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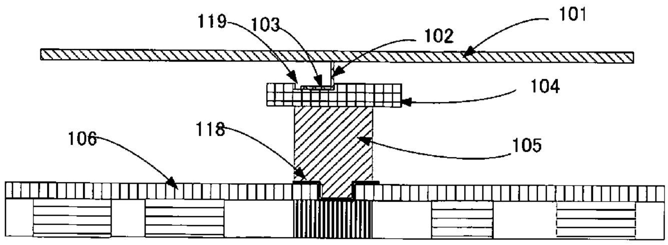

Figure 3

(57) Abstract: This invention discloses a mirror device comprises a mirror array. The mirror array includes multiple mirror elements. Each element comprises a mirror supported on a hinge. The hinge or supporting structures are attached directly to the mirror and is substantially perpendicular to the mirror without any protrusions, holes and dips. Using this technique, structures of embedded electrodes, stiction reduction, stiction free and/or linear analog control of mirror angle are disclosed.

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MIRROR DEVICE WITH FLAT AND SMOOTH MIRROR SURFACE WITHOUT PROTRUSION OR DIP

[0001] This application is a Non-provisional Application and claims a Priority Date of April 9, 2013 based on a previously filed Provisional Application 61/853,633. This Application is also a Continuation-in-Part (CIP) of Application 12/460,206 filed on July 14, 2009 and issued as a US patent, US8331010. The Application 12/460,206 is further a Continuation-in-Part Application of two previously filed Applications 11/136,041 filed on May 23, 2005 (now issued into Patent 7,304,783) and 11/183,216 filed on July 16, 2005 (now issued into Patent 7,215,460). The disclosures made in these Applications are further incorporated by reference.

Technical Field

[0002] This invention relates to manufacturing process by applying the mechanical electrical micro-machining system (MEMS) technology and the improved device configurations produced by applying the manufacturing processes. More particularly, this invention relates to manufacturing processes for producing the Micromirror or Micro-window devices comprise flat mirrors with smooth mirror surface or windows without any protrusions or dips. This invention is particularly advantageous because the micromirrors may be implemented in a high performance image display or sensing system to achieve a high quality of image with high contrast because of no protrusion or hole on mirror surface.

Background Art

[0003] Even though there are significant advances made in recent years on the technologies of manufacturing and implementing the display devices with moving elements such as micro-mirrors (reflective device) or micro-windows (transmissive device) as spatial light modulator. There are still technical limitations and difficulties in the manufacturing process. There is a difficulty in a process of making flat mirrors or windows without any mark, hole, protrusion or dip, because a hinge or a connector is attached to these moving elements.

[0004] MEMS devices have drawn considerable interest because of their application as sensors, actuators and display devices. MEMS devices often have a structure as shown in Fig. 1 where an electronic circuit is formed on a substrate and the circuit provides voltage or current to electrodes or senses voltage or current from the electrodes. MEMS structures are often formed over the top or close to the electrodes with a gap between the electrodes and MEMS structure. The top view shown in Fig. 1 illustrates a typical conventional micromirror device with each mirror formed with a hole in the middle of mirror. The uneven or non-uniform mirror surfaces of a mirror device implemented in the conventional image display system adversely affects the quality of display because of undesired reflection of incoming light by the holes, dips or protrusions on the non-uniform mirror surfaces.

[0005] The invention disclosed in the application of 12/460,206 filed on July 14, 2009 and issued as a US patent, US8331010, enabled to produce micromirrors with completely flat surface. By implementing the invention many fundamental problems of MEMS are resolved. These fundamental problems include stiction caused by a mirror stuck to a stopper thus preventing the movement of the mirror. Another fundamental problem caused by diffraction of light from holes on the mirror surface is also resolved. Therefore, for the ordinary skill in the art of manufacturing the micromirrors, there are still needs to further improve the performance of micromirrors using flat mirror surface and vertical hinge as a Continuation-in-Part (CIP) of Application 12/460,206, such that the difficulties and technical limitations may be overcome.

Summary of the Invention

[0006] An aspect of this invention is to provide new and improved structures for MEMS devices and manufacturing processes to produce mirror device comprises micromirror arrays with flat and smooth mirror surface such that the above mentioned stiction is substantially reduced.

[0007] Another aspect of this invention is to provide new and improved structures for MEMS devices and manufacturing processes to enable very simple manufacturing processes of hinges and flat and smooth mirror surfaces to reduce the production costs and to provide mirrors that can achieve high level of performance by eliminating address electrodes over CMOS etch stop layer.

[0008] Another aspect of this invention is to provide new and improved structures for MEMS devices and manufacturing processes to enable convenient manufacturing processes and to provide stable structures without the penetration of hinge into mirror plate.

[0009] Another aspect of this invention is to provide new and improved structures for MEMS devices and manufacturing processes to manufacture hinges and mirrors with flat and smooth mirror surfaces wherein the hinge is supported on a hinge table on a hinge base whereby the hinge table can serve the function as mirror stoppers and the potential problems of insulation layer breakdown on the electrodes are resolved.

[0010] Another aspect of this invention is to provide new and improved structures for MEMS devices and manufacturing processes to manufacture hinges and mirrors by etching the sidewall of semiconductor and keep fence of side walls on top of foot of hinge which increases the strength of hinges.

[0011] Another aspect of this invention is to provide new and improved structures for MEMS devices and manufacturing processes to enable convenient manufacturing processes and to provide stable and stronger structures by forming alloy between hinge and mirror materials.

[0012] Another aspect of this invention is to provide new and improved structures for MEMS devices and manufacturing processes to enable convenient manufacturing processes and to provide supporting structure for mirror without any protrusion, hole or dip, which is applicable to micromirrors with horizontal hinge.

[0013] Another aspect of this invention is to provide new and improved structures for MEMS devices and manufacturing processes to enable convenient manufacturing processes and to provide a micromirror structure which completely eliminates stiction and more precise control of mirror angle in either analog or digital using horizontal moving electrodes.

[0014] Another aspect of this invention is to provide new and improved structures for MEMS devices and manufacturing processes to enable convenient manufacturing processes and to provide a micromirror structure which completely eliminates stiction and more precise control of mirror angle in either analog or digital using vertical moving electrodes.

[0015] Another aspect of this invention is to provide new and improved structures for MEMS devices and manufacturing processes to enable convenient manufacturing processes and to provide a micromirror structure having metal layers as etch-stop-layer.

Brief Description of Drawings

[0016] Fig. 1 shows a conventional MEMS device having a structure with an electronic circuit is formed on a substrate and the circuit provides voltage or current to electrodes or senses voltage or current from the electrodes wherein MEMS structures are formed over the top or close to the electrodes with a gap between the electrodes and MEMS structure.

[0017] Fig. 2 is a side view for illustrating a micromirror without exposed address electrodes produced by conventional MEMS manufacturing process.

[0018] Fig. 2A shows a plane view and Fig.2B shows a side cross-section view of a micromirror element having a hinge-table as an embodiment of this invention.

[0019] Fig. 3 shows a side cross section view of a micromirror element of this invention with a hinge foot and fences to increase the strength of hinges at the bottom.

[0020] Fig. 4 through Fig. 12 show the manufacturing processes of micro-mirrors.

[0021] Fiig-13, Fig.14 and Fig.16 show the structure of fence. The fence can be formed by stopping etching before etching reaches the bottom of hole.

[0022] Fig.15 shows the structure of foot of hinge.

[0023] Fig.17A and Fig.17B show an example of micromirror having moving electrodes directly connected to the beneath surface of mirror without any protrusion, hole and dip.

[0024] Fig.18A shows a front view of another example of micromirror having horizontal moving electrodes connected with vias to the beneath surface of mirror without any protrusion, hole and dip.

[0025] Fig.18B shows a side view of the above micromirror without showing the hinge and the hinge-base to avoid confusion.

[0026] Fig.18C shows a plain view of the micromirror with a moving electrode and. vias connecting the moving electrodes to mirror

[0027] Fig.18D shows the mirror when a voltage is applied to the right side fixed electrode and it pulls the moving electrode and the mirror is rotated around the hinge in counter-clock wise direction.

[0028] Fig.18E shows the mirror when a voltage is applied to the left side fixed electrode and it pulls the moving electrode and the mirror is rotated around the hinge in clock wise direction.

[0029] Fig.19A shows a front view of another example of micromirror having vertical moving electrodes connected with vias beneath surface of mirror without any protrusion, hole and dip.

[0030] Fig.19B shows the mirror when a voltage is applied to the right side fixed electrode and it pulls the moving electrode and the mirror is rotated around the hinge in counter-clock wise direction.

[0031] Fig.19C shows the mirror when a voltage is applied to the left side fixed electrode and it pulls the moving electrode and the mirror is rotated around the hinge in clock wise direction.

[0032] Fig.20 show an example of the tilt angle of mirror and the applied voltages for micromirrors whose address electrodes(fixed electrodes) is located off the axis of mirror rotation as Fig.1 and Fig.2.

[0033] Fig.21 shows the voltage-angle relation curve of the micromirrors described in Fig.17, 18 and 19.

[0034] Fig.22 shows a simulation result to estimate the rotational force by the applied voltages.

Detailed Description of the Preferred Embodiments

[0035] Fig. 2 is a cross sectional view for illustrating a micromirror manufactured by applying a MEMS technology as exemplary embodiment of this invention. The side view illustrates a micromirror is manufactured without exposed address electrodes produced by conventional MEMS manufacturing process. A mirror (101) is supported by a vertical hinge (102) having a foot of hinge (103) and the hinge is standing on a hinge-base (105). All electrodes (108 and 109) are buried under etch-stop-layer (106). Hinge-base (105) acts as the stopper of mirror.

[0036] This structure enables to reduce stiction substantially, because the force to pull back the mirror from stuck position will increase twice to three times more. The reason why the pull-back force increases is that the total torque generated by the hinge to pull back mirror remains the same, but the distance from hinge to the stopper is substantially reduced from the conventional structures as Fing-1. The pull-back force is inverse proportional to the distance from the hinge rotational position to the stopper position, assuming the total torque remains the same. This means that the newly proposed structure with hinge-table enables to reduce the distance less than half, then to increase twice the pull-back force of mirror from the stuck position of mirror.

[0037] The micromirror includes a mirror 101 supported on a hinge 102. The mirror 101 is formed as an aluminum surface and has a flat and smooth top surface without a hole, dip or protrusion. The hinge 102 is formed as a semiconductor hinge, such as a silicon hinge. The hinge 102 has a foot (103, 122) shown as an L-shaped foot, supported on a hinge-base (105). The mirror (101) is attracted by electro-static force from embedded address electrodes (108 and 109). Because the etch-stop-layer (106) is insulating dielectric material with high permeability, electrical field will come over the layer and pull the mirror. The embedded electrodes can be made with vias as a part of CMOS process and no extra-work is needed for electrodes. The electrical connection to mirror can be made by another via (107).

[0038] Fig. 2A shows a plane view and Fig.2B shows a side cross-section view of a micromirror element having a hinge-table as an embodiment of this invention. A hinge-table (104) is added to control the angle of tilt of mirror more precisely as well as enabling to minimize the size of hinge-base. As shown in Fig. 2A and 2B, a hinge-table can be added to enable smaller hinge-base as well as more precise dimensional control of stopper (110) where the mirror hits and stops rotation. If the mirror-table is made of the same material as hinge, the adhesion of hinge to the surface (103 in Fig. 2B) and/or side-wall of hinge-table (103 in Fig.3) will increase the strength of the bottom of hinges. The size of hinge-table can be precisely controlled because of semiconductor lithography technology, and then the mirror tilt angle will be very accurate, when it stops at the edge of hinge-table.

[0039] Fig. 3 shows a side cross section view of a micromirror element of this invention with a hinge foot(122 in Fig. 15) and fences(124 in Fig. 14) to increase the strength of hinges at the bottom. Fig.3 shows another exemplary embodiment of this invention by creating fences connected to hinge to increase the strength of hinge at the bottom. The lower part of hinge is connected to the side wall of hinge-table or hinge base, so that the bottom heel of hinge can be strengthened. Another embodiment to create fences is shown in Fig.13, 14 and 16 by not etching off the side wall of hinge material.

[0040] Fig. 4 through Fig.12 show an example of manufacturing processes for the structure shown in Fig.2B. Fig.2B is a side cross sectional view of a micromirror element as an embodiment of this invention. The micromirror element includes a mirror 101 supported on a semiconductor hinge 102 includes a foot and a hinge tab 103.

[0041] Fig. 4 is a side cross sectional view of a wafer having embedded electrodes (108 and 109). 117 is an ILD (interlayer dielectric). 107 is a via connecting electrically to the hinge base (105). 118 is barrier metal to enhance adhesion. The electrodes can be made of vias. 104 is a hinge-table. 113 is a sacrificial layer and planarized by CMP.

[0042] Fig.5 shows that a hole is etched on the hinge-table, so that hinge material can be deposited inside walls of the hole.

[0043] Fig.6 shows that hinge material is deposited on the side walls (102) and the bottom of the hole (103) as well as the top surface of the wafer (111).

[0044] Fig.7 shows that the side walls and the bottom of the hole except vertical hinge (102) and foot (103) are etched off. By controlling etching time, lower part of the side wall may be remained to create fences (123 in Fing-13).

[0045] Fig.8 shows that the hole is filled with sacrificial layer.

[0046] Fig.9 shows that the dip in the sacrificial layer (115) is plugged (112), so that vertical etch of the sacrificial layer will not create dip at the hole location.

[0047] Fig.10 shows that the sacrificial layer over the top hinge material (101) is etched off. This process eliminates the process variation because the 101 layer will act as an etch-stop-layer.

[0048] Fig.11 shows that the hinge material deposited over the sacrificial layer (101) is polished and eliminated. The vertical hinge (102) shows up on the surface of the sacrificial layer (113) and the surface is completely flat.

[0049] Fig.12 shows that mirror material (101) is deposited and patterned by lithography and etching.

[0050] Fig.17A, 17B, 18A and 18B show another embodiment of this invention. Fig.17A and Fig.17B show an example of micromirror having moving electrodes (203) directly connected to the beneath surface of mirror (201) without any protrusion, hole and dip. These structures enable much more precise control of mirror rotational angle and completely eliminate stiction which is one of the most difficult problems to solve in MEMS technology. 201 is a mirror. 202 is a vertical hinge. 209 is a hinge table. 206 is a hinge base. 203 are moving electrodes attached directly to the beneath surface of mirror (Fig.17A and 17B) or connected with a supporting structure (208 in Fig.18A and 18B) such as via without any protrusion, hole and dip. 205 are fixed electrodes which are connected to the substrate. Fig.18A shows a front view of another example of micromirror having horizontal moving electrodes connected with vias (208) to the beneath surface of mirror without any protrusion, hole and dip, wherein 201 is mirror, 214 is the gap between mirrors. 208 is via to connect a moving electrode (203) and mirror (201), 205 is a fixed electrode. Fig.18B shows a side view of the above micromirror and the hinge (202) and the hinge-base (209) are not shown to avoid confusion. 210 is the first etch-stop-layer and 215 is the second etch-stop-layer. 213 is a gap between two fixed electrodes. 211 is a gap between a fixed electrode (205) and an etch-stop-layer (210) in the first etch-stop-layer (210). 212 is a gap between an etch-stop-layer (215) and an element which is connected to a fixed electrode in the second etch-stop-layer (215). Fig.18C shows a plain view of the micromirror, wherein 203 is a moving electrode. 208 are vias connecting the moving electrodes to mirror (201). 205 are fixed electrodes. 202 is hinge and 209 is a hinge base or a hinge table. Fig.18D shows that a voltage is applied to the right side fixed electrode (205) and it pulls the moving electrode (203), then the mirror is rotated around the hinge (202) in counter-clock wise direction. Fig.18E shows that a voltage is applied to the left side fixed electrode (205) and it pulls the moving electrode (203), then the mirror is rotated around the hinge (202) in clock wise direction when a voltage is applied to the right electrodes of the fixed electrodes as inFing-18D keeping the mirror ground or opposite voltage to the fixed electrodes, an attractive force will be created electro-statically as shown in Fig.22. This structure has a significant advantage because there is no stopper and it will stop by itself if the rotational angle exceeds the saturation point. Conventional micromirrors as Fing-1 and Fig.2 have a pull-in voltage (301 in Fig.20) and as soon as the applied voltage reaches the pull-in voltage, the mirror will move until it hits a stopper and it will be stuck. To pull-back the mirror from the stuck position requires very strong force by hinge and electro-static vibration. Conventional micromirrors usually have flexible fingers contacting landing positions to accumulate energy to let mirrors jump out of stuck position. On top of no stiction problem, this new structure has almost linear voltage-angle relation which is much easier and more precise to control intermediate angles and very suitable for analog control micromirrors.

[0051] Fig.19A and19B show another example of this invention. This structure (Fig.19A) has a mirror (201), a supporting structure (208) connecting moving electrodes (203) to the beneath surface of the mirror (201) without any protrusion, hole and dip. The moving electrodes (203) is facing fixed electrodes (205) with a vertically oriented gap (between 203 and 205). This vertical structure requires less space than the horizontal structure. This also has a similar voltage and angle relation as well as stiction free structure. Therefore, based on above descriptions, Fig.19A shows a front view of another example of micromirror having vertical moving electrodes connected with vias (208) to the beneath surface of mirror without any protrusion, hole and dip. Fig.19B shows that a voltage is applied to the right side fixed electrode (205) and it pulls the moving electrode (203), then the mirror is rotated around the hinge (202) in counter-clock wise direction. Fig.19C shows that a voltage is applied to the left side fixed electrode (205) and it pulls the moving electrode (203), then the mirror is rotated around the hinge (202) in clock wise direction.

[0052] It is noteworthy that all the structures from Fig.17 through Fig.19 with stiction free and linear voltage-angle relation require that the location of the moving electrodes in the mirror rotational axis (216) as shown in Fing-18C, wherein the moving electrodes 203 are located in the extension of the hinge rotational axis (216 in Fig.18C) and the electrodes need to move back and forth over the axis. This means that if the hinge is a horizontal hinge, there will not be sufficient space inside a pixel. Vertical hinge has substantially smaller foot print than horizontal hinge and it enables this stiction free and/or analog control of micromirrors.

[0053] Fig.20 show an example of the tilt angle of mirror and the applied voltages for micromirrors whose address electrodes(fixed electrodes) is located off the axis of mirror rotation as Fig.1 and Fig.2. The relationship between the applied voltages to the address electrode and the mirror rotational angle is non-linear and often exponential (300), because as the mirror gets closer to the address electrode, the electro-static attractive force increases. When the applied voltage reached a certain point (301), the mirror will be pulled in to the position where the mirror hits and contacts the stopper. After the mirror contacts the stopper and the voltage is reduced below the pull-in voltage (301), the mirror will remain at the pull-in position (303) until a certain point (304) or the release voltage (304) and return to the original curve (300). The voltage-angle curve has hysteresis. This characteristics is acceptable for digital use where in only ON and OFF positions are used and the intermediate positions are not used. However, when analog control is needed to use intermediate positions, this system is not adequate.

[0054] Fig.21 shows the voltage-angle relation curve of the micromirrors described in Fig.17, 18 and 19. As shown in Fig.21, these micromirrors do not have pull-in voltage nor exponential curve, but almost linear and beyond the saturation voltage (306), the mirror no longer moves or increases the angle. This mirror device does not have stiction in principle because of no contact to stopper. This structure is very suitable to control mirror devices in either digital or analog. Fig.22 shows a simulation result to estimate the rotational force by the applied voltages.

[0055] Although the present invention has been described in terms of the presently preferred embodiment, it is to be understood that such disclosure is not to be interpreted as limiting. Various alternations and modifications will no doubt become apparent to those skilled in the art after reading the above disclosure. Accordingly, it is intended that the appended claims be interpreted as covering all alternations and modifications as fall within the true spirit and scope of the invention.

Claims

I claim:

1. A mirror device comprising
a mirror array having multiple mirror elements;
each of the mirror elements comprising a mirror supported on a hinge attached directly to said mirror and is substantially perpendicular to said mirror wherein
said hinge is connected to a bottom surface of the mirror and wherein the hinge is bonding to the bottom surface of the mirror through an atom-exchange bonding between the hinge and the mirror with an increased strength of bonding.

2. The mirror device of claim 1 wherein:
said hinge has fence(s) connected at a bottom portion of the hinge.

3. The mirror device of claim 1 wherein:
said hinge has a foot at a bottom portion of the hinge.

4. A mirror device comprising
a mirror array comprising multiple mirror elements;
each of the mirror elements comprises a mirror supported on a hinge attached directly to said mirror and is substantially perpendicular to said mirror; and

each of the mirror elements further comprises address electrodes embedded under an etch-stop-layer.

5. The mirror device of claim 4 wherein:
said etch-stop-layer is composed of a dielectric material.

6. A mirror device comprising
a mirror array comprising multiple mirror elements;
each of the mirror elements comprising a mirror supported on a hinge attached directly to said mirror and is substantially perpendicular to said mirror wherein said hinge is supported by a hinge-table having stoppers to limit a rotational angle of the mirror.

7. A mirror device comprising
a mirror array comprising multiple mirror elements;
each of the mirror elements comprising electrodes attached to a bottom surface of the mirror substantially under a mirror rotational axis; and
each of the mirror elements further comprises fixed and moving electrodes disposed below the mirror having a first fixed electrode disposed at one side of the mirror rotational axis and a second fixed electrode disposed at an opposite side of the rotational axis constituting facing fixed electrodes connected to the substrate

8. The mirror device of claim 7 wherein:
said moving and fixed electrodes are horizontal.

9. The mirror device of claim 7 wherein:
said moving and fixed electrodes are vertical.

10. The mirror device of claim 7 wherein:
said moving electrodes are connected to said mirror without protrusion, hole and dip on the surface of said mirror with connecting structure penetrating into mirror having the penetration between zero and 100% of the thickness of said mirror.

11. A mirror device comprising
a mirror array comprising multiple mirror elements;
etch-stop-layer(s) made of metal to protect internal structure against etchant to remove sacrificial layer(s);
holes in the first etch-stop-layer are staggered from holes in the second sacrificial layer to extend the time of etchant reaching the internal structure.

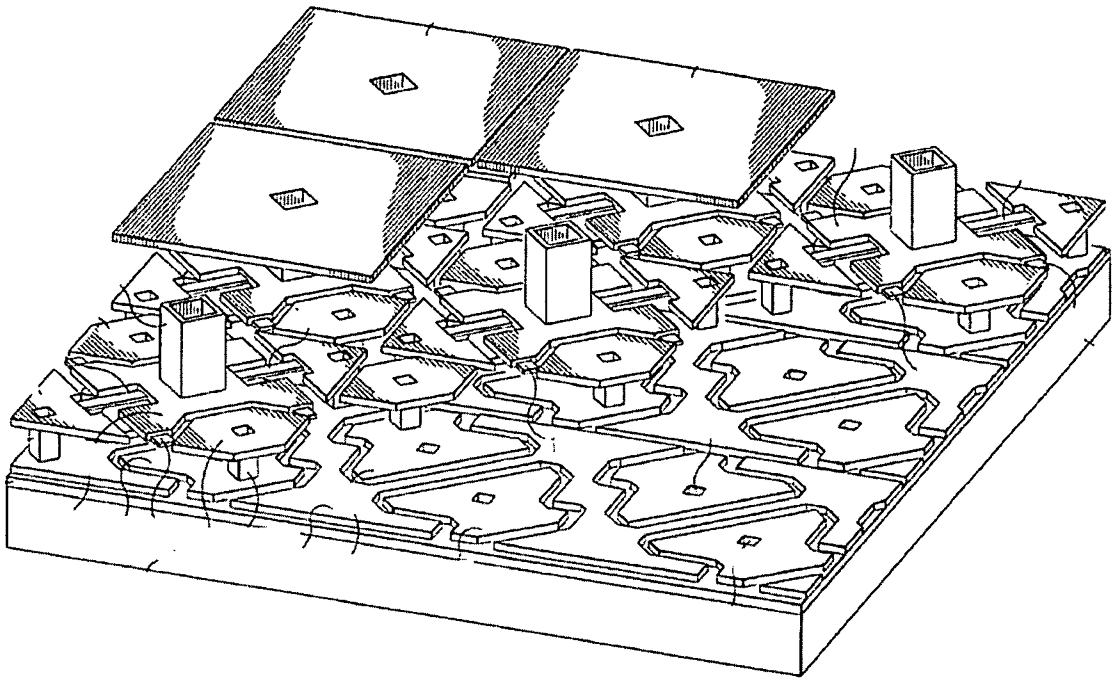


Figure 1 (Prior Art)

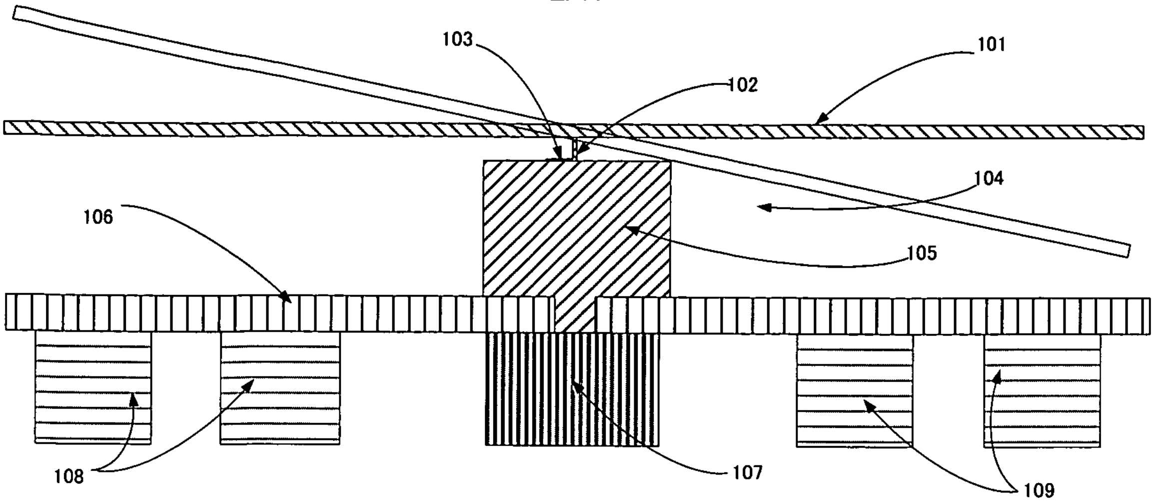


Figure 2

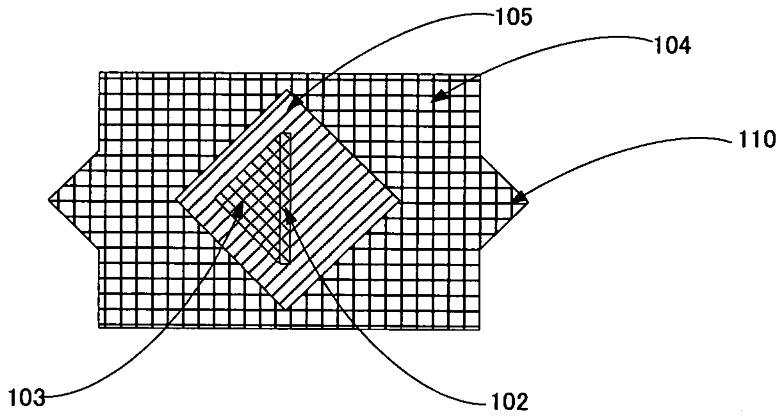


Figure 2A

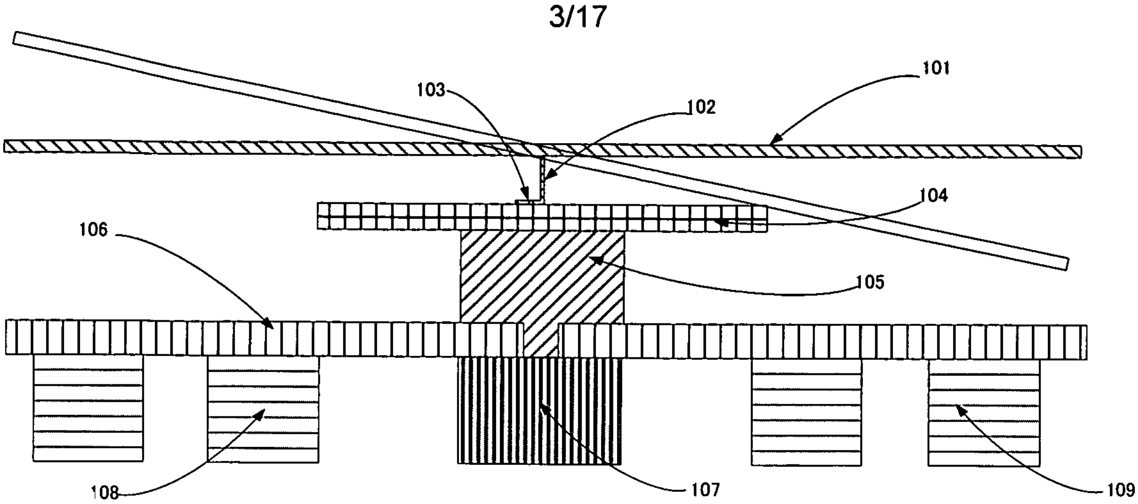


Figure 2B

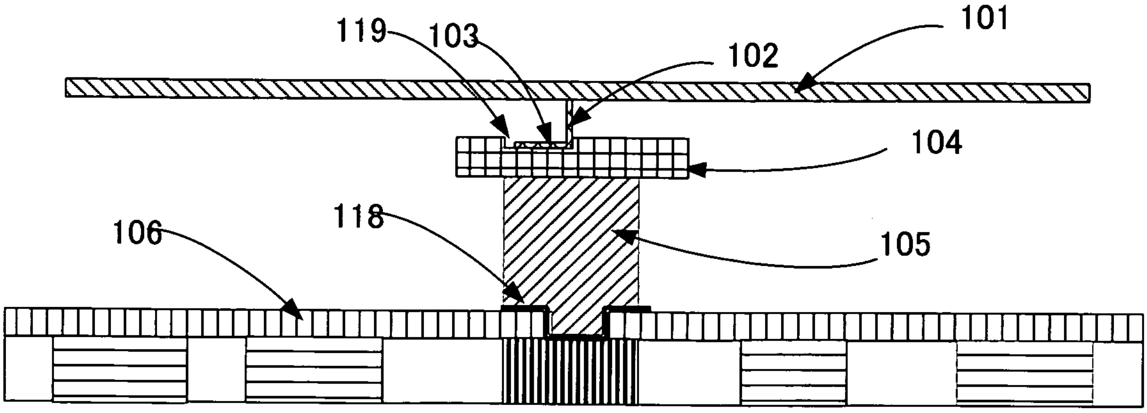


Figure 3

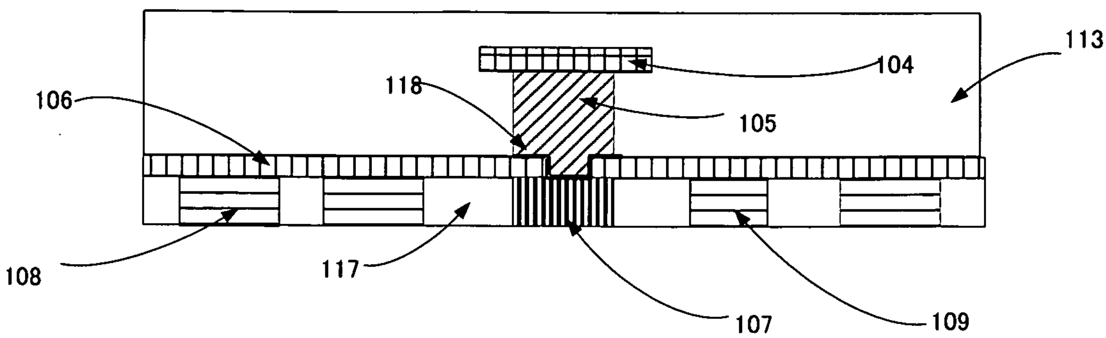
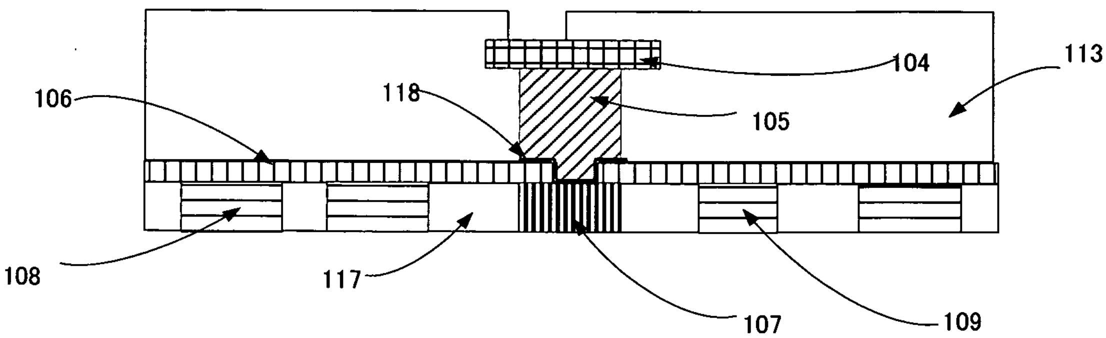


Figure 4



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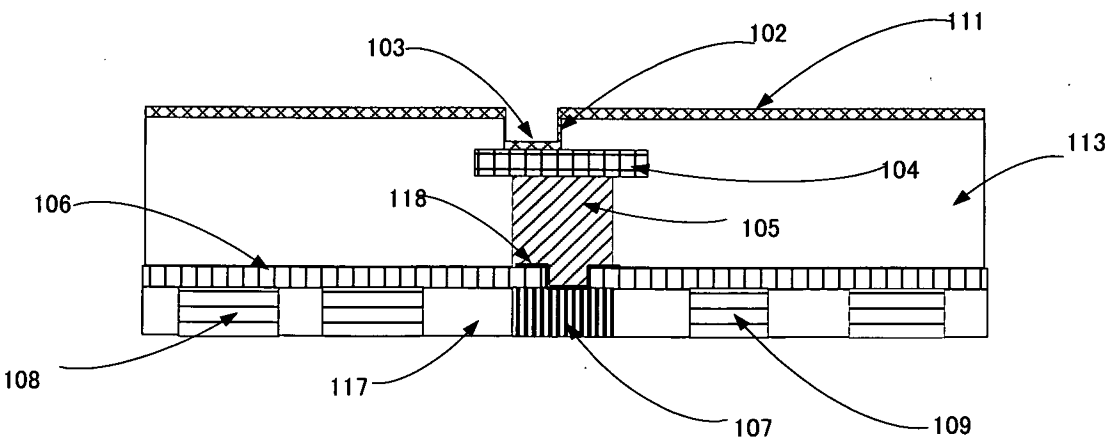
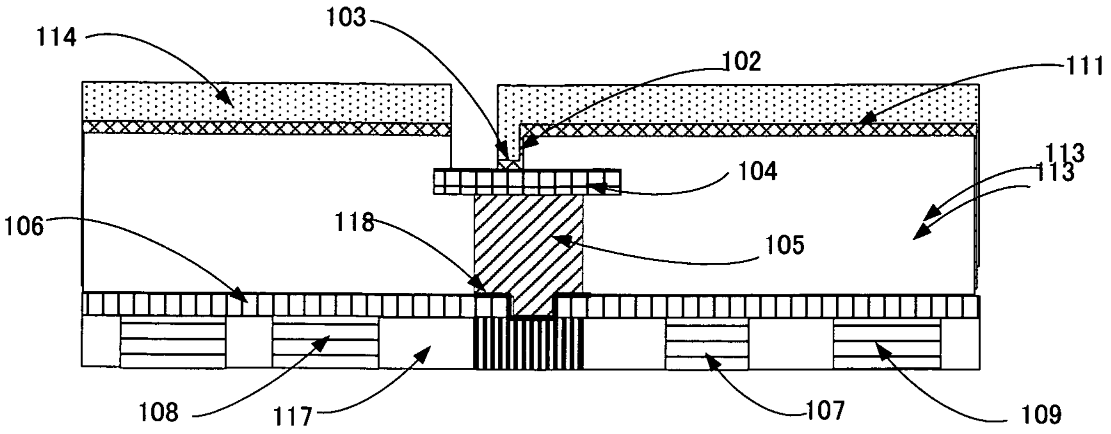


Figure 6



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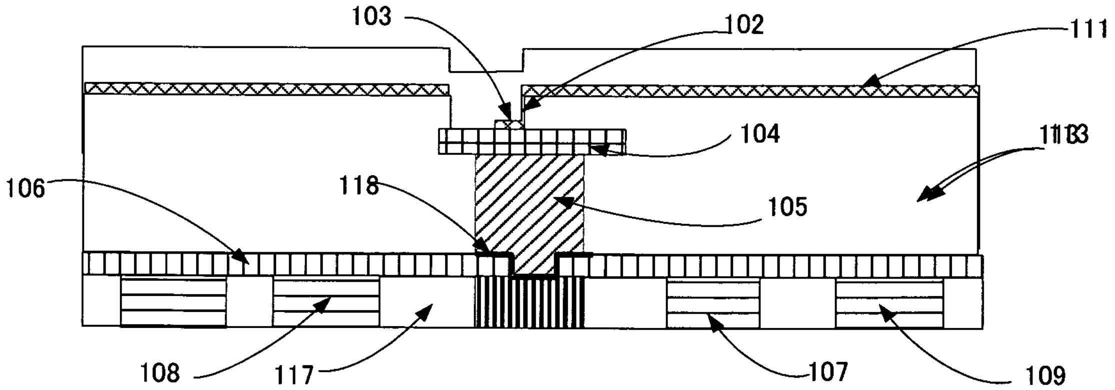

Figure 8

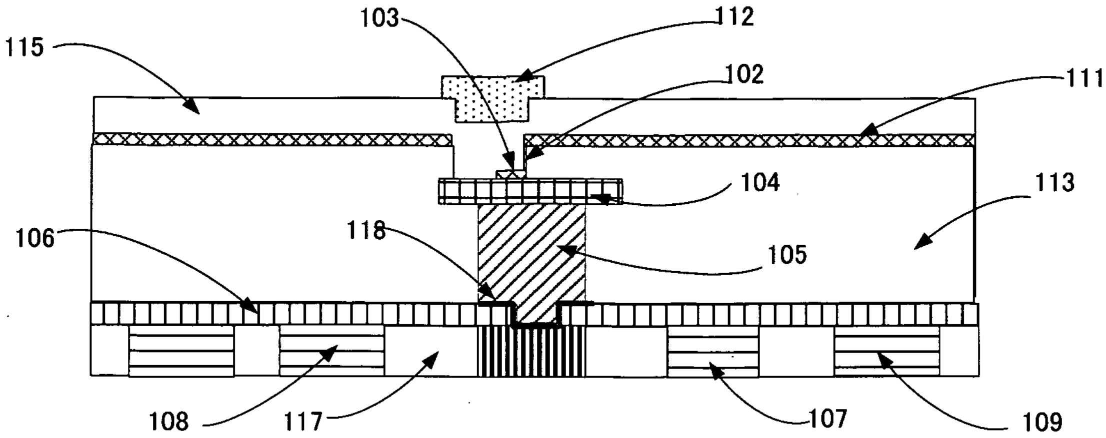

Figure 9

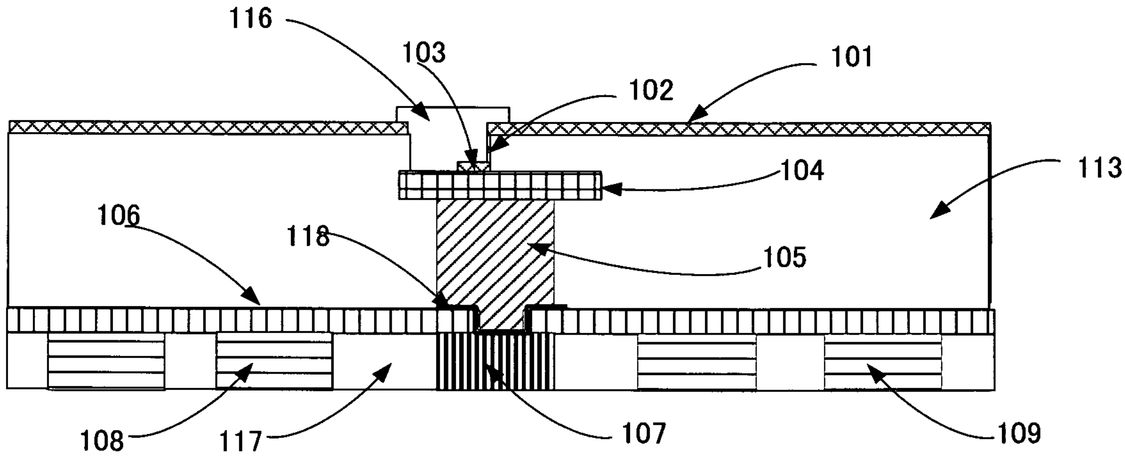

Figure 10

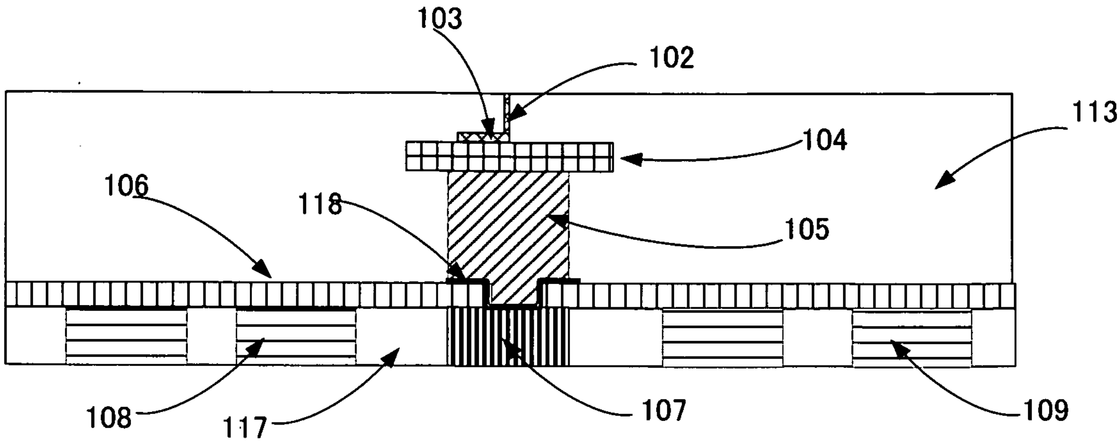

Figure 11

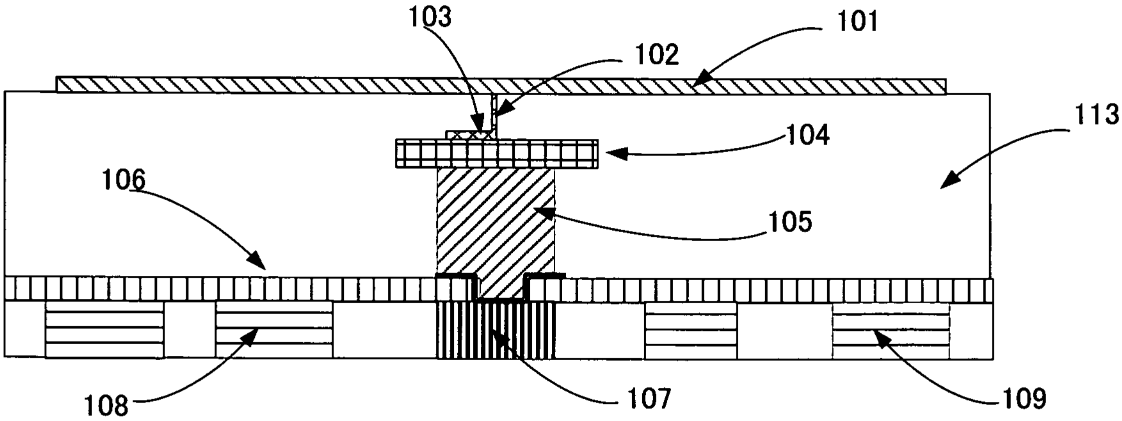

Figure 12

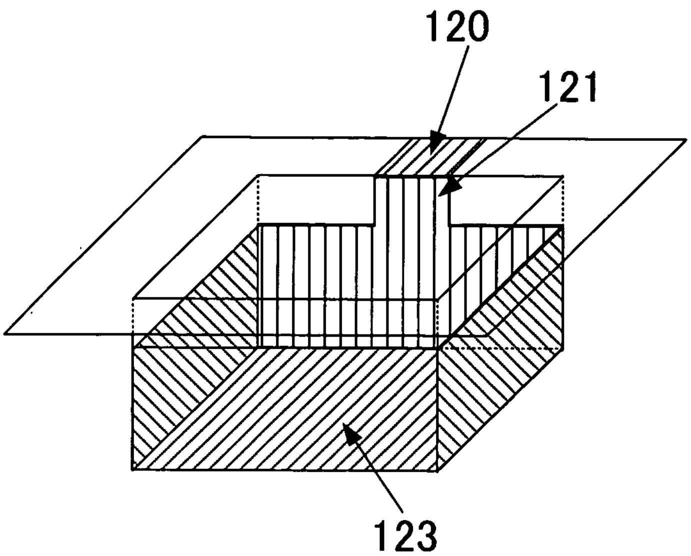

Figure 13

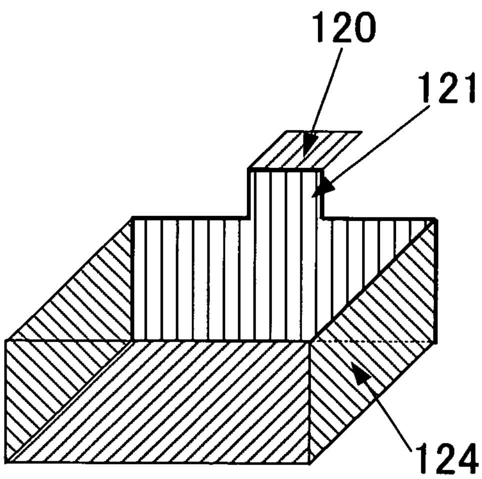

Figure 14

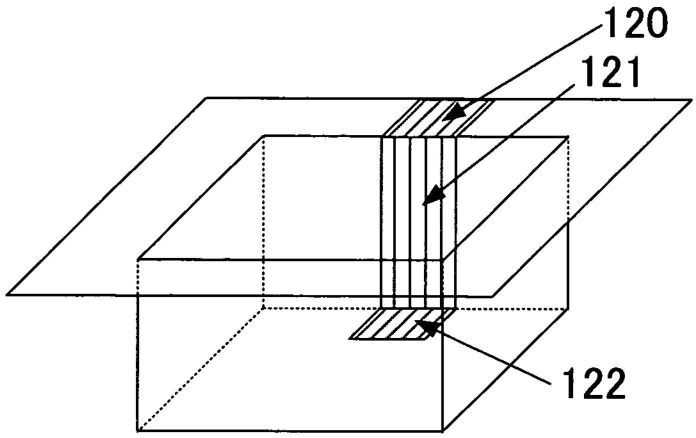

Figure 15

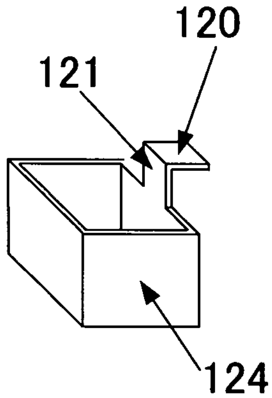

Figure 16

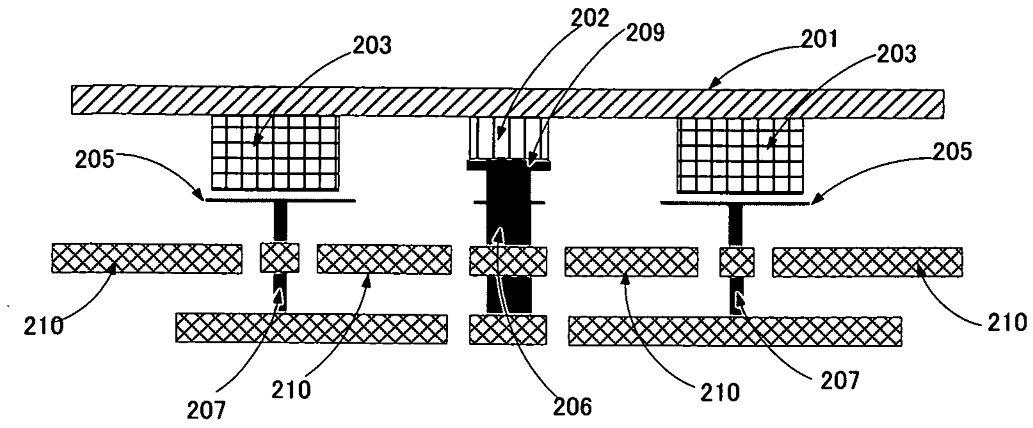

Figure 17A

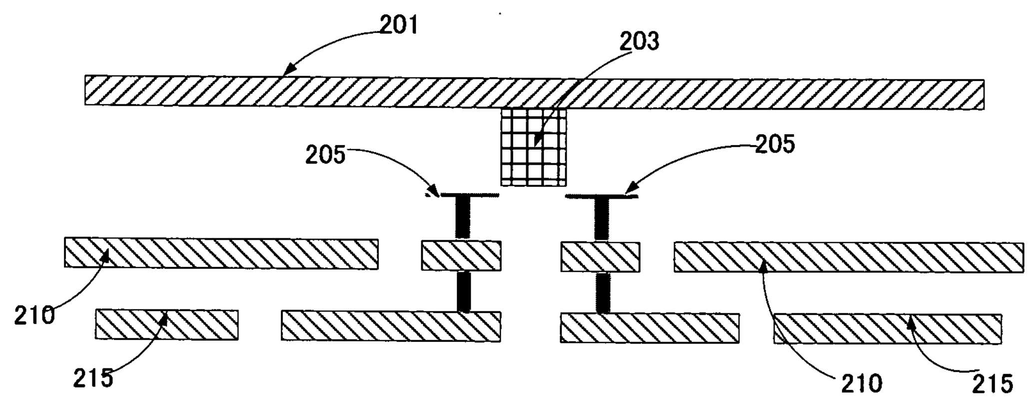

Figure 17B

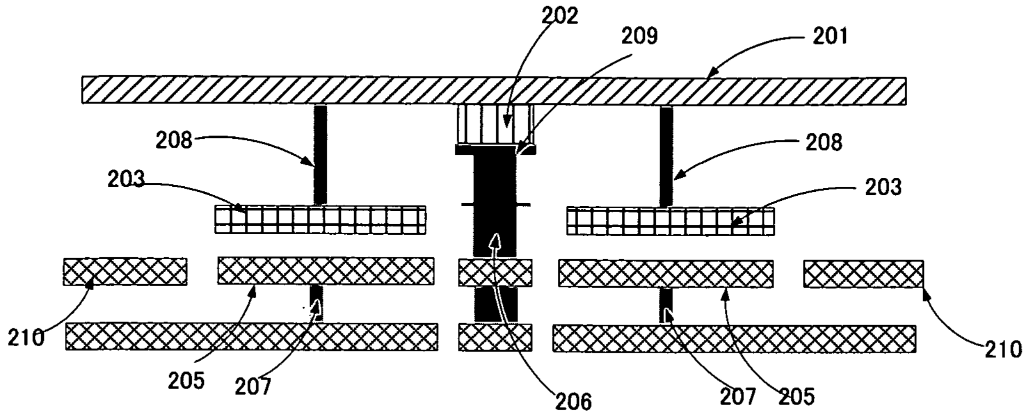

Figure 18A

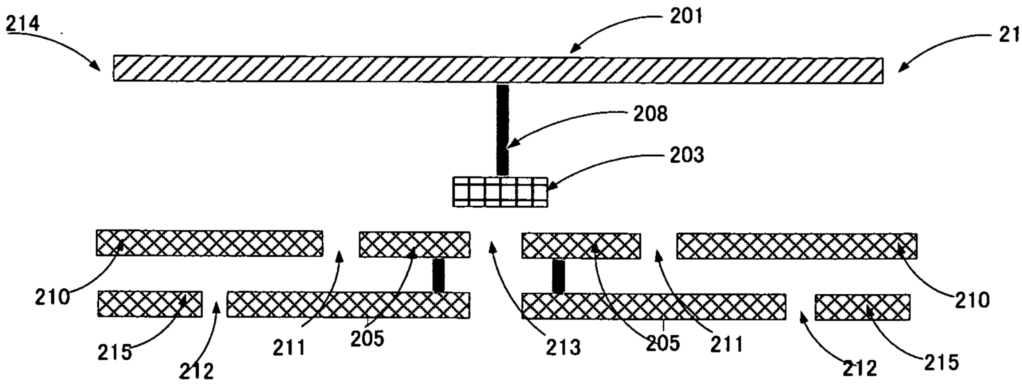

Figure 18B

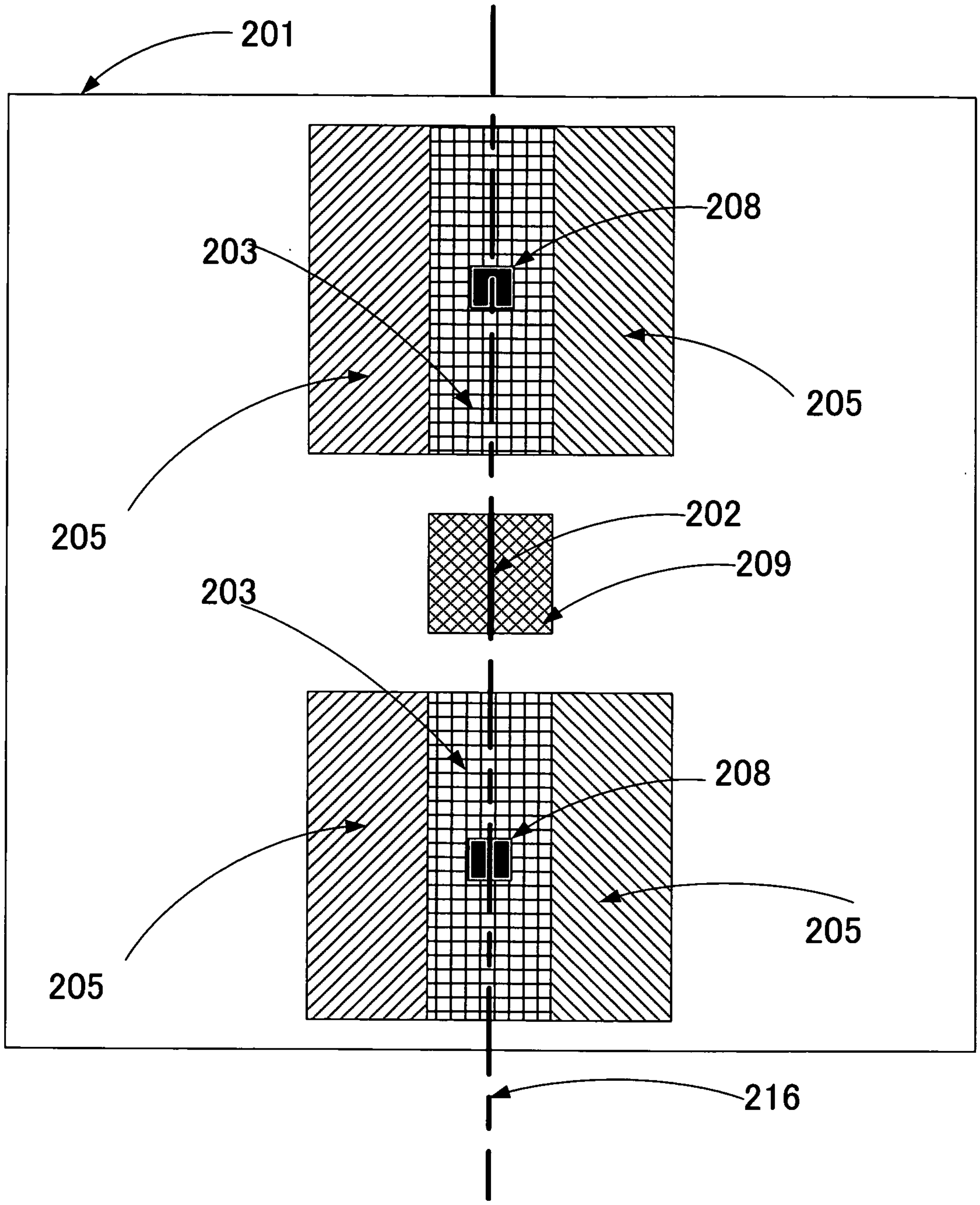

Figure 18C

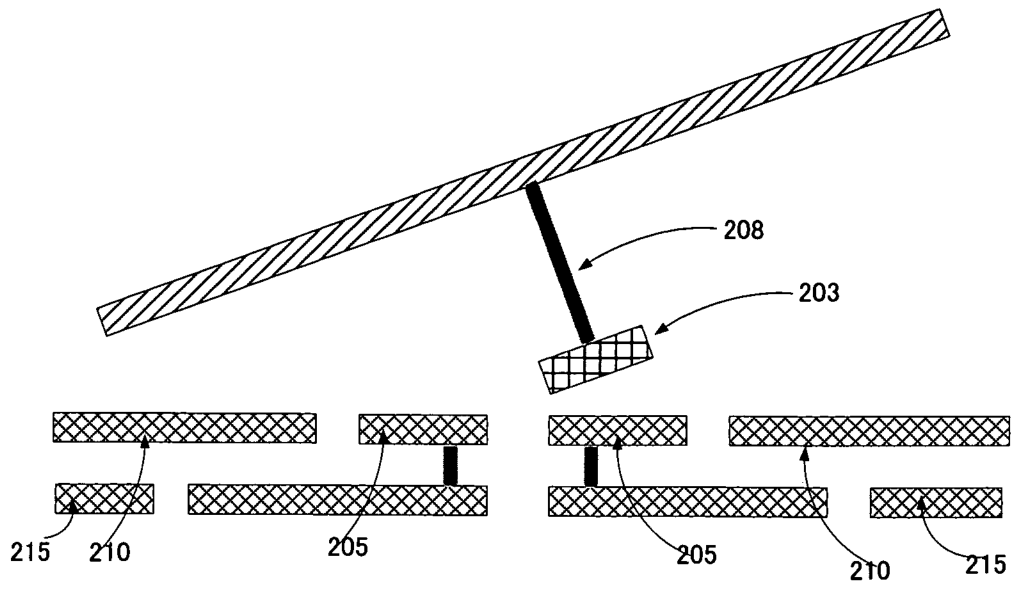

Figure 18D

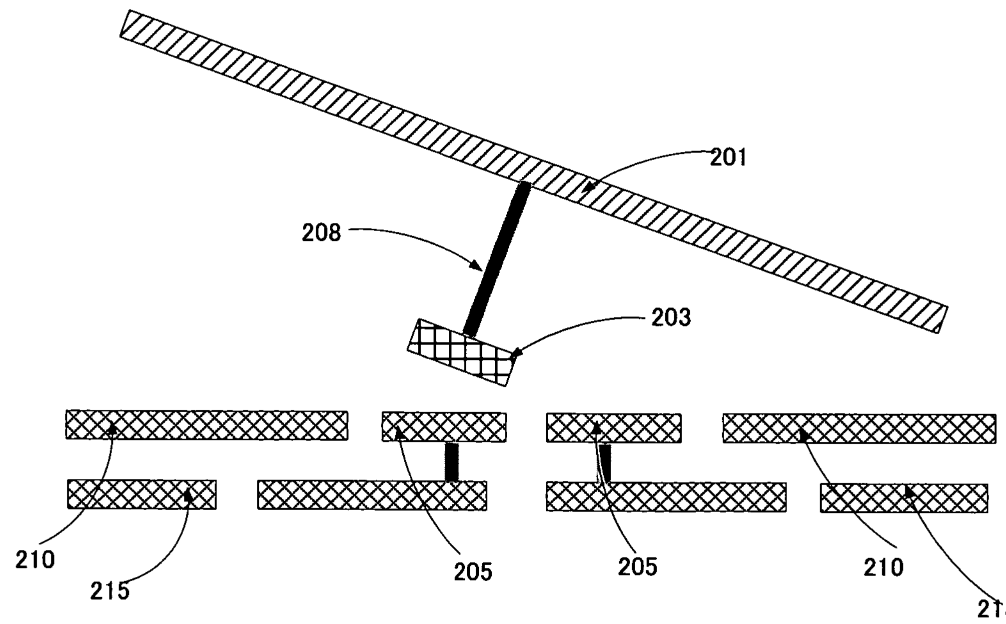

Figure 18E

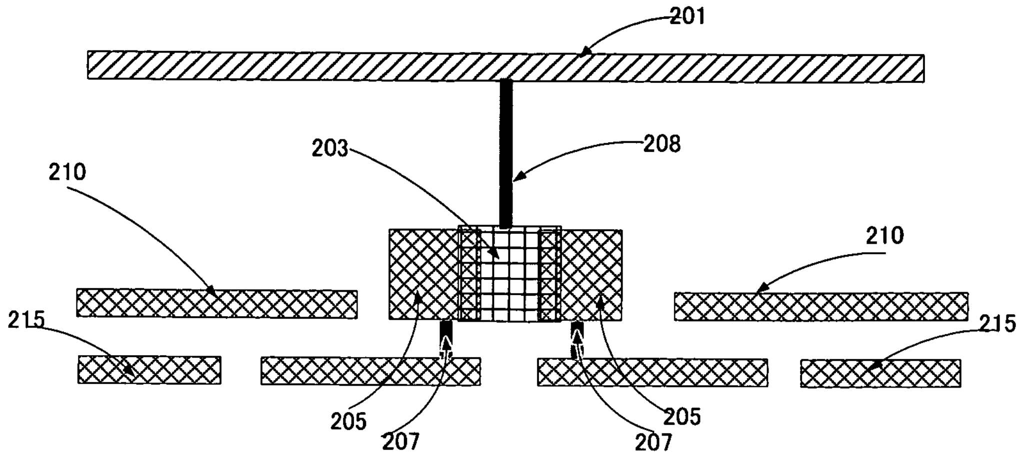

Figure 19A

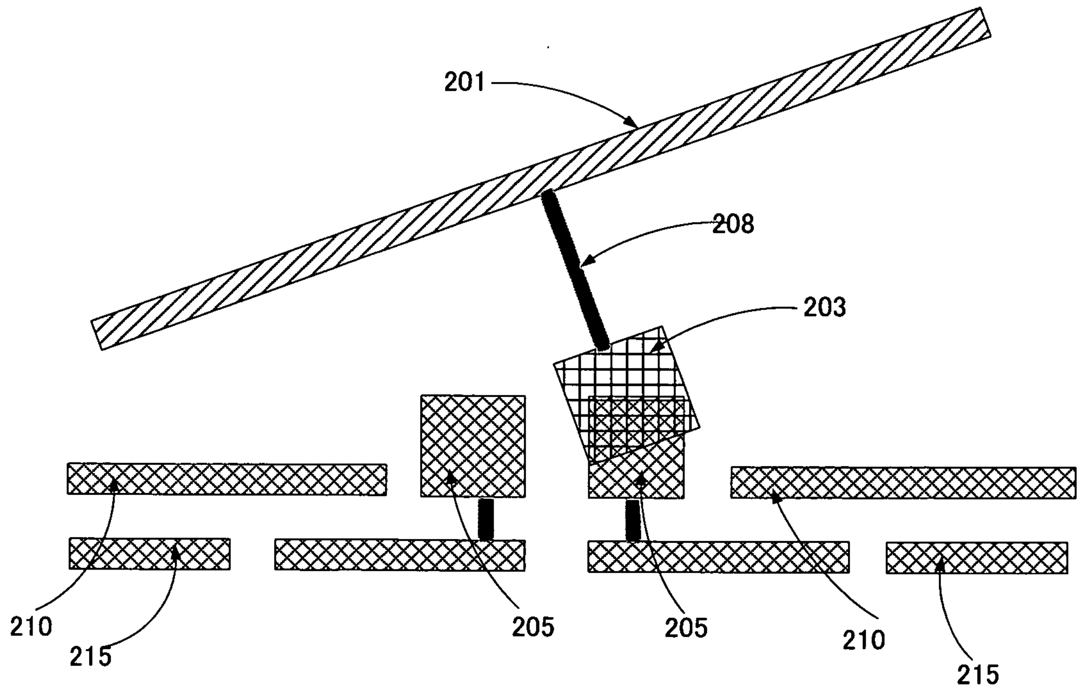

Figure 19B

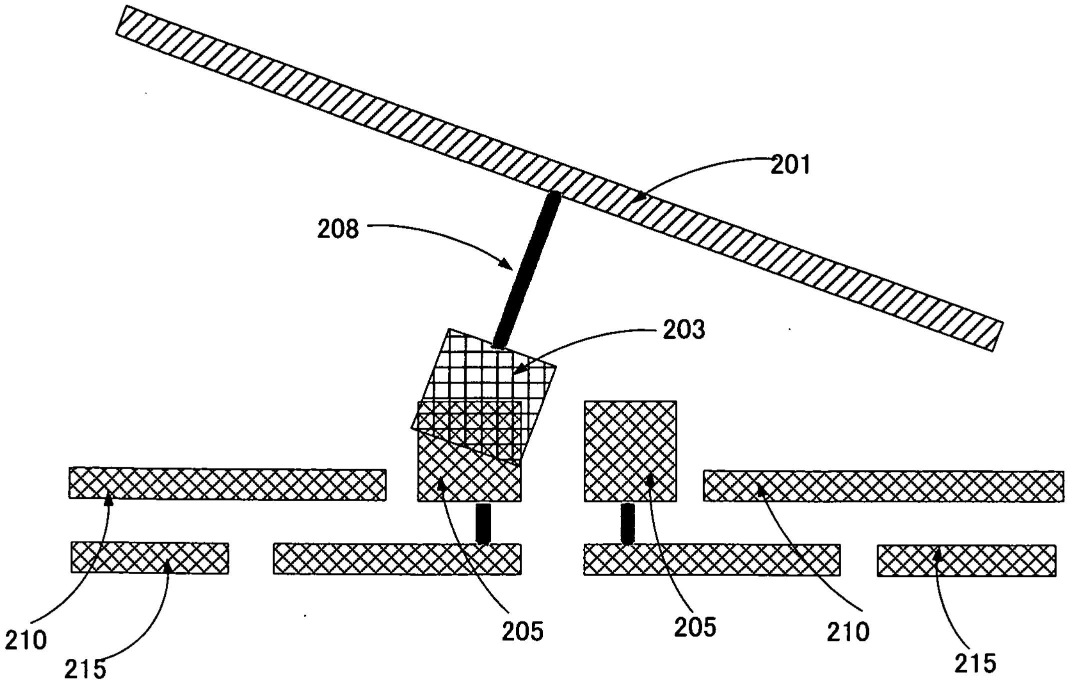

Figure 19C

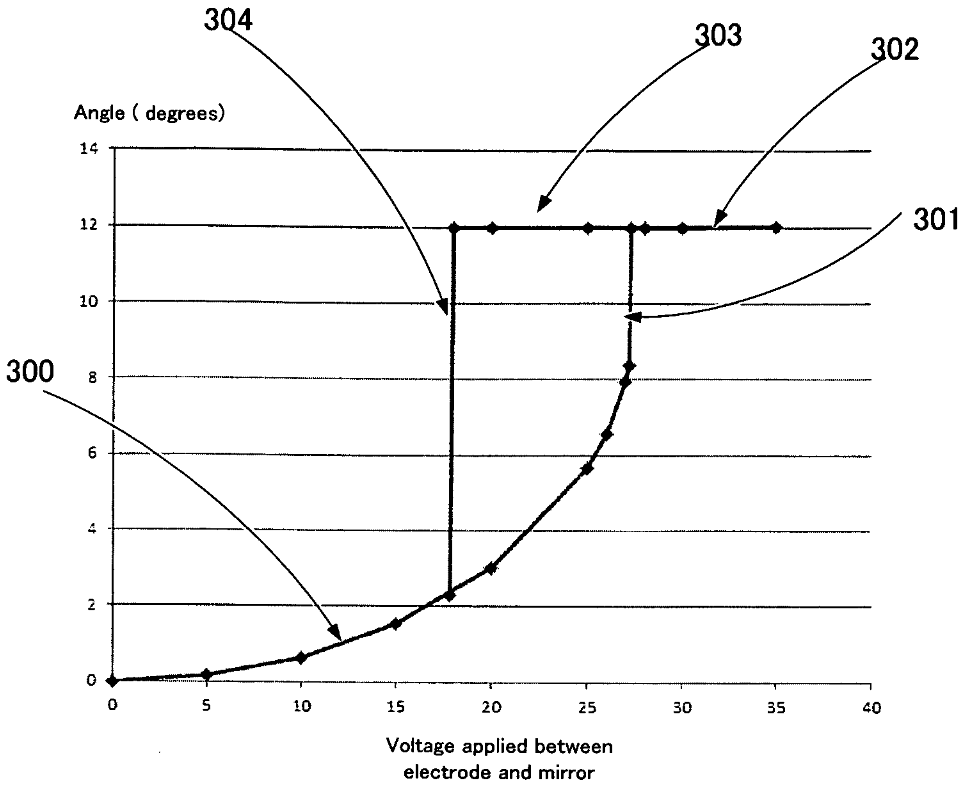
304
303
302
301
300
Angle (degrees)
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
Voltage applied between electrode and mirror

Figure 20

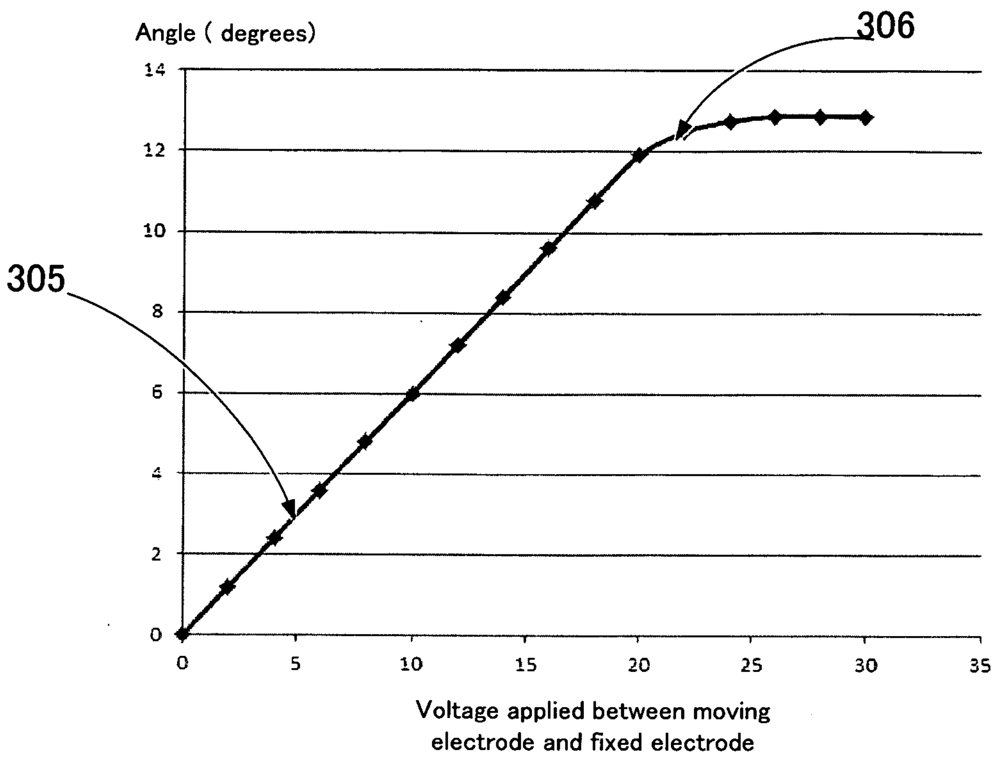

Figure 21

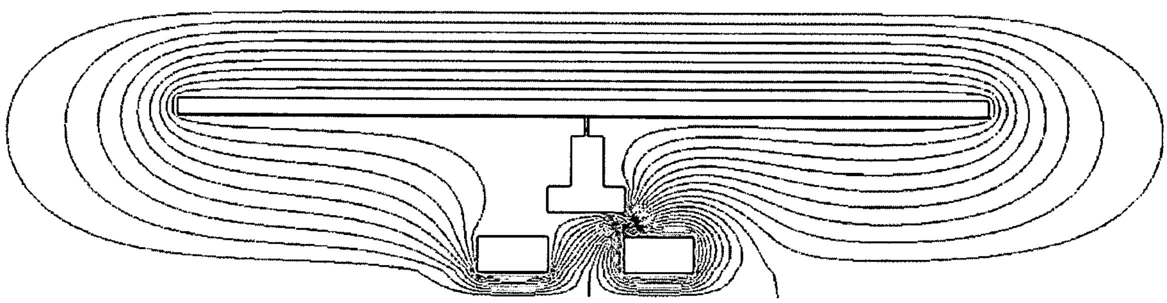

Figure 22

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/000072

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G02B 26/00 (2014.01)
USPC - 359/224.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - B81B 3/00; G02B 26/00, 26/08; G02F 1/29 (2014.01)
USPC - 345/84; 359/224.1, 290, 291, 295

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - G02B 26/0841; G09G 3/346, 2310/0262 (2014.02)

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 2009/0185257 A1 (MAEDA et al) 23 July 2009 (23.07.2009) entire document	1 --- 2,3
Y	US 2008/0180778 A1 (ISHII) 31 July 2008 (31.07.2008) entire document	2,3
A	US 2004/0017625 A1 (VAN DRIEENHUIZEN et al) 29 January 2004 (29.01.2004) entire document	1-3
A	US 2005/0012975 A1 (GEORGE et al) 20 January 2005 (20.01.2005) entire document	1-3

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

* 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
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"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
18 August 2014	05 SEP 2014

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/000072

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
See attached sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-3

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Continuation of Box No. III:

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-3, drawn to a mirror device with atom-exchange bonding between the hinge and the mirror.
Group II, claims 4-5 and 7-10, drawn to a mirror device with mirror elements having electrodes.
Group III, claim 6, drawn to a mirror device having a hinge supported by a hinge-table having stoppers.
Group IV, claim 11, drawn to a mirror device with multiple etch-stop-layers.

The inventions listed as Groups I, II, III or IV do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: wherein the hinge is bonding to the bottom surface of the mirror through an atom-exchange bonding between the hinge and the mirror with an increased strength of bonding as claimed therein is not present in the invention of Groups II, III or IV.

The special technical feature of the Group II invention: wherein each of the mirror elements further comprises electrodes as claimed therein is not present in the invention of Groups I, III or IV.

The special technical feature of the Group III invention:wherein said hinge is supported by a hinge-table having stoppers to limit a rotational angle of the mirror as claimed therein is not present in the invention of Groups I, II or IV.

The special technical feature of the Group IV invention: etch-stop-layer(s) made of metal to protect internal structure against etchant to remove sacrificial layer(s); holes in the first etch-stop-layer are staggered from holes in the second sacrificial layer to extend the time of etchant reaching the internal structure as claimed therein is not present in the invention of Groups I, II or III.

Groups I, II, III and IV lack unity of invention because even though the inventions of these groups require the technical feature of a mirror device comprising a mirror array comprising multiple mirror elements, this technical feature is not a special technical feature as it does not make a contribution over the prior art. Specifically, (US 2009/0185257 A1, Maeda et al, 23 July 2009 (23.07.2009)) teaches a mirror device comprising a mirror array having multiple mirror elements (mirror device 200 comprising a plurality of mirror elements 700, Para. 222 and Figs. 2 and 7G).

Since none of the special technical features of the Group I, II, III or IV inventions are found in more than one of the inventions, unity of invention is lacking.