Thermal Stability Evaluation of MEMS Microactuator for Hard Disk Drives

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ABSTRACT

Advances in hard disk drives have created a need for MEMS actuator to achieve high bandwidth of tracking servo and fine positioning of magnetic head. Thermal stability under operational conditions is one of the critical requirements for the application of MEMS actuators in hard disk drives. In this paper, thermal stability of a comb-drive piggy back MEMS microactuator integrated with Head Gimble Assembly (HGA) is modeled and evaluated. The temperature stability of the microactuator in dimension is analyzed. The thermal deformation and thermal stress of the microactuator are simulated by Finite Element Model. The variance in operational characteristics of the MEMS actuator caused by the thermal deformation is analyzed by electrical-mechanical couple analysis. Different materials and fabrication processes for the actuator microstructures are discussed. A scheme for improvement of the thermal stability of the MEMS microactuator for hard disk drives (HDD) is proposed.

Keywords: Thermal, Stability, MEMS, Microactuator, Hard disk drives

1. INTRODUCTION

The recording density of magnetic hard disk drives (HDD) has been increasing with a speed 60~100% annually. The advances in high density hard disk drives require 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 high 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 engaged [1,2,3]. Among all of the dual stage actuation schemes, the "piggy-back" Micro-Electro-Mechanical-System (MEMS) microactuator has been widely accepted for its high servo bandwidth and easy integration of the microactuator with the Head Gimble Assembly (HGA).

Typical HDD guarantee a stable performance under an operational temperature range. In addition to providing the high bandwidth fine tracking of the magnetic head, a critical requirement for the MEMS actuator in HDD is that the thermal deformation and the variance in operational characteristics of the MEMS actuator induced by the materials mismatch in thermal expansion coefficients must be minimized. Especially for the comb-drive MEMS actuator, the variance in gap width may cause an unacceptable shift in the actuation characteristics or even worse, a short circuit failure.

In this paper, the temperature stability of the MEMS microactuator in dimension is analyzed for different fabrication processes and materials. The thermal deformation of the MEMS actuator integrated with HGA is analyzed by finite element model. The variance in operational characteristics of the MEMS actuator caused by the thermal deformation is analyzed by electrical-mechanical couple analysis. Full die-attach and four spot die-attach schemes for integration of the microactuator with HGA are discussed.

2. TEMPERATURE STABILITY OF MICROACTUATOR IN DIMENSION

A schematic drawing of the piggy-back MEMS actuator assembled with HGA is shown in Fig.1. The Piggy-back microactuator is mounted between the slider and suspension for fine positioning of the magnetic head.

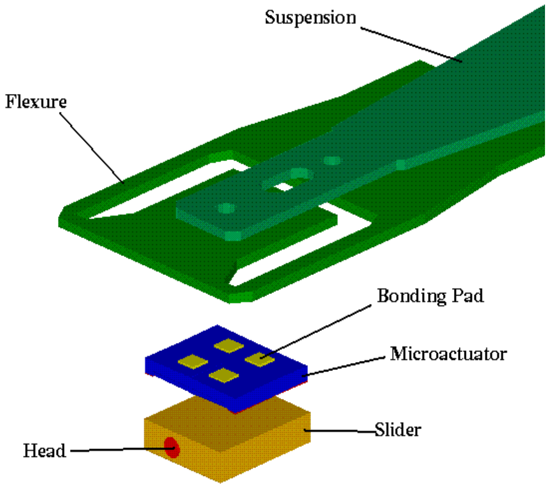

Fig.1. The Piggy-back Microactuator Assembly

The microactuator consists of a stationary structure attached to silicon substrate, and a movable structure connected to an anchored central column via spring beams which works as a rotor. The stationary structure is electrically isolated from 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 rotor that is bonded with the slider. A SEM view of a single crystal silicon (SCS) piggy-back MEMS actuator fabricated by LISA[4] process is shown in Fig.2.

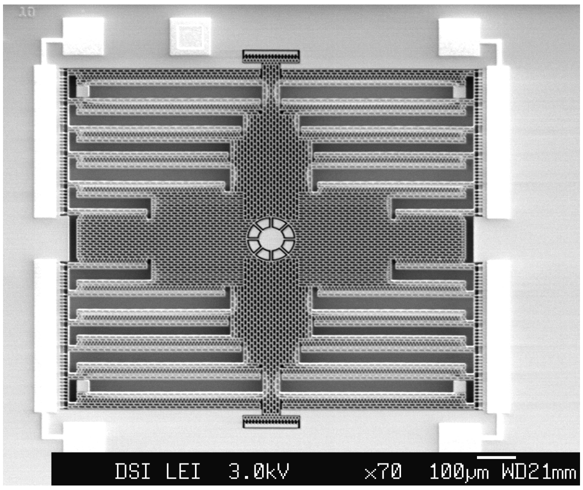

Fig.2.SEM of a SCS piggy-back MEMS actuator

The driving force of the comb-drive actuator is proportional to the reverse of the gap width. Hence the driving force is sensitive to the temperature stability of comb-drive microactuator in dimension. Three types of materials, Nickel, Invar and single crystal silicon (SCS) are evaluated for the actuator microstructures. The Nickel and Invar microactuators are fabricated by LIGA process [1,3,5]. The single crystal silicon microactuator is fabricated by LISA process [4]. The overall dimension of the microactuator is 1.4×1.4×0.15 mm^3. The gap width of the comb-drive is 2μm with a high aspect ratio 40:2. The substrates for all of the actuators evaluated are Silicon. The materials for the electrical isolated layer for LIGA process and the bus bar for LISA process are SiO_2. ANSYS5.6 is used for the finite element modeling and thermal deformation analysis of the microactuator. The microstructure like stator, rotator, electrical isolated layer for LIGA process or the bus bar for LISA process, as well as the silicon substrate, are modeled by 8-node hexahedron elements. The thermal deformation and thermal stress of the microactuators under temperature change 50°C in free space condition are calculated by ANSYS "JCG out-of-core" solver. The thermal deformation and thermal stress simulation results of the SCS microactuator are shown in Fig.3 and Fig.4. Using the command "UPCOORD" in ANSYS, the meshed model of the actuator can be updated by the thermal deformation after the simulation. Then the variances of the gap width are examined and listed in table 1.

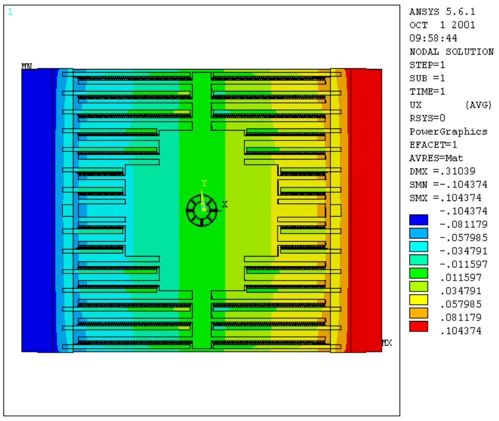

Fig.3 Thermal Displacement in X-Direction (SCS)

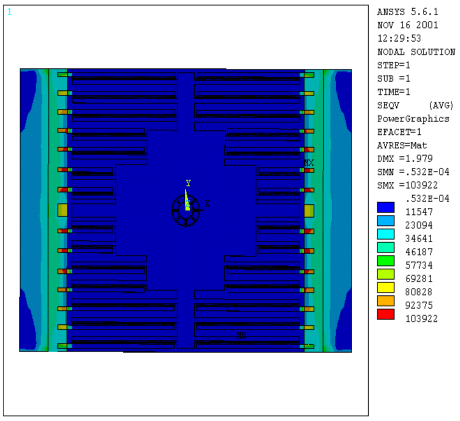

Fig.4 Thermal Stress Von Mises (SCS)

Table 1. Comparison of materials for microactuator

Materials used	Max. gap variance (μm)	Max. Stress Von-Mises (MPa)
Nickle	0.245	141.8
Invar	0.104	118.4
SCS	0.022	103.9

It is demonstrated that the SCS microactuator has the smallest gap variance, followed by the Invar micoactuator. The Nickel microactuator has the worst thermal stability in dimension and the largest gap variance, which is 12.5% of the gap nominal value. The SCS microactuator has the best thermal stability in dimension, because there are no CTE differences among the actuator stator, rotor and substrate, and the thermal deformation is only induced by the bus bar,

3. THERMAL STABILITY OF MICROACTUATOR WITH HGA

3.1 Thermal Deformation and Thermal Stress Analysis

Thermal stability of the single crystal silicon (SCS) microactuator integrated with a HGA is studied. Since the thermal mismatch among the microactuator and other structure materials in the package, thermal deformation and thermal stress will be induced within the package particularly at the interfaces of different materials[6]. The thermal deformation and thermal stress analysis of the microactuator integrated with the HGA are simulated by ANSYS5.6. The microactuator, slider and the suspension are modeled by 8-node hexahedron elements. The cable on the suspension is modeled as 4-node shell elements. The materials for the microactuator are single crystal silicon and silicon oxide. The material for the slider is Altic. The material for the suspension is stainless steel. The microactuator is bounded with the suspension flexure and slider by epoxy. The finite element model of the microactuator integrated with HGA is shown in Fig.5.

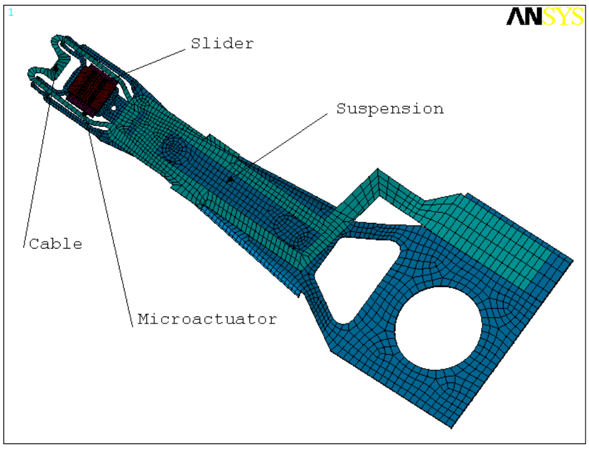

Fig. 5 Meshed Model of the Microactuator with HGA

Two schemes of die-attach, full die-attach integration and four spot die-attach integration of the microactuator with suspension are evaluated. The full die-attach refers to that the entire back surface of the microactuator die is bonded to the suspension flexure by epoxy. The four spot die-attach means that the microactuator die is bonded to the suspension flexure by four patterned spot epoxy pads.

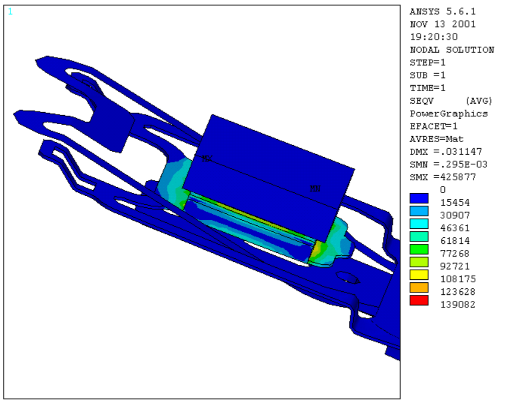

Fig.6 Thermal stress in the microactuator/HGA

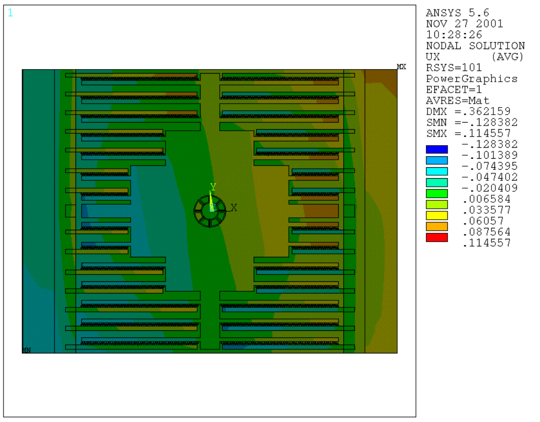

Fig.7 Thermal deformation of the microactuator in HGA package

All of the components in the assembly are assumed in a stress free state at the room temperature 20°C. The thermal deformation and thermal stress in the assembly at temperature 70°C are calculated by ANSYS5.6. The thermal stress Von Mises in the assembly is shown in Fig.6. The thermal deformation of the microactuator in the package is shown in Fig.7.

Table 2 Results for microactuator integrated with HGA

Materials used	Max. gap variance (μm)	Max.stress in MA (MPa)	Max.stress in epoxy (MPa)
Full die-attach	0.097	136.8	29.5
Four spot die-attach	0.075	123.5	32.4

The maximum gap variance of the comb drive, the maximum Von Mises thermal stress in the microactuator (MA) and the epoxy interface between the microactuator die and suspension are listed in table 2. It is demonstrated that the four spot die-attach scheme resulted in a smaller gap variance in the comb drive with a little increase in thermal stress in the epoxy than that of the full die-attach scheme.

3.2 Variances in Operational Characteristics of the Microactuator

As it is shown in Fig.7, the thermal deformation of the microactuator in assembly is not uniform du to the non-symmetrical geometry of the suspension. So it is difficult to predict the variance in operational characteristics of the microactuator under working condition only by theoretical analysis. To evaluate the variance in operational characteristics of the microactuator, the meshed model of the microactuator has been updated by the results of thermal deformation analysis in ANSYS, then the updated meshed model is exported into the Intellisuite software for mechanical-electrical couple analysis. Finite elements and surface elements are created based on the imported mesh in Intellisuite. Displacement constraints are applied to the anchored central column for the rotor and the bus bar of the stator. Then driving voltage is applied to half of the total comb-drive paires between the rotor and stator to drive the rotor to rotate in one tracking direction. The operational characteristics of the microactuator under the room temperature 20°C and the elevated temperature 70°C are simulated. Both of the full die-attach and four spot die-attach schemes are studied. The relationships between the displacement and driving voltage of the microactuator are shown in Fig.8. The microactuator operates in a nearly perfect linear relationship between displacement and driving voltage at room temperature by a stroke of 0.75μm. But at temperature 70°C, the linear relationship is impacted by the thermal deformation. Comparing with the full die-attach scheme, the four spot die-attach schem has a better thermal stability in operational performance.

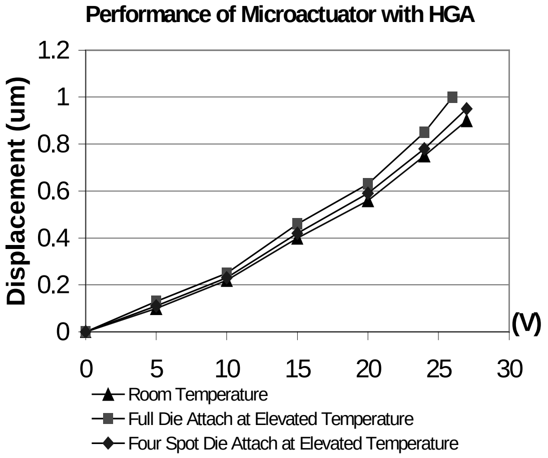

Fig. 8. Displacement of the microactuator under driving voltage

5. CONCLUSION

In this paper, the temperature stability in dimension of the comb-drive piggy back MEMS microactuator is evaluated for Hard Disk Drives. Different fabrication processes and materials for the actuator microstructures are evaluated. Comparing with the Invar micoactuator and the Nickel microactuator fabricated by LIGA process, the Single Crystal Silicon microactuator fabricated by LISA process has the best temperature stability in dimension. The thermal deformation and the variance in operational characteristics of the micoractuator integrated with HGA are analyzed. The four spot die-attach scheme demonstrates a better thermal stability in operational performance than that of the full die-attach scheme.

6. ACKNOWLEDGEMENTS

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