Chapter 2
Mass Storage Memory Market Biography

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Abstract This chapter describes the basic storage technologies such as traditional paper, magnetic, optical, semiconductor, and uncommon memories, providing an outline of the history and a brief technical description of each device in terms of its volatility, accessibility, addressability, capacity, and performance.

Keywords Devices · Storing · Data

Introduction

Right from the beginning, communication activities among the human societies required the capability of storing and passing on information acquired through life experiences through various channels: vocalization or gestures, or backing the case of ancient man, cave paintings, and drawn maps and the written word.

Writing was and probably still is the most common method for storing data all over the world, but the past centuries have seen many kinds of new energies that move from the manual muscle power needed for writing by hand to acoustic vibrations in phonographic recording, to electromagnetic energy that modulates magnetic tape, to digital content written with laser light inside optical disks, and finally data electronically stored in a semiconductor device or molecular materials.

Paper and Book

Ancient History of Paper and Older Memory Methods

From the time that human society first realized the need for written expression, there has been a demand for proper support to store ideas.

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For many centuries paper was the principal means for transmitting and storing all kinds of thought and all manifestations of human inspiration, but it is important to briefly recall the earlier tools that were adopted and used [1–5].

Prior to Paper

We cannot talk about memory support at all without introducing the concept of the written word; in fact the popularity of writing generated a real "revolution" in social, political, and cultural realms.

Writing was invented during the second half of fourth millennium BC, Uruk, the oldest Sumerian town. Its development was due to the need to enlarge communication capabilities so that information would be acquired not only through oral communication, which is basically ephemeral, but also through methods that would widely transmit and preserve all types of data and collected know-how to other people.

Bars of Clay

People in the ancient world did not know that the original primitive implements for transmitting and preserving information were simple bars of clay. At the end of fourth millennium BC, the Sumerians in Mesopotamia became the first people to attempt this extraordinary method of communication by using a sharpened tip to write on bars of clay. At first they realized a kind of logogram, that is a simple object outline, then gradually moved through a process of reproducing simplified figures and wedges until they developed a large index of syllabic signs (around 600), characterized, depending by different cases, of meaning of a real word and so also used to write abstract terms that are not typically expressible using symbols or schematic drawings.

After the bars were written on, they were baked, which turned the clay into a ceramic material that could be preserved for several millennia. Thousands of bars kept valuable information on the historical and political events of the time, the mythology, the religion, and the social and economic organization of the inhabitant of Mesopotamia, western Iran, Turkey, and Syria (Figs. 2.1 and 2.2).

Wax Bars and Papyrus

As in Mesopotamia, inscription on clay bars was the first form of writing in Egypt,. However, it seems that as early as around 3000–3500 BC the Egyptians began to write on foils of papyrus (*Cyprus papyrus*), which was the product of a complex process using material extracted from marsh reeds, which grew plentifully in the Nile Delta. The reeds were cut into strips around 40 cm long and then squeezed. The resulting weft was beaten with a wooden club and then rolled up inside flax, until the plant's sticky marrow spread across the surface to create a foil. This process produced long rolls that could be written on and decorated with pictures. The rolls

Fig. 2.1 Example of on a Sumerian bar

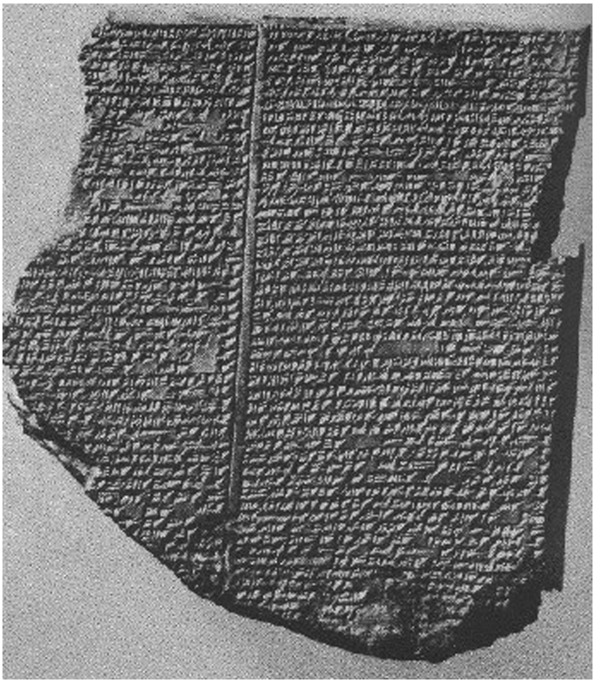


Fig. 2.2 Fragment of terra-cotta of Gilgamesh Poem, Londra, British Museum

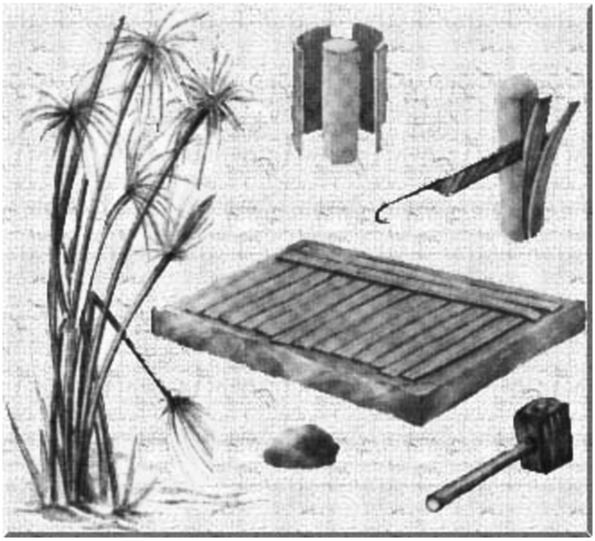


Fig. 2.3 Manufacturing papyrus foils

Fig. 2.4 Papyrus scroll from the famous *Book of the Dead*

were then stored inside sealed amphorae, with an inscription of the content within it (Figs. 2.3 and 2.4).

Papyrus arrived in Greece in the sixth century BC and then found its way to the Roman Empire, where other kind of plants, maple, plane tree, and lime were already being used for writing.

Wax Bars

Papyrus was used in Rome, as was parchment (animal skin), ivory, earthenware, and bars of wax. Egyptian papyrus had an uneven texture and could only be used on one side, but the Romans improved on it and were able to create a perfectly smooth surface using a pressing tool or a hammer. Rome had many papyrus factories (*horrea chartaria, officinae*), the most important located in Fannio.

The paper *fanniana* became famous for its lightness and smoothness respect the Egyptian *amphitheatrica* rough paper, so called because prepared closed to Alessandria amphitheatre.

Several foils of papyrus were glued together to make one long strip that was furled into a roll (*scapus*), which was kept rolled up by a few small sticks (*umbilicus*) on the top and the bottom so that that last foil would not get dirty by trailing on the ground; a label with the title of the book was located on the top side of the roll.

A shape similar to what we know of today was created during the Imperial Age by binding some foils of parchment together (*quaterniones*) to make a kind of exercise book with a cover (*codice membranei*), but the process proved to be too expensive and was not developed.

It was just at this point that the first schools were founded in which pupils made use instead of wooden tables spread by wax (*cerae*), to be able to erase and to correct in easily way.

Were wooden tables with relevant edges and inside was spread the wax and written on it bearing characters with a wooden or metal stick (*stilus*), sharpened on one side and flatten on the other side, to erase. Some holes on the borders allow binding two or more tables together in order to create an exercise book, a set of tables has been called *caudexes* or *codex* (Figs. 2.5 and 2.6).

Parchment

Parchment (a writing material made from animal's skins (lamb, colt, ram, donkey, calf and pig) was introduced in Rome in the first half of the second century BC. The parchment (also called *cartapecora or carta pecudina*) made from untanned of animal skins was very popular until the fourteenth century. From Latin *membrane*

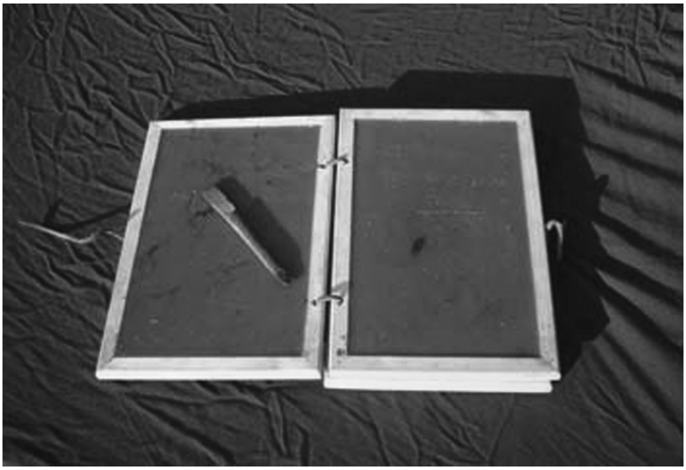


Fig. 2.5 Wax table with stylus

Fig. 2.6 Round portrait made of Roman fresco, ca. 50 AD, woman with book and stick came from Pompei Napoli, National Archeological Museum

Fig. 2.7 Parchment manufacturing process

o vellum was so called due to the city *Pergamo* (in Asia Minor) where, based on traditions referred to "Pliny the Elder" (Gaio Plinio Second, known as Pliny the Elder), was invented around the second century BC, as a replacement for papyrus (Fig. 2.7).

It has stayed some medieval prescription to the parchment manufactory process and the oldest one is stored inside *Compositions* a manuscript of 490 located in Capital Lucca's library (VIII century).

The animal skin was placed in a *calcinatory* (a solution of water and quicklime), over a "back of donkey" tripod and a sharp blade was used firm to removed the fur. The denuded skin was then placed tautly on a frame and left to dry. It was important to eliminate residual flesh and this was done with a special knife. After the skin was completely dried, the parchment could be removed from the frame and finally used. Further steps to refine this material were carried out using a pumice stone to reduce the differences between rough side, which was hard to the touch, and meat side, which was soft and smooth.

. . . And finally paper.

Etymology of Paper

The meaning of the word "paper" is quite uncertain. Someone suppose that it derives, from the Latin *charta*, from the Greek *charassò*, which means *to etch, to carve.* The terminology corresponding to the Anglo-Saxon word *paper, papel* Spanish and *papier* French comes from the papyrus plant, used in ancient Egypt until 3000 BC and, subsequently by the Greeks and the Romans.

Based on Chinese documents, paper was invented in 105 AD towing to Ts'ai Lun, a civil servant of Ho-ti from the Han dynasty, emperor's court. As paper was discovered in territories owned by the Chinese empire, with little evidence of its use earlier than 105 AD, is likely that Ts'ai Lun introduced it in the vicinity of the imperial factory, and perhaps improved on a technique that had been in use for many years. The Chinese process made use of tree bark, probably from the mulberry tree (*Brussonetia papyrifera*), and old fish net, which was treated and filtered in a bamboo mold.

The oldest well-known paper extant today was made around 150 AD using rags. For the next 500 years the art of paper making was confined to China but it was introduced in Japan in 610 AD and in the Central Asia around 750 AD.

One of the first pieces of evidence in Italian concerning the Chinese ability to produce paper was received from Marco Polo inside a *Milione* passage in which he mentions the material used to fabricate the stamp paper, referring in particular to the quality of the bamboo and waste hemp.

Writing about the Emperor of China, he noted "they bring bark of the tree called Mulberry, – whose leaves are eaten by silk worms,—and take the thin bark that is between the thick bark and the core of wood, and from this bark extract paper similar to cotton wool."

The Chinese emperors long kept the secrets of these techniques, which were only known elsewhere beginning in the seventh century, first in Korea, then in Japan, and finally in Central Asia in Samarkand city, where the Arabs learned directly from Chinese people and subsequently introduced them in the Middle East and elsewhere in the Mediterranean area.

The Arabs spread the knowledge of paper making in Europe in the twelfth century, particularly in Spain at Jativa (where they built the first European paper mill) and in Italy in Palermo. During thirteenth century the city of Fabriano became the most important center of paper manufacturing, using local workforce; from Italy production moved across all of Europe, primarily to France (fourteenth century), the Netherlands (fifteenth century) and to England (fifteenth century), where, in the

Fig. 2.8 Paper's ancient route around Asia

sixteenth century, development benefited from the availability of cash assets and low-cost combustibles for manufacturing (Fig. 2.8).

History of Paper in Italy

The first paper mill in Italy was founded in Fabriano (the Marches, Province of Ancona) in 1276. The first official document on Fabriano paper dated 1283, was a legal document recording the purchase of a building from a "carthaio," and six other paper-making masters served as witnesses of the event.

In brief, the Italian paper manufacturing process consisted of few steps.

A hydraulic pile based on multiple power hammers, invented by a paper-making master from Fabriano, was made up of a large wooden container, in which a large nailed pestles or mullers, powered by a big water mill, threshed some vegetable fiber rags until they formed a mash. This mash was transferred to large wooden vats full of water and stirred with a stick. A sieve was then inserted into the vat and moved around until the mash formed a layer of uniform paste that could be spread all over the surface of a cloth. The foils so obtained were placed on wool felts and squeezed in a mechanical press to remove all the water inside. The foils were then hung up to dry (Figs. 2.9, 2.10, and 2.11).

Other Italian cities had paper-making factories, including the sea-faring cities of Amalfi, Venice, Genoa, and Palermo as well as university towns such as Padova and Bologna.

The year 1456, which saw Johann Gutenberg's invention of the printing press, a method of printing using movable type, marked a fundamental change in the history of paper production and the evolution of writing. Very people could afford to purchase expensive parchment, but with the availability of relatively inexpensive paper and the new method of printing, general knowledge rapidly spread worldwide.

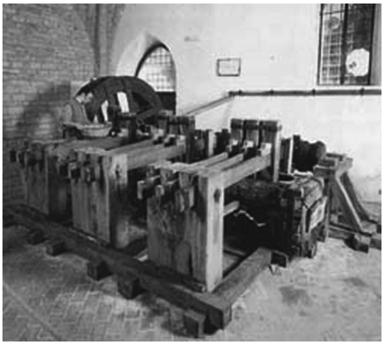


Fig. 2.9 Hydraulic pile based on multiple power hammers

Fig. 2.10 Soaking

Fig. 2.11 Drying the foils

Punch Cards

Basile Bouchon was the inventor of the first perforated paper loop used in couture arte to store some outlines on a textile. But the first use as data storage is dated back September 23rd, 1884 by Herman Hollerith who patented his invention and subsequently it was adopted for ten years until the mid 1970s.

Figure 2.12 shows an example of a classic punch card. Composed of 90 columns, it held a limited amount of stored data was and was typical used to configure parameters in special devices.

In 1846 Alexander Bain created the first paper tape; he was also the inventor of the electric printing telegraph and the fax machine. Characters were symbolized by a punched rows and owing to the simplicity of the method it was possible to create a fan-folded length of paper that could hold more data than a punch cards (Fig. 2.13).

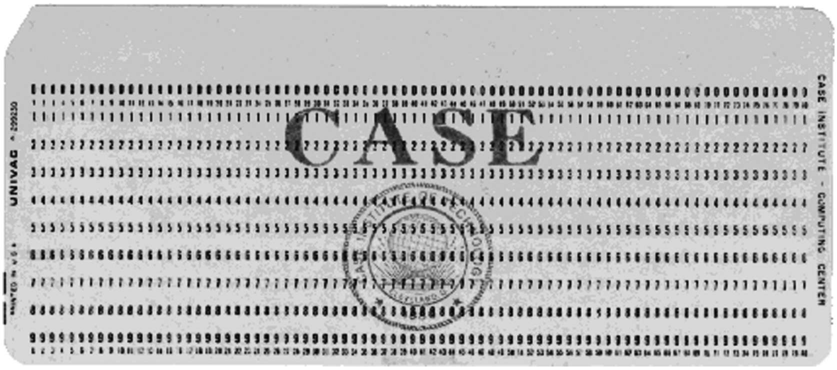
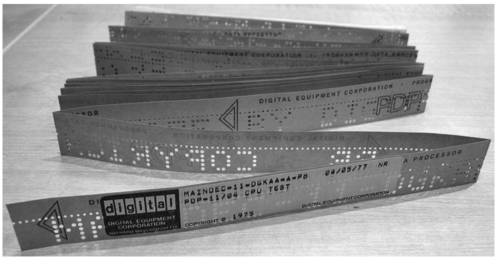


Fig. 2.12 A classic punch card

Fig. 2.13 Example of a punched tape



Magnetic Memories

History

The first description of an audio recording method based on a magnetic storage medium was released in September 1878 by Oberlin Smith, who hadfirst started using magnetic recording 10 years earlier [6–10].

However, it was Valdemar Poulsen, the owner of a patent filed in 1989, who, during the Paris Exposition of 1900, first demonstrated publicly a device for recording a signal on a wire wrapped around a drum. The first magnetic tape, made up of metal strips on paper was patented by Fritz Pfleumer (Figs. 2.14 and 2.15).

Progress in magnetic recording was slow and it was only in 1932 that the first magnetic recording devices appeared on the market.

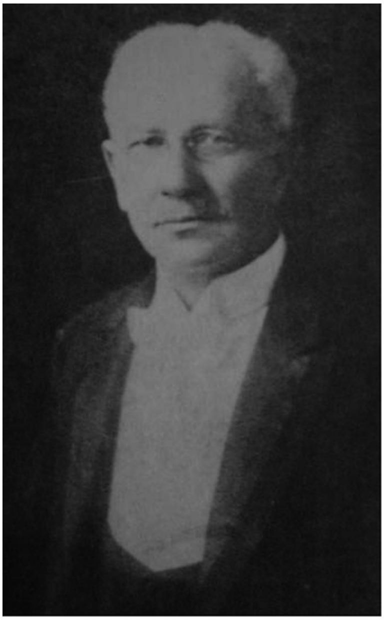


Fig. 2.14 Oberlin Smith

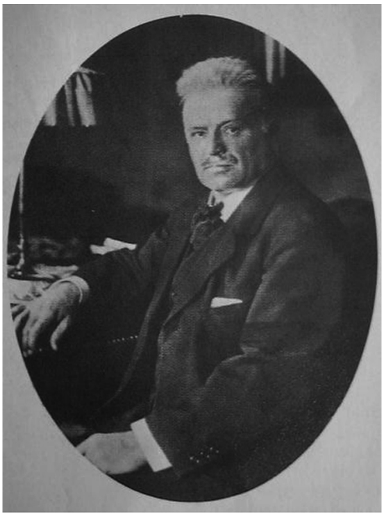


Fig. 2.15 Valdemar Poulsen

During the second half of the twentieth century most of common audio and video contents were based on magnetic recording devices such as the audio and video tapes used professionally or in homes to distribute movies and music.

Several years ago there was a move to replace the tape recordings with hard disks and other kinds of memories that were not volatile, but there are thousands of people still working in the magnetic storage market for companies located around the world.

Historically initial development focused on magnetic tape for audio recording. In 1945 the era of video recording began. From the early 1950s data recording was accomplished using primarily the floppy disk and hard disk drives. Today the latter is becoming the main device used not only for data content but also for audio and video recording. The main four elements in the progress of this technology were as follows:

- The Magnetophon audio recorder was developed in Germany between 1930s and 1940s. The mechanism consists of a magnetically coated plastic tape and a stationary head to read/write and erase information stored in analog way (Fig. 2.16).
- The quadruplex video recorder was based on four heads rotating and connected on a wheel and a magnetic tape, used mainly for video applications, which replaced the earlier photographic method (Fig. 2.17).
- The floppy disk drive developed by IBM in the 1960s introduced data storage in a portable support based on a flexible disk and heads with minimal movement capability but with a semirandom access method, which was an improvement on any radial position of the disk. This was the best cheap device for storing data in a removable medium a few years ago (Fig. 2.18).
- The RAMAC disk file, also known as hard disk drive, developed by IBM in 1956, uses a rigid disk and a head with a random access capability. The growing interest in the electronic computer required storing large amounts of data in a nonvolatile device with a fast access technique and large storage density (Fig. 2.19).

Fig. 2.16 The Magnetophon

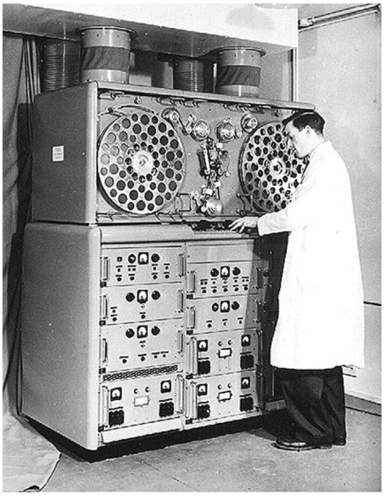


Fig. 2.17 The quadruplex

Fig. 2.18 Different floppy disk sizes

Fig. 2.19 The RAMAC system

Magnetic Recording Classification

The first two developments described in the previous paragraph are based on analog method to record the audio or video information on the medium, whereas the last two are based on a digital system, but there are also two other ways to store information using magnetic effects: optical-magnetic and domain propagation memory.

Analog Recording

Analog recording schemes come from the property of some materials to maintain the magnetic configuration depending by magnetic field applied. The devices are made up of a tape initially not magnetized; during the recording process the tape runs under the charged fixed head to magnetize the support in accordance with the applied magnetic field. The magnetic tape is composed of iron oxide or chrome oxide particles assembled on a thin plastic film. The analog recording was very popular for audio and video recording, but has now been replaced by digital recording systems.

Digital Recording

Unlike the analog method, digital recording requires only two stable conditions, identified by the opposing conditions of a hysteresis loop. The most important examples are the floppy disk drive (FDD) and the hard disk drive (HDD); the latter will eventually replace all other recording magnetic media.

Magneto-Optical Recording

In a magneto-optical device during the writing operation the medium is heated by a laser that brings about a rapid decrease in the coercive field. Subsequently using a small magnetic field it will be possible to modify the magnetic polarization. The reading process is based on the Kerr effect. There are not yet many devices based on magneto-optical behavior, the most well known being Minidisc developed by Sony.

Domain Propagation Memory

The method is based on the capability of controlling domain wall motion in a magnetic medium free of microstructure. It is also called Bubble memory because of its cylindrical domain. The data are recorded depending the presence/absence of bubble domain. Due to the high insensitivity to vibration and shock resistance these devices are used especially in aeronautics.

Access Method

Magnetic storage devices can be classified mainly into two different categories depending on the kind of access: sequential access or random access.

Typically the magnetic tape used for audio and video recording is based on a sequential access method, in which the end user has to wait an average of tens of seconds before accessing the sought for information. On the other hand the HDD and FDD are based primarily on a random access method system, which employs a cylinder and sector structure; when the head is positioned on the right cylinder and sector it may take some time to read the information needed, but the typical access time is tens of milliseconds, several times less than with the sequential system. A ferrite-core memory, not a common magnetic device in the market, can be considered a pure random access based device.

Owing to the huge growth of the personal computer market the HDD is the most important magnetic device on the market today.

Hard Disk and Floppy Disk Drives

Description

The hard disk is composed of one or more aluminum or glass disks covered by iron-magnetic particles; two heads, one for each side of the disk, rotating rapidly disk spinning tens of nanometers from the surface, reading/writing digital data. The heads are kept raised from the air flow itself and the speed rotation can exceed 15.000 revolutions per minute (rpm); currently the standard rotation values are 5.200, 5.400, 7.200, 10.000, and 15.000 rpm.

A floppy disk is a portable and removable storage support system composed of a thin, flexible disk within a plastic wrapping that protects data from the dirt in the environment.

Hard Disk Drive Biography

Hard disk drive commercial use began in 1956 with the first production of IBM RAMAC 305, including the memory system disk IBM 350, the original fixed disk drive. The term hard disk, as opposed to the term used for the removable drives, floppy disks, was only introduced after the 1970s disks.

The IBM 350 disk was invented by Reynold Johnson and was made up of 50 disks, 24 in. in size, with a read/write head made with two components with a typical access time around 1 s and a maximum capacity of 5 MB.

In 1961 IBM introduced the first hard disk drive with spinning heads that skim over an air bearing and named the system IBM 1301. The first portable disk version 1311 was able to store up to 2 million characters.

These first hard disk prototypes were so large and cumbersome that they could only be used in labs or industrial environments; also owing to their high power consumption and fragility they not suitable for home use.

In 1973 IBM introduced the 3340 Winchester version, so-called for a comparison to the popular shotgun “0.30–30 Winchester” since was equipped with two 30 MB disks; this name was widely used and became the synonymous with HDD because it was the predecessor of every current modern hard disks.

Fig. 2.20 Seagate ST-506

Prior to the 1980s hard-disk drive dimensions were between 8 and 14 in. and three-phase power supply was needed to provide enough energy for the large engines used to rotate the disk. This was the reason hard disks were not used for microcomputers until the introduction of first $5\frac{1}{4}$ HDD manufactured by Seagate with a 5-MB formatting capacity. A step-by-step engine to manage the read/write head (voice coil control was introduced in the market only few years later). This Seagate ST-506 model equipped AT&T PCs with 286 microprocessors assembled at Olivetti sites located in Scarmagno near Ivrea in the north of Italy in a collaboration between the American and Italian companies. At the same time, OPE (Olivetti Peripheral Equipment), a Olivetti's partner, provided HDD for the M24 personal computer. Historically this company was the only one in Europe to engage in manufacturing for these types of peripherals (Fig. 2.20).

From this point HDD capacity has grown exponentially during the last three decades, starting from the first portable PC with a 20 MB disk inside.

From the middle to the end of the 1990s, stored content included not only text files but also images and videos, reaching the current capacity of hundreds of GB. Today portable hard disk drives can store up to 350 GB and the HDD in a desktop PC can reach up to 2 TB.

Floppy Disk Drive Biography

The floppy disk drive (FDD) was invented by IBM in 1967 as a simple and low-cost system for loading microcode into mainframe System/370, the first result was a read-only disk with an 8 in. diameter called a "memory disk."

Floppy disk development subsequently underwent many changes during its lifetime, assuming many different form factors, standards, and densities. Olivetti was the first company to produce a personal computer system able to manage the FDD and during the Hannover trade fair in April 1975 unveiled its first P6060 system (Fig. 2.21).

Fig. 2.21 Olivetti P6060 system

The most well-known standards adopted by industry were the 5¼ inches used mainly by IBM for its first personal computer and the latest 3½, introduced by Sony on its MSX platform, subsequently used by Apple and finally used in any kind of laptop or desktop personal computer.

At the moment there are no FDDs on the market because optical media (CD, DVD) and devices such as the USB key and flash card based on NAND solid-state technology have made FDDs obsolete.

Optical Memory

Optical memories are storage devices in which the information is recorded and read using optical methods, for example, the light produced by a laser diode which impacts a material with variable reflection features [6–10].

These types of memory devices provide powerful storage capacity, together with a very low cost per recorded bit. They have longer access times (a few hundred milliseconds) than magnetic memories, but a very high recording density (owing to their ability to focus laser light to a very small point) and a strong resistance to weathering. Optical memory is not yet practical for use in computer processing, but can be an ideal solution for storing large quantities of data very inexpensively. The development of optical memory technology is due to the commercial success of the digital audio Compact Disk, introduced in 1983.

Optical Disk

Data are recorded on an optical disk by means of a laser beam that impacts a reflective surface, resulting in small areas (pits) with a reflectivity different from areas that have not been impacted (lands). A very-low-power laser beam is used by the reading unit to read the sequence of pits and convert it into electrical signals with a scanning photo detector; the laser beam is scattered by the pits and reflected by the lands.

The start and the end of a bit represent a “1,” while a continuous surface represents a “0.” Unlike with magnetic disks, data on optical disks are written sequentially, in a continuous spiral track, from the inner track to the outer one, with a constant recording density. If compared with concentric tracks, the access to the stored information is slower, but spiral tracks are better for reading long strings of data. Furthermore they increase storage capacity.

With this storage technique all sectors have the same length. They must all be read at the same linear velocity so, the disk angular velocity must be gradually reduced when the laser beam goes from the inner area to the outer one.

Optical disks can be divided into three groups:

- Compact Disks
- Digital Versatile Disks
- Others

Compact Disks

A Compact Disk (CD) is a digital storage medium that consists of a disk of transparent thermoplastic resin (polycarbonate) that stores the information on a thin sheet of metal (aluminum or gold). The reflective surface is protected from dust and scratches by an acrylic cover that can also be used to imprint a label.

CDs of 1.2 mm thick, with a 120-mm diameter and a 15-mm central hole; they read and write with a 780-nm infrared laser beam. This technology was introduced in the early 1980s and initially used for audio CDs, offering a significant improvement in audio quality. But apart from this primary application, it also represented an enormous leap from traditional data storage media because of its 650-MB storage capacity at a very low cost.

CDs can be divided into the following types:

- *CD-Read Only Memory* (CD-ROM), which is a prerecorded, read-only device based on a reflective layer made of aluminum.
- *CD-Recordable (CD-R)* which is a one-time recordable device based on a gold sheet covered by a special transparent paint that turns dark if impacted by a laser beam.
- *CD-Rewritable (CD-RW)*, an erasable and re-recordable device in which erasure is accomplished by writing with a beam at a different wavelength.

Write operations are similar on all three CD types but not identical.

A CD-ROM writing process is performed using a glass master disk, written with a high-intensity, finely focused laser beam that etches the tracks into the disk surface. A liquid polycarbonate is injected into the glass matrix in order to reproduce the tracks on the CD. Later the written surface is covered first with a highly reflective layer and then with a protective one (Fig. 2.22).

In a CD-R the pit and land reflectivity is simulated by using a paint layer in between the transparent and the reflective layers. Initially the paint layer is

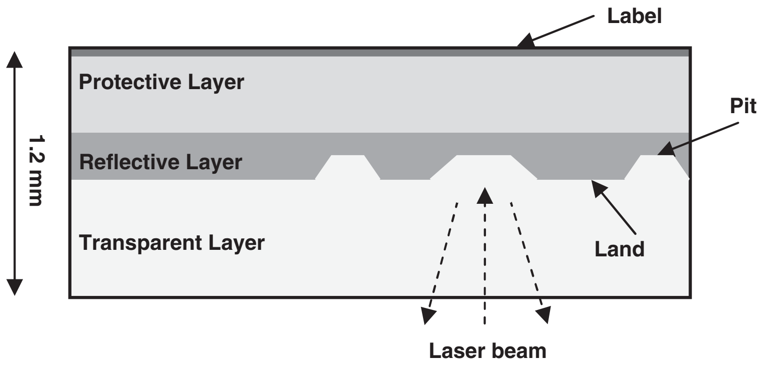


Fig. 2.22 Structure of a CD-R

transparent, but when impacted by a high-intensity laser beam it becomes dark and simulates a pit (Fig. 2.23).

In a CD-RW the reflective layer has amorphous and crystalline states that have different reflectivities: it is slightly reflective in the amorphous state and highly reflective in the crystalline state. When impacted by a high-intensity laser beam, the reflective substance becomes amorphous and simulates a pit. If impacted by a medium-intensity laser beam the mean becomes crystalline again and simulates a land. A low-intensity laser beam can be used to read the information that has been written without changing the mean phase.

For all CD types the reader/writer performances (i.e., write, rewrite, and read performances) are evaluated in comparison with the "standard" data transfer rate of 150 kB/s. So, a throughput of "*nx*" means a transfer rate *n* times greater than the standard throughput.

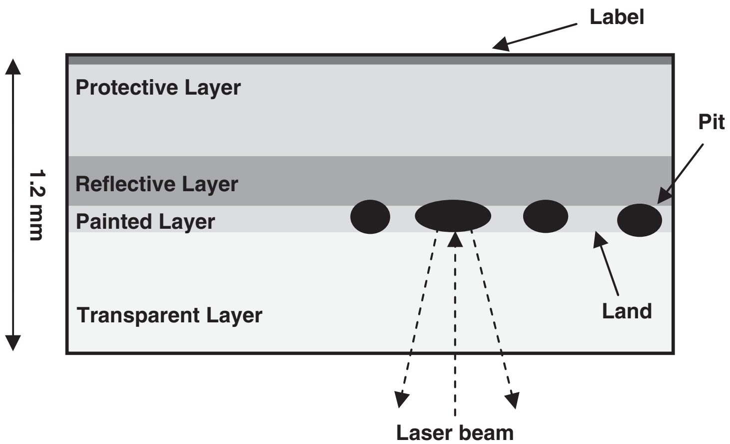


Fig. 2.23 Structure of a CD-RW

Digital Versatile Disk

The 1990s saw a high demand for a new medium with higher storage capacities, which led to the development of the Digital Versatile Disk (DVD), an optical disk with the same form factor as the CD, but an increased capacity.

This increased information density is due to the dimensions of the pits and the lands: the pits and lands of a DVD are smaller and closer to each other than those of a CD. A DVD uses a red laser with a wavelength of 650 nm instead of the 780-nm wavelength of used by a CD.

Furthermore, in a DVD the information can be stored on two different layers. Data contained in the second layer can be read by changing the focus of the laser beam to make it penetrate the first layer, which is semitransparent. This technique doubles the disk capacity. As this procedure can be applied to both sides of the disk, it is possible to quadruple the basic disk capacity.

The laser beam can read only one side at a time, so the disk has to be turned in order to read the second side.

DVDs can be classified into four groups:

- DVD-5: 4.7 GB, single side and single layer.
- DVD-9: 8.5 GB, single side and double layer.
- DVD-10: 9.4 GB, double side and single layer.
- DVD-18: 17 GB, double side and double layer (Fig. 2.24).

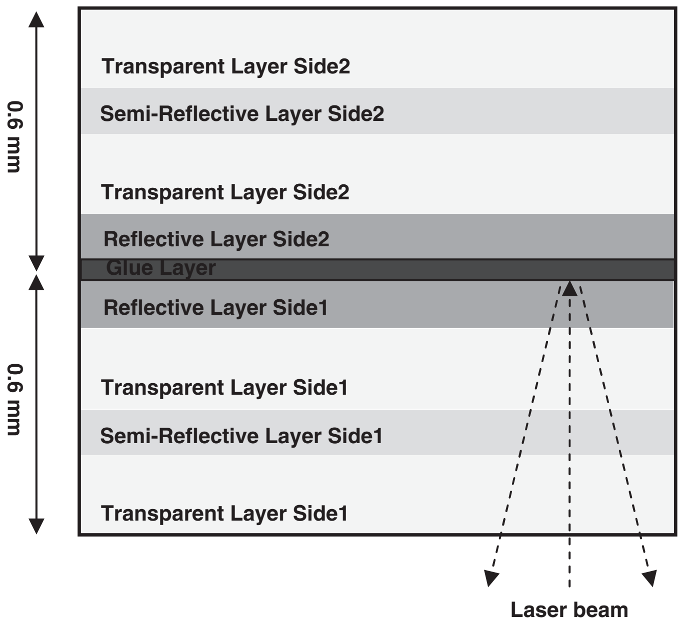


Fig. 2.24 Structure of a DVD

A DVD is also faster than a CD: the standard data rate from a DVD (1350 kB/s) is ninefold greater than that of a CD (150 kB/s).

Other Optical Disks

At the beginning of twenty-first century the development of optical memory technology led to a new generation of high-capacity optical disks that were used primarily for high-definition movies and video games: the High Definition Digital Versatile Disk (HD DVD) and the Blue-Ray Disk (BD).

Both of these devices are optical media with the same form factor as the CD and DVD, and they both use a blue laser beam, which has a wavelength of 405 nm, for writing and reading operations. The reduction in the laser wavelength allows for an increase in disk capacity: HD DVDs have a fixed capacity of 15 GB per layer; BDs can use three different pit sizes, so they can have three different capacities per layer (23.3, 25, and 27 GB). These basic capacities can be increased by using multiple-layer disks.

The data density of the BDs is higher than that of HD DVDs because of a thicker transparent layer (0.1 mm for the BD vs. 0.6 mm for the DVD), which reduces the laser diffusion and the pit dimension and minimum distance between tracks. The higher capacity of BD makes it the winner in the competition with HD DVD (Fig. 2.25).

All the optical disks described up to now are based on reflective materials. The maximum number of layers on these disks is limited by the effects of scatter,

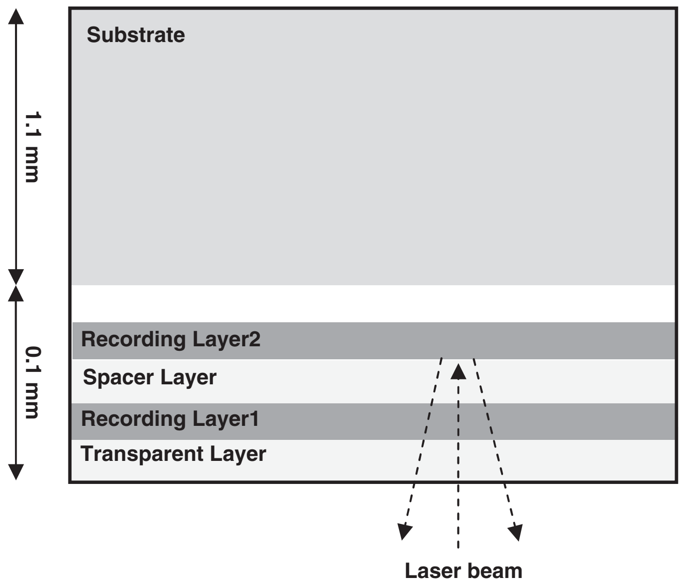


Fig. 2.25 HD DVD structure

interference, and cross-talk. However, this limitation can be overcome by the use of fluorescent materials.

The *Fluorescent Multilayer Disk (FMD)* is an optical disk in which the pits are filled with a fluorescent material. When impacted by a laser beam, the pit emits an incoherent light with a different wavelength, which is decoded by the reader.

An FMD can have up to 100 layers, a limitation that is mainly due to the disk thickness. FMDs that use red laser beams (640 nm) have a maximum capacity of 140 GB, whereas FMDs that use blue laser beams (405 nm) have a maximum capacity of 1 TB.

Magneto-Optical Disk

In magneto-optical memory devices data recording and reading is performed with a laser beam on a magnetic medium.

The magnetic disk is made of special materials that vary their capacity to retain the magnetization induced by an external magnet (coercivity) with temperature: at room temperature, they have high coercivity and do not change their magnetization even in the presence of a magnetic field; when heated by an intense enough laser beam, they can change their magnetization, even with a field that is not very intense. Thus during the writing phase, a well-focused laser beam heats the points where one has to write information bits, while an applied magnetic field alters the direction of the magnetization. The read operation is performed with a laser beam whose polarization direction is changed by the action of the magnetic field of the memory on which it is dropped.

Semiconductor Devices

Semiconductor memory is an electronic data storage device, often used as computer memory, implemented on a semiconductor-based integrated circuit [11–17]. Examples of semiconductor memory include nonvolatile memories such as read-only memory (ROM), magnetoresistive random access memory (MRAM), and flash memory. It also includes volatile memories such as static random access memory (SRAM), which relies on several transistors forming a digital flip-flop to store one bit, and dynamic random access memory (DRAM), which uses one capacitor and one transistor to store each bit. Shift registers, processor registers, data buffers, and other small digital registers that have no memory address decoding mechanism are not considered memories.

Data are accessed by means of a binary memory address to the memory. If the memory address consists of M bits, the address area consists of two raised by M addresses per chip. Semiconductor memories are manufactured with a certain word length (number of 1-bit cells sharing the same memory address) that is a power of two, typically $M = 1, 2, 4$, or 8 bits per chip. Consequently, the amount of data stored in each chip is $M \times N \times 2$ bits. Possible figures are 1, 2, 4, 8, 16, 32, 64, 128, 256 and 512 bits, kbits, Mbits, Gbits, and Tbits, defined here by binary prefixes. By combining several integrated circuits, memory can be arranged for a longer word length and/or larger address space than what is offered by each chip, often but not necessarily a power of two.

As noted before semiconductor memories can be divided in *volatile* and *non-volatile* memories. Typically the volatile memories are SRAM, DRAM, MRAM, and so on. *Nonvolatile* memories, which are also called *storage devices*, include SSD, memory cards, USB drives, and so on.

Flash memory is becoming the primary technology used in storage devices. A particularly important form of semiconductor memory,t is now widely used and is possibly one of the most important forms of medium-term storage.

Flash memory has become increasingly popular in recent years and can be seen in many forms today including flash memory USB memory sticks, digital camera memory cards in the form of compact flash or secure digital, SD, memory. Flash memory storage is also used in many other items from MP3 players to mobile phones, and in many other applications such as SSD.

Flash memory storage is a form of nonvolatile memory: the data held within the flash memory do not disappear when the power is turned off and it can be re-written as required. Each flash memory cell is made up of a single field effect transistor. One of the main advantages of flash memory is the fact that it can be erased electrically. However, it is not possible to erase each cell in a flash memory individually unless a large amount of additional circuitry is added into the chip.

The flash memory is structured in m blocks, typically a power of two (the number of blocks depends on the memory capacity). Each block is divided into k pages; a page is the minimum programmable dimension, whereas the minimum erasable area is a whole block. Each page is divided into several bits physically built by a transistor in floating gate technology (Fig. 2.26).

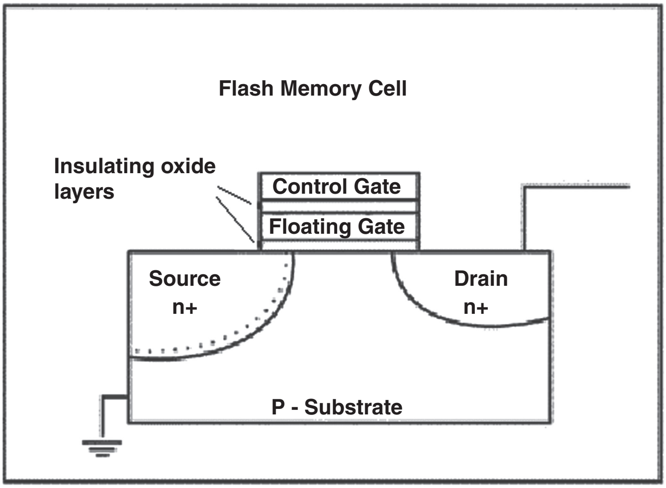


Fig. 2.26 A floating gate cell – 1

Each flash memory cell consists of source and drain electrodes separated by a channel about 1 μm long. Above the channel in the flash memory cell is a floating gate that is separated from the channel by an exceedingly thin oxide layer. The quality of this layer is crucial for the reliable operation of the memory. A control gate located above the floating gate is used to charge up the gate capacitance during the write cycle. The flash memory cell functions by storing charge on the floating gate. The presence of charge then determines whether the channel will conduct or not. During the read cycle a "1" at the output corresponds to the channel being in its low resistance or ON state (Fig. 2.27).

Programming the flash memory cell is a little more complicated and involves a process known as hot-electron injection. When programming, the control gate is connected to a "programming voltage." The drain then sees a voltage of around half this value while the source is at ground. The voltage on the control gate is coupled to the floating gate through the dielectric, raising the floating gate to the programming voltage and inverting the channel underneath. The erase process generally only lasts a few milliseconds. When completed each flash memory cell in the block is checked to ensure it has been completely erased. If not a second erase cycle is initiated.

In the early days of one of the limiting features of flash memories was in their programming, as they had a limited number of erase program cycles, owing to the destructive breakdown of the thin gate oxide layer. Some of the early examples of flash memories only had a few hundred cycles. Now flash memory technology is vastly improved and manufacturers quote figures that indicate that the flash memory life is no longer of concern.

Most of the improvement in flash memory has been brought about by enhancing the quality of the oxide layer. When samples of flash memory chips are found to

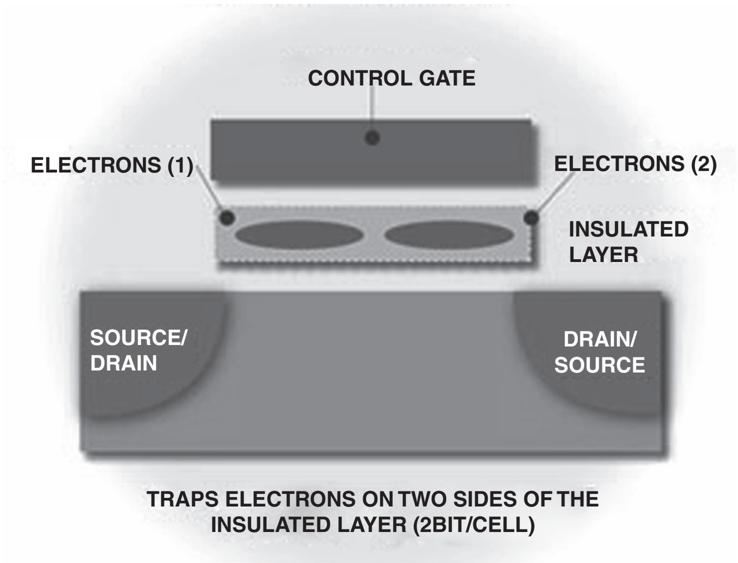


Fig. 2.27 Floating gate cell 2

have a shorter lifetime, it is usually a result of the manufacturing process not being optimized for the oxide growth. Now programming flash memory is not a problem and when using flash memory the chips are, within reason, not treated as items with a limited life.

Flash memory is different from most other types of electronic memories in that while reading data can be performed on individual addresses on certain types of flash memory, erase and write activities can only be performed on a block of a flash memory. A typical block size will be 128, 256, or 512 kB. The low-level control software used to drive flash memories has to take account of this if the read and write operations are to be performed correctly.

There are two basic types of flash memory. Although they use the same basic technology, the ways they are addressed for reading and writing are slightly different.

Over time flash technology has evolved following two different paths originating two different families: NOR and NAND flash. For both, the atomic information is stored in memory cells based on floating gate technology evolving through a progressive lithographic shrink that determines continuous area reduction and cost effectiveness. Each cell is capable of retaining the information represented by a single bit (single-level cell – SLC) or combinations of bits (multilevel cell – MLC). Cells are grouped and organized in arrays whose structures differ in NOR and NAND flash memory:

- NOR flash memory is able to read individual flash memory cells, and as such it behaves like a traditional ROM in this mode. For the erase and write functions, commands are written to the first page of the mapped memory (Fig. 2.28).
- NAND flash memories are accessed much like block devices such as hard disks. When NAND flash memories are to be read, the contents must first be paged into memory-mapped RAM. This makes the presence of a memory management unit essential (Fig. 2.29).

The most common applications are flash memory cards *(Compact flash, SD, miniSD, and microSD)* and USB flash drives, while one of the most recent applications is the SSD *(solid-state drives)*.

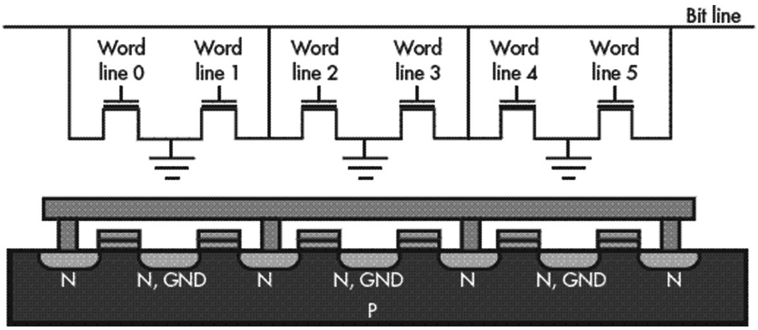


Fig. 2.28 NOR structure

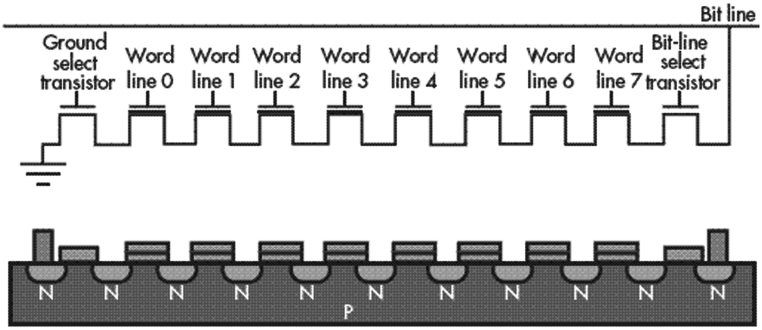


Fig. 2.29 NAND structure

Flash Memory Card

Flashcards are solid-state storage devices, used mostly in small mobile devices such as MP3 players, game consoles, digital and video cameras, mobile phones, and in other portable devices such as PDAs. Through external card readers, PCMCIA-adapters or proprietary slots, the flashcard data can be read in notebooks/PCs. The typical size of a flashcard is that of a large postage stamp. Storage capacity is typically 512 MB up to 32 or 64 GB. Basic types are Compactflash, Smart Media, Multi Media, Secure Digital, and Memory Stick.

The performances offered by these devices may be very high. In fact they can reach up to 40 MB/s in read and 20 MB/s in write. There are lots of different performance values among the various devices depending on which flash memory is used: NAND or NOR. Typically NOR-based flash memory cards are used in applications that require very high-read performances; otherwise NAND-based flash memory cards are used.

Using a flash card, instead of the flash memory stand-alone, guarantees a simplified application. This is due to a series of algorithms implemented in the flash card that gives it a high performance, high reliability, and ensures long life of the device itself.

One of the brand new MMC (multi media card) evolutions is the e·MMC (embedded MMC), which is a nonremovable device that integrates one or more Flash memories and an MMC controller. This device is dominating the market for a lot of wireless and automotive applications.

USB Flash Drives

Introduced in 2002, USB flash drives offer an incredible combination of high storage capacity, fast data transfer rates, and great flexibility, all in the palm of one's hand. Heralded as a floppy or CD drive alternative, USB flash drives have far more storage capacity than a standard floppy disk or a CD-ROM drive replacement. They provide an easy method for quick downloads and transferring digital files to and from a computer or device. USB flash drives incorporate NAND flash and a controller in a capsulated case and work with the vast majority of computers and devices that incorporate the Universal Serial Bus interface, including most PCs, PDAs, and MP3 players.

SSD (Solid State Drives)

A solid-state drive (SSD) is a data storage device that uses solid-state memory to store persistent data. An SSD emulates a hard disk drive interface, and thus easily replaces it in most applications. An SSD using SRAM or DRAM (instead of flash memory) is often called a RAM-drive, not to be confused with a RAM disk.

The original use of the term "solid-state" (from solid-state physics) refers to semiconductor devices rather than electron tubes but, in the present context, has been adopted to distinguish solid-state electronics from electromechanical devices. With no moving parts, solid-state drives are less fragile than hard disks and are also silent (unless a cooling fan is used); as there are no mechanical delays, they usually enjoy low access time and latency (Fig. 2.30).

Owing to these features, SSDs are starting to be used for more and more applications rather than HDDs and are already being employed more often than HDDs for industrial/embedded and phone products. The trend indicates that SSD will completely replace HDD in applications such as ultra low-cost Netbook, Notebook, Smartbook, and Tablet devices by 2014.

Fig. 2.30 Example of an SSD

Uncommon Storage Media

Current predominant nonvolatile memory technologies for mass storage applications rely upon flash memories (used, for instance, on solid-state disk drives and other embedded memory modules) and magnetic-based solutions [18–24].

A general trend is to extend the use of NAND flash technology in solid-state disk applications or for hybrid solutions (with traditional HDD) to create better products in terms of mechanical specifications, robustness, and performance.

Moore's law will continue to drive memory technology scaling but technological complexity will increasing address the fundamental limits of physics. In respect of Moore law's predictions, there is constant research activity in industrial and academic contexts leveraging not only on the future possibilities of current transistor-based solutions but also on the development of material and structural innovations. This research will lead to the identification of scalable nonvolatile technologies for applications in various market segments in the next 5 years and beyond. Such technologies will be used in mass storage solutions or as supportive memory modules in hybrid architectures.

The driving factors for innovative solutions are:

- High performance
- Low power consumption
- Long term scalability
- Cost
- Technological complexity

The best compromise among those parameters will determine the success of a technology with respect to the others.

The following, most of which are based on the use of new materials in the elementary structure to store the information, can be considered uncommon storage media :

- FeRAM or FRAM (ferroelectric RAM)
- PCM (phase change memory)
- PMC (programmable metallization cell RRAM)
- MRAM (magnetoresistive RAM)
- Others (molecular memories, probe storage, carbon nanotube)

The rest of this chapter focuses on the primary alternatives that will be introduced in the memory market.

FeRAM or FRAM (Ferroelectric RAM)

Ferroelectric RAM is a random access memory similar in construction to DRAM but uses a ferroelectric layer instead of a dielectric layer to achieve nonvolatility.

Development of FeRAM began in the late 1980s. Much of the current FeRAM technology was developed by Ramtron, a fabless semiconductor company. One of its major licensees is Fujitsu, which operates what is probably the world's largest semiconductor foundry production line with FeRAM capability. Since 1999 they have been using this line to produce stand-alone FeRAMs, as well as specialized chips (e.g., chips for smart cards) with embedded FeRAMs. Fujitsu produces devices for Ramtron. Texas Instruments has collaborated with Ramtron since 2001 to develop FeRAM test chips in a modified 130-nm process. In the fall of 2005 Ramtron reported that they were evaluating prototype samples of an 8-Mbit FeRAM manufactured using the Texas Instruments' FeRAM process. In 2005 Fujitsu and Seiko-Epson collaborated in the development of a 180-nm FeRAM process.

Storage Mechanism

The physical principle underlying the storing mechanism is the permanent polarization of a ferroelectric dielectric. In a ferroelectric material there is a characteristic nonlinear relationship between the applied electric field and the apparent stored charge, which has the shape of a hysteresis loop (see Fig. 2.31).

Over some range of temperature, ferroelectric materials exhibit a spontaneous electric polarization that can be oriented by application of an electric field. When

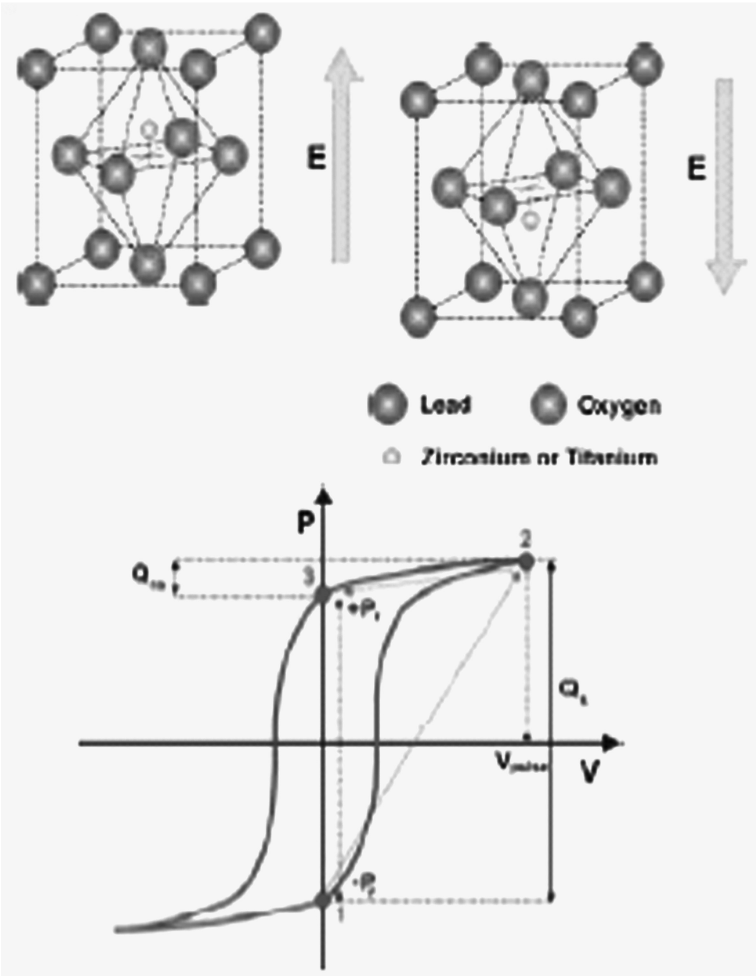


Fig. 2.31 Ferroelectric material polarization and hysteresis loop

an external electric field is applied across a dielectric, the internal semipermanent dipoles in the crystal structure of the material tend to align themselves with the field direction, produced by small shifts in the positions of atoms and shifts in the distributions of electronic charge in the crystal structure. After the charge is removed, the dipoles retain their polarized state. Typically binary "0's" and "1's" are stored as one of two possible electric polarizations in each data storage cell.

Storage Cell Architecture

Each cell consists of one capacitor and one transistor, a so-called "1T-1C" device. The 1T-1C storage cell design in an FeRAM is similar in construction to the storage cell in the widely used DRAM in that both cell types include one capacitor and one access transistor. A linear dielectric is used in a DRAM cell capacitor, whereas in an FeRAM cell capacitor the dielectric structure includes ferroelectric material, typically lead zirconate titanate (PZT), strontium-bismuth-tantalate (SBT), or lanthanum substituted-bismuth-titanate (BLT).

Read/Write Mechanisms

Writing is accomplished by via a field across the ferroelectric layer created by voltage applied to the capacitor plates, which forces the atoms inside into an "up" or "down" orientation (depending on the polarity of the charge), thereby storing a "1" or "0."

Reading, however, is different from a read operation in a conventional DRAM. The transistor forces the cell into a particular state, say "0." If the cell already holds a "0," nothing will happen in the output lines. But if it holds a "1," the reorientation of the atoms in the film will cause a brief pulse of current in the output as they push electrons out of the metal on the "down" side. The presence of this pulse means that the cell held a "1."

Since this process overwrites the cell, reading FeRAM is a destructive process and requires that the cell be re-written if it was changed.

Evaluation of the Pros and Cons

From a power consumption perspective, FeRAM can be considered more effective than DRAM for both the low-power nature of the elementary operations on the cell and for the low externally applied voltages. While DRAM must be periodically refreshed to cope with the loss of charge on the capacitors increasing the refresh rate done by an external application, FeRAM does not need any refresh mechanism which actually determines a continuous power supply. This technology requires power consumption only while reading and writing the cell.

Intrinsic performance is based on the physical displacement of atoms due to an external electric field, which is intrinsically a very fast process (<100 ps). The external circuitry to control the mechanism and to execute read and write operations adds some delay in the overall performances, but write and read operations (<100 ns) can be considered fast when compared to flash technology. The technology is also characterized by a high write endurance (>10^{12}), but the read endurance is limited by the destructive read-out mechanism.

PCM (Phase Change Memory)

Phase change memory (PCM) is a term used to describe a class of nonvolatile memory devices that store information by utilizing a reversible phase change in materials. Materials can exist in various phases—solid, liquid, gas, condensate, and plasma. PCM exploits the differences in the electrical resistivity of a material in different phases.

PCM technology uses a class of materials known as chalcogenides, which are alloys that contain an element in the oxygen/sulfur family of the Periodic Table. Most companies performing research and development in PCM today are using GST (germanium, antimony, and tellurium) or closely related alloys (Fig. 2.32).

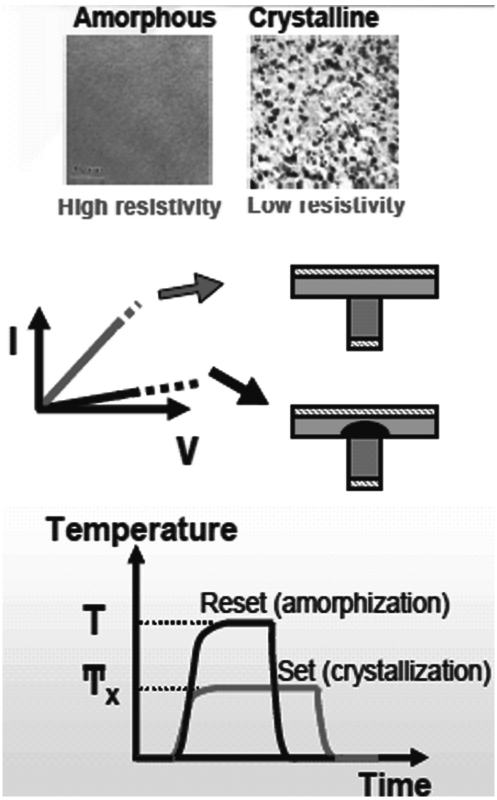
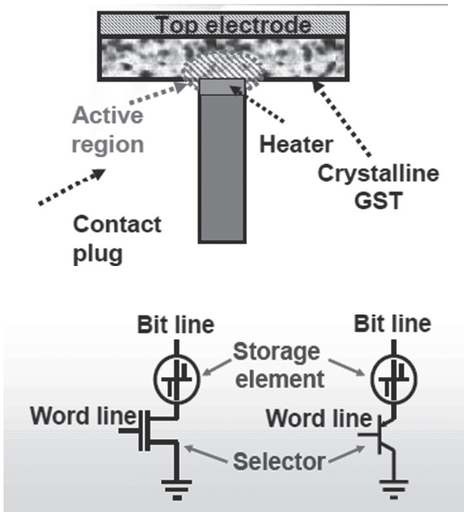


Fig. 2.32 Chalcogenide phase change behavior

Storage Mechanism

Phase change chalcogenides exhibit a reversible phase change phenomenon (see Fig. 2.33) when changed from the amorphous to the crystalline phase. In the amorphous phase, the material is highly disordered–there is an absence of regular order to the crystalline lattice. In this phase, the material demonstrates high resistivity and high reflectivity. In contrast, in the polycrystalline phase, the material has a regular crystalline structure and exhibits low reflectivity and low resistivity. The difference in resistivity between the two phases of the material is what associates the information to be stored in a nonvolatile way.

Fig. 2.33 Structure of a PCM cell



Read/Write Mechanism

The PCM writing mechanism is based on the phase change induced in the material through intense localized Joule heating caused by current injection (see Fig. 2.33). The end phase of the material is modulated by the magnitude of the injected current, the applied voltage, and the duration of the operation.

The reading mechanism is based on the resistance measured after the change in the material phase change induced during the write operation.

The basic cell structure consists of the following:

- A region of chalcogenide material between two electrodes (storage element). One of the electrodes has a small contact area and a high-resistivity region to concentrate Joule heating
- A selector represented by a transistor (BJT or MOSFET)

Pro and Con Evaluation

The particular mechanism behind PCM technology offers a series of functionalities capable of enabling possible new models of a nonvolatile memory peripheral for different applications:

- Bit alterability. Unlike flash technology, no intermediate erase steps are required to write a portion of the memory array, which can be directly written with a smaller granularity.
- Read speed. Fast random access can be achieved through the very low latency in reading a PCM cell making easier the adoption of this technology in the code execution host usage model.
- Write speed. Write speed is faster than NOR flash technology. As with RAMs no separate erase operation is required.
- Retention/endurance. The physical characteristics and the circuitry used do not impact massively on the endurance of the device. In particular the read endurance is especially high.
- Scaling. Scaling is an important factor for cost reduction and with PCM, as the memory cell shrinks, the volume of GST material shrinks as well.

Temperature sensitivity is perhaps its most notable drawback, one that may require changes in the production process of manufacturers incorporating the technology.

MRAM (Magneto Resistive RAM)

Storage Mechanism

For this type of nonvolatile memory, the storage principle is not based on an electronic mechanism but rather on magnetic storage elements. In particular, the basic storage element is made up of two ferromagnetic plates, capable of holding a magnetic field, separated by a thin insulating layer (see Fig. 2.34). One of the two plates is a permanent magnet with its own particular polarity permanently set; the second varies its field to match an external field. This is the basic structure of a cell, and a memory device is built from a grid of such "cells."

Read/Write Mechanisms

Reading consists of measuring the electrical resistance of the cell. An associated transistor is used to select the cell; it switches current from a supply line through the cell to ground. The electrical resistance of the cell changes owing to the orientations of the fields in the two plates. The new value of the resistance is obtained by measuring the resulting current. Typically if the two plates have the same polarity it is conventionally considered as "0," whereas if the two plates have opposite polarity, the resistance will be higher and the associated information is "1."

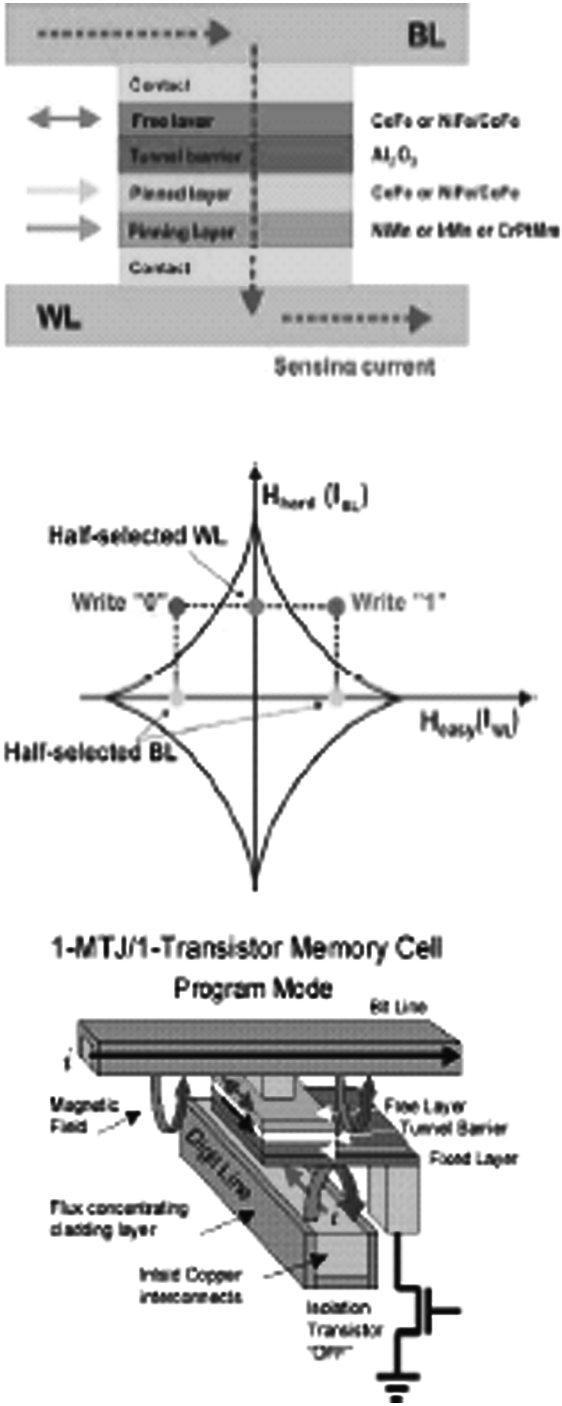


Fig. 2.34 MRAM transistor memory structure

Over the years the writing mechanism has evolved using different methods. The basic technique makes use of the current flowing in the bit and digit lines in the array containing the cell to be written on: the induced external magnetic field modifies the polarity of the plate whose field can be changed. This technique has two immediate implications: power consumption (due to the current flowing in the array) and scaling issues (when the cell size is reduced, the inducted field can cause spurious write operations). The current research effort is to minimize the relevance of these two implications

MRAM does not require a refresh mechanism. However, the write process requires more power in order to overcome the existing field stored in the junction, varying from three to eight times the power required during reading.

Evaluation of the Pros and Cons

MRAMs have some advantages such as fast write operations, high write endurance, and low-voltage writes but, at the same time, there are issues that must be solved (process integration difficulties, large cell size compared to flash and DRAM, high write currents, scaling limitation).

PMC (Programmable Metallization Cell RRAM)

The programmable metallization cell, or PMC, is a new form of nonvolatile memory being studied and developed at Arizona State University and its spin-off, Axon Technologies.

Storage Mechanism

PMC nonvolatile technology is based on the physical relocation of ions within a solid electrolyte. A PMC memory cell is made up of two solid metal electrodes, one relatively inert (e.g., tungsten) the other electrochemically active (e.g., silver or copper), with a thin film of the electrolyte between them. A control transistor can also be included in each cell.

Applying a negative bias to the inert electrode causes a migration of the metal ions in the electrolyte, as well as some originating from the now-positive active electrode, toward the inert electrode, where they are reduced. After a short period of time the ions flowing into the filament form a small metallic "nanowire" between the two electrodes. The "nanowire" reduces the resistance along that path indicating that the "writing" process is complete.

Read/Write Mechanisms

Reading the cell simply requires the control transistor to be switched on and a small voltage applied across the cell. If the nanowire is in place in that cell, the resistance will be low, leading to higher current, which is read as a "1." If there is no nanowire in the cell, the resistance is higher, leading to low current, which is read as a "0."

Erasing the cell is identical to writing, but uses a positive bias on the inert electrode. The metal ions migrate away from the filament, back into the electrolyte, and eventually to the negatively charged active electrode. This breaks the nanowire and increases the resistance again.

Others

Molecular Memories

Molecular memory is a term for data storage technologies that use molecular species as the data storage element, rather than, e.g., circuits, magnetic, inorganic materials, or physical shapes. The molecular component can be described as a molecular switch and can perform this function by any of several mechanisms, including charge storage, photochromism, or changes in capacitance. In a perfect molecular memory device, each individual molecule contains a bit of data, leading to massive data capacity. However, practical devices are more likely to use large numbers of molecules for each bit, in the manner of 3D optical data storage (many examples of which can be considered molecular memory devices). The term "molecular memory" is most often used to indicate very fast, electronically addressed solid-state data storage, as is the term computer memory. At present, molecular memories are still found only in laboratories (see Fig. 2.35).

One approach to molecular memories is based on special compounds, such as porphyry-based polymers, that are capable of storing electric charge. Once a certain voltage threshold is reached the material oxidizes, releasing an electric charge. The process is reversible, in effect creating an electric capacitor. The properties of the material allow for a much greater capacitance per unit area than with conventional DRAM memory, thus potentially leading to smaller and cheaper integrated circuits.

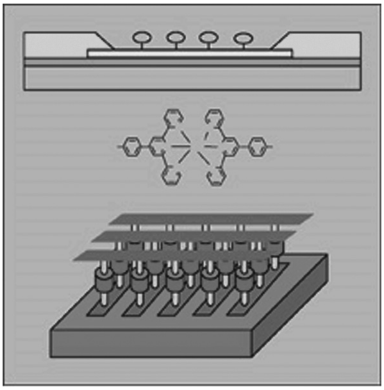


Fig. 2.35 Molecular memories

Millipede

Millipede is a nonvolatile memory stored on nanoscopic pits burned into the surface of a thin polymer layer, read and written on by a MEMS-based probe.

A millipede stores data in a "dumb" medium that is simpler and smaller than any cell used in an electronic medium and accesses the data by moving the medium under a "head" (probe). However, millipede uses many nanoscopic probes that can read and write in parallel, thereby dramatically increasing the throughput to the point where it can compete with some forms of electronic memory. Additionally, millipede's physical medium stores a bit in a very small area, leading to densities even higher than current hard drives. Each probe in the cantilever array stores and reads data thermo-mechanically, handling one bit at a time.

To accomplish a read, the probe tip is heated to around 300°C and moved in proximity to the data sled. If the probe is located over a pit the cantilever will push it into the hole, increasing the surface area in contact with the sled, and in turn increasing the cooling as heat leaks into the sled from the probe. In the case where there is no pit at that location, only the very tip of the probe remains in contact with the sled and the heat leaks away more slowly. The electrical resistance of the probe is a function of its temperature, rising with increasing temperature. Thus when the probe drops into a pit and cools it registers as a drop in resistance. A low resistance is translated to a "1" bit, or a "0" bit otherwise. While reading an entire storage field, the tip is dragged over the entire surface and the resistance changes are constantly monitored.

To write a bit, the tip of the probe is heated to a temperature above the glass transition temperature of the polymer used to manufacture the data sled, which is generally acrylic glass. In this case the transition temperature is around 400 K. To write a "1," the polymer in proximity to the tip is softened and the tip is then gently touched to it, causing a dent. To erase the bit and return it to the zero state, the tip is pulled up from the surface, allowing the surface tension to pull the surface flat again.

Conclusions

This chapter has presented an overview of the evolution of mass storage devices during the past centuries and provided some information on the newer memories currently available in the mass memory market. One important segment that is now interested in mass storage memories is the wireless market: in the last 2 years a lot of mobile phones have begun using big mass storage devices based on NAND technology, especially the Smartphone platforms focusing on multimedia content (audio, video, maps, etc.).

Today there are many mobile phones with, for example, 16/32-GB devices using the widely adopted e·MMC standard interface promoted and described by the JEDEC organization. It appears that this solution and the next evolution, called UFS, will be very familiar item in the future Smartphone market.

In the consumer and personal computer segment HDD is still the predominant choice. An attempt to introduce SDD in the netbook segment met with only limited and temporary success owing to the high cost of the NAND technology compared to the magnetic disk and mechanics of the HDD device.

Currently SSD devices are employed primarily in some dedicated market segments like web servers, banking, military and medical applications.

In the video segment DVD and HD-DVD are still robust in the market but there are a lot of initiatives to distribute these kinds of contents through DVB (Digital Video Broadcasting) and the internet. On the other hand, audio contents using CD devices are not so widespread because they are also distributed via the internet; unfortunately audio magnetic tapes have definitely become extinct.

Finally the most important device used to transmit the greatest amount of information and knowledge during the past centuries is the paper book. There are a few tentative challenges to replace this fundamental tool using solid-state memory-based products but at the moment is not yet clear as to what will be the official new-book replacement for the third millennium.

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