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Silicon Nitride Cantilever Array Integrated with Si Heaters and Piezoelectric Sensors for Probe-based Data Storage

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ABSTRACT

In this paper, a new silicon nitride cantilever integrated with silicon heater and piezoelectric sensor has been firstly developed to improve the uniformity of the initial bending and the mechanical stability of the cantilever array for thermo-piezoelectric SPM(scanning probe microscopy) -based data storages. This nitride cantilever shows thickness uniformity less than 2%. Data bits of 40 nm in diameter were recorded on PMMA film. The sensitivity of the piezoelectric sensor was 0.615 fC/nm after poling the PZT layer. For high speed operation, 128×128 probe array was developed

Key Words : Cantilever, PZT, Probe, Data storage, AFM

1. Introduction

In recent years, SPM-based data storages have been studied extensively to overcome the storage density limits of HDD, optical storages and semiconductor memories.[1] Vettiger et al. suggested a thermo-mechanical data storage system where a resistively heated AFM tip reads and writes data bits while scanning over a polymer substrate.[2] In the previous work, we introduced a thermo-piezoelectric data storage concept[3] where the data bits are recorded with a resistively heated AFM tip and are detected by the integrated PZT sensor to reduce the power consumption and to eliminate the off-set voltage of the sensors.

Besides the density of the storage system, the speed of the operation is very important and researchers of IBM developed an array type of system, improving it by more than thousands times. In implementing the thermo-piezoelectric probe array to SPM based storage system, initial bending uniformity and mechanical stability of the cantilevers are crucial to reliable read/write operation, neither of which are easy to obtain with silicon cantilevers made of SOI wafers. The thickness of silicon cantilever, which greatly affects the initial deflection of the cantilever, is determined by the initial thickness of the device silicon layer and etching depth of silicon during the tip fabrication process, both of which have large variation in general. Silicon nitride cantilevers, however, can have very uniform thickness and good mechanical stability because the LPCVD silicon nitride film is very uniform and has superior mechanical properties to silicon. In this research, we have firstly developed a SPM-based data storage with silicon nitride cantilever array having silicon tip heaters and piezoelectric sensors.

2. Design and Operation

In the previous study, we have introduced the thermo-piezoelectric read/write mechanism with a resistively heated AFM tip and a piezoelectric PZT sensor as shown in Fig.1 The resistively heated tip writes the data bits by scanning over a polymer media and the piezoelectric sensor reads data bits by the self-generated charges induced by the deflection over indentations on the polymer

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media. In a piezoelectric cantilever, like PZT, the mechanism of sensing is as follows; as the PZT cantilever scans across the indentation of a polymer film, the cantilever deflects along with the indentation of the film, causing stress on the PZT film. The variation of stress in the PZT film produces self-generated charges on the surface of the PZT capacitor with no applied voltage. The charge is not generated by the absolute stress, but by the variation in stress. Therefore, the piezoelectric sensing method has advantages of low power consumption, no off-set voltage and high reading speed compared to the thermal sensing method of IBM. And, the power consumption in writing can be reduced by selecting low Tg polymer media because the selection of media is not limited by heating of the media in reading process.

The uniformity in initial bending and the mechanical stability of cantilever array are crucial to reliable read/write operation of SPM based storages using cantilever array, both of which are not easily attainable with PZT cantilevers made of SOI wafer. The thickness of silicon layer in the thermo-piezoelectric cantilever, which greatly affects the initial deflection of the PZT cantilever, is not uniform due to the thickness non-uniformity

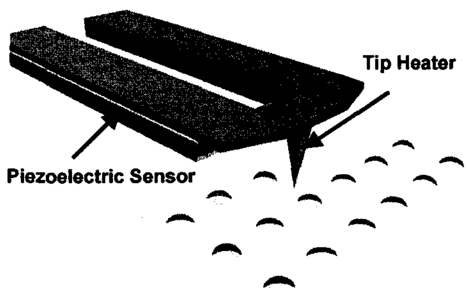


Fig. 1 Thermo-piezoelectric R/W mechanism

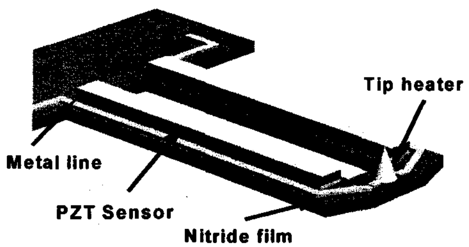


Fig. 2 Schematic drawing of nitride thermo-piezoelectric cantilever.

of the device layer of the SOI wafers and the non-uniformity of the remaining silicon layer after tip etching process.

In this work, the silicon nitride cantilever with PZT sensors and silicon tip heaters was designed for uniform initial bending and good mechanical stability of the cantilever as shown in Fig.2. The PZT sensor and the silicon tip heater are formed on the nitride cantilever. The silicon heater is electrically connected through the shallow metal line. The nitride layer deposited by LPCVD method has very uniform height and superior mechanical properties to silicon layer. Using these nitride cantilevers, very uniform probe array can be made and more reliable read/write operation of SPM based data storage is possible.

3. Fabrication

In this study, silicon tips were formed on silicon itride films. The formation of the nitride cantilevers with the silicon tips is complicated because silicon film cannot be grown epitaxially on nitride film. Grow et al. developed nitride cantilevers with silicon tips by growing nitride films on the silicon tips.[4] The fabrication process is very complex and the protection of silicon tip during the nitride etching process is difficult. We firstly tried to make SOI wafers with nitride buried layer for the nitride cantilevers with silicon tips.

Fabrication process for the cantilevers is summarized in Fig.3 A silicon nitride buried SOI wafer was fabricated by joining and annealing of a oxidized wafer and a low stress nitride deposited wafer with thickness of 500 nm (a, b).

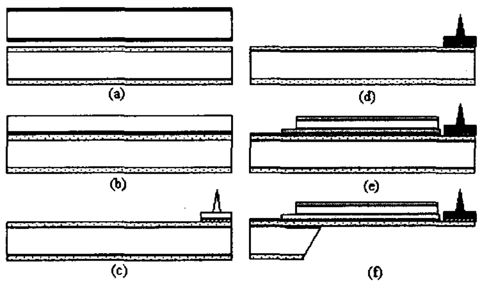


Fig. 3 Fabrication process of nitride thermo-piezoelectric cantilever.

The nitride film was deposited by low press chemical deposition (LPCVD). After the silicon tips and an electrical silicon contact regions were formed on the nitride film (c), the thermal oxide of 50 nm was grown on it to passivate the silicon and to reduce surface damage resulting from ion implantation. Boron was implanted at 40 keV with a dose of 5 x 10^{14} cm^{-2} at the silicon tip heater region and with a dose of 5 $\times 10^{15}$ cm^{-2} at the silicon electric contact region (d). Then, the wafer was subjected to furnace annealing in a N_2 ambient at 900℃ for 30 minutes.

After depositing LPCVD oxide of 200 nm to protect inter-diffusion between PZT and Si layer, the PZT capacitor was formed as described in the previous work.[5] The bottom electrode was formed by sputtering thin titanium (Ti) adhesion layer, followed by 120-nm thick platinum (Pt) layer. The PZT layer was formed by sol-gel process. The PZT films were annealed at 650℃ for 1 minute using the rapid thermal process. The resulting PZT film is 300 nm thick and its composition is near the morphotropic phase boundary. On the PZT, a RuO_2 film was deposited as the top electrode. The PZT capacitor structure was patterned using an inductively coupled plasma reactive ion etching system (e). The Pt/Ti pad was formed by sputtering and lift-off process. Finally, backside silicon was selectively removed in an aqueous potassium hydroxide (KOH) solution (f).

After the wafer was diced into individual cantilevers, the tip of the cantilever was heated to record a series of data bits on a polymer media. For polymer media, 40 nm thick PMMA film was prepared by spin coating method.

4. Results and Discussion

Fig.4 shows the scanning electron microscopy (SEM) images of the fabricated nitride cantilever integrated with silicon tip and PZT sensor. The silicon heater and PZT sensor on the nitride cantilever are clearly defined in the figure.
The fabricated cantilever is bent upward slightly. The thickness uniformity of the nitride film is

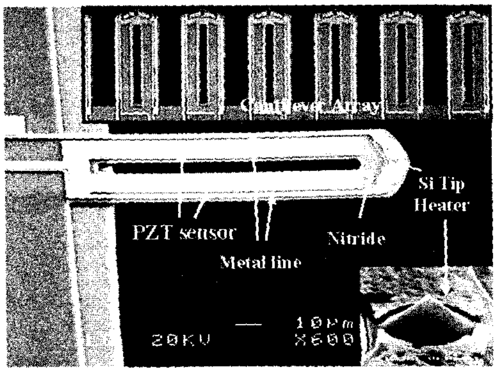


Fig. 4 SEM image of the fabricated cantilever.

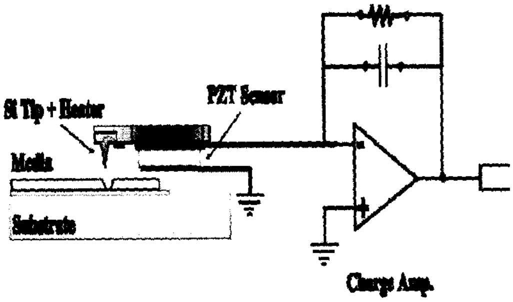


Fig. 5 Schematic of thermo-piezoelectric read/write.

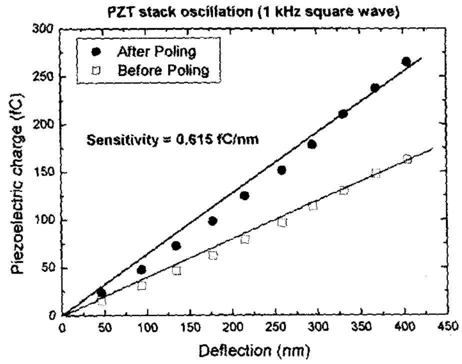
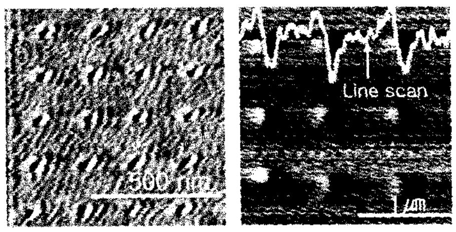


Fig. 6 Piezoelectric charge output as a function of various cantilever deflections.



(a) Written data bit (b) Piezoelectric read -out

Fig. 7 Thermo-piezoelectric read and write on PMMA substrate.

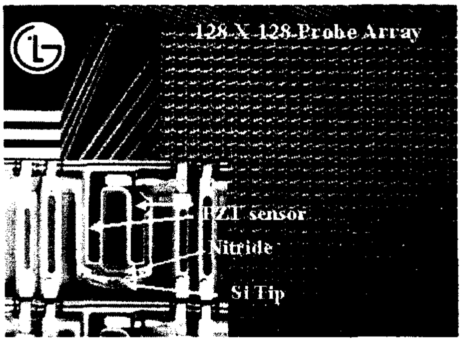


Fig. 8 Nitride thermo-piezoelectric probe array (128×128 array).

below 2% over the 4 inch wafer.The cantilever array shows uniform bending status. The length of cantilever is 120 ㎛, and thickness of nitride film and PZT film is 500 nm and 300 nm, respectively. Fig.5 is the schematic drawing of the piezoelectric sensing system where piezoelectric charges are collected from the PZT sensor as the tip is deflected over the bit indentation.[6] The generated charge is amplified by a charge amplifier (model No.: CS515-2, Clear Pulse Company). The amplified signals can be compared to the initial setting values using a comparator to differentiate the data to be either "0" or "1".

To measure the sensitivity of the PZT sensor, the induced charge signals were collected with various cantilever deflection, as shown in Fig.6. The deflection was measured using a stacked piezoblock which consists of a series of stacked PZT capacitors and produces a known displacement at a given voltage. Piezoelectric charges were generated from the PZT sensor as the piezoblock moves up and down by the applied voltage while the tip of the cantilever just contacted the piezoblock. These charges were collected by a charge amplifier with gain of 2V/pC at a square wave of 1 kHz. The signal was linearly proportional to the cantilever deflection. The sensitivity was 0.4 fC/nm and 0.615 fC/nm without and with poling of the PZT film. The PZT film reaches the saturated state by poling treatment, which leads to the increase of the sensitivity.

Using the fabricated cantilever, a series of data bits were written on a PMMA media, as shown in Fig.7(a). A voltage with pulse width of 20 micro second was applied at 10V. Indentation data bits of about 40 nm were recorded on the PMMA film. The writing voltage can be further decreased by minimizing the silicon heater size. Fig.7(b) shows the piezoelectric charge outputs obtained on PMMA media with the data bits of about 150 nm. The readback signals from PZT sensor were observed from the line scan data. As the tip travels down the indentation, negative charges are generated. The signal from the indentation is clearly distinguished from the noise signal. But, the piezoelectric charge outputs were not clearly differentiated from the noise on the data bits below 150 nm.

To detect smaller bits, we are attempting to increase the aspect ratio of the indentations and increase signal to noise (S/N) ratio. The depth of the indentation was only 20nm while the diameter was 150 nm. To increase indentation depth, new materials for media and writing method are under study. The sensitivity can be more improved by the optimization of the PZT layer and the cantilever structure. The noise signals from the flat area are mostly due to system noise. We are trying to eliminate the exact sources of the electric noises to improve the S/N ratio.

For high speed operation of SPM based data storage, 2D array type cantilever with uniform initial bending are required. We made 128 X 128 2D thermo-piezoelectric probe array using surface micromachining technology. The fabricated probe is very uniform as shown in Fig.8. The tip heaters and the PZT sensors are very well defined. Using this array of cantilevers, parallel read/write operation is under progress.

5. Conclusions

Nitride cantilever integrated with a silicon tip heater and a piezoelectric sensor has been firstly developed using SOI wafer with nitride buried layer for uniform initial bending and mechanical stability of the cantilever array. Data bits of 40 nm in diameter were recorded on PMMA film and readback signals were obtained on the data bits of 150 nm. The sensitivity of the piezoelectric sensor was 0.615 fC/nm. To improve the data rate, the 128 X 128 probe array was fabricated, whose initial bending was very uniform.

Acknowledgment

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