

IBM Storage Products and IBM San Jose Sites
Random Historical Facts
Including Almaden Research Center Innovative Contributions

- **1878:** Oberlin Smith, 1840-1926, was the first to conceive and describe the principles of magnetic recording. The principles of magnetic recording were described by Oberlin Smith in 1878. But it was not until 1898 that a device using these principles was demonstrated and patented by the Danish inventor Valdemar Poulsen.
- **1898:** Valdemar Poulsen, 1869-1942, was the first to demonstrate a working model of a magnetic recorder, and obtain a patent on his invention.
- **1898-Present:** Three main application areas of magnetic recording: audio (sound) recording – all there was between 1898 and 1945, video (television) recording began in the 1950s, and data (computer and instrumentation) recording also started in the early 1950s.
- **1940's:** Data was stored on punched paper tape. This medium had the advantages of low cost, non-volatility, and relatively good reliability. However, access time to data was very long due to slow serial access required to get to a specific data record.
- **1943:** IBM established a punched-card plant in San Jose.
- **1952:** NRZI (Non-Return to Zero, IBM) coding created for tape drives. This code simplified the way data was recorded and read, and permitted bit densities to exceed the density of magnetic transitions.
- **1952:** Reynolds 'Rey' B. Johnson, veteran inventor arrived in San Jose from from the Endicott, NY laboratory to recruit 30-50 electronic engineers and establish a small new advanced development IBM research laboratory in San Jose to cope with the nascent data processing industry's changing technologies.
- In a speech long afterward, Rey Johnson described his charter for the new laboratory: "During the first week of January 1952, I was told of my appointment as West Coast Laboratory manager. I was told that I would have free rein in hiring a staff of 30 to 50, and I would be free to choose projects to work on. One-half of my projects were to be new products and one-half were to be devices in support of customers' special engineering needs. No projects were to be duplicates of work in progress in other IBM laboratories. The laboratory was to be dedicated to innovation. To be given freedom to choose our projects and our staff made the San Jose Laboratory an exciting opportunity, especially since funding was guaranteed – at least for a few years." (Transcript of an address given at a dinner meeting of the Independent Disk Equipment Manufacturers Association – IDEMA).
- **1952:** IBM established its first West Coast laboratory in a modest commercial building at 99 Notre Dame Avenue (a former printing establishment with few amenities) in downtown San Jose. It was at this site that the newly formed team of free-thinking researchers, led by Rey Johnson, was chartered to pursue radically new approaches to information processing problems.
- **1952:** The IBM research team began exploring several novel technologies – most of which did not work. Although many people in the San Jose lab initially thought it was a mistake to base magnetic storage on a disk geometry, the decision gained favor

as solutions were found to such key problems as air-bearing support for the read/write head.

- **1952-1956:** The IBM researcher pioneers quickly focused on what they believed to be the single most promising idea – magnetically storing and randomly accessing data on spinning disks, providing an alternative to conventional, yet cumbersome, punched card, magnetic drum and tape systems.
- **1952-1956:** The first disks were fashioned with a home workshop router from magnesium lithographer's metal, but this material was soon replaced by a special high finish aluminum alloy that Alcoa had developed for the substrate of master LP records. The stock material was only 0.051 inch thick; so after coating on one side, two disks were laminated, clamped between platens and, while under pressure, heated in an oven above the annealing temperature. The resulting disk was "dead" (no ringing) and fairly flat.
- The first magnetic coating – a mixture of iron oxide particles in a paint base similar to that used as a primer on the Golden Gate Bridge – was manually strained through nylon hosiery and poured onto the disk from a paper cup. This mixture was soon replaced by an epoxy base paint, which was used for many years for particulate disks. Initially the disks were spray-coated, but this technique could not give uniform surfaces. More uniform coatings were obtained by a spin-coating technique in which a measured amount of paint was applied at the center of a rotating disk and spread by centrifugal force. Spin coating was used for many years to coat particulate disks.
- **August 25, 1955:** *San Jose Mercury News* broke this story: "IBM Plans Giant New San Jose Plant – Firm eventually may employ more than 5,000 here."
- **1956:** From the small IBM Research Laboratory emerged the disk drive industry. IBM's four-plus years of seminal research came to fruition in the form of the first commercial magnetic hard disk drive – IBM's **305 Random Access Method of Accounting and Control (RAMAC)**, an IBM product that offered a revolutionary approach to on-line direct access to massive databases. This product debut signaled the advent of the Direct Access Storage Device (DASD) industry.
- At the dawn of the disk drive industry, IBM's first RAMAC was capable of storing an incredible 5 million characters of data – roughly the complete works of Shakespeare – on 24-inch platters, stacked 50 high, with a data density of 2,000 bits per square inch. This level of areal density was possible because the magnetic read/write head was supported above the disk surface by a hydrostatic (pressurized) air bearing.
- Data processing equipment was typically leased in those days, but a RAMAC could be purchased for about \$50,000 or \$10,000 per megabyte.
- **RAMAC:** This development by IBM, introduced fast-access data recorders using coated rigid disks, and heads having random access to any recorded track. The development followed the introduction of electronic computers, and it became urgent to provide data storage devices having much faster access than tape. The RAMAC established the generic format for all hard disk drives, in which heads fly close to the surface of a disk rotating at high speed and can be moved randomly to any radial position.

- **September 4, 1956:** T.J. Watson, Jr., President of IBM, announced the RAMAC. He said in part, "This is the greatest product day in IBM's history, and I believe in the office equipment industry."
- This invention signaled the beginning of a new technology sector with forecasted annual revenues in 2001 in excess of \$200 billion and led to the creation of IBM's world-renowned Hard Disk Drive Division.
- **Late 1956:** The 513-acre San Jose site on Cottle Road opened for business. Half of the property was left in its original agricultural state.
- **Late 1956:** IBM formed a research organization to which Rey Johnson's advanced development group, the San Jose Research Laboratory, reported. The laboratory's first IBM-owned home was Building 025 at the IBM Cottle Road facility.
- **The year was 1956.** IBM had just invented the world's first magnetic hard disk drive, capable of storing five million characters of data on 50 disks, each 24 inches in diameter. This was just one of the many IBM milestones in the storage arena. Not long after that, IBM led the industry with 14-inch and 10-inch disk drives for large computer systems. By the early 1980's, IBM had adapted its technology to 3.5-inch and later 2.5-inch drives. In April 1996, continuing to build on IBM disk drive leadership, the world's first magnetic disk drive products to exceed one billion bits of data per square inch of disk space (that's equivalent to 62,500 double-spaced, typewritten pages) were brought to market by IBM.
- **1957:** IBM's revenues were augmented by the \$3,200 sale of the San Jose site's alfalfa.
- **1957:** "Write-wide, read-narrow" head design first used in tape drives. Now also used in disk drives, this technique improved signal-to-noise ratio, assuring that data could be read accurately under a wide range of operating conditions.
- **1960's:** Magnetic disks are dominant form of storage device. Initially, magnetic drums were the preferred large-capacity storage device, but disks were much cheaper and had potential for great capacity.
- **1960's & '70's:** IBM Major Restructuring led to the formation of the Advanced Systems Development Division (ASDD). Rey Johnson was selected as manager of ASDD, and Gardiner Tucker was chosen as manager of an 18-member Research staff. Research moved to Building 028.
- **1961:** First disk drive with one head per disk and air bearing heads.
- **1962:** Co-invented the semiconductor diode laser, technology that enabled compact form-factor packaging for optical disk drive products.
- **1963:** First disk drive with removable disk pack.
- **1964:** Cyclical Redundancy Check (CRC) Error Check and Correction allowed a system to check itself for errors and correct most of them automatically.
- **1964:** Read backwards in tape drives. Still used today, reading backwards, improves tape performance dramatically.
- **1966:** First disk drive with wound-coil ferrite recording head.
- **1971:** First flexible "floppy" disk drive.
- **1971:** First track-following servo system.
- **1971:** First lubricated particulate hard disk used in a product. (IBM 3735 Programmable Buffered Terminal)

- 1973: First disk drive to use low-mass heads, lubricated disks and sealed assembly, which came to be known as Winchester disk technology.
- 1973: Discovered the amorphous rare-earth/transition metal alloys that enabled rewritable magneto-optical data storage.
- 1973: Group Coded Recording improved tape performance by as much as 700 percent over prior systems.
- 1975: Patented the “soft-adjacent layer” magneto-resistive head structure that first provided signal characteristics essential for products. (US: 3,864,751)
- 1976: Non-removable Winchester disks led to a dramatic reduction in the cost of disk drives (to \$100/MB) in the IBM 3350, which became the first successful Winchester disk drive product.
- 1976: First flexible disk drive with two-sided recording.
- 1977: The Santa Teresa Laboratory (STL) – now known as Silicon Valley Lab (SVL), brought programmers from seven different IBM South Bay locations together under the same roof to work in one of the first laboratories designed specifically for programmers.
- 1978: IBM received the first Redundant Array of Independent Disks (RAID) technology patent (US: 4,092,732). Almaden Research Center scientists invented and helped develop new and practical techniques for enhancing the performance and reliability, while lowering the cost, of RAID data-storage systems.
- 1978: Hierarchical Storage Management (HSM), the first software product that moved inactive data from disk to less-expensive media.
- 1979: First disk drive to feature thin-film inductive heads and a run-length-limited (RLL) coding scheme. Thin-film heads led to a new era in higher-performance recording head design, while the “2-7” RLL code permitted higher performance while reducing errors.
- “Smaller, faster, denser, cheaper” is the mantra of the data storage industry – an industry characterized by fierce competition and rapid change. In the midst of this never-ending revolution, one fact has remained constant: IBM’s technological leadership. IBM has played a key role in the development of hard disk drive technology in the past decade. Much of the advanced technology in the field of data storage that keeps IBM ahead of the competition comes from IBM’s Almaden Research Center.
- IBM Research is one of the few industrial research organizations to successfully meld fundamental scientific research with the development of innovative product-related technologies.
- Three IBM Almaden Research Center inventions have greatly improved the efficiency of magnetic hard disk drives:
 - “Banded sector servo” disk architecture increases data storage capacities by changing the control electronics processing of data. Because no changes are needed to any other magnetic recording components, nearly every disk drive in the industry uses this invention.
 - Adaptive Battery Life Extender intelligently manages the transition between the active, three idle and standby modes to reduce disk drive power consumption by up to 20%, increasing mobile system battery life by 5 to 8%.

- “No-ID” disk formatting stores disk-sector-identification information electronically, rather than in front of every data block on the disk. This change frees up about 10-15 percent of the disk area for storing more user data. When used in conjunction with the sensitive magnetoresistive (MR) and Giant MR (GMR) recording heads, this format also permits data tracks to be closer together, further raising the capacity gain. No-ID formatting also permits faster and more reliable data reading and writing operations through a variety of other, subtler impacts.
- Almaden innovations include building high-performance storage systems from common inexpensive parts, emulating costly mainframe disk drives using industry-standard components, and initiating the creation of an industry standard for data storage networks using the well-known and “open” internet protocol: iSCSI. iSCSI is a new standard for accessing storage over IP networks. It is being sponsored by the IETF standards body and is intended to enable applications that access block storage over SCSI busses or Fibre Channel networks to access storage over IP networks. The potential advantages that iSCSI offers are exploitation of low cost IP hardware, minimized total cost of ownership by leveraging existing network management technology, and the possibility for extremely long distance attachment of block storage over the network.
- **1980:** Data Facility Data Set Services (DFDSS) enabled users to reclaim and consolidate unused storage space and move data between like and unlike storage devices.
- **1981:** The first use of data compaction in a hierarchical storage management product.
- **August 1981:** IBM announced its first commercial PC. It came with one or two floppy disk drives.
- **1983:** IBM broke ground for the Almaden Research Center.
- **1984:** Thin-film magneto-resistive head first used in a tape drive.
- **1984:** IBM PC/AT introduced with 20MB hard disk drive.
- **1986:** IBM Almaden Research Center fully occupied.
- **1986:** First disk drive to use the more efficient 1-7 RLL code, now widely used in the industry.
- **1987:** One gigabit per square inch data-density magneto-optical recording with a blue-wavelength laser.
- **1988:** The first full-function, automatic environment for managing storage devices.
- **1989:** Laboratory demonstration of one gigabit per square inch recording density in magnetic media; used a magneto-resistive (MR) head.
- **1989:** Improved Data Recording Capability (IDRC) improved tape capacity by as much as five times.
- **1989:** IBM PS/2 PC introduced with 30 MB fixed disk drive.
- **1990:** First disk drive to use Partial-Response, Maximum-Likelihood (PRML) data channel. (IBM 0681)
- **1991:** First one-gigabyte capacity 3.5-inch disk drive; first disk drive product to use an MR head.

- **1991:** IBM introduced the magnetoresistive 'MR' head products. The industry's annual rate of data-density increases doubled from the historical rate of 25-30 percent per year to 60 percent per year.
- **1991:** A 36-track, thin-film tape head, which reads and writes in both directions, doubling cartridge capacity.
- **1991:** Predictive Failure analysis (PFA) introduced to monitor the key disk drive operating parameters so impending failures could be noticed and corrected before they caused a drive or system shutdown.
- **1993:** The world's first 1-inch high, 1 GB capacity disk drive, stores 354 million bits of data per square inch.
- **1993:** Introduced the ADSTAR Distributed Storage Manager (ADSM) family of client/server data management products – including backup/restore and archive/retrieve – for multi-platform and multi-vendor environments.
- **1993:** Hard disk drives feature the first 4-burst-on-the-fly error-correction code. These were the first disk-drive hardware implementations of an iterative, multiple-burst error-correction algorithm.
- **1993:** No-ID and zoned sector-servo disk formats permit higher performance and more efficient use of the disk for storing data.
- **1993:** World's most sensitive magnetic recording head demonstrated in the laboratory; used the giant magneto-resistive effect in a "spin valve" design.
- **July 1, 1993:** Almaden researchers used the blue laser solid-state light source demonstrated in 1990 to not only demonstrate, but set an optical data-storage density record of 2.5 gigabits per square inch.
- **May 12, 1994:** Multilevel optical disk capable of both reading and writing announced and demonstrated. IBM's multi-layer technology is incorporated into the industry standard for the 2-layer DVD.
- **1994:** Development laboratory demonstrated 10 GB tape cartridge capacity with 9 MB/sec data rates.
- **June 15, 1994:** Announced first spin-valve (GMR) head: world's most sensitive read head. IBM's introduction of the GMR head lead to doubling data density (a 100 percent increase) every year. From science to products, IBM has led the industry in giant magnetoresistance (GMR) discoveries and the development of the GMR read head for magnetic hard disk drives. The increased sensitivity of the GMR head (and its predecessor, the MR head) permitted IBM to set six data-storage-density world records with demonstrations at 1 (1989), 3 (1995), 5 (1996), 11.6 (1997), 20.3 (1998) and 35.3 (1999) gigabits per square inch.
- Almaden's scientific understanding of the physics underlying the giant magnetoresistive head has also had great impact on IBM's development of magnetic random access memory – which has the potential to exhibit the best properties of computer memories: the speed of SRAM, the high-density and low cost of DRAM and the non-volatility of Flash – and advanced magnetic hard disk media.
- **March 30, 1995:** Laboratory demonstration of three billion bits (3 gigabits) per square inch recording in magnetic storage using extensions of currently manufactured technology.
- **1996:** One billion bits of data in a square inch exceeded for the first time in the 2.5-inch Travelstar 3LP, with 13 gigabits/sq. in.

- **December 30, 1996:** 5-gigabit data-density magnetic recording demonstrated.
- **December 30, 1997:** 11.6-gigabit data-density magnetic recording demonstrated.
- **1998:** The book *Magnetic Recording The First 100 Years* edited by Eric D. Daniel, C. Denis Mee, and Mark H. Clark was published. The book compares the 1956 RAMAC with state-of-the-art 1998 storage technology: "RAMAC, the first hard disk storage device, occupied a space of about 1 million cubic centimeters (1 cubic meter), and it achieved a storage density of about 3 bits per square millimeter. A modern disk drive occupies less than 100 cm and stores data at a density of more than 4 million bits/mm. On a bits-per-unit-volume basis, the improvement is quite spectacular – a factor of over 10 million. Today, the hard disk drive has the highest areal density of any magnetic recording device." A trend cited in the same book: ". . . the density of data storage on magnetic media of all types will continue to increase. In particular, the increase in the area density of hard disks from 1988-1998 was truly phenomenal, amounting to over 50% annually. This, in conjunction with smaller, lower cost drives, has driven the cost per megabyte down to 5 cents in 1998 compared with \$10 in 1988. The decline cannot continue indefinitely, but there is no sign of any immediate slowdown."
- **September 9, 1998:** IBM Microdrive announced. Almaden's Microdrive – the world's smallest, lightest drive – can contain a gigabyte of data – roughly 10 meters of shelved books – in a matchbook-sized device with a data density of 15.2 billion bits per square inch. The Microdrive brings the benefits of magnetic data storage – high performance, high data density and low cost – to handheld digital electronics, such as digital cameras, MP3 players and personal digital assistants. One card-sized Microdrive could hold the data contained on 200 refrigerator-sized RAMACs.
- **May 12, 1998:** 20.3-gigabit data density magnetic recording demonstrated.
- **1998:** 100th Anniversary of the invention of Magnetic Recording. "It may be called Silicon Valley in homage to the microprocessor, but the heritage of the disk drive in this region is just as strong and just as important", stated Ron Kilpatrick, General Manager, IBM Storage Systems Products Division, in his opening remarks at the 100th Anniversary Conference on Magnetic Recording and Data Storage, sponsored by the Institute for Information Storage Technology (IIST) and the Center for Science, Technology and Society.
- **October 4, 1999:** 35.3 gigabit data-density magnetic recording demonstrated.
- **2000:** IBM awarded the National Medal of Technology for its leadership in developing and commercializing data storage technology.
- **May 2000:** Almaden scientists demonstrated holographic data storage, both writing and reading, at a density of 254-gigabits per square inch – 80 times that of a DVD. This is one of the crowning achievements of two government/industry/academia holographic storage research consortia in which Almaden took a leadership role. IBM has a long history in pursuing the potential of holographic data storage for high-speed access to huge amounts of data. In the early 1960s, IBM scientists developed the world's first holographic data storage system –based on photographic film – for an Air Force-funded project. The project succeeded, but the process required chemical development, which made it quite slow and read-only. With advanced imaging technologies recently created for video camcorders and computer displays, holographic storage is tantalizingly close to reality. But still lacking is a

suitable holographic storage material with all the properties needed for a reliable and affordable read-write product.

- Introduced in September 1998 at 340-megabyte capacity (or the equivalent of 200 standard size floppy disks), the IBM Microdrive was upgraded to 1-gigabyte capacity in **June 2000**.
- **May 2001:** IBM ships disk drives with new “antiferromagnetically coupled” magnetic media, developed at Almaden and enabling future data densities of 100 gigabits per square inch or more.
- Almaden scientists were first to develop a revolutionary new three-layer form of magnetic hard-disk coating that is eventually expected to quadruple the data density of current hard disk drive products – a level previously thought to be impossible. The superparamagnetic effect (data is lost when the magnetic areas of the disk get too small) was overcome with new magnetic coating “antiferromagnetically coupled” media. The new coating permits tiny, high-density magnetic bits to be much more stable than they would be in traditional, single-layer media. The key to IBM’s new data storage breakthrough is a three-atom-thick layer of the element ruthenium, a precious metal similar to platinum, sandwiched between two magnetic layers. The fact that only a few atoms could have such a dramatic impact caused some IBM scientists to refer to the ruthenium layer informally as “pixie dust.” Known technically as “antiferromagnetically-coupled (AFC) media,” the new multi-layer coating is expected to permit hard-disk drives to store 100 billion bits (gigabits) of data per square inch of disk area by 2003 -- as much as four times the current industry standard.
- In **May 2001**, IBM announced that it was first to ship AFC media in products – the IBM Travelstar notebook hard-disk drive products with data densities up to 25.7 gigabits per square inch, packs data nearly 13 million times as efficiently as RAMAC. In time, IBM plans to implement AFC media across all of its disk drive product lines.
- **2001:** High-end storage shifting rapidly from attached to networked.
- **Summer 2001:** IBM’s Extreme Blue Computer Science and MBA students from around the globe research two storage-related projects at Almaden Research Center – the Consumers’ All-Purpose Storage Appliance (CASA) and Internet Protocol Small Computer system Interface (iSCSI) projects. The projects are collaborations between Technology Group and Research, and explore emerging business opportunities in the storage field.
- **One of many 2001 Almaden Research Center’s Storage Projects:** Development of a theorem that could eventually lead to a more efficient data-compression algorithm that could in turn someday result in putting a server’s worth of data in a wristwatch.
- With further discoveries, the vision of IBM Fellow Emeritus David Thompson may come true. The scientist who pioneered thin-film recording heads for disk drives in the 1970’s says if data storage improves in the next 35 years at the same rate as it has in the past 45, in the year 2036 a pocket sized data storage system will be able to store everything its owner sees, hears and says over a 10-year period.

- IBM has led the way in data storage technology for nearly 50 years. Hard Disk Storage – one of the hallmarks of the IBM Almaden team – has advanced some eight orders of magnitude since the technology was born more than 40 years ago.