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(54) LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

(57) An electromagnetic motor is described, the electromagnetic motor comprising:

a magnet assembly configured to generate a two-dimensional alternating magnetic field having a pitch Pm1 in a first direction and a pitch Pm2 in a second direction;

a coil assembly configured to co-operate with the magnet assembly to generate a first force in the first direction and a second force in the second direction, wherein the coil assembly comprises a first coil set comprising a plurality of first coils for generating the first force and a second coil set comprising a plurality of second coils for generating the second force, wherein a ratio R1 of a coil pitch Pc1 in the first coil set in the first direction over Pm1 is different from a ratio R2 of a coil pitch Pc2 in the second coil set in the second direction over Pm2.

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LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

BACKGROUND

Field of the Invention

[001] The present invention relates to an electromagnetic motor, a stage, a lithographic apparatus and a method for manufacturing a device.

Description of the Related Art

[002] A lithographic apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern to be formed on an individual layer of the IC. This pattern can be transferred onto a target portion (e.g. including part of, one, or several dies) on a substrate (e.g. a silicon wafer). Transfer of the pattern is typically via imaging onto a layer of radiation-sensitive material (resist) provided on the substrate. In general, a single substrate will contain a network of adjacent target portions that are successively patterned. Conventional lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at once, and so-called scanners, in which each target portion is irradiated by scanning the pattern through a radiation beam in a given direction (the “scanning”-direction) while synchronously scanning the substrate parallel or anti-parallel to this direction.

[003] In order to synchronously scan the pattern through the radiation beam and the substrate through the patterned image, the patterning device and the substrate are mounted on object tables that are positioned using positioning devices. Typically such positioning devices comprise a combination of electromagnetic actuators and motors. In a typical arrangement, such a positioning device may include a short-stroke module for accurate positioning, over comparatively small distances, of the patterning device or substrate in 6 degrees of freedom, the short stroke module including the patterning device or substrate being movable over comparatively large distances by a long stroke module, e.g. comprising one or more linear or planar motors. The design of such a long stroke module has to meet a variety of constraints such as force requirements, constraints with respect to available footprint, constraints with respect to allowable dissipation.

SUMMARY

[004] It is desirable to improve the design freedom of an electromagnetic motor as applied for positioning objects. According to an embodiment of the invention, there is provided an electromagnetic motor comprising:

a magnet assembly configured to generate an alternating magnetic field having a magnetic pitch in a first direction;

a coil assembly comprising a plurality of coils that are configured to co-operate with the magnet assembly to generate a first force in the first direction, the plurality of coils being arranged in a first set of coils and a second set of coils; and wherein a first coil pitch of the first set of coils in the first direction is different from a second coil pitch of the second set of coils in the first direction.

[005] According to another aspect of the present invention, there is provided An electromagnetic motor comprising:

a magnet assembly configured to generate a two-dimensional alternating magnetic field having a first magnetic pitch in a first direction and a second magnetic pitch in a second direction;

a coil assembly configured to co-operate with the magnet assembly to generate a first force in the first direction and a second force in the second direction, wherein the coil assembly comprises a first coil set comprising a plurality of first coils for generating the first force and a second coil set comprising a plurality of second coils for generating the second force, wherein a ratio R1 of a first coil pitch in the first coil set in the first direction over the first magnetic pitch is different from a ratio R2 of a second coil pitch in the second coil set in the second direction over the second magnetic pitch.

[006] According to another aspect of the present invention, there is provided a stage apparatus configured to position an object, the stage apparatus comprising:

- an object table configured to hold the object and;
- one or more electromagnetic motors according to the present invention, the one or more electromagnetic motors being configured to displace the object table.

[007] According to another aspect of the present invention, there is provided a lithographic apparatus comprising an illumination system configured to condition a radiation beam;

a support constructed to support a patterning device, the patterning device being capable of imparting the radiation beam with a pattern in its cross-section to form a patterned radiation beam;

a substrate table constructed to hold a substrate; and

a projection system configured to project the patterned radiation beam onto a target portion of the substrate, wherein the apparatus further comprises a stage apparatus according to the present invention or positioning the support or the substrate table.

[008] According to another aspect of the present invention, there is provided a device manufacturing method comprising transferring a pattern from a patterning device onto a substrate, wherein the transferring the pattern comprises positioning the pattering device or the substrate using a stage apparatus according to the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[009] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

[0010] - Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;

[0011] - Figure 2 depicts a top view of a planar motor as known in the art;

[0012] - Figure 3 depicts a top view of an electromagnetic motor according to a first embodiment of the present invention;

[0013] - Figures 4 (a) – 4 (c) depict cross-sectional views of coil assemblies as can be applied in an electromagnetic motor according to the present invention;

[0014] - Figure 5 depicts a cross-sectional view of an electromagnetic motor according to a second embodiment of the present invention.

DETAILED DESCRIPTION

[0015] Figure 1 schematically depicts a lithographic apparatus according to one embodiment of the invention. The apparatus includes an illumination system (illuminator) IL configured to condition a radiation beam B (e.g. UV radiation or any other suitable radiation), a mask support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask) MA and connected to a first positioning device PM configured to accurately position the patterning device in accordance with certain parameters. The apparatus also includes a substrate table (e.g. a wafer table) WT or "substrate support" constructed to hold a substrate (e.g. a resist-coated wafer) W and connected to a second positioning device PW configured to accurately position the substrate in accordance with certain parameters. The apparatus further includes a projection system (e.g. a refractive projection lens system) PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g. including one or more dies) of the substrate W.

[0016] The illumination system may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic or other types of optical components, or any combination thereof, for directing, shaping, or controlling radiation.

[0017] The mask support structure supports, i.e. bears the weight of, the patterning device. It holds the patterning device in a manner that depends on the orientation of the patterning device, the design of the lithographic apparatus, and other conditions, such as for example whether or not the patterning device is held in a vacuum environment. The mask support structure can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The mask support structure may be a frame or a table, for example, which may be fixed or movable as required. The mask support structure may ensure that the patterning device is at a desired position, for example with respect to the projection system. Any use of the terms "reticle" or "mask" herein may be considered synonymous with the more general term "patterning device."

[0018] The term "patterning device" used herein should be broadly interpreted as referring to any device that can be used to impart a radiation beam with a pattern in its cross-section so as to create a pattern in a target portion of the substrate. It should be noted that the pattern imparted to the radiation beam may not exactly correspond to the desired pattern in the target portion of the substrate, for example if the pattern includes phase-shifting features or so called assist features. Generally, the pattern imparted to the radiation beam will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

[0019] The patterning device may be transmissive or reflective. Examples of patterning devices include masks, programmable mirror arrays, and programmable LCD panels. Masks are well known in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. An example of a programmable mirror array employs a matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming radiation beam in different directions. The tilted mirrors impart a pattern in a radiation beam which is reflected by the mirror matrix.

[0020] The term "projection system" used herein should be broadly interpreted as encompassing any type of projection system, including refractive, reflective, catadioptric, magnetic, electromagnetic and electrostatic optical systems, or any combination thereof, as appropriate for the exposure radiation being used, or for other factors such as the use of an immersion liquid or the use of a vacuum. Any use of the term "projection lens" herein may be considered as synonymous with the more general term "projection system".

[0021] As here depicted, the apparatus is of a transmissive type (e.g. employing a transmissive mask). Alternatively, the apparatus may be of a reflective type (e.g. employing a programmable mirror array of a type as referred to above, or employing a reflective mask).

[0022] The lithographic apparatus may be of a type having two (dual stage) or more substrate tables or "substrate supports" (and/or two or more mask tables or "mask supports"). In such “multiple stage” machines the additional tables or supports may be used in parallel, or preparatory steps may be carried out on one or more tables or supports while one or more other tables or supports are being used for exposure.

[0023] The lithographic apparatus may also be of a type wherein at least a portion of the substrate may be covered by a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the projection system and the substrate. An immersion liquid may also be applied to other spaces in the lithographic apparatus, for example, between the mask and the projection system. Immersion techniques can be used to increase the numerical aperture of projection systems. The term “immersion” as used herein does not mean that a structure, such as a substrate, must be submerged in liquid, but rather only means that a liquid is located between the projection system and the substrate during exposure.

[0024] Referring to figure 1, the illuminator IL receives a radiation beam from a radiation source SO. The source and the lithographic apparatus may be separate entities, for example when the source is an excimer laser. In such cases, the source is not considered to form part of the lithographic apparatus and the radiation beam is passed from the source SO to the illuminator IL with the aid of a beam delivery system BD including, for example, suitable directing mirrors and/or a beam expander. In other cases the source may be an integral part of the lithographic apparatus, for example when the source is a mercury lamp. The source SO and the illuminator IL, together with the beam delivery system BD if required, may be referred to as a radiation system.

[0025] The illuminator IL may include an adjuster AD configured to adjust the angular intensity distribution of the radiation beam. Generally, at least the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL may include various other components, such as an integrator IN and a condenser CO. The illuminator may be used to condition the radiation beam, to have a desired uniformity and intensity distribution in its cross-section.

[0026] The radiation beam B is incident on the patterning device (e.g., mask MA), which is held on the mask support structure (e.g., mask table MT), and is patterned by the patterning device. Having traversed the mask MA, the radiation beam B passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioning device PW and position sensor IF (e.g. an interferometric device, linear encoder or capacitive sensor), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the radiation beam B. Similarly, the first positioning device PM and another position sensor (which is not explicitly depicted in Figure 1) can be used to accurately position the mask MA with respect to the path of the radiation beam B, e.g. after mechanical retrieval from a mask library, or during a scan. In general, movement of the mask table MT may be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which form part of the first positioning device PM. Similarly, movement of the substrate table WT or "substrate support" may be realized using a long-stroke module and a short-stroke module, which form part of the second positioning device PW. In the case of a stepper (as opposed to a scanner) the mask table MT may be connected to a short-stroke actuator only, or may be fixed. Mask MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2. Although the substrate alignment marks as illustrated occupy dedicated target portions, they may be located in spaces between target portions (these are known as scribe-lane alignment marks). Similarly, in situations in which more than one die is provided on the mask MA, the mask alignment marks may be located between the dies.

[0027] The depicted apparatus could be used in at least one of the following modes:

[0028] 1. In step mode, the mask table MT or "mask support" and the substrate table WT or "substrate support" are kept essentially stationary, while an entire pattern imparted to the radiation beam is projected onto a target portion C at one time (i.e. a single static exposure). The substrate table WT or "substrate support" is then shifted in the X and/or Y direction so that a different target portion C can be exposed. In step mode, the maximum size of the exposure field limits the size of the target portion C imaged in a single static exposure.

[0029] 2. In scan mode, the mask table MT or "mask support" and the substrate table WT or "substrate support" are scanned synchronously while a pattern imparted to the radiation beam is projected onto a target portion C (i.e. a single dynamic exposure). The velocity and direction of the substrate table WT or "substrate support" relative to the mask table MT or "mask support" may be determined by the (de-)magnification and image reversal characteristics of the projection system PS. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height (in the scanning direction) of the target portion.

[0030] 3. In another mode, the mask table MT or "mask support" is kept essentially stationary holding a programmable patterning device, and the substrate table WT or "substrate support" is moved or scanned while a pattern imparted to the radiation beam is projected onto a target portion C. In this mode, generally a pulsed radiation source is employed and the programmable patterning device is updated as required after each movement of the substrate table WT or "substrate support" or in between successive radiation pulses during a scan. This mode of operation can be readily applied to maskless lithography that utilizes programmable patterning device, such as a programmable mirror array of a type as referred to above.

[0031] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

[0032] In the lithographic apparatus according to the present invention, either the first or second positioning devices PW, PM or both may comprise one or more electromagnetic motors according to the present invention for positioning the patterning device or the substrate.

[0033] In an embodiment, the long-stroke module of the second positioning device PW comprises a planar motor according to the present invention. Typically, a substrate as applied in a lithographical apparatus according to the present invention, needs to be displaced in a horizontal plane, further on referred to as the XY-plane, over comparatively large distances, e.g. 500 mm or more in both the X-direction and the Y-direction.

[0034] In Figure 2, a top view of a planar motor as know in the art is schematically shown. The planar motor 200 comprises a magnet assembly 210 comprising a plurality of permanent magnets 210.1 configured to generate a spatially alternating magnetic field in two directions; X-direction and Y-direction. The magnets as indicated by the grey squares have an opposite magnetic polarization compared to the magnets indicated by the white squares. The alternating magnet field has a magnetic pitch Pm in the X-direction and in the Y-direction.

The planar motor 200 further comprises a coil assembly 220 configured to generate forces in both the X-direction and the Y-direction, by providing an appropriate current to the coils or coil sets 220.1, 220.2, 220.3 and 220.4 of the coil assembly 220. In the embodiment as shown, each coil set comprises a triplet of coils, the coils having a coil pitch Pc in both the X-direction and the Y-direction. In the embodiment as shown, the coil pitch Pc as applied in the coils of the four coil set equals:

$$Pc = \frac{4}{3} Pm \qquad (1)$$

[0035] In accordance with the present invention, coil pitch or coil span may be referred to as the distance between two coil sides or the width of a coil as applied in an electromagnetic motor along the direction of the alternating magnetic field. As shown by equation (1), it may be expressed as a function of the magnetic pitch Pm, i.e. the width of a magnetic pole of the magnetic field distribution. In the embodiment as shown, coil sets 220.1 and 220.3 are configured to generate a force in the first direction (X-direction), whereas the coil sets 220.2 and 220.4 are configured to generate a force in the second direction (Y-direction). As can be seen, the coil sets as applied to generate forces in the first direction (X-direction) are substantially equal in size to the coil sets as applied to generate force in the second direction (Y-direction). Such an arrangement may be suited in case the force requirements of the motor in both directions are substantially equal.

[0036] In general, however, the force requirements may be different. In addition, there may be geometrical constraints limiting the options to optimize a usage of the area available for the application of coils or coil sets. As such, merely shortening or elongating the coils exerting forces in first direction compared to the coils exerting forces in the second direction may not be a suitable or realistic option. As such, the present invention introduces another degree of freedom that enables to realize an improved usage of the available footprint of a coil assembly of a planar motor or a linear motor. Within the meaning of present invention, ‘footprint’ is used to denote the available area onto which coils for a coil assembly can be positioned.

Figure 3 schematically depicts a first embodiment of an electromagnetic motor according to the present invention. The electromagnetic motor 400 according to the first embodiment of the present invention is a planar motor comprising a magnet assembly 410 and a coil assembly 420 configured to co-operate with the magnet assembly 410, thereby generating forces in both a first direction (X-direction) and a second direction (Y-direction).

In the embodiment as shown, the magnet assembly comprises a plurality of permanent magnets configured to generate an alternating magnetic field with a magnetic pitch Pm1 in the first direction and a magnetic pitch Pm2 in the second direction. It can be pointed out that, in order to increase the magnetic strength of the spatially alternating magnetic field, use may e.g. be made of a Halbach configuration of magnets. In such configuration, use may e.g. be made of permanent magnets having a magnetic polarization with a component parallel to the XY-plane. In the embodiment as shown, the first magnetic pitch Pm1 is equal to the second magnetic pitch Pm2. It should however be noted that this is not essential, i.e. the first magnetic pitch Pm1 may also be different from the second magnetic pitch Pm2. In order to generate a force in the

Y-direction, the coil assembly 420 of the electromagnetic motor according to the present invention comprises a first coil set comprising four triplets of coils 420.1, 420.2, 420.3 and 420.4, the coils of the first coil set having a coil pitch Pc1. In order to generate a force in the X-direction, the coil assembly 420 of the electromagnetic motor according to the present invention comprises a second coil set comprising two triplets of coils 420.5 and 420.6 having a coil pitch Pc2.

It can be pointed out that, in general, an electromagnetic motor according to the present invention may also be controlled in such manner that a force is generated in a direction perpendicular to the direction or directions of the alternating magnetic field. As such, by appropriate control of the currents supplied to the coil assembly 420, a force in the Z-direction, perpendicular to the XY-plane may be generated as well. In accordance with the embodiment of the present invention, and in contrast with the planar motor as shown in Figure 2, a ratio R1 of the coil pitch Pc1 over the magnetic pitch Pm1 is different from a ratio R2 of the coil pitch Pc2 over the magnetic pitch Pm2:

$$R_1 = \frac{Pc1}{Pm1} \neq R_2 = \frac{Pc2}{Pm2} \qquad (2)$$

In case Pm1 = Pm2, the coil pitch Pc1 would thus be different from the coil pitch Pc2. By doing so, the electromagnetic motor according to the present invention applies an additional degree of freedom which enables to make better use of the available footprint for the coil assembly 420. In the embodiment as shown, the coil pitch Pc1 as applied in the first coil set, e.g. in the first triplet of coils 420.1, and the coil pitch Pc2 as applied in the second coil set, e.g. in coil set 420.5 or 420.6, are given by:

$$\begin{aligned} Pc1 &= \frac{4}{3} Pm1 \\ Pc2 &= \frac{5}{3} Pm2 \end{aligned} \qquad (3)$$

The coils of the second coil set are thus wider, i.e. have a larger coil pitch than the coils in the first coil set, with respect to their respective magnetic pitch. The application of a larger coil pitch enables to generate the same force with a smaller current density (under the assumption of applying substantially the same coil height), resulting in a reduced power dissipation. Alternatively, in case the same current density would be applied, a larger force could be obtained. By selecting different ratios R1 and R2, one may fill, in an optimal manner, the available footprint with coils, thereby meeting the force requirements in both directions.

[0037] In case the available footprint is substantially covered by the coil assembly, a more favorable thermal behavior of the motor may be obtained as well. By allowing the selection of different ratios R1 and R2, the lengths of the applied coils in the first and second direction may be tuned such that the dissipation is more evenly spread over the entire footprint. Due to differences in force requirements and duty cycles between the first and second direction, the dissipation in both coil sets could be substantially different. Selecting different ratios R1 and R2 however provides in additional freedom for the dimensioning of the coils of the first and second coil sets such that the dissipation in both coil sets may become more balanced. In particular, one may obtain, in an embodiment, a substantially even distribution of the average power dissipation over the footprint. This may result in a more even temperature distribution over the coil assembly.

[0038] In a preferred embodiment, the coil sets as applied in the electromagnetic motor are arranged in triplets, whereby the triplets are configured to be powered by a three-phase power supply. In this respect, it should be pointed out that the requirement to supply power to a coil set using a three-phase power supply limits the available choices of the ratio of the coil pitch over the magnetic pitch.

[0039] Figure 4 (a) schematically shows a cross-sectional view of part of a magnet assembly 520 as can be applied in an electromagnetic motor according to the present invention, the part of the magnet assembly comprises 4 permanent magnets 520.1, 520.2, 520.3 and 520.4 that are alternatingly polarized (indicated by the arrows in the magnets) and having a magnetic pitch Pm. Figure 4 (a) further schematically shows a coil set 510 comprising three coils 510.1, 510.2 and 510.3 having a coil pitch Pc according to equation (1), i.e. Pc equals 4/3 x Pm, the magnetic pitch of the magnet assembly 520. As such, the depicted arrangement is similar to the layout of the coil sets 420.1, 420.2, 420.3 or 420.4 relative to the magnet assembly 410 in Figure 3. In Figure 4 (a), the symbols 522 and 524 indicate the direction of the current through the coils. In the illustrated case, i.e. whereby Pc equals 4/3 x Pm, the magnetic pitch, the three coils 510.1, 510.2 and 510.3 of the coil assembly 510 may be connected to an R- S- and T-phase of a three phase power supply. By doing, a substantially constant force between the magnet assembly 520 and the coil assembly 510 may be generated during use.

[0040] Figure 4 (b) schematically shows a cross-sectional view of part of a magnet assembly 620 as can be applied in an electromagnetic motor according to the present invention, the part of the magnet assembly comprises 5 permanent magnets 620.1, 620.2, 620.3, 620.4 and 620.5 that are alternatingly polarized (indicated by the arrows in the magnets) and having a magnetic pitch Pm. Figure 4 (b) further schematically shows a coil set 610 comprising three coils 610.1, 610.2 and 610.3 having a coil pitch Pc equal to 5/3 times the magnetic pitch Pm of the magnet assembly 620. As such, the depicted arrangement is similar to the layout of the coil sets 420.5 or 420.6 relative to the magnet assembly 410 in Figure 3. In such an arrangement, the three coils of the coil set 610 may still be supplied by a three-phase power supply, provided that the direction of the current through the second coil 610.2 is reversed, as indicated by the symbols 622, 624. This may e.g. be realized by reversing the winding direction of the second coil 610.2 or by rotating the coil 180 degrees about an axis perpendicular to the plane of the drawing.

[0041] Yet another manner of applying a different coil pitch that is suitable for supply by means of a three-phase power supply is schematically illustrated in Figure 4 (c). Figure 4 (c) schematically shows part of a magnet assembly 720 comprising 10 alternatingly polarized magnets configured to cooperate with a coil assembly 710 comprising 6 coils, each coil having a coil pitch Pc equal to 5/3 x Pm, the magnetic pitch of the magnets of the magnet assembly 720. In the arrangement as shown, the coils are grouped in pairs of two adjacent coils, each pair of two adjacent coils, e.g. coils 710.1 and 710.2, being supplied by the same phase (R, S or T-phase as indicated) of the three-phase power supply. Such pair of coils has a pitch Pw, referred to as the winding pitch, equal to:

$$Pw = 2 \cdot Pc = \frac{10}{3} Pm \tag{4}$$

[0042] By doing so, there is no need to reverse the direction of the current through the coils that are supplied by the second phase, i.e. the S-phase as indicated.

[0043] With respect to the embodiment as shown in Figure 4 (c), it may be worth noting that the pairs of coils belonging to the same phase need not be supplied by the same power supply. As such, the coil assembly 710 as shown may e.g. be supplied, in an embodiment, by a two three-phase power supplies, one three-phase power supply e.g. powering the left-most coil of each of the indicated R, S and T phases, another three-phase power supply e.g. powering the right-most coil of each of the indicated R, S and T phases. In such an arrangement, a different current, either different in amplitude or in phase angle, may be applied in the coils belonging to the same phase, such as the coils 710.1 and 710.2.

[0044] Figures 3 and 4 (a)-(c) illustrate the application of different coil pitches for different coil sets as can e.g. be applied in an electromagnetic motor according to the first embodiment of the present invention. In this first embodiment, different coil pitches, or different ratios of coil pitches over magnetic pitches are applied in different driving directions of the electromagnetic motor.

It is worth pointing out however that, in addition to applying different coil pitches in the different driving directions, it may also be advantageous to apply, in case multiple coil sets per driving direction are used, different coil pitches in these multiple coil sets as well, thereby further increasing the flexibility to fill up the available footprint. As an example, referring to Figure 3, the four triplets of coils 420.1, 420.2, 420.3 and 420.4 as used for generating a force in the Y-direction, need not have the same coil pitch Pc1. Rather, the triplets of coils 420.1, 420.2, 420.3 and 420.4 may e.g. be grouped in coil sets having a different coil pitch. As an example, the triplets of coils 420.1 and 420.4 could be considered one coil set, whereby a pitch Pc1 is applied for this coil set, while the triplets of coils 420.2 and 420.3 could be considered another coil set, whereby a third coil pitch, different from Pc1 is applied. In an embodiment, the third coil pitch may e.g. be selected equal to Pc2. The third coil pitch may however be different from Pc2 as well.

Combining coil sets having different coil pitches may also be advantageous in a linear motor. Therefore, in a second embodiment, the present invention provides in an electromagnetic motor having a magnet assembly that is configured to generate an alternating magnetic field having a pitch Pm in a first direction and a coil assembly configured to co-operate with the magnet assembly to generate a first force in the first direction and comprising a plurality of coils, whereby the plurality of coils are arranged in a first set of coils and a second set of coils, a coil pitch Pc1 of the first set of coils being different from a coil pitch Pc2 of the second coil set. Figure 5 schematically shows a cross-sectional view of such a motor. Figure 5 schematically shows part of a magnet assembly 820 of an electromagnetic motor according to the present invention, the magnet assembly 820 comprising a plurality of alternatingly polarized permanent magnets such as magnets 820.1 and 820.2, (the polarization direction being indicated by the arrows in the magnets). The electromagnetic motor further comprises a coil assembly 810 comprising a first coil set 812 and a second coil set 814. In the embodiment as shown, the first coil set comprises three coils, each coil having a coil pitch Pc1, the second coil set also comprises three coils, each coil having a coil pitch Pc2. During use, the coil assembly 810 may be configured to co-operate with the magnet assembly 820 to generate a force, e.g. along the Y-direction, i.e. the same direction along which the alternating magnetic field is generated by the magnet assembly 820. In general, the first coil set 812 may e.g. comprise one or more coil triplets, referred to as the first coil triples, and the second coil set 814 may e.g. also comprise one or more coil triplets, referred to as the second coil triples. In the embodiment as shown, the coil pitches Pc1 and Pc2 of the respective first coil set 812 and second coil set 814 satisfy the conditions of equation (3). As each coil set has one coil triplet, the coil assembly 810 as shown spans 9 magnets, i.e. 9 times the magnetic pitch Pm, i.e. the distance between adjacent North and South poles of the alternating magnetic field. It can further be pointed out that the middle coil of the second coil set 814 has a reversed winding direction, similar to the coil set 610 of Figure 4 (b). In such embodiment, the coil triplets of the first coil set and the coil triplets of the second coil set may be configured to be powered by a common three-phase power supply, whereby coils of the first coil triplets and of the second coil triplets that are configured to be powered by the same phase of the three-phase power supply can be connected in series. In the embodiment as shown, coils 812.1 and 814.1 may be connected in series, coils 812.2 and 814.2 may be connected in series and coils 812.3 and 814.3 may be connected in series. In such embodiment, it may be preferred to apply the same conductor dimensions in the first coil set and in the second coil set. In particular, a cross-section of a winding of a coil of the first coil set may be selected substantially equal to a cross-section of a winding of a coil of the second coil set. By doing so, the current density may be kept substantially equal in both coil sets, when the coils of the coil triplets are connected in series as mentioned above. As such, a substantially uniform dissipation may be obtained in the coil assembly. In an embodiment, a height H of a winding of a coil of the first coil set is selected substantially equal to a height of a winding of a coil of the second coil set. By doing so, a back surface of the coil assembly, i.e. a surface formed by the coil surfaces not facing the magnets (indicated by the dotted line 850) may be substantially flat, enabling the application of a common cooling arrangement for both coil sets.

[0045] With respect to the embodiment as shown in Figure 5, it can be pointed out that by combining coil sets having a different coil pitch, an increased flexibility or design freedom is obtained. As indicated, the overall width of the coil assembly as shown spans 9 magnets. Such a width could not be obtained when combining coil sets having the same coil pitch. The electromagnetic motor according to the invention which applies coil sets with different coil pitches to generate a force thus has a higher design freedom with respect to the overall width of the coil assembly, for a given magnetic pitch. In an embodiment, this increased design freedom may be realized by selecting Pc2 as $Pc1 < Pc2 < 2 \times Pc1$.

[0046] The electromagnetic motor according to the present invention may advantageously be implemented in a stage apparatus according to the present invention. In an embodiment, the present invention provides in a stage apparatus configured to position an object, e.g. a patterning device or a substrate as applied in a lithographic apparatus. Such a stage apparatus comprises an object table for holding the object to be positioned and one or more electromagnetic motors according to the present invention for displacing the object table.

[0047] In an embodiment of the stage apparatus according to the present invention, the coil assembly of the electromagnetic motor as applied is mounted to the object table. Alternatively, the magnet assembly of the electromagnetic motor as applied may be mounted to the object table.

[0048] In an embodiment, the stage apparatus may further comprise a control unit such as a microcontroller, microprocessor, computer or the like for controlling the power as supplied to the electromagnetic motor, in particular the current as supplied to the coil assembly of the electromagnetic motor. In such embodiment, the control unit may be configured to receive a position set point (i.e. representative of a desired position of the object table) as an input signal, e.g. at an input terminal of the control unit, and generate appropriate control signals, e.g. outputted at an output terminal of the control unit, for controlling the current through he coils of the coil assembly. In such an embodiment, the stage apparatus may advantageously be provided with a position measurement system as well, such position measurement system e.g. providing a position signal, representative of the position of the object table relative to a reference frame, to the input terminal of the control unit. Examples of such position measurement systems may e.g. include interferometer based measurement systems or encoder based measurement systems.

[0049] In an embodiment, the magnet assembly of the electromagnetic motor according to the present invention is mounted to a magnetic member, e.g. a ferromagnetic member, in order to increase the magnetic field strength.

[0050] Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications, such as the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms “wafer” or “die” herein may be considered as synonymous with the more general terms “substrate” or “target portion", respectively. The substrate referred to herein may be processed, before or after exposure, in for example a track (a tool that typically applies a layer of resist to a substrate and develops the exposed resist), a metrology tool and/or an inspection tool. Where applicable, the disclosure herein may be applied to such and other substrate processing tools. Further, the substrate may be processed more than once, for example in order to create a multi-layer IC, so that the term substrate used herein may also refer to a substrate that already contains multiple processed layers.

[0051] Although specific reference may have been made above to the use of embodiments of the invention in the context of optical lithography, it will be appreciated that the invention may be used in other applications, for example imprint lithography, and where the context allows, is not limited to optical lithography. In imprint lithography a topography in a patterning device defines the pattern created on a substrate. The topography of the patterning device may be pressed into a layer of resist supplied to the substrate whereupon the resist is cured by applying electromagnetic radiation, heat, pressure or a combination thereof. The patterning device is moved out of the resist leaving a pattern in it after the resist is cured.

[0052] The terms “radiation” and “beam” used herein encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g. having a wavelength of or about 365, 248, 193, 157 or 126 nm) and extreme ultra-violet (EUV) radiation (e.g. having a wavelength in the range of 5-20 nm), as well as particle beams, such as ion beams or electron beams.

[0053] The term “lens”, where the context allows, may refer to any one or combination of various types of optical components, including refractive, reflective, magnetic, electromagnetic and electrostatic optical components.

[0054] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. For example, the invention may take the form of a computer program containing one or more sequences of machine-readable instructions describing a method as disclosed above, or a data storage medium (e.g. semiconductor memory, magnetic or optical disk) having such a computer program stored therein.

The descriptions above are intended to be illustrative, not limiting. Thus, it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the clauses set out below. Other aspects of the invention are set out as in the following numbered clauses:

1. An electromagnetic motor comprising:

a magnet assembly configured to generate an alternating magnetic field having a magnetic pitch in a first direction;

a coil assembly comprising a plurality of coils that are configured to co-operate with the magnet assembly to generate a first force in the first direction, the plurality of coils being arranged in a first set of coils and a second set of coils; and wherein a first coil pitch of the first set of coils in the first direction is different from a second coil pitch of the second set of coils in the first direction.

2. The electromagnetic motor according to clause 1, wherein the coils of the first set of coils are arranged in one or more first coil triplets configured to be powered by a first three-phase power supply.

3. The electromagnetic motor according to clause 1 or clause 2, wherein the coils of the second set of coils are arranged in one or more second coil triplets configured to be powered by a second three-phase power supply.

4. The electromagnetic motor according to clause 1, wherein the coils of the first set of coils are arranged in one or more first coil triplets, the coils of the second set of coils are arranged in one or more second coil triplets, the one or more first coil triplets and the one or more second coil triplets being configured to be powered by a three-phase power supply, whereby coils of the one or more first coil triplets and of the one or more second coil triplets that are configured to be powered by the same phase of the three-phase power supply, are connected in series.

5. The electromagnetic motor according to clause 4, wherein a cross-section of a winding of a coil of the one or more first coil triplets substantially equals a cross-section of a winding of a coil of the one or more second coil triplets.

6. The electromagnetic motor according to any of the preceding clauses, wherein a height of a winding of a coil of the one or more first coil triplets substantially equals a height of a winding of a coil of the one or more second coil triplets.

7. The electromagnetic motor according to any of the preceding clauses, wherein the magnet assembly comprises a plurality of permanent magnets configured to generate the alternating magnetic field having the magnetic pitch in the first direction.

8. The electromagnetic motor according to any of the preceding clauses, wherein:

$Pc1 < Pc2 < 2\, Pc1$,

whereby:

Pc1 = the first coil pitch;

Pc2 = the second coil pitch.

9. The electromagnetic motor according any of the preceding clauses wherein:

$$Pc1 = \frac{4}{3} Pm$$

$$Pc2 = \frac{5}{3} Pm$$

whereby:

Pc1 = the first coil pitch;

Pc2 = the second coil pitch;

Pm = the magnetic pitch.

10. An electromagnetic motor comprising:

a magnet assembly configured to generate a two-dimensional alternating magnetic field having a first magnetic pitch in a first direction and a second magnetic pitch in a second direction;

a coil assembly configured to co-operate with the magnet assembly to generate a first force in the first direction and a second force in the second direction, wherein the coil assembly comprises a first coil set comprising a plurality of first coils for generating the first force and a second coil set comprising a plurality of second coils for generating the second force, wherein a ratio R1 of a first coil pitch in the first coil set in the first direction over the first magnetic pitch is different from a ratio R2 of a second coil pitch in the second coil set in the second direction over the second magnetic pitch.

11. The electromagnetic motor according to clause 10, wherein:

Pm1 = Pm2 = Pm,

whereby:

Pm1 = the first magnetic pitch;

Pm2 = the second magnetic pitch;

Pm = a magnetic pitch.

12. The electromagnetic motor according to clause 11, wherein:

$$Pc1 = \frac{4}{3} Pm$$

$$Pc2 = \frac{5}{3} Pm$$

13. The electromagnetic motor according to clause 10, 11, or 12, wherein the plurality of first coils of the first coil set are arranged in one or more first coil triplets configured to be powered by a first three-phase power supply.

14. The electromagnetic motor according to clause 10, 11, 12 or 13, wherein the plurality of second coils of the second coil set are arranged in one or more second coil triplets configured to be powered by a second three-phase power supply.

15. A stage apparatus configured to position an object, the stage apparatus comprising:

- an object table configured to hold the object and;
- one or more electromagnetic motors according to any of the preceding clauses, the one or more electromagnetic motors being configured to displace the object table.

16. A lithographic apparatus comprising:

an illumination system configured to condition a radiation beam;

a support constructed to support a patterning device, the patterning device being capable of imparting the radiation beam with a pattern in its cross-section to form a patterned radiation beam;

a substrate table constructed to hold a substrate; and

a projection system configured to project the patterned radiation beam onto a target portion of the substrate,

wherein the apparatus further comprises a stage apparatus according to clause 15 for positioning the support or the substrate table.

17. A device manufacturing method comprising transferring a pattern from a patterning device onto a substrate, wherein the transferring the pattern comprises positioning the pattering device or the substrate using a stage apparatus according to clause 15.

CONCLUSIE

1. Een lithografieinrichting omvattende:
een belichtinginrichting ingericht voor het leveren van een stralingsbundel;
een drager geconstrueerd voor het dragen van een patroneerinrichting, welke patroneerinrichting in staat is een patroon aan te brengen in een doorsnede van de stralingsbundel ter vorming van een gepatroneerde stralingsbundel;
een substraattafel geconstrueerd om een substraat te dragen; en
een projectieinrichting ingericht voor het projecteren van de gepatroneerde stralingsbundel op een doelgebied van het substraat, met het kenmerk, dat de substraattafel is ingericht voor het positioneren van het doelgebied van het substraat in een brandpuntsvlak van de projectieinrichting.

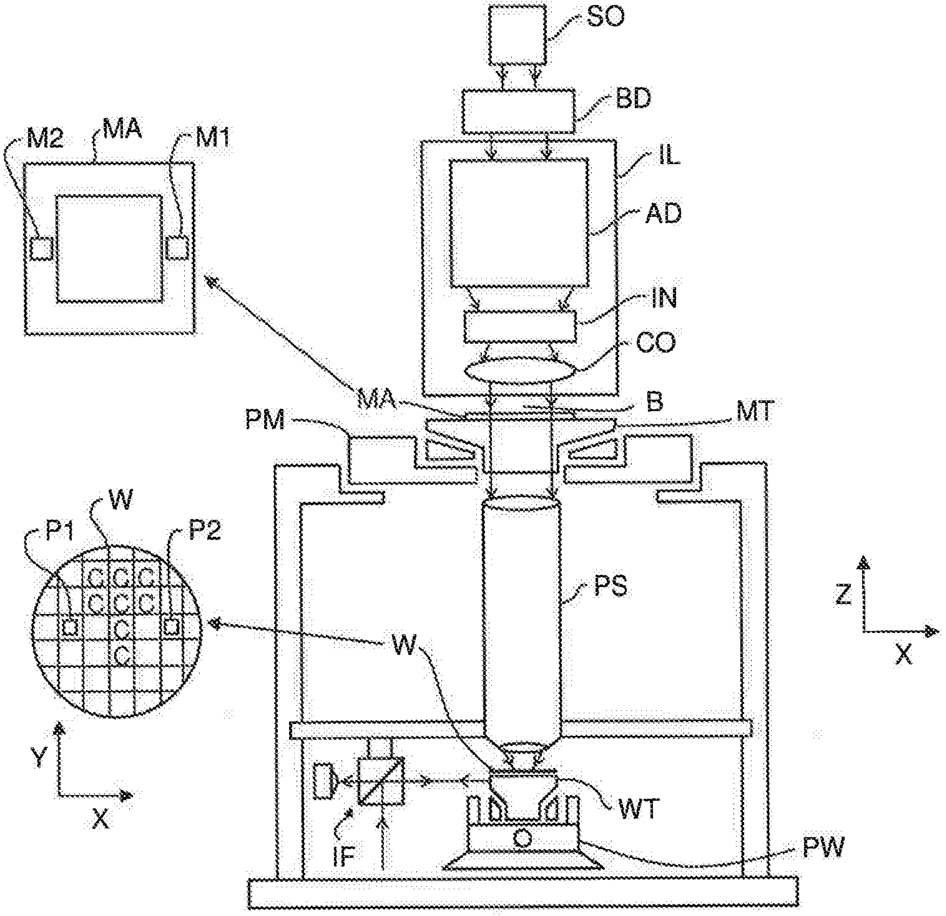

Figure 1

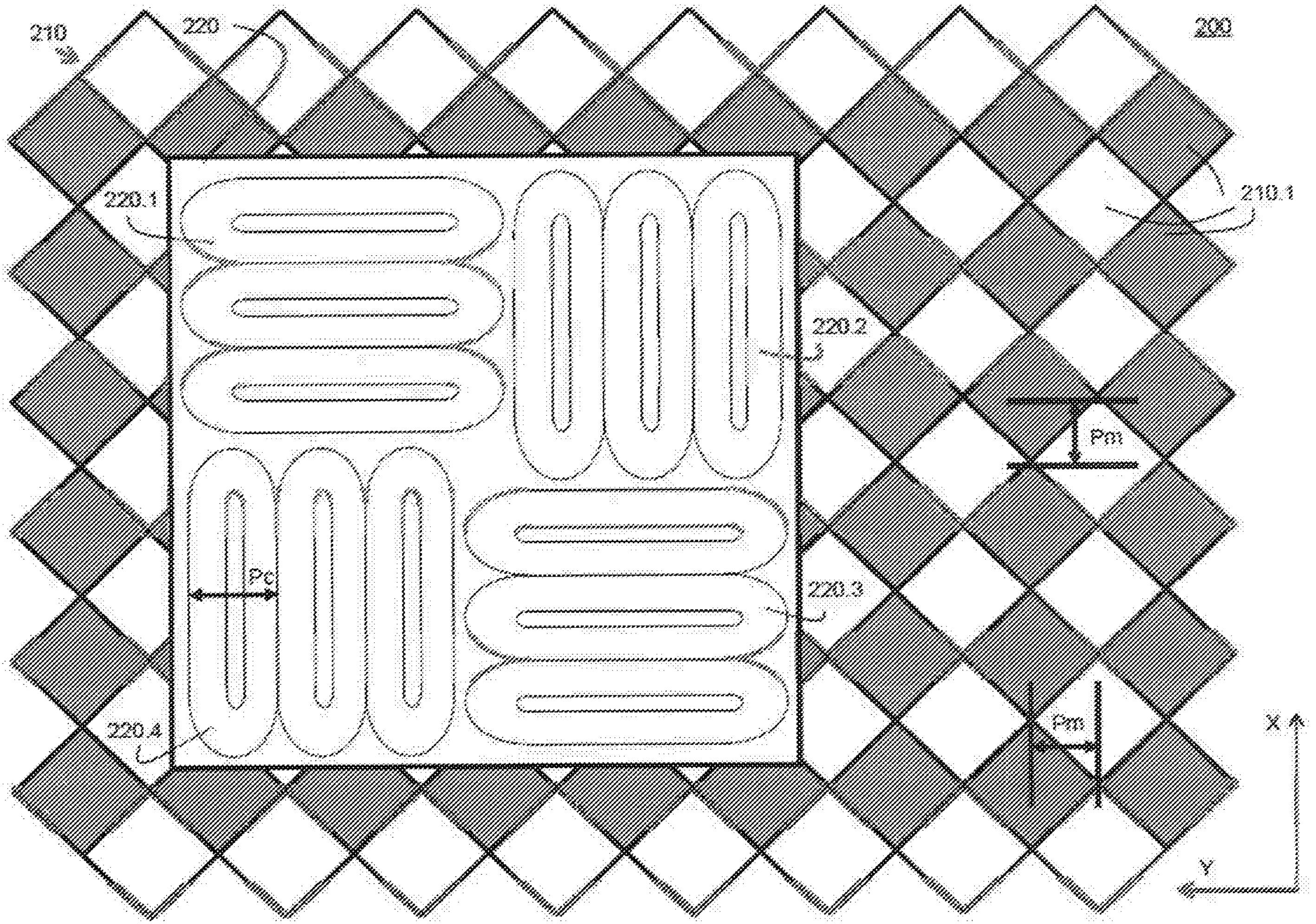

Figure 2

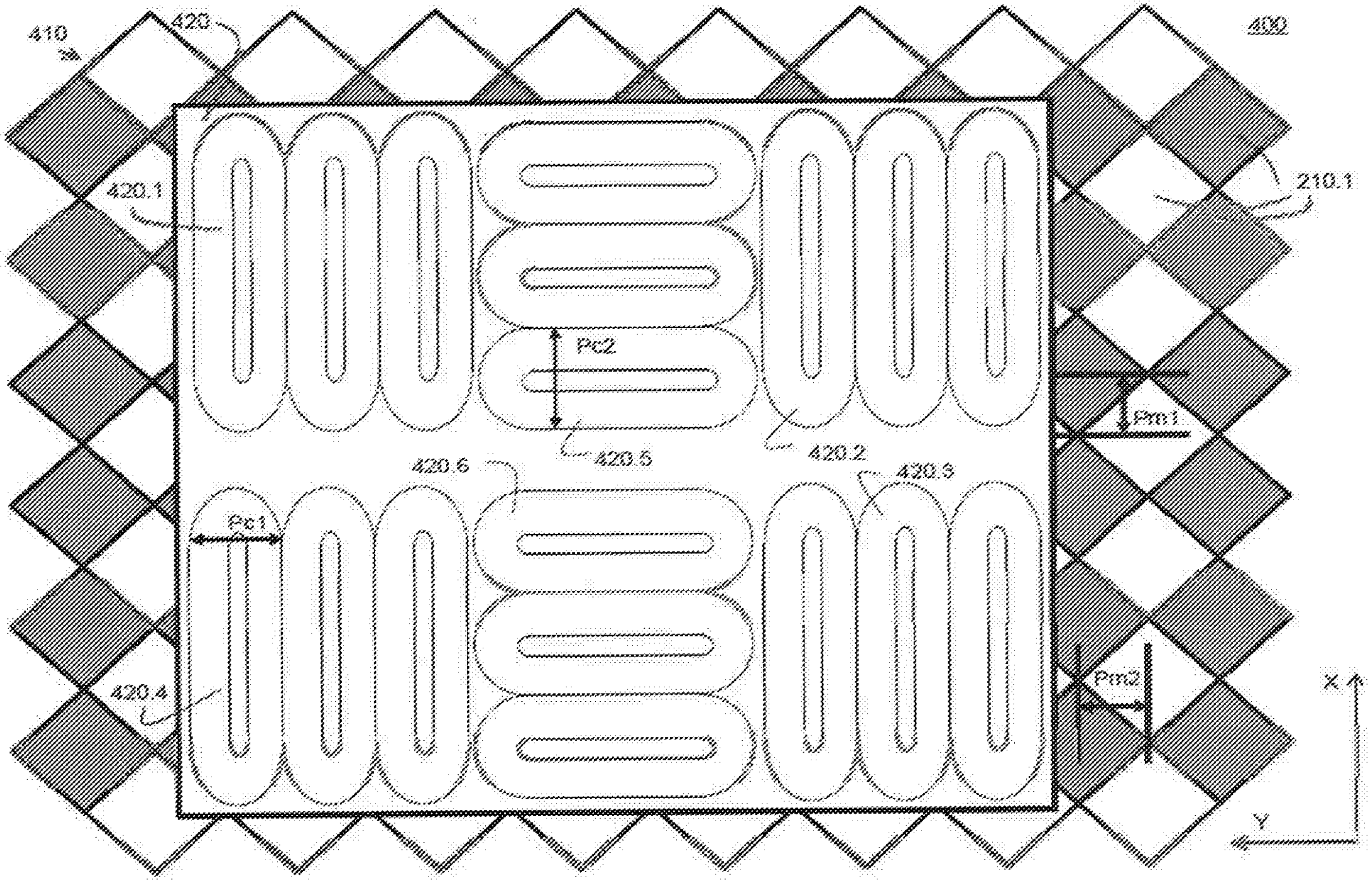
410
420
400
420.1
210.1
Pc2
Pm1
420.5
420.2
420.6
420.3
Pc1
420.4
Pm2
X
Y

Figure 3

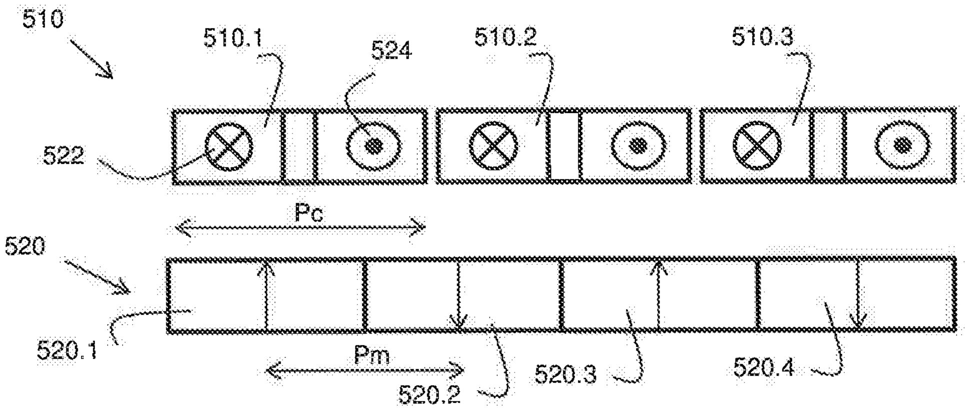

Figure 4 (a)

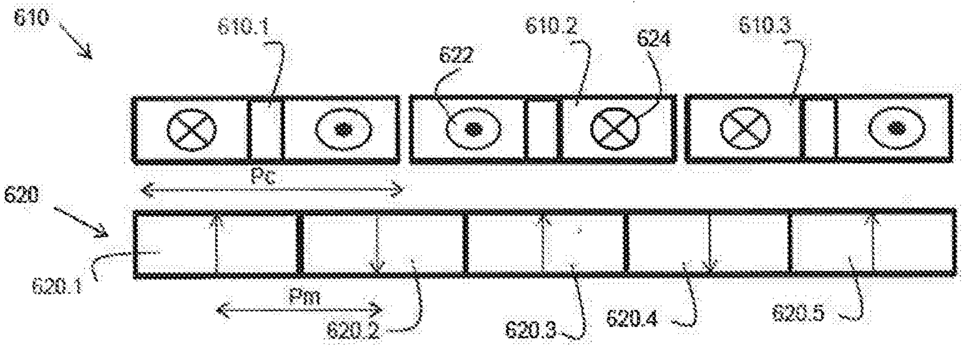

Figure 4 (b)

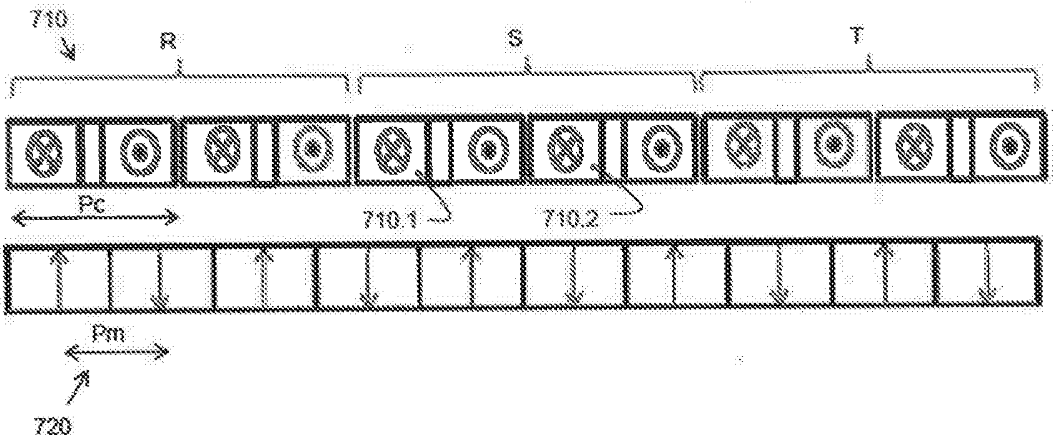

Figure 4 (c)

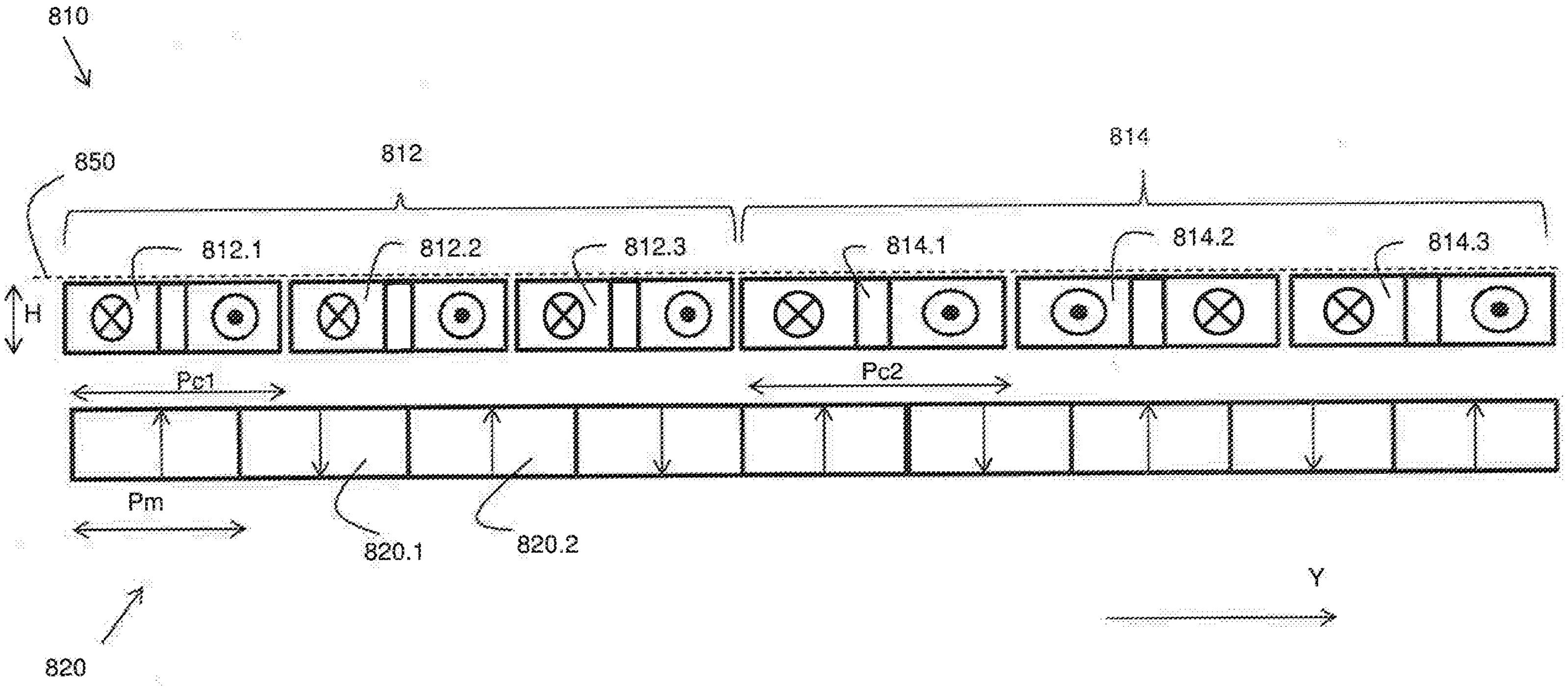
810
850
812
814
812.1
812.2
812.3
814.1
814.2
814.3
H
Pc1
Pc2
Pm
820.1
820.2
Y
820

Figure 5

ABSTRACT

An electromagnetic motor is described, the electromagnetic motor comprising:

a magnet assembly configured to generate a two-dimensional alternating magnetic field having a pitch Pm1 in a first direction and a pitch Pm2 in a second direction;

a coil assembly configured to co-operate with the magnet assembly to generate a first force in the first direction and a second force in the second direction, wherein the coil assembly comprises a first coil set comprising a plurality of first coils for generating the first force and a second coil set comprising a plurality of second coils for generating the second force, wherein a ratio R1 of a coil pitch Pc1 in the first coil set in the first direction over Pm1 is different from a ratio R2 of a coil pitch Pc2 in the second coil set in the second direction over Pm2.