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Yuan, Yanhui; Wong, Yoke Rung; Xia, Xin; Du, Hejun

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FABRICATION AND CHARACTERIZATION OF SMART SLIDERS WITH INTEGRATED ZNO THIN-FILM SENSORS AND ACTUATORS

XIA XIN, DU HEJUN*, WONG YOKE RUNG

*School of Mechanical and Aerospace Engineering, Nanyang Technological University,
50 Nanyang Avenue, Singapore, 639798*

YUAN YANHUI

*Zhongshan Institute, University of Electronic Science and Technology of China
Zhongshan, Guangdong Province, China, 528402*

ABSTRACT: To realize higher areal densities in hard disk drive (HDD), it is necessary to decrease distance between slider and disk, i.e. flying height. The low flying height may result in severe damage occurring on the head-disk interface. Therefore, it is essential to monitor head-disk interactions to prevent instability and damage. In this paper, a smart slider integrated with micro-sensor and micro-actuator is proposed. The fabrication and characterization of the smart slider with integrated zinc oxide (ZnO) thin-film sensor and actuator is presented here. A possible 3D printing manufacturing approach is also proposed to replace the current complex MEMS fabrication processes for producing the smart slider.

INTRODUCTION

In hard disk drive, the head-disk contact becomes inevitable when flying height of the magnetic slider approaches sub-5 nanometer in order to achieve areal densities beyond 500 Gb/in². To achieve higher areal density, the flying height could decrease to 2 to 3 nm or even less when HDD is working (Marchon & Olson (2009)). As shown in Figure 1, to avoid read/write interruptions and damage to the head disk interface, it is vital to sense head-disk contact and adjust the flying height, quicker than current thermal control, on slider-level (Xia et al. (2013)). A study demonstrated thin-film piezoelectric contact sensors fabricated on the top of the slider, however fabrication processes required by this design is not compatible with the standard slider fabrication process (Imai et al. (1995)).

Figure 1. Proposed slider-level contact sensing and head actuation

ZnO, being as good piezoelectric material, has been chosen due to its cheap manufacturing cost, low temperature requirement, environmentally friendly fabrication process and compatibility with

the hard disk drive (HDD) industry (Tadigadapa et al. (2009)). The radio frequency (RF) sputtering is chosen for fabrication due to it is the most commonly used facility in different types of deposition techniques.

DESIGN, FABRICATION AND TESTING RESULTS

Integration process of ZnO sensors and actuators

The existing slider fabrication flow it is not convenient to fabricate features on the top of the slider. Therefore, within the existing framework of slider fabrication process, additional sensors should be fabricated on the wafer. As shown in Figure 1, to fit the process compatibility, this configuration put the sensors close to the read/write elements, thus the head-disk interface which is the point of interest for the sensors to monitor. As a result, the sensors can be less prone to noise and transmission loss. Figure 2 shows the integration process of the ZnO sensors and actuators on the wafer level. Firstly, the ZnO sensors and actuators are fabricated followed by the standard fabrication of existing features (reader, writer, heater and overcoat). Then, before fabrication of pads, additional vias must be machined to allow connection between the pads and the ZnO sensors and actuators. Lastly, pads will be fabricated for the standard electrical elements (reader, writer and heater) and the additional ZnO sensors and actuators.

Figure 2. Integration process of ZnO sensors and actuators

Design of the smart sliders with integrated ZnO thin-film sensors and actuators

Due to the aim of investigating the force contact detection from different directions and positions, four versions of the smart slider were designed as shown in Figure 3. Design 1 and design 3 feature a single sensor with different widths. Design 2 has two sensors on each side, while design 4 is a sensor array consisting of three sensors.

Regarding ZnO RF sputtering process, researches had been conducted extensive studies on ZnO thin film RF deposition process and effects of different factors, which could influence the physical and electrical characterizations of ZnO thin film (Fu et al. (2010)). Extensively experiments have been done in our group to determine the optimum parameters for ZnO thin film deposition (Wang et al. (2012) and Wang et al. (2012)). Those values are shown in Table 1.

Figure 3 Designs of the smart slider

Table 1. Best parameters for ZnO thin film RF deposition

Target distance (mm)	Target material	RF Power (W)	Working pressure (Pa)	O ₂ /Ar Ratio	Rotation speed
70	ZnO (99.99%)	90	0.8	1:3	30R/min

Fabrication of the smart sliders with integrated ZnO thin-film sensors and actuators

The whole unit was fabricated on a p-type (100) silicon wafer by microfabrication. Major processes included oxidation, RF sputtering, RIE etching and dicing. The fabrication process started with oxidation of the silicon wafer. The oxide layer provides insulation between the bottom electrode and the silicon substrate. Au/Cr of 100 nm thick was firstly deposited as the bottom electrode. A ZnO layer of 1 μm thick was then sputtered at room temperature, followed by deposition of the top electrode, another 100 nm of Au/Cr. Afterwards, 2 μm thick silicon dioxide layer was deposited on the wafer. Subsequently, vias were etched to allow access to the top and bottom electrodes. The fabricated sensors with the vias are shown in Figure 4.

Figure 4 Fabricated ZnO sensors on silicon wafer

Pads were then fabricated before the wafer was diced into individual sliders. To remove the flange, the fabricated wafer was bonded to a substrate and the wafer could be diced through. The sliders with clean side-cut were shown in Figure 5.

Figure 5 Smart sliders with ZnO sensor pads after dicing

Characterizations of the smart sliders for force sensing

The fabricated sliders were tested for their performance in force sensing. Impedance analysis was also performed for the sliders. In the force sensing test, a force was applied by pressing a probe on the top electrode. Since the piezoelectric layer is located underneath the top electrode, the ZnO layer experiences strain. Thus, a voltage will be generated across the bottom and top electrodes. The two electrodes were connected to an oscilloscope to display the output voltage.

Figure 6 Probing test: (a) light press; (b) heavy press

Figure 6 shows the force sensing results of Design 3. The force was adjusted by adjusting the screw of the probe. For a lighter press, the peak output voltage was 1.5 mV as shown in Figure

6(a); for a heavier press, the output voltage increased to 2 mV as shown in Figure 6(b). The probe force was quantified by using a precision weighing instrument. The probe force was found in the lower range of mN.

Impedance analysis was performed to identify the resonance of the sliders. The resonance of Design 1 was found at 724 kHz. The resonance of Design 3 which has a narrower ZnO strip than Design 1 was lower at 501 kHz. It was found that the resonance was dependent on the width of the ZnO films.

DISCUSSIONS

Although the smart sliders integrated with sensors have been fabricated and tested, some significant issues, which could cause system failure, remain to be solved.

Firstly, the actuators could only be fabricated without the slider overcoat which is up to 50 μm thick. Fabrication of the slider overcoat requires specialized process and further advanced equipment is needed.

Secondly, it is difficult to mount the fabricated sliders for integration with suspensions due to the small scale.

Thirdly, the fabrication process is quite time consuming and faced with high risk of peel-off on fabricated layers.

To overcome those shortcomings, a possible approach is to employ the additive manufacturing (AM) technology for the fabrication. A method for additive layer-by-layer fabrication of arbitrarily shaped 3D silicon micro and nanostructures has been reported by KTH (Fischer et al. (2012)). The fabrication was based on the following procedures: 1) chemical vapor deposition (CVD) on desired places of silicon; 2) local implantation of gallium (Ga) ions by focused ion beam (FIB) writing to provide the etching selectivity of Si, and 3) forming the defined 3D structures by etching the silicon in potassium hydroxide (KOH) to generate the desired 3D structure. They demonstrated three layers Si structure with 10 nm level resolution. Other groups also presented the feasibility of multi-materials (metal and semiconductors) AM process with laser assisted CVD (LCVD) (Hon & Hutchings (2008) and Gibson et al. (2010)).

Figure 7. Comparison of traditional MEMS fabrication process and AM fabrication process

Figure 7 demonstrates the comparison of traditional MEMS fabrication process and AM fabrication process. It is obvious that AM has shorter manufacturing processes than that of

traditional MEMS fabrication technology, and therefore saves time and reduces risk of failure during the process.

However, to realize LCVD 3D direct writing for manufacturing MEMS device, there are many issues to be considered and solved, such as limited material choices (especially for piezoelectric materials), low-deposition rate and productivity, high temperature during the deposition, requirement of atmosphere control chamber, metal oxidation, long preparation time required for design, setup and validation of processes before manufacturing.

To improve the AM system and structure quality, it is necessary to broaden suitable candidate material choices, obtain their working performances such as adhesion of different layers and assess their mechanical properties. Those issues would present challenging and interesting research topics to researchers.

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