



(51) International Patent Classification:

*B81B 3/00* (2006.01)      *G03B 5/00* (2006.01)  
*G02B 7/04* (2006.01)      *H04N 5/232* (2006.01)  
*G03B 3/00* (2006.01)

(21) International Application Number:

PCT/US2012/058068

(22) International Filing Date:

28 September 2012 (28.09.2012)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

13/247,898 28 September 2011 (28.09.2011) US

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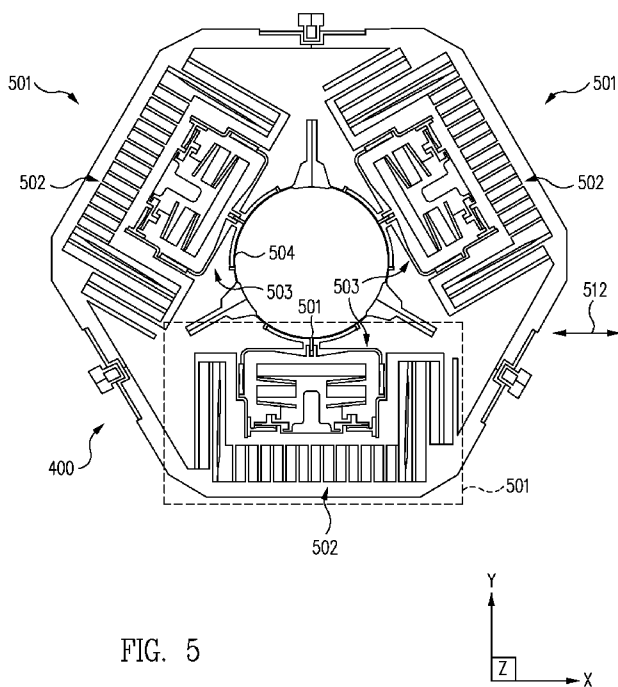
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

[Continued on next page]

(54) Title: MULTIPLE DEGREE OF FREEDOM ACTUATOR



(57) Abstract: A multiple degree of freedom actuator can have at least one first MEMS actuator configured to move a platform in translation and at least one second MEMS actuator configured to move the platform in a different direction, e.g., tangentially. The first MEMS actuator(s) can facilitate autofocus and/or zoom, for example. The second MEMS actuator(s) can facilitate optical image stabilization (OIS), for example.



**(84) Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,

SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Published:**

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

## MULTIPLE DEGREE OF FREEDOM ACTUATOR

## TECHNICAL FIELD

[00001] One or more embodiments relate generally to microelectromechanical systems (MEMS) and, more particularly, to MEMS electrostatic actuators.

## BACKGROUND

[00002] Microelectromechanical systems (MEMS) actuators are well known. Examples of MEMS actuators include comb drives, scratch drives, and thermal drives. MEMS actuators can be made using integrated circuit (IC) fabrication techniques. MEMS actuators can be used in a variety of applications.

[00003] For example, MEMS drives can be used move a lens so as to facilitate the focusing of a miniature camera. As such, it would be beneficial to provide improved MEMS drives for such applications.

## SUMMARY

[00004] In accordance with an embodiment, a device can comprise at least one first MEMS actuator configured to move a platform in translation along a first axis. At least one second MEMS actuator can be configured to move the platform in a direction that is generally perpendicular to the first axis.

[00005] In accordance with an embodiment, an actuator assembly can comprise at least one first MEMS actuator configured to move a platform in translation and at least one second MEMS actuator configured to move, e.g., rotate, the platform tangentially.

[00006] In accordance with an embodiment, a MEMS actuator assembly can comprise a plurality of nested actuators configured to focus a camera and to provide optical image stabilization for the camera.

[00007] In accordance with an embodiment, a method for operating a camera can comprise moving a platform in translation with at least one first MEMS actuator and moving the platform tangentially with at least one second MEMS actuator.

**[00008]** In accordance with an embodiment, a multiple degree of freedom actuator can comprise a fixed frame, a platform that is movable with respect to the fixed frame, and three independently movable MEMS actuators interconnecting the fixed frame and the platform. The three MEMS actuators can be configured to cooperate to move the platform in three degrees of freedom.

**[00009]** In accordance with an embodiment, a method can comprise providing a platform that is movable with respect to a fixed frame. The platform can be moved in three degrees of freedom using three independently movable MEMS actuators.

**[00010]** The scope of the invention is defined by the claims, which are incorporated into this Summary by reference. A more complete understanding of embodiments of the invention will be afforded to those skilled in the art, as well as a realization of additional advantages thereof, by a consideration of the following detailed description of one or more embodiments. Reference will be made to the appended sheets of drawings that will first be described briefly.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[00011]** Fig. 1 shows an electronic device having a multiple degree of freedom actuator, in accordance with an embodiment.

**[00012]** Fig. 2 shows a miniature camera having a lens barrel, in accordance with an embodiment.

**[00013]** Fig. 3A shows miniature camera with the lens barrel having the actuator module disposed therein, in accordance with an embodiment.

**[00014]** Fig. 3B shows the lens barrel and the actuator module in an exploded view, in accordance with an embodiment.

**[00015]** Fig. 4 shows the actuator module having the multiple degree of freedom actuator disposed therein, in accordance with an embodiment.

**[00016]** FIG. 5 shows a multiple degree of freedom actuator, in accordance with an embodiment of the invention.

[00017] FIG. 6 is an enlarged view showing one sector of the multiple degree of freedom actuator of FIG. 5, in accordance with an embodiment of the invention.

[00018] FIG. 7 shows the sector of FIG. 6 with the comb drive teeth removed 8 for clarity, in accordance with an embodiment of the invention

[00019] FIG. 8 is an enlarged view showing the out-of-plane actuator of FIG. 7, in accordance with an embodiment of the invention.

[00020] FIG. 9 is an enlarged view showing a portion of the in-plane actuator and a portion of the out-of-plane actuator of FIG. 6, in accordance with an embodiment of the invention.

[00021] FIG. 10 is a flow chart showing an example of operation of the multiple degree of freedom actuator, in accordance with an embodiment of the invention.

[00022] Embodiments of the invention and their advantages are best understood by referring to the detailed description that follows. It should be appreciated that like reference numerals are used to identify like elements illustrated in one or more of the figures.

#### DETAILED DESCRIPTION

[00023] A multiple degree of freedom actuator suitable for use in a wide variety of different electronic devices is disclosed in accordance with various embodiments. The multiple degree of freedom actuator may be adapted for use in a camera, such as a miniature camera, for example.

[00024] The multiple degree of freedom actuator may be used to either manually or automatically focus the miniature camera. The multiple degree of freedom actuator may be used to zoom the miniature camera. The multiple degree of freedom actuator may be used to facilitate centration of an optical element. The multiple degree of freedom actuator may be used to provide optical image stabilization (OIS) for the miniature camera. The multiple degree of freedom actuator may be used to align optics (such as to actively align the optics during use thereof), e.g., provide fine alignment for lenses or other optical elements, within the camera. The multiple degree of freedom actuator may be used for optical correction, e.g., to mitigate undesirable effects of flaws in optical elements. For example, a lens may be rotated to place a defect therein

in a more desirable (or less harmful) position. The multiple degree of freedom actuator may be used for any other desired application in an electronic device or in any other device.

**[00025]** In accordance with one or more embodiments, the multiple degree of freedom actuator may comprise one or more MEMS actuators. For example, the multiple degree of freedom actuator may comprise linear comb drives and rotational comb drives.

**[00026]** The multiple degree of freedom actuator may be formed using monolithic construction. The multiple degree of freedom actuator may be formed using non-monolithic construction. The multiple degree of freedom actuator may be formed using contemporary fabrication techniques, such as etching and/or micromachining, for example. Various other fabrication techniques are contemplated.

**[00027]** The multiple degree of freedom actuator may be formed of silicon (e.g., single crystal silicon and/or polycrystalline silicon). The multiple degree of freedom actuator may be formed of various semiconductor materials such as silicon, germanium, diamond, and/or gallium arsenide. The material of which the multiple degree of freedom actuator is formed may be doped to obtain a desired conductivity thereof. The multiple degree of freedom actuator may be formed of a metal such as tungsten, titanium, germanium, aluminum, and/or nickel. Any desired combination of these and other materials may be used.

**[00028]** Motion control of the multiple degree of freedom actuator and/or items moved by the multiple degree of freedom actuator is disclosed in accordance with various embodiments. The motion control may be used to facilitate a desired movement of an item while mitigating undesired movement of the item. For example, the motion control may be used to facilitate movement of a lens along an optical axis of the lens, while inhibiting other movements of the lens. Thus, the motion control may be used to provide focusing and/or zoom by facilitating movement of the lens in single desired translational degree of freedom while inhibiting movement of the lens in all other translational degrees of freedom and while inhibiting movement of the lens in all rotational degrees of freedom.

**[00029]** In another example, the motion control may facilitate movement of the lens in all three translational degrees of freedom while inhibiting movement of the lens in all three rotational degrees of freedom. For example, focusing and/or zoom, as well as optical image stabilization, may be facilitated by providing movement of the lens in all three translational

degrees of freedom while inhibiting movement of the lens in all three rotational degrees of freedom.

**[00030]** Thus, an enhanced miniature camera for standalone use and for use in electronic devices may be provided. The miniature camera is suitable for use in a wide variety of different electronic devices. For example, the miniature camera is suitable for use in electronic devices such as cellular telephones, laptop computers, televisions, handheld devices, tablets, car cameras, web cams, and surveillance devices.

**[00031]** According to various embodiments, smaller size and enhanced shock resistance are provided. Enhanced shock resistance can result from the smaller size (and the consequent lower mass) of the miniature camera and its components. Enhanced shock resistance can result from features of the multiple degree of freedom actuator discussed herein.

**[00032]** Fig. 1 shows an electronic device 100 having a miniature camera 101 in accordance with an embodiment. The miniature camera 101 can have a multiple degree of freedom actuator 400, such as in a lens barrel 200 thereof. The multiple degree of freedom actuator 400 can facilitate focus, zoom, optical image stabilization and/or optical correction as discussed herein.

**[00033]** The electronic device 100 may be a cellular telephone, a laptop computer, a surveillance device, or any other desired device. The miniature camera 101 may be built into the electronic device 100, may be attached to the electronic device 100, or may be separate (e.g., remote) with respect to the electronic device 100.

**[00034]** Fig. 2 shows the miniature camera 101 having the lens barrel 200 extending therefrom, in accordance with an embodiment. The lens barrel 200 may contain one or more optical elements, such as a movable lens 301, which may be moved by the multiple degree of freedom actuator 400 (see Fig. 5). The lens barrel 200 may have one or more optical elements which may be fixed. For example, the lens barrel 200 may contain one or more lenses, apertures (variable or fixed), shutters, mirrors (which may be flat, non-flat, powered, or non-powered), prisms, spatial light modulators, diffraction gratings, lasers, LEDs and/or detectors. Any of these items may be fixed or may be movable by the multiple degree of freedom actuator 400.

**[00035]** The multiple degree of freedom actuator 400 may be used in non-camera applications. The multiple degree of freedom actuator 400 may be used to move either optical or

non-optical devices in various applications. For example, the multiple degree of freedom actuator 400 may be used to move samples that are provided for scanning. The samples may be either biological samples or non-biological samples.

**[00036]** Examples of biological samples include organisms, tissues, cells, and proteins. Examples of non-biological samples include integrated circuits, MEMS devices, solids, liquids, and gases. The multiple degree of freedom actuator 400 may be used to manipulate structures, light, sound, or any other desired thing.

**[00037]** The optical elements may be partially or fully contained within the lens barrel 200. The lens barrel 200 may have any desired shape. For example, the lens barrel 200 may be substantially round, triangular, rectangular, square, pentagonal, hexagonal, octagonal, or of any other shape or cross-sectional configuration. The lens barrel 200 may be either permanently or removably attached to the miniature camera 101. The lens barrel 200 may be defined by a portion of a housing of the miniature camera 101. The lens barrel 200 may be partially or completely disposed within the miniature camera 101.

**[00038]** Fig. 3A shows an actuator module 300 disposed within the lens barrel 200, in accordance with an embodiment. The actuator module 300 may contain the multiple degree of freedom actuator 400. The multiple degree of freedom actuator 400 may be completely contained within the lens barrel 200, partially contained within the lens barrel 200, or completely outside of the lens barrel 200. The multiple degree of freedom actuator 400 may be adapted to move optical elements contained within the lens barrel 200, optical elements not contained within the lens barrel 200, and/or any other desired items.

**[00039]** Fig. 3B shows the lens barrel 200 and the actuator module 300 in an exploded view, in accordance with an embodiment. The movable lens 301 is an example of an optical element that may be attached to or in mechanical communication with the multiple degree of freedom actuator 400 and may be moved thereby. The movable lens 301 can be moved along an optical axis 410 of the miniature camera 101 to facilitate focus and/or zoom, for example. The multiple degree of freedom actuator 400 may be disposed between an upper module cover 401 and a lower module cover 402.

**[00040]** Additional optical elements, such as fixed (e.g., stationary) lenses 302 may be provided. The additional optical elements may facilitate focus, zoom, and/or optical image



stabilization, for example. Any desired number and/or type of movable (such as via the multiple degree of freedom actuator 400) and fixed optical elements may be provided.

**[00041]** Fig. 4 shows the actuator module 300, in accordance with an embodiment. The actuator module 300 may be disposed partially or completely within the miniature camera 101. The multiple degree of freedom actuator 400 may be disposed partially or completely within the actuator module 300. For example, the multiple degree of freedom actuator 400 may be sandwiched substantially between an upper module cover 401 and a lower module cover 402.

**[00042]** The actuator module 300 may have any desired shape. For example, the actuator module 300 may be substantially round, triangular, square, rectangular, pentagonal, hexagonal, octagonal, or of any other shape or cross-sectional configuration.

**[00043]** In an embodiment, the lens barrel 200 may be substantially round in cross-sectional configuration and the actuator module 300 may be substantially round in cross-sectional configuration. The use of a substantially round lens barrel 200 and a substantially round actuator module 300 may facilitate an advantageous reduction in size. The reduction in size may be facilitated, for example, because round lenses are commonly preferred. The use of a substantially round lens barrel 200 and a substantially round actuator module 300 with round lenses tends to result in a reduction of wasted volume and thus tends to facilitate a reduction in size.

**[00044]** As discussed herein, one or more optical elements, such as the movable lens 301, may be disposed in an opening 405 (e.g., a hole) formed in the actuator module 300. The multiple degree of freedom actuator 400 may effect movement of the optical elements along their optical axis 410, for example. Thus, the multiple degree of freedom actuator 400 may move one or more lenses, such as lens 301, to effect focusing or zoom, for example.

**[00045]** The actuator module 300 may have cutouts 403 formed therein to facilitate assembly of the actuator module 300 and alignment of the multiple degree of freedom actuator 400 contained therein. The cutouts 403 and/or electrical contacts 404 partially disposed within the cutouts 403 may be used to facilitate alignment of the actuator module 300 with respect to the lens barrel 200.

**[00046]** FIG. 5 shows the multiple degree of freedom actuator 400, in accordance with an embodiment of the invention. The multiple degree of freedom actuator 400 can provide motion controlled movement in six degrees of freedom for used in a variety of applications. The multiple degree of freedom actuator 400 can provide three degrees of linear or translational motion and three degrees of angular or rotational motion.

**[00047]** The multiple degree of freedom actuator 400 can comprise three substantially identical sectors 501. Each sector 501 can comprise both a tangential or in-plane actuator 502 and a Z-motion or out-of-plane actuator 503. The in-plane actuators 502 can be linear electrostatic comb drives, for example. The out-of-plane actuators 503 can be rotational electrostatic comb drives, for example. The out-of-plane actuators 503 can be linear, e.g., vertical or 2-axis, electrostatic comb drives, for example. Each of the in-plane actuators 502 and each of the out-of-plane actuators 503 can be independently controllable and movable with respect to one another.

**[00048]** The in-plane actuators 502 and the out-of-plane actuators 503 can control the motion of a platform 504. The platform 504 can define a lens ring and can be used to mount one or more lenses. For example, the platform 504 can mount the lens 301, which can be a focusing lens and/or a zoom lens. The platform 504 can be moved in all six degrees of freedom.

**[00049]** Since the platform 504 can be moved in all six degrees of freedom, it can facilitate focus, zoom, optical image stabilization, optical element alignment, and/or optical correction for example. Focus and/or zoom can be facilitated by translating one or more lenses along a z-axis. Optical image stabilization and/or optical element alignment can be facilitated by translating one or more lenses or another optical element within an x-y plane and/or by rotating the lens or other optical element(s) about an x-axis and/or a y-axis.

**[00050]** Although FIG. 5 shows the multiple degree of freedom actuator 400 as having three in-plane actuators 502, the multiple degree of freedom actuator 400 can have any number of in-plane actuators 502. For example, the multiple degree of freedom actuator 400 can have one, two, three, four, five, six, or more in-plane actuators 502.

**[00051]** Each in-plane actuator 502 can provide tangential movement of the platform 504. That is, each in-plane actuator 502 can move a point 511 on a periphery of the platform 504 in a direction that is substantially tangential with respect to the periphery of the platform 504, as indicated by arrow 512.

**[00052]** All of the in-plane actuators 502 can cooperate to provide translational movement of the platform 504 within the x-y plane (within the plane of the multiple degree of freedom actuator 400). Such x-y plane movement of the platform 504 can be used to translate the lens 301 for optical image stabilization or alignment, for example.

**[00053]** All of the in-plane actuators 502 can cooperate to provide z-axis rotational movement of the platform 504. Such z-axis rotational movement can be used to rotate a direction sensitive optical element, such as a polarizer or a diffraction grating, for example.

**[00054]** Although FIG. 5 shows the multiple degree of freedom actuator 400 as having three out-of-plane actuators 503, the multiple degree of freedom actuator 400 can have any number of out-of-plane actuators 503. For example, the multiple degree of freedom actuator 400 can have one, two, three, four, five, six, or more out-of-plane actuators 503.

**[00055]** The out-of-plane actuators 503 can cooperate to provide translational movement of the platform 504 along the z-axis (which is perpendicular with respect to the plane of the multiple degree of freedom actuator 400). Such z-axis movement of the platform 504 can be used to translate the lens 301 for focus and/or zoom, for example. The out-of-plane actuators 503 can cooperate to provide rotational movement of the platform 504 about the x-axis and/or y-axis. Such rotational movement can be used to rotate the lens 301 for optical image stabilization or alignment, for example.

**[00056]** FIG. 6 is an enlarged view showing one sector 501 of the multiple degree of freedom actuator 400 of FIG. 5, in accordance with an embodiment of the invention. As shown in FIG. 5, the multiple degree of freedom actuator 400 comprises three sectors 501. The multiple degree of freedom actuator 400 can comprise any desired number of sectors 501. For example, the multiple degree of freedom actuator 400 can comprise one, two, three, four, five, six, or more sectors 501.

**[00057]** The in-plane actuators 502 can each comprise a fixed x-y frame 601 and a movable x-y frame 602. Comb fingers or teeth 603 can extend from the fixed x-y frame 601 and the movable x-y frame 602 and can cooperate to define an electrostatic actuator that effects substantially linear movement of the movable x-y frame 602 with respect to the fixed x-y frame 601. The movable x-y frame 602 moves within the x-y plane. The movable x-y frame 602 moves back and forth in the directions indicated by arrow 512.

[00058] The fixed x-y frame 601 of each sector 501 can cooperate to define an outer frame 610 of the multiple degree of freedom actuator 400. The outer frame 610 can substantially rigidly interconnect each of the sectors 501 to one another.

[00059] The out-of-plane actuators 503 can each comprise an out-of plane, deployed z-frame 620 and a movable z-frame 621. Comb fingers or teeth 623 can extend from the deployed z-frame 620 and the movable z-frame 621 and can cooperate to define an electrostatic actuator that effects movement of the movable z-frame 621 with respect to the deployed z-frame 620. The movable z-frame 621 rotates so as to provide movement of at least a portion of the platform 504 substantially along the z axis.

[00060] The deployed z-frame 620 can be deployed to a position such that the deployed z-frame 620 is angularly disposed with respect to the plane of the multiple degree of freedom actuator 400. That is, the deployed z-frame 620 can be rotated about a hinge line 551 that passes through a proximal portion 552 of the deployed z-frame 620 so as to cause a distal portion 553 of the deployed z-frame 620 to move out of the plane of the multiple degree of freedom actuator 400 and into the deployed position of the deployed z-frame 620. The deployed position of the deployed z-frame 620 can be either above or below (on either side of) the plane of the multiple degree of freedom actuator 400.

[00061] FIG. 7 shows the sector of FIG. 6 with the teeth 603 and 623 removed for clarity, in accordance with an embodiment of the invention. Motion control features can be used to limit the motion of the in-plane actuators 502 and the out-of-plane actuators 503. The motion control features can consequently limit the motion of the platform 504, since the motion of the platform 504 is controlled by the in-plane actuators 502 and the out-of-plane actuators 503.

[00062] For example, tangential movement flexures 701, cantilever flexures 702, torsional flexures 703, outer hinge flexures 704, and inner hinge flexures 705 can be used to facilitate motion control.

[00063] The tangential movement flexures 701 can facilitate lateral movement of the in-plane actuators 502 so as to provide tangential movement of the platform 504. This can be done while the tangential movement flexures 701 inhibit movement of the in-plane actuators 502 in other degrees of freedom.

**[00064]** The cantilever flexures 702 can transfer z-axis motion of the out-of-plane actuators 503 to the platform 504 while accommodating the varying distance between out-of-plane actuators 503 and the platform 504. This can be done while the cantilever flexures 702 inhibit movement of the out-of-plane actuators 503 in other degrees of freedom.

**[00065]** The torsional flexures 703 can facilitate rotational movement of the movable z-frames 621 of the out-of-plane actuators 503 so as to provide movement of the platform 504 along the z-axis. This can be done while the torsional flexures 703 inhibit movement of the movable z-frames 621 in other degrees of freedom. In particular, the torsional flexures 703 inhibit movement of the movable z-frames 621 along the x axis.

**[00066]** The outer hinge flexures 704 can facilitate rotational movement of the movable z-frame 621 of the out-of-plane actuators 503 so as to provide movement of the platform 504 along the z-axis. This can be done while the outer hinge flexures 704 inhibit movement of the movable z-frame 621 in other degrees of freedom. In particular, the outer hinge flexures inhibit movement of the y direction.

**[00067]** The inner hinge flexures 705 can facilitate rotational movement of the out-of-plane actuators 503 as the cantilever flexures 702 transfer z-axis motion of the out-of-plane actuators 503 to the platform 504. This can be done while the inner hinge flexures 705 inhibit movement of the platform 504 in other degrees of freedom.

**[00068]** Each of the out-of-plane actuators 503 can have two proximal lateral snubber assemblies 706 and one distal lateral snubber assembly 707 to provide further motion control, for example. The proximal lateral snubber assemblies 706 can inhibit lateral movement of the movable z-frame 621 with respect to the deployed z-frame 620. The distal lateral snubber assembly 707 can inhibit later movement of the platform 504 with respect to the movable z-frame 621.

**[00069]** FIG. 8 is an enlarged view showing the out-of-plane actuator of FIG. 7, in accordance with an embodiment of the invention. The teeth 603 of the in-plane actuators 502 and the teeth 623 out-of-plane actuators 503 are shown.

**[00070]** FIG. 9 is an enlarged view showing a portion of the in-plane actuator of FIG. 9, in accordance with an embodiment of the invention. Some of the motion control features can be more clearly seen in this view. For example, one of the tangential movement flexures 701, one

of the cantilever flexures 702, one of the torsional flexures 703, one of the outer hinge flexures 704, and one of the inner hinge flexures 705 can be more clearly seen.

**[00071]** In operation, the three out-of-plane actuators 503 can move in unison to translate one or more lenses and thus facilitate focus and/or zoom. The three out-of-plane actuators 503 can move independently to rotate one or more lenses to facilitate optical image stabilization or alignment of the lens(es). The three in-plane actuators 502 can move independently to translate one or more lenses or another optical element to facilitate optical image stabilization or alignment of the lens(es) or optical element.

**[00072]** Any of the in-plane actuators 502 and the out-of-plane actuators 503 can be biased or moved to a given position that can be considered a zero or centered position. The centered position can be anywhere along the range of travel for the in-plane actuators 502 and the out-of-plane actuators 503. The centered position can be an aligned position of the lens(s) or other optical elements. The in-plane actuator(s) 502 and/or the out-of-plane actuator(s) 503 can remain in this centered position until driven to a different position to effect focus, zoom, or optical image stabilization.

**[00073]** The state or position of each of the in-plane actuators 502 and each of the out-of-plane actuators 503 can be controlled by providing a control signal or voltage thereto. Generally, higher voltages will result in greater movement of the in-plane actuators 502 and the out-of-plane actuators 503.

**[00074]** FIG. 10 is a flow chart showing an example of operation of the multiple degree of freedom actuator 400, in accordance with an embodiment of the invention. On power up of the electronic device 100 and/or the miniature camera 101, the in-plane actuators 502 and/or the out-of-plane actuators 503 can move the lens 301 to an aligned position proximate a center of travel of the lens 301.

**[00075]** More particularly, the out-of-plane actuators 503 can move the lens to a position proximate the center of travel of the lens 301, as indicated in block 1001 and the in-plane actuators 502 can cooperate with the out-of-plane actuators 503 to align the lens in all six degrees of freedom, as indicated in block 1002.

[00076] During an autofocus process, the lens 301 can be moved by the out-of-plane actuators 503 to a position that provides a desired focus of the miniature camera 101, as indicated in block 1003. This movement can be accomplished while maintaining the alignment of the lens 301.

[00077] During an optical image stabilization process, the in-plane actuators 502 and/or the out-of-plane actuators 503 can cooperate to move the lens 301 in a manner that provides optical image stabilization as indicated in block 1004. Aligning the lens 301, focusing with the lens 301, and providing optical image stabilization with the lens 301 can occur serially, in parallel with one another, or partially serially and partially in parallel (e.g. can overlap) with one another.

An improved MEMS actuator has multiple degrees of freedom. The improved MEMS actuator has motion control to limit undesirable movement. The improved MEMS actuator is suitable for use in a miniature camera to facilitate focus, zoom, optical image stabilization, and/or alignment of optical elements for example.

The improved MEMS actuator can embed or nest plural electrostatic drives, such as linear and rotational comb drives, to tend to minimize space, e.g., real estate, used therefore. Any desired number of electrostatic drives can be nested in any desired fashion.

[00078] While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

## CLAIMS

What is claimed as new and desired to be protected is:

1. A device comprising:
  - at least one first MEMS actuator configured to move a platform in translation along a first axis; and
  - at least one second MEMS actuator configured to move the platform in a direction that is generally perpendicular to the first axis.
2. The device as recited in Claim 1, wherein the first MEMS actuator(s) comprise a plurality of independently actuatable actuators.
3. The device as recited in Claim 1, wherein the second MEMS actuator(s) comprise a plurality of independently actuatable actuators.
4. The device as recited in Claim 1, wherein the first MEMS actuator(s) comprise a plurality of substantially identical actuators.
5. The device as recited in Claim 1, wherein the second MEMS actuator(s) comprise a plurality of substantially identical actuators.
6. The device as recited in Claim 1, wherein three first MEMS actuators are configured to cooperate to move the platform.
7. The device as recited in Claim 1, wherein three first MEMS actuators are configured to cooperate to rotate the platform about a second axis and a third axis that are perpendicular to the first axis.
8. The device as recited in Claim 1, wherein three second MEMS actuators are configured to cooperate to move the platform.



9. The device as recited in Claim 1, wherein three second MEMS actuators are configured to cooperate to move the platform in any direction within a plane that is perpendicular to the first axis.
10. The device as recited in Claim 1, where the three second MEMS actuators are configured to rotate the platform about the first axis.
11. The device as recited in Claim 1, wherein the first MEMS actuator(s) are nested at least partially within the second MEMS actuator(s).
12. The device as recited in Claim 1, wherein each of the first MEMS actuators is nested within one of the second MEMS actuators.
13. The device as recited in Claim 1, wherein the first MEMS actuators comprise rotational comb drives.
14. The device as recited in Claim 1, wherein the second MEMS actuators define a plane and at least a portion of each first MEMS actuator is deployed to a position out of the plane.
15. The device as recited in Claim 1, wherein the platform comprises a lens ring.
16. The device as recited in Claim 1, wherein the first MEMS actuators are configured to facilitate focusing of a camera.
17. The device as recited in Claim 1, wherein the second MEMS actuators are configured to facilitate optical image stabilization of a camera.
18. The device as recited in Claim 1, wherein the device is a camera.
19. The device as recited in Claim 1, wherein the device is a cellular telephone.
20. A MEMS actuator assembly comprising a plurality of nested actuators configured to focus a camera and to provide optical image stabilization for the camera.

21. A method for operating a camera, the method comprising:  
moving a platform in translation with at least one first MEMS actuator; and  
moving the platform tangentially with at least one second MEMS actuator.
22. The method as recited in claim 21, wherein:  
an optical element is attached to the platform; and  
moving the platform effects centration of the optical element.
23. The method as recited in claim 21, wherein:  
an optical element is attached to the platform; and  
moving the platform effects alignment of the optical element.
24. A multiple degree of freedom actuator comprising:  
a fixed frame;  
a platform that is movable with respect to the fixed frame;  
three independently movable MEMS actuators interconnecting the fixed frame  
and the platform; and  
wherein the three MEMS actuators are configured to cooperate to move the  
platform in three degrees of freedom.
25. The multiple degree of freedom actuator as recited in claim 24, wherein the three  
degrees of freedom are rotational degrees of freedom.
26. A method comprising:  
providing a platform that is movable with respect to a fixed frame; and  
moving the platform in three degrees of freedom using three independently  
movable MEMS actuators.

27. The method as recited in claim 26, wherein the three degrees of freedom are rotational degrees of freedom.

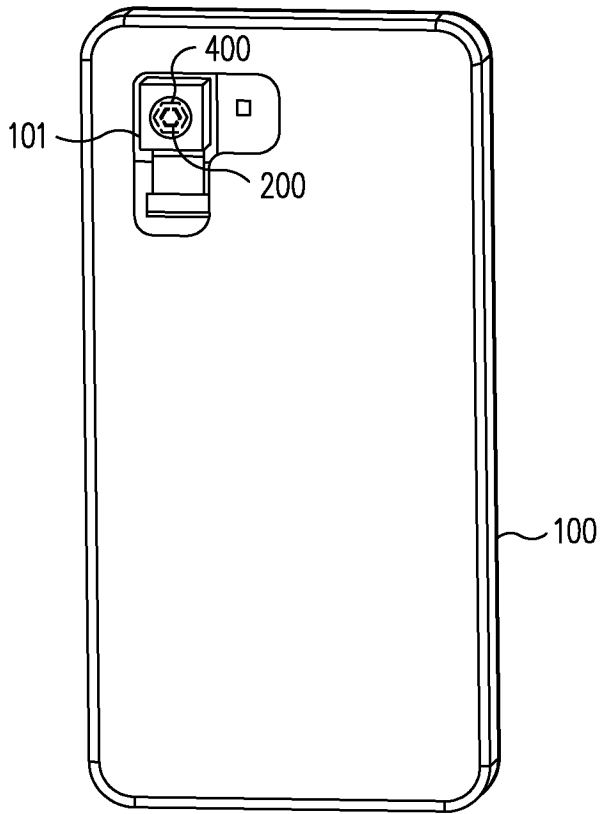


FIG. 1

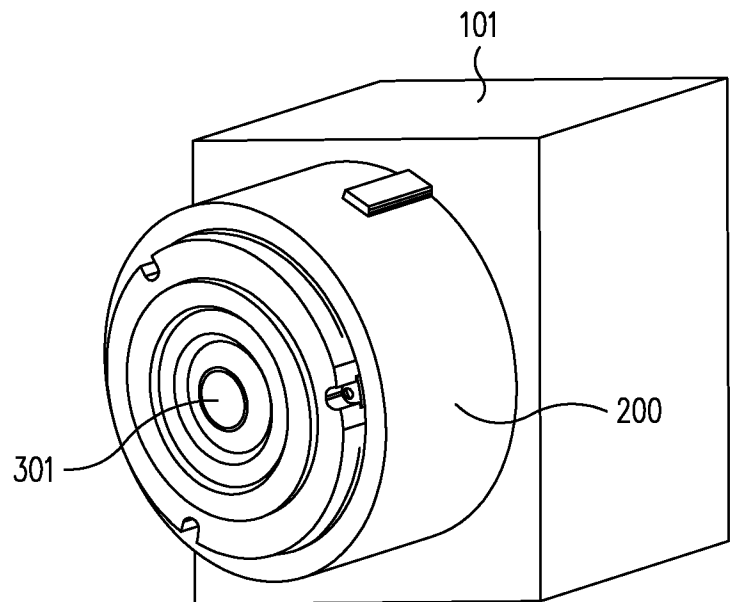


FIG. 2

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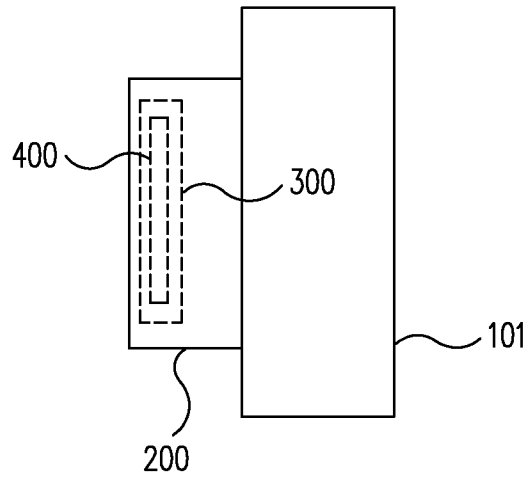


FIG. 3A

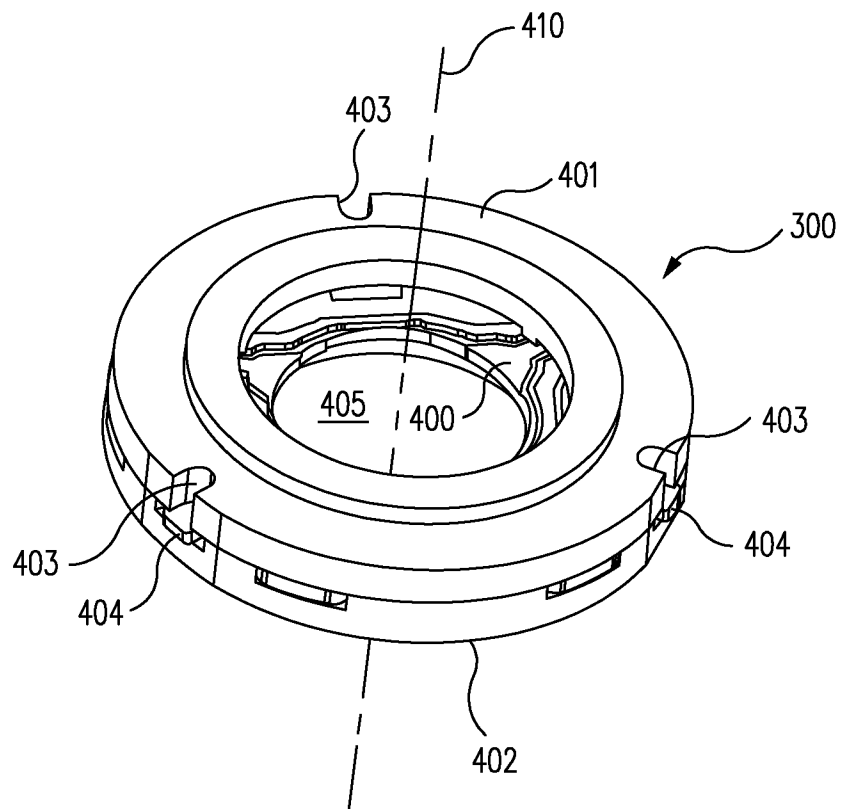


FIG. 4

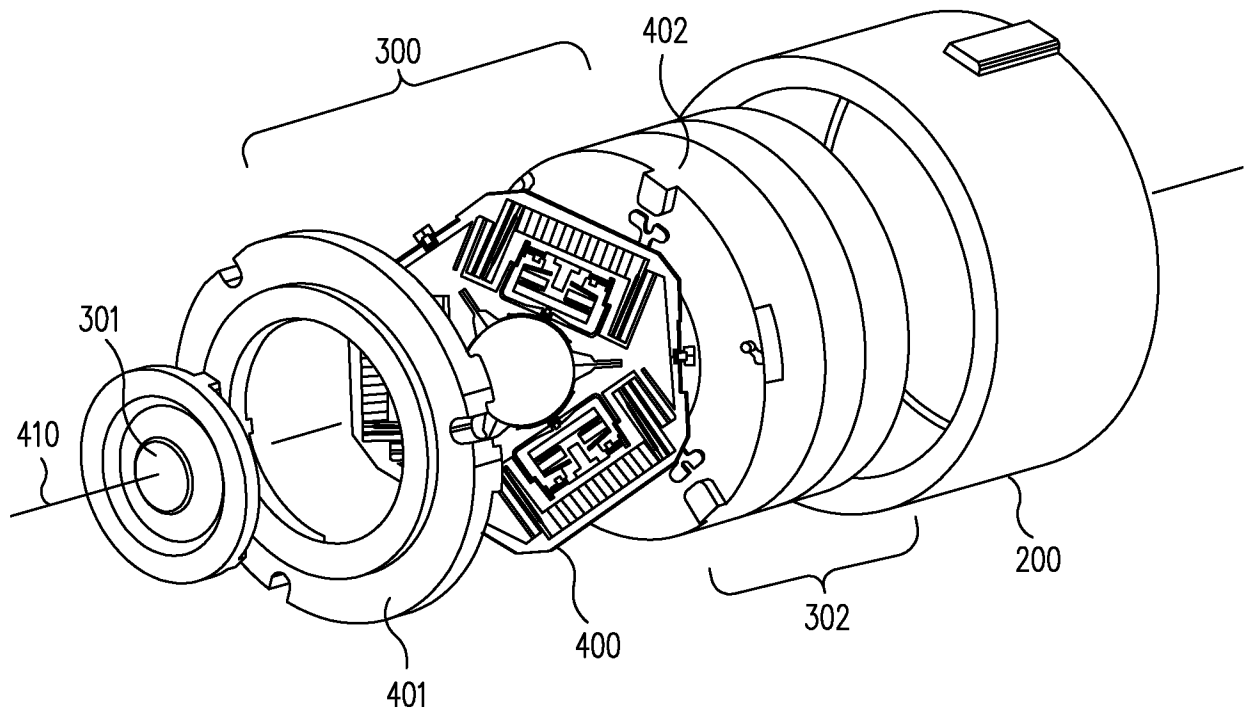


FIG. 3B

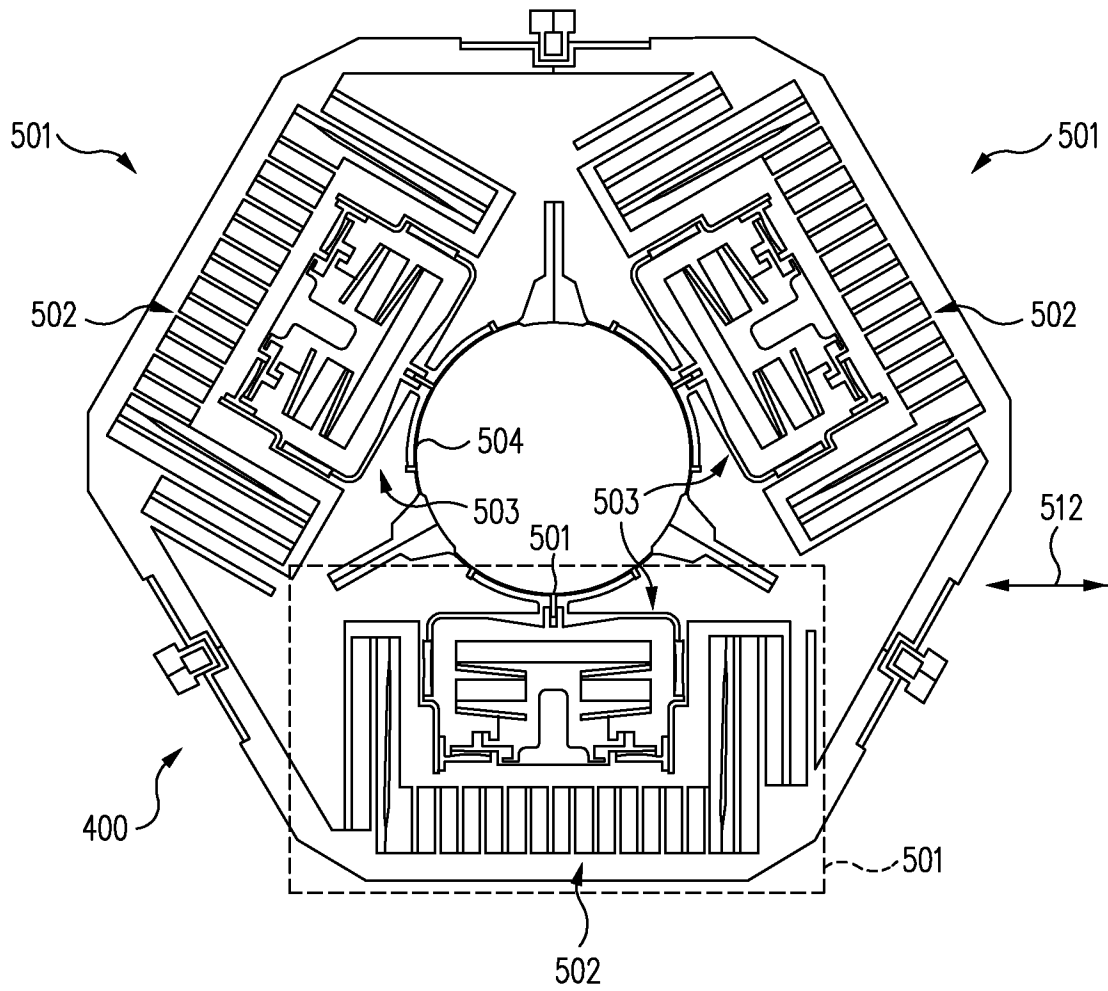
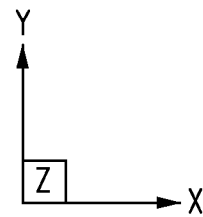


FIG. 5



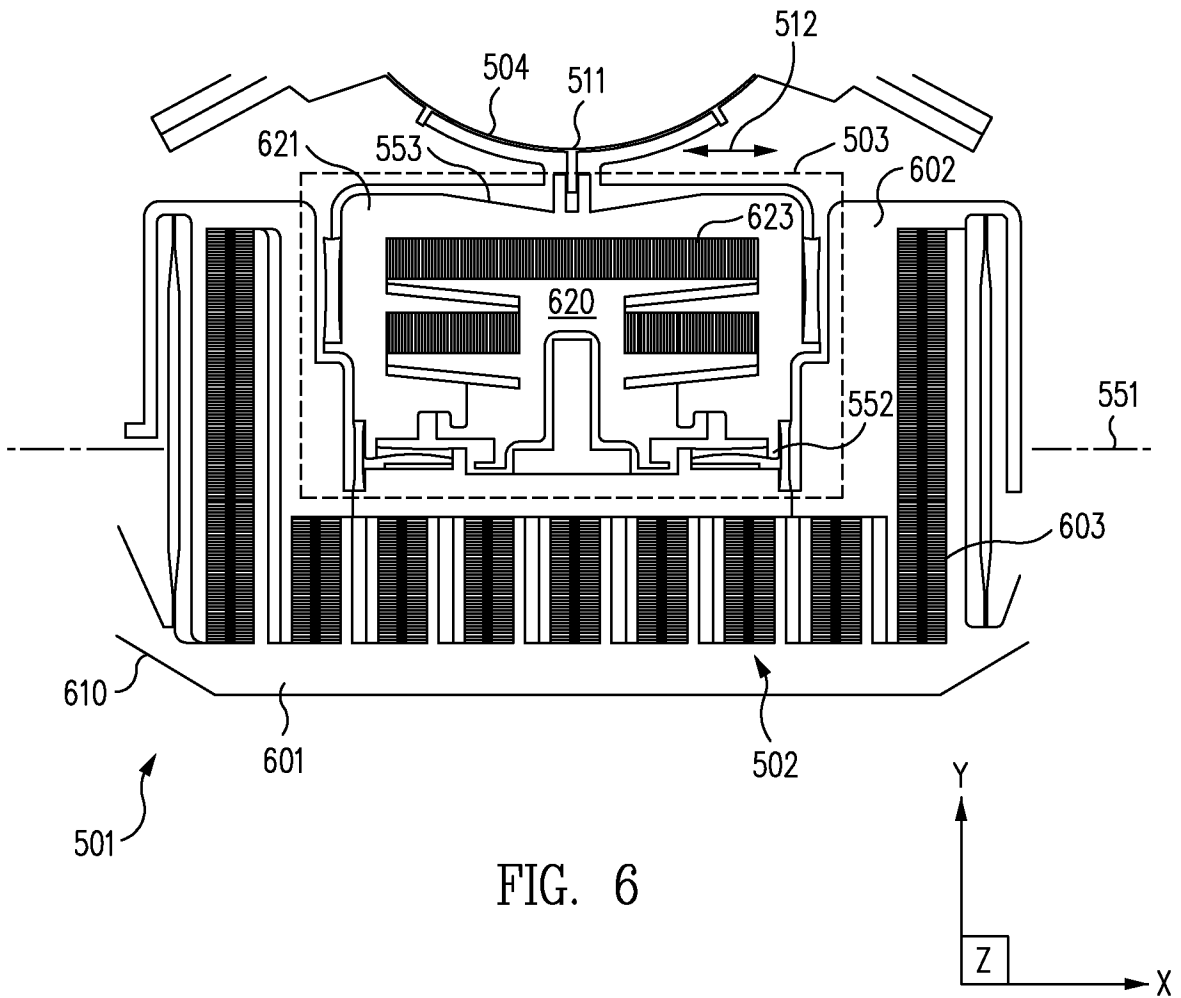


FIG. 6



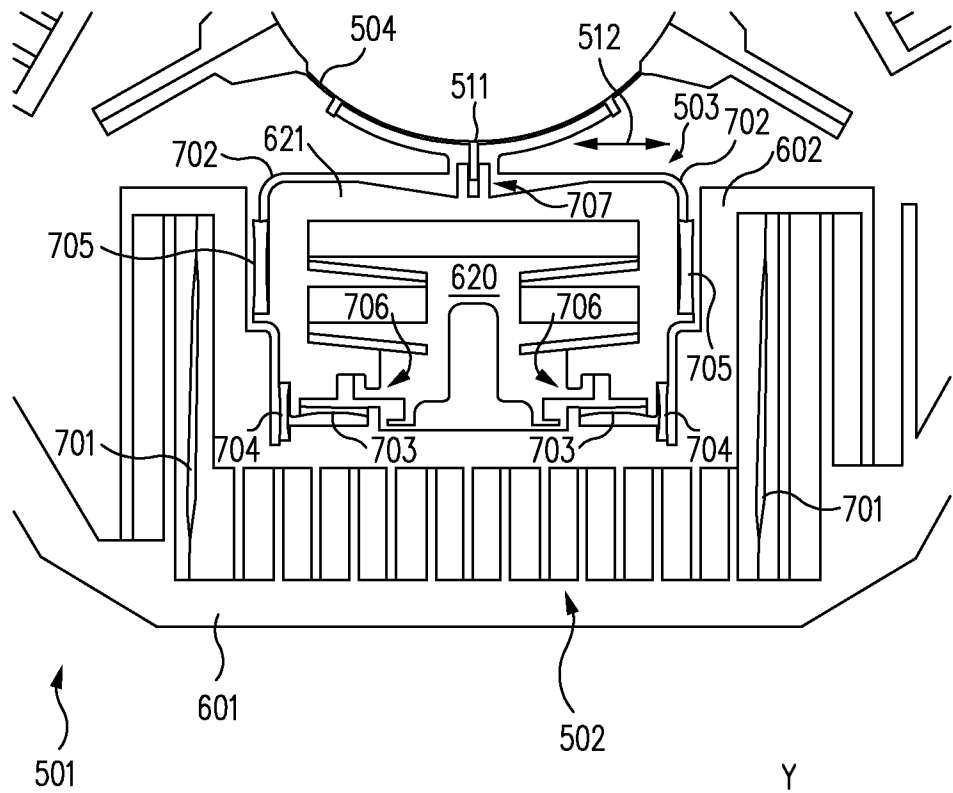
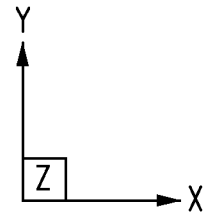


FIG. 7



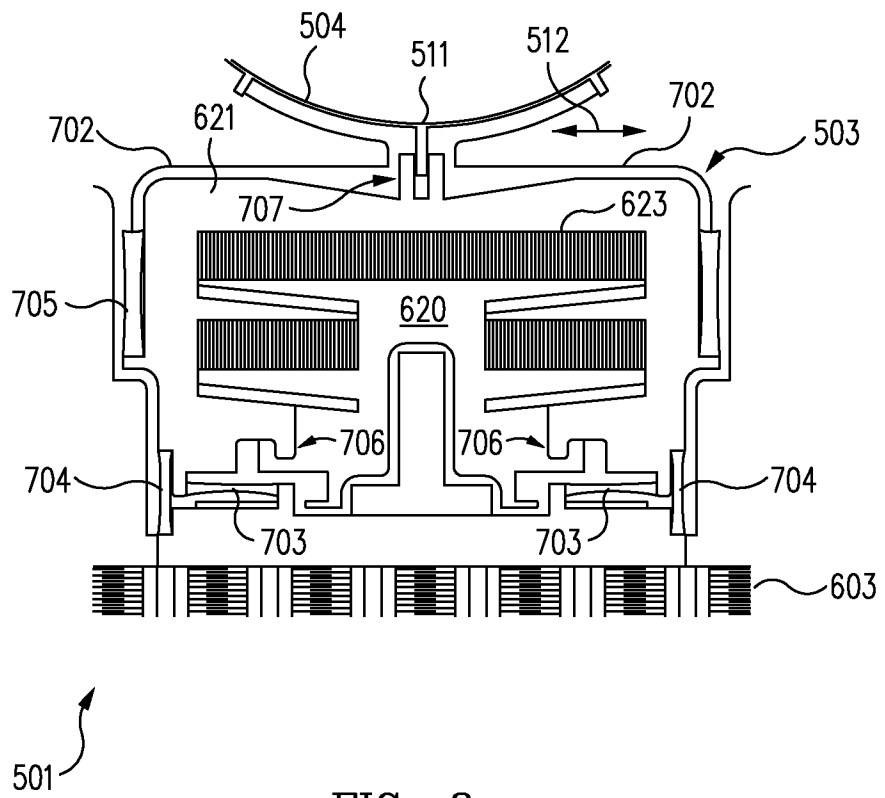


FIG. 8

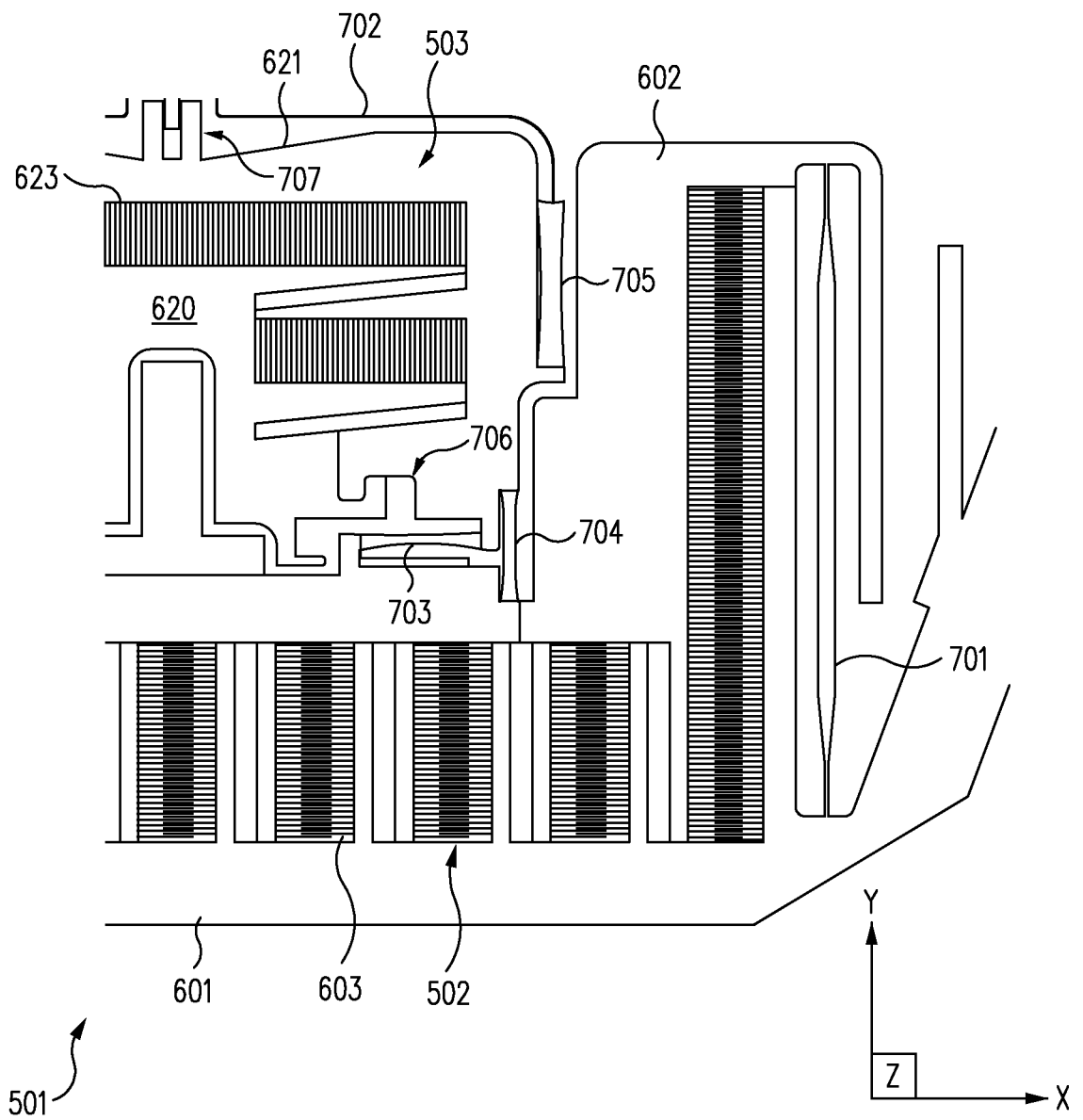


FIG. 9

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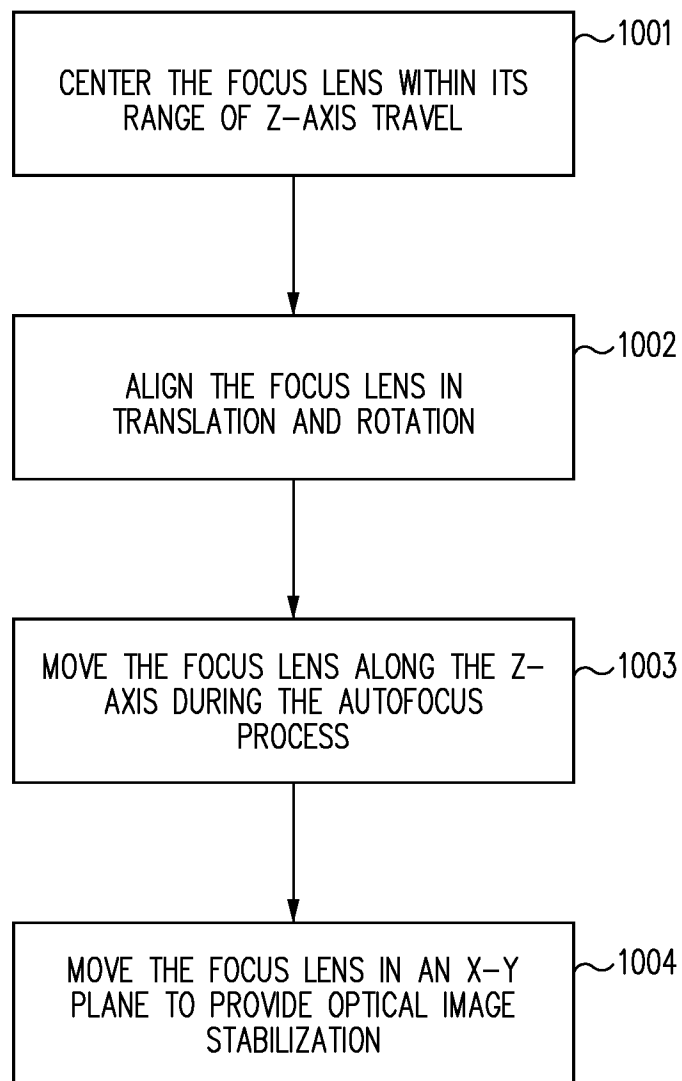


FIG. 10