in particular through relative axial movement of its rod and casing, by way of an individual, separately operable drive (not shown). Variation in the strut lengths causes movement of the stage 10 relative to the base 14. Each drive can be, for example, a linear motor preferably of a kind without permanent magnets or otherwise not liable to generate stray magnetic fields and preferably with low heat dissipation. Each linear motor can be coupled to an absolute linear encoder. Another suitable form of drive would be a ballscrew driven by a direct current servo motor, again coupled to an absolute encoder. Linear motor drives could be accommodated entirely in the vacuum chamber, whereas ballscrew and servo motor drives would be accommodated partly within (ballscrew) and partly outside (motor) the chamber. Whichever form of drive is employed, it is preferably controlled for initial coarse adjustment of the strut length and then for fine adjustment. The fine adjustment can be achieved by way of, for example, an integral piezo-electric stack.

By virtue of the arrangement of the three pairs of length-adjustable struts 15 to 17 and separately operable drives, the stage 10 is capable of axial movement along each of the X, Y and Z axes and additionally capable of rotational movement about each of the X, Y and Z axes. The movement of the stage in X and Y directions can be employed to dispose individual areas of the substrate 13 in turn and in a predetermined sequence in a working zone of the beam approximately centred on the column axis 12. Each such area can correspond with an individual section of a pattern, which is fractured into fields and then sub-fields, to be written on the substrate 13. Writing of the sub-fields within each field can be performed by controlled deflection of the beam to scan the sub-fields on a path corresponding with the pattern features to be recorded on the substrate.

The operation of the strut drives for the purpose of X and Y axial displacement of the stage can be controlled by a laser interferometer system (not shown) as conventionally used for precise monitoring of stage position in a horizontal plane.

The connections of the pairs of struts 15 to 17 to the stage 10 and base 14 are shown in more detail in Figs. 2 to 4. As apparent from Fig. 2, the struts of each pair have the same spacing a from one another as the struts of each other pair and are also disposed symmetrically with respect to a line intersecting the centre M of the stage 10. The horizontal pivot axes of the universal joints 18 of each strut pair 15, 16 or 17 lie on a common line. These lines have the same spacing b from the centre M. In order to reduce the angle through which the joints 18 must travel in normal use, the part of each joint attached to the stage 10 is preferably inclined downwardly at an angle s to the horizontal, as shown in Fig. 3. The angle s is the same for all struts.

In the case of the connections of the strut pairs to the base 14, as shown in Fig. 4, the horizontal pivot axis of the top one of the lower universal joints 19 in each strut pair has a spacing c and the horizontal pivot axis of the bottom one of these universal joints 19 a spacing d from the plane of an uppermost surface of the base. The spacings c and d are the same for all three strut pairs. A line connecting the two horizontal axes of the joints 19 is inclined at an angle t to the vertical. The angle t is the same for all strut pairs.

The described and illustrated relationship of the strut connection points allows smooth movement of the stage 10 along the X, Y and Z axes without conflicts in the strut travel geometries and without interference of the strut drives with each other during the movement. Other relationships are possible, however, including transposition of the universal joint relationships at the stage 10 and base 14.

Apart from movement of the stage 10 along the X and Y axes for the afore-mentioned purpose, the stage can be moved along the Z axis so that the stage and thus the substrate 13 can be maintained at a constant spacing from the lower end of the column 11. The Z axis directional movement is thus primarily applied as a correction to eliminate upward or downward travel of the stage during X and/or Y axial movement. Superimposed on X, Y and Z axial movements can be rotational movements about the X, Y and Z axes, so that the substrate is constantly maintained in a plane normal to the column axis 12. The pivot movement of the stage is readily achieved by length adjustment of individual ones of the struts and is applied primarily to correct errors in attitude of the substrate.

Operation of the strut drives for the purpose of corrective displacement in the Z axis direction or corrective rotation about the X, Y and Z axes is controlled by a mensuration system which measures the vertical spacing of the stage from a reference surface at several points on this surface and issues a signal to operate an appropriate one or appropriate ones of the drives in dependence on the measurement result, in particular recognised deviation of the stage elevation or attitude from a predetermined elevation or attitude. The mensuration system can be in the form of an array of three laser height sensors 22 and the reference surface in the form of an optical flat 23 at the top of the base 14. The three sensors are located at the underside of the stage in positions respectively corresponding with the three strut pairs and are each aimed at a respective one of three spaced-apart points on the optical flat 23. The location of the sensors at the stage and the optical flat at the base can be transposed.

The height measurement of the stage 10 can be supplemented by an additional sensor (not shown) measuring the spacing of the top surface of the substrate 13 from a final one of the column lenses. A signal issued by this sensor, such as a laser sensor or a capacitance sensor, can be applied to adjust the final lens to compensate for variations in, for example, the substrate surface profile, the substrate mounting and the thicknesses of different substrates and substrate-holding chucks.

A pattern-writing machine incorporating a stage displacement system described in the foregoing embodiment has considerably enhanced capability for correction of errors in stage position. This should allow more accurate writing of patterns, particularly those with fine details requiring positional tolerances of 20 nanometres or less.

CLAIMS

1. A pattern-writing machine comprising an electron beam column for generating a deflectable electron beam, a displaceable stage for supporting a substrate to be scanned by the beam for the writing of a pattern thereon, and displacing means to displace the stage and thereby the substrate relative to the beam, characterised in that the displacing means comprises a plurality of struts supporting the stage and individually variable in length and drive means for varying the strut lengths to move the stage along each of three mutually orthogonal axes and to pivot the stage about each of the three axes.

2. A machine according to claim 1, characterised by control means controlling the drive means to so move the stage along said axes that individual areas of the stage and thereby of the substrate are disposed in a predetermined working zone of the beam in accordance with a predetermined sequence.

3. A machine according to claim 1 or claim 2, characterised by control means controlling the drive means to so move the stage along said axes that the stage and thereby the substrate can be maintained at a constant spacing from a lower end of the column.

4. A machine according to any one of the preceding claims, characterised by control means controlling the drive means to so pivot the stage about said axes that the substrate can be constantly maintained in a plane normal to the column axis.

5. A machine according to any one of the preceding claims, characterised by measuring means for measuring the vertical spacing of the stage from reference means and control means controlling the drive means to move the stage along a vertical one of said axes in dependence on the measurement result.

6. A machine according to any one of the preceding claims, characterised by measuring means for measuring tilt of the substrate relative to reference means and control means for controlling the drive means to pivot the stage about said axes in dependence on the measurement result.

7. A machine according to claim 5 or claim 6, characterised in that the measuring means is disposed on the stage and the reference means is disposed above or below the stage.

8. A machine according to claim 5 or claim 6, characterised in that the reference means is disposed on the stage and the measuring means is disposed above or below the stage.

9. A machine according to any one of claims 5 to 8, characterised in that the reference means comprises a single planar surface.

10. A machine according to any one of claims 5 to 8, characterised in that the reference means comprises a plurality of planar surfaces disposed in a common plane.

11. A machine according to claim 9 or claim 10, characterised in that the measuring means comprises optical distance-sensing means co-operable with the surface or surfaces.

12. A machine according to any one of the preceding claims, comprising lens adjusting means for measuring a distance indicative of the spacing of the top surface of the substrate from a final lens of the column and adjusting the lens in dependence on the measurement result.

13. A machine according to one of the preceding claims, characterised in that the displacing means comprises three pairs of the struts, wherein the struts of each pair are pivotably connected at lower ends thereof to a fixed base at connecting points disposed one above the other and at upper ends thereof to the stage at connecting points disposed one beside the other.

14. A machine according to any one of claims 1 to 12, in that the displacing means comprises three pairs of the struts, wherein the struts of each pair are pivotably connected at lower ends thereof to a fixed base at connecting points disposed one beside the other and at upper ends thereof to the stage at connecting points disposed one above the other.

15. A machine as claimed in claim 13 or claim 14, wherein the struts are connected to the base and the stage by universal joints.

16. A machine as claimed in any one of claims 13 or claim 15, wherein the pairs of struts are equidistantly spaced apart.

17. A machine as claimed in any one of claims 13 to 16, wherein the struts of each pair are spaced apart by substantially the same amount as the struts of each other pair.

18. A machine according to any one of the preceding claims, wherein the drive means comprises an individual drive arranged at each strut.

19. A machine according to claim 18, wherein the drives are linear motors.

20. A machine according to claim 18, wherein the drives are threaded adjusting members driven by electric motors.

21. A method of operating a machine according to one of the preceding claims, characterised by the steps of deflecting the beam to scan a working zone and displacing the stage by way of the displacing means to dispose individual areas of the stage and thereby of the substrate in the zone in accordance with a predetermined sequence and to maintain a constant spacing of the substrate from a lower end of the column.

22. A method according to claim 21, characterised by the step of pivoting the stage about said axes by the displacing means to maintain the substrate in a plane normal to the column axis.

23. A method according to claim 22 or claim 23, characterised by the step of predetermining tolerances for vertical position and tilt of the stage and displacing the stage in dependence on detected deviation of its position and attitude from the predetermined tolerances.

The
Patent
Office

Application No:	GB 9708459.4	**Examiner:**	Martyn Dixon
Claims searched:	all	**Date of search:**	30 June 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H1K (KMBY); H1D (DAH1,DHD,DHE,DHX)

Int Cl (Ed.6): H01L (21/00); H01J (37/20,37/30,37/317)

Other: online: WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 1193297 A	(Telefunken) see e.g. fig 2	1
A	WO 88/05205 A	(Hughes Aircraft) the whole document	1
X	EP 0511704 A	(Philips) see fig 5	1,18
A	US 4572021 A	(RCA) see e.g. col 2, lines 56-62	1

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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