Thermal actuator integrated with head gimbal assembly (HGA) for disc drive device

Background of the invention

The head positioning of data tracks on hard disks is continually being more accurate so as to increase the data storage density of such disks by using a narrower track width/pitch. A conventional disk drive device 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, a stack of discs carried by a spindle motor which makes discs spin. 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 side (termed the trailing edge) of the slider. VCM is used to control the motion of the actuator arm and, in turn, to control HGA to position the slider and its attachments of head element over a desired recording track across the surface of disc, thereby, to enable the head element to read data from or write data to the disc. Since conventional VCM servo control cannot provide higher level of track accuracy, which is due to inherent mechanical resonance limits of VCM, actuator arm and suspension arm, dual stage actuation scheme, which uses the VCM as a low bandwidth actuator for coarse positioning a suspension arm and a micro actuator as a high bandwidth actuator for fine positioning a read/write head of a slider over a track, has been proposed.

Such microactuator must be capable of quickly and accurately positioning the read/write head elements within a smaller track pitch

and hence increase the tracks per inch (TPI) for disk drive device. The microactuator should also be light weight to minimize detrimental effects on the resonance characteristics of the suspension arm. Furthermore, it is necessary that the microactuator has no significant influence on slider flying capabilities during operation. To be commercially viable the 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 the dimensional accuracy of the microactuators measured in microns.

Various microactuator designs have been considered to achieve high resolution head positioning, including piezoelectric, electromagnetic, electrostatic, and thermal actuators. Various locations for the microactuator have been suggested, including on the slider, on the gimbal, between the slider and the gimbal, and on the suspension of the arm, for example. However, these microactuator designs have limited performance for ultra-density magnetic recording. They are subjected to limitations, such as limited servo control bandwidths for lead zirconate titanate (PZT)/electromagnetic actuated suspension, smaller driving force for electrostatic actuated slider, heavy weight and complicated assembly process for electromagnetic actuated slider, susceptible shock-resistance capability of brittle PZT material for PZT film actuated slider, and heavy weight and high temperature induced (> 100-200°C) for CMOS PolySi based thermal actuated slider.

Therefore, there is still a need to provide a compact and robust microactuator integrated with HGA, which can meet the multiple

kilohertz bandwidth requirement and be mass manufactured and easily integrated into the current HGA assembly process to realize high process yield at low cost.

Brief description of the drawings

A number of preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram showing various components in a conventional hard disk drive;

Figure 2 is a schematic diagram showing a magnified side view of a conventional head gimbal suspension;

Figure 3 is a schematic diagram showing a structure of a conventional head positioning system with dual stage servo system for a hard disc drive;

Figure 4 is a schematic diagram showing the flexure of suspension, the slider, the thermal micro actuator in accordance with an embodiment of the present invention;

Figure 5 shows one example of a thermal micro-actuator, as for Fig 4. This example consists of a comb-like silicon structure, polymeric expansion material filled between fingers of the silicon structure, and a meander-shape heater wires on top of the silicon structure;

Figure 6 shows another example of a thermal micro-actuator, as for Fig 4. This example has U-shape heater wires, instead of the meander-shape heater wires, on the comb-like silicon structure, as in Figure 5;

Figure 7 shows another example of a thermal micro-actuator, as for Fig 4. This example consists of a meandered-shape silicon structure, polymeric expansion material filled between silicon structure, and a double-meander shape heater wires on the silicon structure;

Figure 8 is a schematic illustration of a side view of thermal microactuator integrated with HGA and electrical connections;

Figure 9 is a top view of an embodiment of the thermal microactuator of FIG. 4, where the supporting arms are linked with the front plate via two hinges;

Figure 10 is a top view of another embodiment of the thermal microactuator of FIG. 4, where the front plate is linked with both the two supporting arms and external frame of thermal microactuator via two hinges and another hinge beam, respectveily;

Figure 11 is a top view of another embodiment of the thermal microactuator of FIG. 4, where two sets of the supporting arms are directly linked with the front plate without the hinge scheme as shown in FIG 9-10;

Figure 12 shows a process flow for integrating HGA and thermal micro actuator.

Detailed descriptions

Figure 1 is a schematic diagram showing various components in a conventional hard disk drive. Figure 2 is a schematic diagram showing a magnified side view of a conventional head gimbal suspension. A hard disk drive **1** includes a rotating disc **2** and a head suspension assembly **4** that supports a slider **5** with the attachments of magnetic head elements or transducer **9** on a trailing surface of the slider body for reading/writing of data from/to recording tracks **3** located on the disc **2**. Disc **2** is carried by a spindle motor **6** which makes disc **2** spin. The head suspension assembly **4** consists of a rigid actuator arm **7** and a flexible suspension arm **8**, which is fixed to a tip end of rigid actuator arm **7** using conventional mounting methods (such as screw mounting, bonding). The suspension arm **8** comprises a load beam **10** and a flexure **11**, which are overlapped partially and connected with each other by welding, or gluing or other bonding methods. The load beam **10** serves to supply a supporting force to the flexure **11** and tilt slider **5** toward the surface of disc **2**, while the flexure **11** provides flexibility for slider **5** in roll and pitch directions. Such design ensures slider **5** to maintain a stable altitude at a desired height above the disc surface. A flexible electrical trace (not shown), which transmits signals of transducer **9** from/to a chip **12** within disk drive **1**, is attached to the surface of flexure **11**. Slider **5** is mounted on a tongue **14** (not shown) of flexure **11** using one adhesive material (such as epoxy). Furthermore, a dimple **13** formed on the load beam **10** is physically engaged to tongue **14** in vertical direction.

When disc **2** spins, slider **5** with an aerodynamic pattern on its air bearing surface (ABS) will glide over moving air induced by rotating disc **2** and maintain a uniform distance from the surface of disc **2**, thereby preventing transducer **9** from undesirably contacting disc **2**.

Figure 3 is a schematic diagram showing a structure of a conventional head positioning system with dual stage servo system for a hard disc drive. Two actuators are used in the head positioning system. A suspension arm **31** supports the flexure **32** and a voice coil motor **33** (not shown) runs to move the first actuator arm **34** (not shown) relative to a disc **35** to coarsely position the R/W head elements or transducers **36**. Then, a microactuator **38** that works as a second actuator drives a slider **37** to achieve the fine positioning of the R/W head elements or transducers **36**.

Figure 4 is a schematic diagram showing a slider **41** supported by a thermal microactuator **42** attached to the flexure **43** in accordance with one embodiment of the present invention. A thermal microactuator **42** is located between flexure **43** and slider **41**. The thermal microactuator **42**, includes a rear base plate **44**, which is attached on the tongue **48** of the flexure **43**, a front plate **45**, which holds a slider **41** with attachment of read/write head **40**, a pair of supporting arms **46** and **47** to load the front plate **45** via connection at the one end of each arm and to be mounted on the rear base plate at other end of each arm. Each supporting arm **46** or **47** can be configured with either an actuation element by a side or each element by both sides. The actuation element consists of at least three materials, namely a polymeric thermally expansion material, a structural material which connects to

the structural arms for force and heat transfer but no electrical charge transfer, and a heating element on top of the structural material. The structural material is configured as a high-aspect-ratio structure with a thickness of 40-100 microns, in a shape of a comb, a fin, or a meander, while the expansion material is filled in between the gaps of the structures. A heating element is integrated to the high-aspect-ratio structure to provide controlled heating of the polymeric expansion material. Upon heating the actuation element, the polymer expansion material expands and consequently bends the supporting arm when heated. The mass centre of slider and microactuator will be aligned with the location of dimple **13** on surface of load beam **10** so that the slider **41** flying altitude is maintained in terms of roll stiffness and pitch stiffness.

Figure 5 shows one example of a composite thermal micro-actuator 49. A first material **51**, which has a high thermal conductivity, a small electrical conductivity and a low coefficient of thermal expansion (CTE), constitutes a skeleton structure of the comb-like beam 49 with a metal line **52** on top. The gaps between comb fingers are filled with a second material **53**, which has large CTE. It is a thermally expandable polymer material. When a current via electrical pads **54** on sidewall or the top surface of one end of beam 49 is applied to the metal line **52**, the generated heat is efficiently transferred to the surrounding second materials **53** through the comb-like skeleton structure that has a large interface with the second material **53**. The second material elements **53** expand along the beam longitudinal direction (arrow) due to the

constrained gaps between the comb fingers constructed by the first material **51**, causing the beam **49** to bend in lateral direction as indicated by arrow **56** . In such way, the first material **51** as "skeleton" of the beam serves to conduct heat and to reinforce the second material filler; the meander-shape metal line **52** is responsible for resistive heating; whereas, the second material **53** serves to expand and open the spacing of the "skeleton".

FIG. 6 is a schematic diagram showing another exemplary example of a composite thermal micro-actuator 49. A first material **51**, which has a high thermal conductivity, a small electrical conductivity and a low co-efficient of thermal expansion (CTE), constitutes a skeleton structure of the comb-like beam **49**. The gaps between comb fingers are filled with a second material **53**, which has large CTE. It is preferably a thermally expandable polymer material. A difference from the beam design in FIG. 5 is that the U-shape metal line **52** is formed on the top. When a current via electrical pads **54** on a sidewall or the top surface of one end of the beam 49 is applied to the metal line **52**, generated heat is efficiently transferred to the surrounding second material through the comb-like skeleton structure or first material **51** that has a large interface with the second material **53**. The second material elements **53** expand in a longitudinal direction along the beam 49 due to the constrained gaps between the comb fingers constructed by the first material **51**, causing the beam 49 to bend in a lateral direction as indicated by arrow **56**. In this way, the first material **51** acting as the "skeleton" of the beam **49** serves to conduct heat and to

reinforce the second material filler **53**, with the U-shape metal line **52** being responsible for resistive heating, while the second material **53** serves to expand and open the spacing of the "skeleton" 51.

Figure 7 shows another example of a composite thermal micro-actuator 49. Different from the beam design in Fig 5, this beam will cause the beam 49 to expand in longitudinal direction of the beam as indicated byarrow **56**. This is achieved by forming successive second material **53** alternately on either side of the beam 49. By contrast, all the second material **53** in the beam 49 of FIG. 5-6 are formed on only one side of the beam 49. Since the slider **41** is directly mounted on the front plate **45** supported by such composite supporting arms **46** and **47** in an embodiment of the HGA as shown in FIG. 4, the bending or expanding of the heated arm **46**, **47** in a longitudinal direction will cause the slider **41** to move or sway towards one side.. Likewise, when a current is applied to the metal line of another arm, the generated heat will cause another arm to bend in lateral direction (opposite) and in turn, the slider will move or sway towards to another side. By the current is alternatively applied the two heaters of the supporting arms, the selective movement and direction of the slider/ head element over the desired track will be achievable.

The thermal actuator elements may be used in a variety of other configurations as well. In one embodiment of the HGA, there is provided a thermal microactuator integrated with HGA configured for dual-stage head positioning of hard disk drives as shown in FIG. 3 in an

order of being assembled by HGA manufacturing process and electrical connections, and in FIG. 8 in side view.

FIG. 9 shows the top view of one embodiment of the thermal microactuator **42** as shown in FIG. 4, where two sets of thermal actuator elements **49** are located at the exterior or lateral sides of the supporting arms **46**, **47**, respectively. The supporting arms 46, 47 are linked with the front plate 45 through two hinges **65**, **66** so as the front plate **45** to generate a rotation motion around the dimple **64**. The rear base plate **44** is attached on the flexure **43** by a bond material. A slider **41** with attachment of read/write head **40** is mounted on the patterned bump films **63** of front plate **45** by precise alignment with the dimple location **64**. Electrical pads **60** are used to connect with electrical pads of the read/write head and TFC actuator in the trailing edge of a slider **41**. Through wire tracing (not shown) on the substrate of thermal microactuator, electrical pads **60** are connected to electrical pads **61**, which are further connected to electrical pads on the surface of flexure by bonding, wiring, soldering etc. In an alternative embodiment, the thermal actuator elements **49** may instead be placed at the interior or medial sides of the arms **46**, **47** respectively.

FIG. 10 shows the top view of another embodiment of the thermal microactuator **42** as shown in FIG. 4, where the front plate **45** is linked with not only the supporting arms 46, 47 via two hinges, but also the external frame of thermal microactuator via another hinge beam **67**.

The beam is arranged to facilitate another electrical wire tracing connection between electrical pads **60** and **61** through the surface of the beam **67**.

FIG. 11 shows the top view of another embodiment of the thermal microactuator **42** as shown in FIG. 4, where two sets of the supporting arms **46**, **47** are directly linked with the front plate **45** without the hinge scheme as shown in FIG 9-10.

The thermal microactuator is integrally fabricated by using micromachining technology. The base structure of microactuator is preferably made of silicon, but any other suitable material may be used if they have a lower CTE, a higher thermal conductivity, and a small electrical conductivity. The microactuator is fabricated using micro-machining methods, include thin-film coatings, deep silicon etching, and polymeric filling. A thin layer is deposited on both sides of a silicon wafer. It serves as an electrical insulator on the front and as a mask on the backside of the wafer during etching process. A metal layer (for example gold, copper, or aluminum) is then deposited using a sputtering method or a chemical vapor deposition (CVD) and patterned using photolithography to form the metallic heaters, wire tracing and electrical pads on the top insulating layer of the wafer. Next, one photoresist layer is deposited and patterned on the top layer of wafer by following etching process to form cavities and trenches in the substrate of the wafer. Furthermore, one photopatternable material

(for example, polymer) having a large coefficient of thermal expansion is filled in or cast over the etched cavities and trenches of the wafer. The liquid polymeric filling is thermally or chemically cured into a solid form. The cured polymeric filling and the silicon structure combine into a composite structure. After excess organic materials in the etched cavities for electrical connections are removed by photolithography, another photopatternable metal-epoxy material blend (for example, silver-epoxy) is filled in these cavities to form electrical connection pillars at a specific temperature. The electrical connection pillars are used to connect thermal microactuator and read/write head slider signals to the electrical pads on flexure of HGA. Furthermore, photolithography is again used to remove other excess organic materials in the surroundings of the constrained composite structures to shape the overall layout of the microactuator including one front plate 45, at least a pair of the designed supporting arms 46, 47 with high-aspect-ratio composite structure and one rear base plate 44 extended from the substrate of wafer. The front plate and supporting arm are subsequently released from the patterned backside of the wafer through one etching process. Individual microactuator device with electrical connection pads or pillars is separated by dicing process.

Figure 12 shows the assembly process flow of the HGA having a microactuator in accordance with an embodiment of the present invention. First, flexure of suspension is attached to load beam by welding, suspension trace is attached to flexure-load beam assembly in

a conventional HGA processing manner. During integrating microactuator device die, which is fabricated in a separate micromachining process, with a HGA, slider is first mounted on the front plate of the microactuator by epoxy, slider and microactuator are then attached the flexure of the suspension by epoxy like a conventional HGA processing, Next, electrical wires from R/W head elements on the trailing edge of slider to the electric pads on the top surface of the front plate of microactuator, are connected by bonding process such as ball bonding or soldering. After then, the electrical pads or pillars on the top surface or sidewall of the rear base plate of microactuator are wired to the electrical pads on suspension-flexure to complete the assembly process of HGA with microactuator.

Claims

1. A microactuator for positioning a read/write head of a disc drive device, the microactuator comprising:

a plate for mounting a read/write head slider; and

at least one actuation element connected to the plate and configured to thermally expand in response to an input current or voltage for adjusting a position of the read/write head slider;

wherein the at least one actuation element comprises a composite structure comprising a first structural and heat-conductive material and a second thermal expansion material, and a heating element thermally coupled to the first material.

2. The microactuator as claimed in claim 1, wherein the first material of the composite structure is shaped as an elongated structure that holds, and deforms together with, the second material of the composite structure.

3. The microactuator as claimed in claim 1 or 2, wherein the first material has a smaller thermal expansion coefficient and a higher thermal conductivity than the second material.

4. The microactuator as claimed in any one of claims 1 to 3, wherein the at least one actuation element is configured to expand and bend in a lateral direction for adjusting the position of the read/write head slider upon heating by the heating element.

5. The microactuator as claimed in any one of claims 1 to 3, wherein the at least one actuation element is configured to expand in a longitudinal direction for adjusting the position of the read/write head slider upon heating by the heating element.

6. The microactuator as claimed in any one of the preceding claims, wherein the second material is disposed in gaps between a plurality of elements of the first material for an efficient transfer of heat from the first material to the second material.

7. The microactuator as claimed in any one of the preceding claims, wherein patterned bump films are formed on a surface of the plate based on a precise alignment with a dimple location.

8. The microactuator as claimed in any one of the preceding claims, wherein electrical connection pads or pillars are formed in a rear plate for connecting wires from the read/write head slider and the

thermal microactuator to electrical pads of a suspension-flexure by bonding, soldering.

9. A method for positioning a read/write head of a disc drive device, the method comprising the step of:

mounting a read/write head slider to a plate;

connecting at least one actuation element to the plate; and

supplying an input current for thermally expanding the at least one actuation element for adjusting a position of the read/write head slider;

wherein the at least one actuation element comprises a composite structure comprising a first structural and heat conductive material and a second thermal expansion material, and a heating element thermally coupled to the first material.