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Today, as 40 years ago, hard disk drives with rotating magnetic disks are the storage medium of choice when it comes to storing large amounts of data.

Hard Disk Drives: From Megabytes to the Terabyte Era and Beyond

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The journey of hard disk drives (HDDs) spans more than 60 years, transforming from bulky, low-capacity storage devices to the high-density, cost-effective solutions of today. Originating in the 1950s, early HDDs were cabinet-sized and weighed nearly a ton, revolutionising data processing by enabling more immediate access to information for selected computer and mainframe systems. The true 'triumph' of the hard disk, however, began in the 1980s with the advent of PCs.

Early Evolution and Standardisation

In the early PC era, drives measuring 5.25 inches in form factor offered a mere few Megabytes (MB) of data storage, such as the popular 20MB models. At the time, that storage capacity was sufficient given the lack of graphical user interfaces or storage-hungry digital media. Over the years, storage capacities quickly rose into the triple-digit Megabyte range, accompanied by the standardisation of interfaces. The Molex connec-

tor became standard for power, while Parallel ATA (later PATA) and subsequently Serial ATA (SATA) became prevalent for data transfer, replacing the older ribbon cables.

The period also saw rapid consolidation within the industry. In 1985, there were 75 hard disk manufacturers, with over 200 companies attempting to produce drives over time. Today, only three remain active, as production became economically attractive only with large quantities.

Simultaneously, HDD form factors continuously shrank. The 3.5-inch HDD became widespread from the late 1980s, matching floppy disk drive bays and quickly becoming the standard for servers and storage systems, a position it largely maintains today. Smaller form factors, such as 2.5-inch drives for notebooks, emerged, though these are now primarily found in external USB drives due to the dominance of SSDs in laptops.



Figure 1: A hard disk model from 1984 that stores 20 Megabytes. At that time, the drives were increasingly being installed in PCs, but at 5.25 inches they were still much larger than today's hard disks. The interfaces were also not yet standardised – PATA came later.



Figure 2: At the end of the 1980s, 3.5-inch drives became popular; here is a model from 1994 with 850 Megabytes. The form factor is still standard in PCs, servers and storage systems today.



Figure 3: The increasing demand for notebooks led to a boom in 2.5-inch hard disks, and in the mid-1990s the Gigabyte limit was passed. Since mobile computers are now mainly equipped with SSDs, 2.5-inch drives are now used almost exclusively in external USB enclosures.

Even smaller drives, such as 1.8-inch HDDs (used in the first iPod in 2001) and 1-inch disks (for CompactFlash slots in digital cameras), briefly appeared. In the earlier 2000s, some smartphones even featured 0.85-inch models holding an impressive 4 Gigabytes (GB) of data. However, flash memory ultimately outstripped HDDs in mobile devices, setting a lower limit for physical size reduction.



Figure 4: The audio players, digital cameras and smartphones that emerged at the end of the 1990s were initially equipped with hard disk drives – flash memory was far too expensive at that time. Manufacturers developed HDD drives with 1.8 inches, 1 inch and also this tiny one from 2004, which measures only 0.85 inches and holds 4 Gigabytes.



Figure 5: In the mid-2000s, the new recording method PMR (perpendicular magnetic recording) caused enormous leaps in capacity. Hard disks could suddenly hold well over 100 Gigabytes. The high data volumes made new interfaces necessary: SATA replaced PATA in the client area and SAS followed SCSI in the data centre.



Figure 6: This flat 1.8-inch hard drive from 2009 is equipped with a single magnetic disk that can store 320 Gigabytes and is used in compact notebooks, among other things.

Capacity Breakthroughs: PMR, Helium, and Microwave Technology

The ‘flash boom’ necessitated that HDDs succeed by offering high capacities at favourable costs. A significant leap in capacity was achieved with perpendicular magnetic recording (PMR), a new recording method introduced in the mid-2000s. Unlike previous longitudinal magnetic recording (LMR), which aligned bits horizontally, PMR allowed a vertical arrangement, vastly increasing storage density.

Further capacity enhancements were achieved by filling HDDs with helium from the mid-2010s. This light-weight inert gas reduces friction and turbulence compared to air, enabling the use of thinner disks and creating space for additional platters within the enclosure. With nine disks and PMR, this innovation allowed for up to 16 Terabyte (TB) drives.

More recently, microwave-assisted magnetic recording (MAMR) has emerged as a new recording method. This technology uses microwaves to control and focus the magnetic flux at the write head, reducing the energy needed to magnetise bits and enabling smaller recording heads and denser data writing.



Figure 7: Flash is displacing hard drives from many devices, so HDDs can only succeed with large capacities. The drives broke the Terabyte barrier in the early 2010s, catching the rapidly swelling data wave of the information age in data centres and cloud environments.



Figure 8: In 2021, a new generation of hard disk drives entered the scene, relying on the new MAMR (microwave-assisted magnetic recording) method. The first model had a capacity of 18 Terabytes, and its successor in 2022 has already brought it to 20 Terabytes.

Toshiba launched drives featuring a new form of MAMR, called flux-controlled MAMR (FC-MAMR™), which boosted data storage capacity and improved power efficiency. The MG10 Series, released in 2022, features a 10-disk helium-sealed design that can store up to 22TB of data while maintaining the familiar 3.5-inch form factor.



Figure 9: The advanced MG10 Series is the answer on the data growing at an explosive pace, Announced in 2022, these HDDs, boost the capacity up to 20TB which is 11.1% more than its predecessor. With its improved power efficiency and increased capacity, these HDDs help cloud-scale service providers and storage solution designers to achieve higher storage densities for cloud, hybrid-cloud and on-premises rack-scale storage.

The Future of Storage Technology

Building on FC-MAMR technology, Toshiba introduced the Mx11 family of helium-sealed Enterprise Capacity HDDs last year. This innovation demonstrates the potential for increased capacity within the same form factor, without requiring additional power consumption.

The MG11 Series utilises conventional magnetic recording (CMR) with FC-MAMR to provide capacities of up to 24TB. The MA11 Series, on the other hand, employs shingled magnetic recording (SMR) to offer even higher capacities of up to 28TB. SMR is a technique for writing data to tracks that partially overlap, increasing the density and overall storage capacity per disk.

CMR is suited for Enterprise servers that handle different types of workloads. Whereas the industry is expected to pivot towards SMR technology for homogenous workloads that write in large chunks, with optimised cache buffering absorbing short bursts of random writing.



Figure 10: The Mx11 family delivers even higher levels of density and power efficiency for hyperscalers and data centres in the 3.5-inch form factor. The MG11 Series offers capacities of up to 24TB using conventional magnetic recording (CMR), while the MA11 Series provides capacities of up to 28TB with shingled magnetic recording (SMR).



Figure 11: MAS-MAMR, combined with further SMR development and thinner magnetic disks (now 0.55mm thick, allowing 11 disks in a 3.5-inch enclosure), is expected to increase HDD capacities to around 40TB. Toshiba has already presented a prototype with 11 disks and a capacity of 31.24TB.

In the next development stage, microwave-assisted switching MAMR (MAS-MAMR), microwaves will activate the material of the magnetic disks to reduce energy input further and enable an even smaller write head. This requires new disk coatings and more precise microwave switching. MAS-MAMR, combined with further SMR development and thinner magnetic disks (now 0.55mm thick, allowing 11 disks in a 3.5-inch enclosure), is expected to increase HDD capacities to around 40TB in the next few years. Toshiba has already presented a prototype with 11 disks and a capacity of 31.24TB.

Toshiba First in Industry to Verify 12-Disk Stacking Technology for Hard Drives

In October 2025, Toshiba was the first in the storage industry to verify 12-disk stacking technology for high-capacity HDDs. By combining this achievement with MAMR technology, the company aims to introduce 40TB-class 3.5-inch HDDs for data centers to the market in 2027.



Figure 12: Toshiba is the first in the storage industry to verify 12-disk stacking technology for high-capacity hard disk drives.

This 12-disk stacking technology leverages advanced design and analysis technologies that Toshiba has developed in creating thin, compact products, and adds two disks to the standard 10-disk, 3.5-inch disk track used in the company's nearline HDDs. Key advances include the development of new dedicated parts in the stack and the replacement of the current aluminum substrate medium with a glass substrate that offers greater durability and allows thinner designs. These advances deliver improved mechanical stability and in-plane accuracy, higher density, and greater reliability.

Looking further ahead, heat-assisted magnetic recording (HAMR) technology offers even greater potential. HAMR uses a laser diode to heat up the magnetic material to its Curie point, allowing bits to be aligned with very low magnetic energy. While MAMR primarily increases linear bit density, HAMR focuses on increasing track density.

HAMR will likely enable capacities of more than 40TB per drive, potentially reaching up to 50TB in the next few years, ensuring HDDs continue to bear the brunt of data storage in the information age. However, HAMR still needs further development to achieve the reliability and cost-efficiency of MAMR.

Driving Sustainability and Innovation

As large-scale decommissioning of early cloud infrastructure begins, a significant wave of HDD material is anticipated for recycling. HDDs are notably easier to recycle than other electronics, as they contain only two or three different metals, unlike the complex and potentially toxic compounds found in batteries. Cloud service providers are preparing for this influx, and HDD vendors are expected to become an integral part of the recycling process.

Toshiba recognises the growing importance of closer collaboration with customers and other component manufacturers (such as servers, software, cables, and cards) to build a robust storage ecosystem. This commitment is underscored by the inauguration of the new HDD Innovation Lab in Düsseldorf, Germany, this year.

The lab expands Toshiba's HDD evaluation capabilities to support customers and partners in optimising HDD setups for various applications, including cloud storage, surveillance, and NAS systems. It provides a platform for proof-of-concept activities, benchmarking across various architectures, and sharing knowledge through whitepapers and lab reports. The lab also offers loan samples for self-evaluation and hosts live demonstrations at trade fairs.



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