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

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
**28 June 2001 (28.06.2001)**

**PCT**

(10) **International Publication Number**
**WO 01/46741 A1**

(51) **International Patent Classification**⁷: **G02B 26/08**

(21) **International Application Number:** PCT/US00/35135

(22) **International Filing Date:**
22 December 2000 (22.12.2000)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
09/471,796 23 December 1999 (23.12.1999) US

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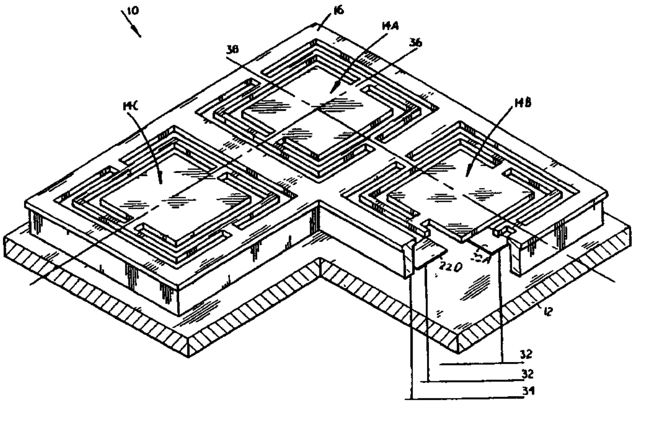
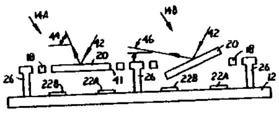
(81) **Designated States** *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) **Designated States** *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

**Published:**
- *With international search report.*
- *Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.*

# (54) Title: A MICROMACHINED REFLECTIVE ARRANGEMENT





(57) **Abstract:** A micromachined reflective arrangement for manipulating beams of light is described. The micromachined reflective arrangement includes a substrate, first and second adjacent reflector arrangements, and at least a first barrier. Each respective reflector arrangement includes a respective mirror component which is secured for pivotal movement to the substrate. The mirror component has a reflective surface from which a respective beam of light can be reflected in a selected direction relative to the substrate. Each reflector arrangement includes at least a first electrostatic contact to which a voltage can be applied to cause electric field interaction between the first electrostatic contact and a first respective area of the respective mirror component so that the respective mirror component pivots relative to the substrate and the selected direction in which the perspective beam of light is reflected is changed. The first barrier is located between the first and second arrangements. The first barrier restricts electric field interaction between the first electrostatic contact of the first reflector arrangement with the first area of the mirror component of the second reflector arrangement. Pivoting of the mirror component of the second reflector arrangement is thereby restricted when a voltage is applied to the first electrostatic contact of the first reflector arrangement.

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# A MICROMACHINED REFLECTIVE ARRANGEMENT

## Field of the Invention

This invention relates to a micromachined reflective arrangement for manipulating beams of light.

## Background of the Invention

One kind of micromachined reflective arrangement typically includes an array of miniature mirrors which are formed on a substrate and which can be individually pivoted by applying voltages to electrostatic contacts located in strategic positions near edges of the mirror component. One problem associated with such a micromachined reflective arrangement is that a voltage applied to one of the electrostatic contacts may cause electric field interference with an adjacent mirror component and thereby cause undesirable pivoting of the adjacent mirror component.

## SUMMARY OF THE INVENTION

A micromachined reflective arrangement for manipulating beams of light is described. The micromachined reflective arrangement includes a substrate, first and second adjacent reflector arrangements, and at least a first barrier. Each respective reflector arrangement includes a respective mirror component which is secured for pivotal movement to the substrate. The mirror component has a reflective surface from which a respective beam of light can be reflected in a selected direction relative to the substrate. Each reflector arrangement includes at least a first electrostatic contact to which a voltage can be applied to cause electric field interaction between the first electrostatic contact and a first respective area of the respective mirror component so that the respective mirror component pivots relative to the substrate and the selected direction in which the perspective beam of light is reflected is changed. The first barrier is located between the first and second arrangements. The first barrier restricts electric field interaction between the first electrostatic contact of the first reflector arrangement with the first area of the mirror component of the second reflector arrangement. Pivoting of the mirror component of the second reflector arrangement is thereby restricted when a voltage is applied to the first electrostatic contact of the first reflector arrangement.

Other features and advantages of the present invention will be apparent from the accompanying drawings and from the detailed description that follows.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated by way of example and not limited in the figures of the accompanying drawings in which like references indicate similar elements and in which:

Figure 1 with a perspective view of a micromachined reflective arrangement according to one embodiment of the invention;

Figure 2 is a plan view of the micromachined reflective arrangement of Figure 1;

Figure 3 is a cross-sectional side view on 3-3 in Figure 2;

Figure 4 is a cross-sectional side view on 4-4 in Figure 1;

Figure 5 is a perspective view of a micromachined reflective arrangement according to another embodiment of the invention; and

Figure 6 is a cross-sectional side view of a micromachined reflective arrangement according to a further embodiment of the invention.

## DETAILED DESCRIPTION

Specific embodiments of the invention are now described in more detail. According to one embodiment of the invention, a micromachined reflective arrangement was provided which includes a substrate, a plurality of gimballed mirror components and a barrier structure. The barrier structure is a grid of metal barriers. Each mirror component is located within a respective opening in the grid. The mirror component is gimballed so that it can pivot about two axes which are located at right angles to one another. A respective electrostatic contact is located below each one of four edges of the mirror component. A voltage which is applied to each of the electrostatic contacts creates an electric field which pivots the mirror component. The barrier is located between adjacent mirror components so that an electric field from an electrostatic contact of one of the mirror components does not cause pivoting of an adjacent mirror component. In one embodiment the mirror components are mounted directly to the barrier structure and in another embodiment the mirror components are mounted to separate support structures than the barrier structure. The barrier structure may be grounded although it has been found that pivoting of a mirror component is more easily accomplished if the barrier structure is biased so that a voltage is created thereon equalling the voltage applied to one of the electrostatic contacts.

Figure 1 to Figure 4 of the accompanying drawings illustrate a portion of a micromachined reflective arrangement 10 according to an embodiment of the invention. The micromachined reflective arrangement 10 is a microelectromechanical system (MEMS) device that is manufactured according to conventional MEMS technology. The micromachined reflective arrangement 10 includes a substrate 12, a plurality of adjacent reflector arrangements of which a first reflector arrangement 14A, a second reflector arrangement 14B, and a third reflector arrangement 14C are shown, and a barrier structure 16.

The substrate 12 is a semiconductor substrate such as a silicon substrate with metal lines (not shown) located therein and thereon for providing signals and power to the reflector arrangements 14. The manufacture of a substrate having metal lines formed therein is conventional in the art.

Each reflector arrangement 14 has a rectangular mounting ring 18, a gimballed mirror component 20, and a first to a fourth electrostatic contact 22A-22D.

The mirror component 20 typically has dimensions of about 0.5 mm by 0.5 mm and is typically made of silicon although other materials such as metals, in particular aluminum, or silicon nitride may be used. The mirror component 20 is located within the mounting ring 18 and is secured to the mounting ring by pivot connections 24 located on opposing sides of the mirror component 20.

The barrier structure 16 is formed on the substrate 12 and includes a plurality of barriers 26. The barriers 26 are located in a grid and are interconnected with one another. The barrier structure 16 is at least in part made of a conductive metal.

Each reflector arrangement 14 is located within a square opening defined by four of the barriers 26. The mounting ring 18 is secured to one barrier 26 by means of a pivot connection 30A and secured to a barrier 26 on an opposing side by means of another pivot connection 30B. Each mirror component 20 is mounted to the substrate 12 via the mounting ring 18 and the barriers 26.

The first and second electrostatic contacts 22A and 22B are located below opposing edges of the mirror component 20. The second and third electrostatic contacts 22C and 22D are respectively located near the other two opposing edges of the mirror component 20.

Each electrostatic contact 22A-22C is connected to a respective signal line 32 located within the substrate 12. A voltage can be applied through a respective one of the signal lines 32 to a respective one of the electrostatic contacts 22. The mirror component 20 is connected through the mounting ring 18 and the barrier structure 16 to a ground line 34 in the substrate 12. A voltage applied to the first electrostatic contact 22A causes electric field interaction between the electrostatic contact 22A and an area near the edge of the mirror component 20 which is closest to the electrostatic contact 22A. The electric field interaction causes pivoting of the mirror component 20 and movement of the edge of the mirror component 20 closest to the first electrostatic contact 22A towards the first electrostatic contact 22A. Pivoting of the mirror component 20 is against a torque developed within the pivot connections 24 and about an axis 36 through the pivot connections 24. Although the mirror component 20 pivots about a fixed axis 36, it should be understood that this need not be the case. Another embodiment may for example make use of a cantilevered beam to which a mirror component is secured. Bending of the beam would cause pivoting of the mirror component but not around a fixed point.

Similarly, when a voltage is applied to the second electrostatic contact 22B, the mirror component pivots about the axis 36 in a direction opposite to the direction when a voltage is applied to the first electrostatic contact 22A. In either case, the mirror component 20 returns to its original position once the voltage is removed from the electrostatic contact 22A or 22B.

The third electrostatic contact 22C is located in a position so that, when a voltage is applied thereto, the mounting ring 18 and the mirror component 20 pivot together about the pivot connections 40 and against a torque in the pivot connections 40. Pivoting of the mounting ring 18 and the mirror component 20 is about an axis 38. The axis 38 is located transversely and at right angles to the axis 36.

Similarly, when a voltage is applied to the fourth electrostatic contact 22D, the mounting ring 18 and the mirror component 20 pivot in a direction opposite to the direction when a voltage is applied to the third electrostatic contact 22C, about the axis 38.

The mirror component 20 has a reflective surface from which a beam of light 42 can be reflected in a selected direction 44 relative to the substrate 12. Pivoting of the mirror component 20 causes a change in the selected direction 44 to a selected direction 46. Reflection of the beam of light 42 can be changed by pivoting or gimballing the mirror component 20 about either the axis 36 or the axis 38, or about both the axis 36 and the axis 38.

The first and second reflector arrangements 14A and 14B are located adjacent one another in a first line on an x-axis and the first and third reflector arrangements 14A and 14C are located adjacent one another in a second line on a y-axis which is transverse and at right angles to the first line. The first electrostatic contact 22A of the first reflector arrangement 14A is located adjacent the second electrostatic contact 22B of the second reflector arrangement 14B. The fourth electrostatic arrangement 22D of the first electrostatic arrangement 14A is located adjacent the third electrostatic contact 22C of the third reflector arrangement 14C. Although only three reflector arrangements are shown, it should be understood that only a portion of the micromachined reflective arrangement 10 is shown and that the micromachined reflective arrangement 10 includes many more reflector arrangements which are located in an array of multiple rows and multiple columns. In a typical arrangement a total of 144 reflector arrangements in 12 rows and 12 columns are provided, although the total number of reflector arrangements may vary from a few to about 1000 or more.

Figure 3 shows the positioning of the mirror component 20 of the second reflector arrangement 14B which is pivoted when a voltage is applied to the second electrostatic contact 22B thereof to cause pivoting of the mirror component 20. Without a barrier 26 located between the first and second reflector arrangements 14A and 14B, the second electrostatic contact 22B of the second reflector arrangement 14B could cause electric field interaction with an edge 41 of the mirror component 20 of the first reflector arrangement 14A. Such an electric field interaction could cause pivoting of the mirror component 20 of the first reflector arrangement 14A. One analysis shows that the electric field of the second electrostatic contact 22B causes a torque on the mirror component 20 of the first reflector arrangement 14A of about 1.8% of a torque created on the mirror component 20 of the second reflector arrangement 14B if there is no barrier 26. However, because of the barrier 26 between the first and second reflector arrangement 14A and 14B, there is almost no electric field interaction between the second electrostatic contact 22B of the second reflector arrangement 14B and the edge 41 of the mirror component 20 of the first reflector arrangement. The analysis shows that the torque on the mirror component 20 of the first reflector arrangement 14A is only 0.0008% of the torque on the mirror component 20 of the second reflector arrangement 14B. Light reflected from the mirror component 20 of the first reflector arrangement 14A is reflected without being influenced by the operation of the second reflector arrangement 14B.

According to the analysis, a 45° pivot of the mirror component 20 of the second reflector arrangement 14B causes only a 0.0004° pivot in the mirror component 20 of the first reflector arrangement 14A.

Similarly, as shown in Figure 4, pivoting of the mirror component 20 of the third reflector arrangement 14C when a voltage is applied to the third electrostatic contact 22C thereof does not influence pivoting of the mirror component 20 of the first reflector arrangement because of a barrier 26 located between the first and third reflector arrangements 14A and 14C. A primary benefit of the barriers 26 is that they are at the same voltage as the mirror components 20 and at a voltage different from any one of the electrostatic contacts 22 when a voltage is applied to the electrostatic contact 22.

One problem with the use of the barriers 26 is that electrical field lines terminate on the barriers 26. Hence, the voltage required to deflect a mirror component 20 increases. One solution is to bias the barrier structure 16 up to the maximum deflection voltage of the electrical contacts 22. All the field lines from the electrical contacts then terminate on the mirror components 20. The mirror components 20 do not deflect because of the voltage of the barrier structure 16 because the barriers are located symmetrically around them.

The barrier structure 16 may be manufactured according to any one of a number of processes. In one process a photoresist layer is spun onto the substrate 12 and etched to define the grid structure of the barrier structure 16. A metal layer is then formed on the remaining photoresist layer by evaporation, electroless plating or any other process. The metal layer is grounded and is typically made of nickel. In another process the grid structure of the barrier structure 16 may be formed out of glass which is subsequently coated with a metal layer.

Figure 5 illustrates a micromachined reflective arrangement 110 according to an alternative embodiment of the invention. The micromachined reflective arrangement 110 includes a substrate 112, first, second, and third reflector arrangements 114A-114C and a barrier structure 16. Each reflector arrangement 114 includes a mounting ring 118 and a mirror component 120 which is pivotally mounted to the mounting ring 118. Each reflector arrangement 114 further includes a support 160. The support 160 is in the form of a square which is located within a square defined by four barriers 126 of the barrier structure 116. The mounting ring 118 is pivotally secured to the support 160. The support 160 and the barrier structure 116 are connected to a ground line 134. The micromachined reflective arrangement 110 is the same as the micromachined reflective arrangement 10 of Figure 1 in all other respects.

Figure 6 of the accompanying drawings illustrates a micromachined reflective arrangement 210 according to a further embodiment of the invention. The micromachined reflective arrangement 210 is the same as the micromachined reflective arrangement 10 of Figure 1 or the micromachined reflective arrangement 110 of Figure 5, except that the micromachined reflective arrangement 210 of Figure 6 further has a conductive metal layer 262 located on a substrate 212. Barriers 226 are formed on and are electrically connected to the layer 262. The micromachined reflective arrangement 210 has first and second reflector arrangements 214A and 214B, as in the embodiments hereinbefore described. Each reflector arrangement 214 includes a mounting ring 218, a mirror component 220 and first and second electrostatic contacts 222A and 222B. Each electrostatic contact 222 is located on an insulated portion 264 which electrically insulates the electrostatic contact 222 from the layer 262.

The layer 262 is grounded and prevents an electric field from passing from one electrostatic arrangement 214B around a base 266 of each barrier 226 to an adjacent reflector arrangement 214A. The adjacent reflector arrangement 214A is isolated from electric field interaction by both the barrier 226, and the layer 262 and the mirror 222 of the reflector arrangement 214B.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

## CLAIMS

What is claimed:

1. A micromachined reflective arrangement for manipulating beams of light, comprising:

at least first and second gimballed mirror components located next to each other; and

a barrier located between the mirror components.

2. The micromachined reflective arrangement of claim 1, further comprising:

an electrostatic contact which causes the first mirror component to pivot when a voltage is applied to the electrostatic contact, the barrier restricting electric field interaction between the electrostatic contact and the second mirror component.

3. The micromachined reflective arrangement of claim 1 comprising a plurality of said mirror components and a plurality of barriers, each barrier located between two of the mirror components located next to each other.

4. The micromachined reflective arrangement according to claim 3 wherein the mirror components are located in rows and columns.

5. The micromachined reflective arrangement of claim 1 wherein a voltage can be applied to the barrier.

6. A micromachined reflective arrangement for manipulating beams of light, comprising:

a substrate;

at least first and second adjacent reflector arrangements, each respective reflector arrangement including a respective mirror component which is secured for pivotal movement to the substrate, the respective mirror component having a reflective surface from which a respective beam of light can be reflected in a selected direction relative to the substrate, and at least a first respective electrostatic contact to which a voltage can be applied to cause electric field interaction between the first respective electrostatic contact and a first respective area of the respective mirror component so that the respective mirror component pivots relative to the substrate and the selected direction in which the respective beam of light is reflected is changed; and

at least a first barrier, the first barrier being located between the first and second reflector arrangements, the first barrier restricting electric field interaction between the first electrostatic contact of the first reflector arrangement with the first area of the mirror component of the second reflector arrangement, thereby restricting pivoting of the mirror component of the second reflector arrangement when a voltage is applied to the first electrostatic contact of the first reflector arrangement.

7. The micromachined reflective arrangement according to claim 6 wherein the barrier restricts electric field interaction between the first electrostatic contact of the second reflector arrangement with the area of the mirror component of the first reflector arrangement, thereby restricting pivoting of the mirror component of the first reflector arrangement when a voltage is applied to the first electrostatic contact of the second reflector arrangement.

8. The micromachined reflective arrangement according to claim 6 wherein the voltage applied to the respective first electrostatic contact has a value other than 0 V and the barrier is grounded.

9. The micromachined reflective arrangement according to claim 6 wherein a voltage is applied to the barrier.

10. The micromachined reflective arrangement according to claim 6 wherein the mirror component of one of the reflector arrangements is secured to the barrier.

11. The micromachined reflective arrangement according to claim 10 wherein the first reflector arrangement includes:

a respective mounting ring which is secured to the first barrier for pivotal movement about a first respective axis, the respective mirror component being located in the mounting ring and being secured to the respective mounting ring for pivotal movement about a second respective axis which is transverse to the first respective axis to that the mirror component pivots about the second respective axis when the voltage is applied to the first respective electrostatic contact.

12. The micromachined reflective arrangement according to claim 6 wherein each reflector arrangement includes a second respective electrostatic contact to which a voltage can be applied to cause electric field interaction between the second respective electrostatic contact and a second respective area of the mirror component so that the respective mirror component pivots relative to the substrate in a direction different to a direction in which the respective mirror component pivots when the voltage is applied to the respective first electrostatic contact.

13. The micromachined reflective arrangement according to claim 12 comprising:

at least a third of said reflector arrangements, the third reflector arrangement being located adjacent the second reflector arrangement, and

at least a second barrier, the second barrier being located between the second and third electrostatic arrangements and restricting electric field interaction between the second electrostatic contact of the second reflector arrangement with the first area of the mirror component of the third reflector arrangement, thereby restricting pivoting of the mirror component of the third reflector arrangement when a voltage is applied to the second electrostatic contact of the second reflector arrangement.

14. The micromachined reflective arrangement according to claim 13 wherein the first, second, and third electrostatic arrangements are located in line after one another.

15. The micromachined reflective arrangement according to claim 13 wherein the first, second, and third electrostatic arrangements form part of an array with the first and second electrostatic arrangements located inline on an x-axis of the array and the second and third electrostatic arrangements located inline on a y-axis of the array.

16. The micromachined reflective arrangement according to claim 13 wherein the first and second barriers are electrically connected to one another.

17. The micromachined reflective arrangement according to claim 16 wherein the first and second barriers contact one another.

18. The micromachined reflective arrangement according to claim 6, further comprising a conductive layer over the substrate which restricts an electric field from passing around a base of the barrier.

19. A micromachined reflective arrangement for manipulating beams of light, comprising:

a substrate;

a plurality of reflector arrangements which are located sequentially one after the other in a first line and sequentially one after the other in a second line which is transverse to the first line, each respective reflector arrangement including a respective mirror component which is secured to the substrate for pivotal movement about a first axis and about a second axis which is transverse to the first axis, at least a first respective electrostatic contact to which a voltage can be applied to cause electric field interaction between the respective first electrostatic contact and a respective first area of the respective mirror component so that the mirror component pivots relative to the substrate about the first axis, and a second electrostatic contact to which a voltage can be applied to cause electric field interaction between the respective second electrostatic contact and a respective second area of the respective mirror component to cause pivoting of the respective mirror component about the second axis, the respective mirror component having a reflective surface from which a beam of light can be reflected in a selected direction relative to the substrate, the selected direction being changed when the mirror component pivots about the first axis or the second axis; and

a plurality of barriers, each barrier being located between adjacent ones of the reflector arrangements and each barrier restricting electric field interaction between a selected one of the electrostatic contacts of the reflector arrangements on a first side thereof with an area of a mirror component or a second, opposing side thereof, thereby restricting pivoting of the mirror component of the reflector arrangement on the second side thereof when a voltage is applied to the selected electrostatic contact of the reflector arrangement on the first side thereof.

20. The micromachined reflective arrangement according to claim 19 wherein the barriers form part of the same barrier structure.

21. A method of manipulating beams of light, comprising:

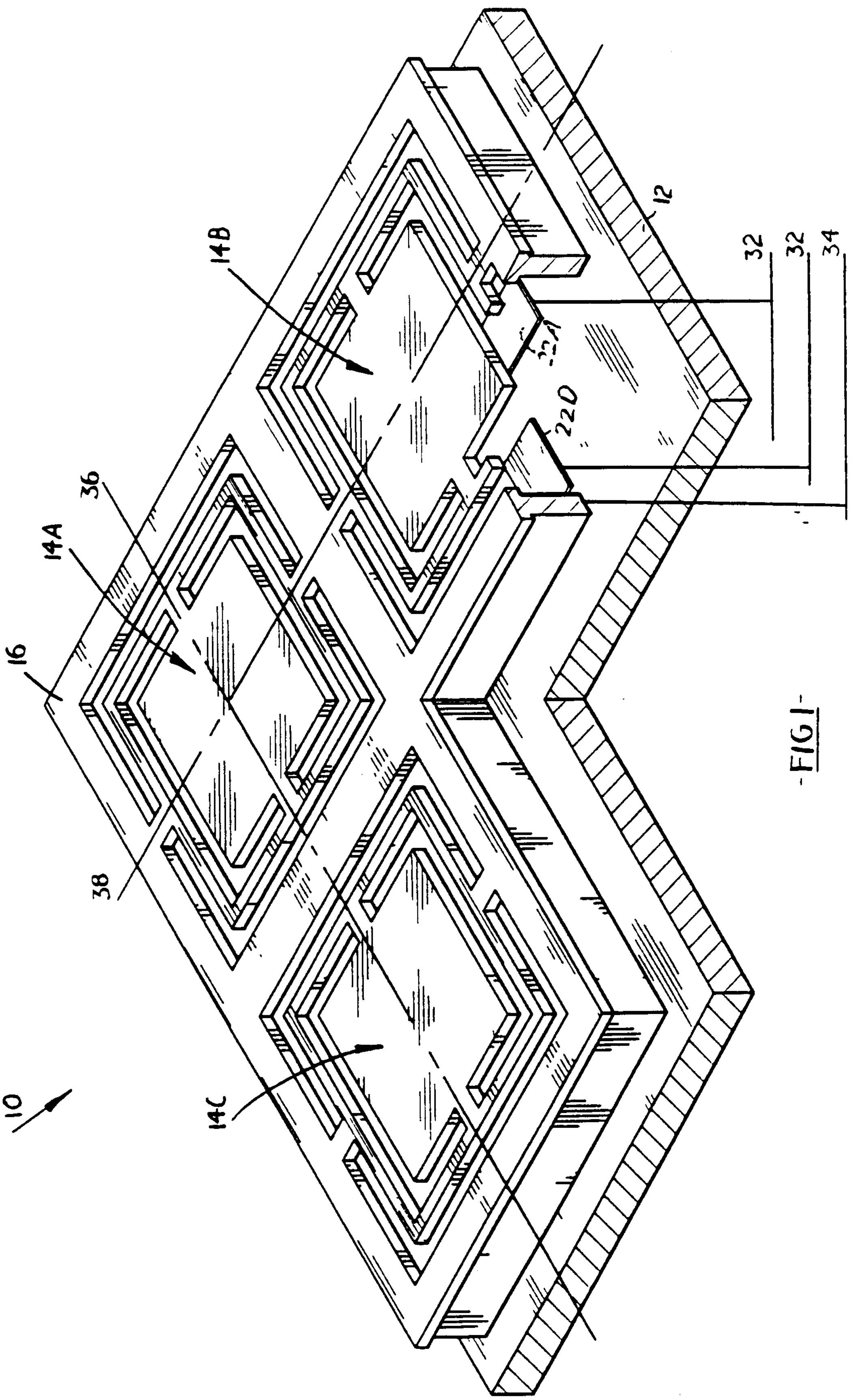
(i) reflecting a respective one of the beams off a respective one of at least first and second mirror components forming part of a micromachined reflective arrangement; and

(ii) applying a voltage to an electrostatic contact near the first mirror components so that the first mirror component is pivoted, while a barrier between the first and second mirror components restricts electric field interaction between the electrostatic contact and a second mirror component.

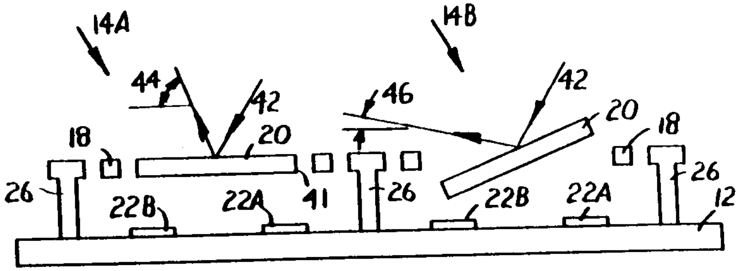
22. The method of claim 21 further comprising:

(iii) applying a voltage to the barrier.

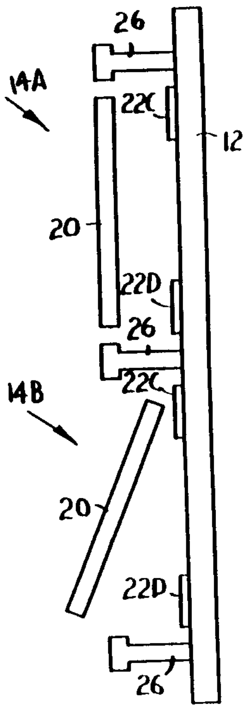
23. The method of claim 22 wherein the voltage applied to the barrier has a magnitude which is similar to the voltage applied to the electrostatic contact.



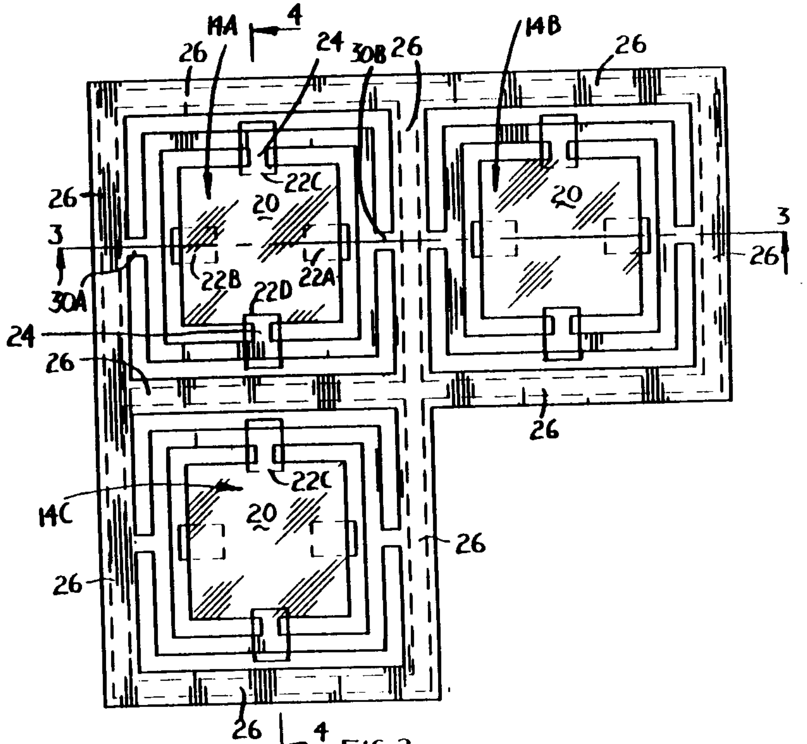
-FIG 1-



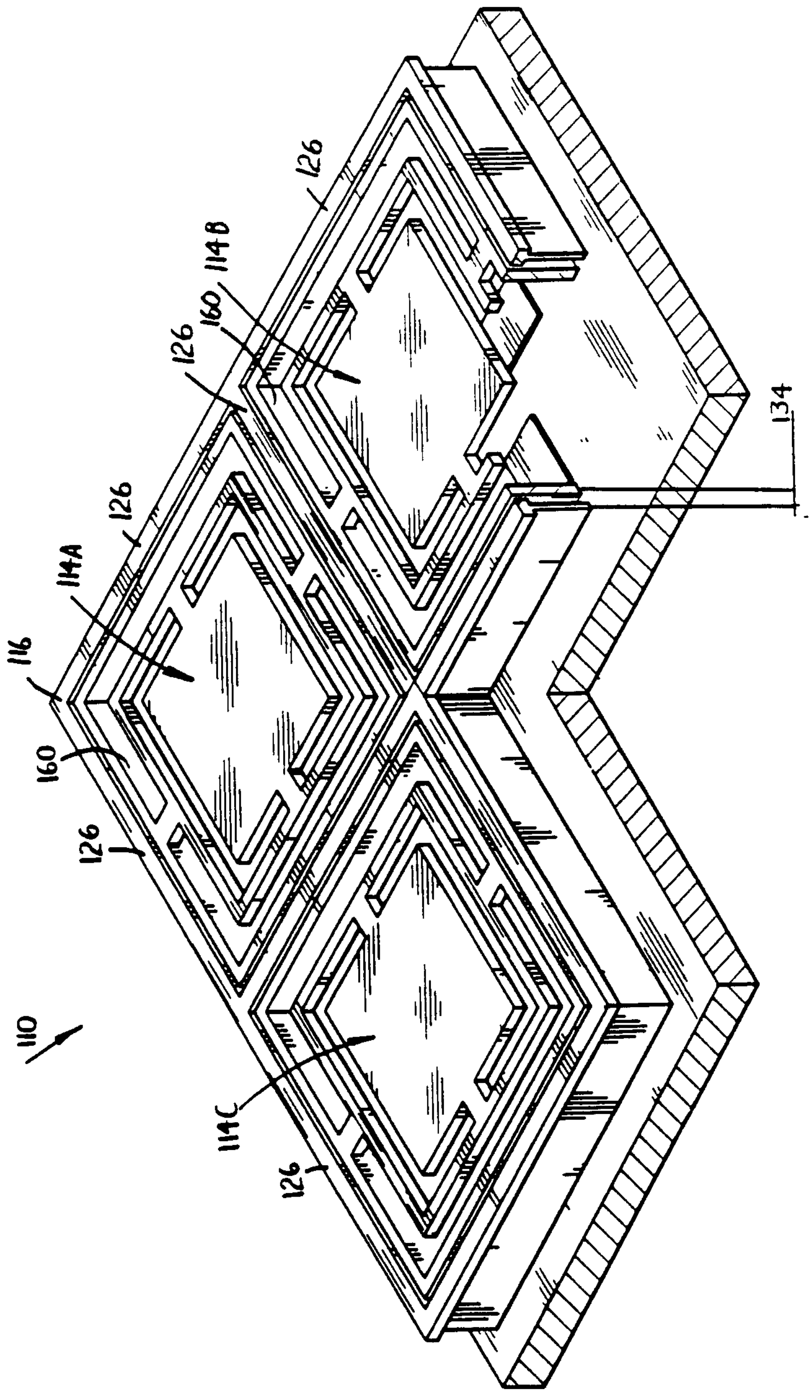
-FIG 3-



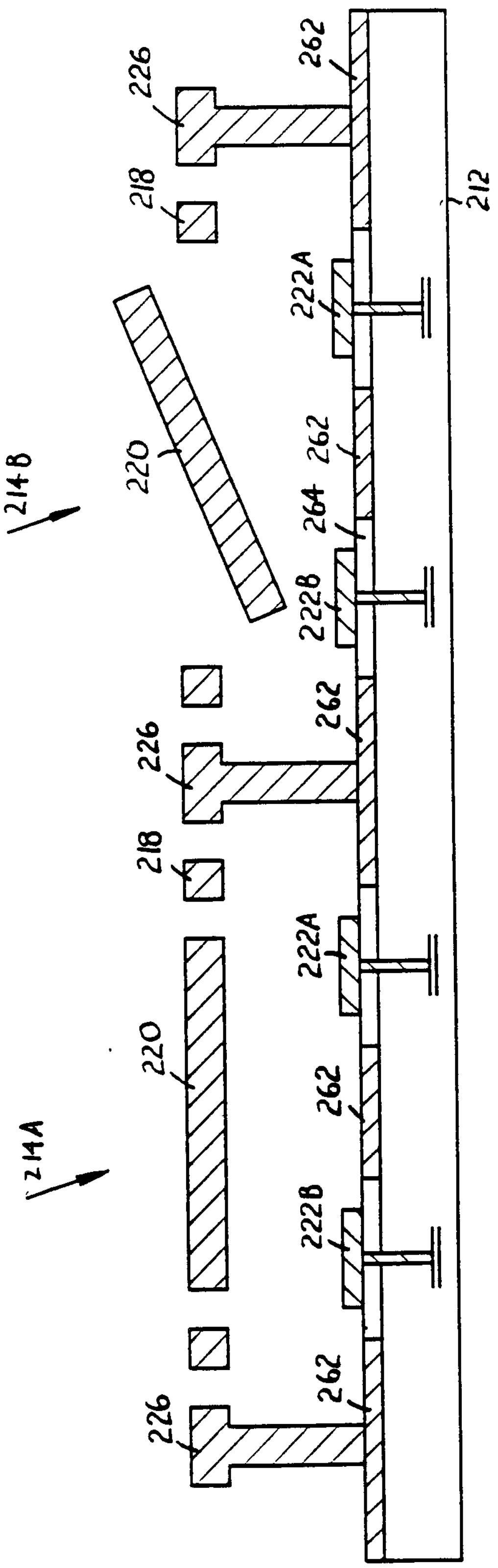
-FIG 4-



-FIG 2-



-FIG 5-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-FIG6-

# INTERNATIONAL SEARCH REPORT

Interna ial Application No
PCT/US 00/35135

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 G02B26/08

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 7 G02B H04N

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

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

EPO-Internal, WPI Data, INSPEC, PAJ

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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| Y | page 7, line 5 -page 8, line 5; figures 3,4<br>--- | 2-23 |
| Y | US 5 247 222 A (ENGLE CRAIG D)<br>21 September 1993 (1993-09-21)<br>column 5, line 43 -column 6, line 13; figures 1,4,5<br>--- | 2-23 |
| A | US 5 600 383 A (HORNBECK LARRY J)<br>4 February 1997 (1997-02-04)<br>column 3, line 3 - line 60<br>column 5, line 38 - line 49; figures 1-6,8<br>---<br>-/-- | 1-23 |

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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| Date of the actual completion of the international search<br>11 April 2001 | Date of mailing of the international search report<br>20/04/2001 |
| Name and mailing address of the ISA<br>European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,<br>Fax: (+31-70) 340-3016 | Authorized officer<br>THEOPISTOU, P |

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# INTERNATIONAL SEARCH REPORT

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**C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT**

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