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(54) Title: A THERMAL MICROACTUATOR FOR A SUSPENSION ARM OF A HARD DISK DRIVE AND A METHOD OF FABRICATING THE THERMAL MICROACTUATOR

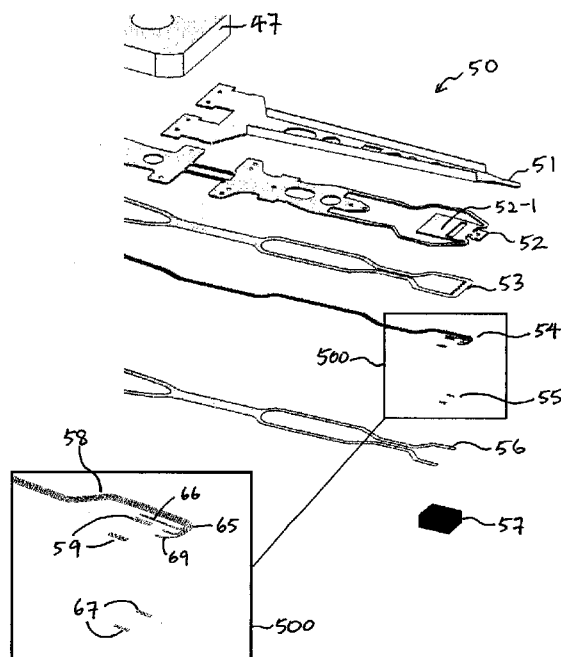


FIG. 5

(57) Abstract: A thermal microactuator for micropositioning a slider on a suspension arm of a hard disk drive, the slider being attached to a flexure, the flexure supporting a conducting layer under a cover layer, the thermal microactuator comprising at least one microactuating beam formed on the flexure under the cover layer. A method of fabricating a thermal microactuator for a suspension arm of a hard disk drive, the suspension arm comprising a slider attached to a flexure, the method comprising forming at least one microactuating beam on the flexure during fabrication of the suspension arm before attaching the slider to the flexure; and laying a cover layer over the at least one microactuating beam.



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A THERMAL MICROACTUATOR FOR A SUSPENSION ARM OF A HARD DISK DRIVE AND A METHOD OF FABRICATING THE THERMAL MICROACTUATOR

TECHNICAL FIELD

5 The application relates to a thermal microactuator for a suspension arm of a hard disk drive for precise positioning of read/write head elements on the suspension arm and a method of fabricating the thermal microactuator.

BACKGROUND

10 Head positioning of data tracks on hard disks is continually increasing in accuracy so as to increase data storage density of the hard disks by using a narrower track width/pitch. A conventional hard disk drive using a voice coil motor (VCM) typically has a semi-rigid actuator arm, a head gimbal assembly (HGA) attached to and mounted on the actuator arm, and a stack of disks carried by a spindle motor which spins the
15 disks. The HGA usually comprises a suspension arm and a slider with attachment of head element. The slider is commonly mounted on a gimbal of the suspension and the head elements are located on one edge (termed the trailing edge) of the slider. The VCM is used to control motion of the actuator arm and, in turn, to control the HGA to position the slider and its attachments of head elements over a desired recording track across the
20 surface of a disk, thereby to enable a head element to read data from or write data to the disk.

For example, as shown in FIG. 1 (prior art), a hard disk drive typically 1 includes a rotating disc 2 and a head suspension assembly 4 that supports a slider 5 with
25 attachments of magnetic head elements or a transducer 9 on a trailing surface of the slider body 5 for reading/writing of data from/to recording tracks 3 located on the disc 2. The disc 2 is carried by a spindle motor 6 which spins the disc 2. The head suspension

assembly 4 comprises a rigid actuator arm 7 and a flexible suspension arm 8 affixed to a tip end of the rigid actuator arm 7 using conventional mounting methods such as screw mounting or bonding. The suspension arm 8 as shown in FIG. 2 (prior art) typically comprises a load beam 10 and a flexure 11, which are overlapped partially and connected with each other by welding, gluing or other bonding methods. The load beam 10 serves to supply a supporting force to the flexure 11 and to tilt the slider 5 toward the surface of the disc 2, while the flexure 11 provides flexibility for the slider 5 in roll and pitch directions. Such a design ensures that the slider 5 is maintained at a stable altitude at a desired height above the surface of the disc 2. A flexible electrical trace (not shown), which transmits signals of the transducer 9 from/to a chip 12 within the disk drive 1, is attached to the surface of the flexure 11. The slider 5 is mounted on a tongue 14 (not shown in FIG. 2) of the flexure 11 using an adhesive material (such as epoxy). A dimple 13 formed on the load beam 10 is provided for physically engaging the tongue 14 in a generally vertical direction. When the disc 2 spins, the slider 5 with an aerodynamic pattern on its air bearing surface (ABS) will glide over moving air induced by the rotating disc 2 and maintain a uniform distance from the surface of the disc 2, thereby preventing transducer 9 from undesirably contacting disc 2.

The series of layers of a conventional head gimbal assembly (HGA) 40 shown in FIG. 4 (prior art), in an order of being laminated by an additive-type process, typically include a load beam 41, a flexure 42, an insulating layer 43, a conductive layer (electrical transmission lines) 44, a cover layer 45 and a transducer/slider 46 in an order of being laminated by an additive-type process. A partial view of an arm 47 for the HGA is also depicted. To begin with, the load beam 41 and the flexure 42 are two metal layers typically formed from a sheet of stainless steel. The metal layers 41, 42 may be shaped by known manufacturing techniques such as forming, stamping and etching into a desired shape and thickness. The two metals layers 41, 42 are then generally bonded

together with two or more welding points. The insulating layer 43 is typically made of photosensitive polyimide to insulate the adjacent metallic flexure 42 from the conductive layer 44. The insulating layer 43 is then laminated or patterned on the flexure 42 by lithography process. The conductive layer 44 may then be patterned on the insulating layer 43 for creating electrical transmission lines by additive deposit processes such as plating or sputtering. The cover layer 45 is typically made of a polyimide material, which is subsequently laminated on the conductive layer 44 to protect the surface of the conductive layer 44. The transducer slider 46 is finally mounted on the flexure tongue 42 with adhesive such as epoxy. Signals of the transducer slider 46 are then permitted to be transmitted to and from the patterned conductive layer 44 by providing wiring using gold ball bonding, wire bonding, soldering, ultrasonic joining, or the like.

However, conventional VCM servo control cannot provide a higher level of track accuracy, due to inherent mechanical resonance limits of the VCM, actuator arm and suspension arm. Therefore, dual stage actuation, which uses the VCM as a coarse low bandwidth actuator moving a suspension arm and a thermal microactuator as a fine high bandwidth actuator moving a read/write head of a slider over a track, has been proposed.

For example, as shown in FIG. 3 (prior art), in a dual stage servo system for a hard disc drive, two actuators are used for head positioning. A suspension arm 31 supports a flexure 32 and a voice coil motor (not shown) runs to move a first actuator arm (not shown) relative to a disc 35 to coarsely position read/write (R/W) head elements or transducers 36 on the flexure 32. A thermal microactuator 38 that works as a second actuator to drive a slider 37 is provided to achieve fine positioning of the R/W head elements or transducers 36.

Such a thermal microactuator must be capable of quickly and accurately positioning the read/write head elements within a smaller track pitch and hence increase tracks per inch (TPI) for a hard disk drive. The thermal microactuator should also be light weight to minimize detrimental effects on resonance characteristics of the suspension arm. Furthermore, it is necessary that the thermal microactuator has no significant influence on slider flying capabilities during operation. To be commercially viable, the thermal microactuator must also be reliable and capable of being efficiently manufactured at low cost. Such viability generally requires mass production fabrication techniques, which must be such as to ensure dimensional accuracy of the thermal microactuators measured in microns.

SUMMARY

A thermal microactuator for a suspension arm of a hard disk drive is provided, where fabrication of the thermal microactuator is integrated into current suspension-flexure fabrication processes to realize high process yield with cost savings by eliminating a post actuator assembly. The thermal microactuator is configured for dual-stage head positioning of hard disk drives. The thermal microactuator may be formed on a surface of a flexure tongue facing a slider body or facing away from the slider body. The thermal microactuator may be located on supporting arms of the flexure or at other locations of the flexure body.

According to a first exemplary aspect, there is provided a method of fabricating a thermal microactuator for a suspension arm of a hard disk drive, the suspension arm comprising a slider attached to a flexure, the method comprising forming at least one microactuating beam on the flexure during fabrication of the suspension arm before attaching the slider to the flexure, and laying a cover layer over the at least one microactuating beam.

Forming the at least one microactuating beam may comprise forming thermal elements on the flexure with spaces between successive thermal elements and forming expansion elements in the spaces between successive thermal elements.

- 5 Forming of the thermal elements and the expansion elements may be configured to provide a dual-material composite structure that bends laterally upon expansion of the expansion elements.

- Alternatively, forming of the thermal elements and the expansion elements is
10 configured to provide a dual-material composite structure that expands longitudinally upon expansion of the expansion elements.

- Forming the expansion elements may comprise filling the spaces between successive thermal elements with a material having a higher coefficient of thermal
15 expansion than the thermal elements.

- Forming the thermal elements may comprise laying a conductive material on a surface of the flexure, the conductive material forming the thermal elements on the surface of the flexure.

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 Forming the thermal elements may be performed simultaneously with forming electrical transmission lines on the flexure, the conductive material forming the electrical transmission lines and the thermal elements.

- 25 The conductive material may be laid in two steps, a first step forming the electrical transmission lines and heater elements of the thermal elements, and a second step completing formation of the thermal elements.

In an alternative embodiment of the method, forming the thermal elements may comprise forming slots on a surface of the flexure such that portions of the flexure between the slots form the thermal elements and the slots form the spaces between successive thermal elements for forming the expansion elements therein.

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The method may further comprise further comprising laying an insulating layer on the flexure before forming the at least one microactuating beam.

The method may also further comprise laying a conducting layer on the
10 insulating layer before laying the cover layer, the conducting layer being configured for heating the at least one microactuating beam.

Forming the at least one microactuating beam on the flexure may comprise forming the at least one microactuating beam on a surface of the flexure facing the slider.
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Alternatively, forming the at least one microactuating beam on the flexure may comprise forming the at least one microactuating beam on a surface of the flexure facing away from the slider.

20 Forming the at least one microactuating beam on the flexure may comprise forming a first microactuating beam on a first arm of the flexure connected to a flexure tongue for attaching the slider thereto. The method may further comprise forming a second microactuating beam on a second arm of the flexure connected to the flexure tongue.

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Forming the first and second microactuating beams may comprise forming the first and second microactuating beams on medial sides of the first and second arms of

the flexure.

Alternatively, forming the first and second microactuating beams may comprise forming the first and second microactuating beams on lateral sides of the first and
5 second arms of the flexure.

In a further alternative, forming the first and second microactuating beams may comprise forming the first and second microactuating beams on a same side of the first and second arms of the flexure.

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According to a second exemplary aspect, there is provided a method of fabricating a suspension arm for a hard disk drive comprising the method of fabricating the thermal microactuator as described above.

15 According to a third exemplary aspect, there is provided a method of fabricating a hard disk drive comprising the method of fabricating the suspension arm as described above.

According to a fourth exemplary aspect, there is provided a thermal microactuator
20 for micropositioning a slider on a suspension arm of a hard disk drive, the slider being attached to a flexure, the flexure supporting a conducting layer under a cover layer, the thermal microactuator comprising at least one microactuating beam formed on the flexure under the cover layer.

25 The at least one microactuating beam may comprise a dual-material composite structure comprising an alternated arrangement of thermal elements and expansion elements formed on the flexure under the cover layer.

The thermal elements and the expansion elements may be formed of different materials, the material forming the thermal elements having a higher thermal conductivity and a smaller co-efficient of thermal expansion than the material forming the expansion elements.

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The alternated arrangement of thermal elements and expansion elements may be configured to result in lateral bending of the at least one dual-material composite structure upon expansion of the expansion elements.

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The alternated arrangement of thermal elements and expansion elements may be configured to result in longitudinal extension of the at least one dual-material composite structure upon expansion of the expansion elements.

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The thermal elements may be integral with a layer of conductive material laid on the flexure. The at least one microactuating beam may be formed on the conducting layer and may project from a surface of the flexure.

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Alternatively, the thermal elements may be integral with the flexure. The expansion elements may be formed in slots formed on a surface of the flexure and wherein portions of the flexure between the slots form the thermal elements.

The at least one microactuating beam may be formed on a surface of the flexure facing the slider.

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Alternatively, the at least one microactuating beam may be formed on a surface of the flexure facing away from the slider.

The at least one microactuating beam may be configured to be heated by passing an electrical current through a metal line disposed on the flexure adjacent the at least one microactuating beam.

- 5 The at least one microactuating beam may be a first microactuating beam located on a first arm of the flexure connected to a flexure tongue, the slider being attached to the flexure tongue.

- The thermal microactuator may further comprise a second microactuating beam
10 located on a second arm of the flexure connected to the flexure tongue.

The first and second microactuating beams may be located on medial sides of the first and second arms of the flexure.

- 15 Alternatively, the first and second microactuating beams may be located on lateral sides of the first and second arms of the flexure.

- In a further alternative, the first and second microactuating beams may be located on a same side of the first and second arms of the flexure.
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The thermal microactuator may comprise hinges connecting the arms to the flexure tongue for allowing rotation of the flexure tongue relative to the flexure.

- The thermal microactuator may further comprise a third arm of the flexure
25 connected to the flexure tongue between the first arm and the second arm, the third arm being configured for heat dissipation.

Movement of the at least one microactuating beam may be controlled by selective application of electrical energy for heating the thermal elements.

5 The material forming the at least one microactuating beam may be a photosensitive synthetic resin.

Alternatively, the material forming the at least one microactuating beam may be a conductive metal.

10 In a fifth exemplary aspect, there is provided a suspension arm for a hard disk drive comprising the thermal microactuator described above.

The suspension arm may further comprise a load beam supporting the flexure.

15 The suspension arm may further comprise an insulating layer between the flexure and the conducting layer.

In a sixth exemplary aspect, there is provided a hard disk drive comprising the suspension arm described above.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 (prior art) is a schematic illustration of various components in a conventional hard disk drive;

25 FIG. 2 (prior art) is a schematic illustration of a magnified side view of a conventional head gimbal suspension;

FIG. 3 (prior art) is a schematic illustration of a structure of a conventional head

positioning system with a dual stage servo system for a hard disc drive;

FIG. 4 (prior art) is an exploded view of a series of layers of a conventional head gimbal assembly (HGA);

FIG. 5 is an exploded view showing an exemplary embodiment of an HGA with
5 an integrated flexure thermal microactuator;

FIG. 6 is a schematic illustration of a side view of an integrated flexure thermal microactuator where a microactuating beam is formed on a surface of flexure tongue;

FIG. 7(a) is a close-up view of a composite structured microactuating beam and a patterned conductive layer on a flexure on a surface of the flexure facing a slider body;

10 FIG. 7(b) is a close-up view of a composite structured microactuating beam and a patterned conductive layer on a flexure on a surface of the flexure facing away from a slider body;

FIG. 8 is an exploded view of another exemplary embodiment of an HGA with an integrated flexure thermal microactuator;

15 FIG. 9 is a schematic illustration of a side view of an integrated flexure thermal microactuator where a microactuating beam is provided on a surface of a flexure tongue facing a slider body;

FIG. 10 is a schematic illustration of a side view of an integrated flexure thermal microactuator where a microactuating beam is provided on a surface of a flexure facing
20 away from a slider body;

FIG. 11 is a top view of an integrated flexure thermal microactuator where microactuating beams are located at supporting arms of a flexure;

FIG. 12 is a schematic illustration of an exemplary example of a thermal microactuator comprising a laterally stacked, comb-like, dual-material composite
25 structured microactuating beam;

FIG. 13 is a schematic illustration of another exemplary example of a thermal microactuator comprising a laterally stacked, comb-like, dual-material composite

structured microactuating beam;

FIG. 14 is a top view of an embodiment of the integrated flexure thermal microactuator of FIG. 11, where two microactuating beams are located at exterior or lateral sides of supporting arms of the flexure;

5 FIG. 15 is a top view of another embodiment of the integrated flexure thermal microactuator of FIG. 11, where two microactuating beams are cast on a same side of two supporting arms of the flexure, the ends of the arms connecting with the tongue plate via hinges;

FIG. 16 is a top view of a further embodiment of the integrated flexure thermal microactuator of FIG. 11, where microactuating beams are located at either exterior or lateral sides of supporting arms of the flexure and one central supporting beam connected to the tongue plate is placed between the two supporting arms of the flexure;

FIG. 17 is a top view of an embodiment of an integrated flexure thermal microactuator comprising a single arm provided with a microactuating beam;

15 FIG. 18 is a top or bottom view of an embodiment of an integrated flexure thermal microactuator with microactuating beams located at exterior or lateral sides of a flexure frame;

FIG. 19 is a top or bottom view of an embodiment of an integrated flexure thermal microactuator with microactuating beams located at interior or medial sides of a flexure frame.

FIG. 20 is an alternative to the embodiment of FIG. 19 with a single material microactuating beam on each of the interior or medial sides of a flexure frame; and

FIG. 21 is an exemplary flowchart of a method of forming a thermal microactuator.

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DETAILED DESCRIPTION

With reference to FIGS. 5 to 21, exemplary embodiments of a thermal

microactuator for an HGA and a method 200 of fabricating the thermal microactuator will be described.

In a first embodiment of the HGA, there is provided an integrated flexure thermal microactuator 50 configured for dual-stage head positioning of hard disk drives as shown in FIG. 5 in an order of being laminated by an additive-type process or method 200, and in FIG. 6 in side view.

The HGA comprises two metal layers 51, 52, namely, the load beam 51 and the flexure 52, which are typically formed from a sheet of stainless steel. Although stainless steel is preferably used, other metal material such as aluminum, copper, titanium, bronze and alloys may also be used. The metal layers 51, 52 may be shaped by known manufacturing techniques such as forming, stamping and etching into a desired opening shape and thickness. Preferably, the flexure 52 has a thickness of about 20 to 25 micrometers. The two metal layers 51, 52 are generally bonded together with two or more welding points. An insulating layer 53 of photosensitive synthetic resins material such as polymeric structure based polyimide, polyethylene and acrylic is provided to insulate the adjacent metal layer 52 from the conductive layer 54. The insulating layer 53 is laminated or patterned on the flexure 52 by lithography process.

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The thermal microactuator 50 is positioned between the insulating layer 53 and a cover layer 56 (not shown in FIG. 6). The thermal microactuator 50 is formed on the surface of the flexure 52 facing the slider body 57 by a semi-additive process. A close-up 500 shows the thermal microactuator 50 comprising a dual-patterned conductive layer 54 on the insulating layer 53 to form electrical transmission lines 65 and pads 69, heaters 66 (not shown in FIG. 6) and a microactuating beam 68, 202 comprising thermal actuator comb-like "skeleton" structures 59. The first patterned thin metal layer 58 constituting

heater elements 66, electrical transmission lines 65 and pads 69 on the insulating layer 53 are formed by an additive process such as sputtering. The thin metal layer 58 has a thickness of 50-200nm. A next thicker conductive layer 54, which has a thickness of 15-20 micrometer, is laminated by the same additive deposit process such as plating to form
5 comb-like "skeleton" structures for thermal elements 59.

A layer 55 made of photosensitive synthetic resins material, such as polymeric structure based polyimide, polyethylene and acrylic, is laminated on the conductive layer 54 by a lithography process and squeezed to fill in the gaps or spaces between the
10 thermal actuator comb-like "skeleton" structures 59 to serve as expansion elements 67, thereby forming microactuating beams 68, 202 of a stacked, comb-like, dual-material composite structure disposed on and projecting from the flexure 52. The dual-material composite structured microactuating beam 68 thus comprises an alternated arrangement of thermal elements 59 and expansion elements 67 as shown, such that application of
15 heat from the thermal elements 59 to the expansion elements 67 results in movement of the dual-material composite structured microactuating beam 68 or micro-positioning of the slider 57.

A cover layer 56 of polyimide material is laminated on the conductive layer 54
20 and the thermal microactuator 50 to protect the surface of the conductive layer 54 and the thermal microactuator 50. The conductive layer 54 and the thermal microactuator 50 are on the flexure 52 under the cover layer 56. The cover layer 56 is thus laid over the microactuating beam 68, 204. A transducer slider 57 is mounted on the flexure tongue 52-1 via adhesive such as epoxy 61. Advantageously, the embodiment 50 provides a
25 thermal microactuator 50 which fabrication can be integrated into current suspension flexure processes.

A dimple 62 formed on the load beam 51 is provided for physically engaging the tongue 52-1 of the flexure 52 in a generally vertical direction. Signals on the transducer slider 57 are transmitted via a contact 64 on the transducer slider 57 connected with an electrical joint 63 to the electrical transmission lines 65 and pads 69 on the flexure 52.

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FIGS. 7(a) and (b) are closer views of the dual-material composite structured microactuating beam 68 and the patterned conductive layer (comprising electrical transmission lines 65 and pads 69) on the flexure 52. Various wiring techniques from the pads to external sources, such as wire bonding, ball bonding, soldering, ultrasonic joining, or the like technique, can be used. As shown in FIG. 7(a), the dual-material composite structured beam 68 and the patterned conductive layer may be on a surface 521 of the flexure 52 facing the slider 57 (not shown), or alternatively, as shown in FIG. 7(b), the dual-material composite structured microactuating beam 68 and the patterned conductive layer may be on a surface 522 of the flexure 52 facing away from the slider 57 (not shown).

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In another embodiment of an HGA as shown in FIG. 8 and FIG. 9 comprising a similar load beam 81 and flexure 82 as the HGA of FIG. 5, slots 89 that are spaced apart are instead formed or patterned on the top or bottom surface of the metal flexure 82 via an etching process. Portions 97 of the flexure 82 between the slots 89 thus form comb-like "skeleton" structures 97 on the flexure 82 to serve as thermal elements 97 that are integral with the flexure 82. The depth of the etched slots 89 is preferably about 15 to 20 micrometers. The load beam 81 and flexure 82 are generally bonded together with two or more welding points. Two plastic film layers 83, 85 made of photosensitive synthetic resins material such as polymeric structure based polyimide, polyethylene and acrylic are provided. The first plastic film layer 83 serves as an insulating layer 83 to insulate the adjacent metal layer from the conductive layer while the second plastic film layer 85 fills

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in the spaces formed by the slots 89 to serve as expansion elements 85 disposed in the slots 89. The alternating thermal elements 97 and expansion elements 85 thus form an integrated microactuating beam 88, 202 of a stacked, comb-like, dual-material composite structure that is integral with the flexure 82. The plastic film layers 83, 85 are laminated
5 or screen-printed and patterned on the flexure 82 by a lithography process. A conductive layer 84 is patterned on the plastic film layers 83, 85 to form electrical transmission lines 84 and thin metal wires constituting heater elements 84-1. The conductive layer 84 is preferably laminated by additive deposit process such as plating or sputtering.

10 A cover layer 86 made of photosensitive synthetic resins material, such as polymeric structure based polyimide, polyethylene and acrylic, is laminated on the conductive layer 84 by lithography process, that is, the conductive layer 84 is under the cover layer 86. The thermal microactuator 80 consisting of the laterally stacked comb-like composite structured microactuating beams 88 and heater elements 84-1 is thus
15 positioned under both the insulating layer 83 and the cover layer 86, 204. The thermal microactuator 80 is incorporated into the flexure tongue 82-1 from the top or bottom surface of the flexure tongue 82-1 by a semi-additive process.

A transducer slider 87 is mounted on the flexure tongue 82-1 via adhesive such
20 as epoxy 91. A dimple 92 formed on the load beam 81 is provided for physically engaging the tongue 82-1 of the flexure 82 in a generally vertical direction. Signals on the transducer slider 87 are transmitted via a contact 94 on the transducer slider 87 connected with an electrical joint 93 to the wires 84 on the flexure 82.

25 An alternative embodiment 100 similar to the thermal microactuator 80 of FIG. 9 is shown in FIG. 10. A flexure 102 engages a load beam 101 via a dimple 104. The thermal microactuator 100 is incorporated into the flexure 102 by etching slots 109 on a

surface 103 of the flexure 102 facing away from the slider body 107 to form spaced-apart thermal elements 110 integral with the flexure 102. The slots or spaces 109 are subsequently filled with a photosensitive synthetic resin material such as polymeric structure based polyimide, polyethylene and acrylic to form expansion elements 112, so
5 that the thermal elements 110 and expansion elements 112 together form a composite structured microactuating beam 108.

FIG. 11 shows an exploded assembly view of the slider 11 and the flexure 143 with a thermal microactuator 140 embedded in the tongue 138 of the flexure 143. The
10 thermal microactuator 140 includes a pair of supporting arms 146 and 147 with a length of about 300 to 500 micrometers to load the tongue plate 138 at one end of each arm 146, 147 and to be connected to the flexure 143 at the other end of each arm 146, 147. The tongue 138 has a small protrusion 145 (not shown) configured for engaging a dimple 13 provided on a load beam of the suspension arm. Each supporting arm 146 or 147 can
15 be configured to be encapsulated on either one or both sides with polymeric material to form laterally stacked, comb-like, dual-material composite structured microactuating beams 142. The composite structured microactuating beams 142 comprise thermal elements with metal heaters deposited on top and expansion elements between successive thermal elements. When a current is applied to the metal line of one arm 146,
20 the generated heat will cause the other arm 147 to bend in a lateral opposite direction and in turn, the slider 141 (mounted to the tongue 138 in use) will move to or sway towards another side. By applying current alternatively to the two heaters of the supporting arms 146 and 147, selective movement and direction of the slider / head element 141 over the desired track is achieved.

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An exemplary embodiment of a laterally stacked, comb-like, dual-material composite structured microactuating beam 150 is shown in FIG. 12. A first material 151,

which has high thermal conductivity and small co-efficiency of thermal expansion (CTE), constitutes a skeleton structure or spaced apart thermal elements of the comb-like microactuating beam 150 with a metal line 152 formed on top. Gaps or spaces between the thermal elements 151 are encapsulated or filled with a second material 153 to form expansion elements 153, which have a relatively large CTE. When a current via electrical pads 154 on a sidewall 157 or top surface 158 of one end of the microactuating beam 150 is applied to the metal line 152, generated heat is efficiently transferred to the surrounding expansion elements 153 through the comb-like skeleton structure of thermal elements 151 that has a large interface with the expansion elements 153. The expansion elements 153 expand in a longitudinal direction along the microactuating beam 150 due to the constrained gaps between the comb fingers constructed by the first material 151, causing the microactuating beam 150 to bend laterally or in a lateral direction as indicated by arrow 156. In this way, the first material 151 acting as the "skeleton" or thermal elements 151 of the microactuating beam 150 serves to conduct heat and to reinforce the second material encapsulant 153, with the metal line 152 being responsible for resistive heating, while the second material 153 serves as expansion elements 153 to expand and open the spacing of the "skeleton" 151.

FIG. 13 is a schematic diagram showing another exemplary example of a laterally stacked comb-like dual-material composite structured microactuating beam 150 comprising a first material or thermal elements 151 and a second material or expansion elements 153, and a metal line 152 on top. A difference from the beam design in FIG. 12 is that the beam 150 of FIG. 13 expands longitudinally or in a longitudinal direction of the beam as indicated by arrow 156 when the microactuating beam 150 is heated via electrical pads 154 on a sidewall 157 or top surface 158 of one end of the beam 150. This is achieved by forming successive expansion elements 153 alternately on either side of the microactuating beam 150 as shown in FIG. 13. By contrast, all the expansion

elements 153 in the microactuating beam 150 of FIG. 12 are formed on only one side of the beam 150. Since the slider 141 is directly mounted on the tongue plate 138 supported by such microactuating beam supporting arms 146 and 147 in an embodiment of the HGA as shown in FIG. 11, the bending or expanding of the heated arm 146, 147 in
5 a lateral or longitudinal direction will cause the slider 141 to move or sway towards one side.

The microactuating beam may be used in a variety of other configurations as well. FIG. 14 shows the top view of one embodiment of the integrated flexure thermal
10 microactuator 140 as shown in FIG. 11, where two microactuating beams 160 are located at the exterior or lateral sides 163, 162 of the supporting arms 146, 147 of the flexure 143 respectively. The tongue 138 has a small protrusion 145 configured for engaging a dimple 13 provided on a load beam of the suspension arm. In an alternative embodiment, the microactuating beams 160 may instead be placed at the interior or
15 medial sides 164, 165 of the arms 146, 147 respectively.

FIG. 15 shows the top view of another embodiment of the integrated flexure thermal microactuator 140 as shown in FIG. 11, where two microactuating beams 160 are cast on a same side 163, 164 (as shown) or 162, 165 of the two supporting arms
20 146, 147 of the flexure 143 respectively. The ends of the arms 146, 147 connect with the tongue plate 138 via a hinge scheme that may comprise a pair of extensions 168 from the supporting arms 146, 147. The pair of extensions 168 are arranged to exert a simple couple force on the tongue plate 138 so as to induce or allow the tongue plate 138 to rotate around one point of dimple supporter 145 due to bending or expanding of only one
25 heated arm 146 or 147. The dimple supporter 145 is configured to engage a dimple 13 provided on a load beam of the suspension arm.

FIG. 16 shows the top view of another embodiment of the integrated flexure thermal microactuator 140 shown in FIG. 11, where microactuating beams 160 are located at the exterior or lateral sides 162, 163 of the supporting arms 146, 147 of the flexure 143 respectively, and one central supporting beam or third arm 169 is connected to the tongue plate 138 from the flexure 143 between the two supporting arms 146, 147 as shown. The central supporting beam 169 will increase heat dissipation speed of the heated supporting arms 146, 147 and result in negligible thermal fluctuations from one heated arm 146, 147 to another arm, 147, 146 respectively. In this embodiment, the third arm 169 is also configured to engage a dimple 13 provided on a load beam of the suspension arm.

Although the microactuating 160 shown are preferably used on pairs of supporting arms, it is also possible to use a single supporting arm 175 provided with a microactuating beam 170 which changes direction by increasing and decreasing applied voltages together with a small constant voltage. FIG. 17 shows the top view of one embodiment of the integrated flexure thermal microactuator 172 comprising the single-arm microactuating beam 170. The microactuating beam 170 may be located at either side 173 or 174 of the supporting arm 175 of the flexure tongue 178. The single supporting arm 175 is also configured to engage a dimple 13 provided on a load beam of the suspension arm. However, for balance, symmetry and response time, a pair or two microactuating beam are generally favored.

Thus, by providing a method of fabricating the thermal microactuator that is integrated into the current process of fabricating the suspension flexure itself, it is now possible to realize a high process yield with cost saving by eliminating the need to have a post actuator assembly in order to provide a thermal microactuator on the flexure.

While various embodiments have been described and illustrated above, it should be understood that these are exemplary and are not to be considered as limiting. For instance, besides being embedded in the tongue part of the flexure, the microactuating beams can also be formed at other locations of the flexure body if they are able to generate enough motion of a slider in the track direction. FIG. 18 shows the top or bottom view of an embodiment of integrated flexure thermal microactuators 183 having microactuating beams 180 located at the exterior or lateral sides 182 of the flexure frame 185. Alternatively, FIG. 19 shows the top or bottom view of an embodiment of integrated flexure thermal microactuators 193 having microactuating beams 190 located at the interior or medial sides 192 of the flexure frame 195. In addition, the thermal elements and expansion elements as shown in FIG. 13 may be applied to any of the embodiments described above.

Moreover, the dual-material composite structured beam as shown in FIGS. 12 or 13 may be replaced by a single material microactuating beam configured for lateral or longitudinal motion at one end of the single material microactuating beam as a result of thermal expansion of the single material microactuating beam due to application of heat to the single material beam. For example, in an alternative to the embodiment of FIG. 19, as shown in FIG. 20, a single material microactuating beam 190 is located at each of the interior or medial sides 192 of the flexure frame 195. It should be noted that the single material of the single material microactuating beam may comprise the conductive metal forming the thermal elements described above, or alternatively, the single material may comprise the photosensitive synthetic resin forming the expansion elements described above.

25

Thus, for all the above exemplary embodiments described, the thermal microactuator comprises at least one microactuating beam formed on the flexure before

laying the cover layer during formation of the flexure. The at least one microactuating beam should be configured to have an appropriate shape and size as well as location on the flexure in order to achieve a desired displacement of the slider upon application of heat resulting in expansion of the at least one microactuating beam. The at least one
5 microactuating beam may therefore be one or more single material microactuating beams, or the at least one microactuating beam may each comprise a composite structure having a plurality of expansion elements disposed between spaced-apart thermal elements as described in the exemplary embodiments above.

10 Furthermore, although it has been described above that the at least one microactuating beam is heated by resistive heating, the thermal microactuator may alternatively be configured to heat the at least one microactuating beam by induction heating instead.

15

CLAIMS

1. A method of fabricating a thermal microactuator for a suspension arm of a hard disk drive, the suspension arm comprising a slider attached to a flexure, the method
5 comprising:
 - a. forming at least one microactuating beam on the flexure during fabrication of the suspension arm before attaching the slider to the flexure; and
 - b. laying a cover layer over the at least one microactuating beam.
- 10 2. The method of claim 1, wherein forming the at least one microactuating beam comprises forming thermal elements on the flexure with spaces between successive thermal elements and forming expansion elements in the spaces between successive thermal elements.
- 15 3. The method of claim 2, wherein forming of the thermal elements and the expansion elements is configured to provide a dual-material composite structure that bends laterally upon expansion of the expansion elements.
4. The method of claim 2, wherein forming of the thermal elements and the expansion
20 elements is configured to provide a dual-material composite structure that expands longitudinally upon expansion of the expansion elements.
5. The method of any one of claims 2 to 4, wherein forming the expansion elements
25 comprises filling the spaces between successive thermal elements with a material having a higher coefficient of thermal expansion than the thermal elements.

6. The method of any one of claims claim 2 to 5, wherein forming the thermal elements comprises laying a conductive material on a surface of the flexure, the conductive material forming the thermal elements on the surface of the flexure.
- 5 7. The method of claim 6, wherein forming the thermal elements is performed simultaneously with forming electrical transmission lines on the flexure, the conductive material forming the electrical transmission lines and the thermal elements.
- 10 8. The method of claim 7, wherein the conductive material is laid in two steps, a first step forming the electrical transmission lines and heater elements of the thermal elements, and a second step completing formation of the thermal elements.
9. The method of any one of claims 2 to 5, wherein forming the thermal elements
15 comprises forming slots on a surface of the flexure such that portions of the flexure between the slots form the thermal elements and the slots form the spaces between successive thermal elements for forming the expansion elements therein.
10. The method of any preceding claim, further comprising laying an insulating layer on
20 the flexure before forming the at least one microactuating beam.
11. The method of claim 10 when dependent on claim 9, further comprising laying a conducting layer on the insulating layer before laying the cover layer, the conducting layer being configured for heating the at least one microactuating beam.

12. The method of any one of the preceding claims, wherein forming the at least one microactuating beam on the flexure comprises forming the at least one microactuating beam on a surface of the flexure facing the slider.
- 5 13. The method of any one of claims 1 to 11, wherein forming the at least one microactuating beam on the flexure comprises forming the at least one microactuating beam on a surface of the flexure facing away from the slider.
- 10 14. The method of any preceding claim, wherein forming the at least one microactuating beam on the flexure comprises forming a first microactuating beam on a first arm of the flexure connected to a flexure tongue for attaching the slider thereto.
- 15 15. The method of claim 14, further comprising forming a second microactuating beam on a second arm of the flexure connected to the flexure tongue.
16. The method of claim 15, wherein forming the first and second microactuating beams comprises forming the first and second microactuating beams on medial sides of the first and second arms of the flexure.
- 20 17. The method of claim 15, wherein forming the first and second microactuating beams comprises forming the first and second microactuating beams on lateral sides of the first and second arms of the flexure.
- 25 18. The method of claim 15, wherein forming the first and second microactuating beams comprises forming the first and second microactuating beams on a same side of the first and second arms of the flexure.

19. A method of fabricating a suspension arm for a hard disk drive comprising the method of fabricating the thermal microactuator of any one of the preceding claims.
20. A method of fabricating a hard disk drive comprising the method of fabricating the suspension arm of claim 19.
21. A thermal microactuator for micropositioning a slider on a suspension arm of a hard disk drive, the slider being attached to a flexure, the flexure supporting a conducting layer under a cover layer, the thermal microactuator comprising at least one microactuating beam formed on the flexure under the cover layer.
22. The thermal microactuator of claim 21, wherein the at least one microactuating beam comprises a dual-material composite structure comprising an alternated arrangement of thermal elements and expansion elements formed on the flexure under the cover layer.
23. The thermal microactuator of claim 22, wherein the thermal elements and the expansion elements are formed of different materials, the material forming the thermal elements having a higher thermal conductivity and a smaller co-efficient of thermal expansion than the material forming the expansion elements.
24. The thermal microactuator of claim 22 or 23, wherein the alternated arrangement of thermal elements and expansion elements is configured to result in lateral bending of the at least one dual-material composite structure upon expansion of the expansion elements.

25. The thermal microactuator of claim 22 or 23, wherein the alternated arrangement of thermal elements and expansion elements may be configured to result in longitudinal extension of the at least one dual-material composite structure upon expansion of the expansion elements.

5

26. The thermal microactuator of any one of claims 22 to 25, wherein the thermal elements are integral with a layer of conductive material laid on the flexure.

10

27. The thermal microactuator of any one of claims 22 to 25, wherein the thermal elements are integral with the flexure.

15

28. The thermal microactuator of any one of claims 21 to 26, wherein the at least one microactuating beam is formed on the conducting layer and projects from a surface of the flexure.

29. The thermal microactuator of claim 27, wherein the expansion elements are formed in slots formed on a surface of the flexure and wherein portions of the flexure between the slots form the thermal elements.

20

30. The thermal microactuator of any one of claims 21 to 29, wherein the at least one microactuating beam is formed on a surface of the flexure facing the slider.

25

31. The thermal microactuator of any one of claims 21 to 29, wherein the at least one microactuating beam is formed on a surface of the flexure facing away from the slider.

32. The thermal microactuator of any one of claims 21 to 31, wherein the at least one microactuating beam is configured to be heated by passing an electrical current through a metal line disposed on the flexure adjacent the at least one microactuating beam.

5

33. The thermal microactuator of any one of claims 21 to 32, wherein the at least one microactuating beam is a first microactuating beam located on a first arm of the flexure connected to a flexure tongue, the slider being attached to the flexure tongue.

10 34. The thermal microactuator of any one of claims 21 to 33, further comprising a second microactuating beam located on a second arm of the flexure connected to the flexure tongue.

15 35. The thermal microactuator of claim 34, wherein the first and second microactuating beams are located on medial sides of the first and second arms of the flexure.

36. The thermal microactuator of claim 34, wherein the first and second microactuating beams are located on lateral sides of the first and second arms of the flexure.

20 37. The thermal microactuator of claim 34, wherein the first and second microactuating beams are located on a same side of the first and second arms of the flexure.

25 38. The thermal microactuator of any one of claims 34 to 37, further comprising hinges connecting the first and second arms to the flexure tongue for allowing rotation of the flexure tongue relative to the flexure.

39. The thermal microactuator any one of claims 34 to 38, further comprising a third arm of the flexure connected to the flexure tongue between the first arm and the second arm, the third arm being configured for heat dissipation.
- 5 40. The thermal microactuator any one of claims 21 to 39, wherein movement of the at least one microactuating beam is controlled by selective application of electrical energy for heating the at least one expansion element.
41. The thermal microactuator of claim 21, wherein the material forming the at least one
10 microactuating beam is a photosensitive synthetic resin.
42. The thermal microactuator of claim 21, wherein the material forming the at least one microactuating beam is a conductive metal.
- 15 43. A suspension arm for a hard disk drive comprising the thermal microactuator of any one of claims 21 to 42.
44. The suspension arm of claim 43, further comprising a load beam supporting the flexure.
20
45. The suspension arm of claim 43 or 44, further comprising an insulating layer between the flexure and the conducting layer.
46. A hard disk drive comprising the suspension arm of any one of claims 43 to 45.
25

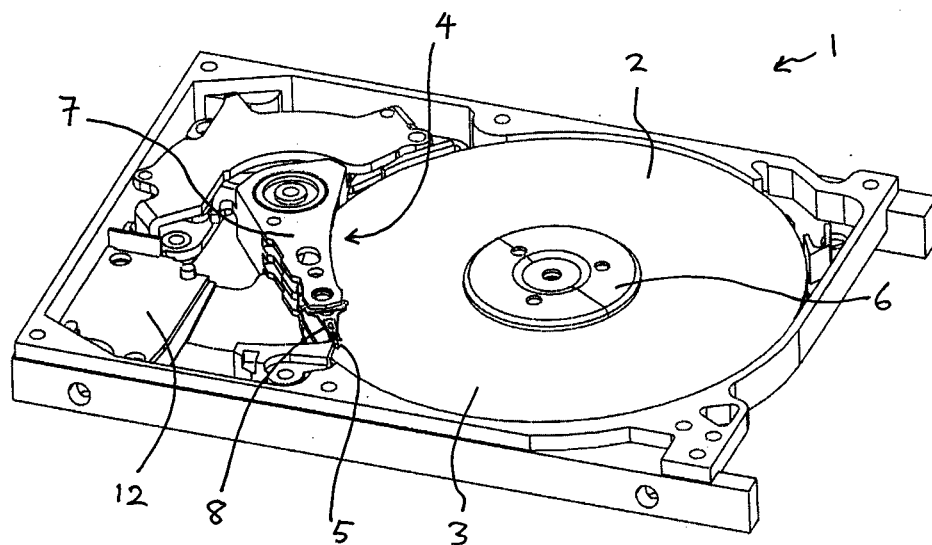


FIG. 1

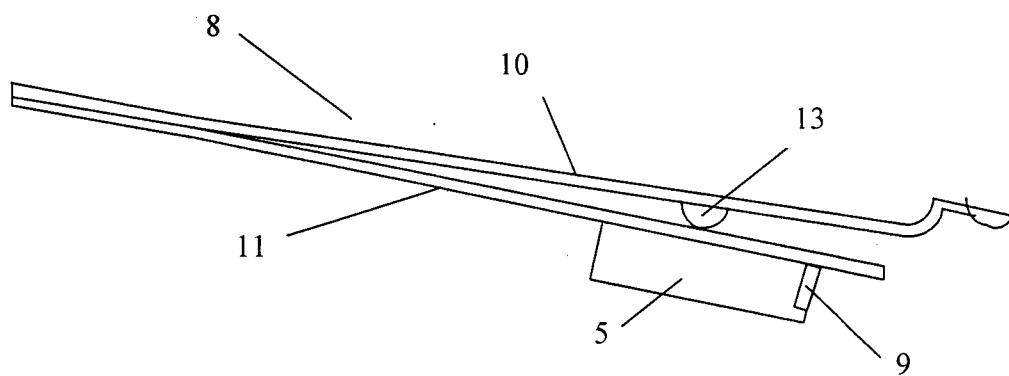


FIG. 2

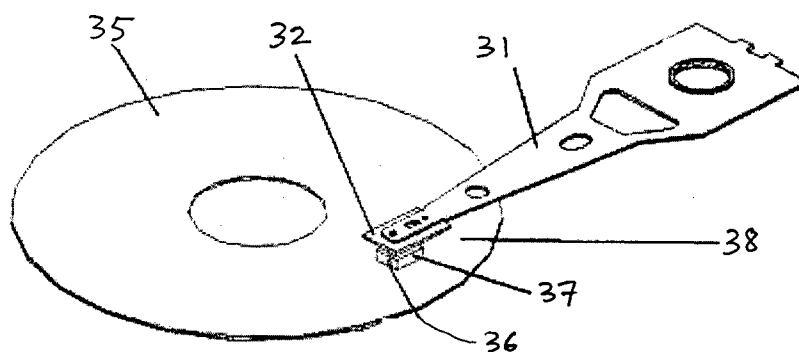


FIG. 3

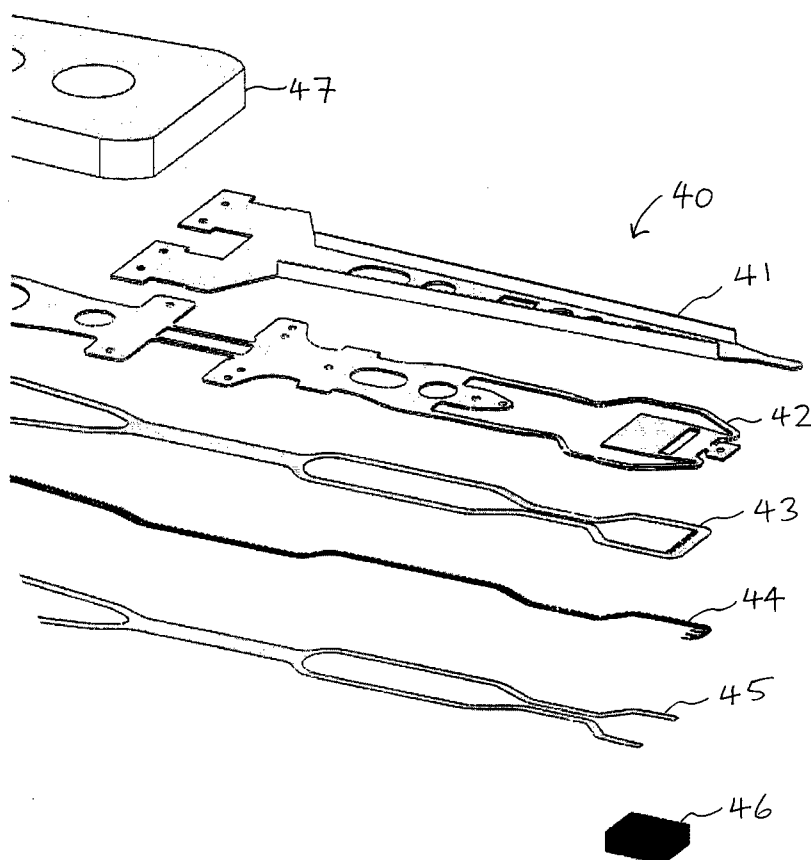


FIG. 4

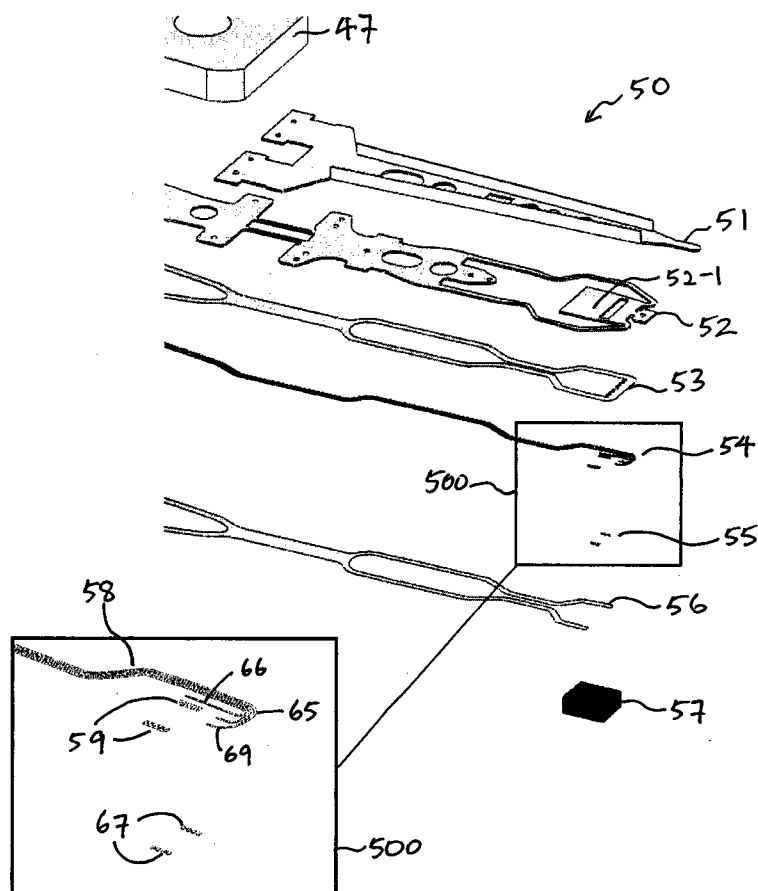


FIG. 5

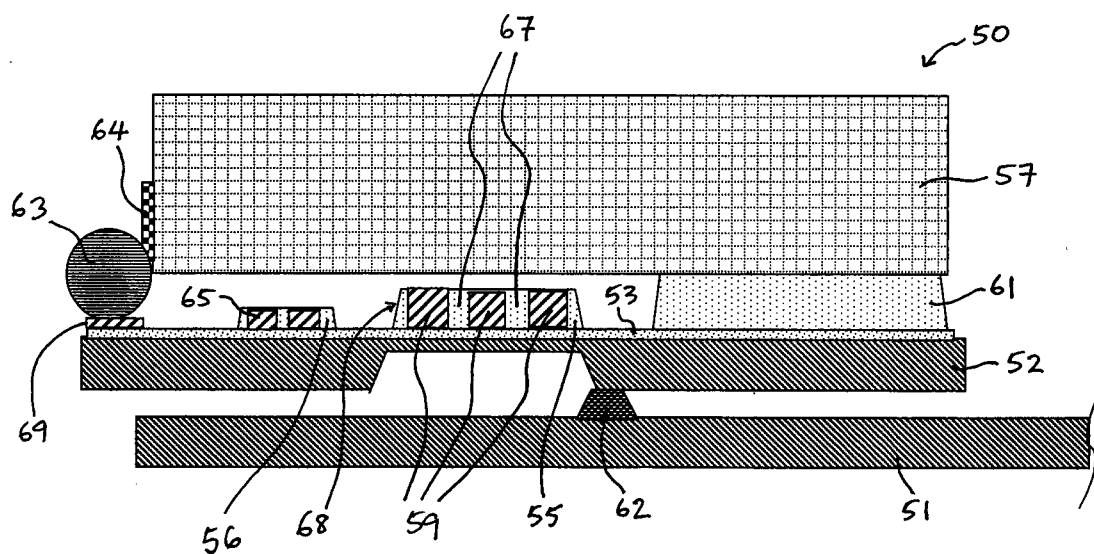


FIG. 6

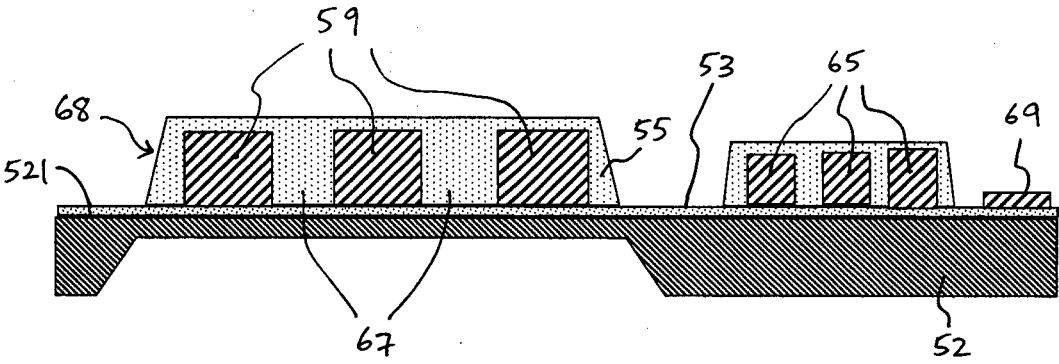


FIG. 7(a)

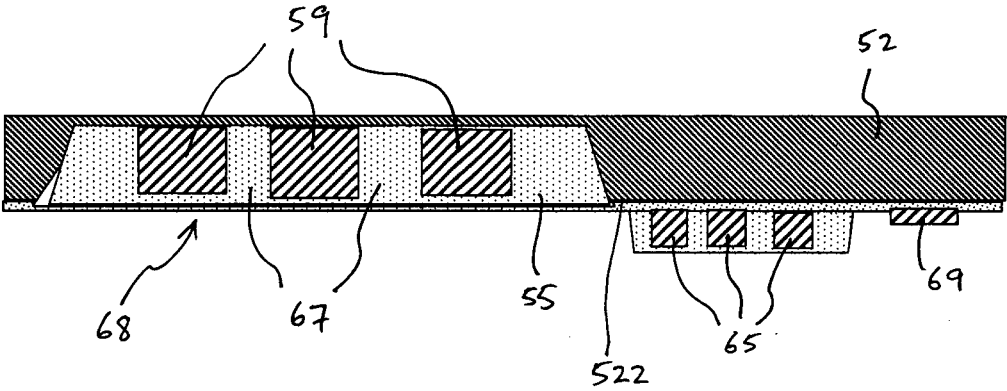


FIG. 7(b)

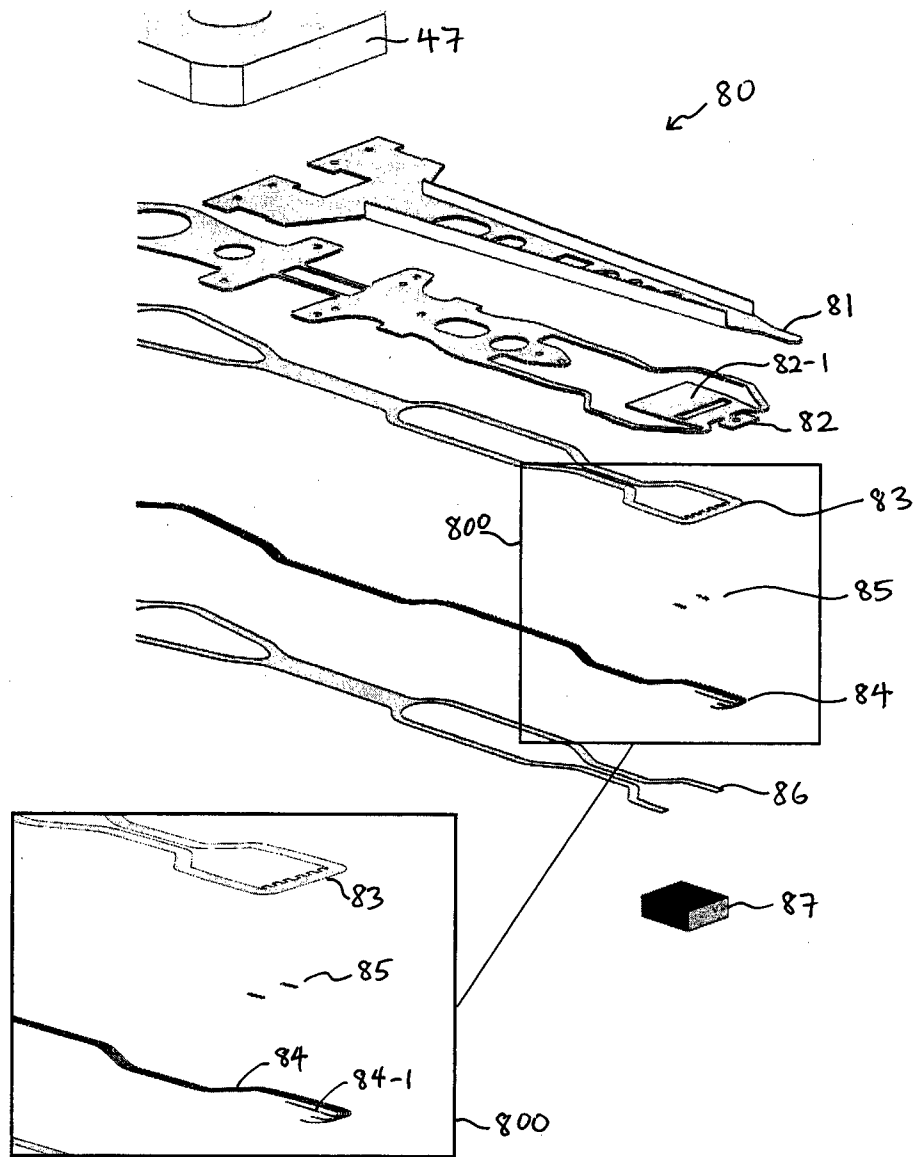


FIG. 8

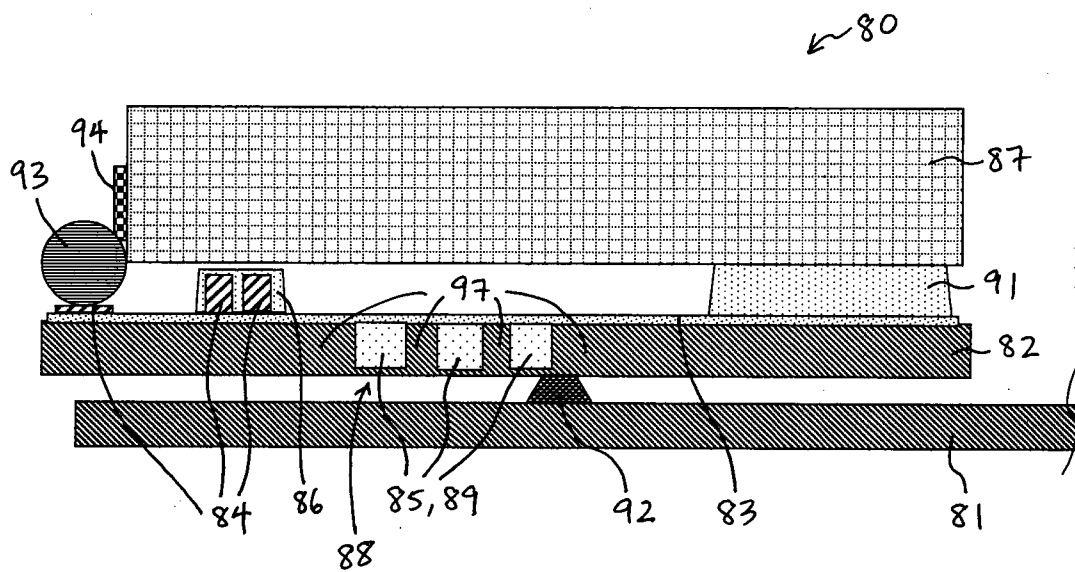


FIG. 9

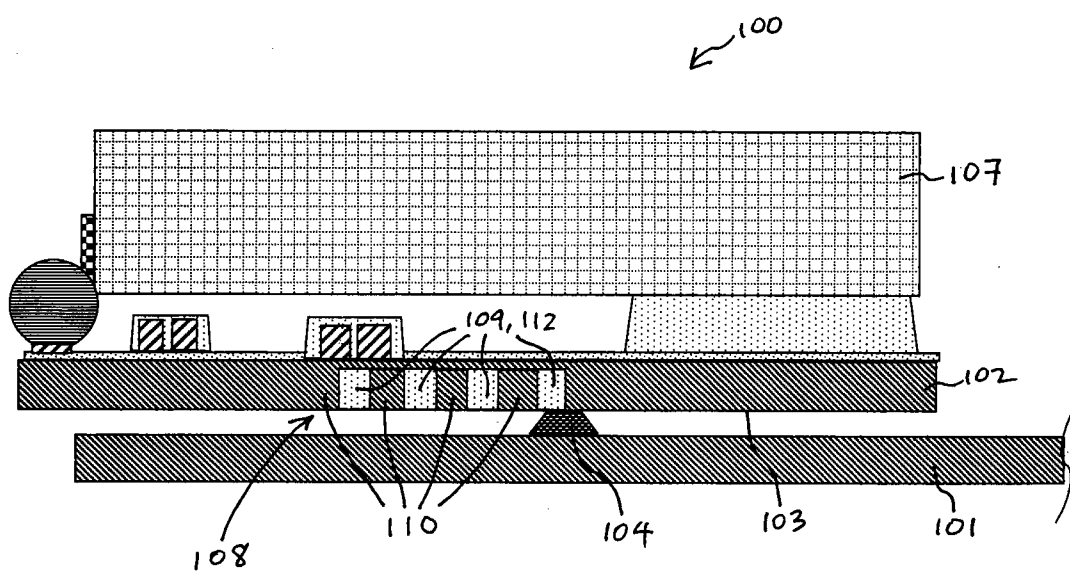


FIG. 10

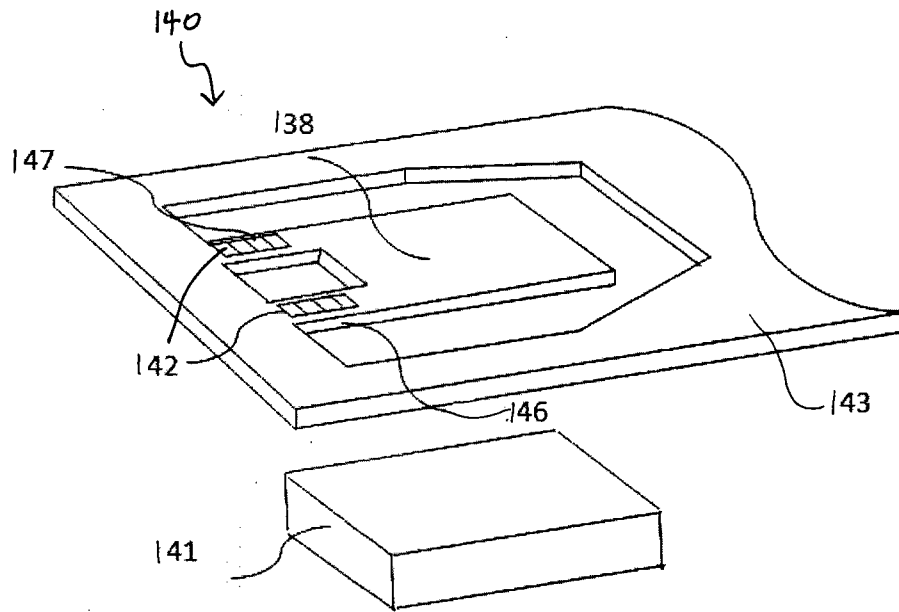


FIG. 11

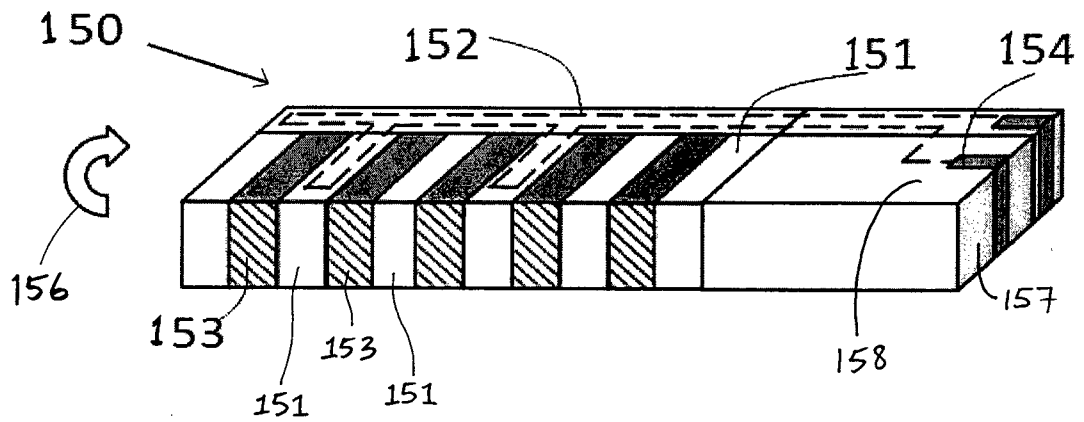


FIG. 12

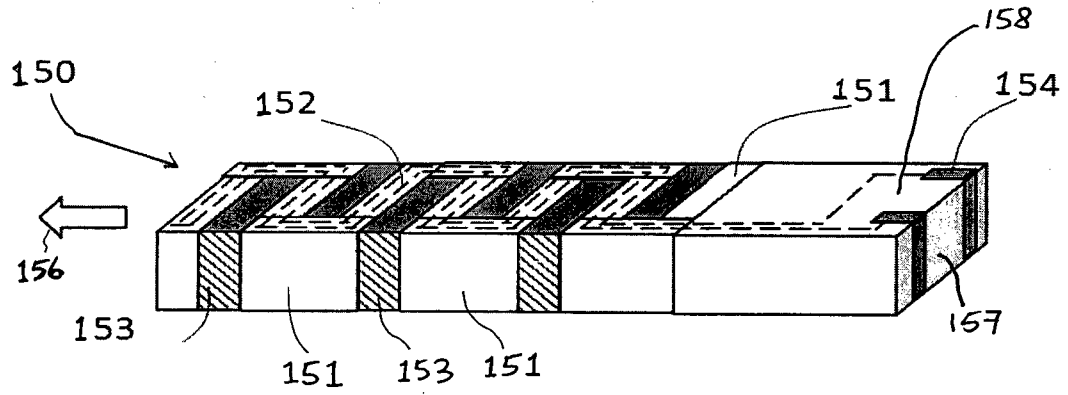


FIG. 13

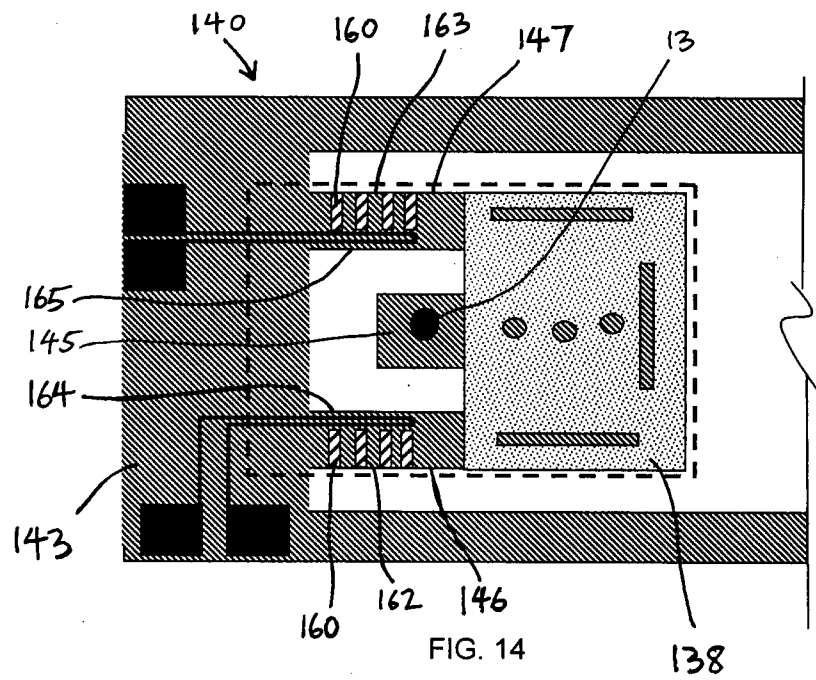


FIG. 14

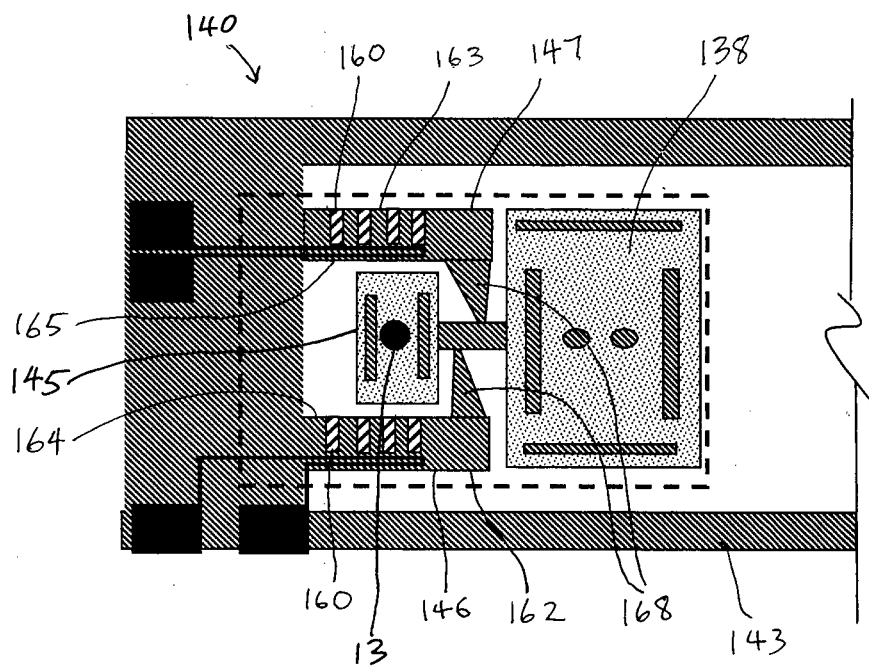


FIG. 15

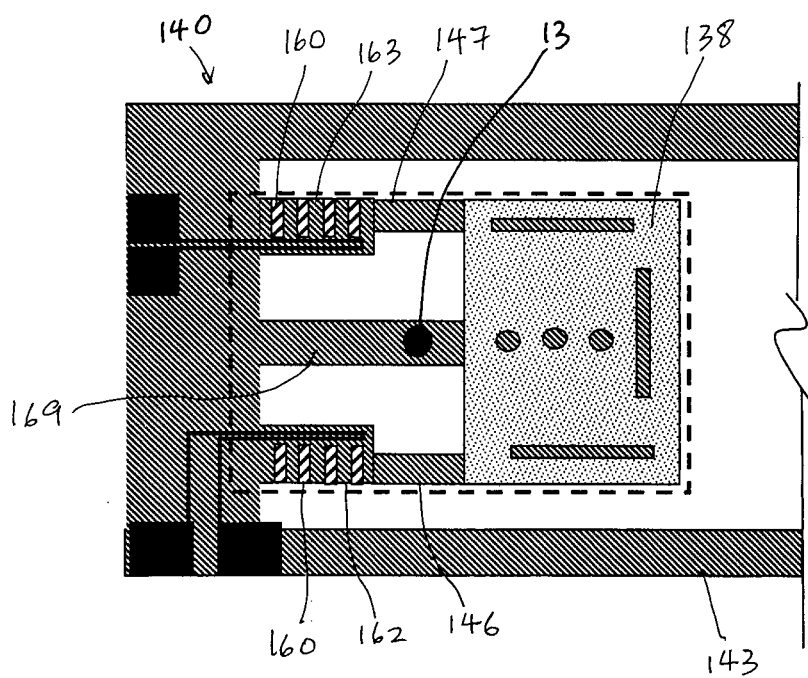


FIG. 16

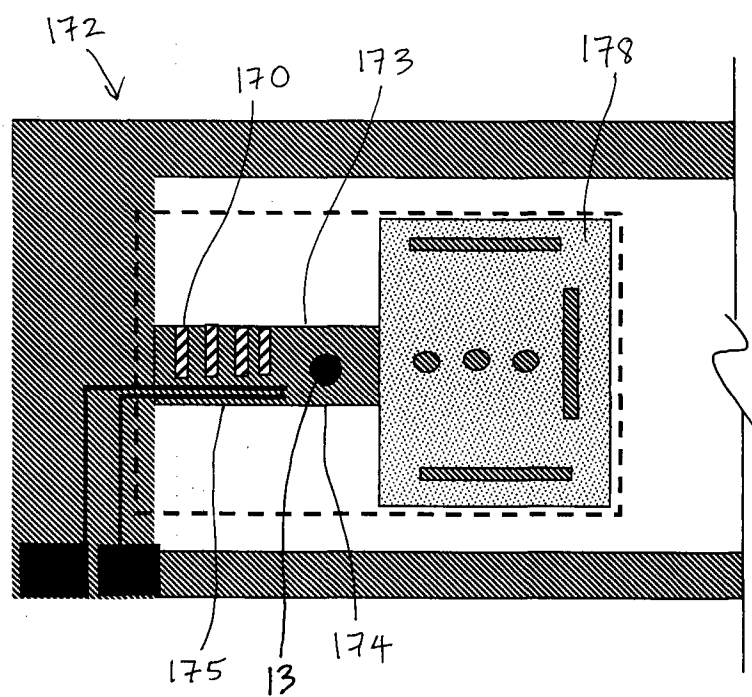


FIG. 17

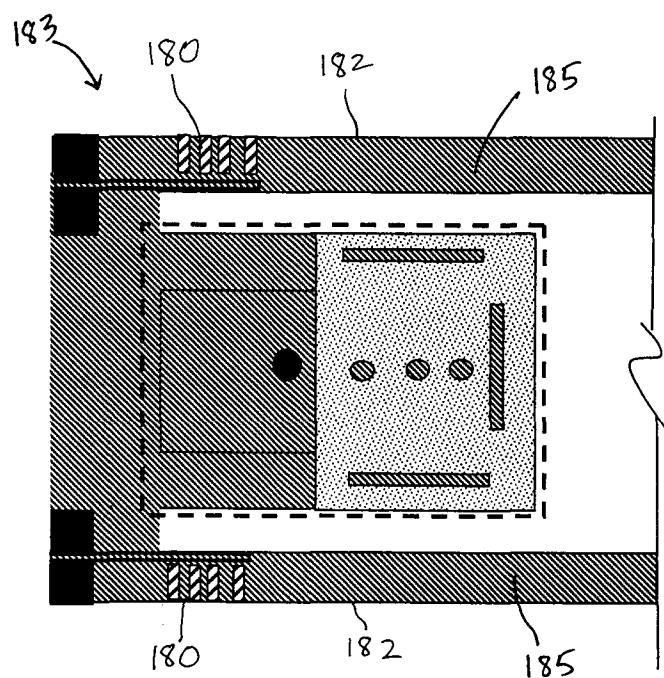


FIG. 18

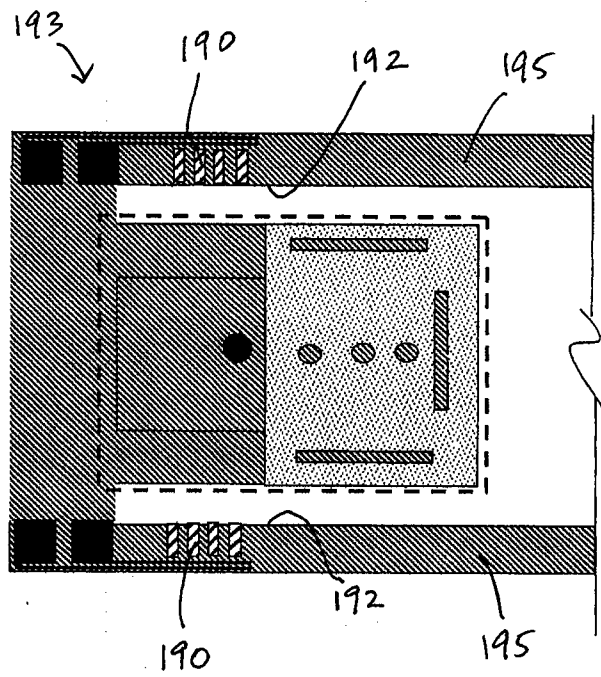


FIG. 19

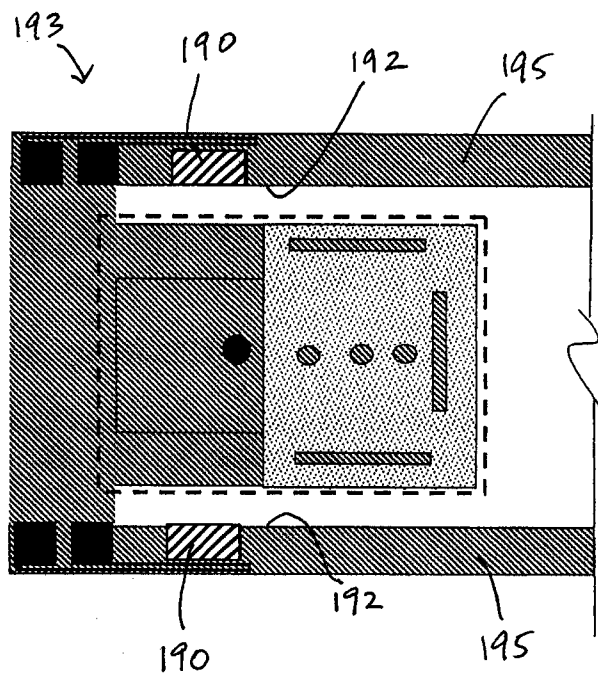


FIG. 20

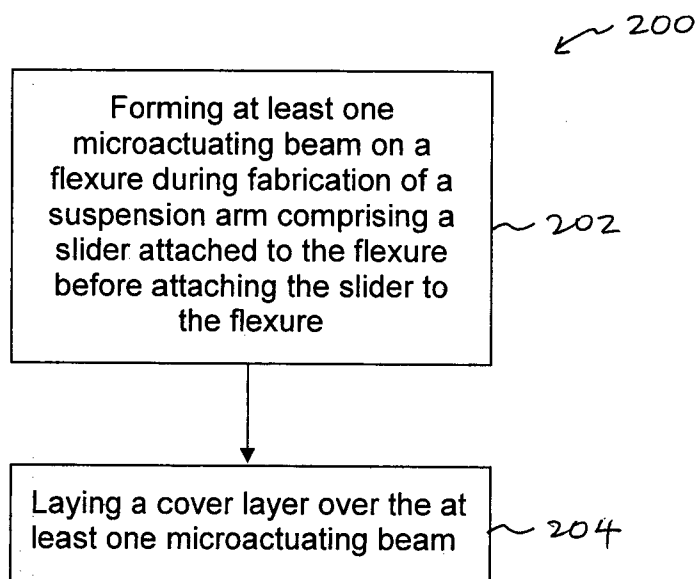


FIG. 21

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2011/000260

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

G11B 21/10 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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

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

EPODOC and WPI: IPC G11B 21/- with Keywords (THERMAL MICRO-ACTUATOR) and like terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003/0133228 A1 (CHEN et al.) 17 July 2003 See the whole document	1 – 46



Further documents are listed in the continuation of Box C



See patent family annex

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
06 October 2011

Date of mailing of the international search report
11/10/2011

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2011/000260

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member	
US	2003133228	SG	118109
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.			
END OF ANNEX			