THOUSANDS OF MICRO-CANTILEVERS FOR HIGHLY PARALLEL AND ULTRA-DENSE PROBE DATA STORAGE

M. Despont*, T. Altebaeumer, P. Bächtold, G. K. Binnig, G. Cherubini, U. Drechsler, U. Dürig, E. Eleftheriou, B. Gotsmann, W. Häberle, C. Hagleitner, D. Jubin, M. A. Lantz, A. Pantazi, H. Pozidis, H. Rothuizen, R. Stutz, P. Vettiger, D. Wiesmann, and J. Windeln

IBM Research, Zurich Research Laboratory, 8803 Rüschlikon, Switzerland
*Email: dpt@zurich.ibm.com

1. Introduction

The thermomechanical scanning-probe based data storage concept internally called "millipede" combines ultra-high density, small form factor, and high data rates through highly parallel operation of large numbers of probes [1]. Ultra-high storage densities of up to 1 Tbit/in^2 or more have been achieved by using local probe techniques to write, read back, and erase data in very thin polymer films. This paper describe the basic principle of operation, the micro/nano-electro-mechanical-system (MNEMS) aspects and a new wafer-to-wafer chip-transfer technology to transfer the probe arrays onto CMOS-based read/write channel array chips [2].

2. System Description

In thermomechanical probe-based storage, information is stored as sequences of topographical indentations formed in polymer films a few tens of nanometers thick. Writing is achieved by applying a local force through a cantilever-mounted tip (Fig. 1) to the polymer layer and simultaneously softening the polymer layer by a local resistive heating of the cantilever. To read the written information, the cantilever is given the additional function of a thermal read-back sensor by exploiting its temperature-dependent resistance [1]. In addition, a novel erase mechanism has been established that exploits the metastable nature of written bits, allowing data sector-level erase as found in hard-disk-drive or flash memory storage system [1].

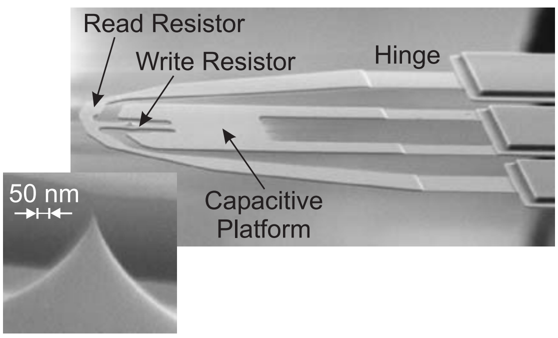

Fig. 1. Silicon cantilever with read/write tip. From [4], © IEEE 2004.

In the parallelized device concept, see schematic in Fig. 2, the tip-to-medium spacing is controlled globally, and write/read operations are synchronized with mechanical *x*/*y* scanning of the storage medium. Scanning is achieved by a miniaturized electromagnetic actuator with *x*/*y*-motion capabilities on the order of 100 μm, i.e. the pitch between adjacent cantilevers. Coarse servo signals for seek operations are derived from thermal position sensors placed at the medium periphery; the finer servo data for timing recovery and position-error signal generation are obtained from dedicated levers and servo marks written in the medium [3]. Parallel operation is achieved by accessing all or a subset of the cantilevers simultaneously, yielding high data rates.

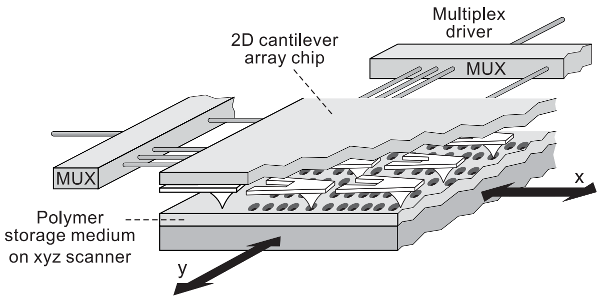

Fig. 2. Schematic view of arrayed system. From [3], © IEEE 2003.

3. System Integration

The data rate of a thermomechanical data-storage system is determined by the mechanical and the thermal time constants of the cantilever, which are in the range of a few microseconds. Orders of magnitude improvements in speed are therefore necessary for scanning-probe-based devices to store and retrieve data as fast as conventional storage devices. One solution to achieve such a substantial increase in the data rates of AFM cantilever-array-based storage devices is to access all or large subset of the cantilevers in the 2D array simultaneously. A first large 2D array of 1024 (32×32) cantilevers with integrated tips and sensors has been successfully fabricated and operated [5]. More recently, a key technological aspect of the integration of the cantilever array with the CMOS channel array chip has been developed. In this new approach the cantilever arrays is transferred and interconnected to its CMOS counterpart chip on a full wafer-to-wafer basis [2]. Figure 3 show a section of cantilever of a large array of 64×64 (4096) cantilevers successfully transferred and interconnected.

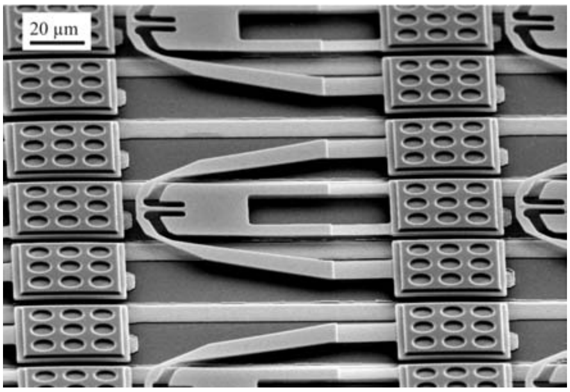

Fig. 3: SEM view of a section of a cantilever array transferred to a CMOS-like wiring chip using the device transfer method. From [2], © IEEE 2003.

Another important aspect of our concept is the need for a low-cost, miniaturized scanner with *x*/*y*-motion capabilities on the order of 100 µm. We have developed a silicon-based microscanner that has *x*/*y*-displacement capabilities of approx. 120 µm [6]. The scanner consists of a 6.8 mm × 6.8 mm scan table, on which the polymer medium has been integrated, and a pair of voice-coil-type actuators, all of which are supported by springs (Fig. 4). This scanner chip is then mounted on a silicon base-plate, which acts as the mechanical ground of the system.

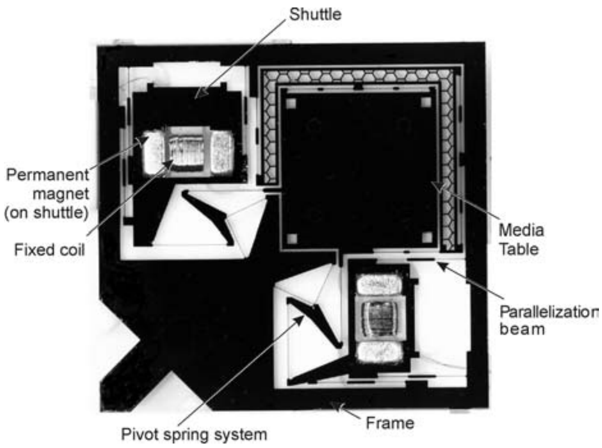

Fig. 4. Optical image of the silicon-based micro-scanner. From [6], © 2004 Wiley-VCH.

4. Experiments

High-density data storage using a single thermo-mechanical cantilever has been demonstrated [4]. Large data sets were written and read back to evaluate the raw error rate at densities up to more than one terabit per square inch. Figure 5 shows the read-back of a fraction of a data set written at 640 Gbit/in^2. At this density the raw error rate was lower than 10^{-4}.

Bit pitch = 18 nm, Track pitch = 37 nm, (1,7) - code

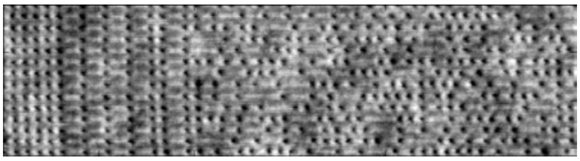

Fig. 5. Image of a recorded field at 641 Gbit/in^2, where (1,7) coding was applied in the horizontal (on-track) direction. Adapted from [3].

Closed-loop operation of the integrated cantilever-array microscanner device was performed and used for both seek/servo and parallel read/write experiments [7].

5. Summary and outlook

We have demonstrated the basic system and fabrication technology building blocks of probe-based storage and are currently prototyping a full functional storage system. Probe-based data storage offers great potential for ultrahigh or even atomic-level storage density. The bit area of the currently achieved 1 Tb/in^2 is still orders of magnitude larger than ultimate atomic density, leaving considerable room for improvement. The high areal storage density and small form factor make this approach very attractive as a potential future storage technology in mobile applications, offering several gigabyte capacity and low power consumption at megabyte per second data rates.

References

[1] P. Vettiger *et al*., *IEEE Trans. Nanotechnol*., vol. 1, pp. 39-55 (2002).
[2] M. Despont *et al*., *Technical Digest*, *Transducers'03*, pp. 1907-1910 (IEEE, 2003).
[3] E. Eleftheriou *et al*., *IEEE Trans. Magn*., vol. 39, pp. 938-945 (2003).
[4] H. Pozidis *et al*., *IEEE Trans. Magn*. (July issue, 2004, in press).
[5] M. Despont et al., *Sensors & Actuators A* ,Vol. 80, pp. 100-107 (2000)
[6] T. Albrecht *et al*., "MEMS in Mass Storage System, in *Advanced Micro and Nanosystem*, Vol. 1, ed. H. Baltes *et al*., Chap. 6 (Wiley-VCH, Weinheim, Germany, in press).
[7] A. Pantazi *et al.*, presented at IEEE Conf. Nanoscale Devices and System Integration "NDSI 2004," Miami, FL 2004, and *Nanotechnology* (special NDSI issue, October 2004, in press).