Single Crystal Silicon MEMS Microactuator for High Density Hard Disk Drive

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ABSTRACT

A single crystal silicon MEMS microactuator for high density hard disk drives is described in this paper. The microactuator is located between a slider and a suspension, and drives the slider on which a magnetic head is attached. The MEMS actuator is fabricated by improved LISA process. It has an electrically isolated 20:1 (40µm thick, 2µm width) high aspect ratio structure directly processed from a single crystal silicon substrate. The overall dimension of the micro-actuator is 1.4mm by 1.4mm and by a thickness of 0.15mm. Experiments show that ±0.6 µm displacement stroke of the Read/Write magnetic head, which is attached on the MEMS actuator, can be achieved when input voltage is 40V. The dynamic performances of the MEMS actuator integrated with a Head Gimbal Assembly (HGA) are analyzed by FEM simulation. The simulation results demonstrated that the controllable in-plane resonance frequency of the MEMS actuator is 1.5 kHz, and the first uncontrollable out-of-plane resonance frequency of the MEMS actuator integrated with the HGA is 16.6kHz. The single crystal silicon microactuator has good shock reliability, and eliminates large material creep and thermal mismatch problems.

Keywords: Single crystal silicon, MEMS, Microactuator, Hard disk drive

1. INTRODUCTION

The recording density of magnetic hard disk drives (HDD) has been increasing with a speed 60–100% per year. This achievement has attributed to various technological breakthroughs, including magneto-resistive sensing devices, novel signal processing techniques, and high-density recording media. In order to maintain this pace, another technical leap, which allows for much narrower data track width, is required. This requires high bandwidth servo position control of the recording head because the head must follow the narrow data track with high accuracy 1. Since conventional servo actuators cannot provide higher level of track accuracy, dual stage actuation scheme, which uses the voice-coil motor (VCM) as a coarse low bandwidth actuator and the microactuator as a fine high bandwidth actuator, has been studied 1,2.

Various micro actuators based on the electrostatic, piezoelectric and electromagnetic principles are being developed for HDD 3. According to the position where microactuators are placed and the object to be actuated, the microactuators are classified into three distinct types. The first type of the microactuator is placed around the suspension base and actuates the suspension for head positioning 4,5. This type can achieve a large displacement of the head element by using the suspension length as a swinging radius. However, the increase of the servo bandwidth is limited by the resonant frequency of the suspension. The second type of the microactuator is located between the slider and the head element and actuates the head 1. A critical limitation of this type of actuator is that the actuator fabrication process must be compatible with the head/slider fabrication process. The third type of the microactuator is inserted between the suspension and slider and actuates the slider on which a head element is formed 2,6,7. The advantage of the third type of microactuator is that it is not influenced by the mechanical resonance of suspension and its fabrication process is independent of the head/slider fabrication process.

The third type of Micro-Electro-Mechanical-System (MEMS) microactuator is discussed in this paper. Most of the published works have utilized nickel based metals or polysilicon for this type of MEMS actuator. However, the microstructure may have problems in the materials thermal mismatch, mechanical property stability and residual stress. Single crystal silicon has been proposed as the structure material of microactuator for high density hard disk
drives. As compared with that of nickel based metals and polysilicon, the single crystal silicon microstructure has better material stability and smaller thermal coefficient of expansion (TCE), and eliminates material thermal mismatch problem.

The single crystal silicon microactuator described in this paper has an electrically isolated 20:1 (40µm thick, 2µm width) high aspect ratio microstructure directly processed from a single crystal silicon substrate. The overall dimension of the micro-actuator is 1.4 mm by 1.4mm and by a thickness of 0.15 mm. The microactuator design, fabrication process, and electrical mechanical performance are discussed. The dynamic performance of the MEMS actuator integrated with a Head Gimbal Assembly (HGA) is simulated with Finite Element Method.

2. MICROACTUATOR DESIGN

A schematic drawing of the single-crystal-silicon microactuator assembled with HGA is shown in Fig.1. The piggyback microactuator is mounted between the slider and suspension for fine positioning of the magnetic head. The microactuator consists of a stationary structure attached to silicon substrate by bus bar, and a movable structure connected to an anchored central column via silicon spring beams which works as a rotor. The stationary structure is electrically isolated from the movable structure by the bus bar. Both the stationary and movable structures are suspended from the silicon substrate. The slider is bonded on the top surface of the movable structure. When a voltage is provided on the actuator, the microactuator will drive the head move in the track direction by rotational motion of the slider. The design requirements for the microactuator are flexible in operational direction with 1µm displacement in track direction, and stiff in the out of plane direction with a resonance frequency higher than 10 kHz.

![Figure 1. Schematic Diagram of the Microactuator Assembly](image)

Thin silicon beams are used as the spring elements for the connection between the movable structure and the central column. The structure needs to be very stiff in vertical direction to sustain the vertical load caused by the pre-stress in suspension, and to be very soft in the rotational direction to achieve a large displacement of the head. So the stiffness ratio between the vertical direction and the operation rotational direction must be maximized. For the straight beam spring design, the stiffness ratio is proportional to the square of the ratio between the beam depth and width.

$$K_z/K_\theta \propto (h/w)^2$$  \hspace{1cm} (1)

Where, h is the beam depth and w is the beam width. Consequently, the high aspect ratio of the spring beam must be maximized.
Electrostatic torque is produced by 2N capacitive plate pairs. For small rotational angles \( \theta \), these plate pairs may be modeled as parallel plate capacitors separated by gaps. Applying a voltage \( V \) to one half of the structure creates a net torque.

\[
T(v, \theta) = \frac{1}{2} N r \varepsilon_0 A \left( \frac{V}{x_n - r \theta} \right)^2
\]  

(2)

Where, \( r \) is the distance from the centroid of the plate to the center of the rotation of the rotor and \( x_n \) is the nominal capacitive gap with zero rotation, \( A \) is the area of each plate and \( \varepsilon_0 \) is the permittivity of air. To obtain a large electrical force, small gap of the parallel plate pair and large area of the plates should be used.

Table 1. Parameters of Microactuator

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over size</td>
<td>1400 ( \mu )m x 1400 ( \mu )m x 150 ( \mu )m</td>
</tr>
<tr>
<td>Plate Length</td>
<td>320 ( \mu )m</td>
</tr>
<tr>
<td>Plate Thickness</td>
<td>2 ( \mu )m</td>
</tr>
<tr>
<td>Depth of Plate</td>
<td>40 ( \mu )m</td>
</tr>
<tr>
<td>Gap of the Plate</td>
<td>4 ( \mu )m</td>
</tr>
<tr>
<td>Total plate pairs</td>
<td>32</td>
</tr>
<tr>
<td>Spring width</td>
<td>2 ( \mu )m</td>
</tr>
<tr>
<td>Depth of spring</td>
<td>40 ( \mu )m</td>
</tr>
<tr>
<td>High aspect ratio</td>
<td>40:2</td>
</tr>
</tbody>
</table>

The design parameters of the electrostatic microactuator are shown in Table 1. To evaluate the displacement of the microactuator under driving voltage, Intellisuite is used for the electro-structural couple analysis of the microactuator. To speed up the modeling process, ANSYS5.6 is used for the creation of the meshed model. The high order 20-node elements are used in ANSYS5.6. Then the meshed model is imported into Intellisuite to create the Finite Elements and Boundary Elements for the couple analysis. Because of the symmetry of actuator structure, only half of the total plate pairs are modeled. Driving voltage is applied to the 16 parallel plate pairs. The displacement of the designed actuator under 40V is shown in Figure 2. According to the simulation results, the equivalent displacement of the magnetic head in track direction is 0.625\( \mu \)m. The overall back and front displacement of the magnetic head in track direction is double the value that is 1.25\( \mu \)m, which meets the design requirement.

Figure 2. Simulation of microactuator displacement under 40V
3. FABRICATION

Improved Lateral Isolated Silicon Accelerometers (LISA) process \(^9\) is used to fabricate the single crystal silicon microactuator. LISA process is one of the silicon surface micro-machining technology for fabrication of high aspect ratio structures. By the LISA technology, the microstructures are processed directly from a crystal silicon substrate using deep Reactive Ion Etching (RIE) process. The microstructures are electrically isolated from the substrate silicon. Fig. 3 shows a cross-section view of the fabrication sequence. The starting wafer is a highly N-doped single crystal silicon wafer (A). Firstly a mask oxide layer is deposited on the silicon substrate and a set of long rectangular strips is fabricated by deep RIE (B). The strips are completely under cut at the bottom and on three sides (C). Trench gaps are thermally oxidized and filled with LPCVD silicon dioxide as anchors, and one end of the strip that is still connected to silicon substrate works as the bus bar to the structures (D). Anchors are then contacted by metal deposition and the structure of the micro-actuator is etched using deep RIE (E). Then the microstructure is released by undercut (F) (G). Finally, the silicon oxide is removed and the micro-actuator is exposed (H).

![Figure 3. Cross-section view of fabrication sequence](image)

Single crystal silicon microactuator with high aspect ratio 20 is fabricated successfully. Fig.4 and Fig.5 show the microstructures of the actuator. The displacement of the microactuator under driving voltage is measured at a microprob station. The voltage is applied to half of the total parallel plate pairs to drive the movable structure to rotate in one direction. One of the test results is shown in Fig. 6. The test results demonstrate that 0.6µm equivalent displacement of the head at each tracking direction is achieved under driving voltage 40V, and 0.8µm displacement is achieved under voltage 45V. The test results have a good agreement with the simulation results. The displacements of the microactuator meet the design requirements.
4. DYNAMIC ANALYSIS OF THE ACTUATOR ASSEMBLY

ANSYS5.6 is used for the finite element modeling and dynamic analysis of the MEMS actuator integrated with a HGA. The MEMS actuator, slider and the suspension are modeled by 8-node hexahedron elements. The cable on the suspension is modeled as 4-node shell elements. The material for the microactuator is single crystal silicon. The material for the slider is Altic. The material for the HGA are stainless steel. The air bearing between the slider and the surface of the hard disk are modeled as four spring elements. The Finite Element model of the microactuator integrated with HGA is shown in Fig.7. A near view of the microactuator meshed model is shown in Fig.8. ANSYS5.6 Block-Lanczos solver is used for the modal analysis. The modal analysis results show that the first mode is an in plane rotational mode with resonance frequency 1.5 KHz, and the first uncontrollable out-of-plane resonance frequency is 16.6KHz. The mode shapes and resonance frequencies are shown in Fig.9 and Fig.10. The simulation results demonstrate that the microactuator is soft in the operational direction and stiff in the vertical direction. The resonance frequencies of the microactuator integrated with HGA meet the dynamic requirements of high density hard disk drives.
To evaluate the shock resistance of the microactuator under working condition, shock analysis of the microactuator integrated with HGA is conducted. A 1000G acceleration shock load is applied to the basement in the vertical direction. The VonMises stresses are obtained. The simulation results are shown in Fig.11 and Fig.12. The maximum stress at the suspension is 171 MPa with a safety coefficient 2.42. The maximum stress in the microactuator is occurred at the end of the spring beam near the central column. The maximum VonMises stress in the microactuator is 578 MPa, which is much smaller than the yield criteria of single crystal silicon (1.23GPa).
5. CONCLUSION

In this paper, we have designed and fabricated a Single Crystal Silicon MEMS actuator which is used for fine positioning of the magnetic head and increasing the servo control bandwidth for high density hard disk drives. The microactuator is processed directly from a single crystal silicon substrate by LISA process. The stroke of the magnetic head is ±0.6 µm under 40V driving voltage. Dynamic performances of the microactuator integrated with HGA are analyzed by finite element simulation. The first in plane rotational mode has a resonance frequency 1.5 kHz, and the first uncontrollable out-of-plane resonance frequency is 16.6kHz. Shock resistance of the microactuator under working condition is examined. The microactuator is suitable to work as a fine high bandwidth actuator for high density hard disk drives.

6. ACKNOWLEDGEMENTS

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7. REFERENCES