A Thin-Film Piezoelectric Impact Sensor Array Fabricated on a Si Slider for Measuring Head-Disk Interaction

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Abstract —A new type of Acoustic Emission sensor using a thin film piezoelectric material (sputtered ZnO) was developed for measuring head-disk interaction in a rigid magnetic disk system. The sensor is mounted on a Si slider (length : 3 mm) and was fabricated using micro-machining techniques in our on-going efforts to downsize sliders. Some fundamental tests of the sensor were conducted : sensitivity and frequency characteristics, and a flying test over a rotating bump disk.

I. Introduction

Projects aimed at downsizing and lowering flying height in magnetic disk system sliders have increased intensively. At present, the spacing between head and disk in advanced commercial products is in the semi-contact or full-contact range. Because of this, a new type of Acoustic Emission (AE) sensor, which is applicable to smaller sliders and has higher performance, has become necessary. Therefore, we developed a new type of AE sensor, using micro-machining techniques. For the new sensor, we targeted a resolution of 1 mN over a bandwidth of more than 10 MHz.

II. Design and fabrication

With the new sensor, a thin-film piezoelectric material is used for detecting AE waves. The sensor is carried on a Si slider (length : 3 mm), and a backing material is bonded to the backside of the sensor. This measuring system is produced by a micro-machining techniques [1].

The slider is shown in Fig. 1. The piezoelectric sensor array is fabricated on the Si substrate. On the backside of that substrate, an Air Bearing Surface (ABS) is fabricated. This ABS is of the conventional type with two straight rails with steps at the leading edge [2]. As a backing material, a Pyrex glass substrate is bonded to the thin-film piezoelectric sensor array with epoxy adhesive. This material is used for preventing AE waves passing through the sensor after being reflected off the back side of the sensor. Pyrex glass is used because it has almost the same acoustic impedance as Si. The backing material also plays a role in increasing the sensitivity. Although mass of this slider is different from a conventional slider, we do not think that dynamic behavior of the slider changes except contact force.

The sensor is shown in Fig. 2. It is located at the trailing edge of one of the rails, where the minimum spacing occurs, and consists of a sputtered ZnO layer sandwiched by a tungsten common lower electrode and arrayed aluminum upper electrodes. Sputtered ZnO (thickness : 2 μm) is used to simplify the process. The upper electrode array is in a 2x2 matrix pattern and the size of each sensor element is 0.1 mm x 0.1 mm. This pattern is to examine the relationship between the sensor output and the contact position.

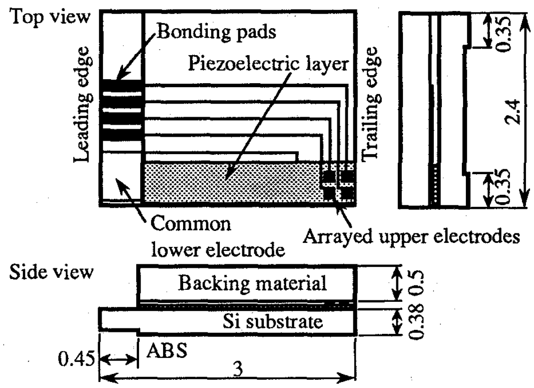

Fig.1. Structure of the slider with thin-film piezoelectric sensors. Pyrex glass is used as a backing material. The depth of the ABS slot is 20 μm and the depth of the front step is 2 μm.

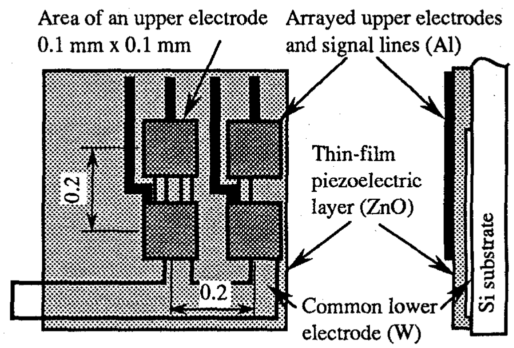

Fig.2. Structure of the thin-film piezoelectric sensor array on its Si substrate. The thickness of the piezoelectric layer is 2 μm.

III. Simulation of output characteristics

The output voltage of the sensor is calculated from stress occurring in the ZnO layer using the dynamic structural analysis program "DYNA3D". The output voltage of the sensor can be calculated from equation (1) [1]. The finite element model of the sensor and slider is shown in Fig. 3.

$$U = \sigma_z \, t_z \, h_{33} \, S^D_{33} \, \frac{Cp}{Cp + Ce} \quad (1)$$

- U :output voltage of the sensor
- σ_z :stress of the ZnO layer in the thickness direction
- t_z :thickness of the ZnO layer
- h_{33} :piezoelectric coefficient of sputtered ZnO
- s_{33}^{D} :compliance of sputtered ZnO
- C_p :capacitance of the sensor element (about 0.3 pF)
- C_e :parasitic capacitance of the total measuring system for one sensor (from the signal line and the bonding pad on the slider, about 3 pF)

Properties of materials used in the simulation are shown in Table 1 [1]. Fig. 4 shows a simulation of stress (σ_z) of the sensor element A in Fig. 3 when the impulse force is applied to the ABS just below the sensor element A. As the sensor output is proportional to the stress occurring in the ZnO layer, the stress is used as the vertical axis in Fig.4. It is clear that in the case with no backing material, the stress of the ZnO layer is quite small (maximum amplitude : 0.17 x10^6Pa), but the sensor with the backing material has more than 30 times higher sensitivity. From the other results of Fig. 4, there seems to be almost no possibility that an AE wave reflected off the back side of the backing material substrate could influence sensor output.

Fig. 5 shows the results of a simulation showing the relationship between the thickness of the backing material substrate and the stress of the ZnO layer caused by the same type of input force as in Fig. 4. It is known that thicker substrates have higher sensitivities, but this relation saturates and a design value of 0.5 mm is considered. As for the thickness of the Si substrate, thinner substrates have generally a higher sensitivity, but thin Si substrates have a possibility of deformation during processing (i.e. sputtering ZnO), so a thickness of 0.38 mm was chosen here.

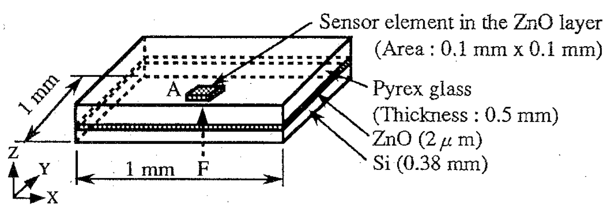

Fig.3. Slider model for the simulation. The boundary conditions of this model in the calculation are free, as in flying conditions of a slider.

TABLE I

MATERIAL PROPERTIES

	Density ρ (kg/m^3)	Compliance s_{33}^{D} x10^{-12}(m^2/N)	Poisson's ratio ν
Si	2332	7.68	0.28
ZnO	5720	5.72	0.3
Pyrex	7650	9.0	0.25

(ZnO : h_{33} = 1.82 x 10^{10} V / N)

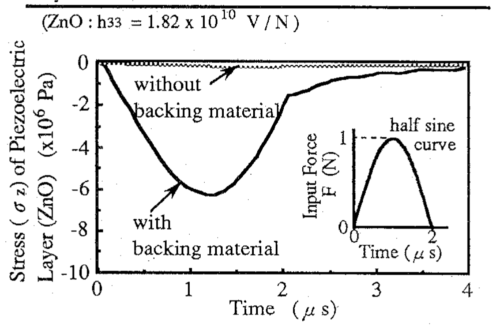

Fig.4. Simulation of stress in the piezoelectric layer (ZnO) caused by the half-sine impulse force.

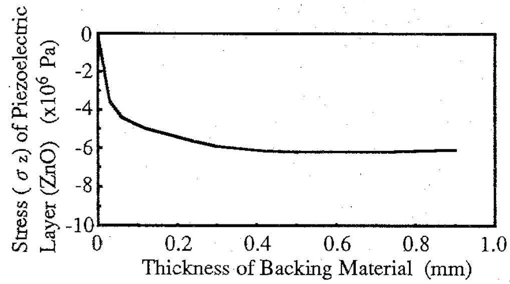

Fig. 5. Simulation of the relationship between stress of the ZnO layer and thickness of the backing material (Pyrex glass).

IV. Characteristics

A. Fundamental Characteristics

Fig. 6 shows the result of testing the sensitivity of the sensor by dropping a steel ball on the ABS. In this test, the calculated maximum input force was 1.88 N under the conditions shown in Fig.6 [3]. The output voltage of the sensor was 84 mV (amplified 6.25x), and the sensitivity of the sensor element was about 7 mV/N.

Fig. 7 shows frequency-characteristic results for the sensor. In this test one of the sensor elements was excited by a sine-shaped input voltage with slowly increasing frequency, and another element detected the generated AE waves. The result shows that the sensor element has a bandwidth of about 10 kHz-30 MHz. The cause of the gain peak which can be seen in the figure at about 40 MHz is unknown so far. The characteristic frequency of the ZnO layer in the thickness direction is much higher (about 1.6 GHz) than the frequency at this gain peak, and the characteristic frequencies of the Si substrate and the Pyrex glass substrate are lower. We think that the peak is due to the AE wave propagating in the lateral direction.

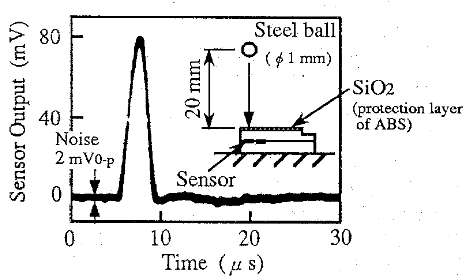

Fig.6. Output signal of the sensor when the steel ball drops onto the ABS just over the center of one of the sensor elements. The signal is amplified by 15.9 dB. The sensitivity of the sensor is about 7 mV/N. (conventional sensor : 10-60 mV/N (in Hitachi, Ltd.)) The noise level in the sensor output was about 2 mVo-p.

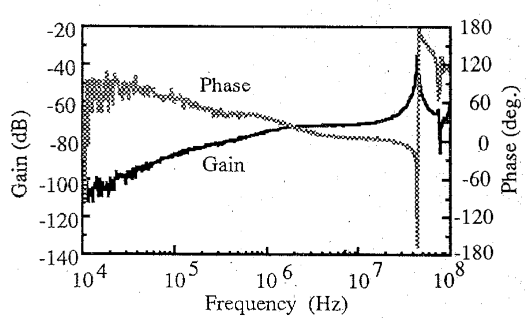

Fig.7. Frequency characteristics of the sensor. One of the sensors is used as an exciter and another sensor is used as a detector for the generated AE wave. Bandwidth of the sensor is about 10 kHz-30 MHz. (conventional sensor : 10 kHz-1 MHz (in Hitachi, Ltd.))

B. Flying over "bump"

Fig. 8 shows the experimental setup for testing the output of the sensor flying over a rotating disk. The slider is bonded to a suspension which is typical for a conventional 70 % slider (micro-slider). The output wire (Al, ϕ 30μ m) for the sensor signal is attached by wire bonding. We took the layout of the wires not to inhibit pitch motion of the slider.

The typical flying height of micro-sliders in rigid disk systems is about 100-130 nm. To measure the output signals of the sensor in a semi-contact condition with the disk, the slider is positioned for a low flying height – around 50 nm. The loading force and position of the slider were determined by a program for flying-height simulation. The values are shown on the right hand side of Fig. 8.

In this test, the sensor output signal was measured as a function of disk velocity [4]. The relationship between disk velocity and maximum amplitude of sensor output is shown in Fig. 9. High pass filters (HPF) with thresholds of 100 kHz and 200 kHz were used in the main amplifier. There is a difference in the amplitudes of the output signal. But both curves in Fig. 9 have almost the same shapes and the peaks in those curves occur when the slider flying height is a little lower than the bump height.

Fig. 10 shows the AE signal for different flying heights as measured at points A-C in Fig. 9. Even though the AE signal varies in amplitude, the three AE signals have almost the same frequency –about 150 kHz.

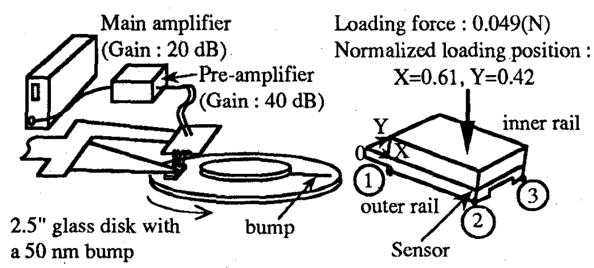

Fig.8. Experimental setup for sensor output test of slider flying over a rotating disk with a bump. The circled numbers show the points where flying heights are calculated.

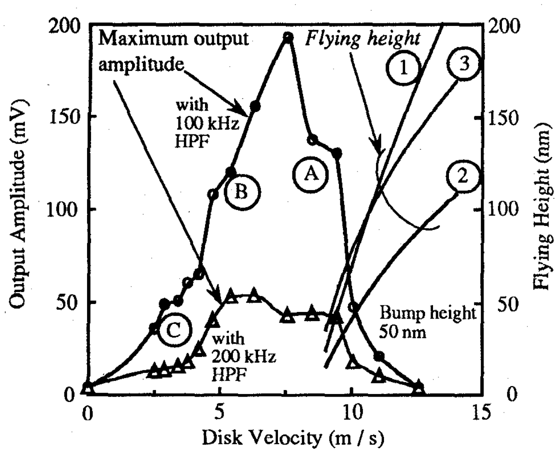

Fig.9. Maximum amplitude of the sensor output signal of the slider flying over the rotating disk with a bump. Calculated flying heights of the slider are also shown for locations defined in Fig.8.

To determine the reason for this frequency, a simulation of the slider using a finite element analysis and an experiment were performed. Based on the results of Table 2, the frequency from Fig. 10 seems to be the first characteristic frequency of the slider. When the 200 kHz HPF was used, a vibration of about 200 kHz is also noticed. (It is considered the 2nd mode of the slider.) In the experiment in Fig. 8, the measured output signal is a result of the elastic vibrations of the slider induced by the mechanical interactions between the slider and the disk. At the same time, the output of the sensor in the flying-height region above 50 nm was negligibly low. It seems that the sensor does not pick up any interference from the air bearing vibration of the slider.

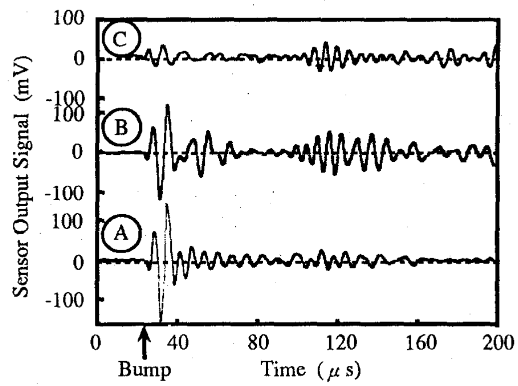

Fig.10. Measured AE signals in the experiment using the 100 kHz HPF in Fig. 9.

TABLE II
CHARACTERISTIC FREQUENCY OF THE SLIDER

Frequency (kHz) Simulation (Mode)	Experiment
213 (Torsion)	137
271 (1st Bending)	240

Summary

A new AE sensor on a Si slider based on a thin-film ZnO layer was developed for measuring the head-disk interaction. The sensor output characteristics were determined experimentally : The sensitivity of the sensor is 7 mV/N, the bandwidth is 10 kHz-30 MHz and the signal-to-noise ratio is approximately 40 : 1. The experiments confirm that this AE sensor is suitable for detecting contacts at the head / disk interface.

References

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