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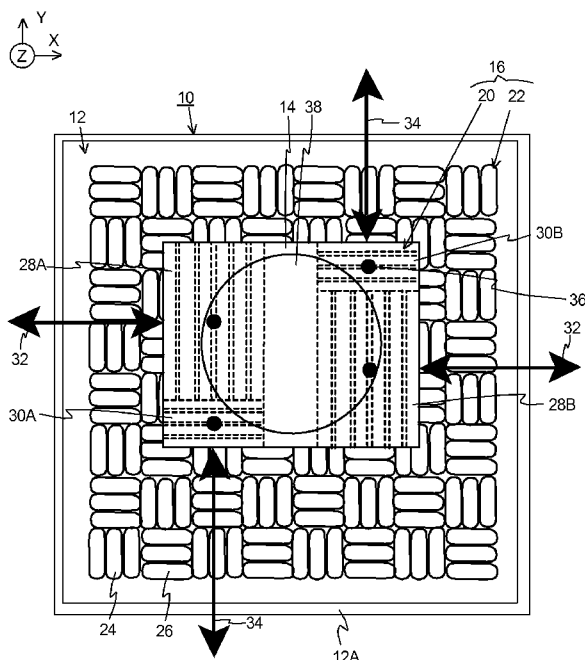
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(54) Title: PLANAR MOTOR WITH ASYMMETRICAL MAGNET ARRAYS



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Figure 1A

(57) Abstract: A stage assembly (10) that moves a device (38) includes a stage mover (16) that moves the stage (14) along a first axis and along a second axis. The stage mover (16) includes a magnet assembly (20), and a conductor assembly (22). The conductor assembly (22) includes a plurality of first axis conductor units (24) and a plurality of second axis conductor units (26). The magnet assembly (20) includes a first axis magnet array (28A) and a second axis magnet array (30A). The first axis conductor units (24) are arranged in an alternating fashion with the second axis conductor units (26) along the first axis and along the second axis. The performance of the stage mover (16) can be different in the first and second axes. Either the conductor units (24) (26) and/or the magnet arrays (28A) (30A) can have a different geometry in the first and second axes.



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PCT PATENT APPLICATION
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MICHAEL B. BINNARD, YUICHI SHIBAZAKI, and J. KYLE WELLS
for
PLANAR MOTOR WITH ASYMMETRICAL MAGNET ARRAYS

RELATED APPLICATION

[0001] This application claims priority on Provisional Application Serial No. 61/590,687 filed on January 25, 2012, entitled "CHECKERBOARD CONDUCTOR ASSEMBLY FOR A PLANAR MOTOR". This application also claims priority on Provisional Application Serial No. 61/591,231 filed on January 26, 2012, entitled "PLANAR MOTOR WITH ASYMMETRICAL PERFORMANCE". This application also claims priority on Provisional Application Serial No. 61/623,201 filed on April 12, 2012, entitled "PLANAR MOTOR WITH ASYMMETRICAL PERFORMANCE". As far as is permitted, the contents of U.S. Provisional Application Serial Nos. 61/590,687; 61/591,231; and 61/623,201 are incorporated herein by reference.

BACKGROUND

[0002] Exposure apparatuses are commonly used to transfer images from a reticle onto a semiconductor wafer during semiconductor processing. A typical exposure apparatus includes an illumination source, a reticle stage assembly that retains a reticle, a lens assembly and a wafer stage assembly that retains a semiconductor wafer.

[0003] Typically, the wafer stage assembly includes a wafer stage base, a wafer stage that retains the wafer, and a wafer stage mover assembly that precisely positions the wafer stage and the wafer. Somewhat similarly, the reticle stage assembly includes a reticle stage base, a reticle stage that retains the reticle, and a reticle stage mover assembly that precisely positions the reticle stage and the reticle. The size of the images and the features within the images transferred onto the wafer from the reticle are extremely small. Accordingly, the precise relative positioning of the wafer and the reticle is critical to the manufacturing of high density, semiconductor wafers.

[0004] Recently, planar motors have been used in the wafer stage mover assembly and/or the reticle stage mover assembly. In many applications, the requirements for

acceleration and duty cycle are different for movements in different directions. Further, these planar motors typically include a conductor assembly that is difficult to build and cool.

SUMMARY

[0005] The present invention is directed to a stage assembly that moves a device along a first axis and along a second axis that is orthogonal to the first axis. The stage assembly includes a stage, a base, and a stage mover that moves the stage along the first axis and along the second axis relative to the base. The stage mover includes a magnet assembly, and a conductor assembly, with one of the assemblies being coupled to the stage, and the other of the assemblies being coupled to the base. The conductor assembly includes a plurality of first axis conductor units and a plurality of second axis conductor units. With this design, current directed to one or more of the first axis conductor units creates a first axis force that is imparted on the stage, and current directed to one or more of the second axis conductor units creates a second axis force that is imparted on the stage.

[0006] Further, the magnet assembly includes a first axis magnet array and a second axis magnet array. As provided herein, in certain embodiments, the first axis magnet array is different from the second axis magnet array. In many applications, the requirements for the first axis and the second axis acceleration and duty cycle are different. With the present invention, the characteristics of the magnet arrays can be independently adjusted to improve the efficiency of the planar motor for movements along the first axis or along the second axis.

[0007] As provided herein, the problem of optimizing the first axis and the second axis performance of a checkerboard moving magnet planar motor can be solved by making the magnet arrays for the first axis and second axis magnet arrays different sizes. For example, the first axis magnet array can be larger than the second axis magnet array. More specifically, the first axis magnet array includes a plurality of first axis magnets, and the second axis magnet array includes a plurality of second axis magnets. Further, the number of first axis magnets can be greater than the number of second axis magnets.

[0008] Alternatively or additionally, the problem of optimizing the first axis and the second axis performance of a checkerboard moving magnet planar motor can be solved by changing the magnetic pitch for the first axis and second axis magnet arrays, and correspondingly changing the coil geometry of the first axis and second axis conductor units. For example, the first axis magnets can have a first magnetic pitch that is greater than a second magnetic pitch of the second axis magnets. In this embodiment, each first axis conductor unit can include three adjacent first axis conductors that are aligned along the first

axis, and each second axis conductor unit can include three adjacent second axis conductors that are aligned along the second axis. As provided herein, the first axis conductors can be larger than the second axis conductors.

[0009] In yet another embodiment, the problem of optimizing the first axis and the second axis performance of a checkerboard moving magnet planar motor can be solved by changing the coil geometry of the first axis and second axis conductor units. Stated in another fashion, as provided herein, the efficiency of a planar motor with a “checkerboard” type conductor assembly can be adjusted by making the conductor units different sizes, and staggering each row of the conductor assembly.

[0010] In certain embodiments, the magnet assembly is coupled to the stage, and the conductor assembly is coupled to the base. Further, current can be directed to conductor assembly to move the stage about a third axis relative to the stage base, the third axis being orthogonal to the first axis and the second axis.

[0011] In one embodiment, each first axis conductor unit can include three adjacent first axis conductors that are aligned along the first axis, and each second axis conductor unit can include three adjacent second axis conductors that are aligned along the second axis. Further, each first axis conductor can be a substantially oval shaped coil, and each second axis conductor can be a substantially oval shaped coil. With this design, a plurality of first axis conductors form a three phase motor with the first axis magnet array, and a plurality of second axis conductors form a three phase motor with the second axis magnet array.

[0012] In another embodiment, the first axis conductor units are arranged in an alternating fashion with the second axis conductor units along the first axis and along the second axis. Stated in another fashion, in one embodiment, the first axis conductor units are alternatively interspersed with the second axis conductor units along the first axis and along the second axis. With this design, the conductor assembly is relatively easy to build and relatively easy to cool.

[0013] The present invention is also directed to an exposure apparatus, a device manufactured with the exposure apparatus, and/or a wafer on which an image has been formed by the exposure apparatus. Further, the present invention is also directed to a method for moving a device, a method for making an exposure apparatus, a method for making a device and a method for manufacturing a wafer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The novel features of this invention, as well as the invention itself, both as to its structure and its operation, will be best understood from the accompanying drawings, taken in conjunction with the accompanying description, in which similar reference characters refer to similar parts, and in which:

[0015] Figure 1A is a top view of a stage assembly having features of the present invention;

[0016] Figure 1B is a top view of a conductor assembly and an outline of a magnet assembly having features of the present invention;

[0017] Figure 1C is a bottom view of a stage and the magnet assembly;

[0018] Figure 1D is a perspective view of a first axis magnet having features of the present invention;

[0019] Figure 1E is a perspective view of a second axis magnet having features of the present invention;

[0020] Figure 1F is a perspective view of a first axis conductor unit and a second axis conductor unit having features of the present invention;

[0021] Figure 2A is a top view of another embodiment of a stage assembly having features of the present invention;

[0022] Figure 2B is a top view of a conductor assembly and an outline of a magnet assembly from Figure 2B;

[0023] Figure 2C is a bottom view of the stage and the magnet assembly of Figure 2A;

[0024] Figure 2D is a bottom view of the stage and another embodiment of a magnet assembly having features of the present invention;

[0025] Figure 3A is a top view of a portion of another embodiment of a stage assembly having features of the present invention;

[0026] Figure 3B is a bottom view of the stage and the magnet assembly of Figure 3A;

[0027] Figure 4A is a top view of another embodiment of a stage assembly having features of the present invention;

[0028] Figure 4B is a top view of a conductor assembly and an outline of a magnet assembly of Figure 4A;

[0029] Figure 4C is an exploded perspective view of a modified conductor unit and a temperature controller having features of the present invention;

[0030] Figure 4D is a bottom view of a stage and the magnet assembly of Figure 4A;

[0031] Figure 5A is a top view of another embodiment of a stage assembly having features of the present invention;

[0032] Figure 5B is a top view of still another embodiment of a stage assembly having features of the present invention;

[0033] Figure 6A is an exploded perspective view of another embodiment of a conductor unit and a temperature controller having features of the present invention;

[0034] Figure 6B is an exploded perspective view of yet another embodiment of a conductor unit and a temperature controller having features of the present invention;

[0035] Figure 6C is a perspective view of another embodiment of a first axis conductor unit and a second axis conductor unit having features of the present invention;

[0036] Figure 7 is a schematic illustration of an exposure apparatus having features of the present invention;

[0037] Figure 8A is a flow chart that outlines a process for manufacturing a device in accordance with the present invention; and

[0038] Figure 8B is a flow chart that outlines device processing in more detail.

DESCRIPTION

[0039] Referring initially to Figure 1A, a stage assembly 10 having features of the present invention includes a base 12, a stage 14, a stage mover 16 that moves the stage 14, and a control system 18 that controls the stage mover 16. The design of each of these components can be varied to suit the design requirements of the stage assembly 10.

[0040] Some of the Figures provided herein include an orientation system that designates the X axis, the Y axis, and a Z axis that are orthogonal to each other. In these Figures, the Z axis is oriented in the vertical direction. It should be understood that the orientation system is merely for reference and can be varied. For example, the X axis can be switched with the Y axis and/or the stage assembly 10 can be rotated. Moreover, these axes can alternatively be referred to as the first, the second, or a third axis. For example, the X

axis can be referred to as the first axis, the Y axis can be referred to as the second axis, and the Z axis can be referred to as the third axis.

[0041] A number of alternative embodiments of the stage mover 16 are provided herein. In certain embodiments, the stage mover 16 is uniquely designed to have asymmetrical performance. For example, the stage mover 16 can be designed to have better acceleration and improved performance characteristics for moving the stage 14 along a first axis (e.g. an X axis) than for moving the stage 14 along a second axis (e.g. a Y axis). With this design, the characteristics of the stage mover 16 can be tailored to suit the acceleration and performance requirements for movements in different directions.

[0042] In certain embodiments, the stage mover 16 includes a magnet assembly 20 (illustrated in phantom), and a conductor assembly 22. Further, (i) the conductor assembly 22 can include a plurality of first axis conductor units 24 (sometimes referred to as “X conductor units”), and a plurality of second axis conductor units 26 (sometimes referred to as “Y conductor units”); and (ii) the magnet assembly 20 can include a pair of spaced apart, first axis magnet arrays 28A, 28B (sometimes referred to as “a first X magnet array 28A and a second X magnet array 28B”), and a pair of spaced apart, second axis magnet arrays 30A, 30B (sometimes referred to as “a first Y magnet array 30A and a second Y magnet array 30B”). In many applications, the requirements for the first axis and the second axis acceleration and duty cycle are different.

[0043] Uniquely, as provided herein, in certain embodiments, one or both of the first axis magnet arrays 28A, 28B are different from the second axis magnet arrays 30A, 30B. With the present invention, the characteristics (e.g. the physical characteristics) of the magnet arrays 28A, 28B, 30A, 30B can be independently adjusted to improve the efficiency of the stage mover 16 for movements along the first axis or along the second axis. The characteristics can include, for example, size of the magnet array, number of magnets included in the magnet array, magnet pitch of magnets disposed in the magnet array, dimension of magnet active area of the magnet array, and/or thickness of the magnet.

[0044] Alternatively or additionally, in another embodiment, one or more of the X conductor units 24 can be designed to be different than the Y conductor units 26. With this design, the characteristics of the conductor units 24, 26 can be adjusted to improve the efficiency of the stage mover 16 for movements along the first axis or along the second axis.

[0045] The stage assembly 10 is particularly useful for precisely positioning a device 38 during a manufacturing and/or an inspection process. The type of device 38 positioned and moved by the stage assembly 10 can be varied. For example, the device 38 can be a

semiconductor wafer, and the stage assembly 10 can be used as part of an exposure apparatus 534 (illustrated in Figure 5) for precisely positioning the semiconductor wafer during manufacturing of the semiconductor wafer (semiconductor device). Alternatively, for example, the stage assembly 10 can be used to move other types of devices during manufacturing and/or inspection, to move a device under an electron microscope (not shown), or to move a device during a precision measurement operation (not shown).

[0046] The base 12 is coupled to the stage mover 16, receives the reaction forces generated by the stage mover 16, and can be any suitable structure. In Figure 1, the base 12 is generally rectangular shaped and is rigid. In certain embodiments, the base 12 can be a reaction assembly that counteracts, reduces and minimizes the influence of the reaction forces from the stage mover 16 on the position of other structures on the exposure apparatus 534. For example, the base 12 can be a rigid, rectangular shaped counter mass that is maintained above a counter mass support 12A with a reaction bearing (not shown) that allows for motion of the base 12 relative to the counter mass support 12A along the X axis, along the Y axis, and about the Z axis. For example, the reaction bearing can be a vacuum preload type fluid bearing, a magnetic type bearing, or a roller bearing type assembly. Alternatively, for example, the stage assembly 10 can include a reaction frame (not shown), that couples the conductor assembly 22 to the base 12 or another structure.

[0047] With the present design, (i) movement of the stage 14 with the stage mover 16 along the X axis, generates an equal and opposite X reaction force that moves the base 12 in the opposite direction along the X axis; (ii) movement of the stage 14 with the stage mover 16 along the Y axis, generates an equal and opposite Y reaction force that moves the base 12 in the opposite direction along the Y axis; (iii) movement of the stage 14 with the stage mover 16 about the Z axis generates an equal and opposite theta Z reaction moment (torque) that moves the base 12 about the Z axis; and (iv) depending on the position of stage 14, movement of the stage 14 with the stage mover 16 along the X axis or along the Y axis may generate a theta Z reaction moment (torque) that moves the base 12 about the Z axis.

[0048] In one embodiment, the stage assembly 10 includes a single stage 14 that is moved relative to the stage base 12. Alternately, for example, the stage assembly 10 can be designed to include multiple stages that are independently moved relative to the stage base 12.

[0049] In Figure 1A, the stage 14 retains the device 38. In this embodiment, the stage 14 is generally rectangular shaped and includes a device holder (not shown) for retaining the device 38. The device holder can be a vacuum chuck, an electrostatic chuck, or some other

type of clamp. Alternatively, for example, the stage 14 can be a coarse stage, and the stage assembly 10 can include a fine stage (not shown) that retains the device 38 and a fine stage mover (not shown) that moves the fine stage.

[0050] In Figure 1A, the stage 14 is precisely moved by the stage mover 16 to precisely position the device 38. The stage 14 can be maintained and levitated above the base 12 along the Z axis with the stage mover 16. Alternatively, for example, the stage 14 can be maintained above the base 12 with a vacuum preload type fluid bearing, a roller bearing type assembly, or another type of bearing.

[0051] The stage mover 16 controls and adjusts the position of the stage 14 and the device 38 relative to the stage base 12. For example, the stage mover 16 can be a planar motor that moves and positions of the stage 14 with six degrees of freedom, e.g. along the X, Y, and Z axes, and about the X, Y, and Z axes, relative to the stage base 12. Alternatively, the stage mover 16 can be designed to move the stage 14 with less than six degrees of freedom, e.g. with three degrees of freedom.

[0052] As provided above, in Figure 1A, (i) the conductor assembly 22 includes a plurality of X conductor units 24, and a plurality of Y conductor units 26; and (ii) the magnet assembly 20 includes a pair of spaced apart, X magnet arrays 28A, 28B, and a pair of spaced apart, Y magnet arrays 30A, 30B. With this design, (i) current from the control system 18 directed to certain X conductor units 24 can create an interaction with the magnetic field(s) of the X magnet arrays 28A, 28B to generate two first axis forces 32 (illustrated with arrows) along the first ("X") axis that are imparted on the stage 14, and (ii) current from the control system 18 directed to certain Y conductor units 26 can create an interaction with the magnetic field(s) of the Y magnet arrays 30A, 30B to generate two second axis forces 34 (illustrated as arrows) along the second ("Y") axis that are imparted on the stage 14. Further, in certain embodiments, (i) current from the control system 18 directed to certain X conductor units 24 can create an interaction with the magnetic field(s) of the X magnet arrays 28A, 28B to generate two third axis forces 36 (illustrated with a dot) along the third ("Z") axis that are imparted on the stage 14, and (ii) current from the control system 18 directed to one or more of the Y conductor units 26 can create an interaction with the magnetic field(s) of the Y magnet arrays 30A, 30B to also generate two, third axis forces 36.

[0053] The first axis forces 32 can be used to move the stage 14 back and forth along the first ("X") axis, the second ("Y") axis forces 34 can be used to move the stage 14 back and forth along the second axis, and the third axis forces 36 can be used to move the stage

14 back and forth along the third ("Z") axis. Further, the forces 32, 34, 36 can be adjusted to control rotation of the stage 14 about the X, Y, and Z axes.

[0054] In certain embodiments, the X conductor units 24 are arranged in an alternating fashion with the Y conductor units 26 along the first axis and along the second axis. Stated in another fashion, the X conductor units 24 are alternatively interspersed with the Y conductor units 26 along the X axis and along the Y axis to create a checkerboard pattern. Further, in certain embodiments, all of the conductor units 24, 26 are in substantially the same plane and have the same Z axis position. With this design, the conductor assembly 22 is relatively easy to build and relatively easy to cool.

[0055] Further, in certain embodiments, one or both of the first axis magnet arrays 28A, 28B are different from the second axis magnet arrays 30A, 30B. With the present invention, the characteristics of the magnet arrays 28A, 28B, 30A, 30B can be independently adjusted to improve the efficiency of the planar motor for movements in the first axis and in the second axis.

[0056] In Figure 1A, the magnet assembly 20 is secured to and moves with the stage 14, and the conductor assembly 22 is secured to the base 12. With this design, when the stage mover 16 applies forces to move the stage 14, equal and opposite reaction forces are applied to the base 12.

[0057] Unfortunately, the electrical current supplied to the conductor assembly 22 also generates heat, due to resistance in the conductor assembly 22. In Figure 1, the heat from the conductor assembly 22 is subsequently transferred to the base 12. This can cause expansion and distortion of the base 12. Further, the heat from the conductor assembly 22 can be transferred to the surrounding environment, including the air surrounding the conductor assembly 22. This can adversely influence a measurement system (not shown) that measures the position of the stage 14 and the device 38. For example, certain measurement systems utilize one or more interferometers. The heat from the conductor assembly changes the index of refraction of the surrounding air. This reduces the accuracy of the measurement system and degrades machine positioning accuracy.

[0058] In certain embodiments, to reduce the influence of the heat from the conductor assembly 22, a temperature controller (not shown in Figure 1A) can actively control (i.e. cool) the temperature of the conductor assembly 22 to minimize the distortion of the base 12 and improve the positioning performance of the stage assembly 10. Stated in another fashion, the temperature controller can be used to reduce the influence of the heat from the conductor assembly 22 from adversely influencing the other components of the stage assembly 10 and

the surrounding environment. With this design, the stage mover 16 can position the device 38 with improved accuracy.

[0059] The control system 18 is electrically connected and directs and controls electrical current to the conductor assembly 22 of the stage mover 16 to precisely position the device 38. The control system 18 can include one or more processors.

[0060] As provided herein, in certain embodiments, the problem of optimizing the first axis (X axis) and the second axis (Y axis) performance of a planar motor 16 is solved by making one or both of the first axis magnet arrays 28A, 28B a different size than the second axis magnet arrays 30A, 30B.

[0061] For the embodiment illustrated in Figure 1A, the desired goal is to provide increased efficiency in the first axis (X direction), while accepting lower performance in the second axis (Y direction) as a tradeoff. In this example, one or both of the first axis magnet arrays 28A, 28B can be larger than the second axis magnet arrays 30A, 30B. With this design, the stage mover 16 will have improved efficiency in the first axis (X direction), while accepting lower performance in the second axis (Y direction) as a tradeoff. In the embodiment shown in Figure 1A, both of the first axis magnet arrays 28A, 28B are approximately three times larger than the second axis magnet arrays 30A, 30B.

[0062] Alternatively, if the desired goal is to provide increased efficiency in the second axis (Y direction), while accepting lower performance in the first axis (X direction), one or both of the second axis magnet arrays 30A, 30B can be larger than the first axis magnet arrays 28A, 28B.

[0063] Figure 1B is a top view of the conductor assembly 22 and an outline of the magnet assembly 20 (illustrated with dashed lines) of Figure 1A. The number of X conductor units 24 and Y conductor units 26 in the conductor assembly 22 can be varied according to the movement requirements of the stage assembly 10 (illustrated in Figure 1). For example, in Figure 1B, the conductor assembly 22 includes thirty-two X conductor units 24, and thirty-two Y conductor units 26. Alternatively, the conductor assembly 22 can be designed to include more than thirty-two or fewer than thirty-two of the X conductor units 24 and the Y conductor units 26.

[0064] In Figure 1B, the conductor assembly 22 is a checkerboard pattern with the X conductor units 24 arranged in an alternating fashion with the Y conductor units 26 along the X axis and along the Y axis. Stated in another fashion, the conductor assembly 22 illustrated in Figure 1B is organized as a square grid that includes eight rows (aligned with the X axis)

of conductor units 24, 26 and eight columns (aligned with the Y axis) of conductor units 24, 26. Further, (i) in each row, the X conductor units 24 are alternatively interspersed with the Y conductor units 26; and (ii) in each column, the X conductor units 24 are alternatively interspersed with the Y conductor units 26. Moreover, the conductor units 24, 26 are all approximately in the same Z plane. With this design, the conductor assembly 22 is relatively easy to build and relatively easy to cool.

[0065] In the alternating checkerboard pattern, the conductor units 24, 26 are arranged to provide a precisely controlled force in the X or Y direction. Each conductor unit 24, 26 can also provide an independently controlled force in the Z direction.

[0066] As provided herein, if the amplifiers of the control system 18 (illustrated in Figure 1A) are powerful enough, the checkerboard pattern conductor assembly 22 can reduce the number of amplifiers, coils, and lead wires by half compared to a conductor assembly (not shown) in which each "square" of the array comprises both X and Y conductors stacked over each other.

[0067] Further, as provided herein, this type of conductor assembly 22 is relatively easy to build and cool compared to a conductor assembly that includes stacked X and Y conductors. This type of conductor assembly 22 can be made in a modular fashion with regular shaped conductor units 24, 26 for ease of manufacturing.

[0068] As provided above, the magnet assembly 20 includes (i) the first X magnet array 28A, (ii) the second X magnet array 28B that is spaced apart from the first X magnet array 28A, (iii) the first Y magnet array 30A, and (iv) the second Y magnet array 30B that is spaced apart from the first Y magnet array 30A. Further, in certain embodiments, all of the magnet arrays 28A, 28B, 30A, 30B are in substantially the same plane and have substantially the same Z axis position.

[0069] Figure 1B also illustrates the conductor units 24, 26 that can be used to move the stage (not shown) at the present position of the magnet assembly 20. More specifically, at this position, (i) the X conductor units 24 labeled with X1 in Figure 1B interact with the first X magnet array 28A, (ii) the X conductor units 24 labeled with X2 in Figure 1B interact with the second X magnet array 28B, (iii) the Y conductor units 26 labeled with Y1 in Figure 1B interact with the first Y magnet array 30A, and (iv) the Y conductor units 26 labeled with Y2 in Figure 1B interact with the second Y magnet array 30B. Stated in another fashion, at this position, the highlighted conductor units X1, X2, Y1, Y2 would be energized to provide 6 degree of freedom magnetic levitation control of the moving stage 14.

[0070] It should be noted that with the unique design illustrated in Figure 1B, at any position of the stage, because the first axis magnet arrays 28A, 28B are larger than the second axis magnet arrays 30A, 30B, more the X conductor units 24 can be used than Y conductor units 26 to move that stage. With this design, the stage mover 16 will have improved efficiency in the first axis (X direction), while accepting lower performance in the second axis (Y direction) as a tradeoff.

[0071] Figure 1C is a bottom view of the stage 14 and the magnet assembly 20 including the first X magnet array 28A, the second X magnet array 28B, the first Y magnet array 30A, and the second Y magnet array 30B. As provided herein, each first axis magnet array 28A, 28B includes a plurality of first axis magnets 44 (sometimes referred to as “X magnets”), and the second axis magnet array 30A, 30B includes a plurality of second axis magnets 46 (sometimes referred to as “Y magnets”). Further, the number of first axis magnets 44 in one or both of X magnet arrays 28A, 28B can be greater than the number of second axis magnets 46 in one or both of the Y magnet arrays 30A, 30B. Moreover, in this embodiment, each X axis magnet array 28A, 28B is larger than each Y axis magnet array 30A, 30B, and each first axis magnet 44 is longer along the Y axis than each second axis magnet is along the X axis.

[0072] In one embodiment, (i) each X magnet array 28A, 28B includes six X magnets 44 that extend along the Y axis and that are spaced apart along the X axis; and (ii) each Y magnet array 30A, 30B includes four Y magnets 46 that extend along the X axis and that are spaced apart along the Y axis. Alternatively, (i) each X magnet array 28A, 28B can be designed to include more than six or fewer than six X magnets 44; and (ii) each Y magnet array 30A, 30B can be designed to include more than four or fewer than four Y magnets 46. Further, in this embodiment, the X magnets 44 are longer than the Y magnets 46.

[0073] As provided herein, (i) the first X magnet array 28A has a first X magnet active area 48A; (ii) the second X magnet array 28B has a second X magnet active area 48B; (iii) the first Y magnet array 30A has a first Y magnet active area 50A; and (iv) the second Y magnet array 30B has a second Y magnet active area 50B. Further, the magnet assembly 20 has a total active area 52 that is equal to the sum of the magnet active areas 48A, 48B, 50A, 50B.

[0074] As provided herein, in certain embodiments, one or both of the X magnet active areas 48A, 48B is different in size from one or both of the Y magnet active areas 50A, 50B. For example, if it is desired to make a mover having improved efficiency for X axis movements, one or both of the X magnet active areas 48A, 48B is made larger in size than

one or both of the Y magnet active areas 50A, 50B. Alternatively, if it is desired to make a mover having improved efficiency for Y axis movements, one or both of the X magnet active areas 48A, 48B is made smaller in size than one or both of the Y magnet active areas 50A, 50B.

[0075] In the embodiment illustrated in Figure 1C, (i) the X magnet active areas 48A, 48B are approximately the same size; (ii) the Y magnet active areas 50A, 50B are approximately the same size; and (iii) the X magnet active areas 48A, 48B are both approximately three times larger than the Y magnet active areas 50A, 50B. In alternative non-exclusive embodiments, one or both of the X magnet active areas 48A, 48B can be approximately 2, 5, 10, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, 300, 320, 340, 360, 380, or 400 percent larger than one or both of the Y magnet active areas 50A, 50B.

[0076] In Figure 1C, the X magnet arrays 28A, 28B cover (e.g. the sum of the X magnet active areas 48A, 48B) approximately seventy-five percent (three quarters) of the total magnet active area 52 (instead of one-half) while the Y magnet arrays 30A, 30B cover (e.g. the sum of the Y magnet active areas 50A, 50B) approximately twenty-five percent (one quarter) of the total magnet active area 52 (instead of one-half). These changes make the X axis efficiency much greater than the Y axis efficiency.

[0077] As provided herein, the magnet assembly 20 can be defined as a magnet area ratio between (i) the total size of the X magnet arrays 28A, 28B (e.g. the sum of the X magnet active areas 48A, 48B) relative to the total magnet active area 52; and (ii) the total size of the Y magnet arrays 30A, 30B (e.g. the sum of the Y magnet active areas 50A, 50B) relative to the total magnet active area 52. In the example provided above, the mover has a seventy-five to twenty-five (75/25) ratio. As provided herein, and assuming the coil array has equal size and shape X and Y conductors, (i) a 50/50 magnet area ratio will provide approximately equal performance along the X and Y axes, (ii) a magnet area ratio of greater than 50/50 will provide improved performance along the X axis, and (iii) a magnet area ratio of less than 50/50 will provide improved performance along the Y axis.

[0078] In alternative non-exclusive embodiments, for improved performance along the X axis, the magnet area ratio can be approximately 90/10, 85/15, 80/20, 75/25, 70/30, 65/35, 60/40, 55/45, or 52/48. Somewhat similarly, in alternative non-exclusive embodiments, for improved performance along the Y axis, the magnet area ratio can be approximately 10/90, 15/85, 20/80, 25/75, 30/70, 35/65, 40/60, 45/55, or 48/52.

[0079] In one embodiment, the X magnets 44 in each X magnet array 28A, 28B are arranged so that X magnets 44 alternate with the North pole and the South pole facing the conductor array as you move along the X axis. Similarly, the Y magnets 46 in each Y magnet array 30A, 30B are arranged so that Y magnets 46 alternate with the North pole and the South pole facing the conductor array as you move along the Y axis. With this design, each magnet array 28A, 28B has a substantially sinusoidal magnetic flux. In certain embodiments, the spaces between adjacent X magnets 44 is filled with additional magnets (not shown) with a horizontal or diagonal magnetization direction to form a Halbach magnet array, as is well-known to those skilled in the art.

[0080] As provided herein, each X magnet array 28A, 28B has a X magnetic pitch that is defined by the distance along the X axis between adjacent North (or South) poles. Further, each Y magnet array 30A, 30B has a Y magnetic pitch that is defined by the distance along the Y axis between adjacent North (or South) poles. In the embodiment illustrated in Figure 1C, (i) the X magnetic pitch is the same for each X magnet array 28A, 28B; (ii) the Y magnetic pitch is the same for each Y magnet array 30A, 30B; and (iii) the X magnetic pitch is the same as the Y magnetic pitch.

[0081] As one non-exclusive example, each magnet 44, 46 can be made of a permanent magnetic material such as NdFeB.

[0082] Figure 1D is a perspective view of one first axis magnet 44 and Figure 1E is a perspective view of one second axis magnet 46. In this embodiment, each magnet 44, 46 is generally rectangular, long and narrow. Further, the first axis magnet 44 is longer than the second axis magnet 46. Moreover, in this embodiment, the magnets 44, 46 have the same thickness along the Z axis. However, in another embodiment, one or more of the magnets 44, 46 can be thicker than the other magnets 46, 44 along the Z axis. For example, at least some of the first axis magnets 44 can be thicker along the Z axis than the second axis magnets 46. With this design, at least a portion of the first axis magnet array is thicker along the Z axis than the second axis magnet array. This will improve the performance along the X axis. In alternative, non-exclusive embodiments, the first axis magnets 44 can be approximately 5, 10, 15, 20, 30, 40, or 50 percent thicker along the Z axis than the second axis magnets 46. However, other percentages can be utilized.

[0083] Figure 1F is a perspective view of one X conductor unit 24, and one Y conductor unit 26. As provided herein, each conductor unit 24, 26 includes one or more conductors. In Figure 1F, (i) the X conductor unit 24 includes three, adjacent, X conductors 40 that are aligned side by side along the X axis; and (i) the Y conductor unit 26 includes

three, adjacent, Y conductors 42 that are aligned side by side along the Y axis. With this design, a plurality of first axis conductors 40 form a three phase motor with the first axis magnet arrays 28A, 28B (illustrated in Figure 1C), and a plurality of second axis conductors 42 form a three phase motor with the second axis magnet arrays 30A, 30B (illustrated in Figure 1C).

[0084] Further, each conductor 40, 42 can be substantially oval shaped, i.e. a race track type conductor. Moreover, each conductor 40, 42 can be made by coiling a metal wire such as copper or any substance or material responsive to electrical current and capable of creating a magnetic field such as superconductors. The race track type conductor has a regular shaped that is relatively easy to make and assemble in a modular fashion. Further, the race track type conductor provides space for fasteners and coolant plumbing. This facilitates cooling and assembling of the conductor assembly 22. Other conductor shapes which are known in the use of linear and planar motors can also be used in alternative embodiments.

[0085] Figure 2A is a top view of another embodiment of a stage assembly 210 that includes (i) a base 212, a stage 214, and a control system 218 that are similar to the corresponding components described above and illustrated in Figure 1A; and (ii) a stage mover 216 that slightly different from the stage mover 16 described above. In this embodiment, the stage mover 216 again is a planar motor that precisely moves the stage 214 relative to the base 212 with six degrees of freedom. Further, the stage mover 216 includes a conductor assembly 222 that is similar to the conductor assembly 22 described above, and a magnet assembly 220 (illustrated in phantom) that is slightly different from the magnet assembly 20 described above.

[0086] In this embodiment, (i) the conductor assembly 222 includes a plurality of first axis conductor units 224 (sometimes referred to as "X conductor units"), and a plurality of second axis conductor units 226 (sometimes referred to as "Y conductor units"); and (ii) the magnet assembly 220 includes a pair of spaced apart, first axis magnet arrays 228A, 228B (sometimes referred to as "a first X magnet array 228A and a second X magnet array 228B"), and a pair of spaced apart, second axis magnet arrays 230A, 230B (sometimes referred to as "a first Y magnet array 230A and a second Y magnet array 230B").

[0087] Uniquely, in this embodiment, only one of the first axis magnet arrays 228A, 228B is larger than both of the second axis magnet arrays 230A, 230B. More specifically, in this embodiment, only the first X magnet array 228A is larger than both of the Y axis magnet arrays 230A, 230B. In this embodiment, the desired goal is to provide increased efficiency in

the first axis (X direction), while accepting somewhat lower performance in the second axis (Y direction) as a tradeoff.

[0088] Figure 2B is a top view of the conductor assembly 222 and an outline of the magnet assembly 220 (illustrated with dashed lines) including (i) the first X magnet array 228A, (ii) the second X magnet array 228B that is spaced apart from the first X magnet array 228A, (iii) the first Y magnet array 230A, and (iv) the second Y magnet array 230B that is spaced apart from the first Y magnet array 230A.

[0089] Figure 2B also illustrates the conductor units 224, 226 that can be used to move the stage (not shown) at the present position of the magnet assembly 220. More specifically, at this position, (i) the X conductor units 224 labeled with X1 interact with the first X magnet array 228A, (ii) the X conductor units 224 labeled with X2 interact with the second X magnet array 228B, (iii) the Y conductor units 226 labeled with Y1 interact with the first Y magnet array 230A, and (iv) the Y conductor units 226 labeled with Y2 interact with the second Y magnet array 230B. Stated in another fashion, at this position, the conductor units X1, X2, Y1, Y2 would be energized to provide six degree of freedom magnetic levitation control of the moving stage 14.

[0090] It should be noted that with the unique design illustrated in Figure 2B, at any position of the stage, because the first X magnet array 228A is larger than the second axis magnet arrays 30A, 30B, more the X conductor units 224 can be used than Y conductor units 226 to move that stage. With this design, the stage mover 216 will have improved efficiency in the first axis (X direction), while accepting lower performance in the second axis (Y direction) as a tradeoff.

[0091] Figure 2C is a bottom view of the stage 214 and the magnet assembly 220 including the first X magnet array 228A, the second X magnet array 228B, the first Y magnet array 230A, and the second Y magnet array 230B. In this embodiment, (i) each X magnet array 228A, 228B includes six X magnets 244 that extend along the Y axis and that are spaced apart along the X axis; (ii) the first Y magnet array 230A includes three Y magnets 246 that extend along the X axis and that are spaced apart along the Y axis; and (iii) the second Y magnet array 230B includes six Y magnets 246 that extend along the X axis and that are spaced apart along the Y axis. In this embodiment, the X magnets 244 of the first X magnet array 228A are longer (along the Y axis) than the X magnets 244 of the second X magnet array 228B.

[0092] In this embodiment, (i) the first X magnet active area 248A is the largest, (ii) the second X magnet active area 248B is approximately equal in size to the second Y magnet

active area 250B, and (iii) the first Y magnet active area 250A is the smallest. In Figure 2C, the X magnet arrays 228A, 228B cover (e.g. the sum of the X magnet active areas 248A, 248B) approximately 62.5 percent of the total magnet active area 252 (instead of one-half) while the Y magnet arrays 230A, 230B cover (e.g. the sum of the Y magnet active areas 250A, 250B) approximately 37.5 percent of the total magnet active area 252 (instead of one-half).

[0093] Stated in another fashion, in Figure 2C, compared to a design with four equal-sized magnet arrays, the first X magnet array 228A is increased in size by fifty percent and the first Y magnet array 230A is reduced by fifty percent. The second X magnet array 228B and the second Y magnet array 230B are kept the same size. In contrast to the embodiment shown in Figures 1A-1F, this configuration provides a more reasonable balance of the X and Y performance, but makes the stage design less symmetrical, which may be disadvantageous in some circumstances.

[0094] Figure 2D is a bottom view of the stage 214D and another non-exclusive embodiment of the magnet assembly 220D including the first X magnet array 228AD, the second X magnet array 228BD, the first Y magnet array 230AD, and the second Y magnet array 230BD that can be used with the conductor arrays (not shown in Figure 2D) disclosed herein. In this embodiment, (i) the first X magnet array 228AD includes nine X magnets 244D that extend along the Y axis and that are spaced apart along the X axis; (ii) the second X magnet array 228BD includes six X magnets 244D that extend along the Y axis and that are spaced apart along the X axis; and (iii) each Y magnet array 230AD, 230BD includes six Y magnets 246D that extend along the X axis and that are spaced apart along the Y axis. In this embodiment, three of the X magnets 244D of the first X magnet array 228AD are longer (along the Y axis) than the other twelve X magnets 244D of the first and second X magnet arrays 228AD, 228BD. Further, in this embodiment, the three extra X magnets 244D of the first X magnet array 228AD fill the open space (illustrated in Figures 2C and 3B) on the bottom of the stage 214D.

[0095] In this embodiment, (i) the first X magnet active area 248AD is the largest, and (ii) the second X magnet active area 248BD is approximately equal in size to the Y magnet active areas 250AD, 250BD. In Figure 2D, the X magnet arrays 228AD, 228BD cover (e.g. the sum of the X magnet active areas 248AD, 248BD) a higher percentage of the total magnet active area 252D (instead of one-half) while the Y magnet arrays 230AD, 230BD cover (e.g. the sum of the Y magnet active areas 250AD, 250BD) a lower percentage of the total magnet active area 252D (instead of one-half).

[0096] It should be noted that numerous other arrangements of the magnet arrays 228AD, 228BD, 230AD, 230BD are possible. In addition, other arrangements with more or fewer than four magnet arrays are also possible.

[0097] Figure 3A is a top view of a portion of another embodiment of a stage assembly 310 that includes (i) a stage 314 (illustrated in phantom), and a control system 318 that are similar to the corresponding components described above and illustrated in Figure 1A; and (ii) a portion of a stage mover 316 that is slightly different from the stage mover 16 described above. In this embodiment, the stage mover 316 again is a planar motor that precisely moves the stage 314 with six degrees of freedom. Further, the stage mover 316 includes a conductor assembly 322 (only a portion is illustrated in Figure 3A) and a magnet assembly 320 (an outline of which is illustrated in phantom) that are slightly different from the corresponding components described above.

[0098] In this embodiment, (i) the conductor assembly 322 includes a plurality of first axis conductor units 324 (sometimes referred to as “X conductor units”), and a plurality of second axis conductor units 326 (sometimes referred to as “Y conductor units”); and (ii) the magnet assembly 320 includes a pair of spaced apart, first axis magnet arrays 328A, 328B (sometimes referred to as “a first X magnet array 328A and a second X magnet array 328B”), and a pair of spaced apart, second axis magnet arrays 330A, 330B (sometimes referred to as “a first Y magnet array 330A and a second Y magnet array 330B”).

[0099] Uniquely, in this embodiment, the first axis magnet arrays 328A, 328B have a different magnetic pitch than the second axis magnet arrays 330A, 330B. More specifically, in this embodiment, the X magnet arrays 328A, 328B have a larger magnetic pitch than the Y magnet arrays 330A, 330B. In this embodiment, the desired goal is to provide increased efficiency in the first axis (X direction), while accepting lower performance in the second axis (Y direction) as a tradeoff.

[00100] In Figure 3A, the conductor assembly 322 is again a checkerboard pattern with the X conductor units 324 arranged in an alternating fashion with the Y conductor units 326 along the X axis and along the Y axis. Stated in another fashion, the conductor assembly 322 is organized as a grid that includes eight columns (aligned with the Y axis) of conductor units 324, 326. Further, in each column, the X conductor units 324 are alternatively interspersed with the Y conductor units 326. Moreover, the conductor units 324, 326 are all in the same Z plane. With this design, the conductor assembly 322 is relatively easy to build and relatively easy to cool.

[00101] Uniquely, as provided herein, in certain embodiments, one or both of the first axis conductor units 328A, 328B are different from the second axis conductor units 340A, 340B. With the present invention, the characteristics (e.g. the physical characteristics) of the conductor arrays 328A, 328B, 340A, 340B can be independently adjusted to improve the efficiency of the stage mover 16 for movements along the first axis or along the second axis. In this embodiment, the characteristics of the conductor units can include, for example, size of the conductor unit, length of the conductor unit, and/or thickness of the conductor unit. In this embodiment, the problem of optimizing the first axis and the second axis performance of a magnet planar motor is solved by changing the magnetic pitch for the first axis and second axis magnet arrays 328A, 328B, 340A, 340B, and correspondingly changing the coil geometry of the first axis and second axis conductor units 324, 326. For example, the first axis magnet arrays 328A, 328B can have a first axis ("X") magnetic pitch that is greater (different) than a second axis ("Y") magnetic pitch of the second axis magnet arrays 330A, 330B. Further, the first axis conductor units 324 can be larger than the second axis conductor units 326, and the units 324, 326 can be staggered in each row of the conductor assembly 322. In this embodiment, for a three phase motor, each first axis conductor unit 324 can include three adjacent X conductors 340 that are aligned along the X axis, and each second axis conductor unit 326 can include three adjacent Y conductors 342 that are aligned along the Y axis. Moreover, in this embodiment, (i) each first axis conductor unit 324 is larger than each second axis conductor unit 326; (ii) each first axis conductor unit 324 is longer along the second axis (in the Y direction) than each second axis conductor unit 326 is along the first axis (in the X direction); and (iii) each X conductor 340 is larger along the second axis (in the Y direction) than each Y conductor 342 is along the first axis (in the X direction). Further, in this embodiment, a majority of the X conductors 340 are a first size and a majority of the Y conductors 342 are a second size, and the first size is larger than the second size.

[00102] In one embodiment, the magnetic pitch for the first axis and second axis magnet arrays 328A, 328B, 340A, 340B are sized to correspond to the sizes of the conductor units 324, 326. Stated in another fashion, in one embodiment, the first axis ("X") magnetic pitch is different than the second axis ("Y") magnetic pitch to correspond to the sizes of the conductor units 324, 326 to provide the optimal performance in both X and Y. The magnetic pitch can be adjusted by adjusting the width of the magnets and/or reducing the separation between adjacent magnets.

[00103] In alternative embodiments, the first axis ("X") magnetic pitch can be the same as the second axis ("Y") magnetic pitch, or the first axis ("X") magnetic pitch can be less than

the second axis ("Y") magnetic pitch. In the embodiment illustrated in Figure 3A, the X magnet active areas are approximately equal to the Y magnet active areas, although other configurations are possible.

[00104] In one embodiment, the Y magnet pitch of the Y magnet arrays 330A, 330B is reduced approximately to 2/3 of the nominal value, which correspondingly reduces the size of the Y conductors 342. In contrast, the X magnet pitch of the X magnet arrays 328A, 328B is unchanged, but the size of the X conductors 340 can be increased to improve the X efficiency.

[00105] In alternative, non-exclusive embodiments, the X magnetic pitch can be at least approximately 2, 5, 10, 20, 30, 40, 50, or 60 percent greater than the Y magnetic pitch. These changes allow changing the balance of X and Y efficiency to match a specific application.

[00106] Figure 3B is a bottom view of the stage 314 and the magnet assembly 320 including the first X magnet array 328A, the second X magnet array 328B, the first Y magnet array 330A, and the second Y magnet array 330B. In this embodiment, (i) the first X magnet active area 348A is approximately equal to the second X magnet active area 348B, the first Y magnet active area 350A, and the second Y magnet active area 350B. Stated in another fashion, in this embodiment, the magnet active areas 348A, 348B, 350A, 350B are equally sized. Alternatively, the sizes of the magnet active areas 348A, 348B, 350A, 350B can also be adjusted to be different.

[00107] However, in this embodiment, as provided above, the first axis magnet arrays 328A, 328B can have a first axis ("X") magnetic pitch 331 that is greater/larger than a second axis ("Y") magnetic pitch 333 of the second axis magnet arrays 330A, 330B. As provided herein, the magnetic pitch can be reduced by making the magnets less wide and/or reducing the separation between adjacent magnets.

[00108] As provided herein, for each X magnet array 328A, 328B, (i) each X magnet 344 has a X magnet width 360 (along the X axis), and (ii) adjacent X magnets 344 are spaced apart a X separation distance 362 (along the X axis). Similarly, for each Y magnet array 330A, 330B, (i) each Y magnet 346 has a Y magnet width 364 (along the Y axis), and (ii) adjacent Y magnets 346 are spaced apart a Y separation distance 366 (along the Y axis). Further, as provided herein, (i) the X magnet width 360 is larger than the Y magnet width 364; and (ii) the X separation distance 362 is larger than the Y separation distance 366. Further, in this embodiment, the length of X magnets 344 (along the Y axis) is substantially

equal to the length of the Y magnets 346 (along the X axis). Alternatively, length of some of the X magnets 344 can be different from the lengths of some of the Y magnets 346.

[00109] Moreover, in this embodiment, (i) each X magnet array 328A, 328B includes six X magnets 344 that extend along the Y axis and that are spaced apart along the X axis; and (ii) each Y magnet array 330A, 330B includes eight Y magnets 346 that extend along the X axis and that are spaced apart along the Y axis. Alternatively, (i) each X magnet array 328A, 328B can be designed to include more than six or fewer than six X magnets 344; and (ii) each Y magnet array 330A, 330B can be designed to include more than eight or fewer than eight Y magnets 346.

[00110] Further, in this embodiment, the X magnets 344 in each X magnet array 328A, 328B are arranged so that X magnets 344 alternate with the North pole and the South pole facing the conductor array as you move along the X axis. Similarly, the Y magnets 346 in each Y magnet array 330A, 330B are arranged so that Y magnets 346 alternate with the North pole and the South pole facing the conductor array as you move along the Y axis.

[00111] In alternative embodiments, the first axis ("X") magnetic pitch can be the same as the second axis ("Y") magnetic pitch, or the first axis ("X") magnetic pitch can be less than the second axis ("Y") magnetic pitch.

[00112] In the embodiment illustrated in Figure 3B, the X magnet active areas are approximately equal to the Y magnet active areas, although other configurations are possible.

[00113] Referring back to Figure 3A, in one embodiment, the conductor assembly 322 is designed so that in one direction (e.g. along X axis this example), all of the conductor units 324, 326 are $1/(2*n)$ the width of each magnet array 328A, 328B, 330A, 330B, where n is an integer. In Figure 3A, each of the conductor units 324, 326 is half the width of each magnet array 328A, 328B, 330A, 330B along the X axis. Further, in the orthogonal direction (e.g. along the Y axis in this example), the size of each magnet array 328A, 328B, 330A, 330B is equal or approximately equal to an integer multiple of the sum of one X conductor unit 324 and one Y conductor unit 326 along the Y axis. In Figure 3A, each magnet array 328A, 328B, 330A, 330B has a length along the Y axis that is the same size as the combined size of one X conductor unit 324 and one Y conductor unit 326 along the Y axis. In this example, the sum of one X conductor unit 324 and one Y conductor unit 326 along the Y axis is designated here as b . Further, in the embodiment illustrated in Figure 3A, each X conductor unit 324 has a length along the Y axis that is approximately twice the length of each Y conductor unit 326 along the Y axis.

[00114] In one embodiment, each adjacent column of the conductor units is staggered by an amount $b/(n+1)$, which ensures that the i and $i+n+1$ columns are aligned (in the Y direction in this example) with each other.

[00115] With these constraints, each magnet array 328A, 328B, 330A, 330B always overlaps a constant number of X conductor units 324 and Y conductor units 326. Therefore the planar motor can produce controlled X, Y, and Z forces with minimal force ripple.

[00116] Figure 4A is a top view of another embodiment of a stage assembly 410 that includes (i) a base 412, a stage 414, and a control system 418 that are similar to the corresponding components described above and illustrated in Figure 1A; and (ii) a stage mover 416 that slightly different from the stage mover 16 described above. In this embodiment, the stage mover 416 again is a planar motor that precisely moves the stage 414 relative to the base 412 with six degrees of freedom. However, in this embodiment, the stage mover 416 has substantially symmetrical performance along the X axis and along the Y axis. Further, the stage mover 416 includes a conductor assembly 422 that is similar to the conductor assembly 22 described above, and a magnet assembly 420 (illustrated in phantom) that is slightly different from the magnet assembly 20 described above.

[00117] In this embodiment, (i) the conductor assembly 422 includes a plurality of first axis conductor units 424, and a plurality of second axis conductor units 426; and (ii) the magnet assembly 420 includes a pair of spaced apart, first axis magnet arrays 428A, 428B, and a pair of spaced apart, second axis magnet arrays 430A, 430B.

[00118] As is known, the electrical current supplied to the conductor assembly 422 also generates heat, due to resistance in the conductor assembly 422. In Figure 4A, the X conductor units 424 are again arranged in an alternating fashion with the Y conductor units 426 along the first axis and along the second axis. With this design, the conductor assembly 422 is relatively easy to build and relatively easy to cool. As provided herein, the problem of providing a convenient and easy-to-build conductor assembly 422 for a planar motor 416 is solved by arranging X conductor units 424 and the Y conductor units 426 in a checkerboard pattern.

[00119] In Figure 4A, the magnet assembly 420 is secured to and moves with the stage 414, and the conductor assembly 422 is secured to the base 412.

[00120] Figure 4B is a top view of the conductor assembly 422 and an outline of the magnet assembly 420 (illustrated with dashed lines) of Figure 4A. In this embodiment, the conductor assembly 422 is a checkerboard pattern with the X conductor units 424 arranged

in an alternating fashion with the Y conductor units 426 along the X axis and along the Y axis. Stated in another fashion, the conductor assembly 422 illustrated in Figure 4B is organized as a square grid that includes eight rows (aligned with the X axis) of conductor units 424, 426 and eight columns (aligned with the Y axis) of conductor units 424, 426. Further, (i) in each row, the X conductor units 424 are alternatively interspersed with the Y conductor units 426; and (ii) in each column, the X conductor units 424 are alternatively interspersed with the Y conductor units 426. Moreover, the conductor units 424, 426 are all in substantially the same Z plane. With this design, the conductor assembly 422 is relatively easy to build and relatively easy to cool.

[00121] Figure 4B also illustrates the conductor units 424, 426 used to move the stage (not shown) at the current position of the magnet assembly 420. At this position, (i) the X conductor units 424 labeled with X1 interact with the first X magnet array 428A, (ii) the X conductor units 424 labeled with X2 interact with the second X magnet array 428B, (iii) the Y conductor units 426 labeled with Y1 interact with the first Y magnet array 430A, and (iv) the Y conductor units 426 labeled with Y2 interact with the second Y magnet array 430B. It should be noted that the conductor units 424, 426 are similar to the corresponding components described above and illustrated in Figure 1F.

[00122] For a three phase motor, in Figure 4A, (i) each X conductor unit 424 includes three, adjacent, X conductors 440 that are aligned side by side along the X axis; and (ii) each Y conductor unit 426 includes three, adjacent, Y conductors 442 that are aligned side by side along the Y axis. Further, as provided herein, this type of conductor assembly 422 is relatively easy to build and cool. This type of conductor assembly 422 can be made in a modular fashion with regular shaped conductor units 424, 426 for ease of manufacturing. Depending on the power requirements of the stage assembly 410, and the capabilities of the drive electronics (power amplifiers), each of the X conductors 440 and Y conductors 442 can consist of multiple coils connected together or driven independently. For example, each X conductor 440 and each Y conductor 442 can consist of two coils stacked on top of each other with respect to the Z axis.

[00123] Figure 4C is an exploded perspective view that illustrates one, non-exclusive example of how one of the conductor units, e.g. the second axis conductor unit 426 can be modified to allow for cooling. Also, Figure 4C illustrates a temperature controller 470 that can be used to control the temperature of the second axis conductor unit 426. In Figure 4C, to reduce the influence of the heat from the conductor assembly 422 (illustrated in Figure 4A), the temperature controller 470 actively controls (i.e. cool) the temperature of the

conductor assembly 422 to reduce the influence of the heat from the conductor assembly 422 from adversely influencing the other components of the stage assembly 10 and the surrounding environment.

[00124] It should be noted that each first axis conductor unit (not shown in Figure 4C) can be cooled in a similar fashion to the second axis conductor unit 426 illustrated in Figure 4C. Alternatively, each conductor unit can be cooled in a fashion different from that illustrated in Figure 4C.

[00125] In Figure 4C, the second axis conductor unit 426 includes (i) the three, adjacent, Y conductors 442 that are aligned side by side along the Y axis; (ii) a lower unit housing 472 (e.g. a cooling plate) positioned below and adjacent to the Y conductors 442 along the Z axis; (iii) an upper unit housing 474 (e.g. a cooling plate) positioned above and adjacent to the Y conductors 442 along the Z axis; and (iv) a surface housing 476 (e.g. a cooling plate) positioned above and adjacent to the upper housing 474 along the Z axis. In this embodiment, each housing 472, 474, 476 can include a plurality of micro-channels. Further, the surface housing 476 is the exposed surface of the second axis conductor unit 426 that faces the magnet assembly 420 (illustrated in Figure 4A). With the unique checkerboard pattern of the conductor array 422, it is easier to direct the cooling fluid around each conductor unit 424, 426.

[00126] The design of the temperature controller 470 can vary. In one embodiment, the temperature controller 470 includes (i) a first circulation system 478A that directs a first circulation fluid 478B (illustrated as small circles) through the lower housing 472 and the upper housing 474; and (ii) a second circulation system 479A that directs a second circulation fluid 479B (illustrated as small circles) through the surface housing 476.

[00127] With this design, the flow rate and/or temperature of the first circulation fluid 478B can optionally be adjusted (as needed based on the power consumption) to remove the bulk of the heat from each conductor unit. Further, the second circulation fluid 479B can be used to maintain the surface temperature of each conductor unit at the desired temperature to inhibit the transfer of heat from each conductor unit. In alternative embodiments, the surface housing 476 can be a simple plate of a preferably low thermal conductivity material that provides thermal insulation without the use of a second circulation fluid 479B.

[00128] The design of each circulation system 478A, 479A can vary. For example, each circulation system 478A, 479A can include (i) a reservoir, (ii) a fluid pump, and (iii) a chiller/heat exchanger.

[00129] Figure 4D is a bottom view of the stage 414 and the magnet assembly 420 including the first X magnet array 428A, the second X magnet array 428B, the first Y magnet array 430A, and the second Y magnet array 430B that are somewhat similar to the corresponding components described above and illustrated in Figures 1C and 3B. However, in the embodiment illustrated in Figure 4D, the first X magnet active area 448A is approximately equal to the second X magnet active area 448B, the first Y magnet active area 450A, and the second Y magnet active area 450B. Stated in another fashion, in this embodiment, the magnet active areas 448A, 448B, 450A, 450B are equally sized. Further, in Figure 4D, the first axis ("X") magnetic pitch of the first axis magnet arrays 428A, 428B is approximately equal to the second axis ("Y") magnetic pitch of the second axis magnet arrays 430A, 430B.

[00130] In this embodiment, (i) each X magnet array 428A, 428B includes six X magnets 444 that extend along the Y axis and are spaced apart along the X axis; and (ii) each Y magnet array 430A, 430B includes six Y magnets 446 that extend along the X axis and are spaced apart along the Y axis. Alternatively, (i) each X magnet array 428A, 428B can be designed to include more than six or fewer than six X magnets 444; and (ii) each Y magnet array 430A, 430B can be designed to include more than six or fewer than six Y magnets 446.

[00131] Figure 5A is a top view of another embodiment of a stage assembly 510A that is similar to the stage assembly 410 described above and illustrated in Figure 4A. However, in this embodiment, the stage assembly 510A includes two similarly sized stages 514A that are independently moved relative to the base 512A. It should be noted that any of the different magnet assemblies and conductor assemblies disclosed herein can be used with the dual stage 514A arrangement.

[00132] Figure 5A is a top view of another embodiment of a stage assembly 510A that is similar to the stage assembly 410 described above and illustrated in Figure 4A. However, in this embodiment, the stage assembly 510A includes two similarly sized stages 514A that are independently moved relative to the base 512A. It should be noted that any of the different magnet assemblies and conductor assemblies disclosed herein can be used with the dual stage 514A arrangement. For example, this stage assembly 510A can be used to independently position two wafers.

[00133] Figure 5B is a top view of another embodiment of a stage assembly 510B that is similar to the stage assembly 510B described above and illustrated in Figure 5A. However, in this embodiment, the stage assembly 510B includes two, different sized stages

514B that are independently moved relative to the base 512B. It should be noted that any of the different magnet assemblies and conductor assemblies disclosed herein can be used with the dual stage 514B arrangement. For example, this stage assembly 510B can be used to independently position a wafer and a measurement stage.

[00134] Figure 6A is an exploded perspective view of another embodiment of a conductor unit 626A and a temperature controller 670A that are similar to the corresponding components described above and illustrated in Figure 4C. These components can be used in any of the assemblies disclosed herein. Further, in this embodiment, the conductor unit 626A again includes three, adjacent, Y conductors 642A that are aligned side by side along the Y axis. However, in this embodiment, each of the Y conductors 642A is split into two separate coils 643A that are stacked vertically along the Z axis. With this design, the control system (not shown in Figure 6A) can independently direct to each of the coils 643A.

[00135] Figure 6B is an exploded perspective view of yet another embodiment of a conductor unit 626B and a temperature controller 670B that are similar to the corresponding components described above and illustrated in Figure 6A. These components can be used in any of the assemblies disclosed herein. Further, in this embodiment, the conductor unit 626B again includes three, adjacent, Y conductors 642B that are aligned side by side along the Y axis. Further, in this embodiment, each of the Y conductors 642B is split into two separate coils 643B. However, in Figure 6B, the coils 643B are spaced apart vertically along the Z axis. The control system (not shown in Figure 6B) again can independently direct to each of the coils 643B.

[00136] Additionally, in this embodiment, conductor unit 626B also includes an intermediate unit housing 673 (e.g. a cooling plate) that is positioned between the spaced apart coils 643B. The intermediate unit housing 673 can include plurality of micro-channels. Further, in this embodiment, the first circulation system 678A can also direct the first circulation fluid 678B (illustrated as small circles) through the intermediate unit housing 673 to remove the bulk of the heat from each conductor unit 626B.

[00137] Figure 6C is a perspective view of another embodiment of one X conductor unit 624, and one Y conductor unit 626 that are somewhat similar to the corresponding components described above and illustrated in Figure 1F. However, in this embodiment, (i) the X conductors 640 are thicker along the Z axis than the Y conductors 642, and (ii) each first axis conductor unit 624 is thicker (along the Z axis) than each second axis conductor unit 626. Further, the X conductors 640 can be the same length as the Y conductors 642 or the X conductors 640 can be longer than the Y conductors 642 (see Figure 3A).

[00138] With the design illustrated in Figure 6C, the stage mover will have better performance for movements along the X axis than the Y axis. It should be noted that the X conductors 640 and/or the Y conductors 642 can be split similar to the designs illustrated in Figures 6A and 6B.

[00139] Alternatively, (i) the X conductors can be thinner along the Z axis than the Y conductors, and (ii) each first axis conductor unit is thinner (along the Z axis) than each second axis conductor unit. With this design, the stage mover will have better performance for movements along the Y axis than the X axis.

[00140] Figure 7 is a schematic view illustrating an exposure apparatus 734 useful with the present invention. The exposure apparatus 734 includes the apparatus frame 780, an illumination system 782 (irradiation apparatus), a reticle stage assembly 784, an optical assembly 786 (lens assembly), and a wafer stage assembly 710. The stage assemblies provided herein can be used as the wafer stage assembly 710. Alternately, with the disclosure provided herein, the stage assemblies provided herein can be modified for use as the reticle stage assembly 784.

[00141] The exposure apparatus 734 is particularly useful as a lithographic device that transfers a pattern (not shown) of an integrated circuit from the reticle 788 onto the semiconductor wafer 790. The exposure apparatus 734 mounts to the mounting base 719, e.g., the ground, a base, or floor or some other supporting structure.

[00142] The apparatus frame 780 is rigid and supports the components of the exposure apparatus 734. The design of the apparatus frame 780 can be varied to suit the design requirements for the rest of the exposure apparatus 734.

[00143] The illumination system 782 includes an illumination source 792 and an illumination optical assembly 794. The illumination source 792 emits a beam (irradiation) of light energy. The illumination optical assembly 794 guides the beam of light energy from the illumination source 792 to the optical assembly 786. The beam illuminates selectively different portions of the reticle 788 and exposes the semiconductor wafer 790. In Figure 7, the illumination source 792 is illustrated as being supported above the reticle stage assembly 784. Alternatively, the illumination source 792 can be secured to one of the sides of the apparatus frame 780 and the energy beam from the illumination source 792 is directed to above the reticle stage assembly 784 with the illumination optical assembly 794.

[00144] The optical assembly 786 projects and/or focuses the light passing through the reticle to the wafer. Depending upon the design of the exposure apparatus 734, the optical assembly 786 can magnify or reduce the image illuminated on the reticle.

[00145] The reticle stage assembly 784 holds and positions the reticle 788 relative to the optical assembly 786 and the wafer 790. Similarly, the wafer stage assembly 710 holds and positions the wafer 790 with respect to the projected image of the illuminated portions of the reticle 788.

[00146] There are a number of different types of lithographic devices. For example, the exposure apparatus 734 can be used as scanning type photolithography system that exposes the pattern from the reticle 788 onto the wafer 790 with the reticle 788 and the wafer 790 moving synchronously. Alternatively, the exposure apparatus 734 can be a step-and-repeat type photolithography system that exposes the reticle 788 while the reticle 788 and the wafer 790 are stationary.

[00147] However, the use of the exposure apparatus 734 and the stage assemblies provided herein are not limited to a photolithography system for semiconductor manufacturing. The exposure apparatus 734, for example, can be used as an LCD photolithography system that exposes a liquid crystal display device pattern onto a rectangular glass plate or a photolithography system for manufacturing a thin film magnetic head. Further, the present invention can also be applied to a proximity photolithography system that exposes a mask pattern by closely locating a mask and a substrate without the use of a lens assembly. Additionally, the present invention provided herein can be used in other devices, including other semiconductor processing equipment, elevators, machine tools, metal cutting machines, inspection machines and disk drives.

[00148] As described above, a photolithography system according to the above described embodiments can be built by assembling various subsystems, including each element listed in the appended claims, in such a manner that prescribed mechanical accuracy, electrical accuracy, and optical accuracy are maintained. In order to maintain the various accuracies, prior to and following assembly, every optical system is adjusted to achieve its optical accuracy. Similarly, every mechanical system and every electrical system are adjusted to achieve their respective mechanical and electrical accuracies. The process of assembling each subsystem into a photolithography system includes mechanical interfaces, electrical circuit wiring connections and air pressure plumbing connections between each subsystem. Needless to say, there is also a process where each subsystem is assembled prior to assembling a photolithography system from the various subsystems.

Once a photolithography system is assembled using the various subsystems, a total adjustment is performed to make sure that accuracy is maintained in the complete photolithography system. Additionally, it is desirable to manufacture an exposure system in a clean room where the temperature and cleanliness are controlled.

[00149] Further, semiconductor devices can be fabricated using the above described systems, by the process shown generally in Figure 8A. In step 801 the device's function and performance characteristics are designed. Next, in step 802, a mask (reticle) having a pattern is designed according to the previous designing step, and in a parallel step 803 a wafer is made from a silicon material. The mask pattern designed in step 802 is exposed onto the wafer from step 803 in step 804 by a photolithography system described hereinabove in accordance with the present invention. In step 805 the semiconductor device is assembled (including the dicing process, bonding process and packaging process), finally, the device is then inspected in step 806.

[00150] Figure 8B illustrates a detailed flowchart example of the above-mentioned step 804 in the case of fabricating semiconductor devices. In Figure 8B, in step 811 (oxidation step), the wafer surface is oxidized. In step 812 (CVD step), an insulation film is formed on the wafer surface. In step 813 (electrode formation step), electrodes are formed on the wafer by vapor deposition. In step 814 (ion implantation step), ions are implanted in the wafer. The above mentioned steps 811 - 814 form the preprocessing steps for wafers during wafer processing, and selection is made at each step according to processing requirements.

[00151] At each stage of wafer processing, when the above-mentioned preprocessing steps have been completed, the following post-processing steps are implemented. During post-processing, first, in step 815 (photoresist formation step), photoresist is applied to a wafer. Next, in step 816 (exposure step), the above-mentioned exposure device is used to transfer the circuit pattern of a mask (reticle) to a wafer. Then in step 817 (developing step), the exposed wafer is developed, and in step 818 (etching step), parts other than residual photoresist (exposed material surface) are removed by etching. In step 819 (photoresist removal step), unnecessary photoresist remaining after etching is removed.

[00152] Multiple circuit patterns are formed by repetition of these preprocessing and post-processing steps.

[00153] While the particular stage assembly as shown and disclosed herein is fully capable of obtaining the objects and providing the advantages herein before stated, it is to be understood that it is merely illustrative of the presently preferred embodiments of the

invention and that no limitations are intended to the details of construction or design herein shown other than as described in the appended claims.

What is claimed is:

1. A stage assembly that moves a device along a first axis and along a second axis that crosses the first axis, the stage assembly comprising:
 - a stage that is adapted to retain the device;
 - a base; and
 - a stage mover that moves the stage along the first axis and along the second axis relative to the base, the stage mover including a magnet assembly, and a conductor assembly; wherein one of the assemblies is coupled to the stage, and the other of the assemblies is coupled to the base; wherein the conductor assembly includes a plurality of first axis conductor units and a plurality of second axis conductor units; wherein current directed to one or more of the first axis conductor units causes a first axis force to be imparted on the stage; wherein current directed to one or more of the second axis conductor units causes a second axis force to be imparted on the stage; wherein the magnet assembly includes a first axis magnet array and a second axis magnet array; and wherein a characteristic of the first axis magnet array is different from a characteristic of the second axis magnet array.
2. The stage assembly of claim 1 wherein the first axis magnet array is larger than the second axis magnet array.
3. The stage assembly of claim 1 wherein at least a portion of the first axis magnet array is thicker than at least a portion of the second axis magnet array.
4. The stage assembly of claim 1 wherein the first axis magnet array has a first magnet active area and the second axis magnet array has a second magnet active area, and wherein the first magnet active area is different than the second magnet active area.
5. The stage assembly of claim 4 wherein the first axis magnet array has a first magnetic pitch that is greater than a second magnetic pitch of the second axis magnet array.

6. The stage assembly of claim 1 wherein the first axis magnet array includes a plurality of first axis magnets, and the second axis magnet array includes a plurality of second axis magnets; and wherein the number of first axis magnets is greater than the number of second axis magnets.

7. The stage assembly of claim 1 wherein the first axis magnet array includes a plurality of first axis magnets, and the second axis magnet array includes a plurality of second axis magnets; and wherein the first axis magnet array has a first magnetic pitch that is greater than a second magnetic pitch of the second axis magnet array.

8. The stage assembly of claim 1 wherein each first axis conductor unit includes a plurality of first axis conductors that form a three phase motor with the first axis magnet array; and wherein each second axis conductor unit includes a plurality of second axis conductors that form a three phase motor with the second axis magnet array.

9. The stage assembly of claim 1 wherein the first axis conductor units are arranged in an alternating fashion with the second axis conductor units along the first axis and along the second axis.

10. The stage assembly of claim 9 wherein each first axis conductor unit includes three adjacent first axis conductors that are aligned along the first axis, and wherein each second axis conductor unit includes three adjacent second axis conductors that are aligned along the second axis.

11. The stage assembly of claim 1 wherein the stage mover moves the stage about a third axis relative to the stage base, the third axis being orthogonal to the first axis and the second axis.

12. The stage assembly of claim 11 wherein the stage mover moves the stage about the first axis, about the second axis, and along the third axis.

13. The stage assembly of claim 1 wherein the base includes a counter mass that is moved by reactions from the first axis force and the second axis force; wherein the conductor assembly is coupled to the counter mass and the magnet assembly is coupled to the stage.

14. The stage assembly of claim 1 wherein each conductor unit includes at least one unit housing that contains a first circulation fluid which removes heat from the conductor unit.

15. The stage assembly of claim 14 wherein each conductor unit further includes a surface housing that contains a second circulation fluid which improves the temperature uniformity of a surface of the conductor unit.

16. An exposure apparatus comprising an illumination system and the stage assembly of claim 1.

17. A method for moving a device along a first axis and along a second axis, the method comprising the steps of:

retaining the device with a stage;

providing a base;

providing a stage mover that includes a magnet assembly, and a conductor assembly; wherein one of the assemblies is coupled to the stage, and the other of the assemblies is coupled to the base; wherein the conductor assembly includes a plurality of first axis conductor units and a plurality of second axis conductor units; wherein the magnet assembly includes a first axis magnet array and a second magnet array, and wherein a characteristic of the first magnet array is different from a characteristic of the second axis magnet array; and

directing current with a control system (i) to one or more of the first axis conductor units to generate a first axis force on the stage, and (ii) to one or more of the second axis conductor units to generate a second axis force on the stage.

18. The stage assembly of claim 17 wherein the step of providing a stage mover includes the first axis magnet array being larger than the second axis magnet array.

19. The method of claim 17 wherein the step of providing a stage mover includes the first axis magnet array having a plurality of first axis magnets, and the second axis magnet array having a plurality of second axis magnets; and wherein the number of first axis magnets is greater than the number of second axis magnets.

20. The method of claim 19 wherein the step of providing a stage mover includes the first axis magnet array having a first magnetic pitch that is greater than a second magnetic pitch of the second axis magnet array.

21. The method of claim 17 wherein the step of providing a stage mover includes the first axis magnet array having a plurality of first axis magnets, and the second axis magnet array having a plurality of second axis magnets; and wherein the first axis magnet array has a first magnetic pitch that is greater than a second magnetic pitch of the second axis magnet array.

22. The method of claim 17 wherein the step of providing a stage mover includes the first axis magnet array having a first magnet active area and the second axis magnet array having a second magnet active area, and wherein the first magnet active area is greater than the second magnet active area.

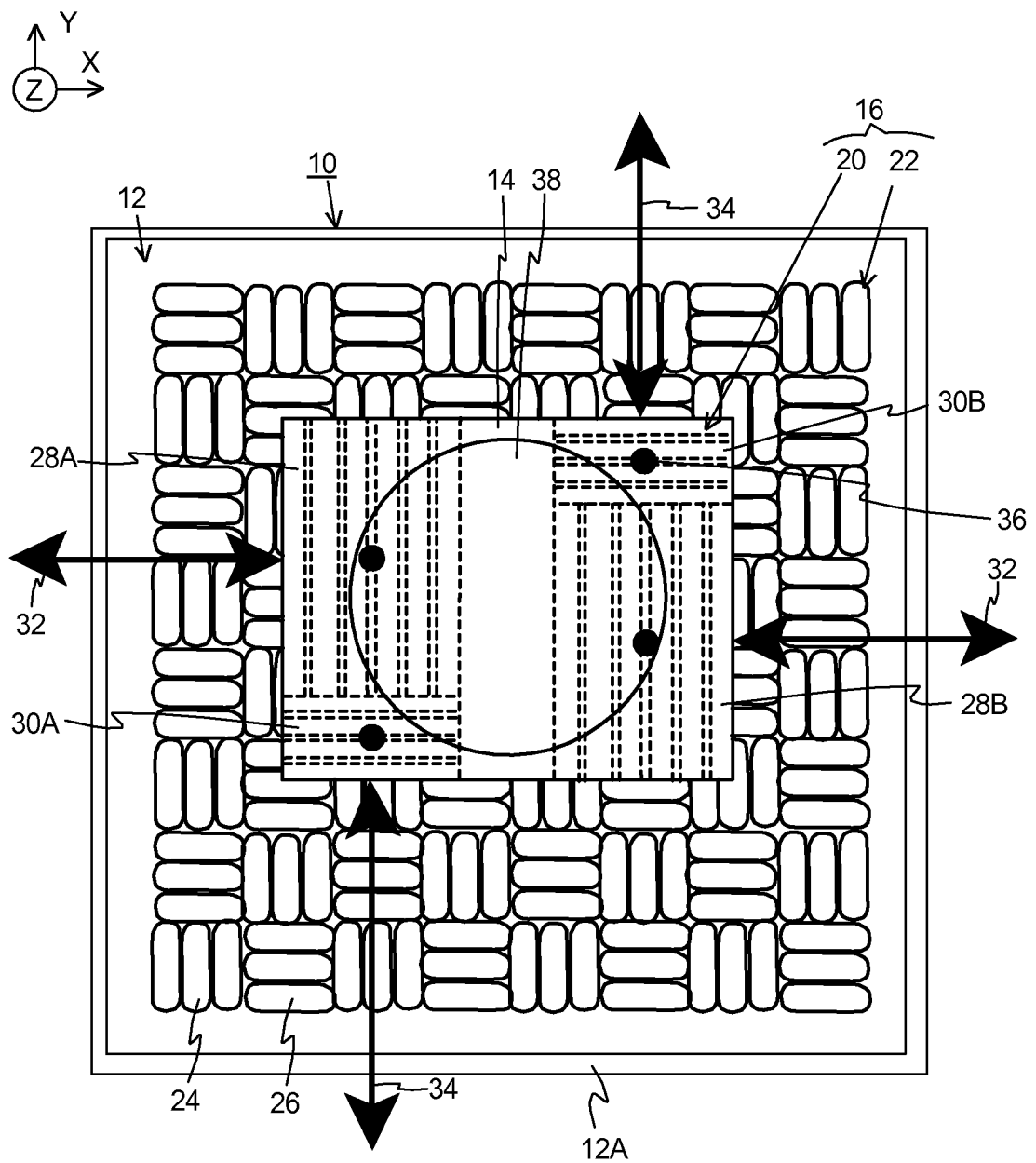
23. The method of claim 17 wherein the step of providing a stage mover includes at least a portion of the first axis magnet array being thicker than at least a portion of the second axis magnet array.

24. The method of claim 17 wherein the step of providing a stage mover includes each first axis conductor unit including first axis conductors that form a 3-phase motor with the first axis magnet array; and each second axis conductor unit including second axis conductors that form a 3-phase motor with the second axis magnet array.

25. The method of claim 17 within the step of providing a stage mover includes arranging the first axis conductor units in an alternating fashion with the second axis conductor units along the first axis and along the second axis.

26. The method of claim 17 wherein the step of providing a base includes the step of providing a counter mass that is moved by reactions from the first axis force and the second axis force; wherein the conductor assembly is coupled to the counter mass and the magnet assembly is coupled to the stage.

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Figure 1A

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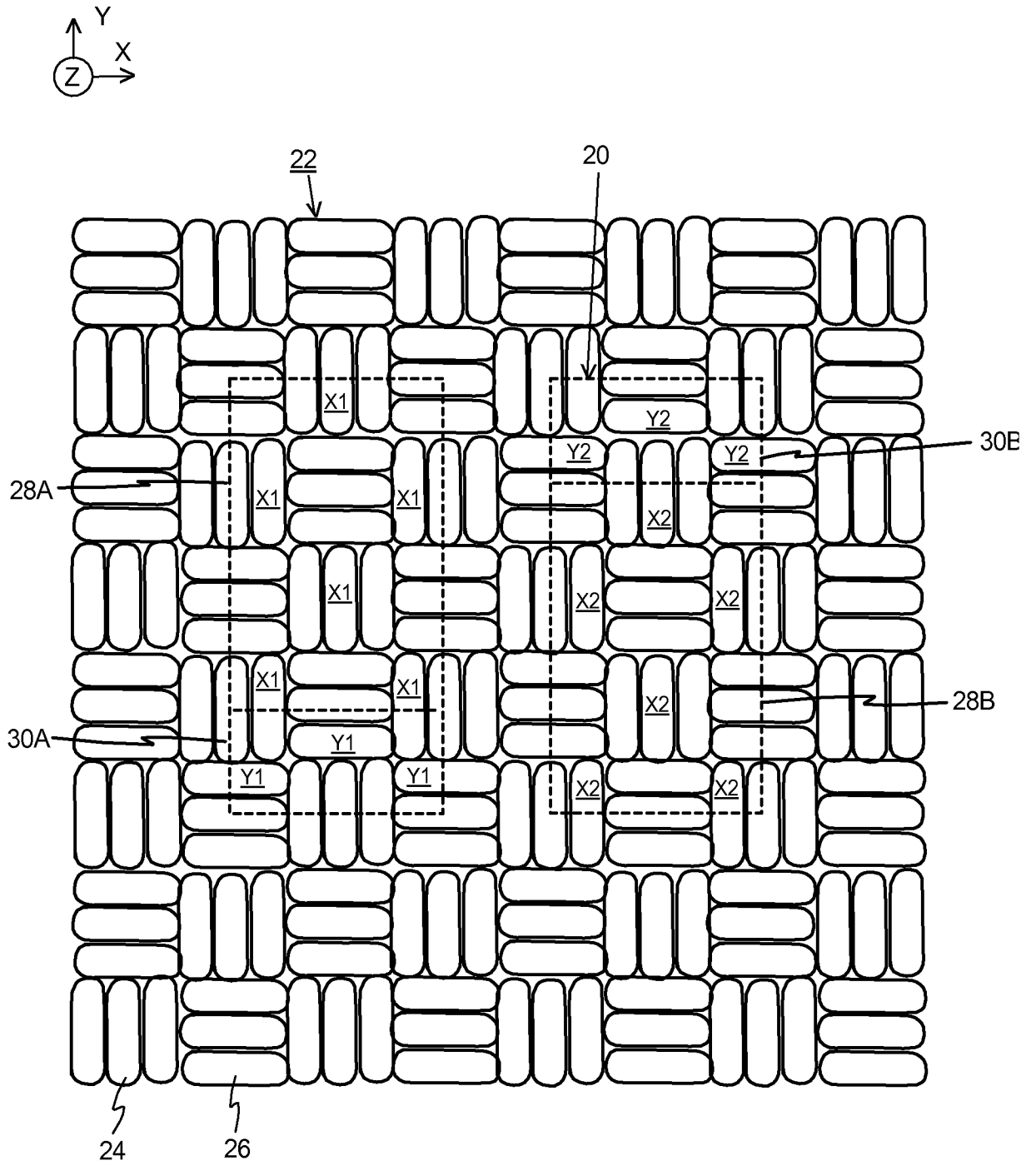


Figure 1B

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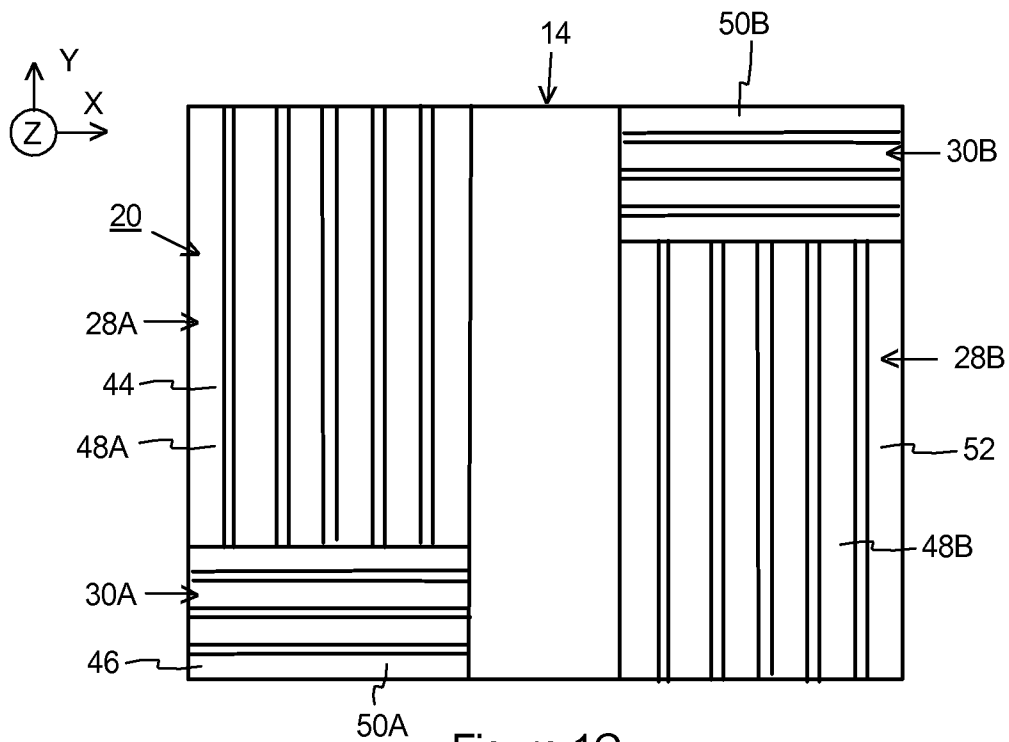


Figure 1C

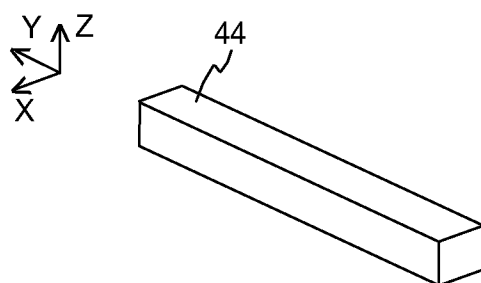


Figure 1D

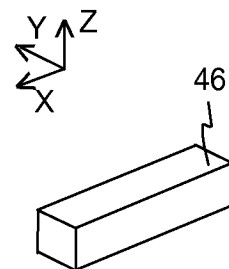


Figure 1E

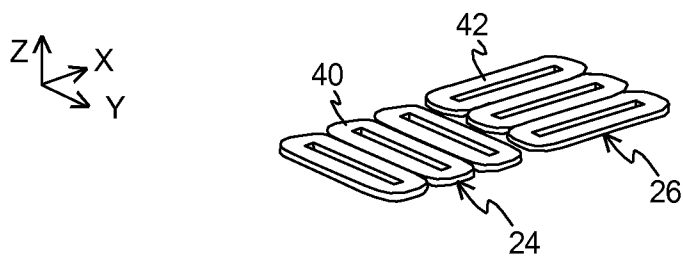
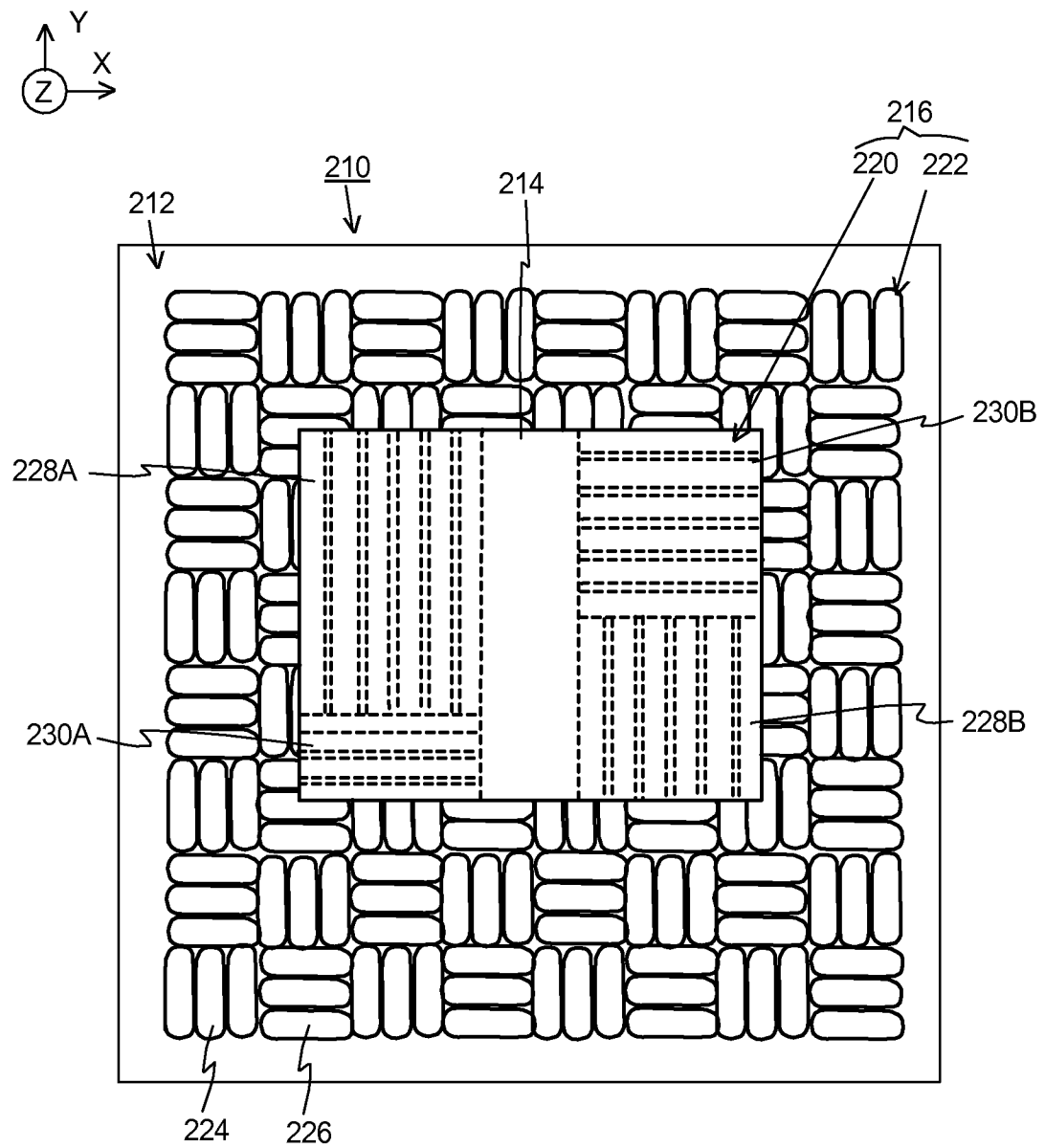


Figure 1F

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Figure 2A

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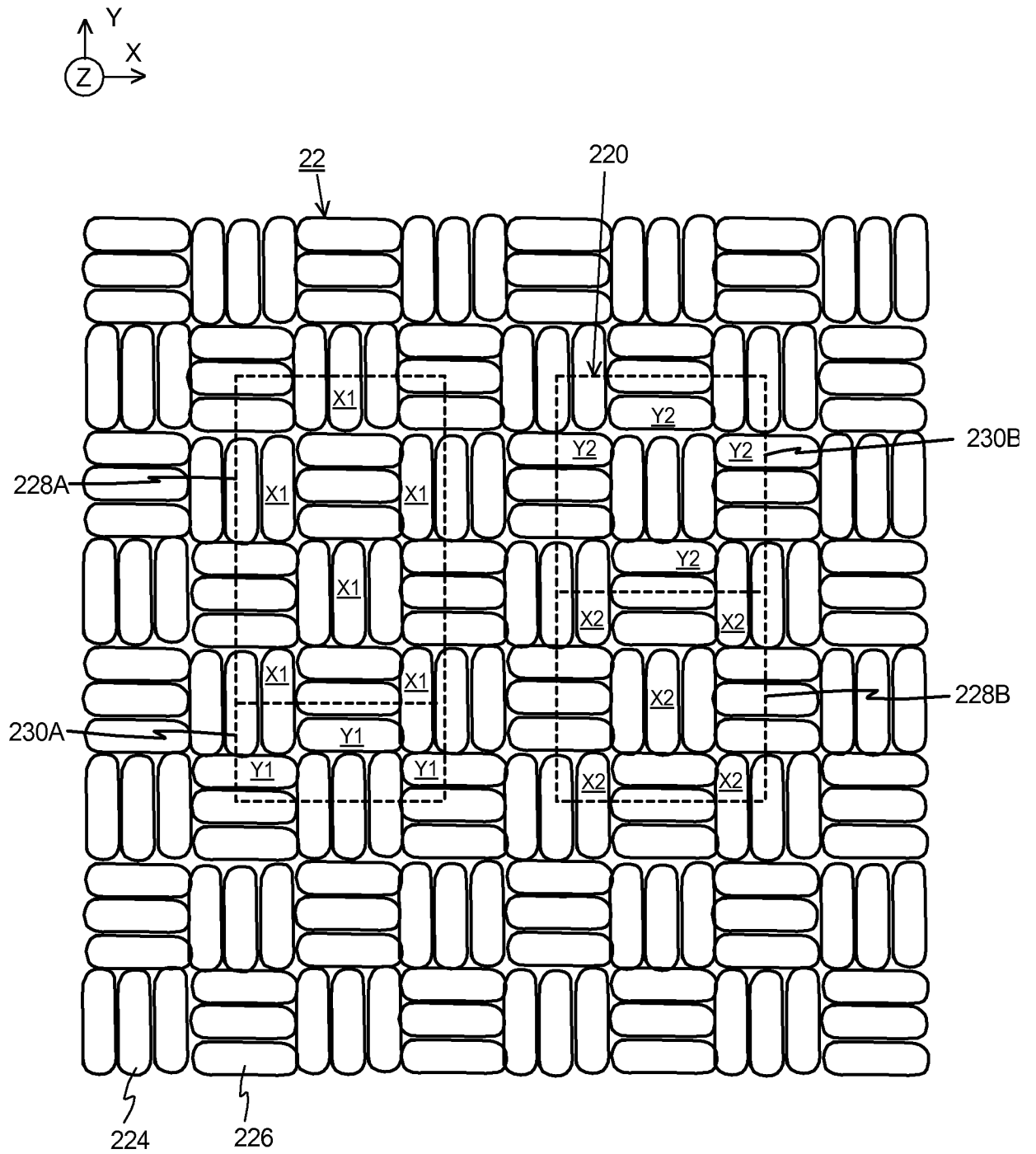


Figure 2B

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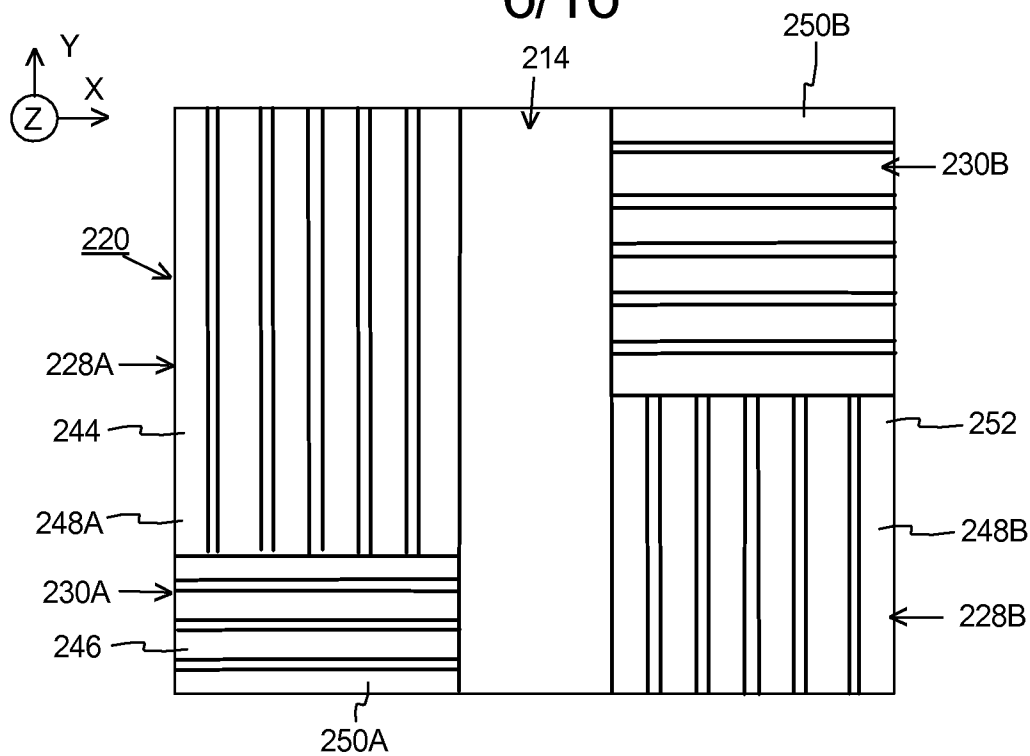


Figure 2C

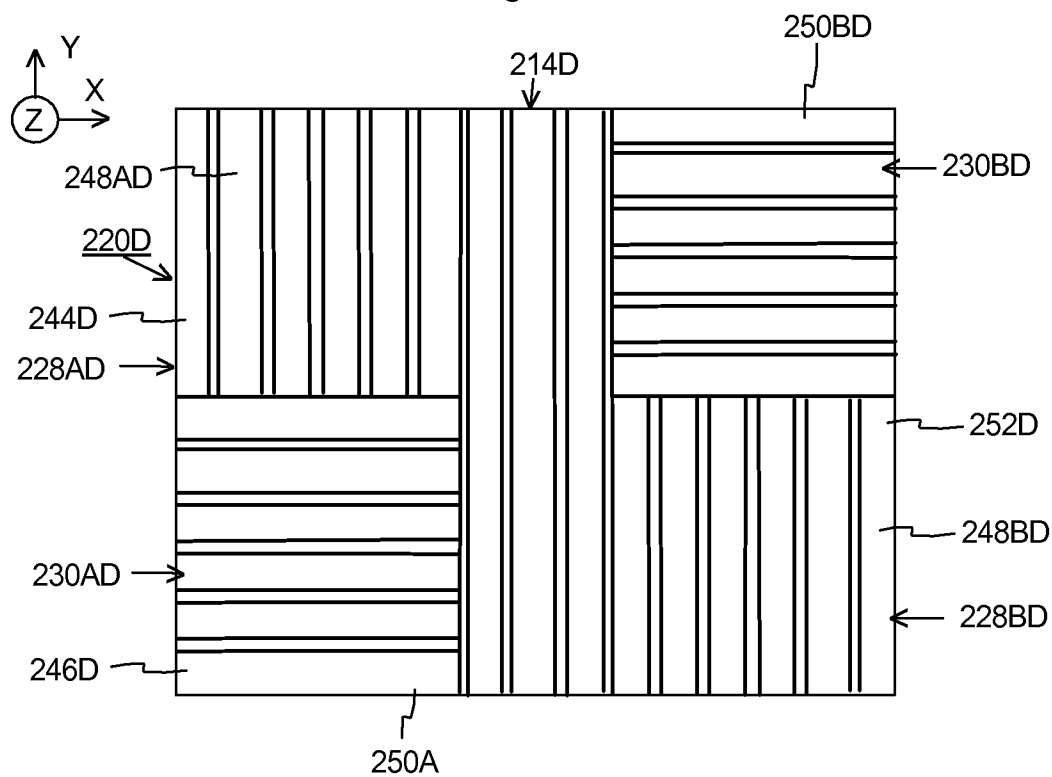


Figure 2D

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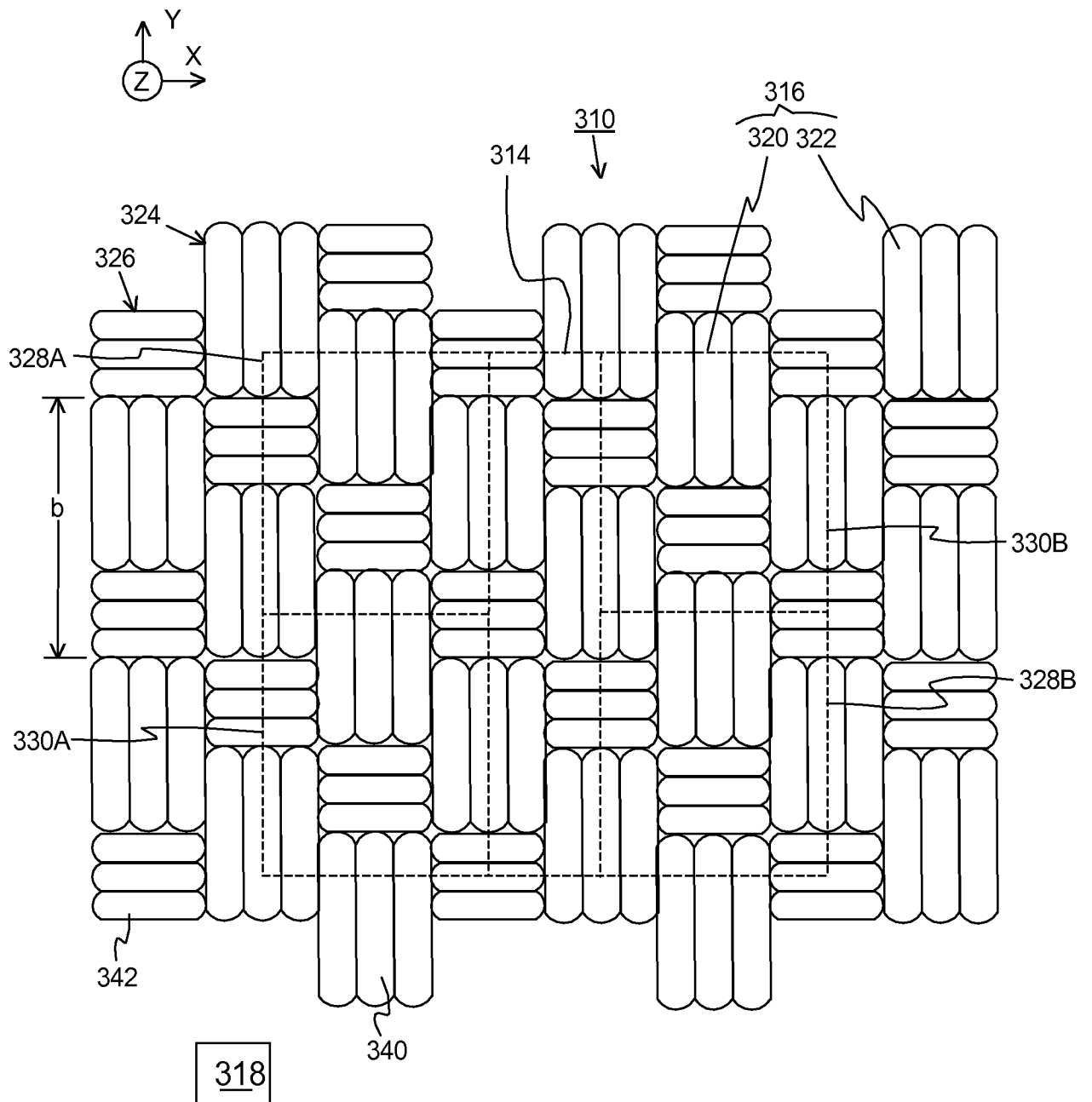


Figure 3A

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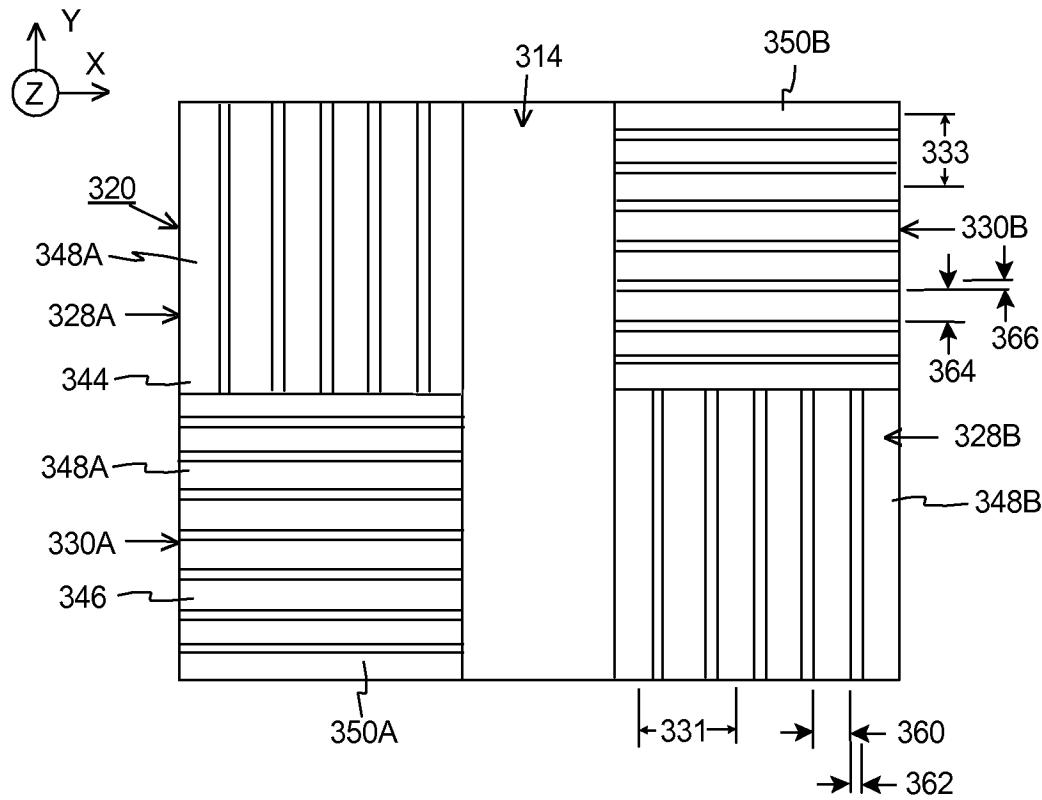
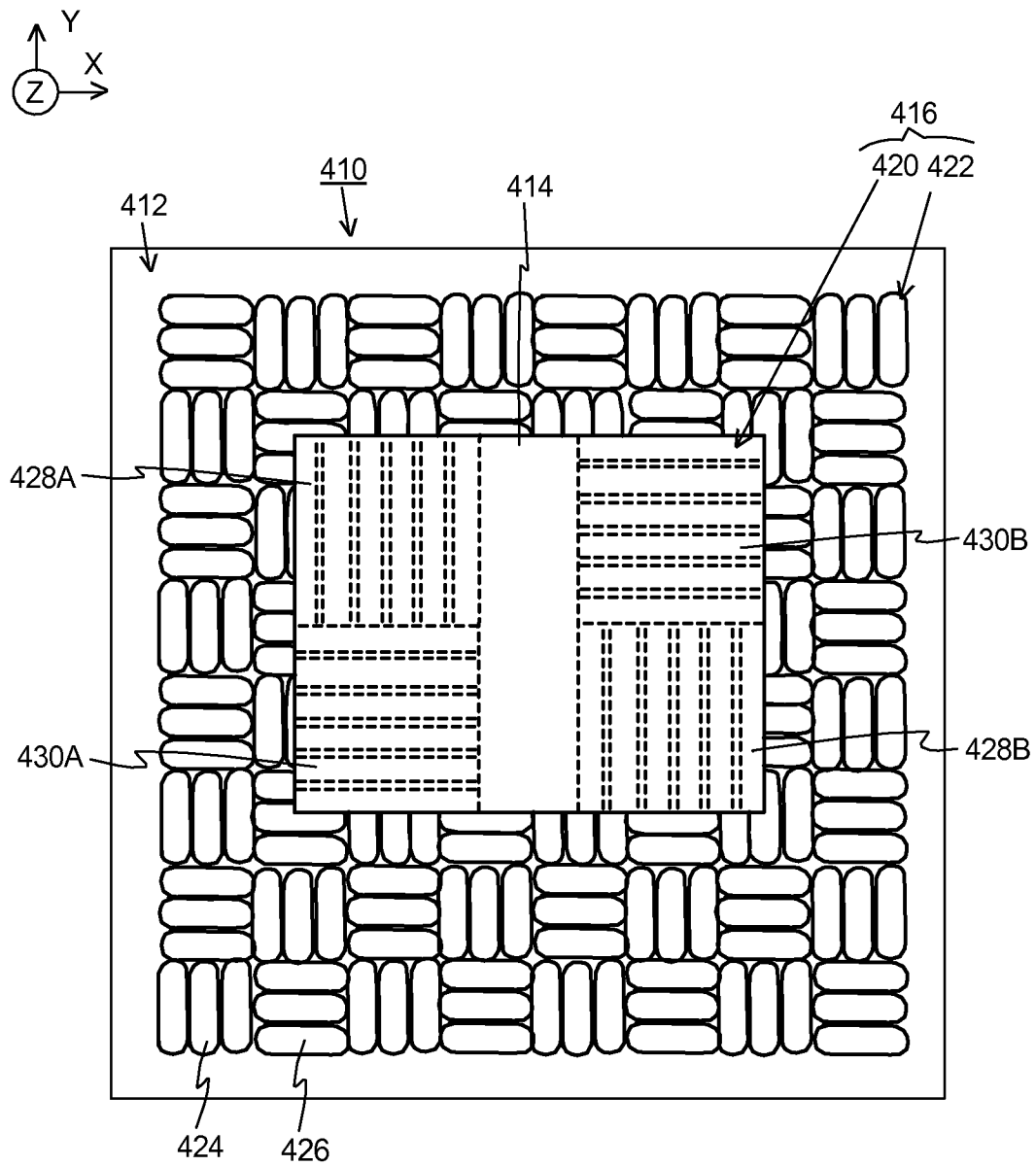


Figure 3B

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Figure 4A

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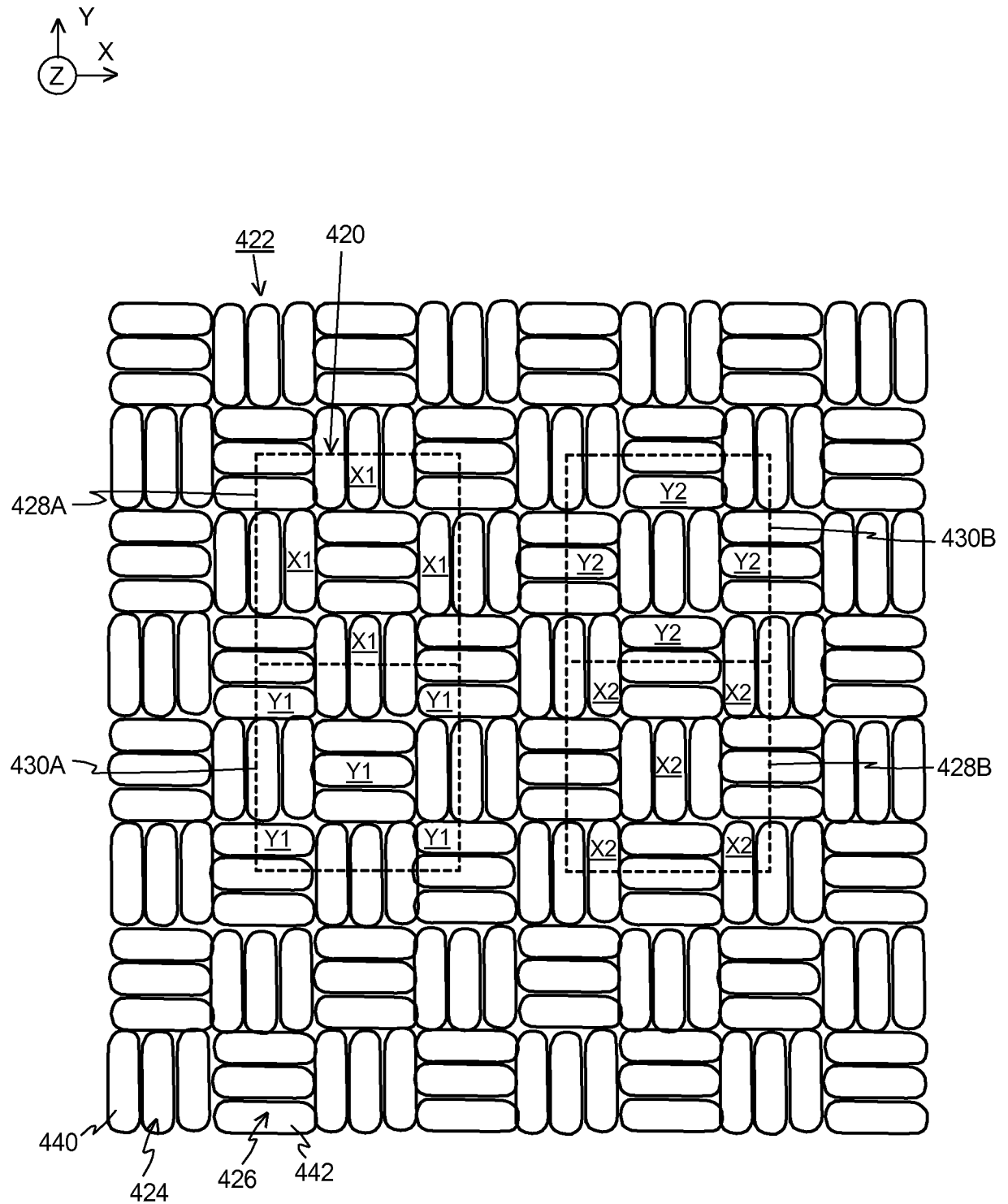


Figure 4B

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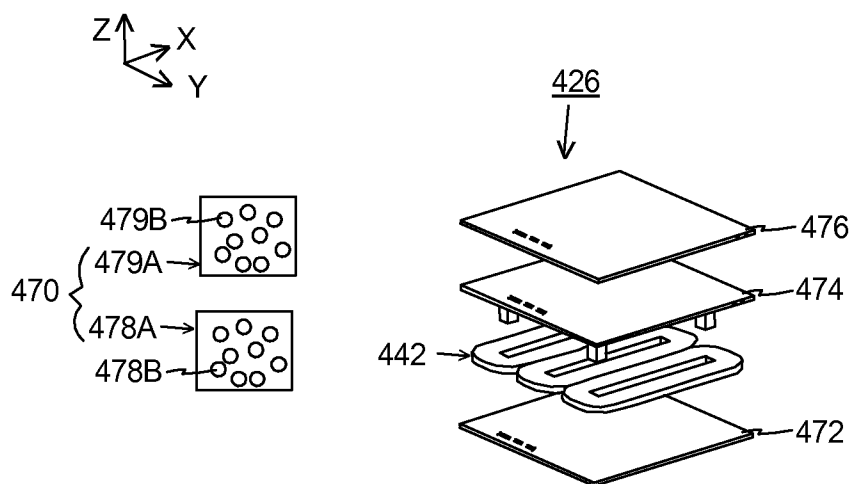


Figure 4C

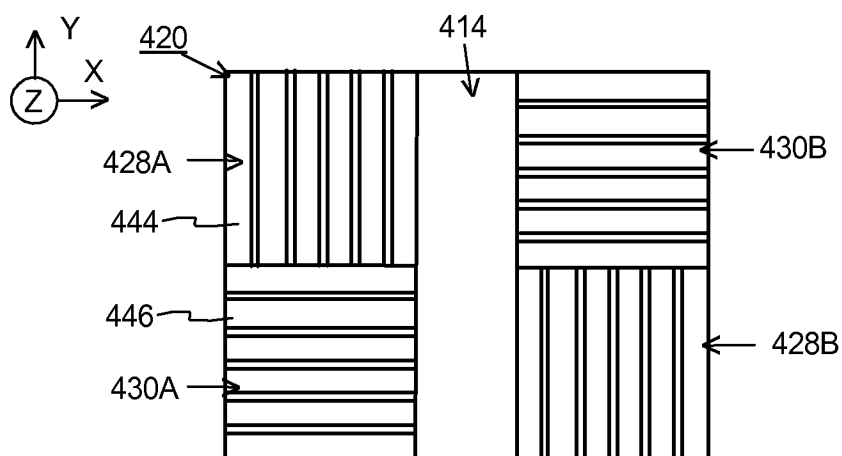


Figure 4D

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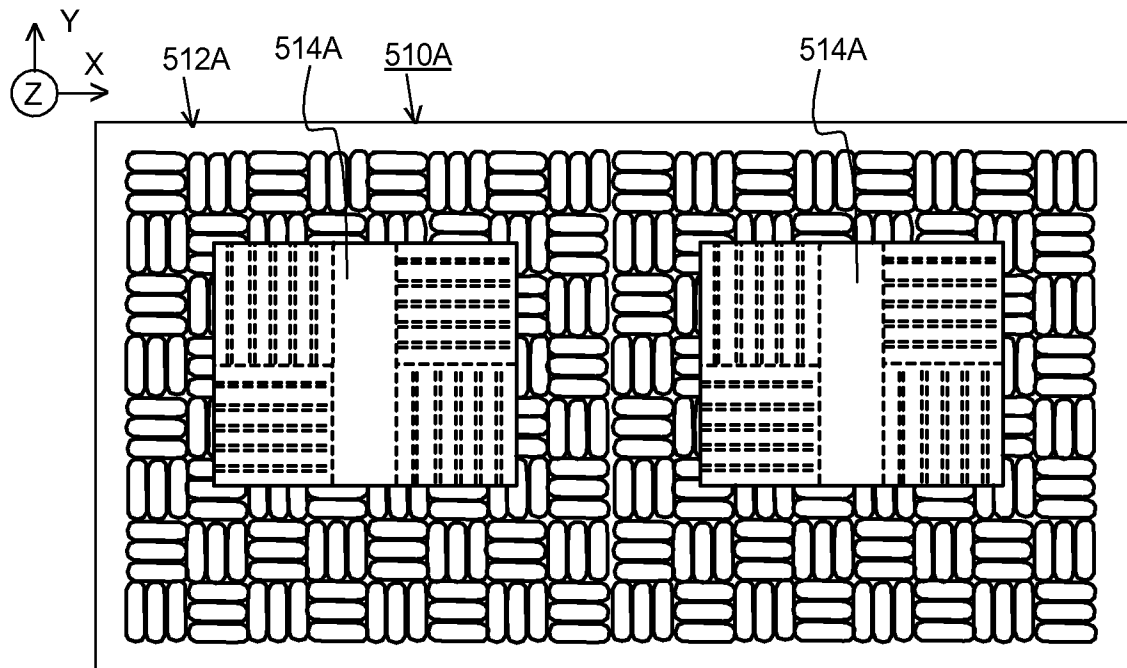


Figure 5A

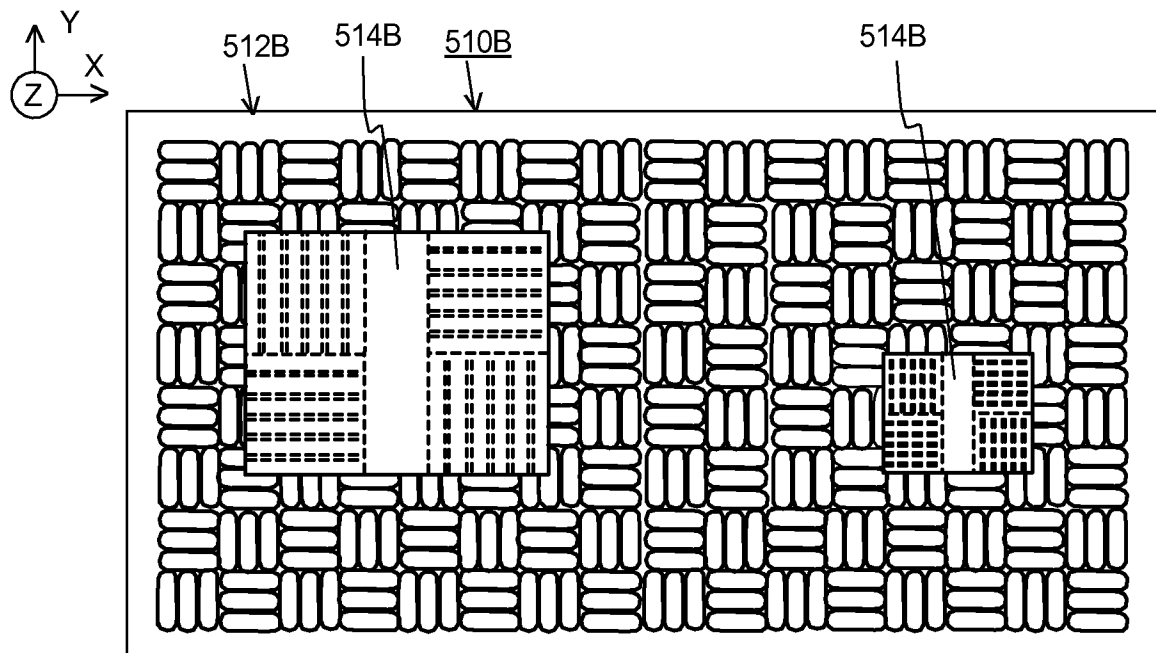


Figure 5B

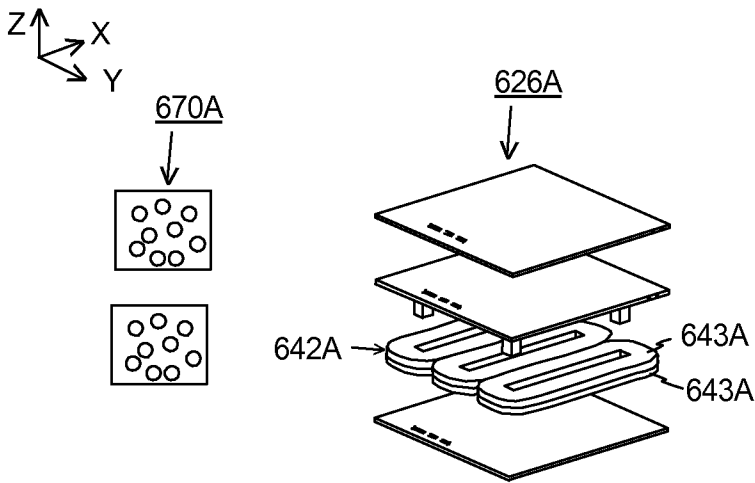


Figure 6A

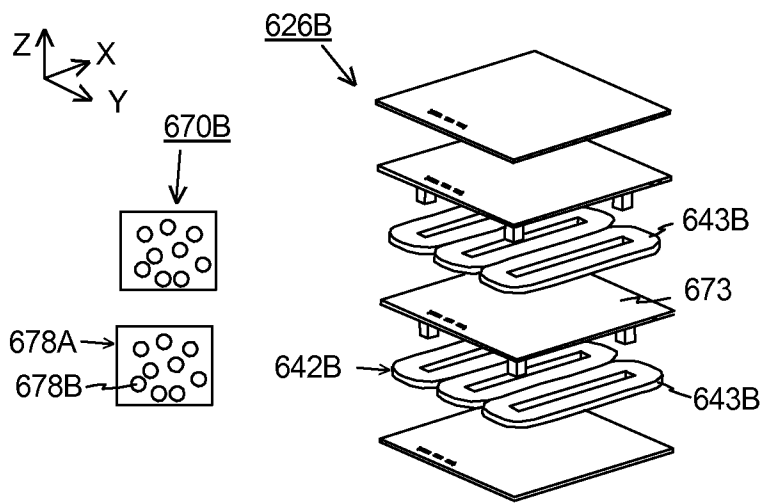


Figure 6B

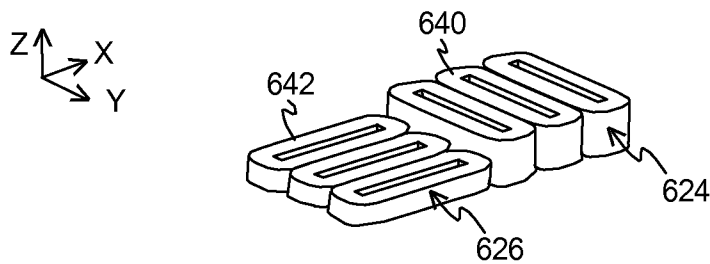


Figure 6C

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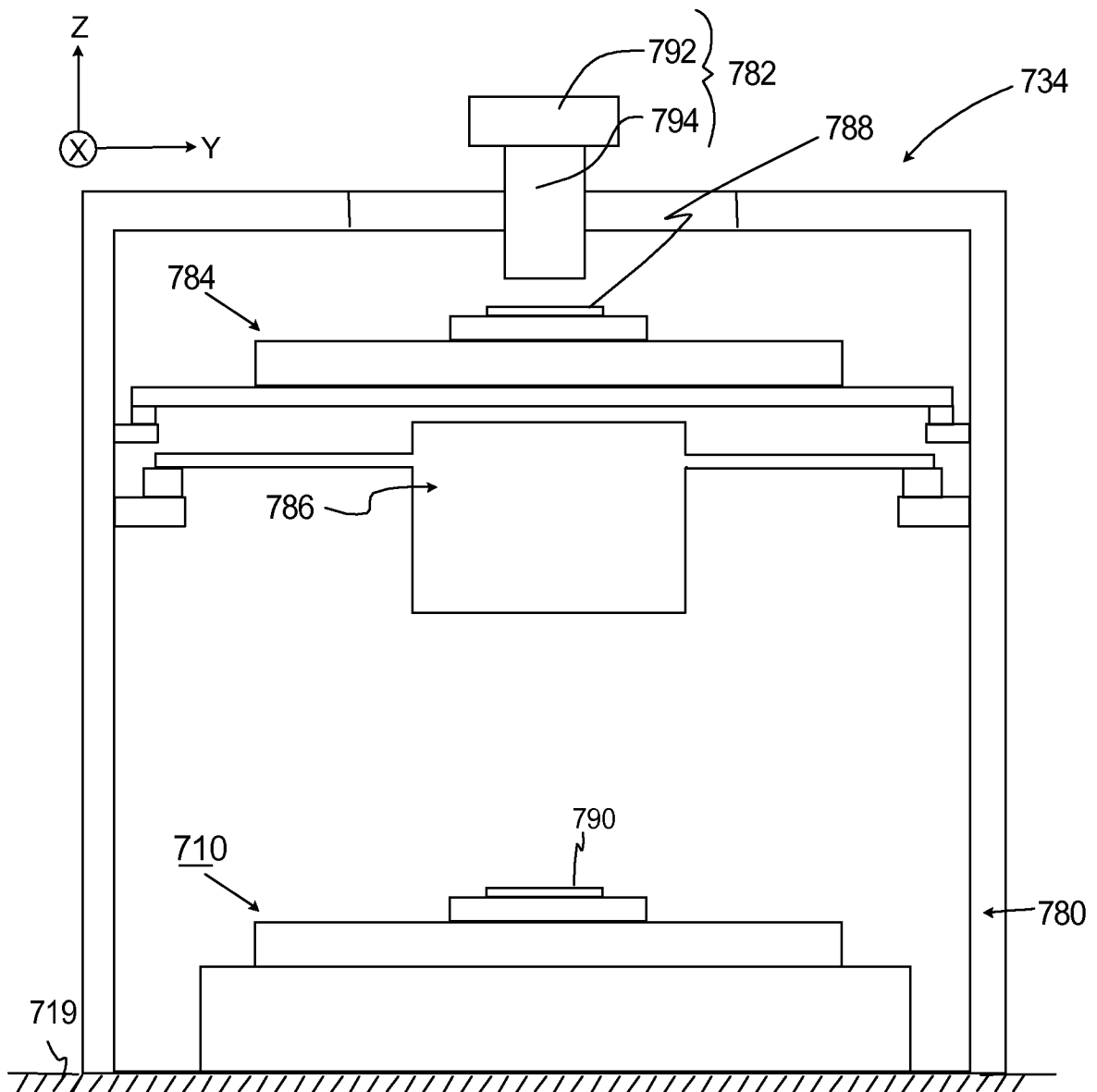


Fig. 7

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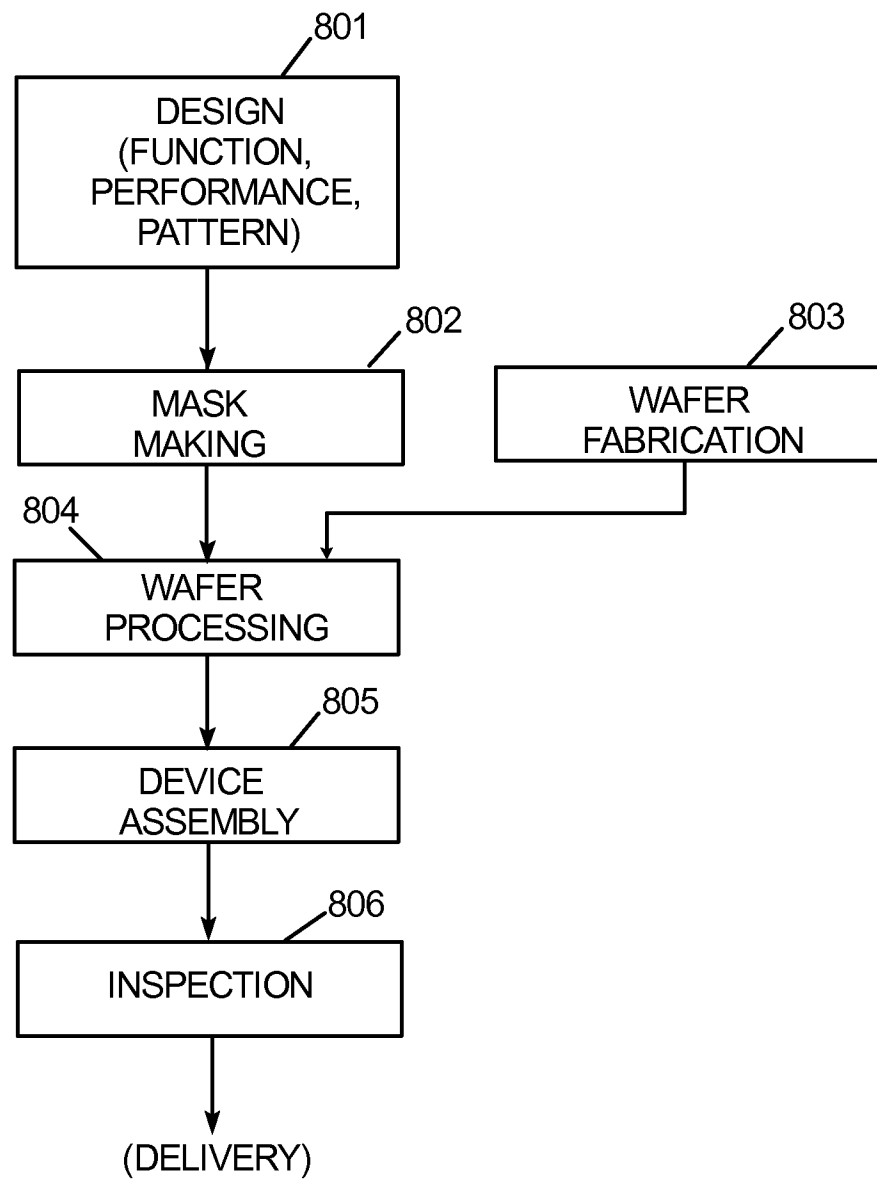


FIG. 8A

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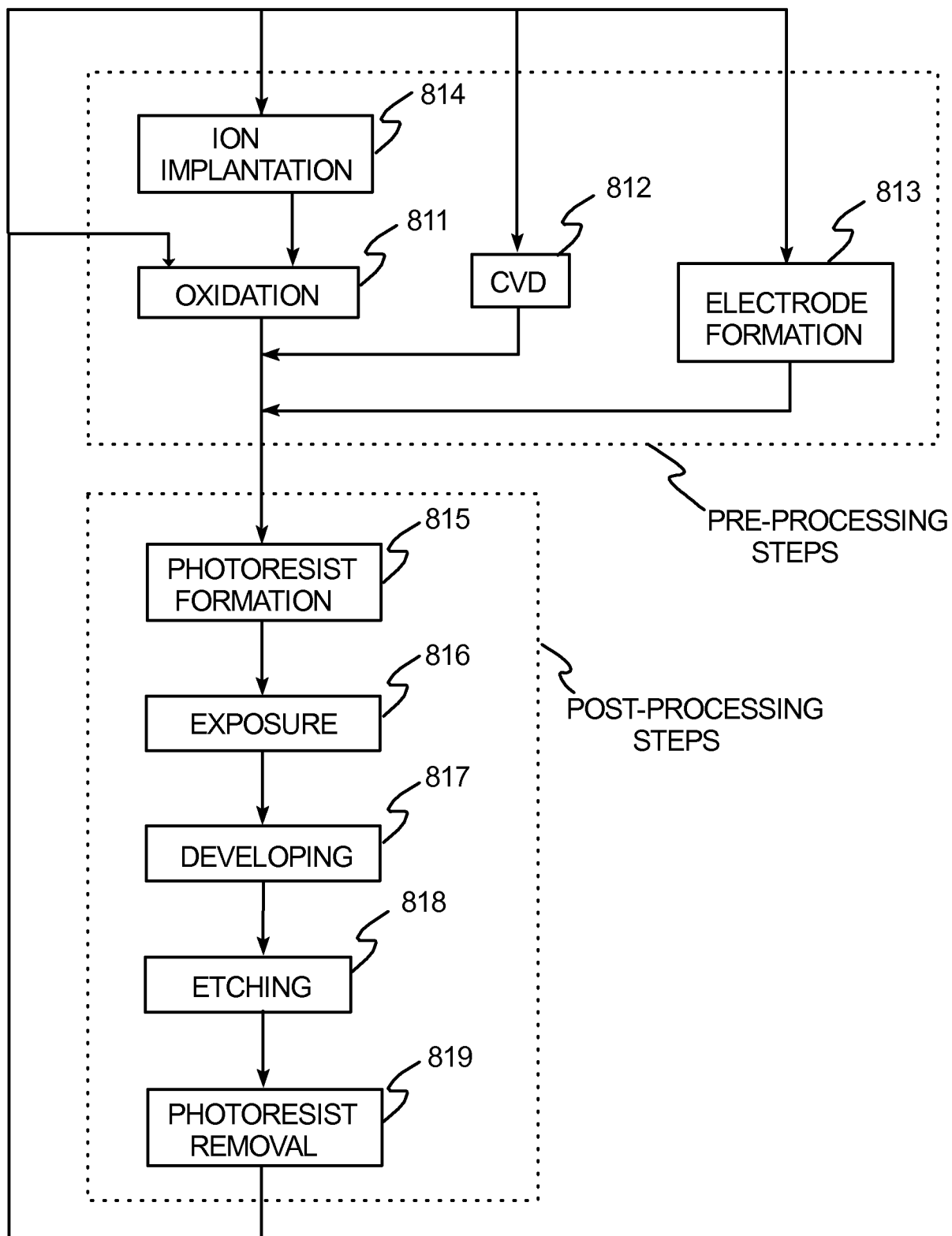


FIG. 8B

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2013/023020

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H02K 41/02 (2013.01)

USPC - 310/12.01

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)

IPC(8) - H02K 1/17, 41/02, 41/03 (2013.01)

USPC - 310/12.01, 12.05, 438/795

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

CPC - H02K 33/16, 41/03, 41/0031

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

Google, MicroPatent, Orbit.com, Google Patents

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2010/041771 A2 (BINNARD et al) 15 April 2010 (15.04.2010) entire document	1-26
Y	KRONE et al. Investigation of the magnetization reversal of a magnetic dot array of Co/Pt multilayers. J Nanopart Res (2011). DOI 10.1007/s11051-010-0123-z 13:5587-5593. [retrieved on 2013-03-31]. Retrieved from the internet: <URL: http://www.lpn.cnrs.fr/Documents/Production/JNR-Krone2011iot.pdf > entire document	1-26
Y	US 2003/0209431 A1 (BROWN) 13 November 2003 (13.11.2003) entire document	3 and 23
Y	US 2010/0167556 A1 (TOTSU et al) 01 July 2010 (01.07.2010) entire document	8, 10, 13, 24, and 26
Y	US 7,355,308 B2 (HAZELTON) 08 April 2008 (08.04.2008) entire document	14-15

☐ Further documents are listed in the continuation of Box C.

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"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 when the document is taken alone

"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

Date of the actual completion of the international search

11 March 2013

Date of mailing of the international search report

29 MAR 2013

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