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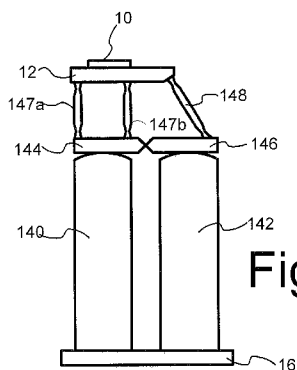


Fig. 1a

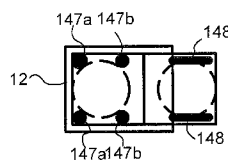


Fig. 1b

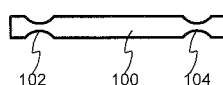


Fig. 1c

(57) Abstract: A scanning probe microscope comprises a base, a positioning stage mounted on the base, a platform mounted on the positioning stage and a probe tip on the platform, the positioning stage comprising - a first and second linear displacement actuator, each having a main direction of displacement, the main directions of displacement of the first and second linear displacement actuator being oriented substantially parallel to each other, - a first and second strut or struts coupled directly or indirectly between the platform and ends of the first and second actuators where the first and second actuators terminate in the main direction of displacement respectively, at least the first strut or struts being directed at an oblique angle to the main direction of displacement of the actuators.

Title: Scanning microscope

Field of the invention

The invention relates to a scanning probe microscope and a method of positioning the sensing tip of a scanning probe microscope.

5

Background

An article by Schitter et al, IEEE transactions on control systems technology, VOL. 15, NO. 5, September 2007 discloses a positioning stage
10 for a scanning probe microscope. A scanning probe microscope comprises sensing tip and a positioning stage that allows positioning of the tip three dimensions. Schitter's positioning stage comprises three piezo-stack actuators, to provide for x, y and z motion respectively. In a piezo-stack actuator a stack of a plurality of piezo layers is used to provide for a
15 cumulatively combined stroke of displacement. This results in an actuator of elongate shape in the displacement direction.

A first and second pair of such piezo-stack actuators are provided with their displacement direction in the xy plane, along the x and y directions respectively. On one side these in the first and second piezo-stack
20 actuators are attached to a frame and on the other side to a movable platform. A third piezo-stack actuator is provided on the platform with its displacement direction in the z-direction.

In order to allow for displacement in two directions, the first and second pair of piezo-stack actuators are each coupled to the platform via a
25 parallelogram formed by a plurality of parallel struts. As used herein, a strut is a bar connected to the platform and the actuators by joints that allow for rotation of the axial direction of the bar, in this case in the xy plane. The parallelogram ensures that the platform does not rotate when the platform is displaced.

This positioning stage has the disadvantage that it is bulky. Moreover, one of the actuators may need to be provided in series with the others, which reduced stability. The bulkiness limits the application in fields of application where space is limited

5 US 2008/0030851 discloses an arrangement for positioning a platform for a sample in an optical microscope system. Two actuators are used that act along the same direction on the top of a first and second parallelograms in a stack of parallelograms with flexures respectively. The platform is located on top of the stack. Deformation of each parallelogram
10 results in a displacement with horizontal and vertical components of the top of the parallelogram relative to each base.

The first parallelogram acts on the platform in series with the second parallelogram, that is, via a path through that parallelogram. Because the parallelograms lie in the same plane, the horizontal and
15 vertical components of the overall displacement of the platform are sums of the horizontal and vertical displacements vectors produced by the individual parallelograms. Use of the two actuators enables independent deformation of the parallelograms, and hence independent adjustment of the horizontal and vertical components of the overall displacement.

20 This arrangement requires a substantial amount of vertical space for the stacked parallelograms. The two stacked parallelograms in the same also result in a low stiffness of the structure. Moreover, it supports only displacement in two directions. For displacement in more directions more parallelograms would need to be stacked.

25

Summary

Among others, it is an object to provide for a reduced size scanning probe microscope.

A scanning probe microscope is provided that comprises a base, a positioning stage mounted on the base, a platform mounted on the positioning stage and a probe tip on the platform, the positioning stage comprising

- 5 - a first and second linear displacement actuator, each having a main direction of displacement, the main directions of displacement of the first and second linear displacement actuator being oriented substantially parallel to each other, the first and second linear displacement actuator each having an end where the first and second actuators terminates in the
- 10 main direction of displacement;
- a first and second transmission structure coupled via distinct paths between the platform and the ends of the first and second linear displacement actuators respectively, the first and second transmission structure defining first and second lines between contacts of the first and
- 15 second transmission structure to the platform and to the ends of the first and second linear displacement actuators respectively, the first and second lines being directed at an oblique angle to the main direction of displacement of the actuators and at an angle to each other.

Thus the first transmission structure acts on the platform

20 functionally in parallel with the second transmission structure rather than in series with the second transmission structure. By substantially parallel arrangement of the main direction of displacement, and displacement direction translation by means of functionally parallel transmission structures a compact probe is realized, or at least a probe with a more

25 compact footprint at its base. The first and second actuator may be part of a larger number of actuators, which may all have substantially parallel main direction of displacement: for example three actuators that provide for displacement of the platform in three independent spatial directions. Alternatively, two actuators may be used to provide for displacement of the

30 platform in two independent spatial directions. The actuators may be piezo

stack actuators, or electromagnetic actuators, for example, which are known per se. Both are elongate, with a largest size in the main direction of displacement. Parallel arrangement of the main directions of displacement within manufacturing tolerances maximizes compactness, but increased compactness is already realized when the directions are substantially parallel. Increased compactness may be realized when the main directions of displacement of the actuators are at less than thirty and more preferably less than fifteen degrees to a common axis.

In an embodiment the transmission structures comprise linear struts with first bearings between central parts of said struts and the platform; and second bearings between the central parts of the first and second struts and the ends of the first and second actuators respectively. The first and second bearings allow for rotation of the central parts of the first and second struts relative to the platform and the ends of the first and second actuators respectively. In this way, a flexible transmission is provided, which makes it possible to decouple displacement of the platform from orientation changes of the platform.

In a further embodiment the first and second transmission structure comprise first and second further struts forming a first and second parallel pair of a struts with the first strut and the second strut respectively, positions of the first and second bearings of the struts in each pair forming corners of a parallelogram. In this way it is ensured that, during displacement, the platform remains parallel to the base lines of the parallelograms.

In an embodiment the first transmission structure comprises a lever structure connected by a hinging connection to a support post on the base, the hinging connection allowing for rotation around an axis of rotation parallel to a line between the second bearings of the first strut and the first further strut, the lever structure extending over the end of the first linear displacement actuator, the first strut and the first further strut being

coupled between the platform and the lever structure. In this way it is ensured that, during displacement, the platform remains parallel to the hinging connection on the post. Similar lever structures on the same support post or on one or more other support posts may be used in conjunction with
5 other actuators, such as in conjunction with the second actuator using a second further strut.

In an embodiment the first and second strut are directed at oblique angle to the main direction of displacement of the linear displacement actuators, the first and second strut being directed at said
10 angle to each other. In this way movements of the different actuators in the main direction can be converted into movements of the platform in another direction.

In an embodiment a lever structure is used that uses rotation of the lever structure to convert the motion of the first actuator along the main
15 direction into motion in another direction that is transmitted to the struts. This is achieved by using a lever structure that acts as a pair of arms that both rotate around the rotation action of the hinge connection, at a fixed angle to each other, a first arm moving with the actuator and a second arm moving the struts. Preferably, the angle between the arms is substantially
20 ninety degrees, which allows for changing of the motion direction by ninety degrees at the struts relative to the main direction of displacement. Similar lever structures may be used in conjunction with other actuators, such as in conjunction with the second actuator using a second further strut.

In an embodiment a further linear displacement actuator is
25 provided to below the platform to move it up and down. A further transmission structure may be provided coupled between the platform and the end of the further linear displacement actuator. Preferably the further transmission structure comprises struts and bearings between central parts of the struts and the platform and the end of the further linear displacement
30 actuator, the bearings forming one or more parallelograms. Alternatively,

other structures may be used that define a least a further line between contacts of the first and second transmission structure to the platform and to the end of the further linear displacement actuator.

In an embodiment three actuators are arranged in a configuration
5 that is symmetric under one hundred and twenty degree rotations. This balances the effect of the actuators. Distance sensors may be provided between the actuators for sensing a distance from the distance sensors to the platform. This provides for suppression of errors in the distance measurement.

10 The platform, the levers and the struts are integrally formed, for example by spark erosion from a starting material, such as an aluminum block. In this way a structure that provides for accurate movements can more easily be realized.

15 Brief description of the drawing

These and other objects and advantageous aspects will become apparent from a description of exemplary embodiments, with reference to the following figures.

20 Figure 1a shows a cross-section of a scanning probe microscope

Figure 1b shows a schematic top view

Figure 1c shows a strut

Figure 2 shows cross-section of a further scanning probe
microscope

25 Figure 3, 4 show schematic top views of further scanning probe
microscopes

Figure 5, 5a show a scanning probe microscope with sensors

Figure 6 shows a cross-section of a scanning probe microscope

Figure 7 shows a schematic top view

30

Detailed description of exemplary embodiments

Figure 1a shows a cross section of a scanning probe microscope. The microscope comprises a probe tip 10 located on a platform 12 and a
5 positioning stage between platform 12 and a base 16. The positioning stage may provide for scanning of platform 10 in two directions (the vertical and horizontal directions of figure 1a), or it may be part of a larger positioning stage with more degrees of freedom. The positioning stage comprises a first and second elongate piezo stack actuator 140, 142, with parallel main
10 displacement directions oriented between base 16 and platform 12. As is known per se, a piezo electric stack actuator comprises a stack of layers of piezo electric material, stacked in the main displacement direction, so that displacements created by the layers add up in that direction.

Furthermore, the positioning stage comprises an intermediate
15 platform 144, a lever 146, and struts 147a,b, 148. Intermediate platform 114 is located attached on top of first piezo stack actuator 140. Lever 146 is hingingly connected to intermediate platform 144 and extends over a top of second piezo stack actuator 142. As used herein hingingly means that only rotation around a hinge axis is allowed. In the example of figure 1a, the
20 hinge axis extends perpendicular to the plane of the drawing. A hinging connection may be realized by a linear flexure bearing for example, i.e, by providing by a linear narrow part at connection between intermediate platform 114 and lever 146, but instead other types of hinge may be used. The hinging connection allows for rotation of lever 146 around the hinge
25 axis, when its end is moved up or down by second piezo stack actuator 142. Preferably, the tops of piezo stack actuators 140, 142 are rounded e.g. cylindrically to facilitate rotation around the hinge. A rounded cap may be used on piezo stack actuators 140, 142 for this purpose.

Platforms 12, intermediate platform 114, levers 146 and the
30 struts may be of a metal like aluminum.

The struts have internal flexure bearings. As is known per se, a flexure bearing involves a relatively thinner point in a structure that allows for relative rotation of the parts on different sides of the bearing. Figure 1c shows an example of a strut with a first and second flexure bearing. The struts are bar shaped. To allow for the rotation, the struts have narrowed parts 102, 104 adjacent the points where the bars are fixed to the other structures. In an embodiment struts may be formed integrally with the other structures. Spark erosion may be used to form the struts and the other structures from a piece of starting material. Alternatively, other types of bearing may be used, such as ball bearings between the struts and the platform and the levers.

First struts 147a,b are connected in parallel from intermediate platform 144 to platform 12. A second strut 148 is connected from the end of lever 146 to platform 12, at an oblique angle to lever 146 and platform 12, and at an angle to first struts 147a,b. The angle of second strut 148 to first struts 147a,b may be in a range of thirty to sixty degrees for example. The angle may be substantially forty five degrees for example.

Figure 1b shows a top view, schematically indicating the tops of piezo stack actuators 140, 142. As can be seen further first and second struts 147a,b, 148 may be present in parallel with the first and second struts 147a,b, 148 shown in figure 1a. Intermediate platform 144 and lever 146 may extend along the axis of rotation of the hinge, so that first and second struts 147a,b, 148 may be connected at different locations. Although first struts 147a,b are all shown to be vertical, that is, parallel to each other, this is not necessary. The upper first struts 147a,b in figure 1a may be parallel to each other in a first direction and the lower first struts 147a,b in figure 1a may be parallel to each other in a second direction, the first and second direction having a non zero angle. In fact this may stabilize against unwanted motion in the vertical direction of figure 1a.

In operation, electrical voltages are applied to first and second piezo stack actuator 140, 142 at electrodes (not shown). Temporal variation of the electrical voltages causes the piezo stack actuators 140, 142 to expand and shrink mostly in their elongate direction, i.e. in the direction between
5 base 16 and platform 12. This results in displacements of the top of piezo stack actuators 140, 142 in that direction, which will be called the displacement direction of piezo stack actuators 140, 142.

Joint displacement of the top surfaces of first and second piezo stack actuators 140, 142 causes platform 12 to be moved in the displacement
10 direction of piezo stack actuators 140, 142. Differential displacement, wherein the top surface of second piezo stack actuator 142 is displaced relative to that of first piezo actuator 140 causes lever 146 to rotate relative to intermediate platform 144, around their hinged connection. This moves the end of second strut 148, which transmits the motion to platform 12, at
15 least partly in a direction perpendicular to the displacement direction of piezo stack actuators 140, 142 (the horizontal direction in figure 1a). Because first struts 147a,b form a parallelogram with intermediate platform 144 and lever 146, the orientation of platform 12 remains unchanged during this movement. Although the parallelogram corresponds with intermediate
20 platform 144 and lever 146, it may be noted that at the same time another parallelogram is formed by the positions of the flexure bearings at the corners of the other parallelogram. Properly speaking, this parallelogram controls the parallel nature of the movement of platform. Preferably the line between corresponding bearings on the struts is parallel to the hinge
25 direction of the lever. In this way, the hinge direction of the lever, which is fixed, fixes part of the orientation of the platform.

Figure 2 shows a cross section of a further scanning probe microscope. The microscope comprises a probe tip 10 located on a platform 12 and a positioning stage between platform 12 and a base 16. Again, the
30 positioning stage may provide for scanning of platform 10 in two directions

(the vertical and horizontal directions of figure 2), or it may be part of a larger positioning stage with more degrees of freedom. The positioning stage comprises a first and second elongate piezo stack actuator 240, 242, with parallel main displacement directions oriented between base 16 and platform 12. Furthermore, the positioning stage comprises a post 244, levers 246a,b, and struts 247a,b, 248. Post 244 is located between first and second piezo stack actuator 240, 242 in parallel with the main displacement directions. The positioning stage is symmetric about post 244. Levers 246a,b are hingingly connected on two sides of post 244 and extend over a top of first and second piezo stack actuator 240, 242 respectively. First struts 247a,b are connected from platform 12 to post 244. First struts 247a,b are substantially parallel to each other. Second struts 248a,b are connected from platform 12 to the ends of levers 246a,b, at an angle to first struts 247a,b. The angle may be in a range of thirty to sixty degrees. The angle may be substantially forty five degrees for example. As in the embodiment of figure 1a-b, pairs of parallel struts may be used, only one strut 247a,b, 248a,b of each pair being shown. Each pair may be part of a respective parallelogram formed by platform 12 and a lever 246a,b or post 244.. Here too another parallelogram may be identified with positions of the flexure bearings at the corners of the other parallelogram. Properly speaking, this parallelogram controls the parallel nature of the movement of platform.

Although the connection between levers 246a,b and post 244 is shown beyond the point where first struts 247a,b connect to posts 244, it should be appreciated that this is not necessary. Levers 246a,b may leave an opening to connect first struts 247a,b to posts even if the connection between levers 246a,b and post 244 do not lie beyond the point where first struts 247a,b connect to posts 244.

In operation, joint displacement of the top surfaces of first and second piezo stack actuators 240, 242 causes platform 12 to be moved in the displacement direction of piezo stack actuators 240, 242. Differential

displacement, wherein the top surface of first and second piezo stack actuator 240, 242 are displaced with opposite sign along the main displacement direction relative the top of post 244, causes levers 246a,b to rotate relative to post 244, around their hinged connections. This moves the ends of second struts 148a,b, which transmits the motion to platform 12, at least partly in a direction perpendicular to the displacement direction of piezo stack actuators 240, 242 (the horizontal direction in figure 2). Because first struts 247a,b are part of a parallelogram together with platform 12 and post 244, the orientation of platform 12 remains unchanged during this movement.

The positioning stage may be used to provide for displacement of the probe in two directions as described: the direction of displacement of the piezo stack actuators 140, 142 and a direction perpendicular to that direction. In other embodiments displacement in three directions or in another combination of directions may be provided for.

Figure 3 shows a top view of scanning probe microscope that allows for movement in three directions. A first, second and third piezo stack actuator 30, 31, 32 are used, with first and second struts 36, 38. The main displacement directions of first, second and third piezo stack actuator 30, 31, 32 are oriented parallel to each other. First and second piezo stack actuator 30, 31 are used to perform the functions of first and second piezo stack actuator 240, 242 of the embodiment of figure 2, with second struts 36 in the role of second struts 248a,b of the embodiment of figure 2. Third piezo stack actuator 32 is used similar to second piezo stack actuator 142 of the embodiment of figures 1a,b. Together, first and second piezo stack actuator 30, 31 take over the function of first piezo stack actuator 140 of the embodiment of figures 1a,b and their struts 36 take over the role of struts 247a,b. Common displacement of first and second piezo stack actuator 30, 31 may provide the displacement of first piezo stack actuator 140 of the embodiment of figures 1a,b.

In an alternative embodiment four piezo stack actuators may be used, forming two pairs, each pair providing for movement in a respective direction perpendicular to the main displacement direction, with each pair performing the function of first and second piezo stack actuator 240, 242 of the embodiment of figures 2 for their direction.

Figure 4 shows another scanning probe microscope that allows for movement in three directions. A first, second and third piezo stack actuator 40, 41, 42 are used. The main displacement directions of first, second and third piezo stack actuator 40, 41, 42 are oriented parallel to each other.

First, second and third piezo stack actuator 40, 41, 42 are located on a circle at hundred and twenty degree angles from each other. First, second and third levers 44a-c are provided, extending of the top of respective ones of piezo stack actuators 40, 41, 42. Levers 44a-c may be hingingly connected to a central post (not shown) or respective posts. A pair of first struts 46a is connected in parallel with each other from the ends of first lever 44a to platform 12. First struts 46a are provided at an oblique angle relative to the main displacement directions of first, second and third piezo stack actuator 40, 41, 42. The angle may lie in a range from thirty to sixty degrees. The angle may be substantially forty five degrees for example. First struts 46a and the lines between their attachments to first lever 46a and platform 12 form a parallelogram, i.e. the latter lines are also parallel. It may be noted that at the same time another parallelogram is formed by the positions of the flexure bearings at the corners of the other parallelogram.

Similarly a pair of second struts 46b is connected in parallel with each other from the ends of second lever 44b to platform 12. A pair of third struts 46c is connected in parallel with each other from the ends of third lever 44c to platform 12. The struts of the first pair may be at hundred and twenty degree angles to the struts of the second pair and so on, in a projection on a plane perpendicular to the main displacement directions of piezo stack actuators 40, 41, 42. Second and third struts 46b,c are each part

of a parallelogram, with lines between attachment points to second and third levers 44b,c and platform 12. It may be noted that at the same time another parallelogram is formed by the positions of the flexure bearings at the corners of the other parallelogram.

5 In operation first, second and third piezo stack actuator 40, 41, 42 may be used to generate displacement of platform 12 in three directions. Each different combination of displacements of the tops of piezo stack actuators 40, 41, 42 results in a different three dimensional displacements of platform 12. Voltages may be applied to piezo stack actuators 40, 41, 42
10 independently of one another, via respective electrodes (not shown) for the different piezo stack actuators 40, 41, 42. In a common mode the same voltages may be applied, which will result in displacement of platform 12 in the main displacement direction of piezo stack actuator 40, 41, 42. When the top of one of the piezo stack actuators 40, 41, 42 is displaced in with one sign
15 of displacement (e.g. up) and displacements of the others are equal to each other but of opposite sign (e.g. down) compared to the sign of displacement of the first one of the piezo stack actuators 40, displacement of platform 12 in a direction away from the one of the piezo stack actuators 40, 41, 42 is realized. Dependent on the relative size of the displacements this may be
20 accompanied by an upward or downward displacement or constant height of platform 12.

 The parallelograms comprising the struts 46a-c ensure that the orientation of platform 12 remains the same for all displacements. Properly speaking, the parallelogram with positions of the flexure bearings in the
25 struts controls the parallel nature of the movement of platform.

 In an embodiment one or more position sensors may be used that measure displacement of platform 12 or the probe tip in different directions. Outputs of the sensors may be used to trace the probe tip location with respect to the sample, which may be used to process measurement results
30 obtained with the probe tip.

Figure 5 shows an arrangement wherein sensors 50 are shown schematically, located between respective pairs of the piezo stack actuators 40, 41, 42. Sensors 60 may be capacitive sensors for example, as illustrated in cross-section in figure 5a, each sensor comprising a first capacitor plate 52, platform 10 (shown only partly) forming a second plate. As another example, interferometric sensors may be used, wherein plate 52 may be replaced by an interferometer that uses a surface of platform 10 as a reflector in the interferometric light path. The arrangement of the piezo stack actuators allows the sensors pointed towards the location of the probe tip. By centering all sensors in the direction of the tip location the measurement lines are free of Abbe-errors, which means that slight rotations of the platform 12 cannot cause measurement errors. This increases measurement accuracy.

Each sensor 50 defines a measuring line, i.e. a line along which the distance is measured, for example, this may be a line perpendicular to a fixed plate of the capacitor or a line perpendicular to equal phase wave fronts of the interferometer. Preferably, sensors (50) are aligned so that measuring lines from all sensors intersect at a single point at the probe tip. This makes probe tip position measurements more independent of any possible remaining rotations of the platform. It should be noted that such arrangement is preferably used also when the sensors are not located symmetrically as shown in figure 5. In particular, each sensor 50 may define a central measuring line, e.g. a measuring line from the middle of a fixed plate of the capacitor or the measuring line at the middle of the beam of the interferometer. In a further embodiment sensors (50) are aligned so that the central measuring lines from all sensors intersect at a single point at the probe tip. This makes probe tip position measurements independent of any possible remaining rotations of the platform.

In a further embodiment feed back control of the voltages applied to the piezo stack actuators of any of the earlier embodiments may be used.

A difference between a set position and the measured position indicated by the sensors may then be used to control voltages applied to the piezo stack actuators in a feedback loop. Alternatively, feed forward may be used, which may involve computation of the required voltages from a desired position
5 using a mathematical computation, or use of the desired position to look up the required voltages from a lookup table.

Figure 6 shows a cross section of a further scanning probe microscope. Herein the central post has been replaced by posts 60a,b adjacent a central piezo stack actuator 66, which has a direction of
10 displacement parallel to those of actuators 240, 242. First struts 247a,b are connected from platform 12 to central actuator 66. First struts 247a,b are substantially parallel to each other. Preferably, the positioning stage is symmetric about central actuator 66.

Levers 62a,b are hingingly connected to posts 60a,b. As used herein levers
15 are structures that transmit a force from one or more first points to one or more second points a construction that provides for rotating movement of the structure. A hinging connection is provided that allows for rotation around hinge lines on posts 60a,b on respective sides of central actuator 66 respectively. Levers 62a,b extend over a top of first and second piezo stack
20 actuator 240, 242 respectively. Second struts 64a,b are connected from platform 12 to the ends of levers 62a,b. Second struts 64a,b lie parallel to a plane perpendicular to the direction of displacement of actuators 240, 242 and central actuator 66. Each lever 62a,b defines virtual arms between the hinge line of the levers 62a,b and the contacts between the levers 62a,b and
25 the top of its piezo stack actuator 240, 242 and its struts 64a,b respectively. For each lever 62a,b, these virtual arms are at right angles to each other. Levers 62a,b may comprise a block of solid material that extends between these virtual arms, but alternatively levers 62a,b may substantially consist only of the hinging connection and two planes of solid material at the
30 location of the arms, or structures with additional solid material (e.g. ribs)

in between the planes without necessarily filling the entire space between the planes.

Pairs of parallel struts may be used in respective planes parallel to the plane of figure 6, only one plane with one of the struts 247a,b, 64a,b of each pair being shown in the figure. Each pair of parallel struts is part of a
5 respective parallelogram formed by platform 12, the pair of parallel struts and a lever 62a,b or central actuator 66. Here, another parallelogram may be identified as well, wherein the corners of the other parallelogram are formed by positions of the flexure bearings in the struts. Properly speaking,
10 this other parallelogram controls the parallel nature of the movement of platform. The parallelograms ensure that the sides of platform remain parallel to the lines between the flexure bearings of adjacent pairs of struts, as defined by their connections to levers 62a,b and central actuator 66. In operation, displacement of the top surface of central actuator 66 causes
15 platform 12 to be moved in the main displacement direction of the actuators 66 240, 242. When central actuator 66 is used to provide displacement, first and second piezo stack actuators 240, 242 may both be actuated to produce a displacement by the same amount, to a position as needed to keep struts 64a,b parallel to the plane perpendicular to the main direction of
20 displacement when the top surface of central actuator 66 is displaced. In this case levers 246a,b are kept at fixed angles to their supporting posts 60a,b.

Levers 246a,b can be rotated in opposite directions relative to their posts 60a,b when the top surface of first and second piezo stack
25 actuator 240, 242 are displaced with opposite sign along the main displacement direction, relative to the position corresponding to the same displacement as central actuator 66. In terms of the directions defined by the figure, such differential displacements move the ends of struts of 64a,b, in opposite horizontal directions, transmitting motion to platform 12 in a
30 direction perpendicular to the displacement direction of piezo stack

actuators 240, 242 and central actuator 66. Because first struts 247a,b are part of a parallelogram together with platform 12 and central actuator 66, the orientation of platform 12 remains unchanged during this movement.

The positioning stage may be used to provide for displacement of the probe in two directions as described: the direction of displacement of the piezo stack actuators 140, 142 and a direction perpendicular to that direction. In other embodiments displacement in three directions or displacement in another combination of directions may be provided for. Also, the positioning stage may be part of a larger positioning stage with more degrees of freedom.

Figure 7 shows a top view of scanning probe microscope that allows for movement in three directions. Five piezo stack actuators 66, 240, 242, 70a,b are used, including central actuator 66 and four actuators 240, 242, 70a,b located in the middles of the four edges of a rectangle (preferably a square). Over each of these four actuators 240, 242, 70a,b a lever 62a,b is provided (only two labeled), each of which is connected to the platform 12 via a pair of parallel struts 64a,b (only two labeled). The main displacement directions of all five piezo stack actuators 66, 240, 242, 70a,b are oriented parallel to each other. A first pairs of actuators 240, 242 and a second pair of actuators 70a,b on respective pairs of parallel sides of the rectangle operate to control platform in the same way as described in the context of figure 7, to realize mutually orthogonal directions of movement of platform 12. In this way, out of plane forces to platform 12 can be avoided.

Although embodiments with struts connected to an intermediate platform and/or levers have been shown, it should be appreciated that alternatively the struts may be coupled directly to the top of the piezo stack actuators. The use of additional levers and/or an intermediate platform has the advantage that the structure of the struts and the levers and/or an intermediate platform can be integrally formed, and manufactured for example by spark erosion. The piezo stack actuators may then be added to

the integrally formed structure. Furthermore, although hingingly connected levers are used, it should be appreciated that alternatively auxiliary platforms may be used instead of the levers, the auxiliary platforms being attached on top of piezo stack actuators. However, use of hinging
5 connections makes it easier to provide for accurate parallelograms and it may increase the resulting displacement.

Although embodiments with piezo stack actuators have been described, it should be appreciated that other types of actuators may be used, such as magnetic actuators (comprising a magnet in a coil for
10 example, electric current through the coil being used to move the magnet. In this case too, space can be saved by placing the actuators parallel to each other. The surface of a piezo stack actuators may exhibit displacements in more than one direction when a volgage is applied. The direction wherein the largest displacement occurs is referred to as the main displacement
15 direction.

Although embodiments have been described wherein the main displacement directions are parallel within manufacturing tolerances, it should be appreciated that some deviation from such a parallel arrangement forms no problem when levers are used. The levers determine the
20 displacement of the platform and the actuators move the levers in the same way, independent of whether the main displacement directions are strictly parallel. The parallel arrangement reduces the required space, but deviation from the parallel direction may still result in space saving. deviations that result in space saving will be termed substantially parallel. When the
25 deviations between the main displacement directions of different actuators from a central direction (the vertical in figures 1a, 2) is less than thirty degrees and more preferably less than ten degrees, space savings are realized.

Although embodiments have been described wherein each time
30 two struts are used in parallel, it should be appreciated that more struts

may be used in parallel. Where it is mentioned that a pair of parallel struts is provided, this does not exclude that more than two struts are used. When the pair of parallel struts forms a parallelogram, the bearings of these struts preferably lie in line along the sides of the parallelograms.

- 5 In an embodiment, a scanning probe microscope is provided that comprises a base, a positioning stage mounted on the base, a platform mounted on the positioning stage and a probe tip on the platform, the positioning stage comprising
- a first and second linear displacement actuator, each having a main
 - 10 direction of displacement, the main directions of displacement of the first and second linear displacement actuator being oriented substantially parallel to each other,
 - a first and second strut or struts coupled directly or indirectly between the platform and ends of the first and second actuators where the first and
 - 15 second actuators terminate in the main direction of displacement respectively, at least the first strut or struts being directed at an oblique angle to the main direction of displacement of the actuators.

- In a further embodiment, the scanning probe microscope comprises first bearings between central parts of said struts and the
- 20 platform, and second bearings between the central parts of the first and second struts and the ends of the first and second actuators respectively, the first and second bearings allowing for rotation of the central parts of the first and second struts relative to the platform and the ends of the first and second actuators respectively. The end of each of the first and second
- 25 actuators may be coupled directly or indirectly to the platform by a parallel pair of first struts and a parallel pair of said second struts respectively, positions of the first and second bearings of the struts in each pair forming corners of a parallelogram. In a further embodiment, the scanning probe microscope comprises one or more support posts on the base, and first and
- 30 second levers hingingly connected to the one or more support posts, the first

and second lever extending over the end of the first and second actuators respectively, each struts of each pair being coupled between a respective one of the lever and the platform, the parallelogram of the pair of struts having first legs between the positions of the first bearings and second legs between
5 the positions of the second bearings, the first and second legs running parallel to a hinge axis between the lever and one of the one or more support post to which the lever is hingingly connected.

Claims

1. A scanning probe microscope comprising a base, a positioning stage mounted on the base, a platform mounted on the positioning stage and a probe tip on the platform, the positioning stage comprising
- a first and second linear displacement actuator, each having a main
 - 5 direction of displacement, the main directions of displacement of the first and second linear displacement actuator being oriented substantially parallel to each other, the first and second linear displacement actuator each having an end where the first and second linear displacement actuators terminates in the main direction of displacement;
 - 10 - a first and second transmission structure coupled via distinct paths between the platform and the ends of the first and second linear displacement actuators respectively, the first and second transmission structure defining first and second lines between contacts of the first and second transmission structure to the platform and to the ends of the first
 - 15 and second linear displacement actuators respectively, the first and second lines being directed at an oblique angle to the main direction of displacement of the linear displacement actuators and at an angle to each other.
- 20 2. A scanning probe microscope according to claim 1, comprising
- a first and second strut in the first and second transmission structure respectively;
 - first bearings between central parts of said struts and the platform; and
 - second bearings between the central parts of the first and second struts
 - 25 and the ends of the first and second linear displacement actuators respectively,

the first and second bearings allowing for rotation of the central parts of the first and second struts relative to the platform and the ends of the first and second linear displacement actuators respectively.

- 5 3. A scanning probe microscope according to claim 2, wherein the first and second transmission structure comprise first and second further struts forming a first and second parallel pair of a struts with the first strut and the second strut respectively, positions of the first and second bearings of the struts in each pair forming corners of a parallelogram.
- 10
4. A scanning probe microscope according to claim 3, comprising a support post on the base, the first transmission structure comprising a lever structure connected by a hinging connection to the support post, the hinging connection allowing for rotation around an axis of rotation parallel
- 15 to a line between the second bearings of the first strut and the first further strut, the lever structure extending over the end of the first linear displacement actuator, the first strut and the first further strut being coupled between the platform and the lever structure.
- 20 5. A scanning probe microscope according to claim any one of claims 2-4, wherein the first and second strut are directed at said oblique angle to the main direction of displacement of the linear displacement actuators, the first and second strut being directed at said angle to each other.
- 25 6. A scanning probe microscope according to claim 4, wherein the lever structure, seen in projection on a plane perpendicular to the axis of rotation, defines virtual lines from the hinging connection to the end of the first linear displacement actuator and to a connection between the first strut and the first lever structure respectively, the first virtual lines being
- 30 substantially orthogonal to one another.

7. A scanning probe microscope according to claim 6, comprising
- a further linear displacement actuator on the base, having a main
direction of displacement substantially parallel to main directions of
5 displacement of the first and second linear displacement actuators, the
further linear displacement actuator having an end where the further linear
displacement actuator terminates in the main direction of displacement,
and
- a further transmission structure coupled between the platform and the end
10 of the further linear displacement actuator, the further transmission
structure defining a further line between contacts of the first and second
transmission structure to the platform and to the end of the further linear
displacement actuator, the further line being directed parallel to the main
direction of displacement.

15

8. A scanning probe microscope according to any one of the
preceding claims, comprising
- a third linear displacement actuator, having a main direction of
displacement substantially parallel to main directions of displacement of the
20 first and second linear displacement actuators, the third linear
displacement actuator having an end where the third linear displacement
actuator terminates in the main direction of displacement, and
- a third transmission structure coupled coupled between the platform and
the end of the third linear displacement actuator via a further paths that is
25 distinct from the paths between the platform and the ends of the first and
second linear displacement actuators.

9. A scanning probe microscope according to claim 8, wherein the
third transmission structure comprises a third strut coupled between the
30 platform and the end of the third linear displacement actuator, the third

strut being directed at an oblique angle to the main direction of displacement of the linear displacement actuators.

10. A scanning probe microscope according to claim 8 or 9, wherein
5 first, second and third struts are directed at the same oblique angles to the direction of displacement of the linear displacement actuators in different planes through and radiating from a central axis that is parallel to the main direction of displacement.
- 10 11. A scanning probe microscope according to claim 8, 9 or 10, wherein the first, second and third linear displacement actuators are arranged at successive positions along a virtual circle, at one hundred and twenty degree angles from each other.
- 15 12. A scanning probe microscope according to claim 11, comprising three distance sensors for sensing a distance from the distance sensors to the platform, the distance sensors being located between successive pairs of the first, second and third linear displacement actuator.
- 20 13. A scanning probe microscope according to any one of the preceding claims, comprising a plurality of at least three distance sensors for sensing a distance from the distance sensors to the platform, the plurality of distance sensors having measuring lines that intersect each other at the probe tip.
- 25 14. A scanning probe microscope according to any one claims 2-7 and 9-13, wherein struts between the platform and the ends of at least two of the linear displacement actuators are directed at the same oblique angles to the direction of displacement of the linear displacement actuators in

different planes through and radiating from a central axis that is parallel to the main direction of displacement.

15. A scanning probe microscope according to any one the preceding
5 claims, comprising one or more support posts on the base, the first and second transmission structures each comprising a lever structure hingingly connected to the one or more support posts, each lever structure extending over the end of a respective one of the linear displacement actuators, and a strut coupled between the lever structure and the platform.

10

16. A scanning probe microscope according to claim 15, wherein at least the platform, the lever structure and the struts of the first and second transmission structures are integrally formed.

15 17. A scanning probe microscope according to claim 16, comprising first and second bearings in each of the struts, the first bearings being located between a central part of the strut and the platform; and the second bearings being located between the central part of the strut and the lever structure.

20

18. A scanning probe microscope according to any one of the preceding claims, wherein the linear displacement actuators are piezo stack actuators.

25 19. A scanning probe microscope according to any one the preceding claims, wherein the linear displacement actuators are electromagnetic actuators, each comprising a coil and a magnet movable relative to the each other in the main displacement direction.

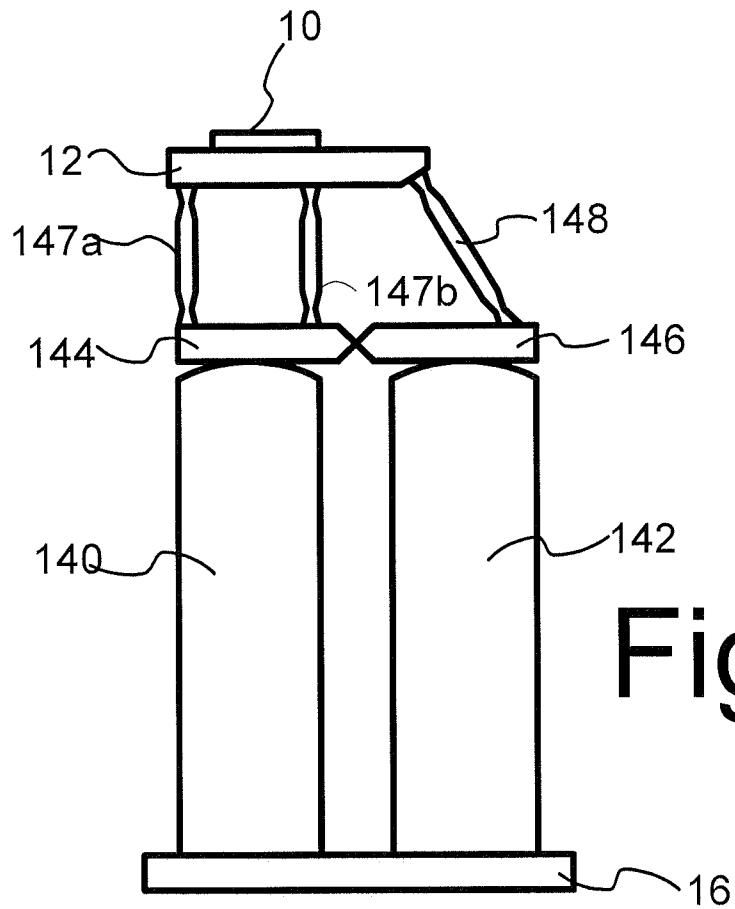


Fig. 1a

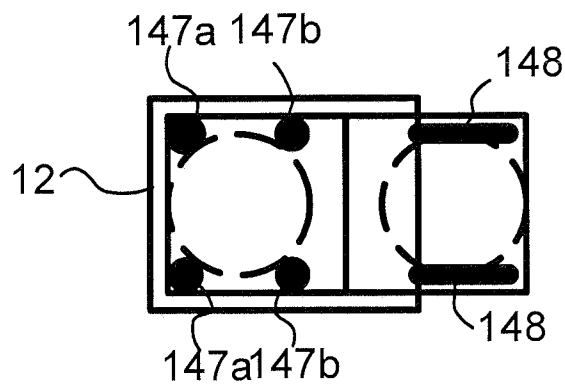


Fig. 1b

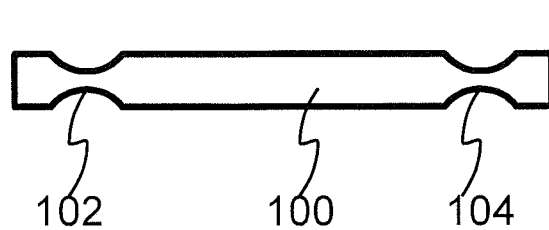
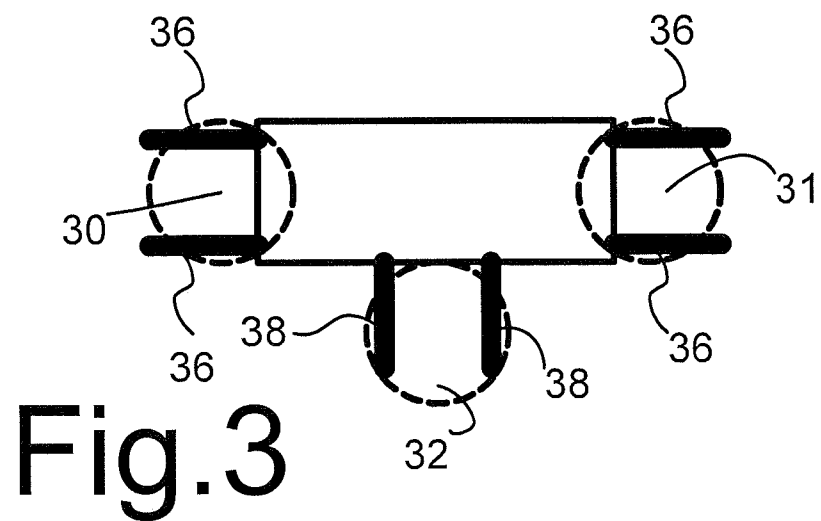
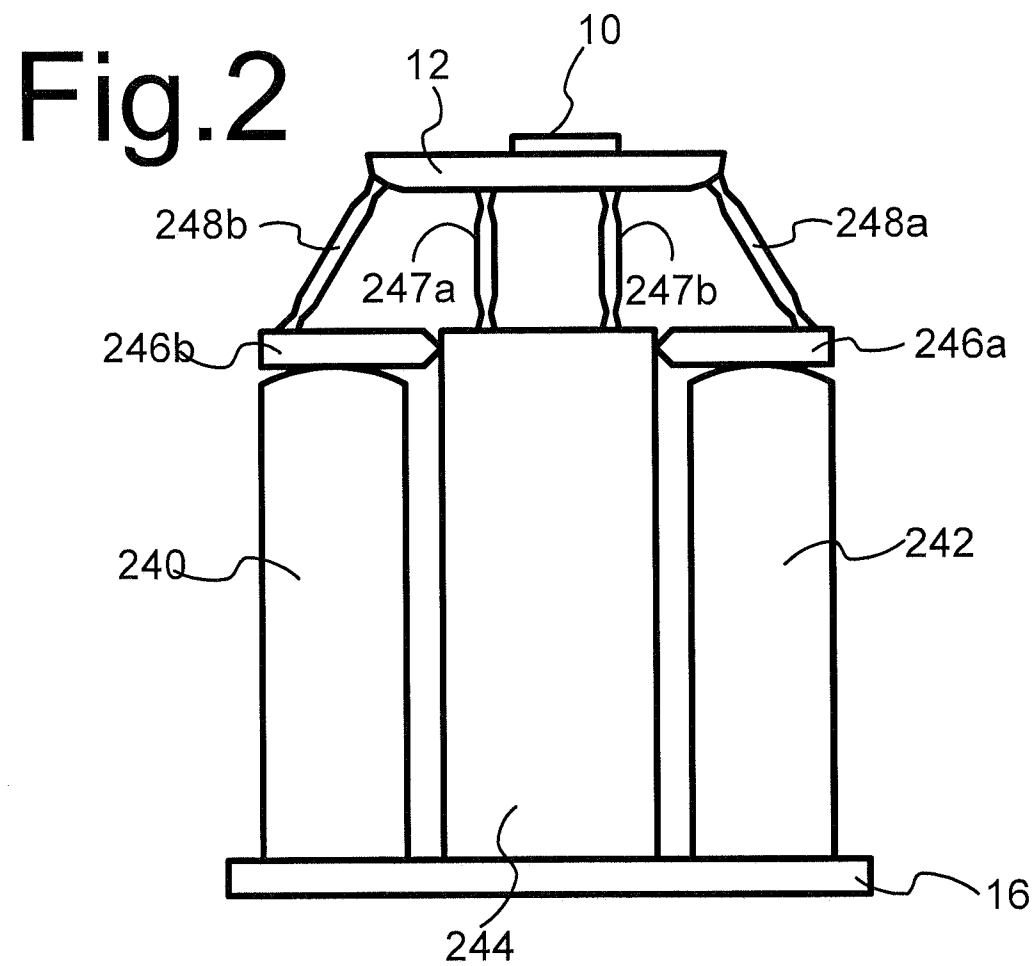


Fig. 1c



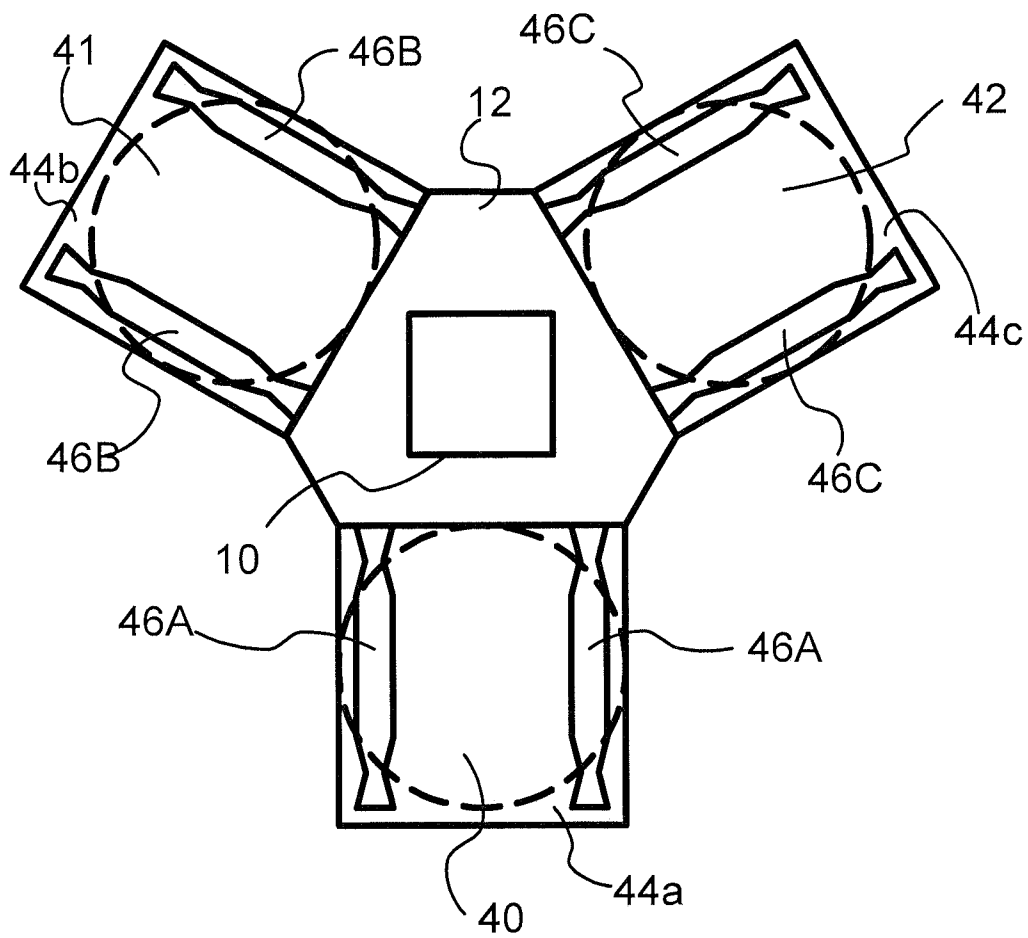


Fig.4

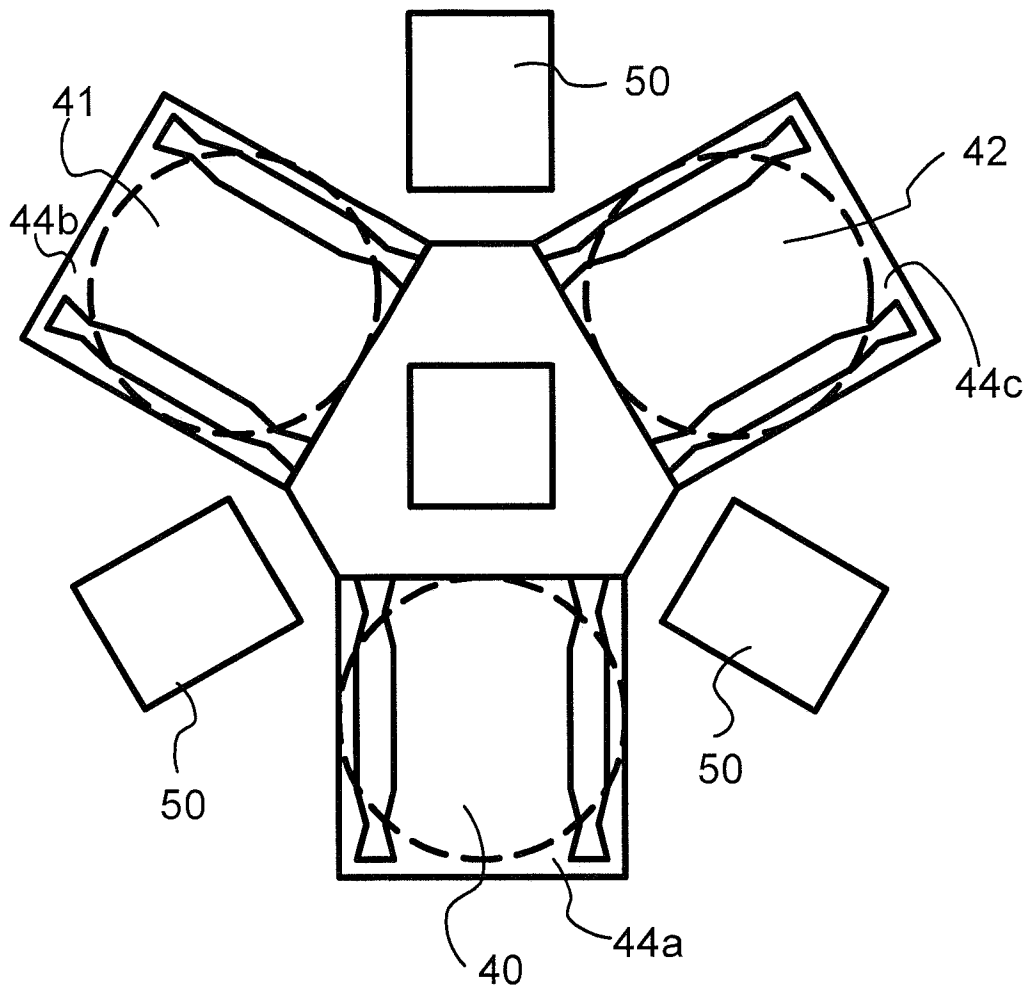


Fig.5

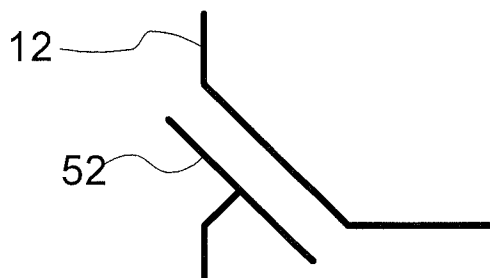


Fig.5a

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2013/050503

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01Q10/04 G02B21/26
ADD.

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)
G01Q G02B

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)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005/119329 A1 (CELLAVISION AB [SE]; ROSENQVIST ANDERS [SE]) 15 December 2005 (2005-12-15) figure 4	1-19
X	----- US 6 294 859 B1 (JAENKER PETER [DE]) 25 September 2001 (2001-09-25) figure 3 -----	1

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Further documents are listed in the continuation of Box C.

☒

See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

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"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

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Date of the actual completion of the international search

18 September 2013

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Name and mailing address of the ISA/

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Authorized officer

Quertemont, Eric

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/NL2013/050503

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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