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Shape memory alloy micro-actuator for handling of head gimbal assembly : manufacturing issues

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Abstract

A Shape Memory Alloy micro-actuator has been designed and fabricated for handling of Head Gimbal Assembly in hard disk drive industry. The micro-actuator consists of finger-like bimorph structures that will upward bend due to the difference in elongation of two materials at high temperature. The simulation results on deformed shape and exerting force are performed, and they reveal a feasibility of using SMA actuators for this kind of application. Prototypes of micro-actuators are fabricated by two processes, i.e. sputtering and lift-off techniques with additional sacrificial and protective layers, and individual structure forming and sputtering techniques. Few unsolved manufacturing issues occurred such as delaminating of material due to poor adhesion, oxidation of structures during the crystallization process, and tearing of fixed end of the structure.

Keywords : Head gimbal assembly, Shape memory alloy, Micro actuator, Micro fabrication, Nitinol

1. Introduction

Nowadays, hard disk drive industry is moving toward a miniaturization. The hard disk drive tends to become smaller every year. This miniaturizing trend creates many challenges in a manufacture and assembly of hard disk drive. One of the challenges in the assembly process is a handling of Head-Gimbal Assembly (HGA). HGA that is shown in Figure 1a is used to hold a reading and writing head in position above or beneath a storage disk, and a number of HGAs is assembled together to produce a Head-Stack Assembly (HSA) as shown in Figure 1b.

Since HGA becomes smaller, it is more difficult to handle during the assembly process. The problems in manufacturing when using a conventional technique, namely vacuum chuck, are classified into two main categories. Firstly, the vacuum might not provide enough force to hold HGA as the size of vacuum pad decreases. Secondly, the vacuum chuck might introduce a misalignment of HGA during the assembly with arm coil resulting in a vacuum leakage problem. Thus, a new methodology of handling HGA is required.

In this study, a shape memory alloy (SMA) actuator as a micro-gripper like human fingers as shown

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in Figure 2a is proposed. It will be inserted into the boss hole of HGA, and used to handle HGA by expanding itself and exerting forces on an inner side wall of the HGA. With this gripper, a precisely position control and an elimination of vacuum piping system are also obtained. Among several principles of micro-actuator, SMA is outstanding for this assembly application since it can provide large actuation stress and strain while requiring low operating voltage about 1-3 V [1-2] that is desirable in hard disk drive industries as well as electronics manufacturing.

This work aims to design and demonstrate the feasibility of using shape memory alloy micro-actuator as a micro-gripper for HGA handling application. In this paper, the effects of micro-actuator dimensions on its deflection and force exerting on HGA are briefly described, and the progress on the fabrication of a prototype is reported. Several issues in the fabrication are discussed.

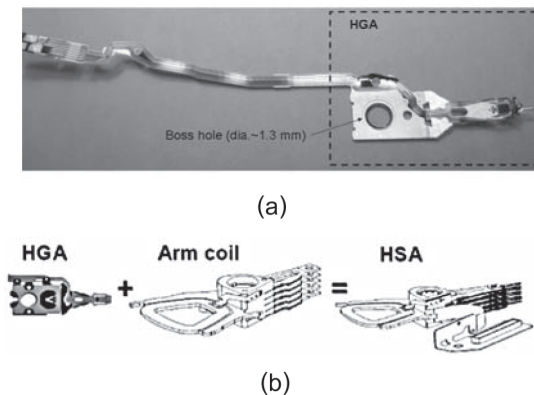


Figure 1 HGA and its assembly; (a) HGA with flexible wires, (b) assembly illustration.

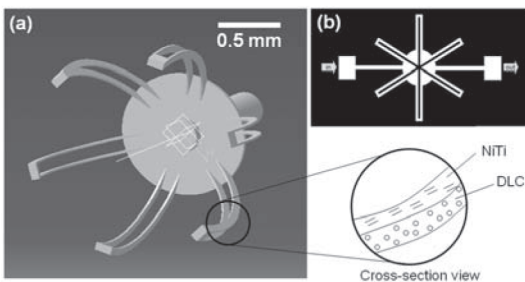


Figure 2 Schematic illustration of designed finger-like micro-gripper.

2. Design of micro-actuator

The SMA is an alloy material that restores its original shape when heated. At low temperature, the phase of the SMA material is martensite that is soft and deformed easily by external force. However, when heating the material above the transformation temperature, it experiences phase change from martensite to high strength austenite resulting in a restoring its original shape.

In this study, the micro-actuator has been initially designed into a paired layer bimorph structure between Nitinol (NiTi) and diamond-like carbon (DLC), or shortly called as DLC/NiTi. NiTi that is the SMA material is deposited over the DLC structure. NiTi is a frequently used SMA material in MEMS [3-4], and its electrical resistivity is high enough for direct Joule heating making structure's simplicity and ease of operation [5]. For DLC, it has large Young's modulus and excellent thermal and electrical resistivity [6]. With this combination, the actuator will be able to generate large force and prevent electrical leakage to the HGA structure.

Temperature of the micro-actuator can be simply controlled by an external heater. However, to make the overall scale of the gripper compact, the structure itself is designed as a heater coil as shown in Figure 2b allowing current to flow through in one direction and providing on-demand Joule heating to its structure directly.

Here, the operating procedures are briefly described. Firstly, the electric current is flowed through NiTi structure resulting in the rising up of beam temperature. The beam then folds up due to the mismatch of elongation between two materials. After that, the folded micro-actuator will be inserted into the boss hole of HGA, and after electric current is released, the temperature drops. When temperature is low enough, the micro-actuator will unfold and press down on the inner wall of boss hole which makes the gripper

be able to hold the HGA and handle to assemble to the arm coil. For releasing step, the heat is applied on NiTi again, and the micro-actuator will fold up, release HGA, and move away.

With this procedure, the criterions of micro-actuator are as followings. The folded actuator must be smaller than the HGA's boss hole, approximately 1,300 μm , and its exerting force must be large enough to hold HGA's weight, approximately 0.4 mN. To verify the feasibility of SMA micro-actuator for handling HGA, FEM analysis is performed, and a brief explanation is in the next section.

3. FEM Analysis

The static structural mode of ANSYS software is used to investigate the effects of micro-actuator's dimensions on its folding deflection when temperature rises, and exerting force when temperature drops.

In this analysis, the micro-actuator is modeled as a NiTi (Ni:Ti composition = 1:1) and DLC bimorph cantilever beam with one fixed end. The number of mesh is about 2,400 meshes (40x10x6 mesh) with mesh size of 0.25 to 37.5 μm . The deflection of NiTi and DLC bimorph cantilever beam is a result of the strain mismatch between two materials due to temperature rising. Upon the temperature rise, shape memory alloys will have both elongation and shrinkage due to thermal effect and shape memory effect, respectively, while DLC has only thermal elongation. To simplify the analysis, for NiTi material, the shrinkage due to shape memory effect and elongation due to thermal effect are combined together and represented as an equivalent thermal expansion coefficient. Details of analysis can be referred from our previous work [7]. In addition, the beam bimorph structure between chromium (Cr) and NiTi is also simulated, and the results are compared together.

3.1 Horizontal deflection simulation

The effects of various beam dimensions have been studied. There are eighteen cases of DLC/NiTi beams investigated. The length of the beam is varied from 750, 1,000, 1,500 μm , the width is varied from 100, 300 μm and the NiTi thickness is varied from 3, 5, 7 μm while the DLC thickness is fixed at 1 μm . For Cr/NiTi, six cases have been conducted for the following NiTi thickness of 2, 3 μm and Cr thickness of 4, 5, 6 μm while their length and width are kept constant at 1,000 and 300 μm , respectively.

When rising temperature from 25 to 80 $^{\circ}\text{C}$, the results of deflection simulation show that there are four cases of folded DLC/NiTi beam that deform with their size smaller than the HGA's boss hole, and their deformed shapes are shown in Figure 3. On the other hand, no case of Cr/NiTi that is smaller than the criteria is found.

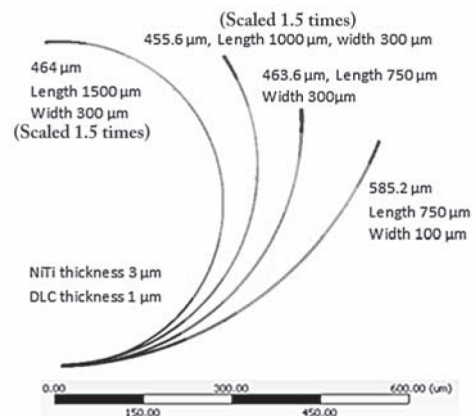


Figure 3 Deformed DLC/NiTi single-beam shape for different beam dimensions and horizontal deflection distances.

3.2 Force simulation

The force analysis is used to predict the contact force between the shape-restored beam and the HGA's inner wall of boss hole. Only one sample for DLC/NiTi beam and another one for Cr/NiTi beam have been simulated. For DLC/NiTi beam, its length, width, NiTi

thickness and DLC thickness is 1,000, 100, 3 and 1 μm , respectively. While those for Cr/NiTi beam, it is 1,000, 100, 1 and 5 μm , respectively. The simulation uses deformed shape of the beams at 80 °C as a starting computational domain. When temperature drops from 80 to 25 °C, the beams unfold and exert force on a fixed vertical wall. Hence, the exerted force is examined from the simulations. From simulations of the single beam, the DLC/NiTi beam creates force of 3.7 mN while the Cr/NiTi beam creates force of 12.6 mN. Therefore, the total force generating from multiple beams of the real micro-gripper would be enough for this handling application.

4. Fabrication process

Various dimensions of micro-actuator are then fabricated as testing micro-grippers. The fabrication process starts with cleaning of a silicon (Si) substrate, and copper (Cu) is sputtered on to the Silicon substrate as a sacrificial layer with thickness about 1 μm . Then, AZ4620 photoresist is spin-coated, the photolithography process is done and Cu layer is etched by Al etch A solution to form a pattern of actuator's anchor. After

that, AZ4620 photoresist as the micro-actuator structure is constructed again, and DLC and NiTi are sputtered with thickness of 1 and 3 μm , respectively, over the substrate. The photoresist is then removed to form the micro-actuator DLC/NiTi structure. To protect the micro-actuator structure from oxidation in annealing process at 500 °C of crystallization, Cu and DLC with 4 and 0.3 μm , respectively, is coated over the substrate. After annealing process, DLC and Cu are then removed, and the micro-actuator is finally released.

The previously described fabrication process is summarized in Figure 4. However in the real trial, it was found that, after sputtering the first layer of DLC and NiTi, NiTi peeled off from DLC, which poor adhesion of NiTi on DLC is considered to be a primary cause. Thus, DLC is replaced with Cr with similar fabrication process. For the new materials, the thickness of Cr and NiTi is equal to 4 and 2 μm , respectively. This replacement is used to verify the feasibility of another part to the end of the fabrication process.

After successfully constructing the Cr/NiTi micro-actuator structure, Cu/DLC is coated over as a protection layer. Then, the substrate was diced into an

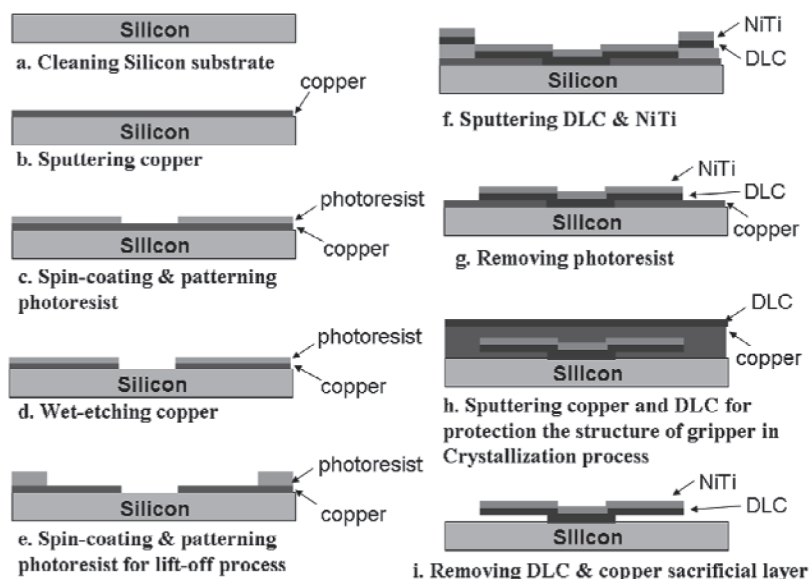


Figure 4 Fabrication process of micro-actuator on silicon substrate.

individual piece, and subsequently annealed at high temperature of 500 °C in Argon environment inside an oven. It was found that copper oxide still occurred and was irremovable. Therefore, to proceed to the end of fabrication, the annealing process was skipped for another set of samples, and Cu protective and sacrificial layers were then removed by iron chloride solution to release the actuator structure. From experiments, it is really hard and consumes time to remove this Cu, especially for the Cu sacrificial layers underneath the beam structure. At the end, the damage of beam structure was also found near the actuator's anchor where the moment on the beam structure is very severely high resulting in only few micro-actuators without crystallization are survived.

From the proposed fabrication process, there are two survived 500- μm wide micro-actuators. The first micro-actuator is 500 μm long, and the second one is 1,500 μm long. The beams consist of NiTi and Cr layers without crystallization at high temperature. Preliminary test of survived micro-actuators has been done to investigate temperature effects. Micro-actuators have been placed on a hot plate at 300 °C to simulate high temperature environment. Figures 5a-c show images of a tested actuator that are taken during the experiment. However, the experimental results showed that they create only small deflection as expected likely due to the ignorance of crystallization and irremovable sacrificial layers.

In addition, there are three main issues in the current fabrication process. The first problem is the peeling off of NiTi from DLC after sputtering process. This problem might be induced due to poor adhesion of NiTi on DLC. The second problem occurred in the crystallization process. Since DLC also partly peeled off from Cu protective layer, there was no protective layer for Cu resulting in oxidation and difficulty to remove protective and sacrificial copper oxide. The last problem is a tearing at the fixed-end of structure near

the anchor after removal of copper sacrificial layer.

Further modification to resolve all mentioned issues has been proposed using Aluminum (Al) sheet which the new process flow is shown in Figure 6. The fabrication process starts with a spin coating of thin film photoresist following by a covering 16 μm thick Al sheet on a Si substrate.

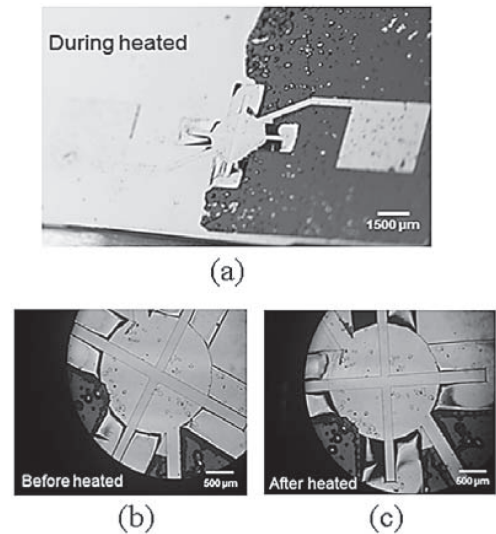


Figure 5 Micro-actuators with 1,500 μm long; (a) the finger-like structure on a silicon wafer, (b-c) magnified images while testing.

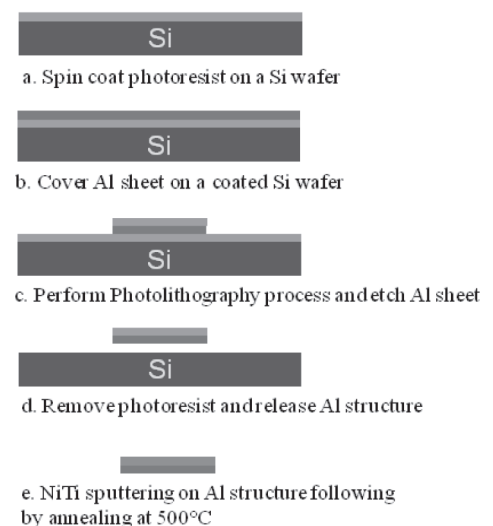


Figure 6 Fabrication process of a micro-actuator made from Al sheet.

Next, another photoresist layer is coated over and patterned using UV light. Aluminum sheet is then etched using Al Etch A solution to form a structure of micro-gripper. After that, the underneath photoresist is removed, and the individual Al structure is spontaneously released from the substrate. Finally, five- μm NiTi is sputtered on the Al structure, and the structure is annealed at 500 °C with overflowing Argon environment for 30 min. With the new proposed process, the tearing on finger structures is avoidable, and the adhesive layer becomes unnecessary.

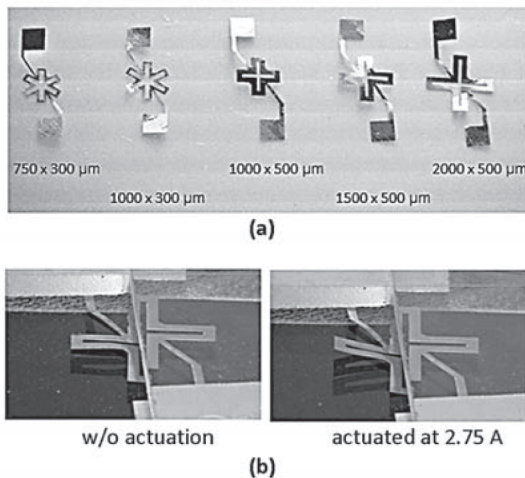


Figure 7 Fabricated Al/NiTi actuators; (a) various actuators, (b) 500x2,000 μm^2 at 2.75 A.

Figure 7a shows the fabricated micro-actuator with various dimensions for 300 and 500 μm wide structures. Although the structure is successfully constructed as planned, the oxide still occurs on the NiTi when heated for crystallization, and it is still a big unsolved issue in this work. However, from examination by X-Ray Diffraction technique, the fabricated Al/NiTi actuators after sputtering process already exhibit a weak crystalline structure between nickel and titanium. Consequently, they are tested to investigate their performance.

From experiments when applying maximum DC current of 2.75 A to the actuator structure, the tip deflection larger than 500 μm is obtained for 500 μm

wide and 2,000 μm long micro-actuator. Figure 7b shows taken images before and after applying DC current. In addition, the loading tests on the 500 μm wide and 2,000 μm long micro-actuator are also examined. Load with different weights is added on the tip of the beam, and the current is then applied. From experiments, it is found that the weight between 0.06 and 1.17 mN is easily lifted up by the actuator with promising fast response in an order of 1 Hz. Although the fabricated actuator shows promising performances, the further study is still necessary.

5. Conclusions

The micro-actuator as a new gripper for handling HGA in an assembly process has been proposed by using shape memory alloy principle. Deflection and force simulations have been performed by using FEM software to assure the feasibility of using the proposed micro-grippers for handling of HGA. The prototype of micro-gripper has been fabricated and tested. The first fabrication process is consisted of sputtering and lift-off techniques above a Cu sacrificial layer. To prevent the oxidation, another Cu/DLC layer is coated over to protect the actuator structure. Both DLC/NiTi and Cr/NiTi actuator structures are constructed, but their fabrications are not successful. There are several problems occurred, i.e. delaminating of NiTi from DLC, oxidation of Cu protective layer, and tearing at the fixed-end of the finger structures. Therefore, further modification has been proposed in order to eliminate those mentioned problems. New fabrication process starts with a patterning of individual Al structure and follows by NiTi sputtering. However, the oxidation is still unavoidable, and remains as a big manufacturing issue. Despite of that, the developed Al/NiTi actuator without annealing process, that has dimensions of 500x2,000 μm^2 with 16- μm -thick Al and 5- μm -thick NiTi, shows large deflection and strong lifting force.

6. Acknowledgements

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