Millipede Memory Technology

B.Tech Seminar report

by

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December 2009

Acknowledgment

I here by express my deep sense of gratitude to **Prof. K V Manojkumar**,Head of Department, Department of Computer Science And Engineering,GEC Thrissur, **Asst.Prof. Valsaraj K S** and **Mr. Ajay James**,Lecturer for their constant help and guidance during the course of the seminar. I am grateful to them for having given me the vital critics and encouragement on my work.I am highly indebted to my friends for their constant moral support.Above all, I thank God.

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Abstract

Millipede Memory is one of the latest innovations in the field of memory and storage technology.The technology was developed by IBM and can achieve ultrahigh average storage density of 1 Tbit/in^2.The millipede memory technology uses local probe techniques to write, read back and erase bits of information on a thermo-active polymer. This thermo-mechanical scanning probe based data storage features ultrahigh storage density, small form factor, terabit capacity, and high data rate.Millipede memory is proposed as the hard disk technology for future, one that will replace the current hard disk technologies. It will be of extensive application in portable devices like mobile phones, music players ,personal digital assistants (PDA) etc. This report will discuss the architecture and operational principles of the Millipede memory.It would also quote the advantages and the applications of the Millipede memory technology.

Chapter 1

Introduction

Imagine, all the data in your hard disk, your DVD collection and all those several Gbs of data, in a single small device,may be as small as the thumb drives of present day. That is what the Millipede memory technology proposes to achieve. Developed by the IBM, this technology is one of the latest innovations in the field of memory and storage technology.

The Millipede memory technology was introduced by the IBM in early 2003. But, the whole concept came into limelight only in late 2005 when the IBM showcased a prototype of the technology in the CeBIT 2005 and proposed to achieve an average areal density of 1 Tbit/in^2[5]. This meant that 1 trillion bits could be stored in a square inch or almost 200 Gbs of storage in a stamp-sized chip. Recently now, the IBM has also promised a maximum areal density of 2.7 Tbit/in^2.

The most widely used secondary storage or the hard disk technology of the present day is the magnetic storage. Also we have the flash memory or the solid state devices in the field of storage and memory technology. The current secondary storage technology of the magnetic hard disk is approaching its limits. With the hard disk capabilities doubling every year, the magnetic storage would soon find its super-paramagnetic limit[4] of areal storage density. That is, the limit of confining the local magnetisation would be reached soon due to the super-paramagnetic effect.Also, the flash drives are not excepted to achieve the proposed storage density in the immediate future. Due to these reasons, the Millipede memory is considered as the technology for the future. That means, the Millipede memory is the proposed technological replacement for the current secondary technologies,once they find their limits.

The Millipede memory technology uses nanoscopic tips such as the Atomic Force Microscope (AFM) tips[1,2,3,5] to attain very precise local confinement in a nanoscopic area. These nanoscopic tips are used to make indentations on a thin layer of polymer.These indentations would represent bits. The result is akin to that in a punch card, the long forgotten technology. The difference being that the millipede memory can be re-written and that the area for a single indentation in the punched cards can store thousands of bits in the millipede memory.

With the use nanometer scale tips as read/write heads and nanoscopic inscription techniques, the Millipede memory technology is a serious candidate for the forthcoming nanoscopic age. It meets all the requirements as a replacement technology for the current secondary storage technologies and also provides the space for further developements and future research.

1.1 Organization Of the Report

1. Chapter 2 reviews the current secondary storage technologies in vital details[6,7].
2. Chapter 3 describes the architecture of the Millipede memory technology[1,2,3].
3. Chapter 4 illustrates operational principles of the Millipede memory technology[1,2,3].
4. Chapter 5 quotes the advantages of the Millipede memory[4,5].
5. Chapter 6 concludes the report with the proposed applications of the technology[4,5].

Chapter 2

Current Secondary Storage- A Review

The secondary storage for a computer system is an auxilliary, non-volatile storage. The secondary storage devices of the present day include the hard disk, flash drives, optical discs etc. The hard disk is the most widely used secondary storage of the present day and is magnetic storage technology. The flash drive on the other hand is a solid state device and the optical discs as the name suggests is an optical storage technology.

Before, we move on to understand the concept of the Millipede memory technology,it is important that we review some of the important concepts of these current secondary storage technologies. This will help us have better understanding of the concepts of the Millipede memory technology.

2.1 Hard disk

Let us first consider the hard disk technology. The hard disk is the most widely used secondary storage technology. It is a magnetic data storage technology. It consists of a non magnetic plate which is covered with a magnetic material. It is on this magnetic material that the information is stored. The information is stored as single bits and are represented by local directional magnetisation of the ferro-magnetic material. This write operation and read back of the bits are done by read/write head in a magnetic hard disk. The medium of storage in the hard disk is called a 'dumb' medium ,in the sense that the information is stored on the medium and not by the medium.

The typical architecture of the hard disk is shown in the Figure 1.The hard disk consists of a spindle that holds one or more flat circular disks called platters[6] coated with magnetic material on to which the bits are recorded. The platters are rotated at very high speed under the read/write heads controlled by the

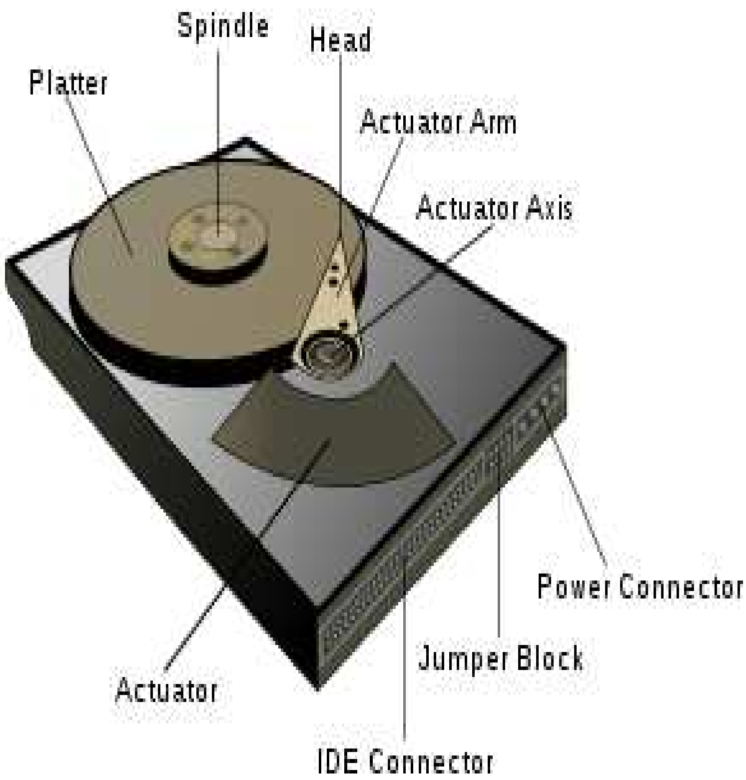

Figure 2.1: Diagram of a hard disk[6]

actuator arms[6] and the head detects and modifies the magnetisation of the area immediately below it.

2.2 Flash drives

This technology is the current hot technology in the field of the memory and secondary storage.It has came into widespread use in the last few years. It is used for general data storage and transfer.Primarily used as the memory cards and USB drives, flash drives are a kind of EEPROM[7]. That is, these devices can be electrically erased and reprogrammed. The most important advantage about this technology is that the electrical erasibility and reprogrammabilty can be achieved in large blocks. This property of the flash drives gives it considerable advantage over the other technologies in the case of data rates. The flash drives also have the merit of a small form factor.

There are other technologies prevailing the field of memory and secondary storage technology in the present day like optical discs exemplified by the Compact Discs(CD), Digital Versatile disc(DVD), Blu-ray Disc etc. But we would not be discussing it here.

Chapter 3

Architecture of the Millipede memory

Now that we have reviewed the vital concepts of the current secondary storage technologies, we can move on to understanding the concepts of the Millipede memory technology.

The Millipede memory technology combines certain advantageous aspects of the hard disk technology, the flash drive technology and several other like the D-RAM to achieve its futuristic properties. As in the case of a Magnetic hard disk the millipede memory uses a 'dumb' medium to store the data. It performs the read, write and erase in large blocks. Also,it performs these operations using a 'head'as in the case of a magnetic hard disk. The millipede memory technology is scanning probe based data storage technology and the read/write/erase head used in this technology is the Atomic Force Microscope(AFM) tips.

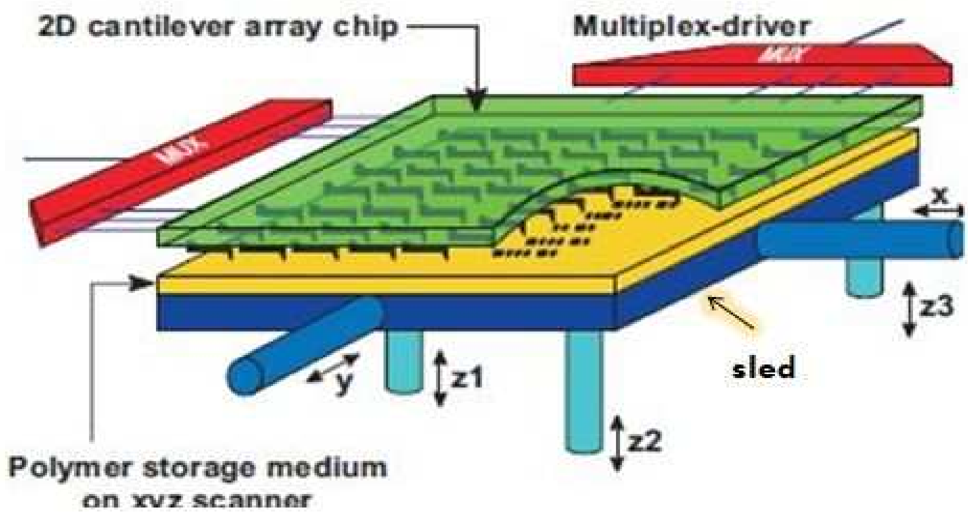

Figure 3.1: Millipede memory Architecture

3.1 The medium

The Millipede memory technology uses a thermoactive polymer[1,2] as the medium to store the information. The data is stored as sequences of single bits represented on the medium by presence or the absence of an indentation or a pit in the medium. Many polymer medias are considered for this purpose, the latest being the 'baroplastic'.

The medium is deposited as thin layer on carrier plate called the *'sled'*[1,2,3,5]. The sled is actuated in the x-y plane and can move either direction facilitating the addressing scheme. The single bits are insribed in a nanoscopically small storage field on this thermoactive polymer medium.

3.2 Atomic Force Microscope

Atomic Force Microscope or AFM tips are usually used in techniques for imaging and investigating the structure of the material to a nanoscopic or an atomic scale. The basic idea of using the AFM tip in the millipede memory technology is to achieve a very precise, nanoscopic local confinement of interaction and inscription.

The use of the AFM tips is the one major reason that helps achieve the revolutionary data storage density.The AFM tip scans only the nanoscopic storage field available to it, read, write or erase the single bit in that storage field. Due to this the data rate is highly reduced. More precisely, the data rate of such a Millipede memory that operates with a single AFM tip would not be even comparable to average data rates of the current secondary storage devices. This disadvantage is overcome by using an MEMS(Micro-Electro-Mechanical-Systems)[3] based array of AFM tips connected to cantilevers.

The cantilever can be considered as a lever which is connected only at one end. The one end is connected to the array structure and the other end has the AFM tip. The latest prototype of the Millipede memory technology has 64x64 array of cantilever AFM tips. The array of cantilevers is arranged in such way that the AFM tips are actuated in the z diection.

Chapter 4

Operation of Millipede memory

Each AFM tip in the cantilever array writes data to or read data from a individual dedicated area of the polymer substrate. This area of the medium is called a storage field. Single bits are repesented in each storage field by the presence or absence of an indentation. An 'indentation' represents a logical '1' and a 'no indentation' represents a logical '0'. These representations of the single bits are called logical marks.

For accurate addressing and reliable storage, all the indentations have to be of equal depth and size. These logical marks are placed along a data track at a fixed horizontal distance from each other. This distance is called the bit pitch (BP)[1] and is measured from centre of one logical mark to the next .Several such tracks are placed adjacently. The cross-track distance or the vertical distance between logical mark centers, the track pitch (TP)[1] is also to be kept fixed.

In the Millipede memory technology, several cantilevers operate simultaneously and corresponding AFM tips can perform read, write or erase operations parallely. The parallelism is achieved by a time multiplexed *x/y* scanning of either the medium or the array.The *x/y* scanning is nothing but probing for a *(x,y)* co-ordinate or a set of co-ordinates in the medium or the array. The accuracy of addressing and reliability of storage is achieved by employing a servo control[1] for the surveillance of the addressing and the operations.

4.1 Addressing schemes

As discussed above, the read, write or erase operations can be performed in parellel in the Millipede memory technology with several cantilevers operating simultaneously. This is achieved by a time multiplexed row-column addressing scheme as in the D-RAM technology.

Two ideas are mainly used for this purpose:

1. **Row enabling and column addressing**- In this method, the row on which operation has to be performed is enabled and the column in that row is addressed by providing the appropriate data.

2. **All or subset of array addressing**-This method is to address all or a two-dimensional subset of the array by providing the appropriate data.

The former idea has a lesser implementation complexity. Latter is rather complex in its implementation but, can provide higher data rates.

4.2 Servo control

The addressing and the operations in a Millipede memory is performed under a sevo control for proper addressing and reliability of storage. In general, the servo system in a millipede memory technology has two functions:

1. **Seek and settle procedure**[1]- This involves locating the track on which the operation has to be performed. It starts from an arbitrary initial scanning position. During the seek, the read/write probes are placed in the beginning of the concerned track with the help of thermo-mechanical sensors. In this settle, the array is moved a small cross track distance to position in the center of the concerned track.

2. **Track follow procedure**[1]- The fine positioning of the array has to be maintained throughout the operation. This task is performed by the track follow procedure. It is done using a feedback mechanism, which sends a PES(position error signal) if the position is deviated and the servo control re-establishes the position.

The synchronization and servo control is accomplished in the Millipede memory technology, by reserving a small number of storage fields exclusively for timing recovery and servo-control purposes.

4.3 Basic operations in Millipede memory

The basic operations for any memory is to write the information, read back the information or erase the information. These operations are basically inscribing the logical marks in the storage field, sensing the logical marks from the storage fields or removing a logical mark from a storage field. In a Millipede memory, the logiacal marks are 'indentations' or 'no indentations' respectively representing a logical '1' and a logical '0'.

4.3.1 Write Operation

The write operation inscribes a logical mark in the storage field of the medium. In Millipede memory,this is achieved by heating the AFM tip and then softly pressing the tip into the medium, thus creating an indentation.

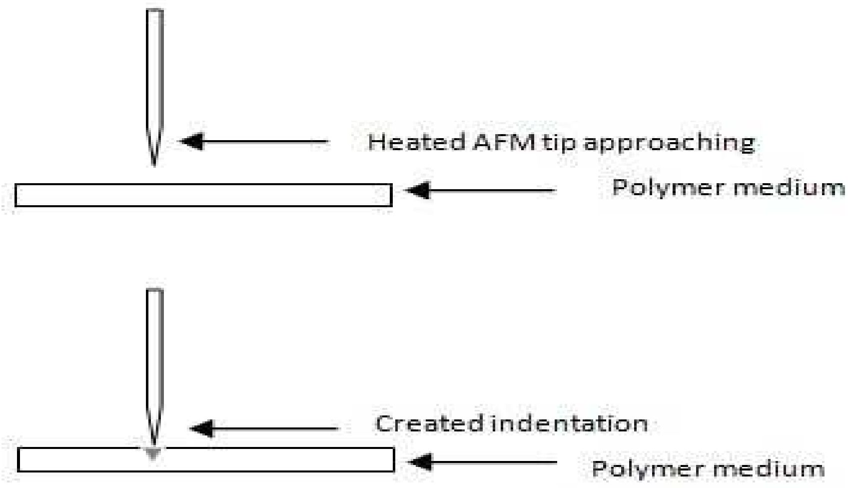

Figure 4.1: An illustration of Write operation

The data to be written to the medium is provided as electric signals which represent a sequence of logical 0's and 1's. A signal for logical 1 is different from that for logical 0 in the sense that it has a higher voltage. Due to this,the resistors at the AFM tips gets heated up and thereby heating up the AFM tip.Only the AFM tip with a logical 1 can produce the heat required to create an indentation when pressed into medium. Hence, the tip with logical 0 leaves the storage field with a 'no indentation'.

The erase operation for the millipede memory is a write operation with a different pitch.

4.3.2 Read Operation

The read operation is sensing the logical marks on the medium and distinguishing among them. In the Millipede technology, it is performed using a thermo-mechanical sensing. The AFM tip is heated to temperature even lesser than for logical 0. The AFM tip and the medium only has a nonoscopic gap between them. When above an indentation, there is more air in betwwen the medium and the tip than at a no indentation. Due to this,the tip cools faster on a indentation than on a no indentation. This difference in cooling is distinguished as the logical marks.

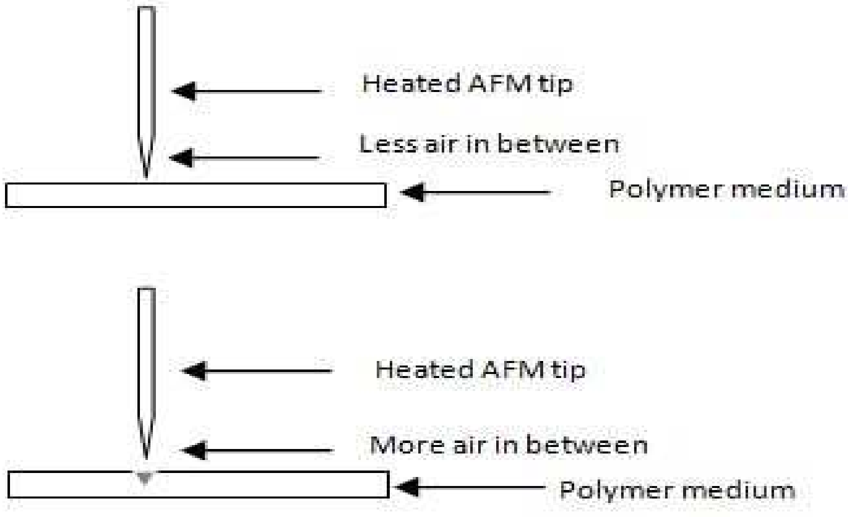

Figure 4.2: An illustration of Read operation

4.3.3 Erase Operation

The erase operation is a variant of write operation with different pitch. The AFM tip heated well above the heat needed to make an indentation. When brought near the medium, the medium is softened. The cantilever is pulled back suddenly to create a surface tension and thus repairing the indentation.

Chapter 5

Advantages of Millipede memory

The Millipede memory is the proposed potential technological replacement for the current Hard disk technologies that would soon reach its limits of storage densities and form factor. The preceding discussion has presented some obvious advantages of the Millipede memory technolgy over the current storage technologies.They are quoted here:

1. Ulta high areal storage densities ranging from 1 Tbit/in^2 to 2.7 Tbit/in^2.
2. Small form factor than any prevalent technologies.
3. The cantilevers operating in parallel provide high data rate comparable to any of prevalent technologies.
4. With only nanoscopic area of movement required, it features low seek time.
5. Low power consumption than the magnetic storage.
6. Comparitively lighter to magnetic hard disks.

Chapter 6

Conclusion

Every new technology introduced in the field of memory and storage technology has led to revolutionary changes in the field and those associated with it. For example, the advent of the flash drives aroused a neverbefore phenomenon in the field. The purpose of mobile phones and several other devices was redefined.

The changes, that the advent of Millipede technology can bring about is something we can only dream about.However,here are some propsed **applications** for the technology:

1. **Nanodrives**[4,5]- These are storage devices with gigabyte capacity having a very small form factor in the range of millimetres or centimetres and low power consumption. Such Nanodrives can be integrated into watches, cellular telephones, laptops,etc. The array chip with integrated or hybrid electronics and the micro-magnetic scanner are key elements demonstrated for the Nanodrive.

2. **High capacity Hard drives**[4,5]- The millipede technology proposes High capacity, yet lighter, cheaper and less power consuming hard disks for personal computers.

The progress of Millipede storage as a commercially useful product has been slower than expected. Huge advances in other competing storage systems, mainly in Flash and hard drives, has made the existing prototypes of the Millipede memory unattractive for commercial production. Millipede appears to be in a race, attempting to mature quickly enough at a given technology level so that it will not been surpassed by newer generations of the existing technologies by the time it is ready for production.

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