Modeling and Simulation of a Single Crystal Silicon Microactuator for Hard Disk Drive

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ABSTRACT

The modeling and simulation of a single crystal silicon microactuator for high-density hard disk drives are described in this paper. The microactuator is fabricated by LISA process, which has an electrically isolated structure directly from a single crystal silicon substrate. The microactuator is located between a slider and a suspension, and drives the slider on which a magnetic head is attached. To make the microactuator achieve high positioning precision and high servo bandwidth, Finite Element Model and Boundary Element Models are built up. The displacement stroke of microactuator is simulated by Electro-Structural couple analysis. The dynamic performances of the microactuator assembled with slider, such as vibration modes and harmonic response, are simulated and analyzed by FEM model. Different designs of the spring elements of the microactuators are investigated. The design of the microactuator is optimized based on the results of simulation. The geometry interface among design, simulation and fabrication are also discussed.

***Keywords*:** Single crystal silicon, Microactuator, Simulation, Hard disk drive

1. INTRODUCTION

The recording density of magnetic hard disc drives (HDD) has been increasing with astonishing speed. 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, is employed [2].

Several MEMS microactuators are being developed based on electrostatic principle[2,3,4]. Most of the electrostatic actuators utilize poly-silicon or nickel based alloy as the micro-structure materials. However, the structures may have problems on stability of mechanical properties, residual stress, and thermal mismatch. This has aroused interest in utilizing single crystal silicon as a structural material. The single crystal silicon structure has better material stability and smaller thermal expansion coefficient (TEC). It also eliminates large material creep, and thermal mismatch problems.

In this paper, a single crystal silicon microactuator for HDD is introduced. The modeling and simulation of the actuator are presented. The electrostatic microactuator is fabricated at the top of a single-crystal-silicon wafer by LISA process and a slider is embedded in the back of the same wafer. The microactuator is a Piggy-back microactuator which is located between a suspension flexure and slider, and drives the slider on which a magnetic head is attached. Finite Element and Boundary Element simulation results demonstrate the performances of the microactuator meet the design requirements for 80kTPI.

2. THE MICROACTUATOR STRUCTURE

The schematic drawing of the single –crystal-silicon microactuator assembly is shown in Fig.1. The Piggy-back microactuator consists of a stationary structure attached to a flexure of the suspension, and a movable structure holding a slider with head. 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.

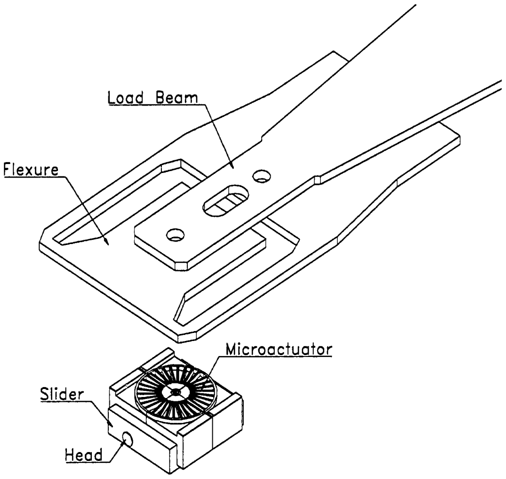

Fig.1 Schematic Diagram of the Microactuator Assembly

Electrostatic torque is produced by n capacitive plate pairs. For small rotational angles θ, these plates may be modeled as parallel plate capacitors separated by gaps. Applying a voltage V to one half of the structure creates a net torque.

$$T(v,\theta)=\frac{1}{2}nr\varepsilon_0 A\left(\frac{V}{x_n-r\theta}\right)^2 \qquad (1)$$

Where, r is 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 ε_0 is the permittivity of air.

There is a yield voltage for the actuator before the actuator collapse. The yield voltage for the actuator remains stable is determined as following [3]:

$$V_{\max}=\sqrt{\frac{8x_n^3K_\theta}{27nr^2\varepsilon_0 A}} \qquad (2)$$

Where, K_θ is overall mechanical spring rotational stiffness of the actuator, which can be determined by the theoretical analysis of the spring.

The requirements for the Piggy-back actuator for 80 kTPI are 1um displacement in track direction and the uncontrollable out of plane resonance frequency higher than 10 kHZ.

Only by theoretical analysis, it is difficult to predict the performances of actuators thoroughly. So the CAE tools are utilized in the modeling and simulation for the development of the actuator.

3. MODELING AND SIMULATION OF THE MICROACTUATOR

3.1 Electro-Structural Couple Analysis of Microactuator

Intellisuite is used for the electro-structural couple analysis of the microactuator. To speed up the modeling process, ANSYS5.6 has been 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. Considering on the actuator structure symmetry, only half of the total plate pairs are modeled. A voltage of 40V is applied to the 16 pairs parallel plate. Different design parameters for the spring and structure have been investigated. The displacement of the actuator for the final design is shown in Figure 2.

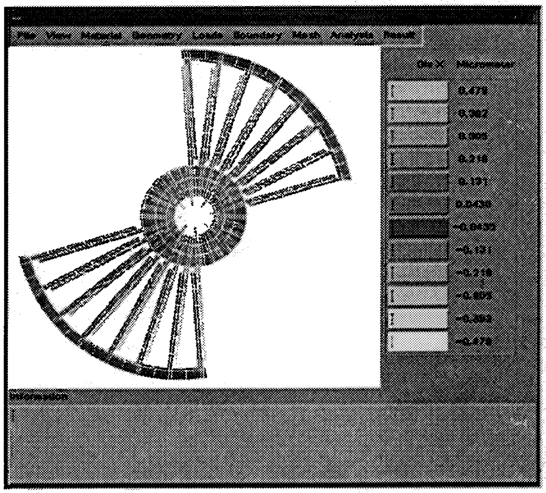

Fig.2 Dispalcement of actuator driven by 40V

The displacement of the magnetic head in track direction is equal to 1.3 times 0.479um because of the structure design, which is 0.623. Considering the structure symmetry of the actuator, the overall displacement of the magnetic head in track direction is double the value that is 1.25um, which meets the design requirement.

The relationship between the actuator dispacement and voltage appllied is also obtained by the simulation. The yield voltage before the actuator collapse is 62.5V. The yield voltage obtained by the theoretical analysis is 67.2V. The difference between the simulation result and theoretical result is about 8%.

The GDS file can be exported by Intellisuite after the simulation which can be used as mask for the microactuator fabrication.

3.2 Dynamic Analysis of the Actuator Assembly

ANSYS5.6 is used for the finite element modeling and dynamic analysis of the MEMS actuator integrated with the slider. The MEMS actuator and slider are modeled by 8-node hexahedron elements. The material for the microactuator is single crystal silicon. High aspect ratio 20 of LISA process is used in the actuator structure. The material for the slider is Altic. The mesh is stretched out in Z direction to allow the thin hexahedron elements in the model. The model consists of 15454 elements and 35692 nodes. The FEM model of the actuator integrated with slider is shown in Fig. 3.

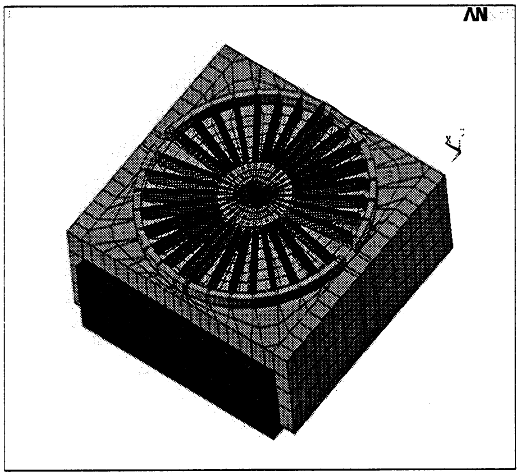

Fig.3 FEM model of parallel plate actuators driving slider rotational

The 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 1.994kHZ. The second mode is an out of plane mode with resonance frequency 11.66kHz, and the third mode frequency is 11.74 kHz that is also an out of plane mode. The fourth mode is an out of plane mode of the spring with a resonance frequency 137kHz, and the fifth mode is a local mode of the parallel plate with a resonance frequency 160kHz.

The fourth mode and fifth mode have resonance frequency over 100 kHz and will not be active under working environment of the microactuator. So only the first three modes have contribution to the dynamic performance of the actuator. The first mode with resonance frequency 1.994kHz is in XY plane and can be compensated by the control system. Both of the second mode and third mode are uncontrollable out of XY plane mode with resonance frequency near 11 kHz, which is only a little bit higher than the design requirement. So the harmonic response of the microactuator assembly on an excitation in Z direction is investigated.

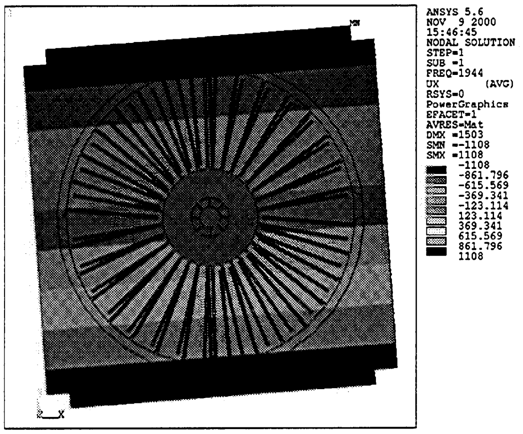

Fig.4 The first resonance frequency 1.994kHZ with a mode in XY plane

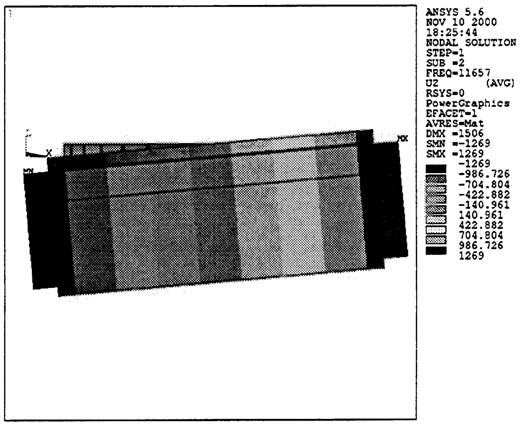

Fig.5 The second resonance frequency 11.66kHZ with a mode out of XY plane

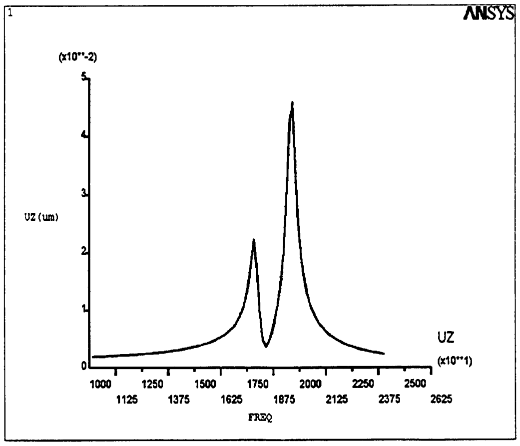

Fig.6 Harmonic Response in Z direction

The harmonic response of the head element to a 1mN force in Z direction, which is located at the trailing edge of the slider, is shown in Fig.6. ANSYS full method is used for the harmonic analysis. The air-bearing acting on the slider is considered in the harmonic response analysis, which is modeled as four spring elements with stiffness in Z direction [5].

When the frequency increases, the out of plane modes of the head element response can be seen at the frequency 17.2kHz and 19.6kHz, which is higher than the value obtained in modal analysis. This phenomena is caused by the air-bearing effects. The harmonic response show that the microactuator assembly has a good out of plane vibration performance in working condition when air-bearing is active.

Dynamic simulation is also conducted for the translational spring design of the microactuator. Extensive simulation results demonstrate the first out of plane mode for this type of spring design has resonance frequency less than 1 kHz. The translational spring elements are not stiff enough to endure the big mass of the slider located out of the actuator plane. The translational spring design does not meet the requirements for dynamic performance of the actuator.

4. SUMMARY

The modeling and simulation of a single crystal silicon microactuator for HDD are presented. Finite Element and Boundary Element model are used. The displacement of microactuator is simulated by Intellisuite Electro-Structural couple analysis. The vibration modes and harmonic response of the microactuator assembly are simulated by ANSYS5.6. The simulation results demonstrate the performances of the microactuator meet the design requirements for 80kTPI hard disk drive.

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