

**IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF COLORADO**

FIBER, LLC,
a Wyoming limited liability company,

Plaintiff,

v.

ALCATEL LUCENT USA, INC.,
a Delaware corporation,

Defendant.

Civil Action Case No.: 15cv2135

COMPLAINT FOR PATENT INFRINGEMENT AND JURY DEMAND

Plaintiff, Fiber, LLC, a Wyoming limited liability company (“Plaintiff”), through its counsel Lewis Brisbois Bisgaard & Smith, LLP, submits the following Complaint for Patent Infringement and Jury Demand, alleging as follows:

INTRODUCTION

1. This is an action for patent infringement and damages under the United States patent laws, 35 U.S.C. § 271 *et seq.* Plaintiff is a Colorado-based company that has been dedicated to the advancement of optical fiber optic switching technology. Plaintiff is the exclusive assignee of patents disclose technology that is instrumental to photonic switch products. Defendant Alcatel Lucent USA, Inc. (“Alcatel”) makes, uses, offers for sale and/or sells within the United States and/or imports into the United States products infringing Plaintiff’s patents-in-suit.

THE PARTIES

2. Plaintiff is a Wyoming corporation with its principal place of business at 621 17th Street, Suite 801, Denver, Colorado 80293. Plaintiff is registered to do business in Colorado as a foreign limited liability company.

3. Defendant Alcatel Lucent USA, Inc., is a Delaware corporation with its principal place of business at 600-700 Mountain Avenue, Murray Hill, NJ, 07974 and, on information and belief, does business in this Judicial District and elsewhere throughout the United States. At all times relevant to this lawsuit, Alcatel manufactured, offered for sale, sold and/or distributed infringing products to customers throughout the United States and elsewhere.

JURISDICTION AND VENUE

4. This is an action for patent infringement and for damages under United States patent laws, 35 U.S.C. §§ 271, *et seq.* This Court has exclusive subject matter jurisdiction under 28 U.S.C. §§ 1331 and 1338(a).

5. This Court has personal jurisdiction over the Defendant. Alcatel conducts continuous and systematic business in the United States including, upon information and belief, in this Judicial District. Alcatel markets, manufactures, offers for sale, sells and/or distributes the infringing products at issue in this case throughout the United States including, upon information and belief, within this Judicial District.

6. Venue is proper in this District under 28 U.S.C. §§ 1391(b), 1391(c) and 1400(b) because each Defendant is subject to personal jurisdiction within this District, has committed acts of infringement of the patents-in-suit in this District and, upon information and belief, transacts business within this District.

GENERAL ALLEGATIONS AND PATENTS-IN-SUIT

7. On May 12, 1999, Patent Application No. 09/310,285 (“the ‘285 Application”) was filed with the U.S. Patent and Trademark Office (“USPTO”) to protect the invention of Herzel Laor, David A. Krozier, and Leo A. Plouffe entitled “OPTICAL SWITCHING APPARATUS”, which application claimed the benefit from Provisional Application No. 60/088,239, filed June 5, 1998. On August 6, 2002, the USPTO issued United States Patent No. 6,430,332 B1 (“the ‘332 Patent”) entitled “OPTICAL SWITCHING APPARATUS” from the ‘285 Application. The ownership rights to the invention disclosed and claimed in the ‘332 Patent have been assigned to Plaintiff as exclusive assignee in an assignment recorded with the USPTO. A copy of the ‘332 Patent is attached as **Exhibit A** and incorporated herein by this reference.

8. On June 17, 2002, Patent Application No. 10/197,636 (“the ‘636 Application”) was filed with USPTO as a Continuation of the ‘285 Application to protect the invention of Herzel Laor, David A. Krozier, and Leo A. Plouffe entitled “OPTICAL SWITCHING APPARATUS”, which application claimed the benefit from Provisional Application No. 60/088,239, filed June 5, 1998. On August 22, 2006, the USPTO issued United States Patent No. 7,095,917 B2 (“the ‘917 Patent”) entitled “OPTICAL SWITCHING APPARATUS” from the ‘636 Application. The ownership rights to the invention disclosed and claimed in the ‘917 Patent have been assigned to Plaintiff as exclusive assignee in an assignment recorded with the USPTO. A copy of the ‘917 Patent is attached as **Exhibit B** and incorporated herein by this reference.

9. Alcatel’s respective divisions, subsidiaries and/or agents are engaged in the business of manufacturing, using, distributing, offering for sale, and selling photonic switches that infringe the ‘332 Patent and the ‘917 Patent (the “Infringing Products”). The Infringing

Products include, without limitation, products marketed and sold by Alcatel as the 1625 LambdaXreme, 1626 Light Manager family, 1695 WSM, 1696 MS ROADM, 1830 Photonic Service Switch Family, 1850 TSS with ROADM, 1850 TSS with DTN,SLM, and other wavelength selective switch (WSS) and reconfigurable optical add drop multiplexer (ROADM) products.

10. Upon information and belief, Defendant markets, offers for sale, sells, and/or distributes the Infringing Products throughout the United States, including in Colorado.

FIRST CLAIM FOR RELIEF
(Infringement of the ‘332 patent)

11. Plaintiff incorporates by reference as though fully set forth herein the allegations of paragraphs 1 through 10.

12. Alcatel infringes, literally or under the doctrine of equivalents, the ‘332 Patent in violation of 35 U.S.C. § 271(a) by making, using, selling, offering for sale, distributing and/or importing the Infringing Products in the United States.

13. Alcatel’s infringement of the ‘332 Patent has caused and will continue to cause great damage to Plaintiff, and Plaintiff is thereby entitled to an award of damages adequate to compensate it for the infringement in an amount that is in no event less than a reasonable royalty pursuant to 35 U.S.C. § 284.

14. Due to Alcatel’s willful infringement of the ‘332 Patent, Plaintiff is also entitled to recover prejudgment interest, post-judgment interest, costs, and enhanced damages under 35 U.S.C. § 284.

15. As a result of Alcatel’s infringement of the ‘332 Patent, Plaintiff will suffer irreparable harm and impairment of the value of its patent rights, and is now suffering the

violation of its patent rights, all of which will continue unless Defendant is permanently enjoined by this Court from infringing the '332 Patent under 35 U.S.C. § 283.

SECOND CLAIM FOR RELIEF
(Infringement of the '917 patent)

16. Plaintiff incorporates by reference as though fully set forth herein the allegations of paragraphs 1 through 15.

17. Alcatel infringes, literally or under the doctrine of equivalents, the '917 Patent in violation of 35 U.S.C. § 271(a) by making, using, selling, offering for sale, distributing and/or importing the Infringing Products in the United States.

18. Alcatel's infringement of the '917 Patent has caused and will continue to cause great damage to Plaintiff, and Plaintiff is thereby entitled to an award of damages adequate to compensate it for the infringement in an amount that is in no event less than a reasonable royalty pursuant to 35 U.S.C. § 284.

19. Due to Alcatel's willful infringement of the '917 Patent, Plaintiff is also entitled to recover prejudgment interest, post-judgment interest, costs, and enhanced damages under 35 U.S.C. § 284.

20. As a result of Alcatel's infringement of the '917 Patent, Plaintiff will suffer irreparable harm and impairment of the value of its patent rights, and is now suffering the violation of its patent rights, all of which will continue unless Defendant is permanently enjoined by this Court from infringing the '332 Patent under 35 U.S.C. § 283.

WHEREFORE, Plaintiff prays for judgment against defendant Alcatel Lucent USA, Inc. as follows:

A. Finding that the '332 Patent has been infringed by Defendant;

- B. Finding that the '917 Patent has been infringed by Defendant;
- C. Awarding Plaintiff a permanent final injunction against continuing infringement by Defendant, and Defendant's respective parents, subsidiaries, divisions, officers, employees, successors, and assigns, enjoining them from making, using, selling, practicing, or offering to sell the inventions disclosed in the '332 and '917 Patents;
- D. Awarding Plaintiff damages adequate to compensate Plaintiff for past and future infringement in an amount that is in no event less than a reasonable royalty attorneys' fees, costs, prejudgment interest, and post-judgment interest;
- E. Awarding Plaintiff an additional sum on account of the willful, intentional and deliberate character of Defendant's infringing acts pursuant to 35 U.S.C. § 284; and
- F. Granting Plaintiff all other legal and equitable relief to which Plaintiff is entitled.

DEMAND FOR JURY TRIAL

Pursuant to Fed. R. Civ. P. 38, Plaintiff Fiber, LLC demands a jury trial on all issues so triable.

Date: September 25, 2015

Respectfully submitted,

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Exhibit A



US006430332B1

(12) **United States Patent**
Laor et al.

(10) **Patent No.: US 6,430,332 B1**
(45) **Date of Patent: Aug. 6, 2002**

(54) **OPTICAL SWITCHING APPARATUS**

(75) Inventors: **Herzel Laor**, Boulder, CO (US); **David A. Krozier**, North Attleboro; **Leo A. Plouffe**, Dighton, both of MA (US)

(73) Assignee: **Fiber, LLC**, Boulder, CO (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/310,285**

(22) Filed: **May 12, 1999**

Related U.S. Application Data

(60) Provisional application No. 60/088,239, filed on Jun. 5, 1998.

(51) **Int. Cl.**⁷ **G02B 6/26**

(52) **U.S. Cl.** **385/18; 385/16; 385/33; 385/47; 385/52; 359/117; 359/128**

(58) **Field of Search** **385/18, 17, 33, 385/47, 50, 52, 16, 19, 22; 359/117, 128**

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,365,863	A	12/1982	Broussaud	350/96.15
4,512,036	A	4/1985	Laor	
4,580,873	A	4/1986	Levinson	
4,995,693	A	2/1991	Wilson	350/96.18
5,056,886	A	10/1991	Hoult	385/20
5,175,780	A	12/1992	Sano et al.	385/47
5,177,348	A	1/1993	Laor	
5,199,088	A	3/1993	Magel	
5,412,506	A	5/1995	Feldblum et al.	359/569
5,440,654	A	8/1995	Lambert, Jr.	385/17
5,444,801	A *	8/1995	Laughlin	385/16
5,524,153	A	6/1996	Laor	
5,647,033	A	7/1997	Laughlin	
5,867,617	A *	2/1999	Pan et al.	385/18
5,872,880	A *	2/1999	Maynard	385/88
5,903,687	A *	5/1999	Young et al.	385/17
5,960,132	A *	9/1999	Lin	385/18

6,002,818	A	12/1999	Fatehi et al.	385/17
6,094,293	A *	7/2000	Yokoyama et al.	359/280
6,097,858	A	8/2000	Laor	385/16
6,097,859	A	8/2000	Solgaard et al.	385/17
6,097,860	A	8/2000	Laor	385/17
6,101,299	A	8/2000	Laor	385/16

FOREIGN PATENT DOCUMENTS

JP 2617054 3/1997

OTHER PUBLICATIONS

Article entitled "Packaged Silicon Micro Optical Deflector Using Electromagnetic Force" by I. Kawakubo et al., published in the Technical Digest of the 13th Sensor Symposium, Jun. 8-9, 1995, pp. 17-20.

Article entitled "Building Microelectromechanical-Based Optical Systems on a Silicon Chip," pp. 11-18, by K.Y. Lau, published in the MEM's the Word for Optical Beam Manipulation, Circuits & Devices—Jul. 1997.

* cited by examiner

Primary Examiner—Hemang Sanghavi

Assistant Examiner—Sung Pak

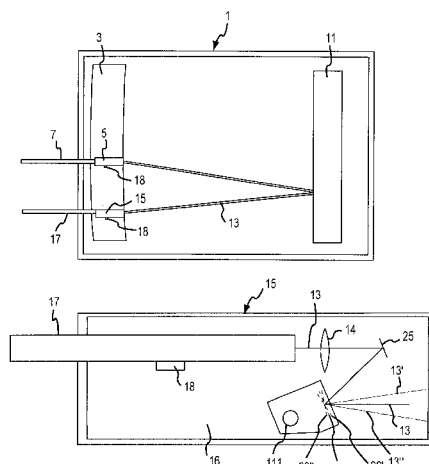
(74) *Attorney, Agent, or Firm*—Marsh Fischmann & Breyfogle LLP

(57)

ABSTRACT

An optical matrix switch station (1) is shown mounting a plurality of optical switch units (15, 17), each of which includes a mirror (29), moveable in two axes, for purpose of switching light beams from one optical fiber to another. A mirror assembly (41) is formed from a single body of silicon and comprises a frame portion (43), gimbals (45), mirror portion (47), and related hinges (55). Magnets (53, 54) and air coils (89) are utilized to position the central mirror surface (29) to a selected orientation. The moveable mirror and associated magnets along with control LED's (71) are hermetically packaged in a header (81) and mounted with the air coils on mounting bracket (85) to form a micromirror assembly package (99) mounted in each optical switch unit.

134 Claims, 16 Drawing Sheets



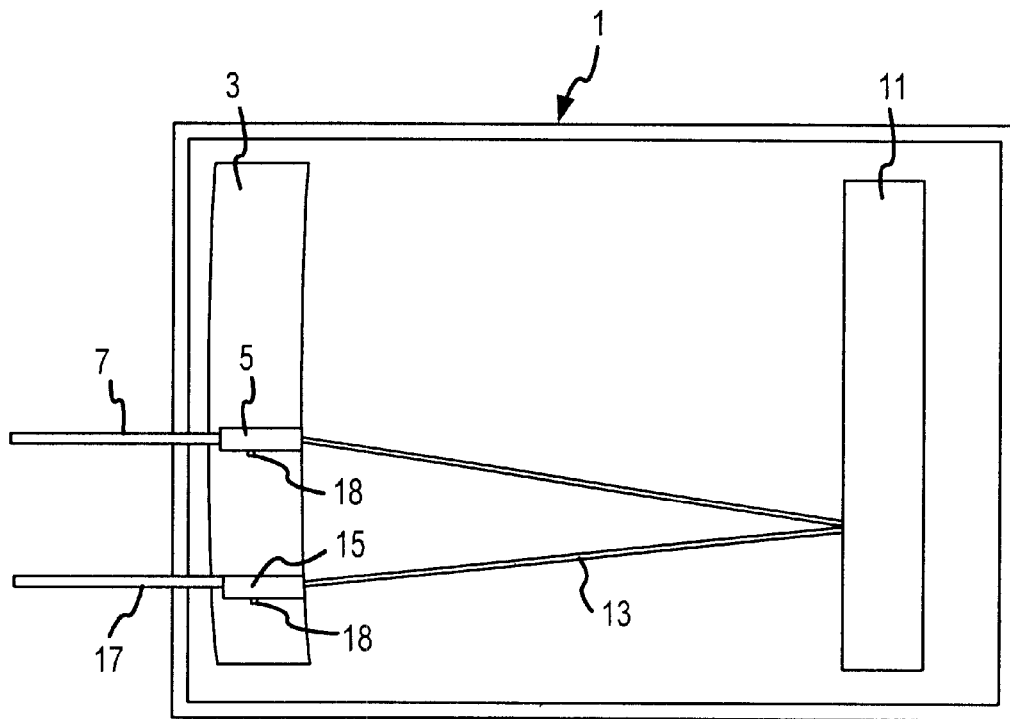


FIG.1

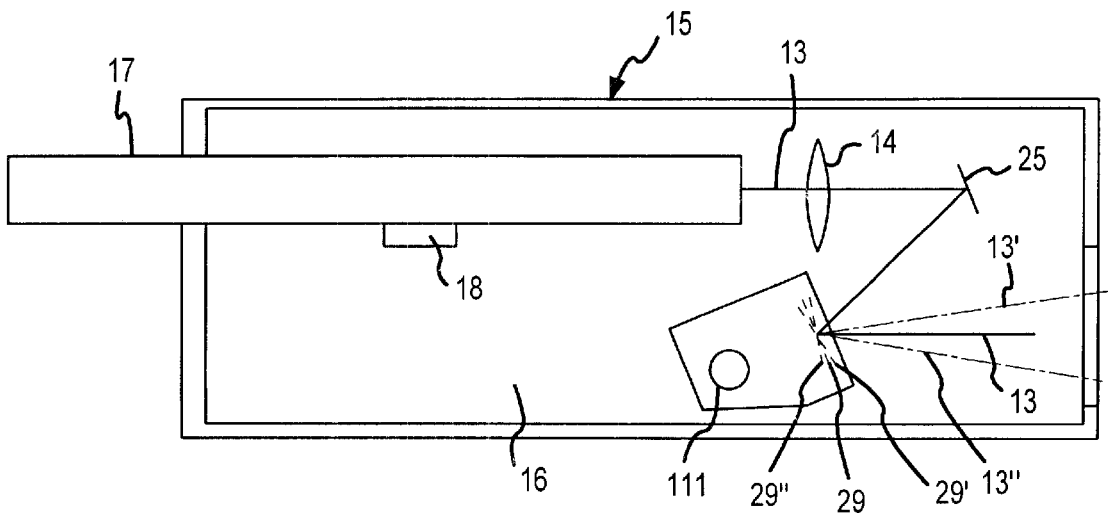


FIG.2

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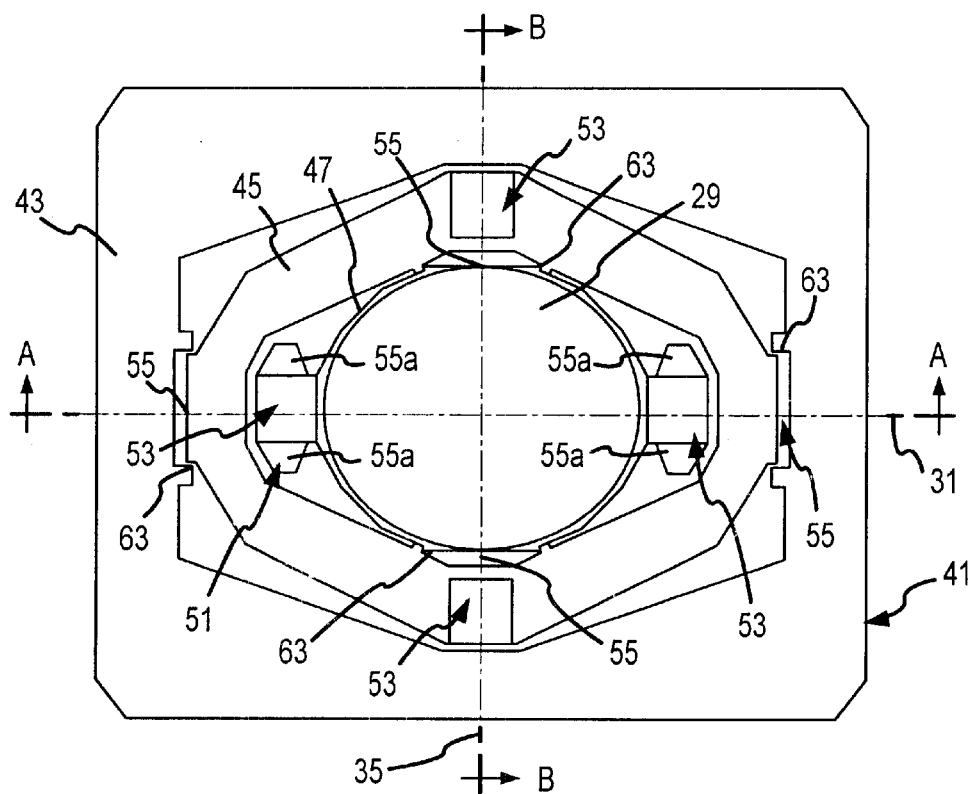


FIG. 3

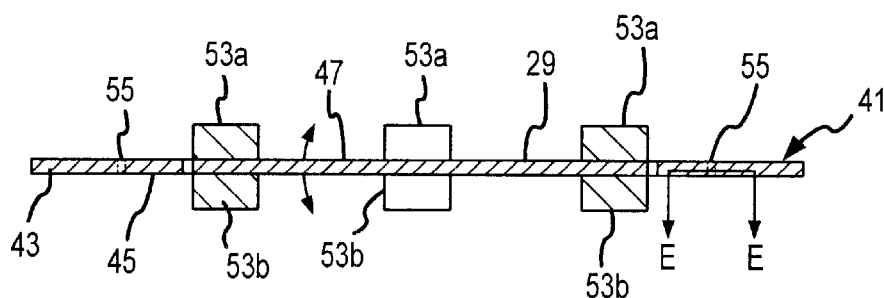


FIG. 3a

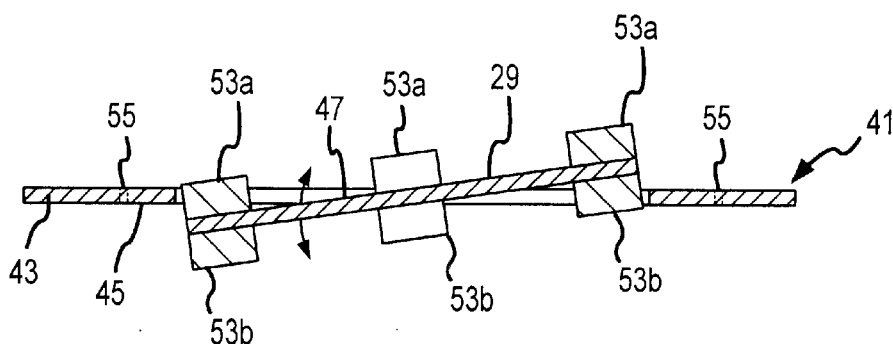


FIG. 3b

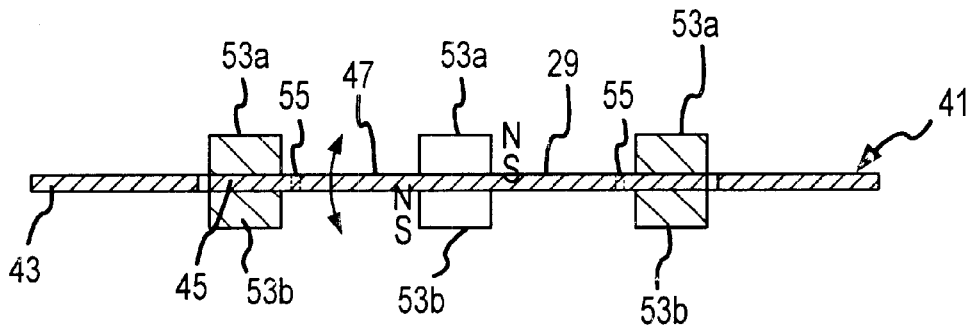


FIG. 3c

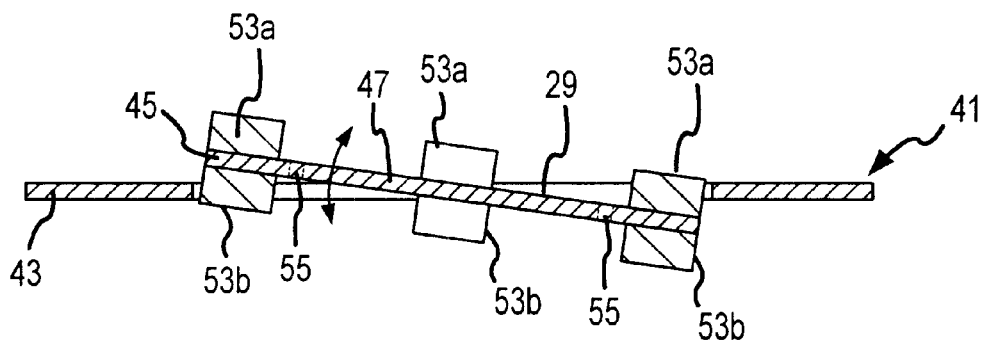


FIG. 3d

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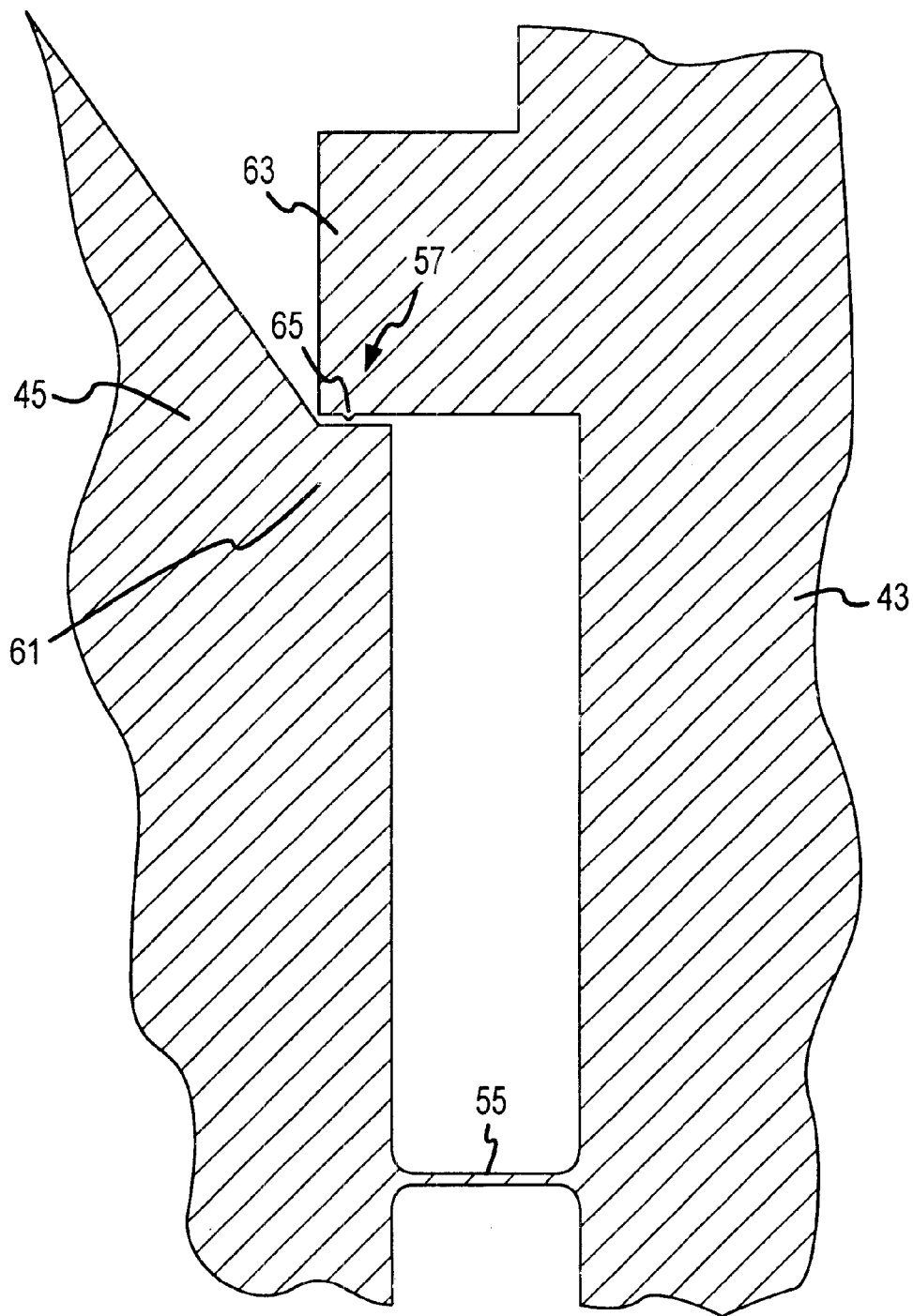


FIG. 4

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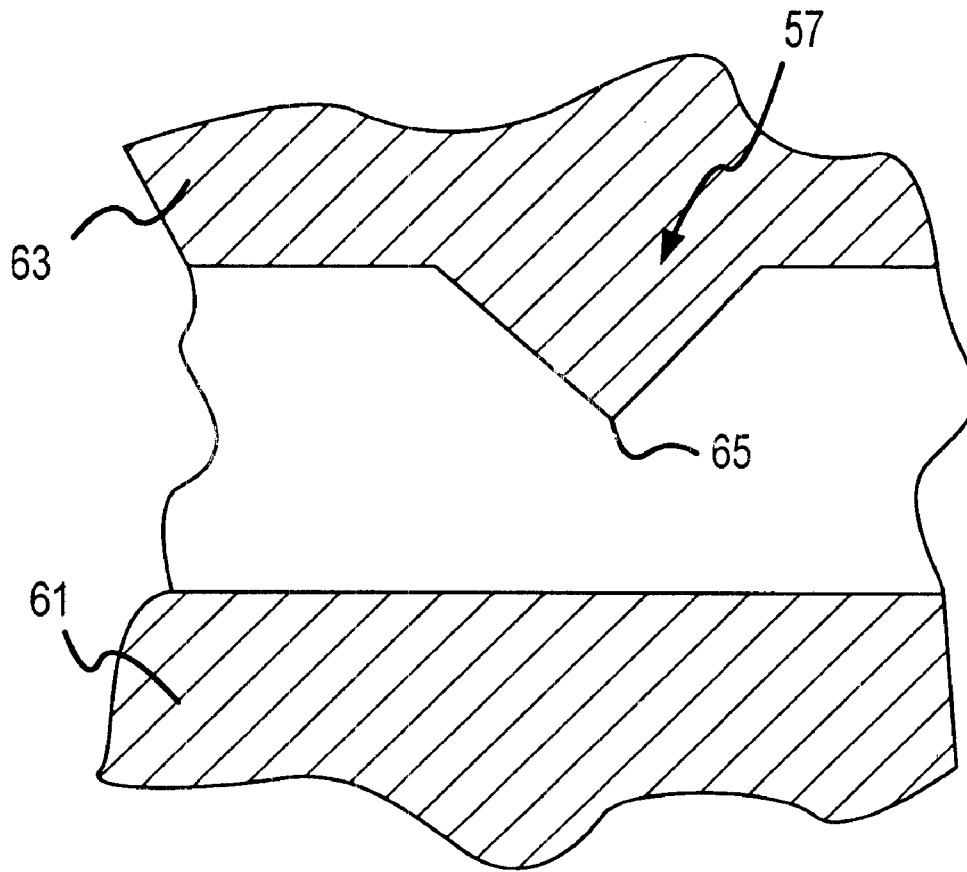


FIG.5

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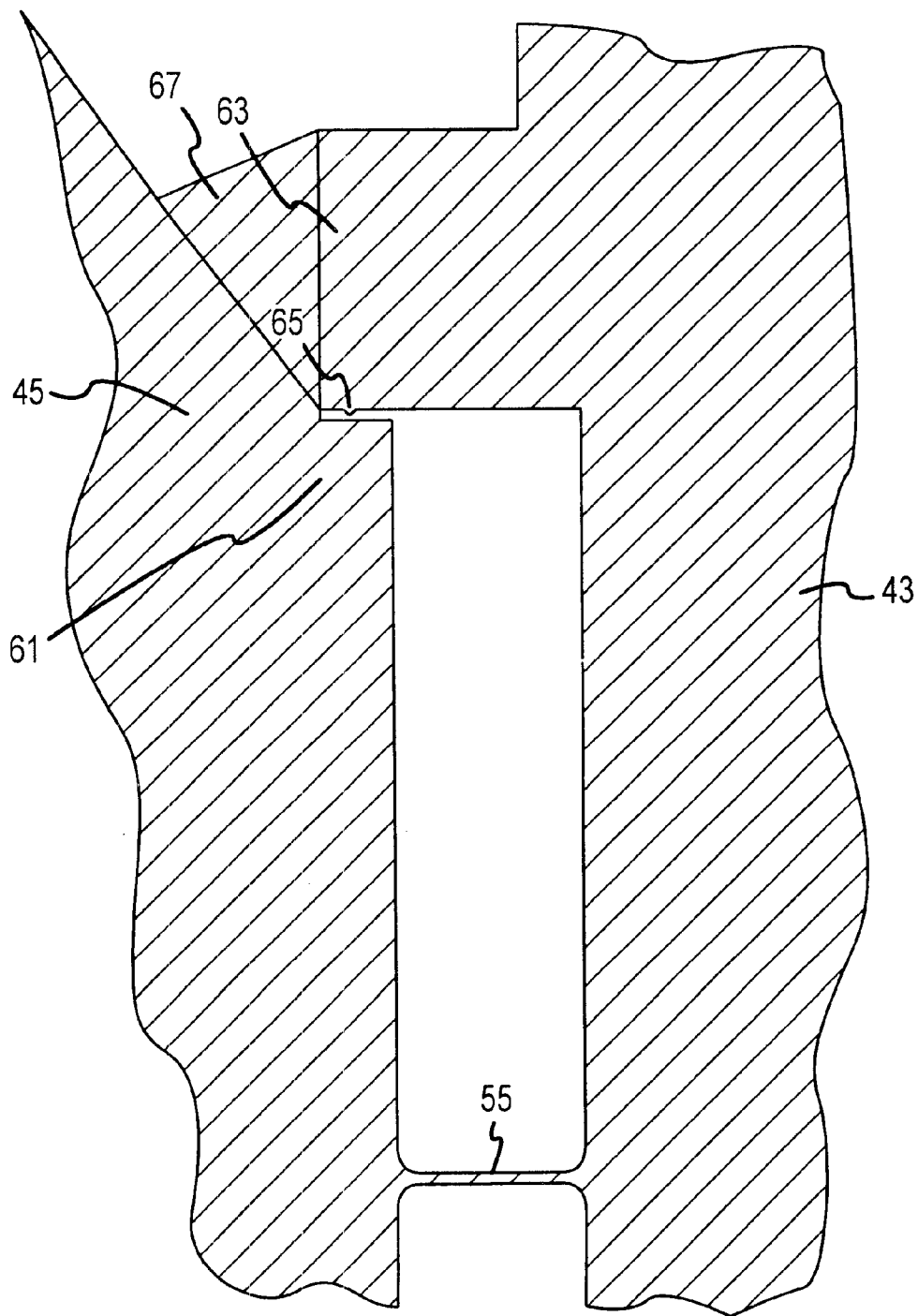


FIG.6

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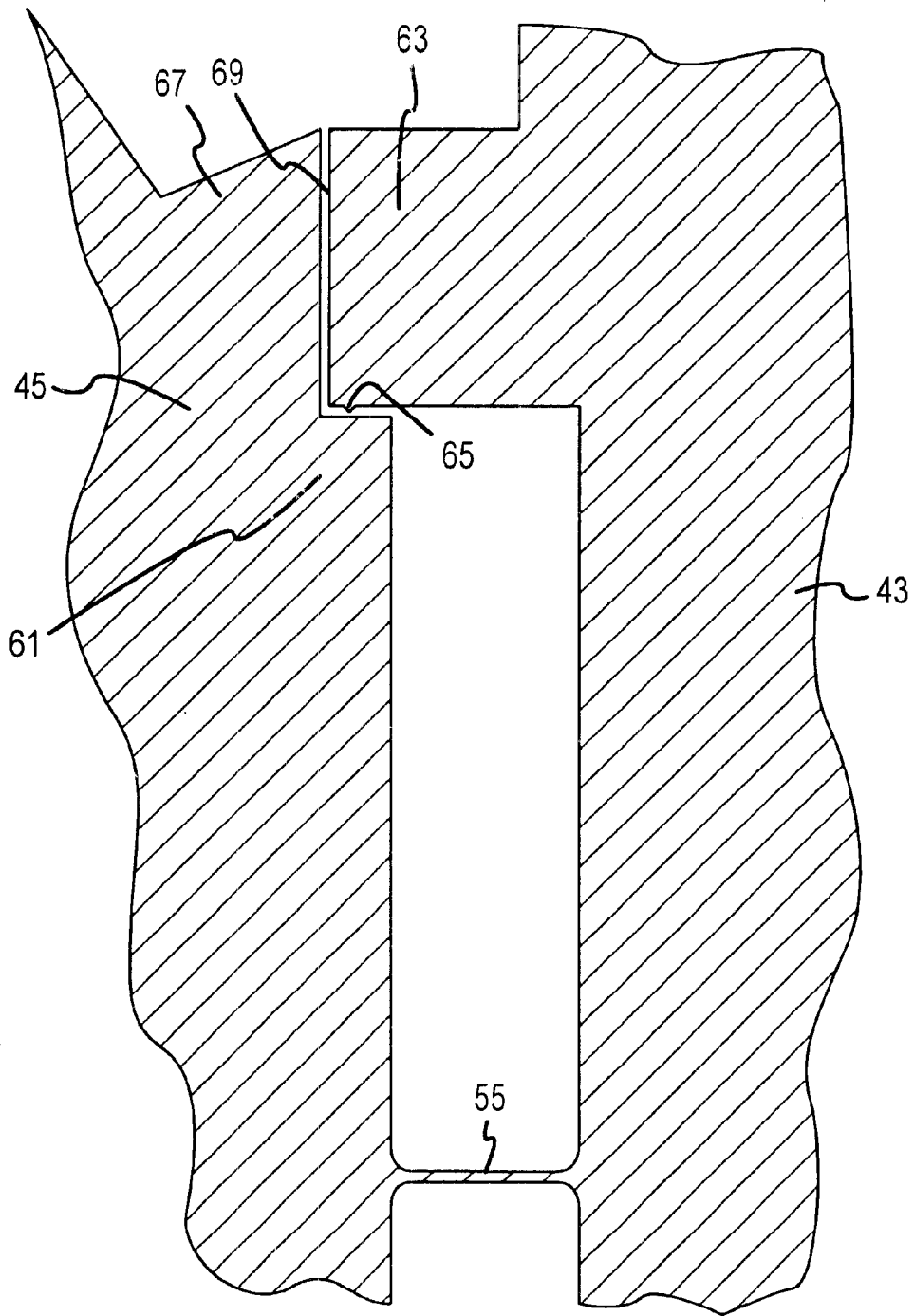


FIG. 6a

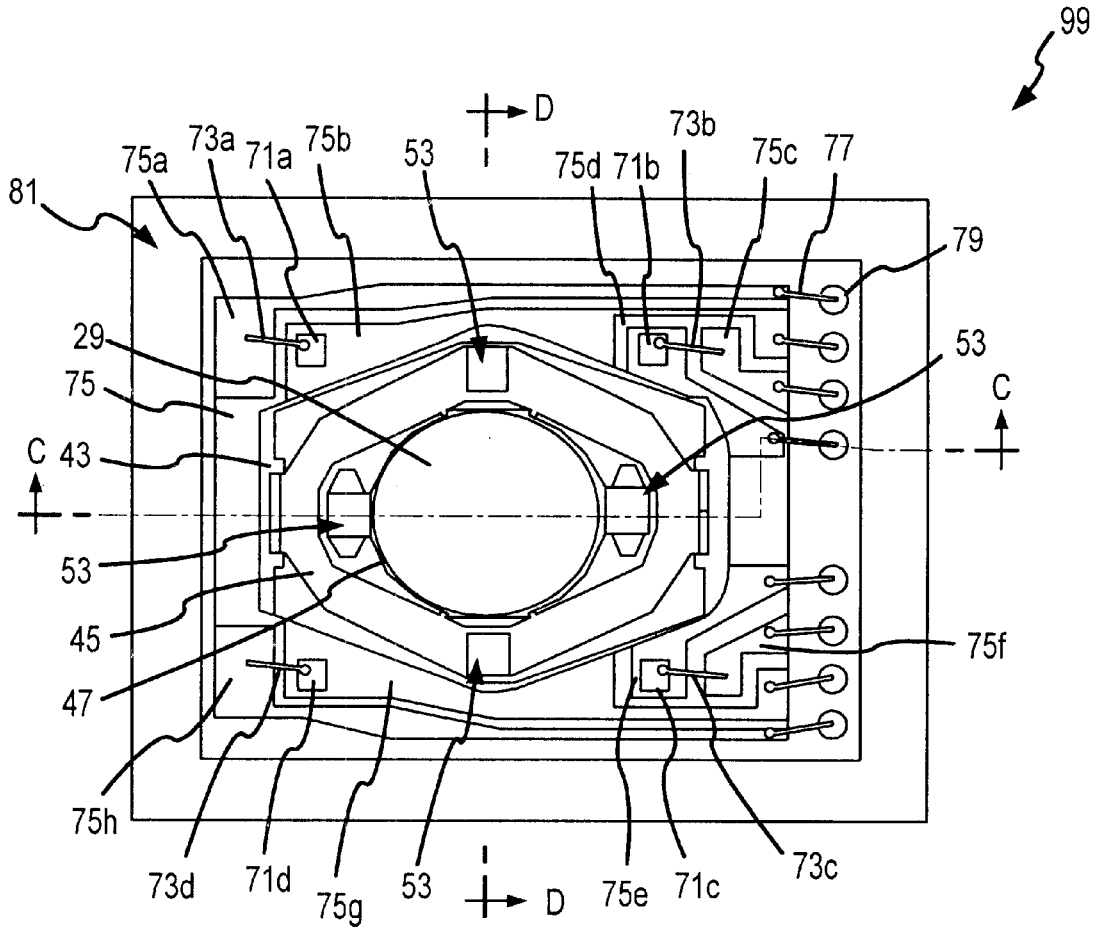


FIG. 7

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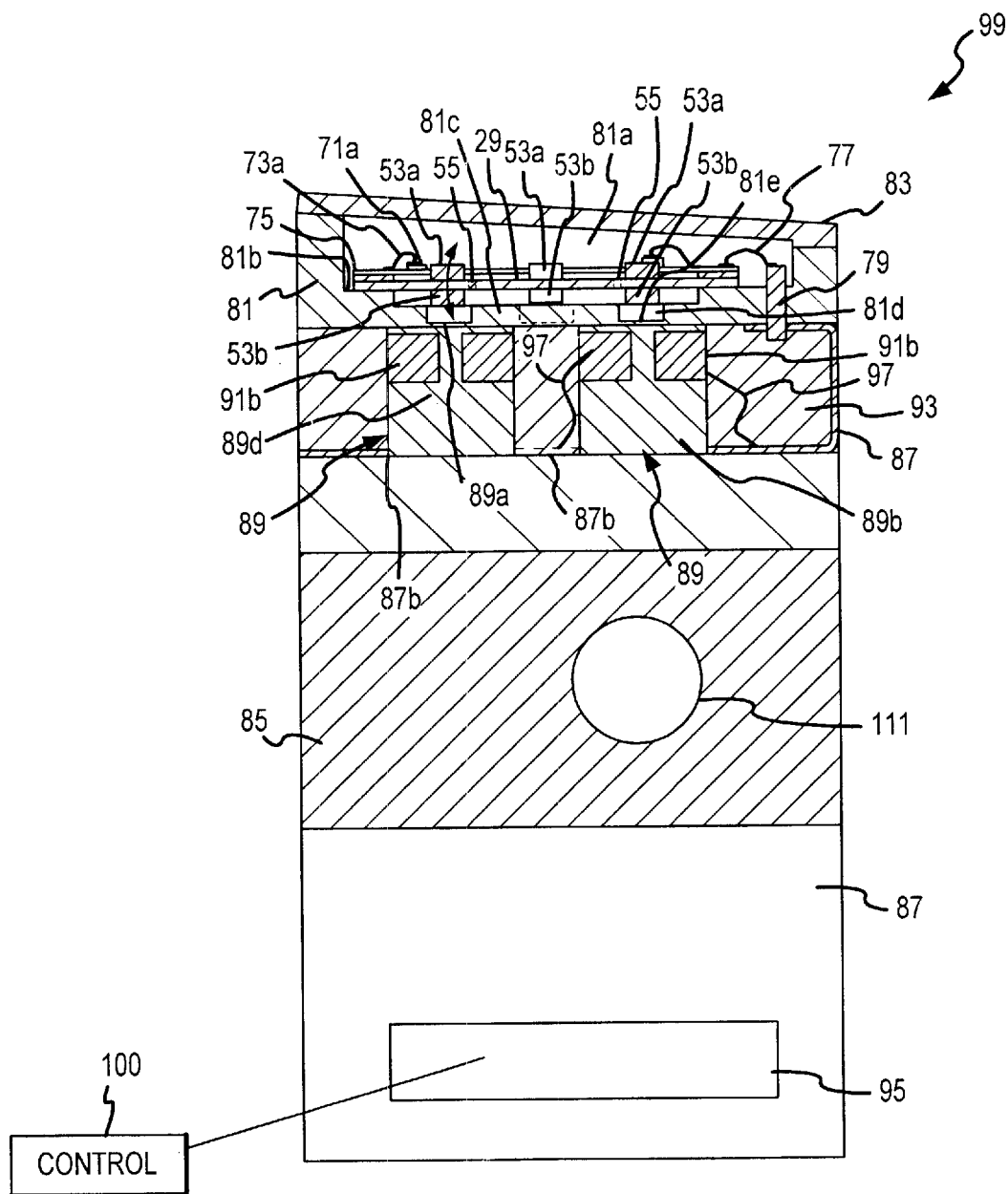


FIG. 7a

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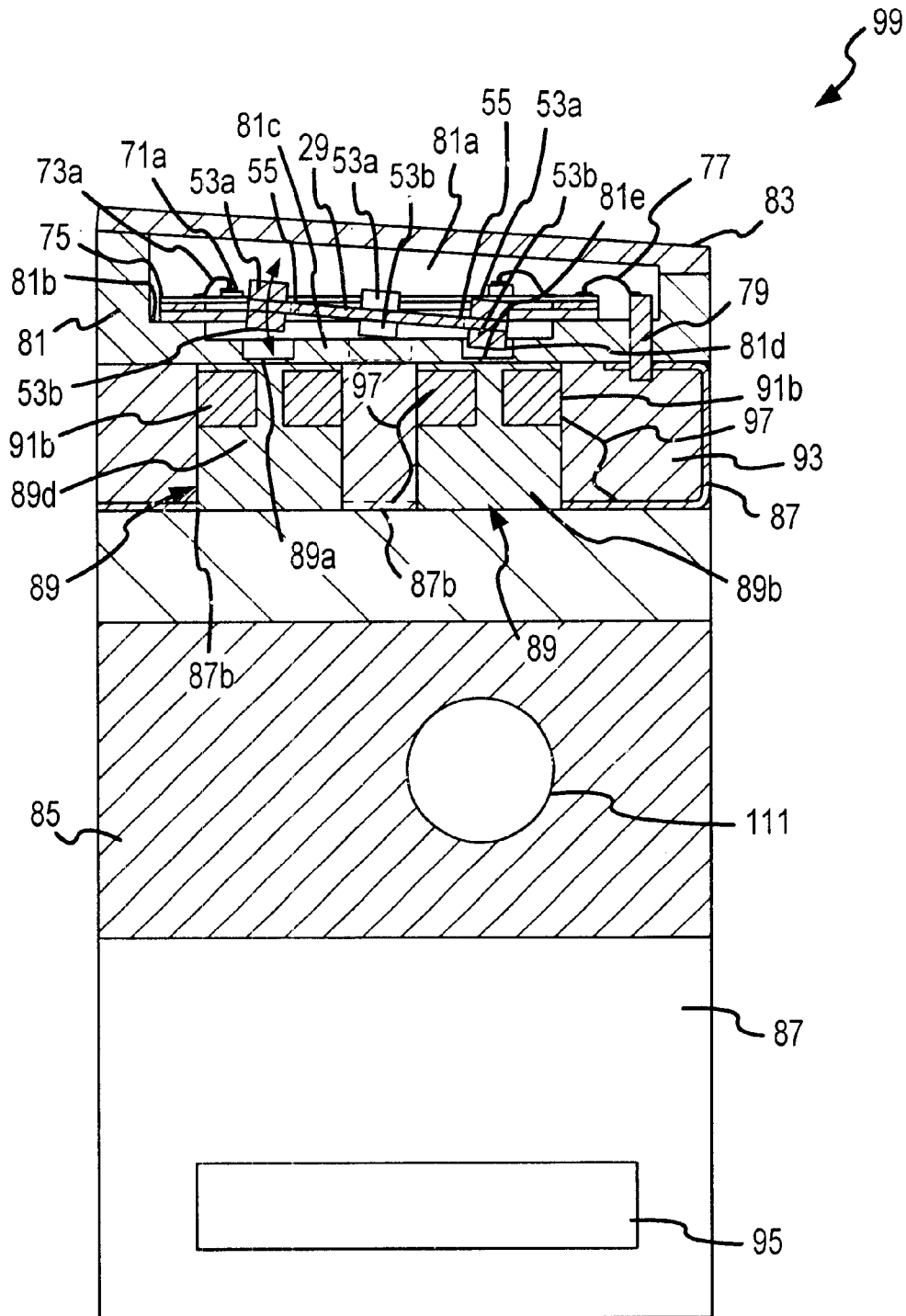


FIG. 7b

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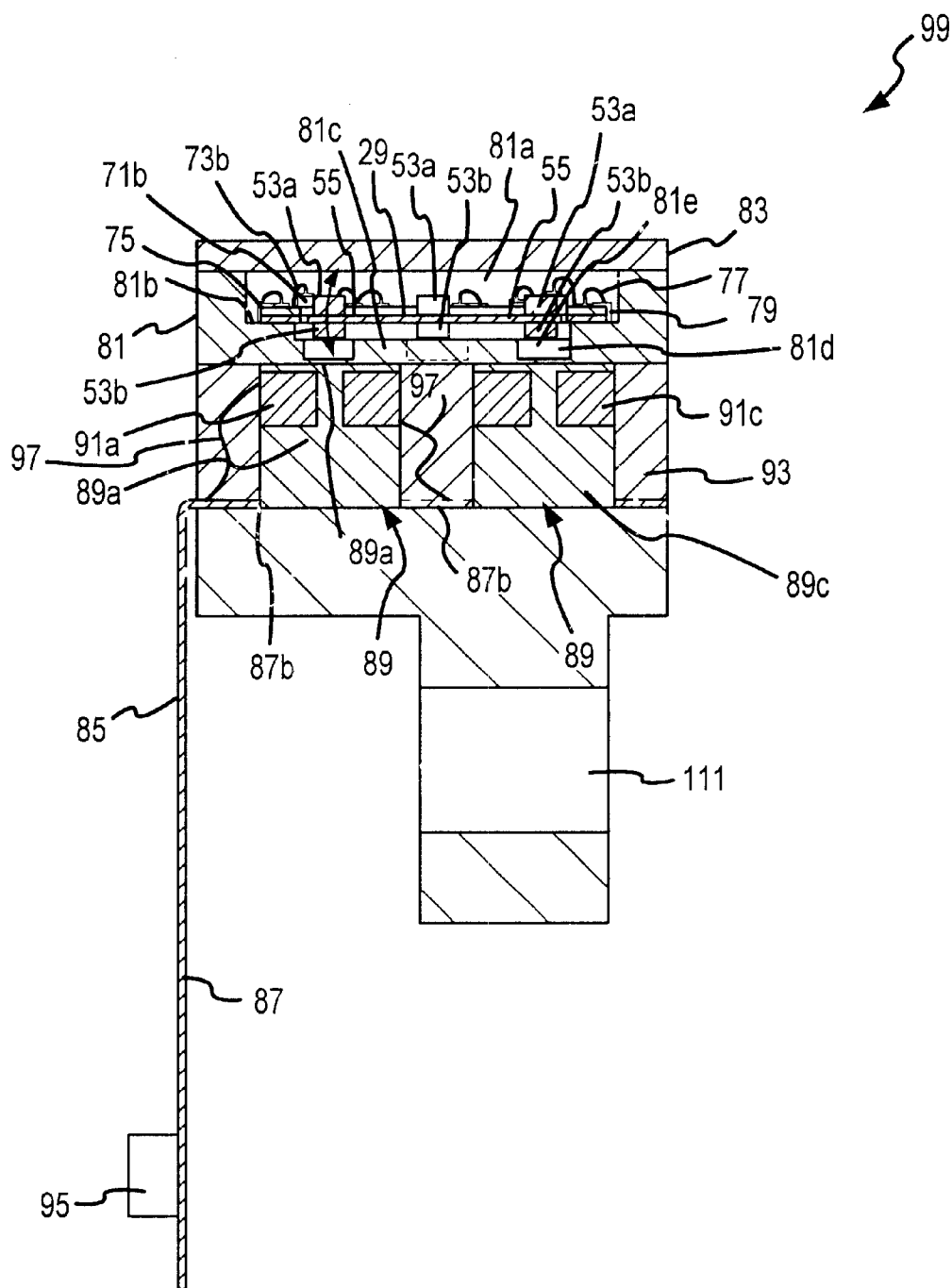


FIG.7c

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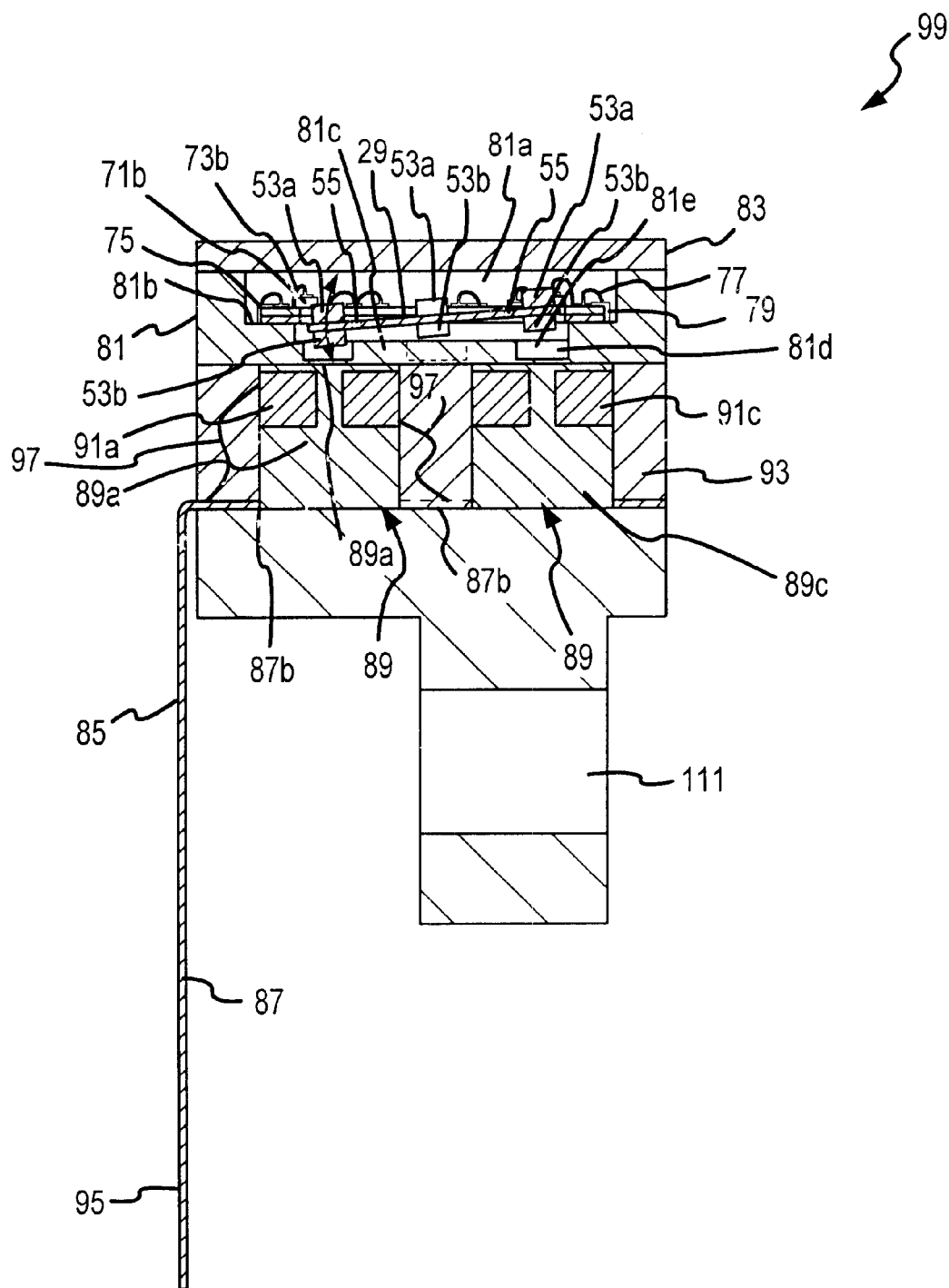


FIG. 7d

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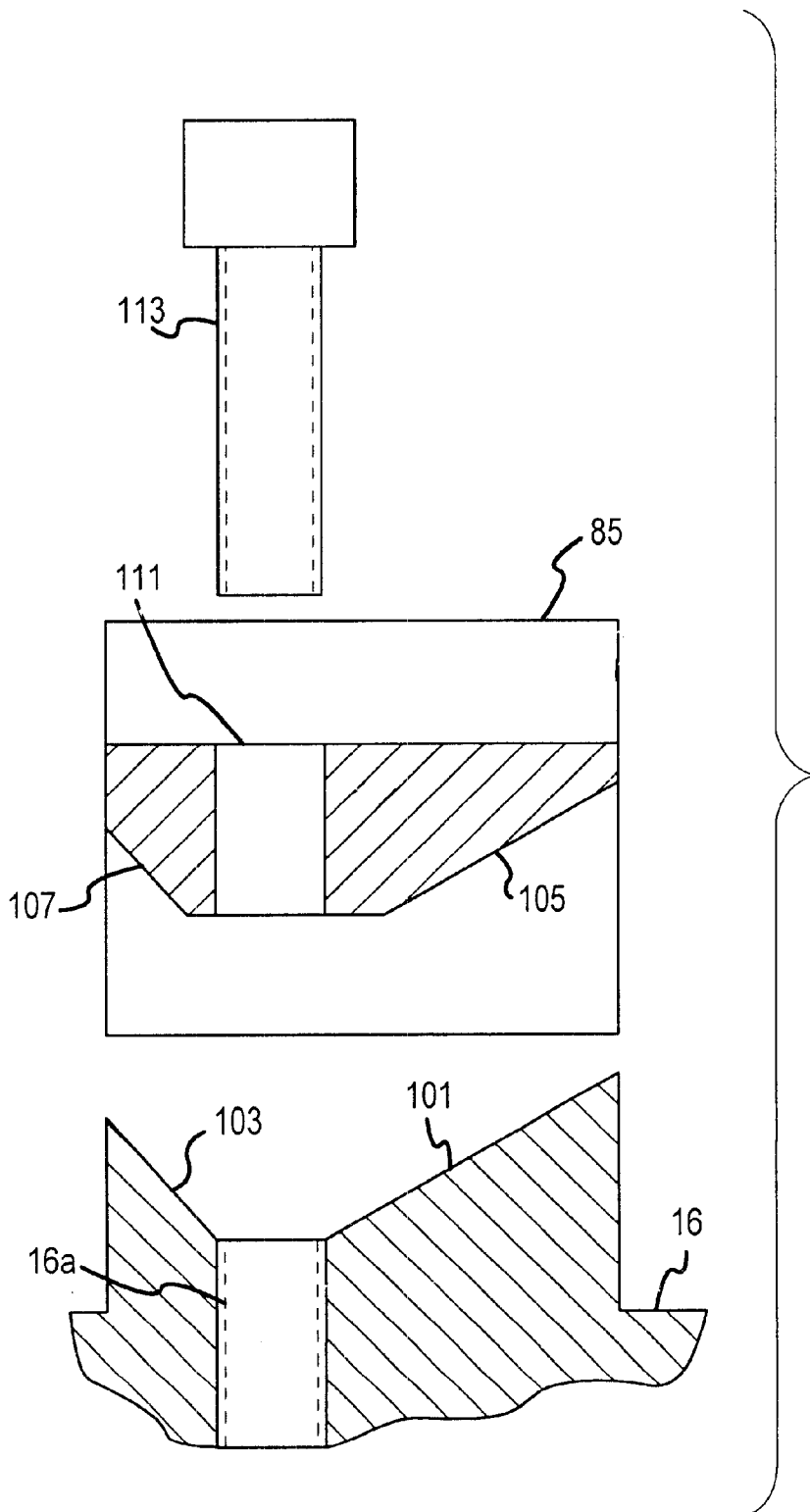


FIG.8

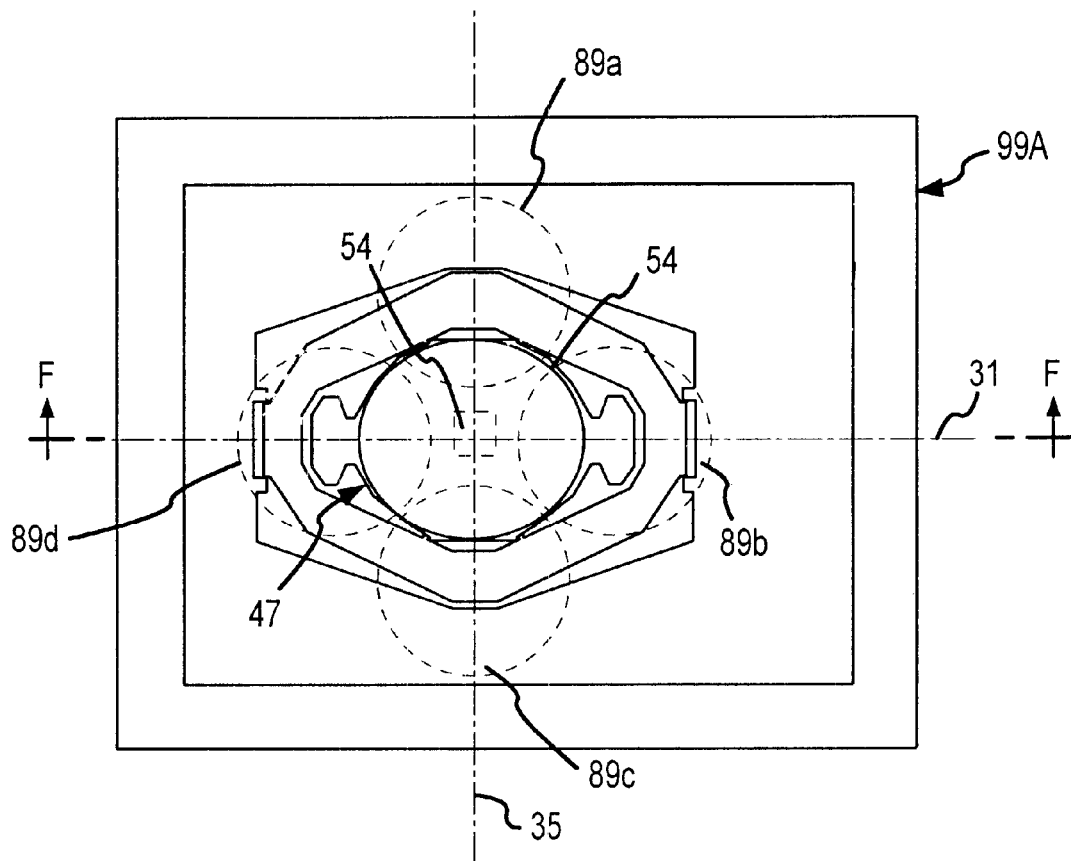


FIG.9

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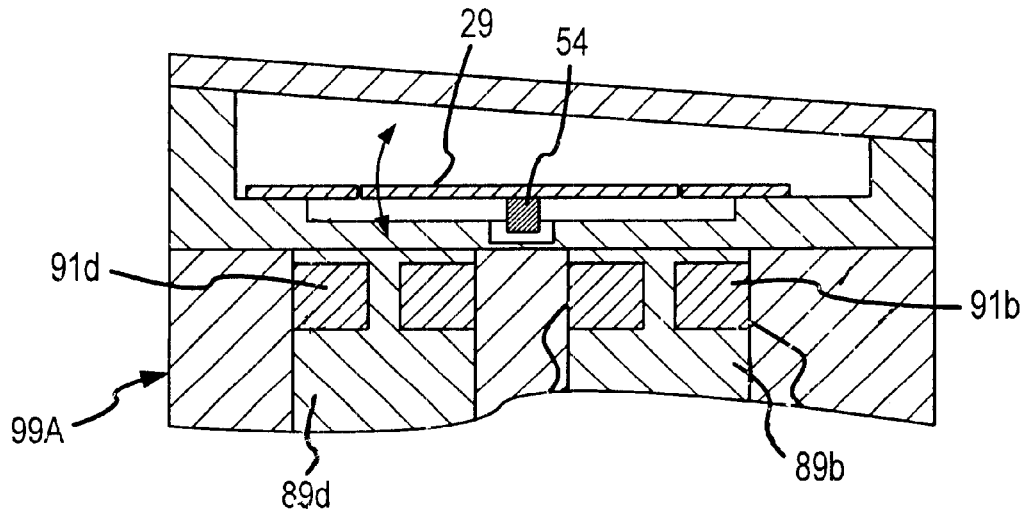


FIG. 9a

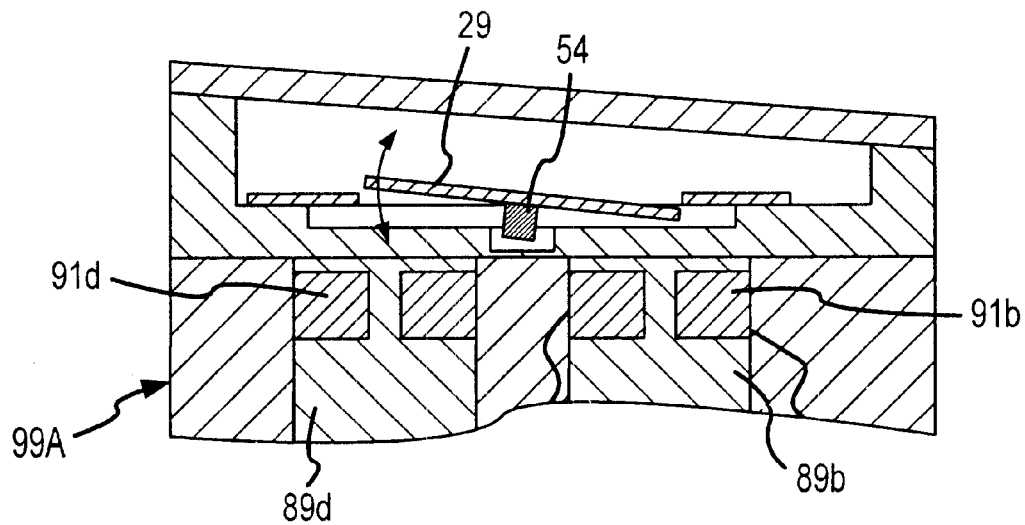


FIG. 9b

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OPTICAL SWITCHING APPARATUS**RELATED APPLICATION**

Benefit is claimed from Provisional Application No. 60/088,239, filed Jun. 5, 1998.

FIELD OF INVENTION

This invention relates generally to optical switching and more particularly to non-electrical switching of laser communication signals.

BACKGROUND OF THE INVENTION

In recent years optical fibers have come into wide spread use in a wide variety of applications in which optical signals are transmitted along such fibers and are switched from one fiber to another by means of an optical switch. Conventional optical switches generally include fiber positioning means, alignment signal emitter means and interconnected computer control means. A fiber positioning means is provided near the end of each fiber to selectively point the end of a given fiber in one fiber group toward the end of a given fiber in another fiber group for switched optical transmission therebetween. An alignment signal emitter means is provided near an end of and in predetermined spaced relationship to the end of each fiber to emit an alignment signal for receipt and use in controlling the fiber positioning means when aligning the ends of selected fibers in the fiber groups for switched optical transmission therebetween, for example as shown in U.S. Pat. Nos. 4,512,036 and 5,177,348. This approach requires considerable complexity and duplication of alignment means for each alignable fiber. It would be very desirable to reduce this complexity and duplication and to increase speed of switching, reliability, as well as to reduce cost in implementation.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an optical switch that overcomes the limitations of the above noted prior art. Another object of the inventions is to provide an optical switching unit which is relatively low in cost, has high speed and is reliable in operation. Briefly in accordance of the invention, an improved optical light transmission switch employs a microelectromechanical (hereinafter MEM) movable mirror assembly with associated electromagnet coils mounted in a package and preferably including control LED's with both drive and LED signals being supplied through a wiring harness. The following described preferred embodiments relate to a hermetic package using inorganic materials in order to provide extended life, however, units can be made which include organic materials for other shorter life applications.

The package comprises an LED lead frame of suitable material such as ceramic, which mounts LED's used by the control system to aim the movable mirror as well as circuitry to electrically connect the LED's to their package terminations. As will be discussed below, the LED's provide signals for controlling the position of the movable mirror so that any two mirrors in an array can be positioned to reflect a light beam precisely at each other so that the light beam is focused entirely on the reflective surface of the mirrors and in that way no energy of the beam is lost in the reflection process of the switched connection. The LED's are die and wire bonded to the lead frame using conventional techniques. The LED's are located so that lines drawn through diagonal pairs would pass through a selected location on the lead

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frame which is referenced the movable mirror. A mirror assembly, described below, is attached to the lead frame so that the center of the mirror portion coincides with the selected location on the lead frame in order to accurately locate the mirror relative to one another for proper control of mirror movement. The mirror assembly and lead frame are mounted in a header of suitable material, such as ceramic which, along with driving means and a wiring harness, are in turn mounted on a bracket. The package is received in a housing in which an optical fiber is received and in which another mirror is disposed in alignment with the fiber for reflecting an optical signal from the fiber to the movable mirror.

MEM micromirrors are presently used to build digital micromirror display (DMD) devices where the mirrors rotate about a single axis by an electrostatic drive. The mirror of the present invention provides two axes of motion and is preferably driven magnetically. The micromirror is preferably made from a single piece of crystal material such as silicon and has three portions connected by two sets of hinges. An inner portion forms the mirror. One of the hinge pairs, one hinge on each of two opposite sides of the mirror portion, ties the mirror portion and the middle gimbals portion, which surrounds the mirror portion. This allows the mirror portion to rotate about the gimbals portion, providing the first axis of rotation. The second set of hinges ties the gimbals portion and the frame portion, one hinge on each of two opposite sides on a line disposed, 90 degrees relative to a line drawn through the first set of hinges. This allows the gimbals portion, which carries the mirror, to rotate about the frame portion, providing a second axis of rotation.

Two pair magnets, one for each axis of rotation, are used to move the mirror portion and are mounted on one face of the single piece to form a mirror assembly. The first pair of magnets are attached by suitable means to the mirror portion of the mirror assembly, one on each of two opposite sides of a line, 90 degrees relative to a line through the mirror/gimbals portions set of hinges. When magnetically stimulated, the mirror portion rotates about the mirror/gimbals portions set of hinges, providing the first axis of motion. The second pair of magnets are suitably attached to the gimbals portion of the mirror assembly, one on each of two opposite sides of a line, 90 degrees relative to a line drawn through the gimbals/frame portions set of hinges. When magnetically stimulated, the mirror and gimbals portions rotate about the second set of axis, to providing the second axis of rotation.

According to a feature of the invention, an additional magnet is provided at each magnet location, with the poles in opposing relationship to each other and disposed on the opposite face of mirror assembly to balance the weight of the magnets relative to the hinge centerlines of the mirror assembly, eliminating undesirable oscillations under external shock or other conditions.

According to a modified embodiment, a single magnet can be utilized located in the center of the mirror portion, on the face opposing the surface serving as the mirror.

According to another feature of the invention, motion stops, disposed in a plane described by the two axes of rotation, are added to the mirror assembly at each hinge location to limit motion and thereby prevent failure of the hinge. Tabs are preferably formed in the plane described by the two axes of rotation, extending from the mirror portion to the gimbals portion and from the gimbals portion to the frame portion, to prevent rotation during initial manufacture. Sometime prior to final assembly, laser or other suitable

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cutting means severs the tabs, preferably perpendicular to each respective axis of the hinges, to allow free rotation.

In order to obtain extended operation without degradation, the mirror assembly is preferably hermetically assembled into a cavity in the package to lock out moisture and allow the provision of a benign atmosphere for micro-mirror operation. The cavity can be filled with selected gases to provide improved heat transfer and, if desired, exclude oxygen or other gases that would adversely affect the micromirror over time. The hermetic package comprises the header in which the cavity is formed and which includes sealed pins for electrical LED connection pins. A peripheral seal surface on the header extending around the cavity is coated with indium or suitable non-organic seal materials, for later attachment of a window over the cavity. The use of indium allows the seal to be made at room temperature to avoid seal temperature induced stresses and window distortions. Indium or other non-organic attach materials are used exclusively to assembly all items within the body cavity of the hermetic package, avoiding any unwanted long term organic out gassing or other similar problems.

According to another feature, the window is tilted at a slight angle, such as 6 degrees, to deflect unwanted stray light away from the desired optical path.

The lead frame assembly described above, containing LED's and the mirror assembly, is placed in and attached to the body on a platform within the cavity. The tabs preventing rotation of the mirror and gimbals portions during assembly may now be released as described above. The body cavity is sealed with a glass window that preferably has been treated with anti-reflective coatings.

An air coil drive assembly is used and preferably employs a push and pull arrangement for driving the mirror magnets to rotate the mirror portion to the desired orientation in its two axes. Four air coil assemblies, comprising copper wire coiled on a bobbin, are attached to a mounting bracket, trapping a flex circuit harness and are aligned with the mirror assembly. The air coil leads are soldered to the flex circuit harness to allow system electrical control of the air coils and their push pull arrangement to drive the mirror assembly. The air coil bobbins are made of aluminum or other eddy current generating material, and sufficient amounts of aluminum are provided at the top and bottom of the bobbins to allow eddy current dampening of the movable portions of the mirror assembly, to prevent unwanted oscillations. In order to prevent overheating and loss of mirror position control, the air coil bobbins are made of high heat transfer material, such as aluminum, and the bobbins are massive relative to the air coils. The mounting bracket is massive relative to the bobbins and is also made of a high heat transfer material, such as aluminum. The bracket is in intimate contact with the optical unit housing, which in turn is in intimate contact with the ultimate heat sinking of the customer's system.

According to yet another feature, the air coil bobbins trap the flex circuit harness to the bracket when the air coil bobbins are attached to the bracket to facilitate later location and assembly of the flex circuit to the bracket. The LED pins of the header assembly are soldered to the appropriate pads on the flex circuit harness. The micromirror can fully be tested at this point. The header assembly is then rotated and aligned with the mounting bracket and joined by fixing the header assembly to the mounting bracket. The open area around the air coils is then potted with heat conductive material to ensure optimum assembly rigidity and improved heat transfer.

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Other objects and advantages of the present invention will be apparent from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and further advantages thereof, reference is now made to the following detailed description of the preferred embodiments taken in conjunction with the drawings in which:

FIG. 1 is a schematic view of an optical switching station showing two optical switching units;

FIG. 2 is a schematic view of one of the optical switching units shown in FIG. 1;

FIG. 3 is a plan view of a mirror assembly used in the FIG. 2 switch unit;

FIG. 3a is a cross sectional view taken on line A—A of FIG. 3;

FIG. 3b is a view similar to FIG. 3a but showing rotation of the mirror portion of the mirror assembly;

FIG. 3c is a cross sectional view taken on line B—B of FIG. 1;

FIG. 3d is a view similar to FIG. 3c but showing rotations of the gimbals portion of the mirror assembly;

FIG. 4 is an enlarged cross sectional plan view taken on line E—E of 3a showing a hinge and an in-plane motion stop;

FIG. 5 is an enlarged, broken away portion of FIG. 4 showing a portion of the in-plane stop;

FIG. 6 is a cross sectional plan view taken on line E—E of FIG. 3a, showing a hinge with an optional lock down tab to stop rotation used during manufacture;

FIG. 6a is a view similar to FIG. 6 showing the lock down tab severed to allow rotation;

FIG. 7 is a top plan view of an optical switch package made in accordance with the invention;

FIG. 7a is a cross sectional view taken on line C—C of FIG. 7;

FIG. 7b is a view similar to FIG. 7 showing rotation of the mirror portion of the mirror assembly;

FIG. 7c is a cross sectional view taken on line D—D of FIG. 7;

FIG. 7d is a view similar to FIG. 7c but showing rotation of the gimbals portion of the mirror assembly;

FIG. 8 is an exploded view of a cross sectional, broken away portion of the bottom wall of the housing of an optical switching unit package and the mounting bracket;

FIG. 9 is a top plan view of a modified embodiment of an optical switch unit with certain parts removed for purposes of illustration;

FIG. 9a is a cross sectional view of the top portion of an optical switch unit taken on line F—F of FIG. 9; and

FIG. 9b is a view similar to FIG. 9a but showing rotation of the mirror portion of the modified mirror assembly.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 shows the layout of a matrix optical switch station comprising a plurality of parallelly extending optical switch units 5 and 15, two being shown for purposes of illustration, but any number can be provided as desired. These switch units are mounted in a frame 3 such that they are aligned with optical switch mirror 11 fixedly mounted in housing 1.

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An end portion of fiber optics cable **17** is mounted in a selected fixed position within housing **15** and fiber optics cable **7** is similarly affixed into the housing of optical switch **5**. A light signal **13** is transmitted in cable **17** and is directed by optical switch unit **15**, by reflecting light signal **13** from optical switch mirror **11** to another selected optical switch unit, such as optical switch **5**, which directs light signal **13** into cable **7**.

A light beam controlled by a single movable mirror will enter various target positions with an angle of incidence that varies with the target position of the beam. The use of two movable mirrors in the system allows a beam of light emitted on a longitudinal axis to be directed at any angle by the first movable mirror and exit the second movable mirror on a defined longitudinal axis that is invariant with changes in the incident angle of the beam. By maintaining a defined axis for the light beam, the use of two movable mirrors acts to simplify any lens used for an optical switch.

The light signal is optimized to minimize transmission losses by the optical units. As seen in FIG. 2, light beam **13** carried by optical cable **17** is reflected by a fixed mirror **25** mounted within optical switch **15** to a moveable mirror **29**, shown in a solid line in its middle or neutral unpowered position. Mirror **29** is moveable between two opposite extremes, **29'**, **29''**, with light beam **13** correspondingly reflected to **13'**, **13''**, respectively.

The first movable mirror **29** selects the target position for creating an optical path. Movable mirror **29** can select any one of a plurality of optical switch units to create an optical connection by directing the light beam **13** to the movable mirror on the second unit. Light beam **13** when it is targeted on the second movable mirror is again reflected at an angle that is based on the incident angle of the beam. By operating the second movable mirror the incident angle of the beam can be changed such that the light is reflected on the longitudinal axis of the second optical switch unit.

LED's mounted in an array adjacent a first movable mirror **29**, as disclosed below, provide radiation which is detected by detector **16**. Radiation from the LED's in the array associated with the first movable mirror is received in a radiation guide of another, selected fiber and individually measured by control **100** (FIG. 7a). The position of the associated movable mirror of the selected fiber is adjusted until radiation received from each LED from the first mirror is substantially equal, as described in relation to moving fiber ends in U.S. Pat. No. 5,177,348, supra.

Although the movement of the mirror shown in FIG. 2 illustrates movement in one plane, mirror movement in a second plane is also included in the operation of the switch and will be described below.

Mirror assembly **41**, FIG. 3, is preferably formed from one piece of crystal material such as silicon, etched to provide an outer frame portion **43** forming an opening in which an intermediate annular gimbals portion **45** is attached at opposing hinge locations **55** along first axis **31**. An inner, centrally disposed mirror portion **47**, having a mirror **29** centrally located thereon, is attached to gimbals portion **45** at hinge portions **55** on a second axis **35**, 90 degrees from the first axis. Mirror **29** is suitably polished on its upper surface to provide specular surface and, preferably, is similarly polished on its lower surface as well, in order to

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prevent stresses in the material which could otherwise cause a certain warpage due to the thinness of the sheet material, e.g., on the order of 100 microns.

A first pair of permanent magnets **53** is mounted on gimbals portion **45** along the second axis and a second pair of permanent magnets **53** is mounted on extensions **51**, which extend outwardly from mirror portion **47** along the first axis. In order to symmetrically distribute mass about the two axes of rotation to thereby prevent oscillation under shock and vibration, each permanent magnet **53** preferably comprises a set of an upper magnet **53a** mounted on the top surface of the mirror assembly **41** using conventional attachment techniques such as indium bonding, and an aligned lower magnet **53b** similarly attached to the lower surface of the mirror assembly as shown in FIGS. 3a-3d. The magnets of each set are arranged serially such as the north/south pole arrangement indicated in FIG. 3c. There are several possible arrangements of the four sets of magnets which may be used, such as all like poles up, or two sets of like poles up, two sets of like poles down, or three sets of like poles up, one set of like pole down, depending upon magnetic characteristics desired.

By mounting gimbals portion **45** to frame portion **43** by means of hinges **55**, motion of the gimbals portion **45** about the first axis **31** is provided and by mounting mirror portion **47** to gimbals portion **45** via hinges **55**, motion of the mirror portion relative to the gimbals portion is obtained about the second axis **35**, thereby allowing independent, selected movement of the mirror portion **47** along two different axes.

The middle or neutral position of mirror assembly **41** is shown in FIG. 3a, which is a section taken through the assembly along line A-A of FIG. 3. Rotation of mirror portion **47** about axis **35** independent of gimbals portion **45** and/or frame portion **43** is shown in FIG. 3b as indicated by the arrow. FIG. 3c shows the middle position of the mirror assembly **41**, similar to that shown in FIG. 3a, but taken along line B-B of FIG. 3. Rotation of the gimbals portion **45** and mirror portion **47** about axis **31** independent of frame portion **43** is shown in FIG. 3d as indicated by the arrow. The above independent rotation of mirror **29** of mirror portion **47** about the two axes allows direction of light beam **13** as needed by the optical switch units.

In order to protect hinges **55** from in-plane shock during handling and shipping, stops **57** are provided according to an optional feature of the invention as best shown in FIGS. 4 and 5, which are enlarged sectional views taken on line E-E of FIG. 3a. At this point it should be noted that the mirror assembly is on the order of 100 microns thick, whereas hinge **55** is on the order of 10 microns wide, thereby providing robust strength in directions normal to the surface of the assembly. In order to provide protection against excess in-plane motion 90 degrees to the axis of the hinge, i.e., axis **31**, cooperating surfaces **61** on gimbals portion **45** and **63** on frame portion **43** are formed on either side of each hinge **55** and extend generally parallel to axis **31**. Surfaces **61** and **63** are spaced apart a selected distance such as 10 microns by way of example. In order to provide less in-plane motion, projection **65**, extending from surface **63** towards surface **61**, is formed to any selected distance such as 5 microns. It will be understood that such projection could be provided on surface **61** instead of **63** if desired. Similar stops

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are provided on the mirror and gimbals portions to provide protection against in-plane motion of hinges **55** relative to axis **35**.

According to another optional feature of the invention, lock down tabs associated with each hinge are provided. As seen in FIG. 6, an example showing one such hinge **55**, bridge portion **67** extends from gimbals portion **45** to frame portion **43** and locks the two portions together isolating hinge **55** from all normal manufacturing stresses. At the appropriate manufacturing step, the bridge portion **67** is cut providing gap **69** as shown in FIG. 6a, which allows normal rotation of gimbals portion **45** relative to frame portion **43** about the hinge **55**. This provides suitable stress protection for all hinges and significantly improves manufacturing yields.

With reference to FIG. 3, extensions **51** are preferably provided with laterally extending tabs **55a** which can be used to clamp down the mirror portion during assembly to thereby provide additional stress protection.

The movable mirror assembly **41** is received in a cavity **81a** of a header **81** which forms part of the mirror assembly package shown in FIGS. 7-7d. Header **81** is formed of any suitable material, such as ceramic in the case of a hermetic package and plastic where hermeticity is not required, and has a circumferentially extending shelf **81b** formed within cavity **81a** on which frame portion **43** of mirror assembly **41** is received. Bottom wall **81c** is spaced from shelf **81b** to provide clearance for movement of gimbals portion **45** and mirror portion **47**. Recesses **81d** are formed in bottom wall **81c** aligned with each set of magnets **53** to provide motion clearance for lower magnets **53b**. The size of the opening of recesses **81d** is maintained as small as possible, allowing suitable motion of the magnets, to facilitate making wall **81e** as thin as practicable, for example 125 microns.

The magnet drive for the magnets comprise four air coils **89** (two shown in FIGS. 7c-7d) each wound on a bobbin in turn mounted on mounting bracket **85** and aligned with respective recesses **81d** and magnets **53**. The bobbin and bracket are made of suitable material for good heat transfer, magnetic dampening, and strength such as aluminum. The air coils are wound using high electrical conductivity materials such as copper. The bobbin has an air coil disposed proximate to top end **89a** of bobbin **89** such that the air coil is as close to magnets **53** as possible, for example, 200 microns, to provide full mirror rotation using minimum power.

An electrical wiring harness **87** is provided for required electrical connections to the micromirror assembly package **99** and comprises an elongated flex circuit **87** mounting a connector **95** at one end thereof for connection to a control system (indicated at **100**, FIG. 7a). An opening **87b** is formed at an opposite end which receives therein bobbins **89**. Coil leads **97** are attached to appropriate traces on the flex circuit as shown in 7c-7d. A plurality of diode pins **79** are mounted in bores provided in shelf **81b** and extend above and below the shelf. The upper portion of the diode pins are connected by leads **77** to respective conductive pads **75a-75h** (see FIG. 7) and on the lower end are connected to respective traces on electrical harness **87**. LED's **71a-71d** are assembled to board **75** in according to conventional semiconductor techniques and are powered by the traces on

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the harness discussed above. The LED's **71a-71d** are positioned so that they can be used to direct the light beam **13** using the optic unit's sensing control system **100**. The control system can be similar to that described in U.S. Pat. No. 5,177,348, as discussed above.

Once the electrical connections are made to the diode pins **79**, window **83** is attached to the open side of header **81**, closing cavity **81a**. The closing of cavity **81a** can be made to be a hermetic seal by using known techniques such as employing indium as the window seal material and glass sealing or the like sealing of the diode pins **79** to the header **81**. If desired, a protective atmosphere such as nitrogen can be trapped within the cavity. The window is of suitable material to allow transmission of light signal **13** with minimum losses and is preferably tilted approximately 6 degrees relative to the plane in which mirror assembly lies, to deflect unwanted stray light. In this respect, the spacing between gimbals portion **45** and mirror portion **47** is maintained sufficiently large to avoid unwanted stray light.

After the electrical connections are made between diode pins **79** and harness **87** completing all electrical connections, header **81** with all of its internal components described above, are aligned with mounting bracket **85** and its components and potted in place with thermally conductive, strong potting material **93** to complete the micromirror assembly package **99**.

With particular reference to FIG. 8, micromirror assembly package **99** is precisely mounted and orientated in optical switch unit **15** utilizing cooperating registration surfaces of mounting bracket **85** and a portion of wall **16** of switch unit **15**. First opposing tapered surfaces **107** and **105** forming a somewhat convex configuration on mounting bracket **85** cooperate with respective second opposing tapered surfaces **103** and **101**, forming a somewhat concave, or cradle configuration, respectively, on bottom wall **16** of the switch unit. Mounting bolt **113** is received through bore **111** in bracket **85** and threaded bore **16a** in the cradle in bottom wall **16** to secure micromirror assembly package **99** within optical switch unit **15**. The cooperating opposed surfaces provide a precise registration in two planes while bolt **113** and its corresponding bore **111** in bracket **85** and threaded bore **16a** in wall **16** provides registration in a third plane.

An alternate embodiment is shown in FIG. 9 in which a single permanent magnet **54** is centrally located on the lower side of the mirror portion **47**. Air coils **89a-89d** are shown located in the same positions as in the FIGS. 3-7 embodiment and can be independently exited so that the interaction of the magnetic field of the permanent magnet and the coils cooperate to produce the appropriate magnetic field to cause movement of the mirror portion along each axis **31** and **35**, as desired. Although four air coils are shown, if desired, three air coils could be used to produce the desired magnetic field.

Although the invention has been described with regards to specific preferred embodiments thereof, variations and modifications will become apparent to those skilled in the art. For example, magnet and air coil locations other than those described above can be employed as long as appropriate currents can be applied by means of control **100** to the air coils to move the gimbaled mirror to a desired orientation. In this respect, with reference to the four coil arrange-

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ment shown, a push-pull drive in control **100** is preferred. Further, although permanent magnets are shown attached to the movable mirror assembly, it will be appreciated that, if desired, magnetic material could be added to the assembly instead of the permanent magnets and polarized perpendicular to the mirror surface. It is therefore the intention that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.

What is claimed:

1. An optical beam switching system for transmitting an optical beam from a source to any one of a group of optical receptors comprising:

- a focusing lens for focusing an optical beam and directing the optical beam along a selected path;
- a first movable mirror mounted in the selected path;
- a plurality of second movable mirrors and a plurality of optical receptors;

a control for moving the first movable mirror to direct the optical beam to any selected second mirror and for moving the selected movable mirror to direct the optical beam to a selected optical receptor for transmission of the optical beam from the focusing lens to the selected optical receptor; and

radiation emitters disposed adjacent each movable mirror to provide a feedback signal to the control for adjusting the position of the movable mirrors to minimize transmission loss of the optical beam to the receptor.

2. An optical beam switching system according to claim **1** in which each optical receptor is mounted in optical receiving relationship with an associated second movable mirror.

3. An optical beam switching system according to claim **1** in which the movable mirrors are movable about at least one axis of rotation.

4. An optical switching system according to claim **1** in which the movable mirrors are movable about two axes of rotation.

5. An optical beam switching system according to claim **4** in which the two axes of rotation are disposed ninety degrees relative to one another.

6. An optical beam switching system according to claim **1** in which each optical receptor is an end of an optical fiber having a longitudinal axis and the position of the movable mirrors are adjusted to direct the optical beam along a path coincident with the longitudinal axis of the selected optical receptor.

7. An optical switching system according to claim **6** in which the focusing lens and the first movable mirror are mounted in a housing and each second movable mirror and associated optical fiber are mounted in a respective separate housing.

8. An optical beam switching system according to claim **7** further comprising a stationary mirror in each housing for folding the path of the optical beam.

9. An optical beam switching system for transmitting an optical beam from any one of a plurality of sources to any one of a plurality of optical receptors comprising:

- a plurality of first movable mirrors mounted across a first area of free space from the sources, for directing said optical beam from at least one source to a selected one of a plurality of second movable mirrors;

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the plurality of second movable mirrors mounted across a second area of free space from the plurality of first movable mirrors for directing said optical beam from at least one of the first movable mirrors to a selected one of the plurality of optical receptors;

a plurality of optical receptors mounted across a third area of free space from said plurality of second movable mirrors;

a control for transmission of the optical beam from the source to a selected optical receptor by means of controlling a controlled mirror by causing at least one of (a) one of the first movable mirrors to direct the optical beam to a selected one of the second movable mirrors and (b) the selected second movable mirror to direct the optical beam to a selected one of the optical receptors; and

radiation emitters for use in providing a feedback signal regarding the current orientation of the controlled mirror or the current location of the optical beam to the control, in either case for the purpose of adjusting the position of the relevant controlled mirror to minimize transmission loss of the optical beam to the optical receptor by fine tuning said orientation of said relevant controlled mirror based on feedback signal.

10. An optical beam switching system according to claim **9**, wherein at least one of the movable mirrors is movable about at least one axis of rotation.

11. An optical beam switching system according to claim **10**, wherein the movable mirror is movable about at least two axes of rotation.

12. An optical beam switching system according to claim **11**, wherein the at least two axes of rotation are disposed ninety degrees relative to one another.

13. An optical beam switching system according to claim **9**, wherein said radiation emitters are disposed adjacent to at least one of the movable mirrors.

14. An optical beam switching system according to claim **9**, wherein said radiation emitters are disposed adjacent to at least one of the optical receptors.

15. An optical beam switching system according to any of claims **9**, **13** and **14**, wherein at least one optical receptor is mounted in optical receiving relationship with an associated one of said plurality of second movable mirrors.

16. An optical beam switching system according to any of claims **9**, **13** and **14**, wherein at least one optical receptor includes an end of an optical fiber having a longitudinal axis and the position of at least one of the plurality of second movable mirrors is adjustable to direct an optical beam along a path coincident with the longitudinal axis of one of the optical fibers.

17. An optical beam switching system according to any of claims **9**, **13** and **14**, further comprising a stationary mirror for folding the path of the optical beam.

18. An optical beam switching system according to any of claims **9**, **13** and **14**, wherein the optical switching system also comprises at least one focusing lens for focusing the optical beam.

19. An optical beam switching system according to claim **18**, wherein said focusing lens is disposed between a source and one of the first movable mirrors.

20. An optical beam switching system according to claim **18**, wherein said focusing lens is disposed between one of the second movable mirrors and an optical receptor.

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21. An optical beam switching system according to claim 18, wherein there are at least two focusing lenses, including a first lens disposed between a source and a first movable mirror and a second lens disposed between a second movable mirror and an optical receptor.

22. An optical beam switching system according to claim 18, wherein at least one of the focusing lenses and at least one of the first movable mirrors are mounted in a housing.

23. An optical beam switching system according to claim 18, wherein at least one of the focusing lenses and at least one of the second movable mirrors are mounted in a housing.

24. An optical beam switching system for transmitting an optical beam from any one of a plurality of sources to any one of a plurality of optical receptors comprising:

a plurality of first movable mirrors mounted across a first area of free space from the sources; at least one additional plurality of additional movable mirrors mounted across a second area of free space from the plurality of first movable mirrors;

a plurality of second movable mirrors mounted across a third area of free space from the plurality of additional movable mirrors;

the plurality of first movable mirrors being operative for directing said optical beam from at least one source to at least one of the plurality of additional movable mirrors;

the at least one additional plurality of additional movable mirrors being operative for directing said optical beam between at least one of the first movable mirrors and at least one of the second movable mirrors;

the plurality of second movable mirrors being operative for directing said optical beam from at least one of the additional movable mirrors to a selected one of the plurality of optical receptors;

the plurality of optical receptors mounted across a fourth area of free space from said plurality of second movable mirrors;

a control for transmission of the optical beam from the source to a selected optical receptor by means of controlling a controlled mirror, causing at least one of (a) one of the first movable mirrors to direct the optical beam to a selected one of the additional movable mirrors, (b) one of the additional movable mirrors to direct the optical beam to a selected second movable mirror, and (c) at least one of the second movable mirrors to direct the optical beam to a selected optical receptor; and

radiation emitters for use in providing a feedback signal regarding the current orientation of the controlled mirror or the current location of the optical beam to the control, in either case for the purpose of adjusting the position of the relevant controlled mirror to minimize transmission loss of the optical beam to the optical receptor by fine tuning said orientation of said relevant controlled mirror based on said feedback signal.

25. An optical beam switching system according to claim 24, wherein at least one of the movable mirrors is movable about at least one axis of rotation.

26. An optical beam switching system according to claim 25, wherein the movable mirror is movable about at least two axes of rotation.

27. An optical beam switching system according to claim 26, wherein the at least two axes of rotation are disposed ninety degrees relative to one another.

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28. An optical beam switching system according to claim 24, wherein said radiation emitters are disposed adjacent to at least one of the movable mirrors.

29. An optical beam switching system according to claim 24, wherein said radiation emitters are disposed adjacent to at least one of the optical receptors.

30. An optical beam switching system according to any of claims 24, 28 and 29, wherein at least one optical receptor is mounted in optical receiving relationship with an associated one of said plurality of second movable mirrors.

31. An optical beam switching system according to any of claims 24, 28 and 29, wherein at least one optical receptor includes an end of an optical fiber having a longitudinal axis and the position of at least one of the plurality of second movable mirrors is adjustable to direct an optical beam along a path coincident with the longitudinal axis of one of the optical fibers.

32. An optical beam switching system according to any of claims 24, 28 and 29, further comprising a stationary mirror for folding the path of the optical beam.

33. An optical beam switching system according to any of claims 24, 28, and 29, wherein the optical switching system also comprises at least one focusing lens for focusing the optical beam.

34. An optical beam switching system according to claim 33, wherein said focusing lens is disposed between a source and one of the first movable mirrors.

35. An optical beam switching system according to claim 33, wherein said focusing lens is disposed between one of the second movable mirrors and an optical receptor.

36. An optical beam switching system according to claim 33, wherein there are at least two focusing lenses, including a first lens disposed between a source and a movable mirror and a second lens disposed between a second movable mirror and an optical receptor.

37. An optical beam switching system according to claim 33, wherein at least one of the focusing lenses and at least one of the first movable mirrors are mounted in a housing.

38. An optical beam switching system according to claim 33, wherein at least one of the focusing lenses and at least one of the second movable mirrors are mounted in a housing.

39. An optical beam switching system for transmitting an optical beam from any one of a complete set of sources of said switching system to any one of a complete set of optical receptors of said switching system comprising:

a plurality of first movable mirrors for directing said optical beam from at least one source to a selected one of a plurality of second movable mirrors, each of said first mirrors mounted across a first area of free space from an associated one of the sources such that a plurality of first optical pathways are defined between the sources and the first movable mirrors, said first movable mirrors comprising substantially a complete set of movable mirrors included in said switching system for directly interfacing with said sources free from any intervening movable mirrors and said first optical pathways comprising substantially a complete set of pathways included in said switching system between said sources and said first movable mirrors;

the plurality of second movable mirrors being operative for directing said optical beam from at least one of the

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first movable mirrors to a selected one of the plurality of optical receptors, each of said second movable mirrors being mounted across a second area of free space from the plurality of first movable mirrors such that a plurality of second optical pathways are defined between the first movable mirrors and the second movable mirrors, said second movable mirrors comprising substantially the full set of movable mirrors included in said switching system for directly interfacing with said receptors free from any intervening movable mirrors and said second optical pathways comprising substantially a complete set of pathways included in said switching system between the first movable mirrors and the second movable mirrors;

- a plurality of optical receptors, each of said optical receptors mounted across a third area of free space from said plurality of second movable mirrors such that a plurality of third optical pathways are defined between the second movable mirrors and the receptors, the third optical pathways comprising substantially a complete set of optical pathways included in said switching system between the second movable mirrors and the receptors;

said sources, said first and second movable mirrors and said receptors being configured such that there is a three dimensional switch interface region optically interposed between said first movable mirrors and said second movable mirrors such that at least most of the second pathways for any possible connection between the first and second movable mirrors traverse said switch interface region and at least most of said first and third pathways are located wholly outside said region;

- a control for transmission of the optical beam from the source to a selected optical receptor by means of controlling a controlled mirror by causing at least one of (a) one of the first movable mirrors to direct the optical beam to a selected one of the second movable mirrors and (b) the selected second movable mirror to direct the optical beam to a selected one of the optical receptors; and

- a servo control element for use in providing a feedback signal regarding the current orientation of the controlled mirror or the current location of the optical beam to the control, in either case for the purpose of adjusting the position of the relevant controlled mirror to minimize transmission loss of the optical beam to the optical receptor by fine tuning said orientation of said relevant controlled mirror based on said feedback signal.

40. An optical beam switching system according to claim 39, wherein at least one of the movable mirrors is movable about at least one axis of rotation.

41. An optical beam switching system according to claim 39, wherein the movable mirror is movable about at least two axes of rotation.

42. An optical beam switching system according to claim 41, wherein the at least two axes of rotation are disposed ninety degrees relative to one another.

43. An optical beam switching system according to claim 39, wherein said servo control elements are disposed adjacent to at least one of the movable mirrors.

44. An optical beam switching system according to claim 39, wherein said servo control elements are disposed adjacent to at least one of the optical receptors.

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45. An optical beam switching system according to any of claims 39, 43 and 44, wherein at least one optical receptor is mounted in optical receiving relationship with an associated one of said plurality of first movable mirrors.

46. An optical beam switching system according to any of claims 39, 43 and 44, wherein at least one optical receptor includes an end of an optical fiber having a longitudinal axis and the position of at least one of the plurality of first movable mirrors is adjustable to direct an optical beam along a path coincident with the longitudinal axis of one of the optical fibers.

47. An optical beam switching system according to any of claims 39, 43 and 44, further comprising a stationary mirror for folding the path of the optical beam.

48. An optical beam switching system according to any of claims 39, 43 and 44, wherein the optical switching system also comprises at least one focusing lens for focusing the optical beam.

49. An optical beam switching system according to claim 48, wherein said focusing lens is disposed between a source and one of the first movable mirrors.

50. An optical beam switching system according to claim 48, wherein a focusing lens is disposed between one of the second movable mirrors and the optical receptor.

51. An optical beam switching system according to claim 48, wherein there are at least two focusing lenses, including a first lens disposed between a source and a movable mirror and a second lens disposed between a second movable mirror and an optical receptor.

52. An optical beam switching system according to claim 48, wherein at least one of the focusing lenses and at least one of the first movable mirrors are mounted in a housing.

53. An optical beam switching system according to claim 48, wherein at least one of the focusing lenses and at least one of the second movable mirrors are mounted in a housing.

54. An optical beam switching system for transmitting an optical beam from any one of a complete set of sources of said switching system to any one of a complete set of optical receptors of said switching system comprising:

- a plurality of first movable mirrors for directing said optical beam from at least one source to a selected one of a plurality of additional movable mirrors, each of said first mirrors mounted across a first area of free space from an associated one of the sources such that a plurality of first optical pathways are defined between the sources and the first movable mirrors, said first movable mirrors comprising substantially a complete set of movable mirrors included in said switching system for directly interfacing with said sources free from any intervening movable mirrors and said first optical pathways comprising substantially a complete set of pathways included in said switching system between said sources and said first movable mirrors;

the plurality of additional movable mirrors mounted across a second area of free space from the plurality of first movable mirrors such that a plurality of second optical pathways are defined between the first movable mirrors and the additional movable mirrors;

- a plurality of second movable mirrors mounted across a third area of free space from the plurality of additional movable mirrors such that a plurality of third optical pathways are defined between the additional movable

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mirrors and the second movable mirrors, the second and third optical pathways collectively comprising substantially a complete set of optical pathways included in said switching system between the first and second movable mirrors;

the plurality of first movable mirrors being operative for directing said optical beam from at least one source to a selected one of the plurality of additional movable mirrors;

the plurality of additional movable mirrors being operative for directing said optical beam between at least one of the first movable mirrors and at least one of the second movable mirrors;

the plurality of second movable mirrors being operative for directing said optical beam from at least one of the additional movable mirrors to selected one of the plurality of optical receptors;

the plurality of optical receptors mounted across a fourth area of free space from said plurality of second movable mirrors such that a plurality of fourth optical pathways is defined between the second movable mirrors and the optical receptors, the fourth optical pathways comprising substantially a complete set of optical pathways included in said switching system between the second movable mirrors and the receptors;

said sources, said first, additional and second movable mirrors and said receptors being configured such that there is a three dimensional switch interface region optically interposed between said first movable mirrors and said second movable mirrors such that at least most of the second and third pathways for any possible connection between the first and second movable mirrors traverse said switch interface region and at least most of said first and fourth pathways are located wholly outside said region;

a control for transmission of the optical beam from the source to a selected optical receptor by means of controlling a controlled mirror by causing at least one of (a) one of the first movable mirrors to direct the optical beam to a selected one of the additional movable mirrors, (b) the selected additional movable mirrors to direct the optical beam to a selected one of the second movable mirrors, and (c) the selected second movable mirror to direct the optical beam to a selected one of the optical receptors; and

a servo control element for use in providing a feedback signal regarding the current orientation of the controlled mirror or the current location of the optical beam to the control, in either case for the purpose of adjusting the position of the relevant controlled mirror to minimize transmission loss of the optical beam to the optical receptor by fine tuning said orientation of said relevant controlled mirror based on said feedback signal.

55. An optical beam switching system according to claim 54, wherein at least one of the movable mirrors is movable about at least one axis of rotation.

56. An optical beam switching system according to claim 55, wherein the movable mirror is movable about at least two axes of rotation.

57. An optical beam switching system according to claim 56, wherein the at least two axes of rotation are disposed ninety degrees relative to one another.

58. An optical beam switching system according to claim 54, wherein said servo control elements are disposed adjacent to at least one of the movable mirrors.

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59. An optical beam switching system according to claim 54, wherein said servo control elements are disposed adjacent to at least one of the optical receptors.

60. An optical beam switching system according to any of claims 54, 58 and 59, wherein at least one optical receptor is mounted in optical receiving relationship with an associated one of said plurality of second movable mirrors.

61. An optical beam switching system according to any of claims 54, 58 and 59, wherein at least one optical receptor includes an end of an optical fiber having a longitudinal axis and the position of at least one of the plurality of second movable mirrors devices is adjustable to direct an optical beam along a path coincident with the longitudinal axis of one of the optical fibers.

62. An optical beam switching system according to any of claims 54, 58 and 59, further comprising a stationary mirror for folding the path of the optical beam.

63. An optical beam switching system according to any of claims. 54, 58 and 59, wherein the optical switching system also comprises at least one focusing lens for focusing the optical beam.

64. An optical beam switching system according to claim 63, wherein said focusing lens is disposed between a source and one of the first movable mirrors.

65. An optical beam switching system according to claim 63, wherein a focusing lens is disposed between one of the second beam movable mirrors and an optical receptor.

66. An optical beam switching system according to claim 63, wherein there are at least two focusing lenses, including a first lens disposed between a source and a first movable mirror and a second lens disposed between a second movable mirror and an optical receptor.

67. An optical beam switching system according to claim 63, wherein at least one of the focusing lenses and at least one of the first movable mirrors are mounted in a housing.

68. An optical beam switching system according to claim 63, wherein at least one of the focusing lenses and at least one of the second movable mirrors are mounted in a housing.

69. An optical beam switching system for transmitting an optical beam from any one of a complete set of sources of said switching system to any one of a complete set of optical receptors of said switching system comprising:

a first plurality of first movable mirrors for directing said optical beam from at least one source to a selected one of a plurality of second movable mirrors, each of said mirrors mounted across a first area of free space from an associated one of the sources such that a plurality of first optical pathways is defined between the sources and the first movable mirrors, said first movable mirrors comprising substantially a complete set of movable mirrors included in said switching system for directly interfacing with said sources free from any intervening movable mirrors and said first optical pathways comprising substantially a complete set of pathways included in said switching system between said sources and said first movable mirrors;

the plurality of second movable mirrors being operative for directing said optical beam from at least one of the first movable mirrors to a selected one of the plurality of optical receptors, each of said second movable mirrors being mounted across a second area of free space from the plurality of first movable mirrors such

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that a plurality of second optical pathways is defined between the first movable mirrors and the second movable mirrors, said first movable mirrors comprising substantially a complete set of movable mirrors included in said switching system for directly interfacing with said sources free from any intervening movable mirrors and said first optical pathways comprising substantially a complete set of pathways included in said switching system between said sources and said first movable mirrors;

a plurality of optical receptors, each of said optical receptors mounted across a third area of free space from said plurality of second movable mirrors such that a plurality of third optical pathways is defined between the second movable mirrors and the receptors, the third optical pathways comprising substantially a complete set of optical pathways included in said switching system between the second movable mirrors and the receptors;

said sources, said first and said second movable mirrors and said receptors being configured such that there is a three dimensional switch interface region optically interposed between said first movable mirrors and said second movable mirrors such that at least most of the second pathways for any possible connection between the first and second movable mirrors traverse said switch interface region and at least most of said first and third pathways are located wholly outside said region;

a control for transmission of the optical beam from the source to a selected optical receptor, by means of controlling a controlled mirror by causing at least one of (a) one of the first movable mirrors to direct the optical beam to a selected one of the second movable mirrors and (b) the selected second movable mirror to direct the optical beam to a selected one of the optical receptors; and

a data gathering and transmitting element for use in providing a feedback signal regarding the current orientation of the controlled mirror or the current location of the optical beam to the control, in either case for the purpose of adjusting the position of the relevant controlled mirror to minimize transmission loss of the optical beam to the optical receptor by fine tuning said orientation of said relevant controlled mirror based on said feedback signal.

70. An optical beam switching system according to claim **69**, wherein at least one of the movable mirrors is movable about at least one axis of rotation.

71. An optical beam switching system according to claim **70**, wherein the movable mirror is movable about at least two axes of rotation.

72. An optical beam switching system according to claim **71**, wherein the at least two axes of rotation are disposed ninety degrees relative to one another.

73. An optical beam switching system according to claim **69**, wherein said data gathering and transmitting element is disposed adjacent to at least one of the movable mirrors.

74. An optical beam switching system according to claim **69**, wherein said data gathering and transmitting element is disposed adjacent to at least one of the optical receptors.

75. An optical beam switching system according to any of claims **69**, **73** and **74**, wherein at least one optical receptor is mounted in optical receiving relationship with an associated one of said plurality of second movable mirrors.

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76. An optical beam switching system according to any of claims **69**, **73** and **74**, wherein at least one optical receptor includes an end of an optical fiber having a longitudinal axis and the position of at least one of the plurality of second movable mirrors is adjustable to direct an optical beam along a path coincident with the longitudinal axis of one of the optical fibers.

77. An optical beam switching system according to any of claims **69**, **73** and **74**, further comprising a stationary mirror for folding the path of the optical beam.

78. An optical beam switching system according to any of claims **69**, **73** and **74**, wherein the optical switching system also comprises at least one focusing lens for focusing the optical beam.

79. An optical beam switching system according to claim **78**, wherein said focusing lens is disposed between a source and one of the first movable mirrors.

80. An optical beam switching system according to claim **78**, wherein said focusing lens is disposed between one of the second movable mirrors and an optical receptor.

81. An optical beam switching system according to claim **78**, wherein there are at least two focusing lenses, including a first lens disposed between a source and a movable mirror and a second lens disposed between a second movable mirror and an optical receptor.

82. An optical beam switching system according to claim **78**, wherein at least one of the focusing lenses and at least one of the first movable mirrors are mounted in a housing.

83. An optical beam switching system according to claim **78**, wherein at least one of the focusing lenses and at least one of the second movable mirrors are mounted in a housing.

84. An optical beam switching system according to either of claims **39** and **69**, wherein substantially all of the second pathways traverse said switch interface region and substantially all of said first and third pathways are located wholly outside said region.

85. An optical beam switching system for transmitting an optical beam from any one of a complete set of sources of said switching system to any one of a complete set of optical receptors of said switching system comprising:

a plurality of first movable mirrors for directing said optical beam from at least one source to a selected one of a plurality of additional movable mirrors, each of said first mirrors mounted across a first area of free space from an associated one of the sources such that a plurality of first optical pathways is defined between the sources and the first movable mirrors, said first movable mirrors comprising substantially a complete set of movable mirrors included in said switching system for directly interfacing with said sources free from any intervening movable mirrors and said first optical pathways comprising substantially a complete set of pathways included in said switching system between said sources and said first movable mirrors;

the plurality of additional movable mirrors mounted across a second area of free space from the plurality of first movable mirrors such that a plurality of second optical pathways is defined between the first movable mirrors and the additional movable mirrors;

a plurality of second movable mirrors mounted across a third area of free space from the plurality of additional movable mirrors such that a plurality of third optical

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pathways is defined between the additional movable mirrors and the second movable mirrors, the second and third optical pathways collectively comprising substantially a complete set of optical pathways included in said switching system between the first and second movable mirrors;

the plurality of first movable mirrors being operative for directing said optical beam from at least one source to a selected one of the plurality of additional movable mirrors;

the plurality of additional movable mirrors being operative for directing said optical beam between at least one of the first movable mirrors and at least one of the second movable mirrors;

the plurality of second movable mirrors being operative for directing said optical beam from at least one of the additional movable mirrors to selected one of the plurality of optical receptors;

the plurality of optical receptors mounted across a fourth area of free space from said plurality of second movable mirrors such that a plurality of fourth optical pathways is defined between the second movable mirrors and the optical receptors, the fourth optical pathways comprising substantially a complete set of optical pathways included in said switching system between the second movable mirrors and the receptors;

said sources, said first, additional and second movable mirrors and said receptors being configured such that there is a three dimensional switch interface region optically interposed between said first movable mirrors and said second movable mirrors such that at least most of the second and third pathways for any possible connection between the first and second movable mirrors traverse said switch interface region and at least most of said first and fourth pathways are located wholly outside said region;

a control for transmission of the optical beam from the source to a selected optical receptor by means of controlling a controlled mirror, by causing at least one of (a) one of the first movable mirrors to direct the optical beam to a selected one of the additional movable mirrors, (b) the selected additional movable mirror to direct the optical beam to a selected one of the second movable mirrors, and (c) the selected second movable mirror to direct the optical beam to a selected one of the optical receptors; and

a data gathering and transmitting element for use in providing a feedback signal regarding the current orientation of the controlled mirror or the current location of the optical beam to the control, in either case for the purpose of adjusting the position of the relevant controlled mirror to minimize transmission loss of the optical beam to the optical receptor by fine tuning said orientation of said relevant controlled mirror based on said feedback signal.

86. An optical beam switching system according to claim **85**, wherein the movable mirror is movable about at least one axis of rotation.

87. An optical beam switching system according to claim **86**, wherein the movable mirror is movable about at least two axes of rotation.

88. An optical beam switching system according to claim **87**, wherein the at least two axes of rotation are disposed ninety degrees relative to one another.

89. An optical beam switching system according to claim **85**, wherein said data gathering and transmitting element is disposed adjacent to at least one of the movable mirrors.

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90. An optical beam switching system according to claim **85**, wherein said data gathering and transmitting element is disposed adjacent to at least one of the optical receptors.

91. An optical beam switching system according to any of claims **85**, **89** and **90**, wherein at least one optical receptor is mounted in optical receiving relationship with an associated one of said plurality of second movable mirrors.

92. An optical beam switching system according to any of claims **85**, **89** and **90**, wherein at least one optical receptor includes an end of an optical fiber having a longitudinal axis and the position at least one of the plurality of second movable mirrors is adjustable to direct an optical beam along a path coincident with the longitudinal axis of one of the optical fibers.

93. An optical beam switching system according to any of claims **85**, **89** and **90**, further comprising a stationary mirror for folding the path of the optical beam.

94. An optical beam switching system according to any of claims **85**, **89** and **90**, wherein the optical switching system also comprises at least one focusing lens for focusing the optical beam.

95. An optical beam switching system according to claim **94**, wherein said focusing lens is disposed between a source and one of the first movable mirrors.

96. An optical beam switching system according to claim **94**, wherein said focusing lens is disposed between one of the second movable mirrors and an optical receptor.

97. An optical beam switching system according to claim **94**, wherein there are at least two focusing lenses, including a first lens disposed between a source and a first movable mirror and a second lens disposed between a second movable mirror and an optical receptor.

98. An optical beam switching system according to claim **94**, wherein at least one of the focusing lenses and at least one of the first movable mirrors are mounted in a housing.

99. An optical beam switching system according to claim **94**, wherein at least one of the focusing lenses and at least one of the second movable mirrors are mounted in a housing.

100. An optical beam switching system according to either of claims **84** and **85**, wherein substantially all of the second and third pathways traverse said switch interface region and substantially all of said first and fourth pathways are located wholly outside said region.

101. An optical beam switching system for transmitting an optical beam from any one of a plurality of sources to any one of a plurality of optical receptors comprising: a plurality of first movable mirrors mounted across a first area of free space from the sources and across a second area of free space from the optical receptors for directing said optical beam from at least one source to a selected one of the optical receptors;

a control for transmission of the optical beam from the source to a selected optical receptor by means of controlling a controlled mirror, by causing one of the first movable mirrors to direct the optical beam to a selected optical receptor; and

radiation emitters for use in providing a feedback signal regarding the current orientation of the controlled mirror or the current location of the optical beam to the control, in either case for the purpose of adjusting the position of the relevant controlled mirror to minimize

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transmission loss of the optical beam to the optical receptor by fine tuning said orientation of said relevant controlled mirror based on said feedback signal.

102. An optical beam switching system according to claim 101, wherein at least one of the movable mirrors is 5 movable about at least one axis of rotation.

103. An optical beam switching system according to claim 102, wherein the movable mirror is movable about at least two axes of rotation.

104. An optical beam switching system according to claim 103, wherein the at least two axes of rotation are disposed ninety degrees relative to one another.

105. An optical beam switching system according to claim 101, wherein said radiation emitters are disposed adjacent to at least one of the movable mirrors.

106. An optical beam switching system according to claim 101, wherein said radiation emitters are disposed adjacent to at least one of the optical receptors.

107. An optical beam switching system according to any of claims 101, 104 and 106, wherein at least one optical receptor is mounted in optical receiving relationship with an associated one of said plurality of first movable mirrors.

108. An optical beam switching system according to any of claims 101, 105 and 106, further comprising a stationary mirror for folding the path of the optical beam.

109. An optical beam switching system according to any of claims 101, 105 and 106, wherein the optical switching system also comprises at least one focusing lens for focusing the optical beam.

110. An optical beam switching system according to claim 109, wherein said focusing lens is disposed between a source and one of the first movable mirrors.

111. An optical beam switching system according to claim 109, wherein at least one of the focusing lenses and at least one of the first movable mirrors are mounted in a housing.

112. An optical beam switching system for transmitting an optical beam from any one of a complete set of sources of said switching system to any one of a complete set of optical receptors of said switching system comprising:

a plurality of first movable mirrors for directing said optical beam from at least one source to a selected one of the optical receptors, said plurality of first movable mirrors mounted across a first area of free space from the sources such that a plurality of first optical pathways are defined between the sources and the first movable mirrors, said first movable mirrors comprising substantially a complete set of movable mirrors included in said switching system for directly interfacing with said sources free from any intervening movable mirrors and said first optical pathways comprising substantially a complete set of pathways included in said switching system between said sources and said first movable mirrors, said plurality of first movable mirrors further mounted across a second area of free space from the receptors such that a plurality of second optical pathways are defined between the first movable mirrors and the receptors, the second optical pathways comprising substantially a complete set of pathways included in said switching system between the first movable mirrors and the receptors;

said sources, first movable mirrors and receptors being configured such that there is a first three dimensional region that is traversed by at least most of said second

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pathways and at least most of said first pathways are located wholly outside said first region;

a control for transmission of the optical beam from the source to a selected optical receptor by means of controlling a controlled mirror, by causing one of the first movable mirrors to direct the optical beam to a selected optical receptor; and

a servo control element for use in providing a feedback signal regarding the current orientation of the controlled mirror or the current location of the optical beam to the control, in either case for the purpose of adjusting the position of the relevant controlled mirror to minimize transmission loss of the optical beam to the optical receptor by fine tuning said orientation of said relevant controlled mirror based on said feedback signal.

113. An optical beam switching system according to claim 112, wherein at least one of the movable mirrors is movable about at least one axis of rotation.

114. An optical beam switching system according to claim 113, wherein the movable mirror is movable about at least two axes of rotation.

115. An optical beam switching system according to claim 114, wherein the at least two axes of rotation are disposed ninety degrees relative to one another.

116. An optical beam switching system according to claim 112, wherein said servo control elements are disposed adjacent to at least one of the movable mirrors.

117. An optical beam switching system according to claim 112, wherein said servo control elements are disposed adjacent to at least one of the optical receptors.

118. An optical beam switching system according to any of claims 112, 116 and 117, wherein at least one optical receptor is mounted in optical receiving relationship with an associated one of said plurality of first movable mirrors.

119. An optical beam switching system according to any of claims 112, 116 and 117, further comprising a stationary mirror for folding the path of the optical beam.

120. An optical beam switching system according to any of claims 112, 116 and 117, wherein the optical switching system also comprises at least one focusing lens for focusing the optical beam.

121. An optical beam switching system according to claim 120, wherein said focusing lens is disposed between a source and one of the first movable mirrors.

122. An optical beam switching system according to claim 120, wherein at least one of the focusing lenses and at least one of the first movable mirrors are mounted in a housing.

123. An optical beam switching system for transmitting an optical beam from any one of a complete set of sources of said switching system to any one of a complete set of optical receptors of said switching system comprising:

a plurality of first movable mirrors mounted across a first area of free space from the sources and across a second area of free space from the optical receptors, for directing said optical beam from at least one source to a selected one of the optical receptors, said plurality of first movable mirrors mounted across a first area of free space from the sources such that a plurality of first optical pathways are defined between the sources and the first movable mirrors, said first movable mirrors comprising substantially a complete set of movable

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mirrors included in said switching system for directly interfacing with said sources free from any intervening movable mirrors and said first optical pathways comprising substantially a complete set of pathways included in said switching system between said sources and said first movable mirrors, said plurality of first movable mirrors further mounted across a second area of free space from the receptors such that a plurality of second optical pathways are defined between the first movable mirrors and the receptors, the second optical pathways comprising substantially a complete set of pathways included in said switching system between the first movable mirrors and the receptors;

said sources, first movable mirrors and receptors being configured such that there is a first three dimensional region that is traversed by at least most of said second pathways and at least most of said first pathways are located wholly outside said first region;

a control for transmission of the optical beam from the source to a selected optical receptor by means of controlling a controlled mirror, by causing one of the first movable mirrors to direct the optical beam to a selected optical receptor; and

a data gathering and transmitting element for use in providing a feedback signal regarding the current orientation of the controlled mirror or the current location of the optical beam to the control, in either case for the purpose of adjusting the position of the relevant controlled mirror to minimize transmission loss of the optical beam to the optical receptor by fine tuning said orientation of said relevant controlled mirror based on said feedback signal.

124. An optical beam switching system according to claim **123**, wherein at least one of the movable mirrors is movable about at least one axis of rotation.

125. An optical beam switching system according to claim **124**, wherein the movable mirror is movable about at least two axes of rotation.

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126. An optical beam switching system according to claim **125**, wherein the at least two axes of rotation are disposed ninety degrees relative to one another.

127. An optical beam switching system according to claim **123**, wherein said data gathering and transmitting element is disposed adjacent to at least one of the movable mirrors.

128. An optical beam switching system according to claim **123**, wherein said data gathering and transmitting element is disposed adjacent to at least one of the optical receptors.

129. An optical beam switching system according to any of claims **123**, **127** and **128**, wherein at least one optical receptor is mounted in optical receiving relationship with an associated one of said plurality of first movable mirrors.

130. An optical beam switching system according to any of claims **123**, **127** and **128**, further comprising a stationary mirror for folding the path of the optical beam.

131. An optical beam switching system according to any of claims **123**, **127** and **128**, wherein the optical switching system also comprises at least one focusing lens for focusing the optical beam.

132. An optical beam switching system according to claim **131**, wherein said focusing lens is disposed between a source and one of the first movable mirrors.

133. An optical beam switching system according to claim **131**, wherein at least one of the focusing lenses and at least one of the first movable mirrors are mounted in a housing.

134. An optical beam switching system according to either of claims **112** and **123**, wherein substantially all of said second pathways traverse said first region and substantially all of said first pathways are located wholly outside said first region.

* * * * *

Exhibit B



US007095917B2

(12) **United States Patent**
Laor et al.

(10) **Patent No.:** **US 7,095,917 B2**
(45) **Date of Patent:** ***Aug. 22, 2006**

(54) **OPTICAL SWITCHING APPARATUS**

(76) Inventors: **Herzel Laor**, 2050 Hillsdale Cir., Boulder, CO (US) 80303; **David A. Krozier**, 123 Westfield Dr., North Attleboro, MA (US) 02760; **Leo A. Plouffe**, 1290 Smith St., Dighton, MA (US) 02764

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 104 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **10/197,636**

(22) Filed: **Jul. 17, 2002**

(65) **Prior Publication Data**

US 2006/0115208 A1 Jun. 1, 2006

Related U.S. Application Data

(63) Continuation of application No. 09/310,285, filed on May 12, 1999, now Pat. No. 6,430,332.

(60) Provisional application No. 60/088,239, filed on Jun. 5, 1998.

(51) **Int. Cl.**

G02B 6/26 (2006.01)

(52) **U.S. Cl.** **385/18; 385/47; 385/52**

(58) **Field of Classification Search** **385/18, 385/17, 33, 47, 50, 52, 16, 19, 22; 359/117, 359/128**

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,365,863 A *	12/1982	Broussaud		385/17
5,872,880 A *	2/1999	Maynard		385/88
6,097,859 A *	8/2000	Solgaard et al.		385/17
6,430,332 B1 *	8/2002	Laor et al.		385/18

FOREIGN PATENT DOCUMENTS

JP 5107485 A * 4/1993

* cited by examiner

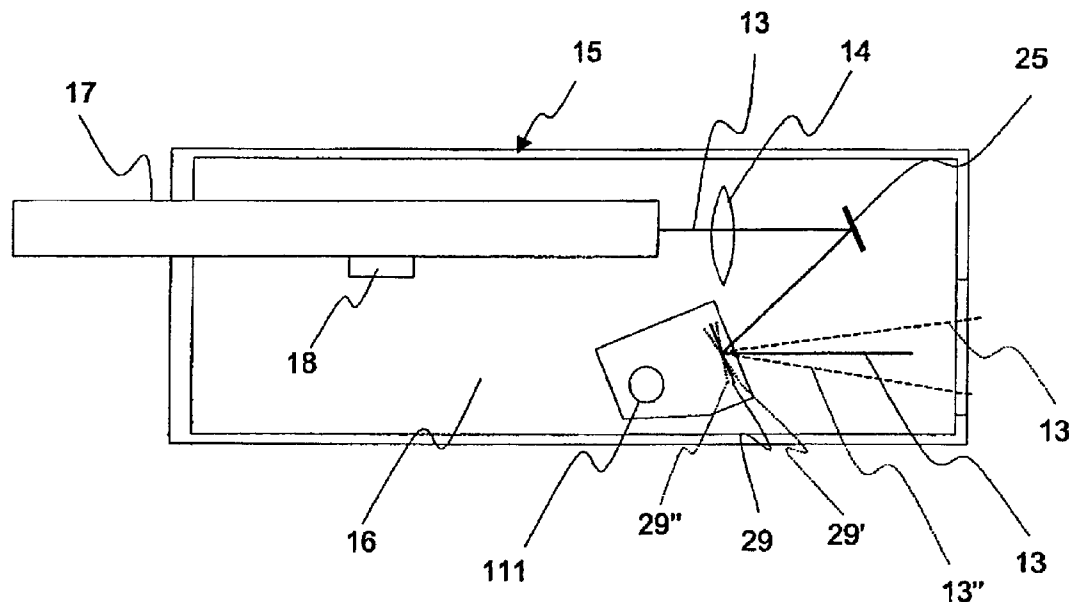
Primary Examiner—Sung Pak

(74) *Attorney, Agent, or Firm*—Marsh Fischmann & Breyfogle LLP

(57) **ABSTRACT**

An optical matrix switch station (1) is shown mounting a plurality of optical switch units (15, 17), each of which includes a mirror (29), moveable in two axes, for purpose of switching light beams from one optical fiber to another. A mirror assembly (41) is formed from a single body of silicon and comprises a frame portion (43), gimbals (45), mirror portion (47), and related hinges (55). Magnets (53, 54) and air coils (89) are utilized to position the central mirror surface (29) to a selected orientation. The moveable mirror and associated magnets along with control LED's (71) are hermetically packaged in a header (81) and mounted with the air coils on mounting bracket (85) to form a micromirror assembly package (99) mounted in each optical switch unit.

74 Claims, 16 Drawing Sheets



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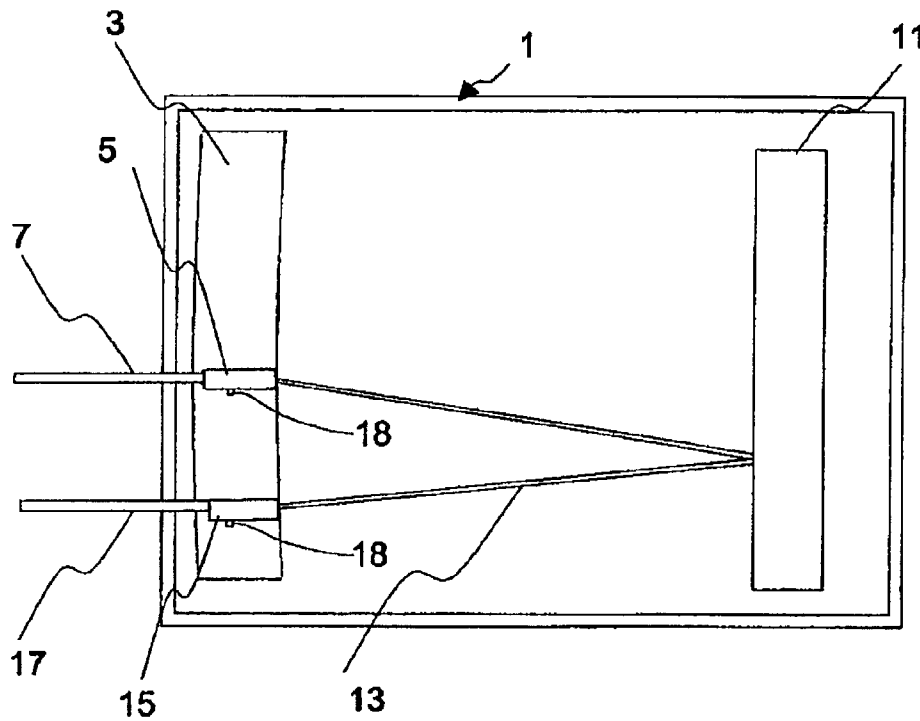


Fig. 1

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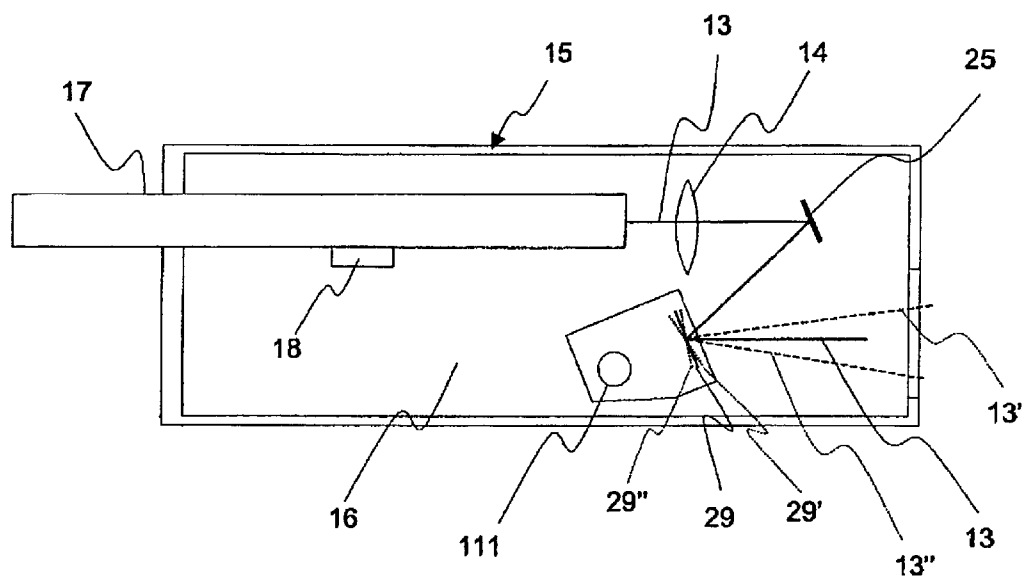


Fig. 2

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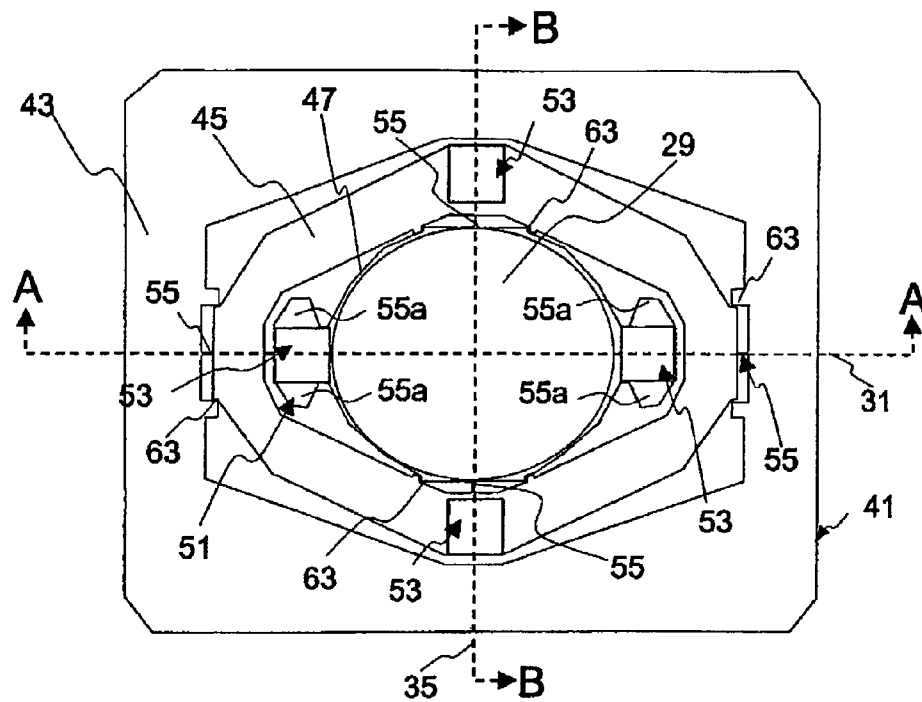


Fig. 3

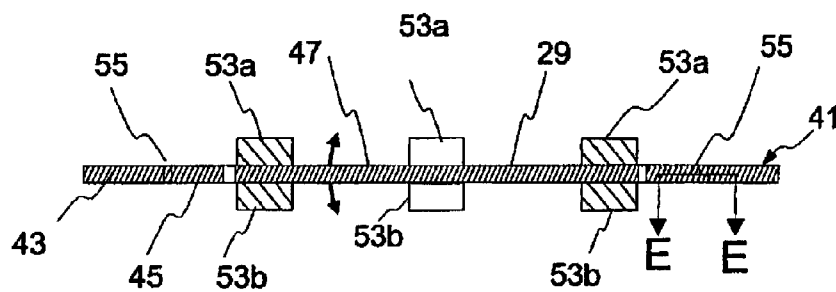


Fig. 3a

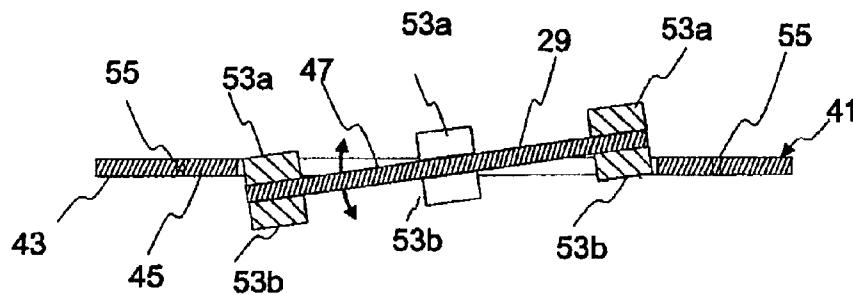


Fig. 3b

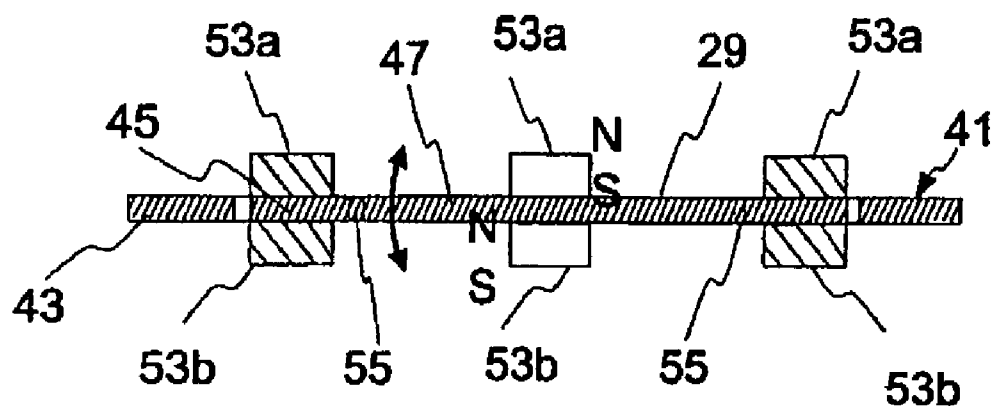


Fig. 3c

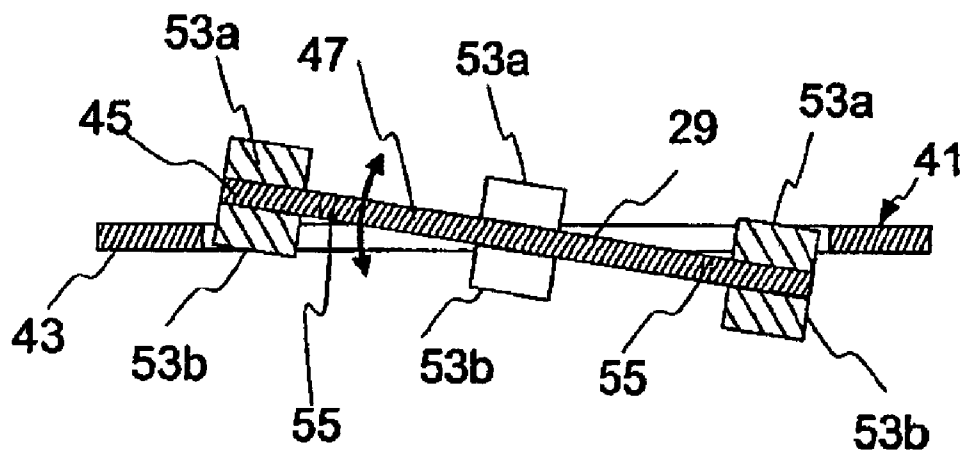


Fig. 3d

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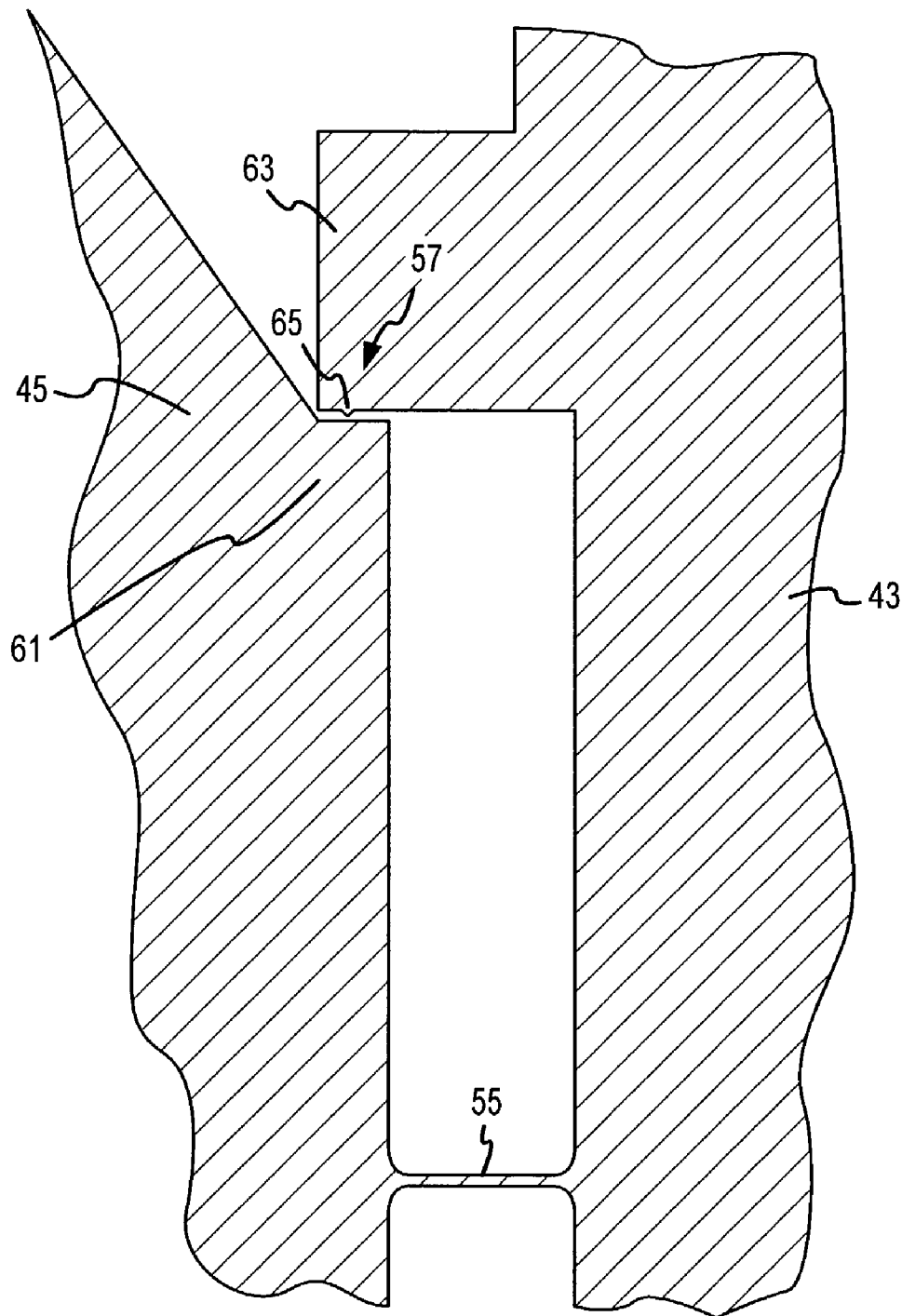


FIG. 4

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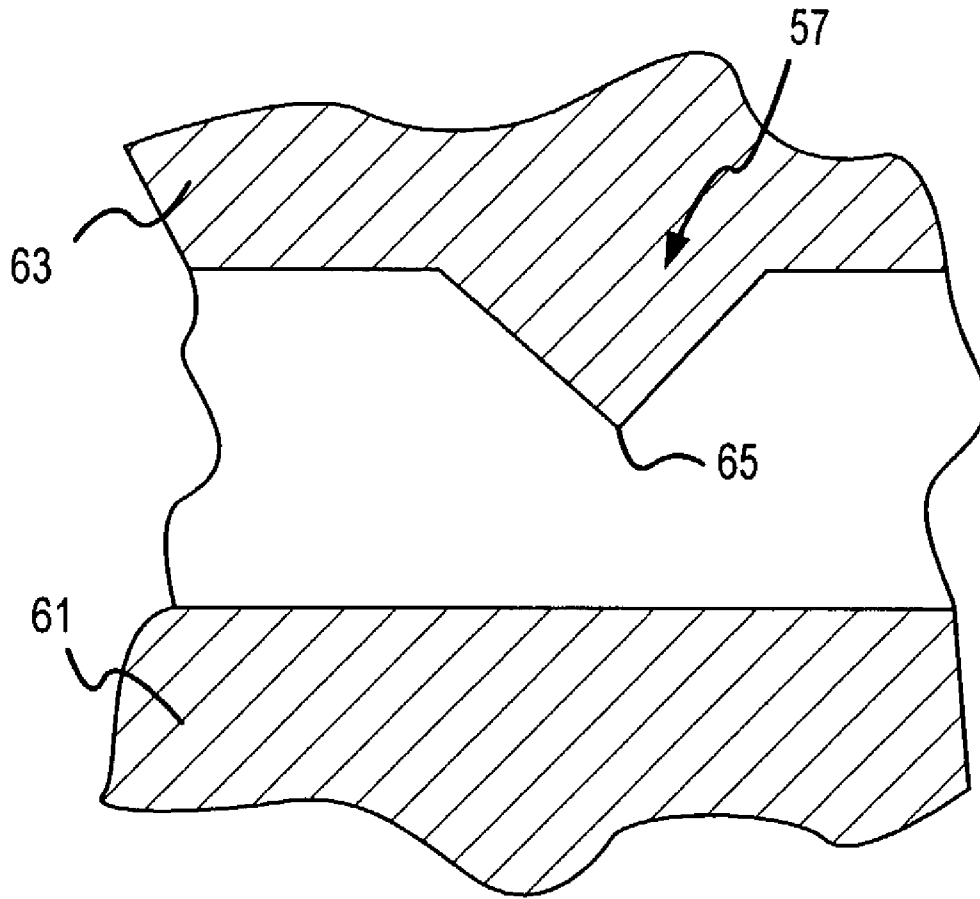


FIG.5

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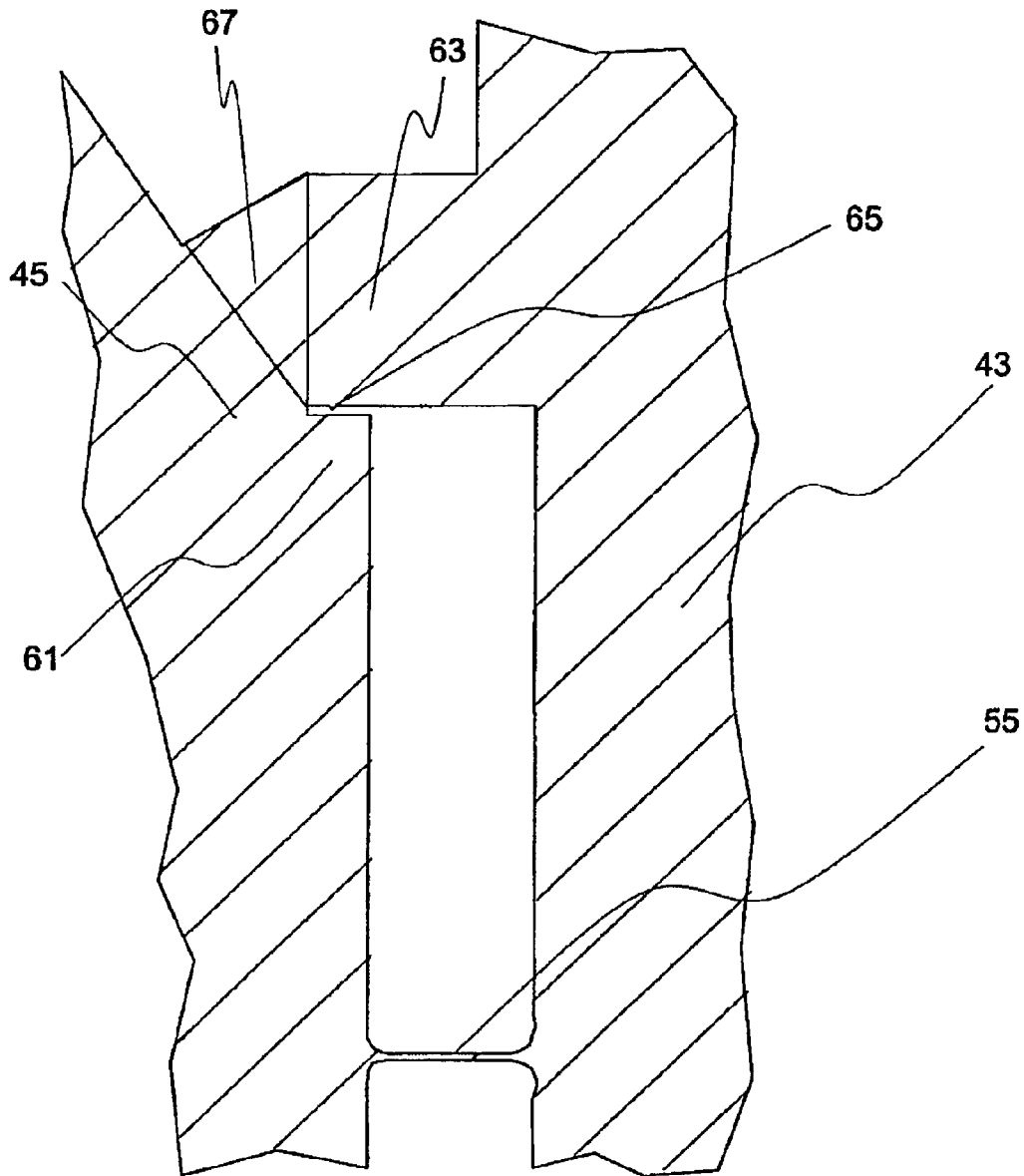


Fig. 6

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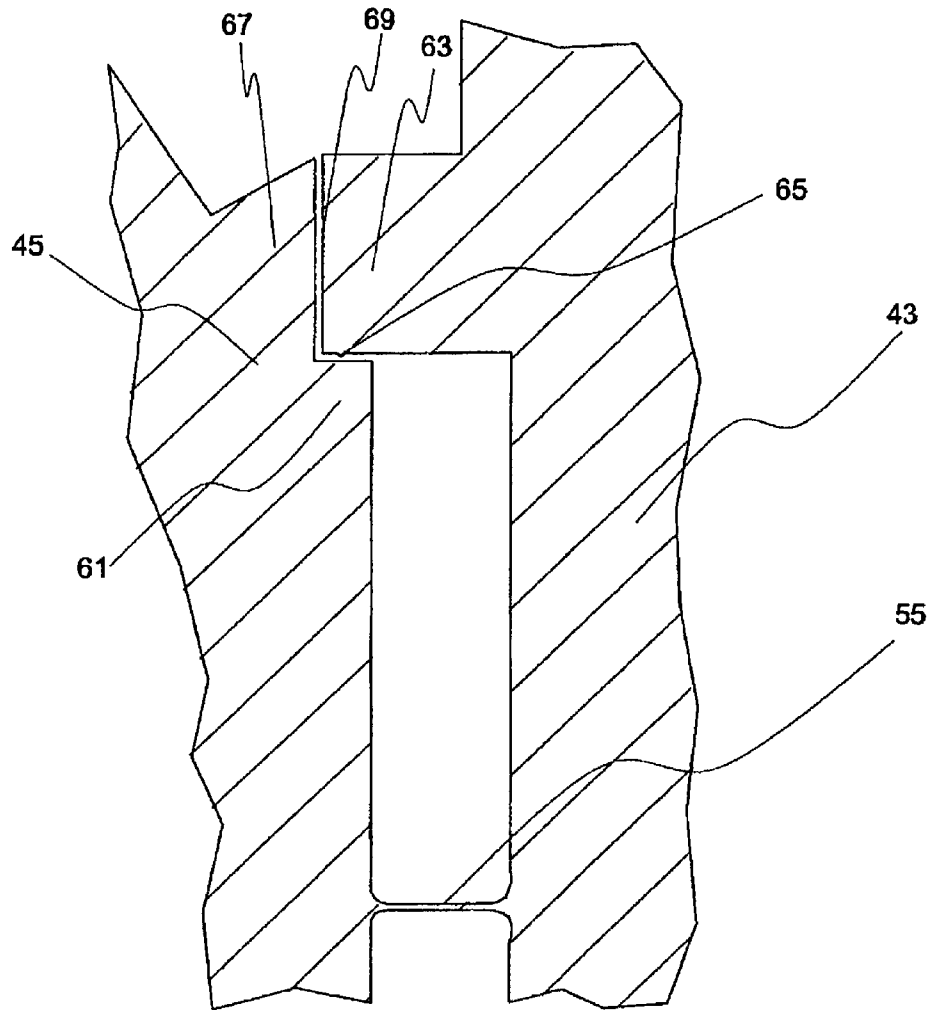


Fig. 6a

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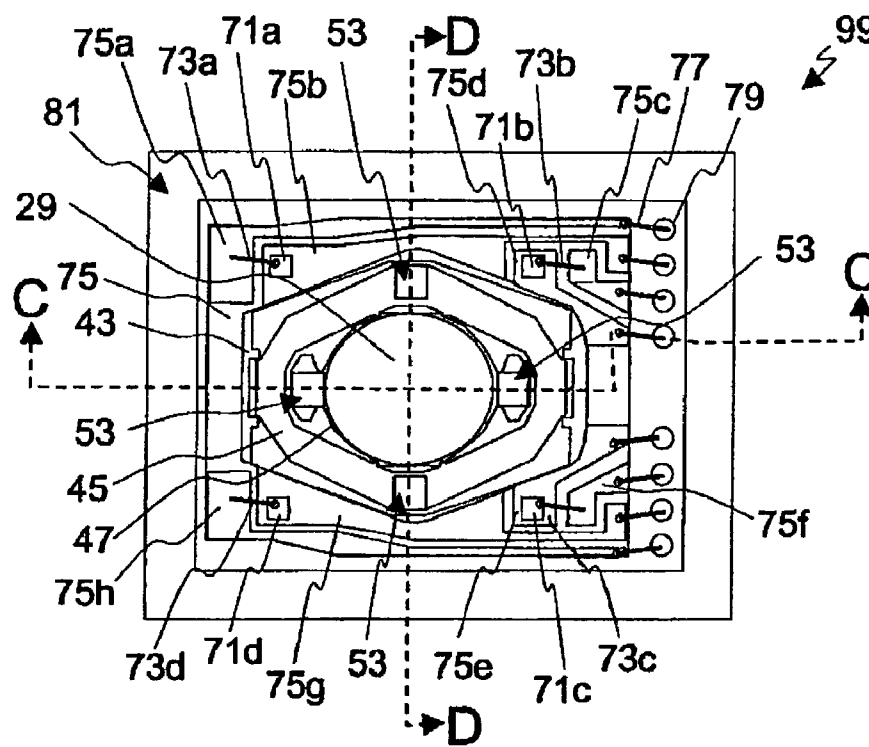


Fig. 7

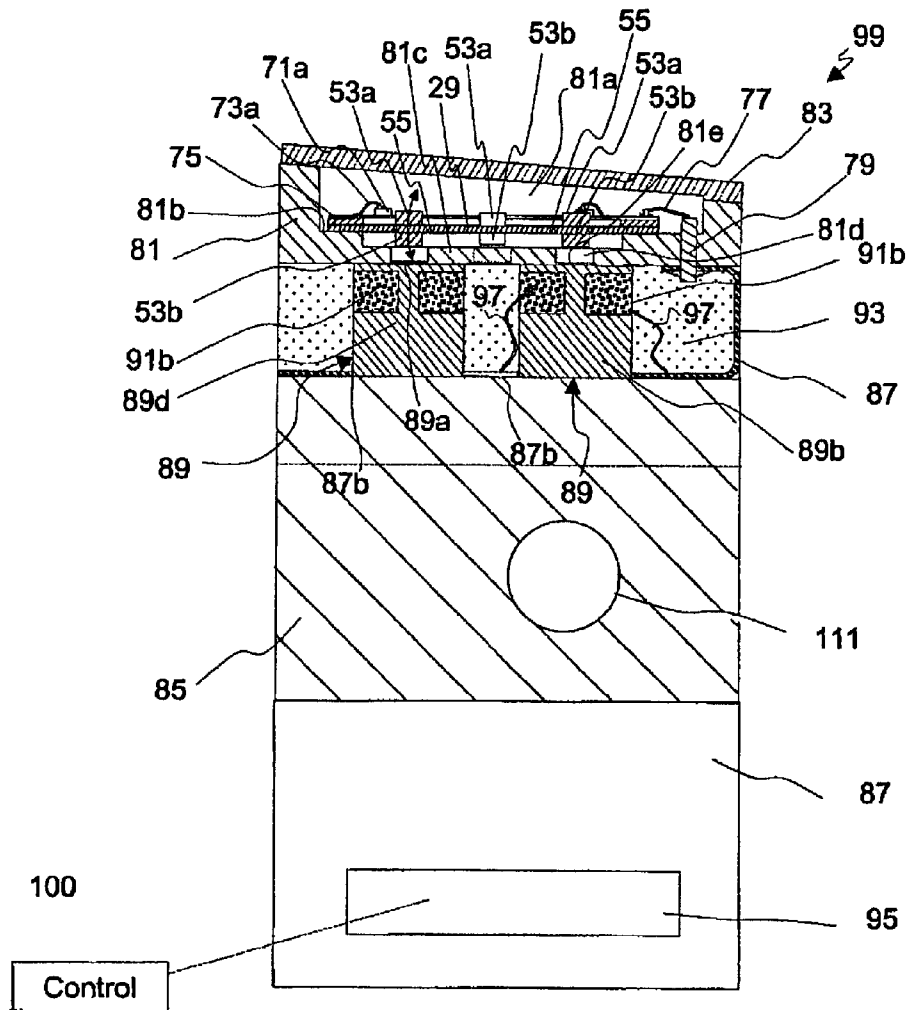


Figure 7a

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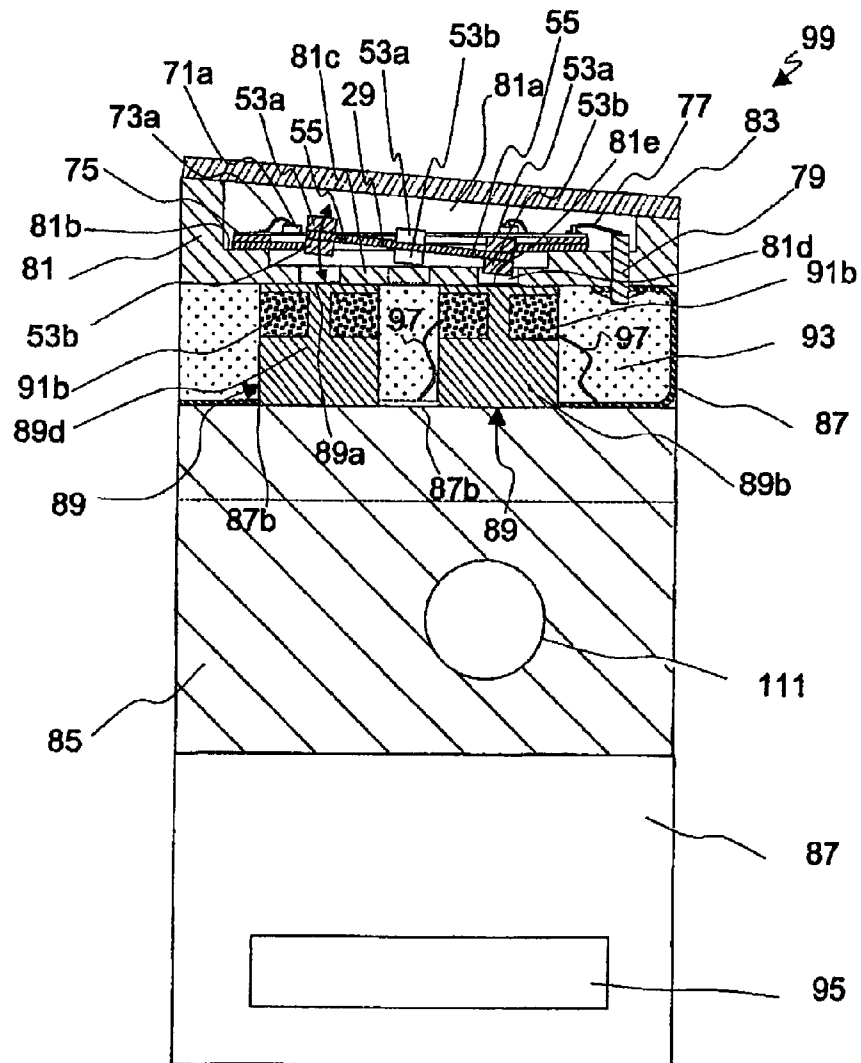


Figure 7b

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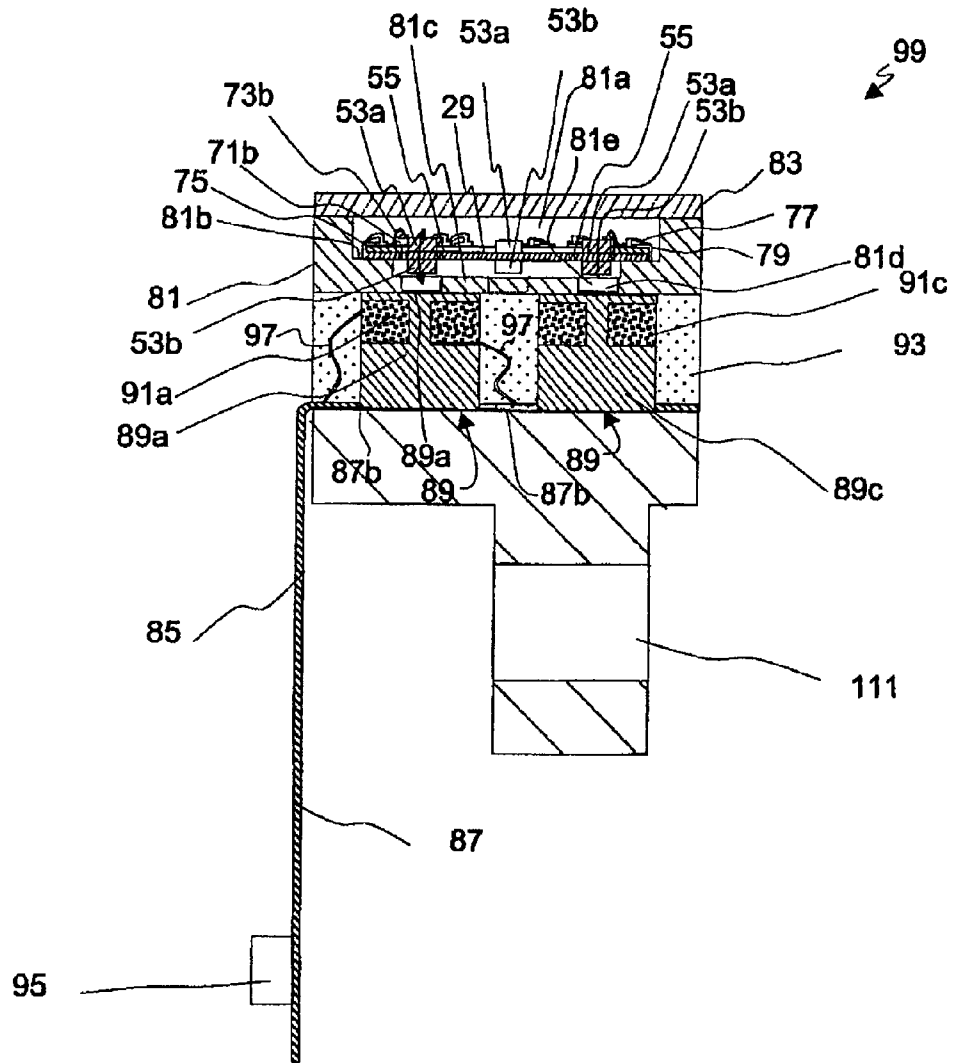


Figure 7c

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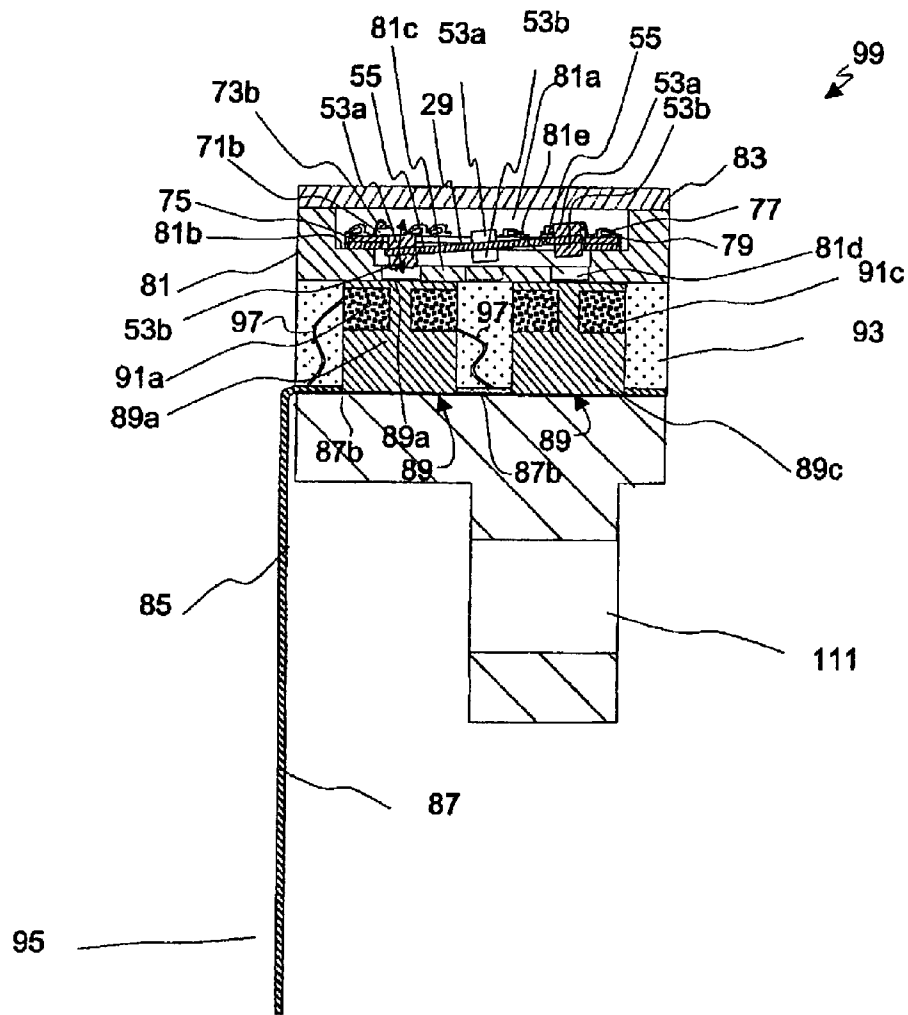


Figure 7d

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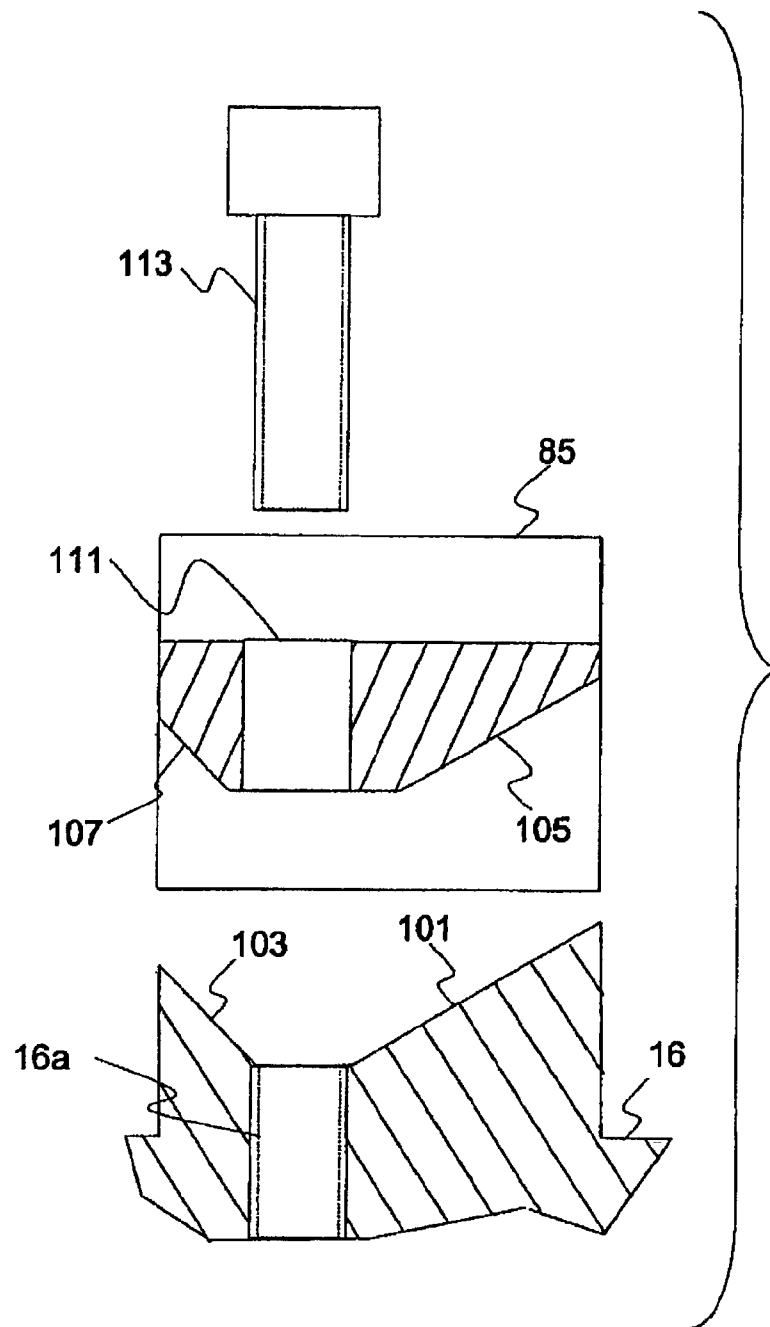


Fig. 8

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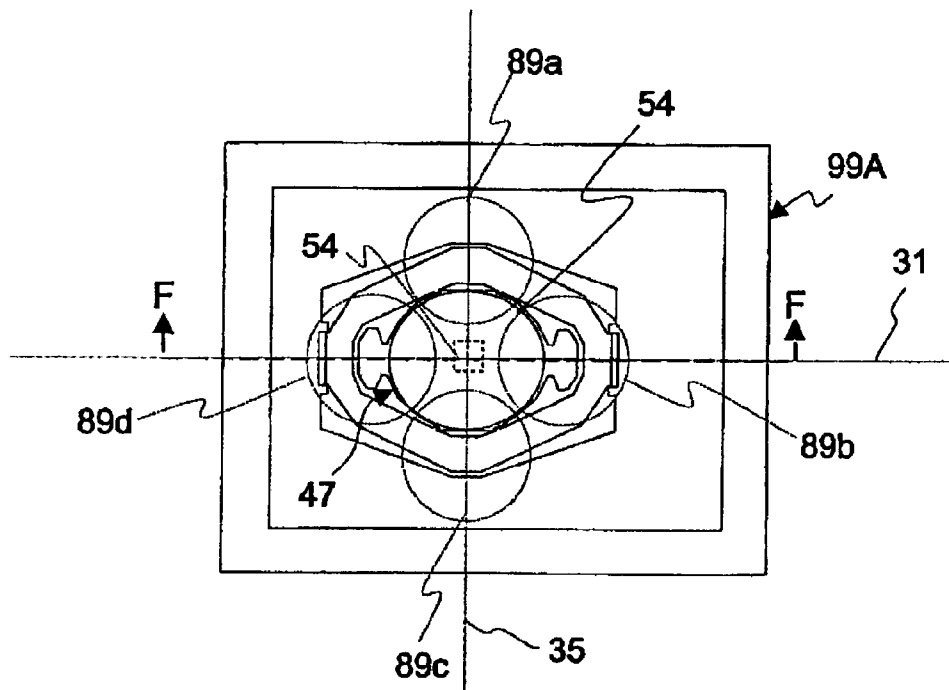


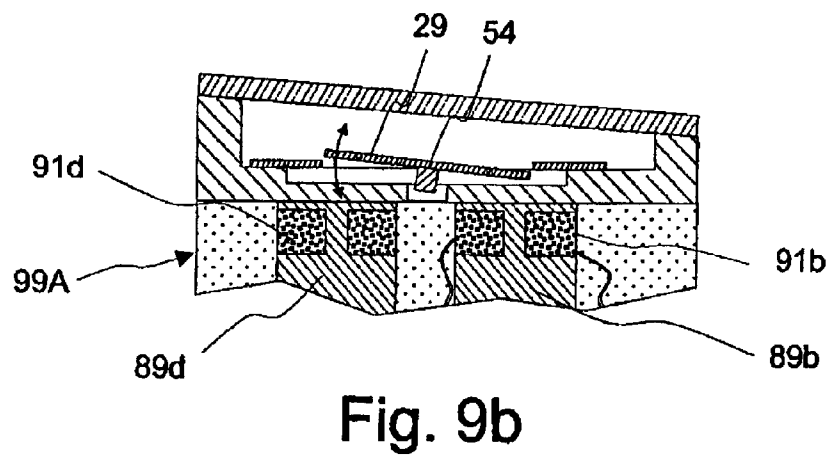
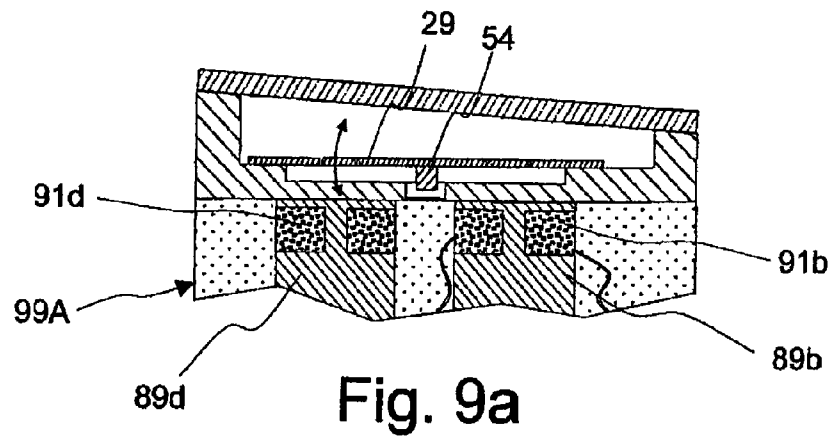
Fig. 9

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OPTICAL SWITCHING APPARATUS**RELATED APPLICATIONS**

This application is a continuation of U.S. patent application Ser. No. 09/310,285 filed on May 12, 1999, now issued as U.S. Pat. No. 6,430,332, which claims the benefit of U.S. Provisional Application No. 60/088,239 filed Jun. 5, 1998.

FIELD OF INVENTION

This invention relates generally to optical switching and more particularly to non-electrical switching of laser communication signals.

BACKGROUND OF THE INVENTION

In recent years optical fibers have come into wide spread use in a wide variety of applications in which optical signals are transmitted along such fibers and are switched from one fiber to another by means of an optical switch. Conventional optical switches generally include fiber positioning means, alignment signal emitter means and interconnected computer control means. A fiber positioning means is provided near the end of each fiber to selectively point the end of a given fiber in one fiber group toward the end of a given fiber in another fiber group for switched optical transmission therebetween. An alignment signal emitter means is provided near an end of and in predetermined spaced relationship to the end of each fiber to emit an alignment signal for receipt and use in controlling the fiber positioning means when aligning the ends of selected fibers in the fiber groups for switched optical transmission therebetween, for example as shown in U.S. Pat. Nos. 4,512,036 and 5,177,348. This approach requires considerable complexity and duplication of alignment means for each alignable fiber. It would be very desirable to reduce this complexity and duplication and to increase speed of switching, reliability, as well as to reduce cost in implementation.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an optical switch that overcomes the limitations of the above noted prior art. Another object of the inventions is to provide an optical switching unit which is relatively low in cost, has high speed and is reliable in operation. Briefly in accordance of the invention, an improved optical light transmission switch employs a microelectromechanical (hereinafter MEM) movable mirror assembly with associated electromagnet coils mounted in a package and preferably including control LED's with both drive and LED signals being supplied through a wiring harness. The following described preferred embodiments relate to a hermetic package using inorganic materials in order to provide extended life, however, units can be made which include organic materials for other shorter life applications.

The package comprises an LED lead frame of suitable material such as ceramic, which mounts LED's used by the control system to aim the movable mirror as well as circuitry to electrically connect the LED's to their package terminations. As will be discussed below, the LED's provide signals for controlling the position of the movable mirror so that any two mirrors in an array can be positioned to reflect a light beam precisely at each other so that the light beam is focused entirely on the reflective surface of the mirrors and in that way no energy of the beam is lost in the reflection process

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of the switched connection. The LED's are die and wire bonded to the lead frame using conventional techniques. The LED's are located so that lines drawn through diagonal pairs would pass through a selected location on the lead frame which is referenced the movable mirror. A mirror assembly, described below, is attached to the lead frame so that the center of the mirror portion coincides with the selected location on the lead frame in order to accurately locate the mirror relative to one another for proper control of mirror movement. The mirror assembly and lead frame are mounted in a header of suitable material, such as ceramic which, along with driving means and a wiring harness, are in turn mounted on a bracket. The package is received in a housing in which an optical fiber is received and in which another mirror is disposed in alignment with the fiber for reflecting an optical signal from the fiber to the movable mirror.

MEM micromirrors are presently used to build digital micromirror display (DMD) devices where the mirrors rotate about a single axis by an electrostatic drive. The mirror of the present invention provides two axes of motion and is preferably driven magnetically. The micromirror is preferably made from a single piece of crystal material such as silicon and has three portions connected by two sets of hinges. An inner portion forms the mirror. One of the hinge pairs, one hinge on each of two opposite sides of the mirror portion, ties the mirror portion and the middle gimbals portion, which surrounds the mirror portion. This allows the mirror portion to rotate about the gimbals portion, providing the first axis of rotation. The second set of hinges ties the gimbals portion and the frame portion, one hinge on each of two opposite sides on a line disposed, 90 degrees relative to a line drawn through the first set of hinges. This allows the gimbals portion, which carries the mirror, to rotate about the frame portion, providing a second axis of rotation.

Two pair magnets, one for each axis of rotation, are used to move the mirror portion and are mounted on one face of the single piece to form a mirror assembly. The first pair of magnets are attached by suitable means to the mirror portion of the mirror assembly, one on each of two opposite sides of a line, 90 degrees relative to a line through the mirror/gimbals portions set of hinges. When magnetically stimulated, the mirror portion rotates about the mirror/gimbals portions set of hinges, providing the first axis of motion. The second pair of magnets are suitably attached to the gimbals portion of the mirror assembly, one on each of two opposite sides of a line, 90 degrees relative to a line drawn through the gimbals/frame portions set of hinges. When magnetically stimulated, the mirror and gimbals portions rotate about the second set of axis, to providing the second axis of rotation.

According to a feature of the invention, an additional magnet is provided at each magnet location, with the poles in opposing relationship to each other and disposed on the opposite face of mirror assembly to balance the weight of the magnets relative to the hinge centerlines of the mirror assembly, eliminating undesirable oscillations under external shock or other conditions.

According to a modified embodiment, a single magnet can be utilized located in the center of the mirror portion, on the face opposing the surface serving as the mirror.

According to another feature of the invention, motion stops, disposed in a plane described by the two axes of rotation, are added to the mirror assembly at each hinge location to limit motion and thereby prevent failure of the hinge. Tabs are preferably formed in the plane described by the two axes of rotation, extending from the mirror portion

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to the gimbals portion and from the gimbals portion to the frame portion, to prevent rotation during initial manufacture. Sometime prior to final assembly, laser or other suitable cutting means severs the tabs, preferably perpendicular to each respective axis of the hinges, to allow free rotation.

In order to obtain extended operation without degradation, the mirror assembly is preferably hermetically assembled into a cavity in the package to lock out moisture and allow the provision of a benign atmosphere for micro-mirror operation. The cavity can be filled with selected gases to provide improved heat transfer and, if desired, exclude oxygen or other gases that would adversely affect the micromirror over time. The hermetic package comprises the header in which the cavity is formed and which includes sealed pins for electrical LED connection pins. A peripheral seat surface on the header extending around the cavity is coated with indium or suitable non-organic seal materials, for later attachment of a window over the cavity. The use of indium allows the seal to be made at room temperature to avoid seal temperature induced stresses and window distortions. Indium or other non-organic attach materials are used exclusively to assembly all items within the body cavity of the hermetic package, avoiding any unwanted long term organic out gassing or other similar problems.

According to another feature, the window is tilted at a slight angle, such as 6 degrees, to deflect unwanted stray light away from the desired optical path.

The lead frame assembly described above, containing LED's and the mirror assembly, is placed in and attached to the body on a platform within the cavity. The tabs preventing rotation of the mirror and gimbals portions during assembly may now be released as described above. The body cavity is sealed with a glass window that preferably has been treated with anti-reflective coatings.

An air coil drive assembly is used and preferably employs a push and pull arrangement for driving the mirror magnets to rotate the mirror portion to the desired orientation in its two axes. Four air coil assemblies, comprising copper wire coiled on a bobbin, are attached to a mounting bracket, trapping a flex circuit harness and are aligned with the mirror assembly. The air coil leads are soldered to the flex circuit harness to allow system electrical control of the air coils and their push pull arrangement to drive the mirror assembly. The air coil bobbins are made of aluminum or other eddy current generating material, and sufficient amounts of aluminum are provided at the top and bottom of the bobbins to allow eddy current dampening of the movable portions of the mirror assembly, to prevent unwanted oscillations. In order to prevent overheating and loss of mirror position control, the air coil bobbins are made of high heat transfer material, such as aluminum, and the bobbins are massive relative to the air coils. The mounting bracket is massive relative to the bobbins and is also made of a high heat transfer material, such as aluminum. The bracket is in intimate contact with the optical unit housing, which in turn is in intimate contact with the ultimate heat sinking of the customers system.

According to yet another feature, the air coil bobbins trap the flex circuit harness to the bracket when the air coil bobbins are attached to the bracket to facilitate later location and assembly of the flex circuit to the bracket. The LED pins of the header assembly are soldered to the appropriate pads on the flex circuit harness. The micromirror can fully be tested at this point. The header assembly is then rotated and aligned with the mounting bracket and joined by fixing the header assembly to the mounting bracket. The open area

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around the air coils is then potted with heat conductive material to ensure optimum assembly rigidity and improved heat transfer.

Other objects and advantages of the present invention will be apparent from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and further advantages thereof, reference is now made to the following detailed description of the preferred embodiments taken in conjunction with the drawings in which:

FIG. 1 is a schematic view of an optical switching station showing two optical switching units;

FIG. 2 is a schematic view of one of the optical switching units shown in FIG. 1;

FIG. 3 is a plan view of a mirror assembly used in the FIG. 2 switch unit;

FIG. 3a is a cross sectional view taken on line A—A of FIG. 3;

FIG. 3b is a view similar to FIG. 3a but showing rotation of the mirror portion of the mirror assembly;

FIG. 3c is a cross sectional view taken on line B—B of FIG. 1;

FIG. 3d is a view similar to FIG. 3c but showing rotations of the gimbals portion of the mirror assembly;

FIG. 4 is an enlarged cross sectional plan view taken on line E—E of 3a showing a hinge and an in-plane motion stop;

FIG. 5 is an enlarged, broken away portion of FIG. 4 showing a portion of the in-plane stop;

FIG. 6 is a cross sectional plan view taken on line E—E of FIG. 3a, showing a hinge with an optional lock down tab to stop rotation used during manufacture;

FIG. 6a is a view similar to FIG. 6 showing the lock down tab severed to allow rotation;

FIG. 7 is a top plan view of an optical switch package made in accordance with the invention;

FIG. 7a is a cross sectional view taken on line C—C of FIG. 7;

FIG. 7b is a view similar to FIG. 7 showing rotation of the mirror portion of the mirror assembly;

FIG. 7c is a cross sectional view taken on line D—D of FIG. 7;

FIG. 7d is a view similar to FIG. 7c but showing rotation of the gimbals portion of the mirror assembly;

FIG. 8 is an exploded view of a cross sectional, broken away portion of the bottom wall of the housing of an optical switching unit package and the mounting bracket;

FIG. 9 is a top plan view of a modified embodiment of an optical switch unit with certain parts removed for purposes of illustration;

FIG. 9a is a cross sectional view of the top portion of an optical switch unit taken on line F—F of FIG. 9; and

FIG. 9b is a view similar to FIG. 9a but showing rotation of the mirror portion of the modified mirror assembly.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 shows the layout of a matrix optical switch station comprising a plurality of parallelly extending optical switch units 5 and 15, two being shown for purposes of illustration, but any number can be provided as desired. These switch units are mounted in a frame 3 such that they are aligned with optical switch mirror 11 fixedly mounted in housing 1.

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An end portion of fiber optics cable 17 is mounted in a selected fixed position within housing 15 and fiber optics cable 7 is similarly affixed into the housing of optical switch 5. A light signal 13 is transmitted in cable 17 and is directed by optical switch unit 15, by reflecting light signal 13 from optical switch mirror 11 to another selected optical switch unit, such as optical switch 5, which directs light signal 13 into cable 7.

A light beam controlled by a single movable mirror will enter various target positions with an angle of incidence that varies with the target position of the beam. The use of two movable mirrors in the system allows a beam of light emitted on a longitudinal axis to be directed at any angle by the first movable mirror and exit the second movable mirror on a defined longitudinal axis that is invariant with changes in the incident angle of the beam. By maintaining a defined axis for the light beam, the use of two movable mirrors acts to simplify any lens used for an optical switch.

The light signal is optimized to minimize transmission losses by the optical units. As seen in FIG. 2, light beam 13 carried by optical cable 17 is reflected by a fixed mirror 25 mounted within optical switch 15 to a moveable mirror 29, shown in a solid line in its middle or neutral unpowered position. Mirror 29 is moveable between two opposite extremes, 29', 29'', with light beam 13 correspondingly reflected to 13', 13'', respectively.

The first movable mirror 29 selects the target position for creating an optical path. Movable mirror 29 can select any one of a plurality of optical switch units to create an optical connection by directing the light beam 13 to the movable mirror on the second unit. Light beam 13 when it is targeted on the second movable mirror is again reflected at an angle that is based on the incident angle of the beam. By operating the second movable mirror the incident angle of the beam can be changed such that the light is reflected on the longitudinal axis of the second optical switch unit.

LED's mounted in an array adjacent a first movable mirror 29, as disclosed below, provide radiation which is detected by detector 16. Radiation from the LED's in the array associated with the first movable mirror is received in a radiation guide of another, selected fiber and individually measured by control 100 (FIG. 7a). The position of the associated movable mirror of the selected fiber is adjusted until radiation received from each LED from the first mirror is substantially equal, as described in relation to moving fiber ends in U.S. Pat. No. 5,177,348, supra.

Although the movement of the mirror shown in FIG. 2 illustrates movement in one plane, mirror movement in a second plane is also included in the operation of the switch and will be described below.

Mirror assembly 41, FIG. 3, is preferably formed from one piece of crystal material such as silicon, etched to provide an outer frame portion 43 forming an opening in which an intermediate annular gimbals portion 45 is attached at opposing hinge locations 55 along first axis 31. An inner, centrally disposed mirror portion 47, having a mirror 29 centrally located thereon, is attached to gimbals portion 45 at hinge portions 55 on a second axis 35, 90 degrees from the first axis. Mirror 29 is suitably polished on its upper surface to provide specular surface and, preferably, is similarly polished on its lower surface as well, in order to prevent stresses in the material which could otherwise cause a certain warpage due to the thinness of the sheet material, e.g., on the order of 100 microns.

A first pair of permanent magnets 53 is mounted on gimbals portion 45 along the second axis and a second pair of permanent magnets 53 is mounted on extensions 51,

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which extend outwardly from mirror portion 47 along the first axis. In order to symmetrically distribute mass about the two axes of rotation to thereby prevent oscillation under shock and vibration, each permanent magnet 53 preferably comprises a set of an upper magnet 53a mounted on the top surface of the mirror assembly 41 using conventional attachment techniques such as indium bonding, and an aligned lower magnet 53b similarly attached to the lower surface of the mirror assembly as shown in FIGS. 3a-3d. The magnets of each set are arranged serially such as the north/south pole arrangement indicated in FIG. 3c. There are several possible arrangements of the four sets of magnets which may be used, such as all like poles up, or two sets of like poles up, two sets of like poles down, or three sets of like poles up, one set of like pole down, depending upon magnetic characteristics desired.

By mounting gimbals portion 45 to frame portion 43 by means of hinges 55, motion of the gimbals portion 45 about the first axis 31 is provided and by mounting mirror portion 47 to gimbals portion 45 via hinges 55, motion of the mirror portion relative to the gimbals portion is obtained about the second axis 35, thereby allowing independent, selected movement of the mirror portion 47 along two different axes.

The middle or neutral position of mirror assembly 41 is shown in FIG. 3a, which is a section taken through the assembly along line A—A of FIG. 3. Rotation of mirror portion 47 about axis 35 independent of gimbals portion 45 and/or frame portion 43 is shown in FIG. 3b as indicated by the arrow. FIG. 3c shows the middle position of the mirror assembly 41, similar to that shown in FIG. 3a, but taken along line B—B of FIG. 3. Rotation off the gimbals portion 45 and mirror portion 47 about axis 31 independent of frame portion 43 is shown in FIG. 3d as indicated by the arrow. The above independent rotation of mirror 29 of mirror portion 47 about the two axes allows direction of light beam 13 as needed by the optical switch units.

In order to protect hinges 55 from in-plane shock during handling and shipping, stops 57 are provided according to an optional feature of the invention as best shown in FIGS. 4 and 5, which are enlarged sectional views taken on line E—E of FIG. 3a. At this point it should be noted that the mirror assembly is on the order of 100 microns thick, whereas hinge 55 is on the order of 10 microns wide, thereby providing robust strength in directions normal to the surface of the assembly. In order to provide protection against excess in-plane motion 90 degrees to the axis of the hinge, i.e., axis 31, cooperating surfaces 61 on gimbals portion 45 and 63 on frame portion 43 are formed on either side of each hinge 55 and extend generally parallel to axis 31. Surfaces 61 and 63 are spaced apart a selected distance such as 10 microns by way of example. In order to provide less in-plane motion, projection 65, extending from surface 63 towards surface 61, is formed to any selected distance such as 5 microns. It will be understood that such projection could be provided on surface 61 instead of 63 if desired. Similar stops are provided on the mirror and gimbals portions to provide protection against in-plane motion of hinges 55 relative to axis 35.

According to another optional feature of the invention, lock down tabs associated with each hinge are provided. As seen in FIG. 6, an example showing one such hinge 55, bridge portion 67 extends from gimbals portion 45 to frame portion 43 and locks the two portions together isolating hinge 55 from all normal manufacturing stresses. At the appropriate manufacturing step, the bridge portion 67 is cut providing gap 69 as shown in FIG. 6a, which allows normal rotation of gimbals portion 45 relative to frame portion 43

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about the hinge **55**. This provides suitable stress protection for all hinges and significantly improves manufacturing yields.

With reference to FIG. 3, extensions **51** are preferably provided with laterally extending tabs **51a** which can be used to clamp down the mirror portion during assembly to thereby provide additional stress protection.

The movable mirror assembly **41** is received in a cavity **81a** of a header **81** which forms part of the mirror assembly package shown in FIGS. 7-7d. Header **81** is formed of any suitable material, such as ceramic in the case of a hermetic package and plastic where hermeticity is not required, and has a circumferentially extending shelf **81b** formed within cavity **81a** on which frame portion **43** of mirror assembly **41** is received. Bottom wall **81c** is spaced from shelf **81b** to provide clearance for movement of gimbals portion **45** and mirror portion **47**. Recesses **81d** are formed in bottom wall **81c** aligned with each set of magnets **53** to provide motion clearance for lower magnets **53b**. The size of the opening of recesses **81d** is maintained as small as possible, allowing suitable motion of the magnets, to facilitate making wall **81e** as thin as practicable, for example 125 microns.

The magnet drive for the magnets comprise four air coils **89** (two shown in FIGS. 7c-7d) each wound on a bobbin in turn mounted on mounting bracket **85** and aligned with respective recesses **81d** and magnets **53**. The bobbin and bracket are made of suitable material for good heat transfer, magnetic dampening, and strength such as aluminum. The air coils are wound using high electrical conductivity materials such as copper. The bobbin has an air coil disposed proximate to top end **89a** of bobbin **89** such that the air coil is as close to magnets **53** as possible, for example, 200 microns, to provide full mirror rotation using minimum power.

An electrical wiring harness **87** is provided for required electrical connections to the micromirror assembly package **99** and comprises an elongated flex circuit **87** mounting a connector **95** at one end thereof for connection to a control system (indicated at **100**, FIG. 7a). An opening **87b** is formed at an opposite end which receives therein bobbins **89**. Coil leads **97** are attached to appropriate traces on the flex circuit as shown in 7c-7d. A plurality of diode pins **79** are mounted in bores provided in shelf **81b** and extend above and below the shelf. The upper portion of the diode pins are connected by leads **77** to respective conductive pads **75a-75h** (see FIG. 7) and on the lower end are connected to respective traces on electrical harness **87**. LED's **71a-71d** are assembled to board **75** in according to conventional semiconductor techniques and are powered by the traces on the harness discussed above. The LED's **71a-71d** are positioned so that they can be used to direct the light beam **13** using the optic unit's sensing control system **100**. The control system can be similar to that described in U.S. Pat. No. 5,177,348, as discussed above.

Once the electrical connections are made to the diode pins **79**, window **83** is attached to the open side of header **81**, closing cavity **81a**. The closing of cavity **81a** can be made to be a hermetic seal by using known techniques such as employing indium as the window seal material and glass sealing or the like sealing of the diode pins **79** to the header **81**. If desired, a protective atmosphere such as nitrogen can be trapped within the cavity. The window is of suitable material to allow transmission of light signal **13** with minimum losses and is preferably tilted approximately 6 degrees relative to the plane in which mirror assembly lies, to deflect unwanted stray light. In this respect, the spacing between

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gimbals portion **45** and mirror portion **47** is maintained sufficiently large to avoid unwanted stray light.

After the electrical connections are made between diode pins **79** and harness **87** completing all electrical connections, header **81** with all of its internal components described above, are aligned with mounting bracket **85** and its components and potted in place with thermally conductive, strong potting material **93** to complete the micromirror assembly package **99**.

With particular reference to FIG. 8, micromirror assembly package **99** is precisely mounted and orientated in optical switch unit **15** utilizing cooperating registration surfaces of mounting bracket **85** and a portion of wall **16** of switch unit **15**. First opposing tapered surfaces **107** and **105** forming a somewhat convex configuration on mounting bracket **85** cooperate with respective second opposing tapered surfaces **103** and **101**, forming a somewhat concave, or cradle configuration, respectively, on bottom wall **16** of the switch unit. Mounting bolt **113** is received through bore **111** in bracket **85** and threaded bore **16a** in the cradle in bottom wall **16** to secure micro mirror assembly package **99** within optical switch unit **15**. The cooperating opposed surfaces provide a precise registration in two planes while bolt **113** and its corresponding bore **111** in bracket **85** and threaded bore **16a** in wall **16** provides registration in a third plane.

An alternate embodiment is shown in FIG. 9 in which a single permanent magnet **54** is centrally located on the lower side of the mirror portion **47**. Air coils **89a-89d** are shown located in the same positions as in the FIGS. 3-7 embodiment and can be independently excited so that the interaction of the magnetic field of the permanent magnet and the coils cooperate to produce the appropriate magnetic field to cause movement of the mirror portion along each axis **31** and **35**, as desired. Although four air coils are shown, if desired, three air coils could be used to produce the desired magnetic field.

Although the invention has been described with regards to specific preferred embodiments thereof, variations and modifications will become apparent to those skilled in the art. For example, magnet and air coil locations other than those described above can be employed as long as appropriate currents can be applied by means of control **100** to the air coils to move the gimbaled mirror to a desired orientation. In this respect, with reference to the four coil arrangement shown, a push-pull drive in control **100** is preferred. Further, although permanent magnets are shown attached to the movable mirror assembly, it will be appreciated that, if desired, magnetic material could be added to the assembly instead of the permanent magnets and polarized perpendicular to the mirror surface. It is therefore the intention that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.

What is claimed is:

1. An optical beam switching system for transmitting an optical beam from at least one source to at least one of a plurality of optical receptors comprising:
 - at least one source of an optical beam;
 - at least one first beam directing device mounted across a first area of free space from the source;
 - at least one second beam directing device mounted across a second area of free space from the first beam directing device;
 - a plurality of optical receptors;
 - a control operative for at least one of 1) positioning a first beam directing device to direct the optical beam from at least one source to a second beam directing device,

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and 2) positioning said second beam directing device to direct the optical beam from said second beam directing device to a selected one of said plurality of optical receptors; and

at least one data gathering and transmission element to provide an indication regarding the current orientation of the controlled beam directing device or the current location of the optical beam to the control for adjusting at least one of the beam directing devices.

2. An optical beam switching system according to claim 1, wherein at least one data gathering and transmission element is disposed adjacent to at least one of the beam directing devices.

3. An optical beam switching system according to claim 1, wherein at least one data gathering and transmission element is disposed adjacent to at least one of the optical receptors.

4. An optical beam switching system according to claim 1, wherein the system also includes at least one optical lens for focusing the optical beam received from at least one source and transmitting such beam to a first beam directing device.

5. An optical beam switching system according to claim 1, wherein the system also includes at least one optical lens for focusing the optical beam received from a second beam directing device and transmitting such beam to an optical receptor.

6. An optical beam switching system according to any of claims 1, 4 and 5, wherein at least one of said beam directing devices is a movable mirror.

7. An optical beam switching system according to claim 6, wherein the movable mirror is movable about at least one axis of rotation.

8. An optical beam switching system according to claim 6, wherein the movable mirror is movable about at least two axes of rotation.

9. An optical beam switching system according to claim 8, wherein the two axes of rotation are disposed ninety degrees relative to one another.

10. An optical beam switching system according to any of claims 1, 4 and 5, wherein at least one first beam directing device is mounted in an optical receiving relationship with at least one source.

11. An optical beam switching system according to any of claims 1, 4 and 5, wherein at least one optical receptor is mounted in an optical receiving relationship with at least one second beam directing device.

12. An optical beam switching system according to any of claims 1, 4 and 5, wherein at least one optical receptor includes an end of an optical fiber having a longitudinal axis and the position of at least one second beam directing device is adjustable to direct an optical beam along a path coincident with the longitudinal axis of the optical fiber.

13. An optical beam switching system according to any of claims 1, 4 and 5, further comprising a stationary mirror for folding the path of the optical beam.

14. An optical beam switching system according to any of claims 4 and 5, wherein at least one focusing lens and at least one first beam directing device are mounted in a housing.

15. An optical beam switching system according to any of claims 4 and 5, wherein at least one focusing lens and at least one second beam directing device are mounted in a housing.

16. An optical beam switching system according to any of claims 1, 4 and 5, wherein there are multiple sources.

17. An optical beam switching system according to claim 16, wherein the multiple sources are mounted in a planar array.

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18. An optical beam switching system according to any of claims 1, 4 and 5, wherein there are multiple first beam directing devices.

19. An optical beam switching system according to claim 18, wherein the multiple first beam directing devices are mounted in a planar array.

20. An optical beam switching system according to any of claims 1, 4 and 5, wherein there are multiple second beam directing devices.

21. An optical beam switching system according to claim 20, wherein the multiple second beam directing devices are mounted in a planar array.

22. An optical beam switching system according to any of claims 1, 4 and 5, wherein there are multiple optical receptors.

23. An optical beam switching system according to claim 22, wherein the multiple optical receptors are mounted in a planar array.

24. An optical beam switching system according to any of claims 1, 4 and 5, wherein said first area of free space is a three dimensional space.

25. An optical beam switching system according to any of claims 1, 4 and 5, wherein said second area of free space is a three dimensional space.

26. An optical beam switching system according to any of claims 1, 4 and 5, wherein at least one first beam directing device and at least one second beam directing device are separated by an area of free space, said free space being a three dimensional space.

27. An optical beam switching system for transmitting an optical beam from at least one source to at least one of a plurality of optical receptors comprising:

at least one source of an optical beam;

at least one first beam directing device mounted across a first area of free space from the source;

at least one additional beam directing device;

at least one second beam directing device mounted across a second area of free space from the first beam directing device;

a plurality of optical receptors;

a control operative for at least one of 1) positioning a first beam directing device to direct the optical beam from at least one source to at least one additional beam directing device, 2) positioning at least one additional beam directing device to direct the optical beam from said additional beam directing device to a second beam directing device, and 3) positioning a second beam directing device to direct the optical beam from said second beam directing device to a selected one of said plurality of optical receptors; and

at least one data gathering and transmission element to provide an indication regarding the current orientation of the controlled beam directing device or the current location of the optical beam to the control for adjusting at least one of the beam directing devices.

28. An optical beam switching system according to claim 27, wherein at least one data gathering and transmission element is disposed adjacent to at least one of the beam directing devices.

29. An optical beam switching system according to claim 27, wherein at least one data gathering and transmission element is disposed adjacent to at least one of the optical receptors.

30. An optical beam switching system according to claim 27, wherein the system also includes at least one optical lens

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for focusing the optical beam received from at least one source and transmitting such beam to a first beam directing device.

31. An optical beam switching system according to claim 27, wherein the system also includes at least one optical lens for focusing the optical beam received from a second beam directing device and transmitting such beam to an optical receptor.

32. An optical beam switching system according to any of claims 27, 30 and 31, wherein at least one of said beam directing devices is a movable mirror.

33. An optical beam switching system according to claim 32, wherein the movable mirror is movable about at least one axis of rotation.

34. An optical beam switching system according to claim 32, wherein the movable mirror is movable about at least two axes of rotation.

35. An optical beam switching system according to claim 34, wherein the two axes of rotation are disposed ninety degrees relative to one another.

36. An optical beam switching system according to any of claims 27, 30 and 31, wherein at least one first beam directing device is mounted in an optical receiving relationship with at least one source.

37. An optical beam switching system according to any of claims 27, 30 and 31, wherein at least one optical receptor is mounted in an optical receiving relationship with at least one second beam directing device.

38. An optical beam switching system according to any of claims 27, 30 and 31, wherein at least one optical receptor includes an end of an optical fiber having a longitudinal axis and the position of at least one second beam directing device is adjustable to direct an optical beam along a path coincident with the longitudinal axis of the optical fiber.

39. An optical beam switching system according to any of claims 27, 30 and 31, further comprising a stationary mirror for folding the path of the optical beam.

40. An optical beam switching system according to any of claims 30 and 31, wherein at least one focusing lens and at least one first beam directing device are mounted in a housing.

41. An optical beam switching system according to any of claims 30 and 31, wherein at least one focusing lens and at least one second beam directing device are mounted in a housing.

42. An optical beam switching system according to any of claims 27, 30 and 31, wherein there are multiple sources.

43. An optical beam switching system according to claim 42, wherein the multiple sources are mounted in a planar array.

44. An optical beam switching system according to any of claims 27, 30 and 31, wherein there are multiple first beam directing devices.

45. An optical beam switching system according to claim 44, wherein the multiple first beam directing devices are mounted in a planar array.

46. An optical beam switching system according to any of claims 27, 30 and 31, wherein there are multiple second beam directing devices.

47. An optical beam switching system according to claim 46, wherein the multiple second beam directing devices are mounted in a planar array.

48. An optical beam switching system according to any of claims 27, 30 and 31, wherein there are multiple optical receptors.

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49. An optical beam switching system according to claim 48, wherein the multiple optical receptors are mounted in a planar array.

50. An optical beam switching system according to any of claims 27, 29 and 31, wherein at least one first beam directing device is separated from at least one source by an area of free space, said area of free space being a three dimensional space.

51. An optical beam switching system according to any of claims 27, 29 and 31, wherein at least one optical receptor and at least one second beam directing device are separated by an area of free space, said area of free space being a three dimensional space.

52. An optical beam switching system according to any of claims 27, 29 and 31, wherein at least one first beam directing device and at least one second beam directing device are separated by an area of free space, said free space being a three dimensional space.

53. An optical beam switching system for transmitting an optical beam from at least one source to at least one of a plurality of optical receptors comprising:

at least one source of an optical beam;

at least one first beam directing device mounted across a first area of free space from the source;

a plurality of optical receptors mounted across a second area of free space from the first beam directing device;

a control so that a first beam directing device will be positioned to direct the optical beam from at least one source to a selected one of said plurality of optical receptors; and

at least one data gathering and transmission element to provide an indication regarding the current orientation of the controlled beam directing device or the current location of the optical beam to the control for adjusting at least one of the beam directing devices.

54. An optical beam switching system according to claim 53, wherein at least one data gathering and transmission element is disposed adjacent to at least one of the beam directing devices.

55. An optical beam switching system according to claim 53, wherein at least one data gathering and transmission element is disposed adjacent to at least one of the optical receptors.

56. An optical beam switching system according to claim 53, wherein the system also includes at least one optical lens for focusing the optical beam received from at least one source and transmitting such beam to a first beam directing device.

57. An optical beam switching system according to claim 53, wherein the system also includes at least one optical lens for focusing the optical beam received from a beam directing device and transmitting such beam to an optical receptor.

58. An optical beam switching system according to any of claims 53, 56 and 57, wherein at least one of said beam directing devices is a movable mirror.

59. An optical beam switching system according to claim 58, wherein the movable mirror is movable about at least one axis of rotation.

60. An optical beam switching system according to claim 58, wherein the movable mirror is movable about at least two axes of rotation.

61. An optical beam switching system according to claim 60, wherein the two axes of rotation are disposed ninety degrees relative to one another.

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62. An optical beam switching system according to any of claims 53, 56 and 57, wherein at least one first beam directing device is mounted in an optical receiving relationship with at least one source.

63. An optical beam switching system according to any of claims 53, 56 and 57, wherein at least one optical receptor is mounted in an optical receiving relationship with at least one beam directing device.

64. An optical beam switching system according to any of claims 53, 56 and 57, wherein at least one optical receptor includes an end of an optical fiber having a longitudinal axis and the position of at least one beam directing device is adjustable to direct an optical beam along a path coincident with the longitudinal axis of the optical fiber.

65. An optical beam switching system according to any of claims 53, 56 and 57, further comprising a stationary mirror for folding the path of the optical beam.

66. An optical beam switching system according to any of claims 56 and 57, wherein at least one focusing lens and at least one first beam directing device are mounted in a housing.

67. An optical beam switching system according to any of claims 53, 56 and 57, wherein there are multiple sources.

68. An optical beam switching system according to claim 67, wherein the multiple sources are mounted in a planar array.

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69. An optical beam switching system according to any of claims 53, 56 and 57, wherein there are multiple first beam directing devices.

70. An optical beam switching system according to claim 69, wherein the multiple first beam directing devices are mounted in a planar array.

71. An optical beam switching system according to any of claims 53, 56 and 57, wherein there are multiple optical receptors.

72. An optical beam switching system according to claim 71, wherein the multiple optical receptors are mounted in a planar array.

73. An optical beam switching system according to any of claims 53, 56 and 57, wherein at least one first beam directing device is separated from at least one source by an area of free space, said area of free space being a three dimensional space.

74. An optical beam switching system according to any of claims 53, 56 and 57, wherein at least one optical receptor and at least one beam directing device are separated by an area of free space, said area of free space being a three dimensional space.

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