

## MEMS-BASED STORAGE

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### ABSTRACT

Abandoning the rotating disk paradigm, a MEMS based storage using simple miniature position probe tips to read and write the storage media underneath, potentially creating a new generation of nonvolatile rewritable mass storage devices is reported. Our analysis of the storage systems show that it can reduce application I/O stall time by 80-99%, with overall performance improvements ranging from 10× to 20× for these applications. Most of these improvements result from the fact that average access times for MEMS-based storage are 5~10 times faster than hard disks (e.g., 1ms). Also we will talk about the optimization design of comb drive actuator and probe tip based on previous result of CMU prototype.

Keywords: MEMS, COMB DRIVE

### INTRODUCTION

While hard disks continue to deliver capacity growth of over 60% per year, the physics of a drive's mechanical positioning system limits disk access time improvements to a modest 7% per year. This causes significant access, bandwidth and cost gaps between RAM, and disk. This RAM/disk performance gap is due directly to the physical characteristics of disk drives.

MEMS-based storage is an exciting new technology that could provide significant performance gains over current disk drive technology. Based on MEMS, this non-volatile storage technology merges magnetic recording material and thousands of recording heads to

provide storage capacity of 1-10 GB of data in under 1 cm<sup>2</sup> area with access time of 1ms and streaming bandwidths of over 50 Mbytes/second. Further, because MEMS-based storage is built using photolithographic IC processes compatible with standard CMOS, MEMS-based storage has costs significantly lower than DRAM and access times an order of magnitude faster than conventional disks. Another very important aspect of MEMS-based storage is its ability to incorporate both storage and processing into the same chip. Because MEMS-storage is CMOS-based, it is possible to integrate several microprocessors or hundreds of custom computational engines directly with the storage device. This integration will significantly improve performance, power consumption, and cost. More importantly, it will lay the foundation for a single chip computer brick that contains processing, and both nonvolatile and volatile storage.

### MEMS-BASED STORAGE DIAGRAM

Fig. 1 shows the prototype of MEMS-based storage. Like disk drives, the device has recording heads and a recording media surface that moves. However, the heads are actually MEMS probe tips fabricated in a parallel wafer-level manufacturing process. This prototype employs magnetic storage media much like that used by disk drives. But the media surface does not rotate. Instead, it moves linearly in the X and Y directions to seek the appropriate data. Data access is accomplished by moving the media at a constant velocity in the Y direction while data is read or written by the stationary probe tips. This design avoids problems with "stiction" that occurs in rotating bearings.

The media for the prototype is deposited on large ( $8\text{m}\times 8\text{m}\times 500\mu\text{m}$ ) square plate (called the “media sled”) and is held above the probe-tip array by a network of springs. A force is applied to the sled using electrostatic comb drive actuators. Although a single probe tip “sweeps” only on the order of 1% of the media sled. However, by using a large array of probe tips, all of the media area can be addressed. A large array of probe tips also provides a significant increase in the data rate and reliability.

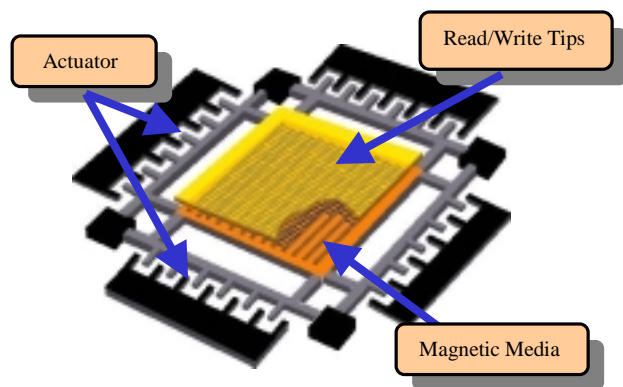


Fig.1 Conceptual view of MEMS-based storage

## LIMITATION OF INCREASING THE AREA DENSITY

The current state of achievement in area density of magnetic HDD is about  $1\text{Gbit}/\text{cm}^2$ , while laboratory demonstrations have achieved around  $5\text{Gbit}/\text{cm}^2$ . The most severe limits facing further advancement of the technology can be separated into the following two classes:

1. Area density limitations
  - Magnetic relaxation (Superparamagnetic limit)
  - Head to medium separation
  - Read head sensitivity
2. Data rate limitations
  - Switching speed of media
  - Switching speed of head

Of the above, the most fundamental roadblock in the current path of the technology is the superparamagnetic limit due to the thermal relaxation of the grains. Superparamagnetic effects are the consequence of random magnetic field fluctuations generated by the interplay of phonons and magnons which may lead to spontaneous magnetization reversal. The relaxation time  $\tau$  is an exponential function of the grain volume given by the Arrheius form

$$\tau = 10^{-9} \exp(KV/kT)$$

where  $K$  and  $V$  are the uniaxial anisotropy constant and volume of a grain, respectively, and  $k$  is Boltzmann’s constant. This translates to values of about 1 min for  $KV/kT = 25$ , 7.5 years for  $KV/kT = 40$  and over  $10^9$  years for  $KV/kT$ .

The above expression is for isolated grains, and the energy barrier will be decreased by an order for an interaction assembly of magnetic particles. Therefore, to push further out the confining limitations of media thermal instabilities, different paths can be considered. One possible candidate is to adapt a new magnetic media material which has much higher anisotropy constant. Another way is to change recording method from longitudinal to perpendicular recording. Finally if we can make one bit by one grain, we can increase energy barrier by an order by reducing boundary effects (grains at the boundary of bits have intermediate magnetic polarization between two bits).

## MAGNETIC WRITE-READ HEAD FOR MEMS STORAGE SYSTEM

If the linear density reduced by 2, the volume of the grains is reduced by 8 (or fewer field holding grains are needed per bit). Therefore, there will be significant reduction in the magnetic field from media if area density is increased. Conventional writing mechanism

can be adapted to high density media. However, to read weak signal from media, new sensing mechanism was desperately needed. One possible candidate is magnetoresistive (MR) head. MR head consists of two lead lines and a soft magnetic layer between lead lines. The soft magnetic layer can be perturbed by any bit passing under it, and the change of resistance of the soft magnetic layer is detected. This MR sensor is much more sensitive and higher signal to noise ratio than conventional reading mechanism. By adapting this MR head, MEMS storage system can achieve high density.

### COMB DRIVE DESIGN

All of the media area must be accessed by the heads to exploit the ultrahigh data density of probe stage. Therefore, the media actuator must move  $\pm 50\mu\text{m}$  in both directions. As considering lateral stability of comb drive, typical motion is about 10% of the actuator length. Since we have to obtain  $50\mu\text{m}$  displacement, one finger of comb is  $500\mu\text{m}$  long. This is quite long structure, which can cause the other lateral instability by small stiffness in y direction. Hence, the width of a finger should thick enough to prevent lateral instability but should be optimized required number of fingers because total force is proportional to the number of fingers.

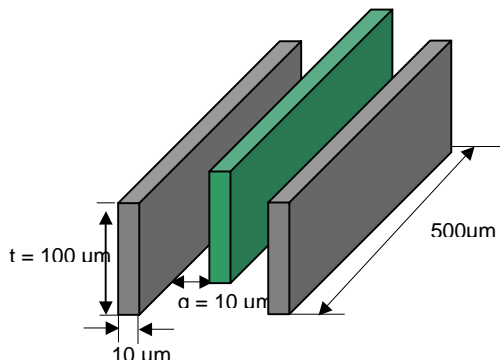


Fig.2 Comb drive design

Considering the constraints of typical DRIE process, thickness and gap ratio should be in the range of 10~20. Finally, a comb drive carries 250 fingers of which length is  $500\mu\text{m}$ , width is  $10\mu\text{m}$ , height is  $100\mu\text{m}$  and gap is  $10\mu\text{m}$ . (Fig. 2)

A boxspring suspension is used to decouple the two lateral direction of actuation, so that comb fingers can be used for X-Y actuation without mechanical interference. (Figure 3)

In Fig. 3 (b), when X-direction force is applied on the actuator, forces exerted on two couples of Y-direction beam springs (in 1-4 quadrant and 2-3 quadrant) have opposite direction, so that they cancel each other.

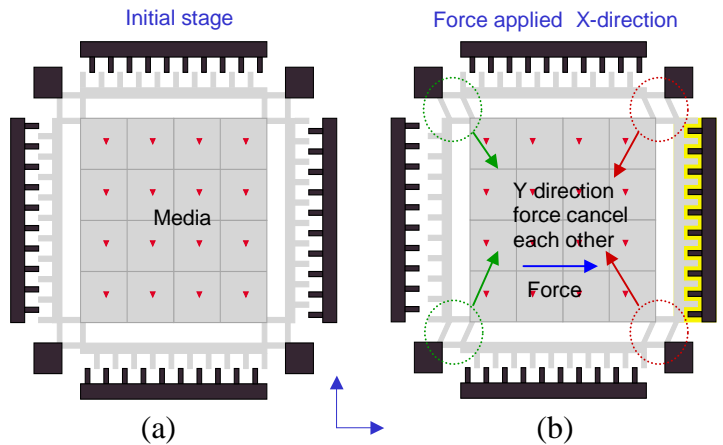


Fig. 3 Decoupling of X-Y direction actuation

### TIP DESIGN

Fig-4 is the tip structure designed by Carnegie Mellon University. The structure can be separated into three parts. Part I is the Serpentine flexure which is used to softening the spring without making it longer. Part II is the comb drive structure in the middle, which is designed to give the tip small lateral movement ( $0.5\mu\text{m}$ ). This part is important because it can compensate the thermal expansion effect such that every tip on the same row can point at the right position and also give the tips some freedom to move in the lateral direction. Independently. Part III is the

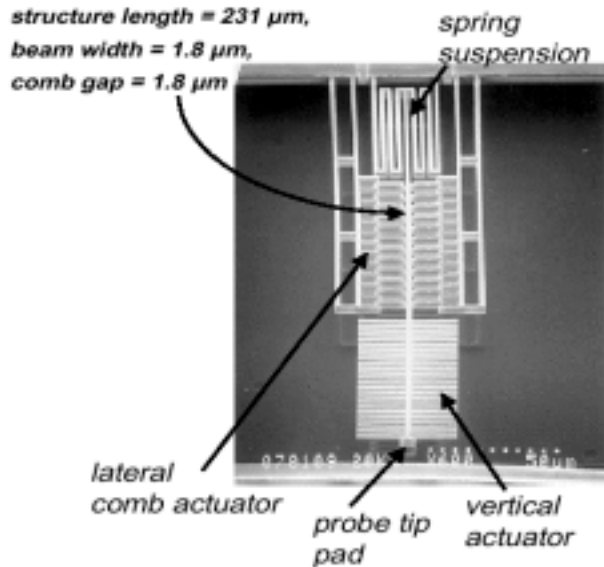


Fig. 4 Tip structure

vertical actuator, which is used to move the tip in the vertical direction so that it can read and write on the magnetic media.

$$f \propto \sqrt{\frac{k}{m}}$$

$$P_{diss} = N \frac{c\omega^2 x_o^2}{2}$$

$$\omega \rightarrow \frac{1}{2}\omega$$

$$N \rightarrow 2N$$

$$P_{diss} = 2N \frac{c(1/2\omega)^2 x_o^2}{2} = \frac{1}{2} N \frac{c\omega^2 x_o^2}{2}$$

Also, because we operate at a lower frequency, we do not need such a high resonant frequency tip structure. This makes softer spring constant possible, which means smaller area of the vertical actuator is able to actuate the tip. The smaller area reduces the damping coefficient, which decreases the power consumption too. To utilize the power efficiently, the maximum number of tips, lowest operation frequency, softest spring constant, smallest area of the actuator need to be used.

## CONCLUSION

A MEMS-based vibration sensor was developed due to the variety of biology

application such as blood pressure, stethoscope and personal health diagnosis. A simple cantilever beam combined with piezoresistive sense technology was the basic idea in the device. In the analysis, we find the compliance of cantilever beam plays an important role on system performance. By optimally designing the dimension of cantilever beam and proof of mass, we can achieve low frequency, low distortion and high sensitive response that meet the requirement on bio-application.

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