MICRO-TIP ASSEMBLED METAL CANTILEVERS WITH BI-DIRECTIONAL CONTROLLABILITY

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ABSTRACT

Layered-metal micro cantilever with a micro tip was fabricated and characterized for high-density data storage device. The cantilevers were fabricated by the sequential depositions of chromium, gold, and chromium layers by sputtering with their stress and thickness controlled. The reversed sputtering technique was utilized for fine patterning of the cantilevers and hence for good uniformity of cantilever's elevation height after sacrificial release. A micro protrusion was formed at the end position of the cantilever by the newly developed contact shadow mask process. The fabricated cantilevers were driven in the upward direction by the electro thermal Joule heat, and also in the downward direction by the electrostatic force between cantilever and the silicon substrate. A series of small dots as recorded in a thin film photoresist by using the indentation of the fabricated protrusion, which showed that the cantilevers would be applied to high-density data storage devices.

Keywords: metal cantilever, bi-directional controllability, shadow mask, micro tip, peel off, data storage

1 INTRODUCTION

The recording density of hard disk drive is limited by the thermal fluctuation of the magnetic boundary and by the superparamagnetic effect [1]. In the mean time, MEMS (Micro Electro Mechanical Systems) based data storage systems utilizing the atomic force microscopy (AFM) have been studied as one of the next-generation storage technologies [1-5]. The researchers including IBM utilizing MEMS based data storage devices have reported that the data density can be upwards of terabit-per-square-inch range [1-5].

In MEMS based data storage, a micro tip on a cantilever is used to write and read data bits on the recording media. The tips have been usually prepared by the chemical etching of silicon [1, 2] that required careful etch-time control to assure the sharpness of the tip. Tips could also be made by depositing a low stress silicon nitride film on an inverted pyramidal pit that had been formed by silicon crystalline etching technique [4]; this technology required subsequent wafer-bonding and layer-transferring processes to release the tip and cantilever. The cantilevers with the micro tip were driven by utilizing one or combination mechanisms of heat transportation, piezo-resistivity, and light reflection [1-5]. Height control of cantilever tips is needed for the mechanical contract with the recording medium for both writing and reading, and the initial elevation height should be uniformly over the cantilever array to equalize the read/write conditions over the surface. In this paper, we proposed a simple fabrication method of micro tips by the peel off process on a layered-metal cantilever. The cantilever's actuation characteristic was made to be uniform in the array thanks to the newly employed dry etch patterning of the cantilevers.

2 FABRICATION

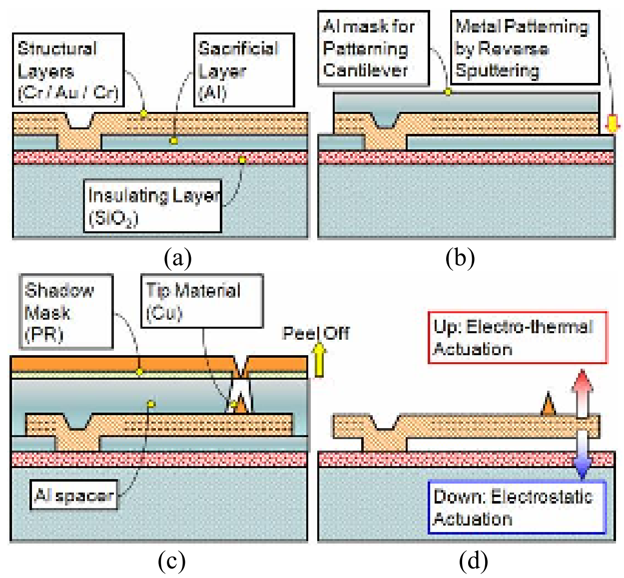


Figure 1: Fabrication steps for metal layered cantilever and micro tip. (a) Insulating layer (SiO_2) and sacrificial layer (Al) are deposited and patterned, which is followed by deposition of structural layers (Cr-Au-Cr). (b) Layered cantilevers were patterned by reverse sputtering with Al mask. (c) Al is deposited on the layers and etched with PR mask, which is used as a shadow mask for continual evaporation of Cu. (d) Cantilever is released by Al removal.

We started the deposition process of glass sputtering of 6000 A (Angstrom) on a silicon wafer for electrical isolation. On the glass layer, an aluminum layer (sacrificial layer) of 6000 A was deposited by vacuum evaporation and patterned in aluminum etchant (Figure 1a). Three metal layers of 1st chromium / gold / 2nd chromium layers were deposited without breaking the vacuum at the thickness combination of 400 A / 5000 A / 1200 A and at the sputtering pressure of 2 / 2 / 20 mTorr, respectively. The argon gas flow rate was 20 sccm to control the internal stresses. On the deposited metal layers, the second aluminum layer was deposited at 6000 A by the thermal evaporation, and was patterned in aluminum etchant. The metal layers were annealed in the oven at 280 degree C for 10 minutes, and then cooled down to room temperature. The cantilever patterns of the second aluminum were transferred to the chromium / gold / chromium layers by the reversed sputtering process at RF 400W for 75 minutes (Figure 1b). The third aluminum layer of 5 microns in thickness was newly deposited on the layers to be used as a tip-spacer (Figure 1c) [6]. The third chromium layer was deposited at 500 A, and patterned for the formation of the contact shadow mask. The through-hole was formed by the wet etching in the aluminum etchant warmed at 60 deg C for 30 minutes. The sharp tip was made by copper deposition (5 um thick or more); the aperture of the contact shadow mask closed itself during metal deposition [6, 7]. The metal deposited on the tip spacer was removed by the peel-off technique utilizing a sticky tape, followed by the removal of the chromium shadow mask layer (Figure 1d and Figure 2).

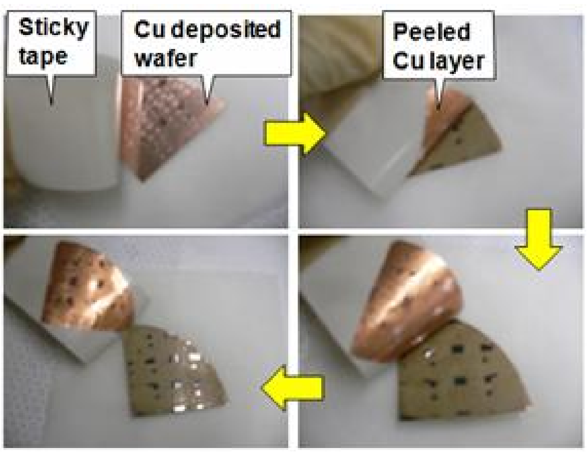


Figure 2: Peel off process with a sticky tape; Sticky tape clings to the copper evaporated wafer, and peels copper off from the wafer.

The sacrificial aluminum was selectively removed to release of the cantilevers with NMD3™, which is a base liquid of 2.38% TMAH (Tetra Methyl Ammonium Hydroxide). By this fabrication steps, we obtained an array of micro tip equipped micro cantilevers as shown in Figure 3. The height of micro tips was about 2-3 um, and the radius of the apex was about 100 nm at minimum. The bi-directional actuator with a micro tip could be used to develop the AFM-based data storage.

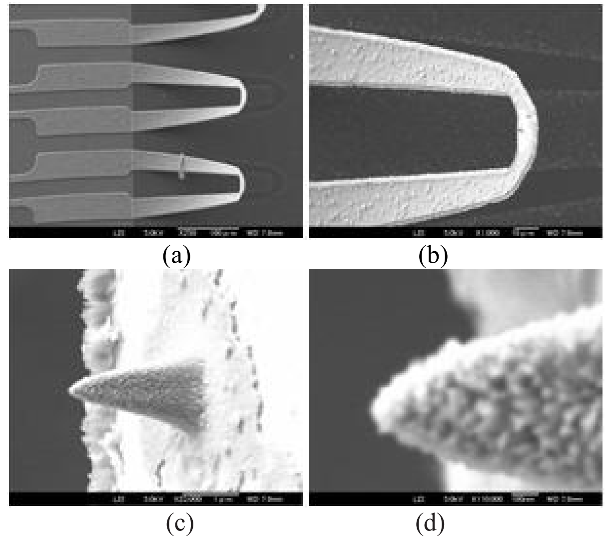


Figure 3: Scanning electron microscopic images of (a) the cantilever array, and enlarged views of (b) a cantilever, (c) micro tip at the end of cantilever, and (d) the end part of a micro tip.

3 DRIVING CHARACTERISTICS

We designed the cantilever that deflected upward by the electro-thermal Joule heat and downward by the electrostatic force; this could be done by changing the driving circuits as shown in **Figure 4** [8]. Electro-thermal driving was utilized to write data pits by indentation on the recording media with the micro tips. At the same time, electrostatic driving would be used to equalize the elevation heights of the arrayed tips and to read data bit by the resonance vibration.

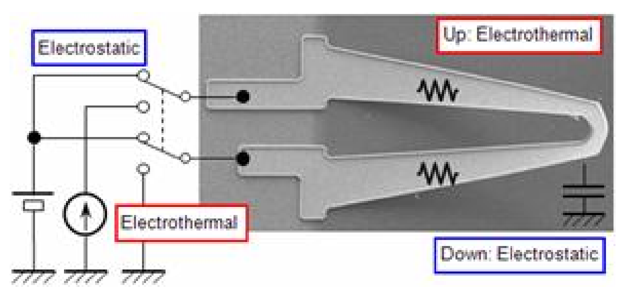


Figure 4: Operating principle of upward and downward operation by electro-thermal and electro-static drive, respectively.

By the prescribed process, we obtained a layered-metal cantilever, in which a chromium layer was positioned on the gold layer for electro-thermal driving. Because the thermal expansion coefficient of chromium (9.5ppm/C) is smaller than that of gold (14ppm/C), the cantilever curled upwards by the Joule heat.

We measured electro-thermal and electrostatic driving with functions of applied power (0.85V x 39mA) and voltage (13.5V) as shown in **Figure 5**. Due to the limitation of optical measurement system, we observed the motion at a spot near the anchor of the metal cantilever, and it was 130 nm and 220 nm by electro-thermal and electrostatic driving, respectively. The actual tip motion was approximately 40 times leveraged, which was thought to be large enough to compensate the tip height variation, by using the FEM analysis.

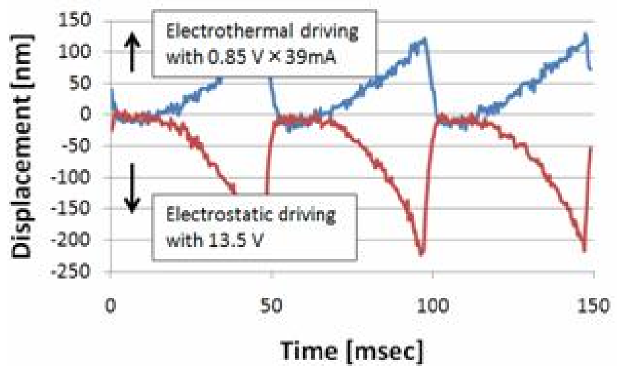


Figure 5: Experimental result of electrostatic and electro-thermal driving of the fabricated Cr/Au/Cr cantilever. The elevation of cantilever was measured at the distance of about 50 um (about one fifth of the length of cantilever) from the anchor because of the measurement limit (numerical aperture) of the laser interferometer.

4 DATA WRITING

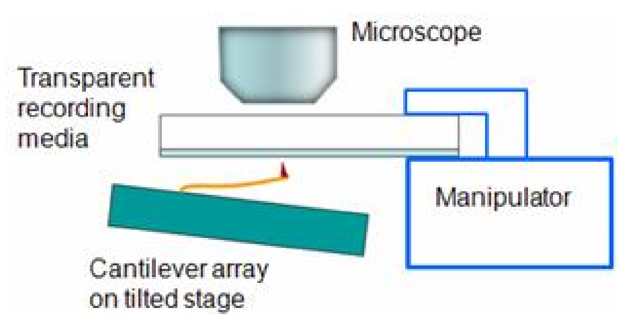
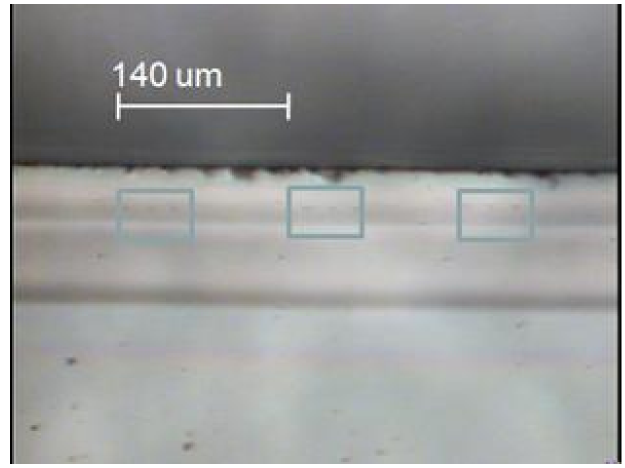
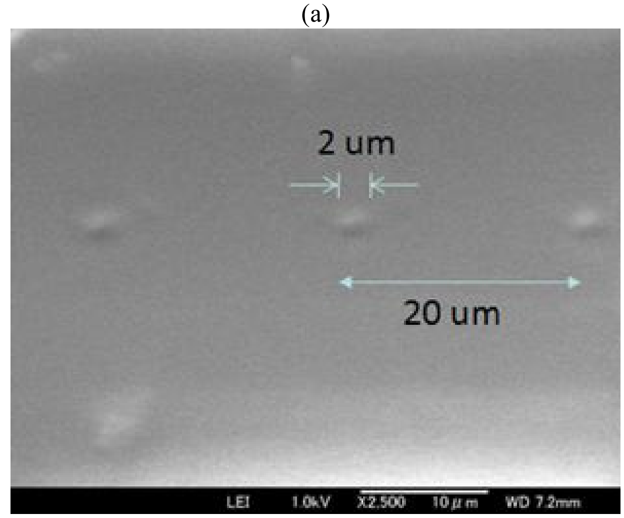


Figure 6: Experimental set up for data writing utilizing fabricated micro cantilever array (not in scale).

Figure 6 shows the experimental set up for writing data pits by utilizing the fabricated cantilever array. On a slide glass, a thin layer of photoresist (S 1805) was spin-coated at the 5000 rpm and baked at 110 degree C. The arrayed cantilevers were heated up to 120 deg C and were brought into contacted with the photoresist on the glass substrate. We obtained data pits separated by the cantilevers pitch (140 um) as shown in **Figure 7 (a)**. **Figure 7 (b)** shows data pits engraved at a 20 um period by the repetitive operation. The size of data bit was about 2 um in diameter, which would be minimized by the control of heating temperature, indenting time and depth.



(a)



(b)

Figure 7: (a) Microscopic images of the written dot data with the fabricated cantilever array, and (b) the scanning electron microscopic image which magnified right hand side square

Apart from reference 6, we utilized three aluminum layers for the sacrificial layer, the dry etch mask, and for the tip spacer, because aluminum could be etched fast in the etchant, which did not etch the cantilever metals. We once tried photoresist for the tip spacer material but it was burned out during the tip material deposition. In addition to this, the photoresist residue was not completely removed in the following processes. Because of the chemical resistance to the etching solutions, we used copper for the tip and aluminum for the sacrificial layer. The characteristics and processes for the tested metal material are compared in **Table 1**.

Table 1: Characteristics of the utilized materials.

	SiO_2	Al	Cr	Au	Cu
	Insulation	Sacrificial / Mask	Cantilever	Cantilever	Tip
Thick (~um) deposition	△	O	X	△	O
Deposition	Sputter	Sputter or Evaporation	Sputter	Sputter	Evaporation
Endurance to Al etchant	O	X	O	O	X
Endurance to PR developer	O	X	O	O	O
Endurance to O_2 ashing	O	O	X	O	O
Patterning	(BHF)	Al etchant	Reverse sputter	Reverse sputter	Peeling off

5 CONCLUSION

For the AFM-based data storage application, we proposed electro thermal driving to write data bits and electrostatic driving to equalize the heights of the arrayed tips and / or to read data bit by the resonance vibration of the metal layered cantilever. A micro tip was fabricated by contact shadow mask process on the bi-directional actuator with chromium-gold- chromium layers. The driving ranges of cantilever were analyzed to cover the height variation of the arrayed cantilever in chip.

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