Thermopiezoelectric Cantilever for Probe-Based Data Storage System

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***Abstract*—Thermopiezoelectric method, using poly silicon heater and a piezoelectric sensor, was proposed for writing and reading in a probe based data storage system. Resistively heated tip writes data bits while scanning over a polymer media and piezoelectric sensor reads data bits from the self-generated charges induced by the deflection of the cantilever. 34 x 34 array of thermopiezoelectric nitride cantilevers were fabricated by a single step wafer level transfer method. We analyzed the noise level of the charge amplifier and measured the noise signal. With the sensor and the charge amplifier 20mn of deflection could be detected at a frequency of 10KHz. Reading signal was obtained from the cantilever array and the sensitivity was calculated.**

***Index Terms*—probe based data storage, charge amplifier, thermopiezoelectric, MEMS data storage.**

I. INTRODUCTION

Reseachers in IBM have suggested a MEMS based read/write device, a probe-based data storage, as a high density memory that can overcome the density limits of HDDs and semiconductor memories [1-3]. This device consists of thermally heated AFM tip that can make nano-size indentation on polymer media and a resistive sensor whose resistance varies along the distance between the sensor and the media.

A thermopiezoelectric cantilever with a resistively heated AFM tip and a piezoelectric PZT sensor was suggested for the probe-based data storage system [4-6]. The resistively heated tip writes data bits by scanning over a polymer media and a piezoelectric sensor reads data bits using the self-generated charges induced by the deflection of cantilever as it scans across the indentations on the polymer media. Thermopiezoelectric read/write mechanism consumes almost no power during the reading process and does not require any compensational circuitry for the offset adjustment.

The piezoelectric sensor in this device can discriminate the charges generated from several nanometers' deflection of the cantilever since the depth of the indentation on the polymer media will be of the order of several nanometers or less. The sensitivity of the sensor depends on the property of the sensor material and the sensing method. We used a charge amplifier for the sensing and analyzed the noise level of the amplifier and calculated the sensitivity of the sensor.

The cantilevers should be transferred to the ASIC circuit that controls the signals to and from the cantilevers. Wafer level transfer method is required in this application. A two step transfer method was developed, where the cantilevers with the tips directed to the surface are fabricated out of SOI (silicon on insulator) wafers. The cantilevers are firstly, transferred to a glass wafer and then to a CMOS wafer to avoid a face to face integration of the tips and the CMOS circuits [7-8].

We have developed a one step bonding method for the cantilever wafer and CMOS wafer. The tips are directed to the bottom of a nitride cantilever so that the cantilevers can be bonded to the CMOS wafer. 34 x 34 array of cantilevers were transferred with this method

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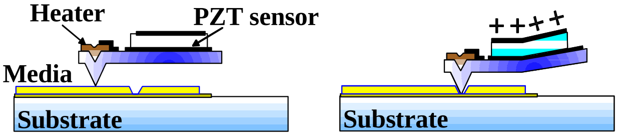
and a reading signals were obtained.

II. THERMOPIEZOELECTRIC READ/WRITE

1. Read/Write Mechanism

The thermopiezoelectric cantilever for the probe based data storage writes data bits by making indentation s on a polymer media with a resistively heated AFM tip. When the cantilever scans the polymer media surface and meets the indentations the cantilever bends down and charges are generated on the surface of the piezoelectric material. These charges are amplified by a charge amplifier and produce data signal. Fig. 1 shows the reading mechanism.



(a) (b)

Fig. 1. Schematic view of the thermopiezoelectric cantilever for the probe based data storage. (a) Indentations on the media is generated by the heated tip. (b) Charges are generated on the surface of the PZT sensor as the cantilever deflects along the indentation.

2. PZT Property

PZT of the MPB composition was used for the piezoelectric sensor as it has very high piezo coefficient. PZT film was sol-gel coated with the solution from INOSTEK Inc. And the piezo coefficient of the PZT film ws measured by the dual beam laser interferrometer of the aixACCT. Fig. 2 shows the piezocoefficient of the PZT film used in the piezoelectric sensor. The area of the test sample was 0.0504mm^2 and the thickness of the film was 300nm. The piezocoefficient of the PZT film was about 50pm/V, which is less than that of the bulk PZT by about one order of magnitude.

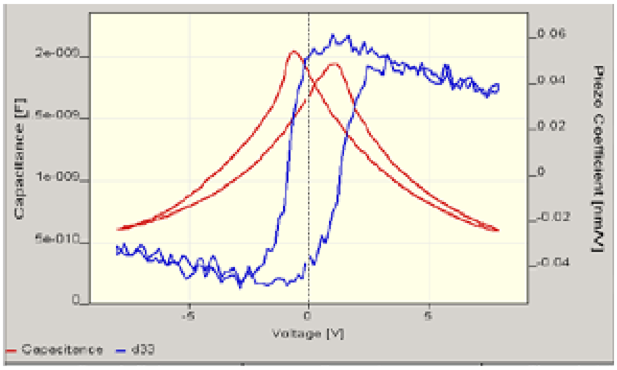


Fig. 2. Piezocoefficient (d33) of the 300nm of PZT film shows a hysteresis curve . The area of the capacitor in this measurement was 0.0504mm^2.

3. Charge Amplifier Circuit

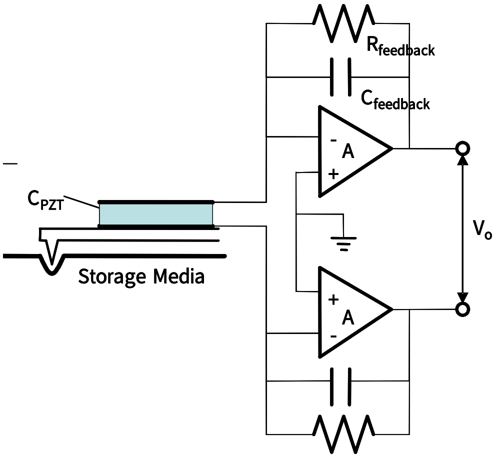


Fig. 3. Differential amplifier configuration with symmetric charge amplifiers. Noises from the external sources can be reduced with this configuration.

The charges generated on the PZT surface are amplified by a charge amplifier circuit. The signals from the charge amplifier can contain high level of external noise since the impedence of the PZT capacitor is very high. Thus a differential amplifer configuration was adaped as shown in Fig. 3. The external noises are compensating each other so that the overall noise can be reduced greatly.

In this configuration, however, the noises from the OP amp itself can not be avoided and can even be doubled.

The noises from the charge amplifier can be one of the following three kinds. Fig. 4 shows the expected noises from the OP amplifier and the measured noise from the open circuit. First one is the input-referred voltage noise (e_n) amplified by the gain,

$$N_g = \frac{C_{PZT}}{C_{feedback}} \times e_n \qquad (1)$$

Second one is the input-referred current noise amplified by feedback resistor,

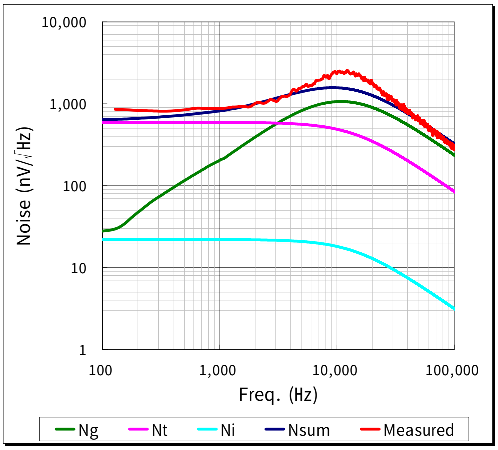


Fig. **4.** Internal noises from the OP amplifier are calculated and compared with the measured noise from the open circuit in Fig. 3.

$$N_i = R_{feedback} \times i_n \qquad (2)$$

And the third ones is the thermal noise induced by the feedback resistor,

$$N_t = \sqrt{2 \cdot k \cdot T \cdot R_{feedback}} \qquad (3)$$

The capacitance of the PZT capacitor was about 200pF and the feedback capacitor and the feedback resistor were 0.5pF and 22Mohm, respectively. The sum of these three noises fits well with the measured noise from the circuit.

With this charge amplifier circuitry, charge signals are obtained from the deflection of 20nm of cantilevers. Fig. 5 shows the signals from the circuit when the piezoelectric cantilever is scanned along the step of 20nm height and the noises when the cantilever is standing still.

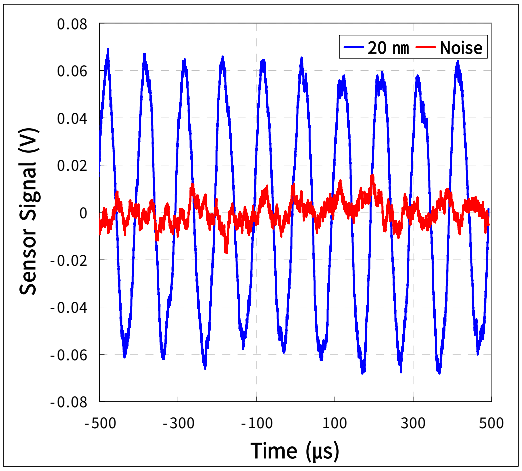


Fig. 5. Signals from the circuit in Fig. 3 while the tip is scanned along steps of 20nm height and noises from the circuit are displayed together.

The signal to noise ratio is higher than 5 in this case, and it still requires further improvement considering the indentation on the polymer media will be on the order of a few nanometers. The signal to noise ratio can be improved by the optimization of piezoelectric material and the configuration of the sensor structure and by the reduction of the noise.

III. WAFER LEVEL TRANSFER OF CANTILEVERS

Previously developed transfer of cantilevers to the CMOS circuit requires two step of bonding process toa void face to face integration of the AFM tips and the CMOS circuit. This transfer process can be simplified to a one step bonding process if the AFM tip is formed below the silicon wafer.

The tips can be formed below the surface of the cantilever wafer by anisotropic etching of silicon surface with KOH solution following a nitride layer deposition for the cantilever and a poly silicon layer for the resistive heater. PZT sensors are formed above the cantilever and bump material is deposited to the bonding site of the cantilever wafer shown on the left top of the Fig. 6. CMOS wafer and the cantilever wafer are bonded together by eutectic bonding process. The bulk silicon of the cantilever wafer is grinded by CMP(chemical

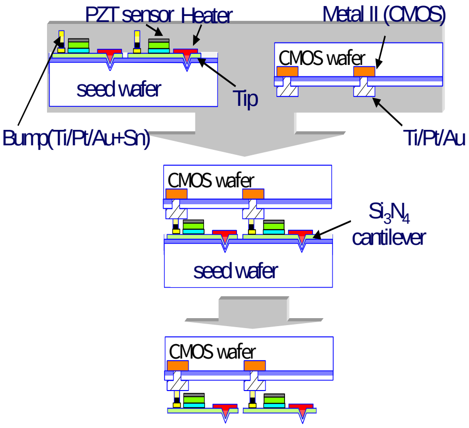


Fig. 6. Simplified view of the one step wafer level bonding process.

mechanical polishing) to about 50 micrometers and removed out by XeF_2 remaining only the thermopiezoelectric cantilevers transferred to the CMOS wafer. The bumps are acting as the electrical connection between the CMOS wafer and the cantilevers.

The process depicted in Fig. 6 does not require a SOI wafer and uses nitride layer as the cantilever, which reduces the overall cost and improves the stability of the cantilever and tips compared to the silicon cantilevers and tips. Moreover, the use of nitride also improves the uniformity of the cantilevers within the wafer greatly, which is of importance since parallel operation of cantileves are required to improve overall operation of the probe-based data storage devices.

We have fabiricated an array of 34 by 34 thermopiezoelectric cantilevers on the CMOS wafer by this one step wafer level bonding process. The cantilevers are 70μm long and 45μm wide and 300nm thick. The two rows and columns at the edge of 34X34 arrays are dummy cantilevers, which was used to guarantee identical fabrication environment for the inner cantilevers. With these dummy cantilevers, the fabrication yield was improved.

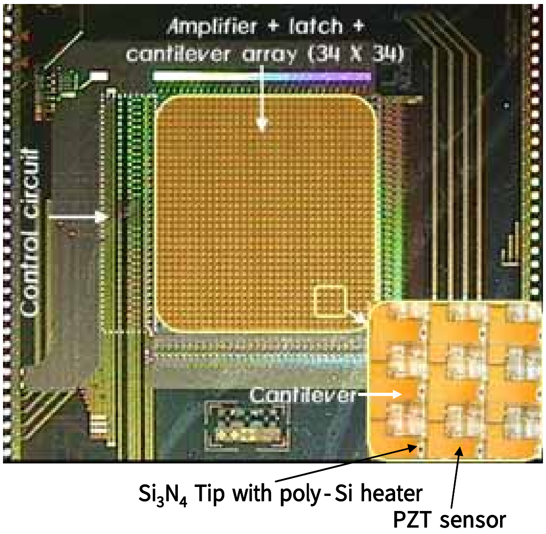


Fig. 7. 34 by 34 array of thermopiezoelectric cantilevers transferred to the CMOS wafer.

IV. CONCLUSIONS

Thermopiezoelectric cantilevers with resistively heated AFM tip was fabricated for the application to probe-based data storage system.

PZT films of MPB composition was used for the piezoelectric material for the sensor and a differential amplifier configuration of charge amplifiers was adapted to reduce the external noises in the circuitry. Noise level of the measurement system was well in accordance with the sum of the noises from the operational amplifier. Signal to noise ration of above 5 was obtained with the piezoelectric sensor and the differential amplifier configuration. The sensitivity of the system should be improved further by the optimization of the piezoelectric materials and the sensor structure and by reducing the noises.

We have developed a one step wafer level bonding process. 34 by 34 array of thermopiezoelectric cantilevers were successfully transferred to the CMOS wafer by one step wafer level bonding process.

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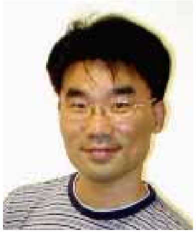

Seongsoo Jang received the B.S., M.S. and Ph.D degrees in materials science and engineering from KAIST (Korea advanced institute of science and technology), Korea, in 1993, 1995 and 2001 respectively. Between 2001 and 2004, he spent 3 years in the memory research center of Hynix semiconductor Ltd. where he worked on the fabrication of DRAMs. In March 2004, he joined the device and materials laboratory of LG Electronics Institute of Technology. He is currently involved in the development of SPM based data storage system.

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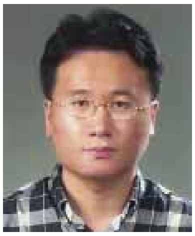

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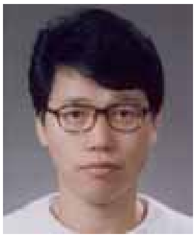

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