(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 June 2016 (23.06.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/100099 A1

(51) International Patent Classification:
H01L 21/304 (2006.01)

(21) International Application Number:
PCT/US2015/065136

(22) International Filing Date:
10 December 2015 (10.12.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/094,414 19 December 2014 (19.12.2014) US
14/624,197 17 February 2015 (17.02.2015) US

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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, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, 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, SA, 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.

(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, ST, 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, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) Title: SYSTEMS, APPARATUS, AND METHODS FOR AN IMPROVED POLISHING HEAD GIMBAL USING A SPHERICAL BALL BEARING

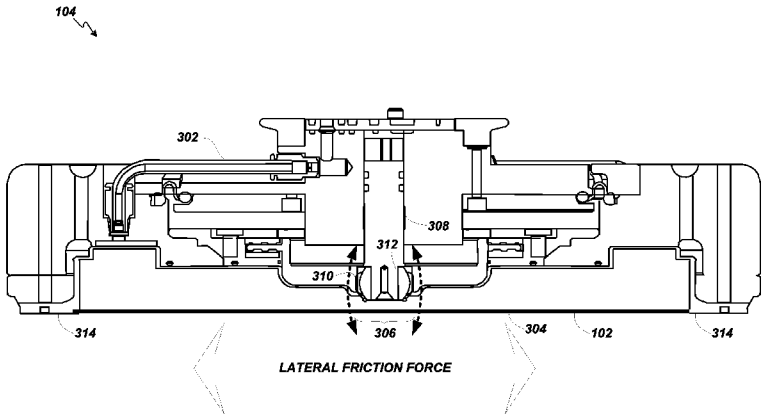


FIG. 3

(57) Abstract: Embodiments of the present invention provide systems, apparatus, and methods for an improved polishing head including an upper portion and a lower portion, the lower portion adapted to hold a substrate and to tilt relative to the upper portion, the tilt enabled by a spherical bearing, wherein the lower portion is adapted to tilt while rotating the substrate against a rotating polishing pad so that the lower portion remains flush against the rotating polishing pad while resisting lateral friction force generated by the rotating polishing pad contacting the substrate and pushing the substrate laterally against the lower portion. Numerous additional aspects are disclosed.

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SYSTEMS, APPARATUS, AND METHODS FOR AN IMPROVED POLISHING HEAD GIMBAL USING A SPHERICAL BALL BEARING

RELATED APPLICATION

[0001] The present application claims priority to U.S. Non-Provisional Patent Application No. 14/624,197 filed February 17, 2015, entitled "SYSTEMS, APPARATUS, AND METHODS FOR AN IMPROVED POLISHING HEAD GIMBAL USING A SPHERICAL BALL BEARING" (Attorney Docket No. 20709/USA) and also from U.S. Provisional Patent Application No. 62/094,414 filed December 19, 2014, and entitled "SYSTEMS, APPARATUS, AND METHODS FOR AN IMPROVED POLISHING HEAD GIMBAL USING A SPHERICAL BALL BEARING" (Attorney Docket No. 20709/USA/L), both of which are hereby incorporated by reference in their entirety for all purposes.

FIELD

[0002] The present invention relates to chemical-mechanical planarization (CMP) polishing heads, and more specifically to systems, apparatus, and methods for an improved polishing head gimbal using a spherical ball bearing.

BACKGROUND

[0003] Semiconductor substrates are a fundamental material in the production of semiconductor devices. Semiconductor devices are found in many different and very common products and components, including PCs, cell phones and other IT devices, digital cameras, TVs and other digital consumer electronics appliances, as well as automotive control systems. The evolution of semiconductor devices has enriched mankind's lives by offering convenience and comfort.

[0004] The history of progress in semiconductor devices involves repeated improvements in packing density, performance and economic rationality. An important contribution to this advancement has been made by the move towards larger semiconductor substrates. For example, a larger substrate diameter makes it possible to produce more semiconductor devices from a single substrate. This means a considerable rise in productivity and economic efficiency.

[0005] Semiconductor substrates have been growing gradually and steadily for the last 50 years, from 100 mm, 150 mm, and 200 mm silicon to the current 300 mm diameter substrates. The historical reasons for this substrate size growth were based on three related trends: growing chip size, growing demand for chips, and the greater chip throughput (and thus lower chip cost) that the larger substrate sizes enabled. And while chip sizes have largely stabilized, the other two factors have remained compelling. The last two substrate size transitions (150 mm to 200 mm and 200 mm to 300 mm) each resulted in about a 30% reduction in the cost per area of silicon (and thus cost per chip). For the next step, the feasibility of increasing substrate size to 450 mm is being studied.

[0006] With increasing substrate size, the surface area to be planarized using chemical-mechanical planarization (CMP) methods is increased. Increased surface area results in higher lateral frictional forces being imposed on components within CMP systems. In particular, the gimbals used in CMP polishing heads bear an increased load due to higher lateral frictional forces of larger substrates. Thus, what is needed are improved systems, apparatus, and methods for a polishing head gimbal that can manage the increased frictional forces.

SUMMARY

[0007] In some embodiments, the present invention provides a system for chemical-mechanical planarization. The system includes a platen supporting a polishing pad and adapted to rotate the polishing pad; and a polishing head adapted to rotate and including an upper portion and a lower portion, the lower portion adapted to hold a substrate and to tilt relative to the upper portion, the tilt enabled by a spherical bearing. The lower portion is adapted to tilt while rotating the substrate against the polishing pad so that the lower portion remains flush against the rotating polishing pad while resisting lateral friction force generated by the rotating polishing pad contacting the substrate and pushing the substrate laterally against the lower portion.

[0008] In some other embodiments, the present invention provides a polishing head for chemical-mechanical planarization. The polishing head includes an upper portion and a lower portion, the lower portion adapted to hold a substrate and to tilt relative to the upper portion, the tilt enabled by a spherical bearing. The lower portion is adapted to tilt while rotating the substrate against a rotating polishing pad so that the lower portion remains flush against the rotating polishing pad while resisting lateral friction force generated by the rotating polishing pad contacting the substrate and pushing the substrate laterally against the lower portion.

[0009] In yet other embodiments, the present invention provides a method for chemical-mechanical planarization. The method includes providing a polishing head including an upper portion and a lower portion, the lower portion adapted to hold a substrate and to tilt relative to the upper portion, the tilt enabled by a spherical bearing; rotating the polishing head while holding the substrate against a moving polishing

pad; and tilting the lower portion while rotating the substrate against the polishing pad so that the lower portion remains flush against the moving polishing pad while resisting lateral friction force generated by the moving polishing pad contacting the substrate and pushing the substrate laterally against the lower portion.

[00010] Still other features, aspects, and advantages of embodiments the present invention will become more fully apparent from the following detailed description, the appended claims, and the accompanying drawings by illustrating a number of exemplary embodiments and implementations, including the best mode contemplated for carrying out embodiments of the present invention. Embodiments of the present invention may also be capable of other and different applications, and its several details may be modified in various respects, all without departing from the spirit and scope of embodiments of the present invention. Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive. The drawings are not necessarily drawn to scale. The description is intended to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[00011] FIG. 1 is a schematic diagram depicting an example chemical-mechanical planarization (CMP) system according to embodiments of the present invention.

[00012] FIG. 2 is a schematic diagram depicting a polishing head according to the prior art.

[00013] FIG. 3 is a schematic diagram depicting an example polishing head apparatus according to embodiments of the present invention.

[00014] FIGs. 4A & 4B are perspective drawings of two different example spherical bearings suitable for use in some embodiments of the present invention.

[00015] FIG. 5 is a flowchart illustrating an example method of chemical-mechanical planarization according to embodiments of the present invention.

DETAILED DESCRIPTION

[00016] Embodiments of the present invention provide systems, apparatus, and methods for an improved polishing head gimbal using a spherical ball bearing. Prior art gimbal mechanisms within CMP polishing heads typically use a flexure bearing design to accommodate vertical platen run-out. This type of run-out occurs when the platen upon which the polishing pad sits is not perfectly parallel with the polishing head that holds the substrate. Vertical platen run-out translates to head tilt while resisting lateral loads resulting from friction during processing. While accommodating the run-out and providing head tilt, the fatigue limit of the flexure bearing design is approached and can be exceeded as process conditions (*e.g.*, which can include larger substrates) result in greater lateral loads. Process conditions may require costly material changes beyond geometric optimizations of the flexure bearing design. Using a spherical bearing instead of a flexure bearing as a gimbal for the polishing head allows for gimbaling on low friction bearings which can also endure the increasing lateral loads to which the polishing head is being subjected.

[00017] Turning to FIG. 1, a side view of an example chemical-mechanical planarization (CMP) system 100 for polishing a substrate 102 is shown. The system 100 includes a polishing head 104 supported by an arm 106 that is operative to move the

polishing head 104 holding a substrate 102 toward a polishing pad 108 on a rotating platen 110. In operation, the polishing head 104 holds the substrate 102 against the polishing pad 108 to remove material from the substrate 102. As the polishing pad 108 is rotated on the platen 110, the polishing head 104 rotates and pushes the substrate down against the polishing pad 108. As discussed above, the major surface of platen 110 supporting the polishing pad 108 and the polishing pad 108 may not be perfectly parallel with the polishing head 104 holding the substrate 102. Without a gimbal to accommodate this run-out (*e.g.*, tilt), a gap between the polishing pad 108 and the lower portion of the polishing head 104 that retains the substrate 102 can exist and the substrate 102 can slip out of the polishing head 104 through the gap.

[00018] Turning to FIG. 2, an example of a prior art head 200 is depicted. The prior art head 200 includes an upper portion 202 and a lower portion 204. A flexure bearing 206 formed from a semi-rigid, flexible material is used to couple the lower portion to a central shaft 208 that is rigidly coupled to the upper portion 202.

[00019] The flexure bearing 206 of the prior art is designed to be flexible enough to accommodate the tilt requirements of the prior art head 200 but also rigid enough to hold up against the lateral frictional forces imposed by pressing the substrate against the polishing pad. If the flexure bearing 206 is too flexible, it will not resist the lateral frictional load and will instantly collapse and fail. If the flexure bearing 206 is not flexible enough, it will not hold the prior art head 200 flush against the polishing pad when a low downforce is applied to the lower portion, creating a gap that will allow the substrate to slip away; with a high downforce to force the lower portion flush with pad in this case, the flexure bearing 206 will fail prematurely from fatigue. This

trade-off provides a window for an optimal design of the flexure bearing 206. However, with increased lateral frictional loads, the design window becomes very narrow and a solution, if possible at all, may not be cost effective or feasible. In addition, the cost of replacing a failed flexure bearing 206 can be high.

[00020] Embodiments of the present invention provide an improved gimbal that has the ability to accommodate much higher lateral friction loads and yet still provide low friction gimbaling to allow the polishing head to easily accommodate vertical platen run-out. Turning to FIG. 3, an example polishing head 104 is depicted. The polishing head 104 includes an upper portion 302 and a lower portion 304. The lower portion 304 is coupled to a spherical bearing 306 and the spherical bearing 306 is coupled to a shaft 308 that is coupled to the upper portion 302 of the polishing head 104. More specifically, the lower portion 304 of the polishing head 104 is rigidly coupled to an outer ring 310 of the spherical bearing 306 while the shaft 308 that is coupled to the upper portion 302 of the polishing head 104, is rigidly coupled to an inner portion 312 of the spherical bearing 306. The inner portion 312 of the spherical bearing 306 tilts freely within the outer ring 310 of the spherical bearing 306.

[00021] The spherical bearing 306 allows the lower portion 304 of the polishing head 104 to tilt (as indicated by the dotted curved lines with arrow heads at either end in FIG. 3) about a point within the spherical bearing 306 relative to the upper portion 302. In operation, a substrate 102 on the bottom of the lower portion 304 of the polishing head 104 is pressed into polishing pad 108 (FIG. 1) by an inflatable membrane and is held in place on the polishing head 104 by retaining ring 314 which surrounds the substrate 102. The retaining ring 314 is coupled to the outer ring 310 of the spherical bearing 306.

This allows the retaining ring 314 to tilt and allows a lower surface of the retaining ring 314 to be held flush against the polishing pad 108 (FIG. 1) thereby trapping the substrate 102.

[00022] Note that the tilt of the polishing head 104 enabled by the spherical bearing 306 does not affect the angle of the down force applied to the substrate 102. Rather, an inflatable membrane within the lower portion 304 of the polishing head 104 provides even pressure across the backside of the substrate 102 to maintain the substrate flush against the polishing pad 108. The spherical bearing 306 only affects the tilt of the retaining ring 314. In other words, the angle of the down force on the substrate 102 is independent of the angle of the down force on the retaining ring 314.

[00023] At the same time the spherical bearing 306 helps maintain the retaining ring 314 flush with the polishing pad 108, the lateral friction force (*e.g.*, indicated by the labeled doubled-ended arrow) pushes the substrate 102 against an inner surface of the retaining ring 314. Since the retaining ring 314 is coupled to the spherical bearing 306, this lateral force is born by the spherical bearing 306. The ability of the spherical bearing 306 to carry the load of the lateral friction force is orders of magnitude higher than the flexure bearing used in the prior art head 200 (FIG. 2). For example, a flexure bearing suitable for a 300 mm prior art head can be difficult to design. It is a challenge to fit a flexure bearing that can take a lateral load of 230 lbs. into the available space. In comparison, a commercially available spherical bearing such as the model GE17-EC manufactured by IKO Nippon THOMPSON CO., LTD. of Tokyo, Japan, has a dynamic load capacity of 7600 lbs. If desired, a spherical bearing with a significantly larger dynamic load capacity can be used. It is anticipated that 450 mm substrates will create lateral

friction loads of two to three times the loads of 300 mm substrates just based upon the larger surface area alone.

[00024] In some embodiments, different types of spherical bearings 306 can be used. For example, FIG. 4A depicts an example of a spherical plain bearing 400 that includes an inner ring 402 with an outer convex toroidal surface that slides against an inner concave toroidal surface of an outer ring 404. The spherical plain bearing 400 includes a locking feature 406 that makes the inner ring 402 captive within the outer ring 404 in the axial direction only. The inner ring 402 slides against the outer ring 404 using a lubricant or a maintenance-free (*e.g.*, polytetrafluoroethylene (PTFE)) based liner 408. In some embodiments, a spherical bearing 410 as shown in FIG. 4B can incorporate a rolling element 412, such as a race of ball-bearings, between the outer ring 414 and the inner ring 416. Note that the inner ring 416 can be a full sphere instead of a toroid.

[00025] Referring back to FIG. 3, in some embodiments, the lower portion 304 of the polishing head 104 can be coupled to the outer ring 310 of the spherical bearing 306 as shown, or in other embodiments, the lower portion 304 can be coupled to the inner portion 312 of the spherical bearing 306. Likewise, in some embodiments, the upper portion 302 (via shaft 308) of the polishing head 104 can be coupled to the inner portion 312 of the spherical bearing 306 as shown, or in other embodiments, the upper portion 302 (via shaft 308) can be coupled to the outer ring 310 of the spherical bearing 306.

[00026] Turning now to FIG. 5, and example method 500 of chemical-mechanical planarization (CMP) is depicted in the form of a flowchart. Initially, a polishing head is provided including an upper portion and a lower portion (502). The lower portion is adapted to hold a substrate and includes a retaining ring adapted to tilt relative to the upper portion.

The tilting or gimbaling is enabled by a spherical bearing having an inner portion and an outer ring. The inner portion is disposed on a shaft coupled to the upper portion of the polishing head. The outer ring is coupled to the lower portion of the polishing head. In some embodiments, the couplings can be reversed.

[00027] Next, the polishing head is rotated while a substrate is held against a moving polishing pad (504). The lower portion of the polishing head is tilted or gimbaled while the substrate is rotated against the polishing pad so that a lower surface of the retaining ring remains flush against the moving polishing pad (506). At the same time, the lateral friction force generated by the moving polishing pad contacting the substrate and pushing the substrate against the retaining ring is resisted.

[00028] Numerous embodiments are described in this disclosure, and are presented for illustrative purposes only. The described embodiments are not, and are not intended to be, limiting in any sense. The presently disclosed invention embodiments are widely applicable to numerous applications, as is readily apparent from the disclosure. One of ordinary skill in the art will recognize that the disclosed invention embodiments may be practiced with various modifications and alterations, such as structural, logical, and mechanical modifications. Although particular features of the disclosed invention embodiments may be described with reference to one or more particular embodiments and/or drawings, it should be understood that such features are not limited to usage in the one or more particular embodiments or drawings with reference to which they are described, unless expressly specified otherwise. The present disclosure is neither a literal description of all embodiments nor a listing of features of the invention that must be present in all embodiments.

[00029] The present disclosure provides, to one of ordinary skill in the art, an enabling description of several embodiments. Some of these embodiments may not be claimed in the present application, but may nevertheless be claimed in one or more continuing applications that claim the benefit of priority of the present application.

[00030] The foregoing description discloses only example embodiments of the invention. Modifications of the above-disclosed apparatus, systems and methods which fall within the scope of the invention will be readily apparent to those of ordinary skill in the art.

[00031] Accordingly, while the present invention has been disclosed in connection with exemplary embodiments thereof, it should be understood that other embodiments may fall within the spirit and scope of the invention, as defined by the following claims.

THE INVENTION CLAIMED IS:

1. A system for chemical-mechanical planarization comprising:

a platen supporting a polishing pad and adapted to rotate the polishing pad; and

a polishing head adapted to rotate and including an upper portion and a lower portion, the lower portion adapted to hold a substrate and to tilt relative to the upper portion, the tilt enabled by a spherical bearing,

wherein the lower portion is adapted to tilt while rotating the substrate against the polishing pad so that the lower portion remains flush against the rotating polishing pad while resisting lateral friction force generated by the rotating polishing pad contacting the substrate and pushing the substrate laterally against the lower portion.

2. The system of claim 1 wherein the lower portion includes a retaining ring adapted to tilt relative to the upper portion.

3. The system of claim 2 wherein the spherical bearing includes an inner portion and an outer ring.

4. The system of claim 3 wherein the inner portion is disposed on a shaft coupled to the upper portion and the outer ring is coupled to the lower portion.

5. The system of claim 3 wherein the outer ring is coupled to a shaft coupled to the upper portion and the inner portion is coupled to the lower portion.

6. The system of claim 3 wherein the retaining ring of the lower portion is adapted to tilt while the substrate is rotated against the polishing pad so that a lower surface of

the retaining ring remains flush against the rotating polishing pad.

7. The system of claim 6 wherein lateral friction force generated by the rotating polishing pad contacting the substrate is resisted by the retaining ring.

8. A chemical-mechanical planarization polishing head comprising:

an upper portion and a lower portion, the lower portion adapted to hold a substrate and to tilt relative to the upper portion, the tilt enabled by a spherical bearing,

wherein the lower portion is adapted to tilt while rotating the substrate against a rotating polishing pad so that the lower portion remains flush against the rotating polishing pad while resisting lateral friction force generated by the rotating polishing pad contacting the substrate and pushing the substrate laterally against the lower portion.

9. The chemical-mechanical planarization polishing head of claim 8 wherein the lower portion includes a retaining ring adapted to tilt relative to the upper portion.

10. The chemical-mechanical planarization polishing head of claim 9 wherein the spherical bearing includes an inner portion and an outer ring.

11. The chemical-mechanical planarization polishing head of claim 10 wherein the inner portion is disposed on a shaft coupled to the upper portion and the outer ring is coupled to the lower portion.

12. The chemical-mechanical planarization polishing head of claim 10 wherein the outer ring is coupled to a shaft coupled

to the upper portion and the inner portion is coupled to the lower portion.

13. The chemical-mechanical planarization polishing head of claim 10 wherein the retaining ring of the lower portion is adapted to tilt while the substrate is rotated against the polishing pad so that a lower surface of the retaining ring remains flush against the rotating polishing pad,

wherein lateral friction force generated by the rotating polishing pad contacting the substrate is resisted by the retaining ring.

14. A method for chemical-mechanical planarization comprising:

providing a polishing head including an upper portion and a lower portion, the lower portion adapted to hold a substrate and to tilt relative to the upper portion, the tilt enabled by a spherical bearing;

rotating the polishing head while holding the substrate against a moving polishing pad; and

tilting the lower portion while rotating the substrate against the polishing pad so that the lower portion remains flush against the moving polishing pad while resisting lateral friction force generated by the moving polishing pad contacting the substrate and pushing the substrate laterally against the lower portion,

wherein the lower portion includes a retaining ring adapted to tilt relative to the upper portion, and

wherein the spherical bearing includes an inner portion and an outer ring.

15. The method of claim 14 wherein the retaining ring of the lower portion is adapted to tilt while the substrate is rotated against the polishing pad so that a lower surface of

the retaining ring remains flush against the rotating polishing pad,

wherein lateral friction force generated by the rotating polishing pad contacting the substrate is resisted by the retaining ring.

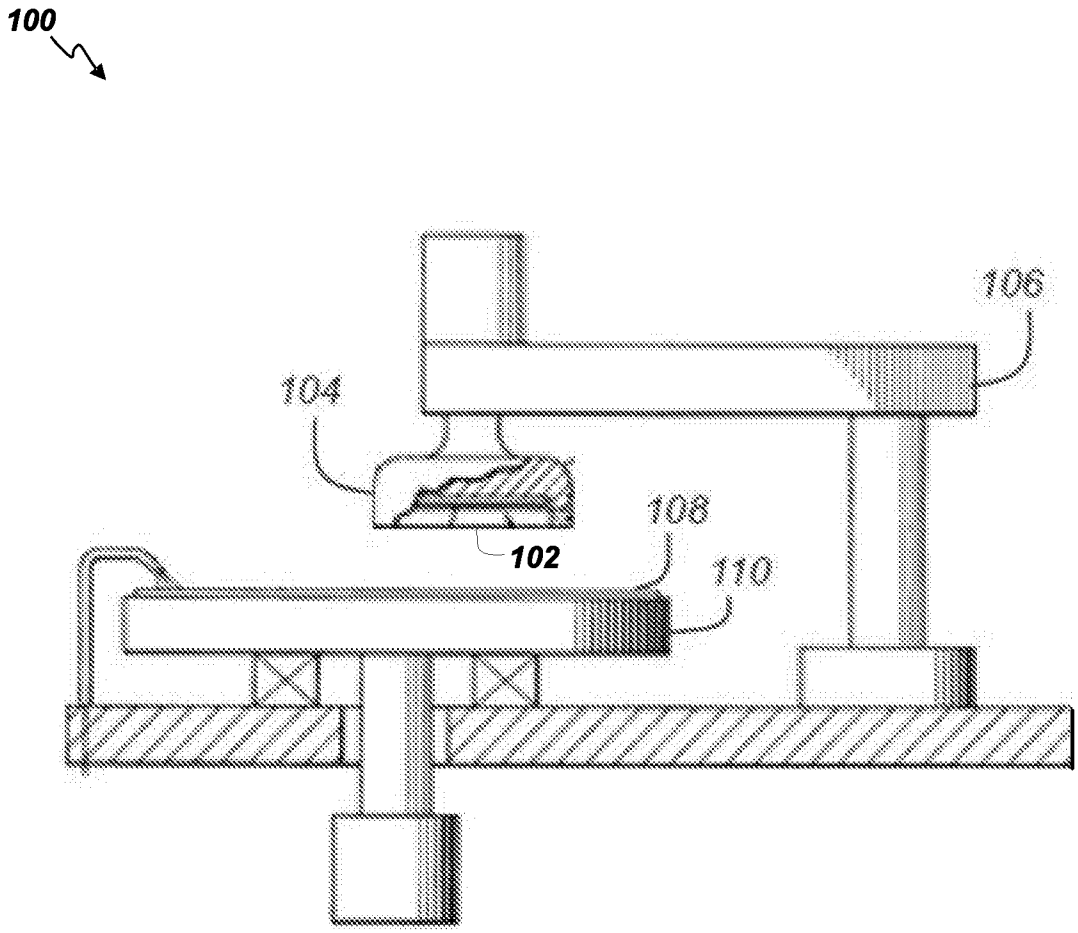


FIG. 1

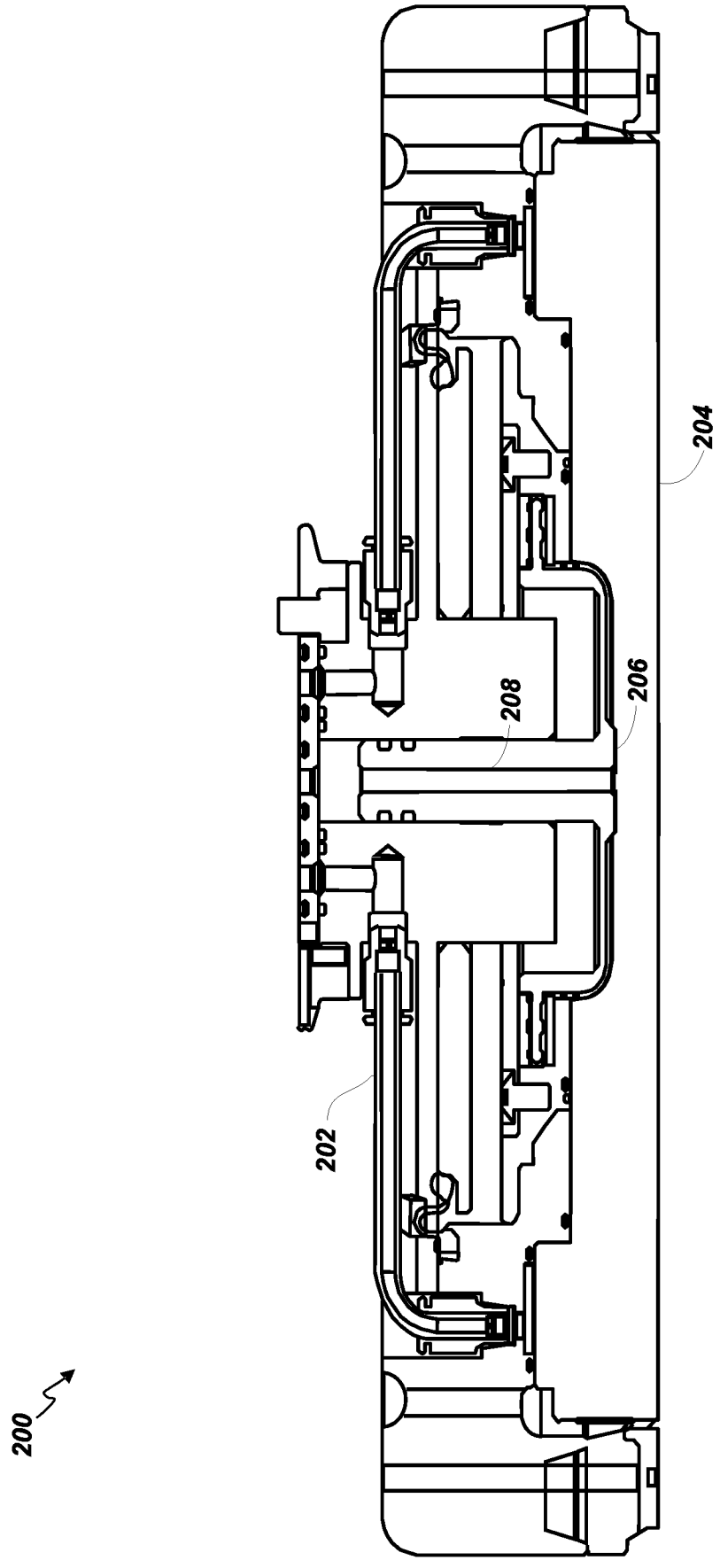


FIG. 2
(PRIOR ART)

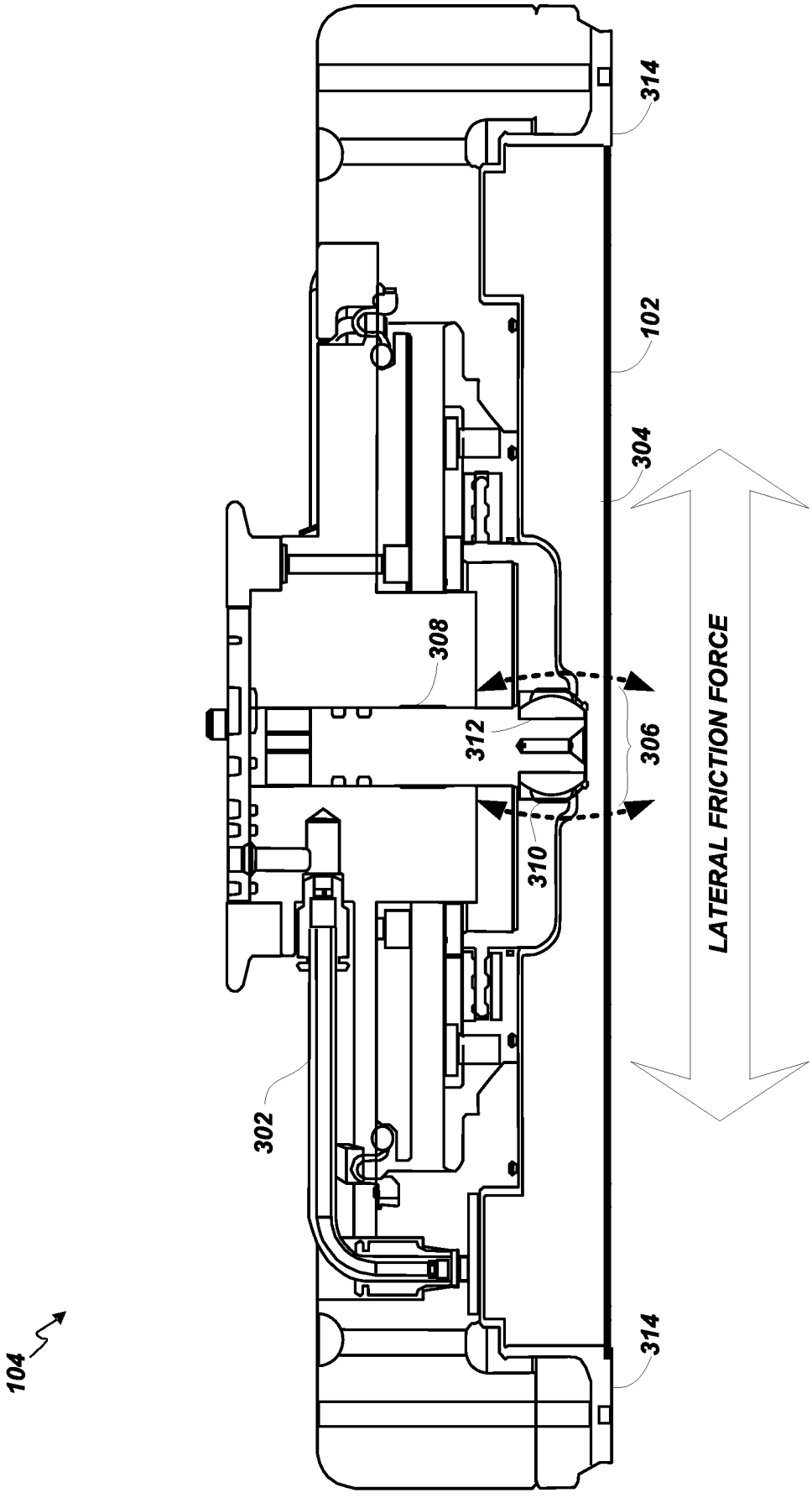

314
102
304
308
312
306
310
LATERAL FRICTION FORCE
302
104
314

FIG. 3

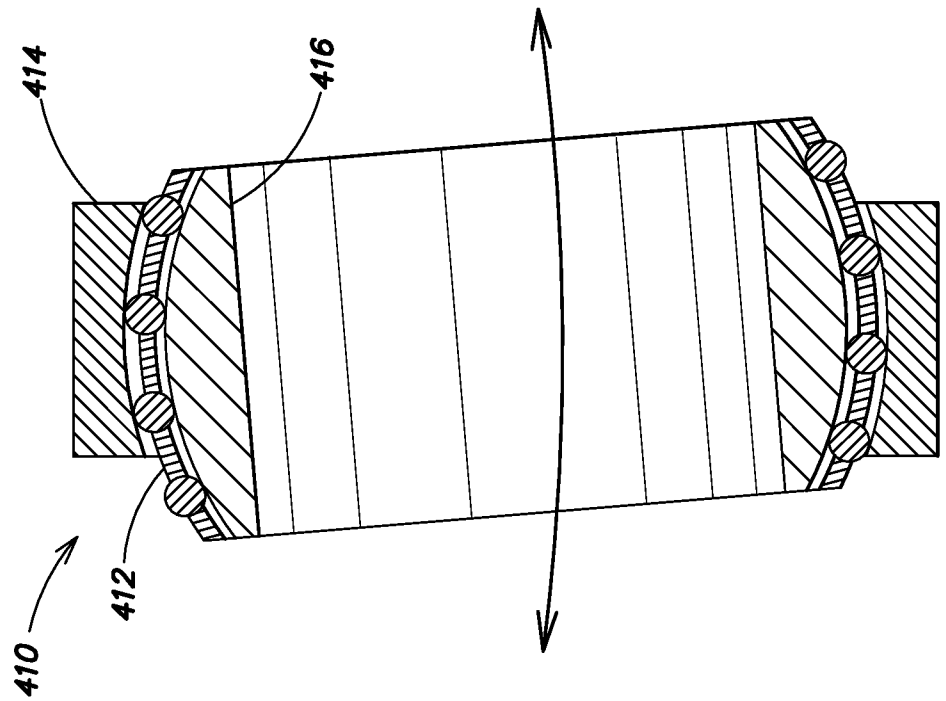


FIG. 4B

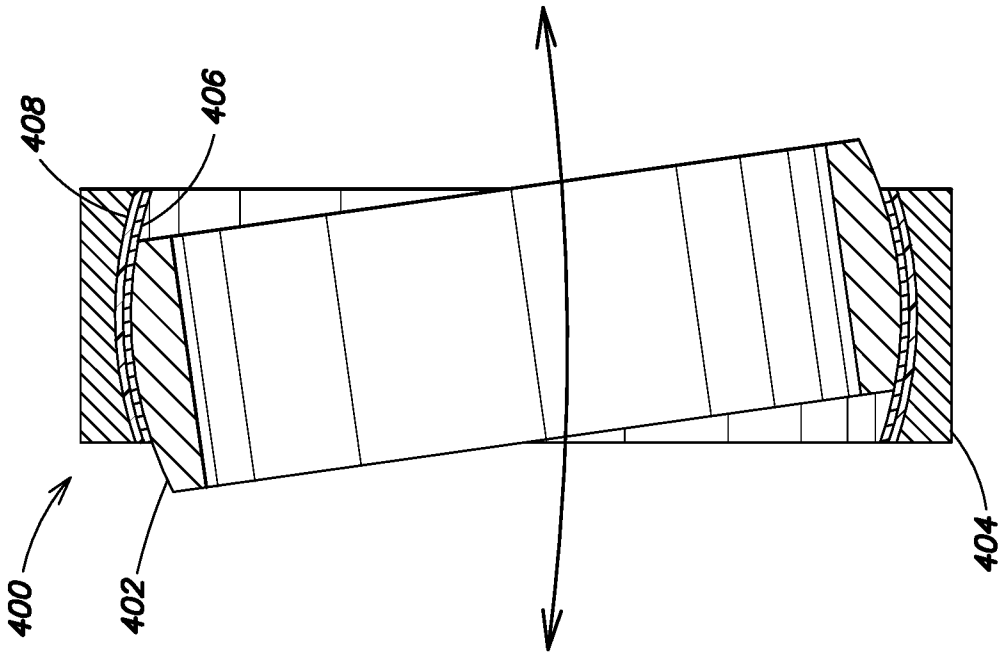


FIG. 4A

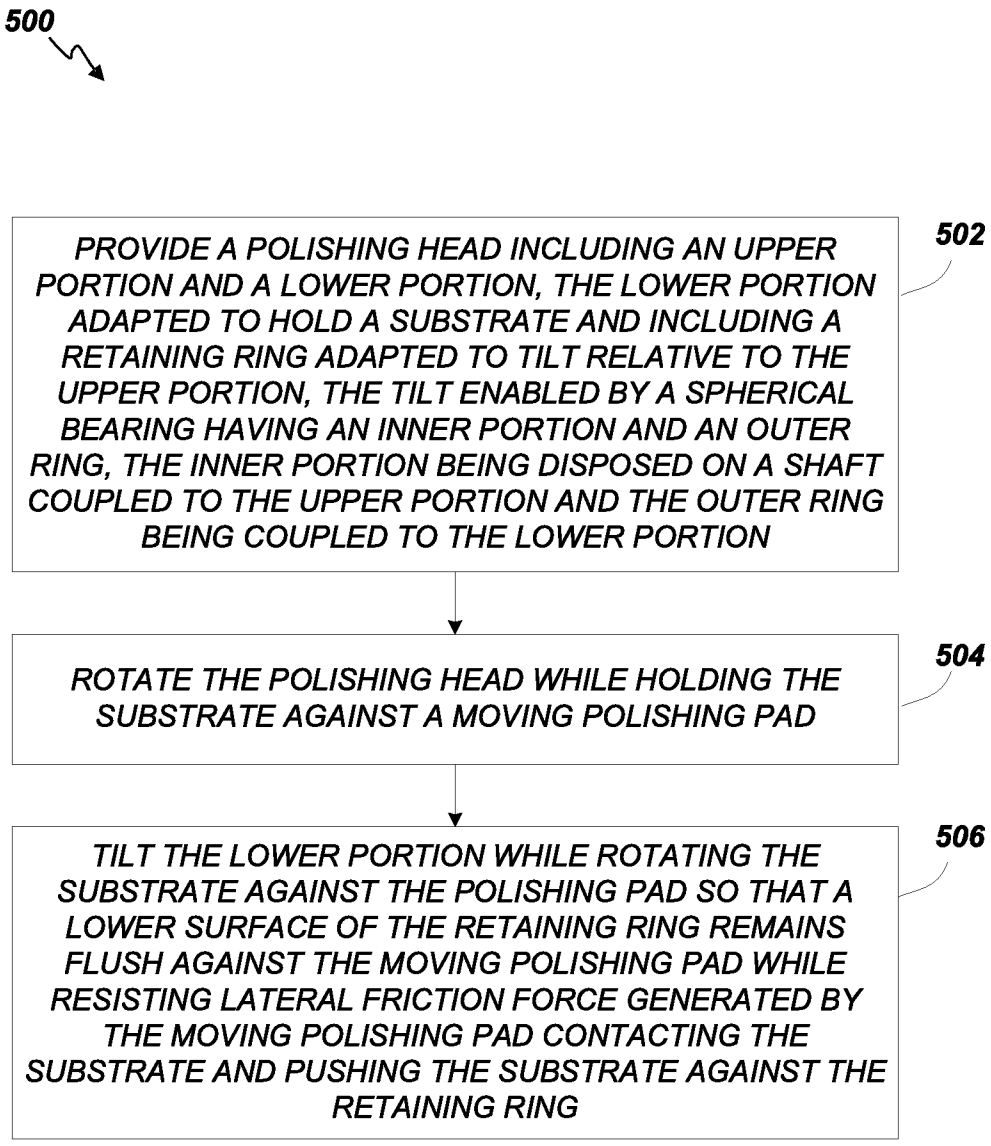

500
PROVIDE A POLISHING HEAD INCLUDING AN UPPER PORTION AND A LOWER PORTION, THE LOWER PORTION ADAPTED TO HOLD A SUBSTRATE AND INCLUDING A RETAINING RING ADAPTED TO TILT RELATIVE TO THE UPPER PORTION, THE TILT ENABLED BY A SPHERICAL BEARING HAVING AN INNER PORTION AND AN OUTER RING, THE INNER PORTION BEING DISPOSED ON A SHAFT COUPLED TO THE UPPER PORTION AND THE OUTER RING BEING COUPLED TO THE LOWER PORTION
502
ROTATE THE POLISHING HEAD WHILE HOLDING THE SUBSTRATE AGAINST A MOVING POLISHING PAD
504
TILT THE LOWER PORTION WHILE ROTATING THE SUBSTRATE AGAINST THE POLISHING PAD SO THAT A LOWER SURFACE OF THE RETAINING RING REMAINS FLUSH AGAINST THE MOVING POLISHING PAD WHILE RESISTING LATERAL FRICTION FORCE GENERATED BY THE MOVING POLISHING PAD CONTACTING THE SUBSTRATE AND PUSHING THE SUBSTRATE AGAINST THE RETAINING RING
506

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/065136

A. CLASSIFICATION OF SUBJECT MATTER

H01L 21/304(2006.01)i

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)
H01L 21/304; G06F 19/00; B24B 37/00; B24B 53/12; B24B 1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: chemical mechanical polishing (CMP), pad, head, tilt, spherical bearing, retaining ring

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2010-172996 A (EBARA CORPORATION) 12 August 2010 See paragraphs [0015], [0029], claims 1-7 and figures 1-6.	1-15
A	US 2002-0188370 A1 (MIGUEL A. SALDANA et al.) 12 December 2002 See paragraphs [0086]-[0119], claims 1-8 and figures 2A, 2B.	1-15
A	KR 10-2005-0100424 A (DOOSAN DND CO., LTD) 19 October 2005 See paragraphs [0042]-[0060], claims 1, 2 and figures 1-4.	1-15
A	US 6241585 B1 (JOHN M. WHITE) 05 June 2001 See column 5, line 14 - column 11, line 22, claims 1-21 and figures 1-8.	1-15
A	JP 2000-190201 A (MOTOROLA INCORPORATED) 11 July 2000 See paragraphs [0020]-[0036], claims 1-4 and figures 1, 2.	1-15

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

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"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	Date of mailing of the international search report
30 March 2016 (30.03.2016)	**31 March 2016 (31.03.2016)**

Name and mailing address of the ISA/KR
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2015/065136

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