

AMR and GMR Heads Increase Hard Drive Capacity in Western Digital Drives

*Anisotropic Magnetoresistive and Giant Magnetoresistive
Head Technology Taking Over Hard Drives*

► OVERVIEW/EXECUTIVE SUMMARY

Error rate, the number of data bits correctly decoded by the recording head and fly height, the distance between the read/write elements of the head and the magnetic layer of the media are key design parameters in the quest for higher areal density.

Designers strive to keep error rate and fly height as large as possible. Error rate for performance reasons and fly height for reliability. For a given head technology, however, these are mutually exclusive goals. To achieve higher areal densities with thin film inductive (TFI) heads, fly heights had to decrease in order to maintain acceptable error rates. Increasing the ability of the head to detect magnetic signals (i.e. head sensitivity) and slow the rate at which fly height decreased was possible for a time. Eventually, new technologies were needed. Hence the development and introduction of Magneto-Resistive (MR), both anisotropic and giant magnetoresistive, technology. See Figure 1 for a comparison of anisotropic MR and giant MR technologies.

Anisotropic Magnetoresistive (AMR) head technology is currently the primary read/write head technology used in hard drives, replacing TFI heads, the previous standard in the marketplace. GMR heads will be the dominant head technology by the end of 1999. Western Digital is incorporating AMR heads from IBM, Read-Rite and others as well as GMR heads from IBM in desktop drives today. GMR heads from other suppliers will be making their way into drives in the second half of 1999.

AMR vs GMR Error Rate / Yield Comparison

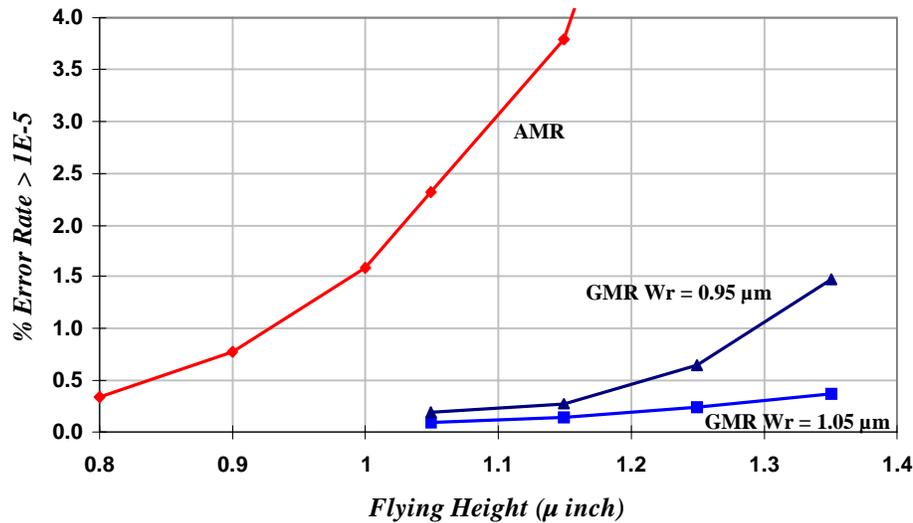


Figure 1

► HISTORY/BACKGROUND

IBM has led in the development of hard drive technologies since the first hard drive in 1954. IBM's Winchester technology, first introduced in 1973, increased storage density by linking the head and disk permanently.

Inductive thin film technology was another important development. Although it was conceived in the 1960s, it did not ship until 1979. The TFI read/write head, which essentially consists of wired, wrapped magnetic cores, had been the standard in the industry for nearly six years up to 1996. In TFI heads a voltage is produced when a permanent magnet, the hard disk platter, moves past the wire-coil-wrapped magnetic core.

Increasing the areal density—i.e., bits per inch multiplied by tracks per inch—of the hard disk is the usual way to increase storage capacity, and one way to do this is to increase the sensitivity of the head to magnetic flux changes by adding turns to the TFI head's coil. However, doing so increases the inductance which unfortunately limits the head's ability to write data.

The search is ongoing for greater data capacity to fit into progressively smaller areas on disk surfaces. Technologies that maximize areal density on disks lead to more affordable, higher capacity data storage products. As data is squeezed more tightly onto disks, heads must read smaller, weaker signals. AMR heads, normally made of nickel-iron alloys, have proven much more sensitive to magnetic fields than TFI heads. AMR heads can detect the bits' magnetic fields weakened by tight packing and reduced size, and still produce strong read signals.

In 1991, IBM developed AMR technology, based on the principle that certain metals undergo changes in electrical resistance in the presence of a magnetic field. AMR heads allowed IBM to store 1 gigabit on one square inch of magnetic recording media, and areal densities have increased to over 3 gigabits per square inch.

AMR heads offer a higher signal-to-noise ratio than TFI heads, resulting in superior error rates in drives using them. However, the most important advantage of AMR heads is that they can read from areal densities about four times denser than TFI heads at higher flying heights. The result is markedly improved hard drive performance.

Outdoing even AMR heads are the giant magnetoresistive (GMR) heads, which Western Digital has incorporated into its latest generation of EIDE hard drives. GMR heads have extended the areal density to greater than 10 gigabits per square inch—more than three times what AMR heads can today.

AMR Heads

AMR heads were introduced first in mobile drives around 1994 and in desktop drives around 1995. Today, all of Western Digital's current desktop and enterprise class (workstations, servers, RAID systems) of hard drives incorporate AMR heads to meet ever increasing capacity requirements. Unlike TFI heads, where the read and write elements are the same, read and write elements in the AMR head are separate in order to optimize read and write capabilities. The write element is a conventional TFI head, while the read element in an AMR head is composed of a thin stripe of magnetic material. The stripe's resistance changes in the presence of a magnetic field, producing a strong signal with low noise amplification and permitting significant increases in areal densities. As the disk passes by the read element, the disk drive circuitry senses and decodes changes in electrical resistance caused by the reversing magnetic polarities. The AMR read element's greater sensitivity provides a higher signal output per unit of recording track width on the disk surface. Not only does magnetoresistive technology permit more data to be placed on disks, but it also uses fewer components than other head technologies to achieve a given capacity point.

The AMR read element is smaller than the TFI write element. In fact, the AMR read element can be made smaller than the data track so that if the head were slightly off-track or misaligned, it would still remain over the track and able to read the written data on the track. Its small element size also precludes the AMR read element from picking up interference from outside the data track, which accounts for the AMR head's desirable high signal-to-noise ratio.

AMR Head Challenges

Manufacturing AMR heads can present difficulties. AMR thin film elements are extremely sensitive to electrostatic discharge, which means special care and precautions must be taken when handling these heads. The AMR thin film stripe is also sensitive to contamination and, because of the materials used in its design, subject to corrosion.

AMR heads also introduced a new challenge not present with TFI heads: thermal asperities—i.e., the instantaneous temperature rise that causes the data signal to spike and momentarily disrupt the recovery of data from the drive. Thermal asperities are transient electrical events, usually associated with a particle, and normally do not result in mechanical damage to the head. Although they can lead to misreading data in a large portion of a sector, new design features can detect these events. A thermal asperity detector determines when the read input signal exceeds a predetermined threshold, discounts that data value and signals the controller to re-read the sector.

GMR Technology

GMR technology signals a major advance over AMR technology. GMR sensors are the most sensitive yet developed for reading computer data on hard drives. Based on the “giant magnetoresistive effect,” a discovery in magnetism made ten years ago in Europe, IBM’s further research transformed the effect into a practical reality. IBM’s commercial production of GMR heads is well underway. In 1998 Western Digital entered into an agreement with IBM to purchase advanced GMR heads for its EIDE desktop hard drives. Read-Rite Corp., TDK/SAE Corp. and others continue to supply Western Digital with AMR and GMR heads for its enterprise class as well as some of the EIDE desktop hard drives.

Like AMR heads, GMR heads incorporate separate MR read and TFI write elements. However, the GMR read elements are formed from more complex structures with a higher sensitivity to the changing magnetization on the disk. While in AMR sensors, a single film changes resistance in response to a change in magnetic field on the disk, in GMR sensors, two films, separated by a very thin electrically conductive layer, perform this function. The result is that GMR heads achieve even higher areal densities and performance levels than AMR heads.

While AMR heads can read areal densities over 3 gigabits per square inch, the newer GMR heads can be scaled to very small dimensions to read areal densities in excess of 10 gigabits per square inch while still maintaining good signal amplitude. Looked at another way, GMR heads can read data on hard drives that can pack over three times more data into the same space.

How GMR Sensors Work

GMR sensors work by exploiting the quantum nature of electrons. Electrons have two spin directions: up and down. Electrons with spin direction parallel to a film’s magnetic orientation move freely, thereby producing low electrical resistance. When electrons move in the opposite spin direction, they are hampered by more frequent collisions with atoms in the film, thereby producing higher resistance.

IBM has developed structures called spin valves in which one magnetic film is “pinned,” i.e., its magnetic orientation is fixed, and the second magnetic film, or sensor film, has a free,

variable magnetic orientation. These films are very thin and very close together so that electrons of either spin direction can move back and forth between the films. Changes in the magnetic field originating from the disk cause a rotation of the sensor film's magnetic orientation, which in turn, increases or decreases the resistance of the entire structure. Low resistance occurs when the sensor and pinned films are magnetically oriented in the same direction, since electrons with parallel spin direction move freely in both films. Higher resistance occurs when the magnetic orientations of the sensor and pinned films oppose each other, since the movement of electrons of either spin direction is restrained by one or the other of these magnetic films.

Where the resistance changes in AMR heads are approximately 2 percent, in GMR heads, they are typically 7 to 8 percent. Because their percent change in resistance is as much as four times greater than in AMR sensors, GMR sensors can operate at significantly higher areal densities as they are more sensitive to magnetic fields from the disk.

GMR heads' greater sensitivity makes it possible to detect smaller recorded bits and read them at higher data rates. Larger signals from GMR heads also help to overcome electronic noise.

Beyond GMR, the next step in hard drive technology will be "Synthetic Spin Valve" GMR or Colossal MR (CMR). This development is underway utilizing materials and layers yet being proven in research labs.

► SUMMARY

The current predominant hard drive technology is AMR technology. AMR heads are a substantial improvement over TFI heads, the previous reigning industry standard. AMR heads markedly improved performance of hard drives and enabled the increase in areal densities to over 3 gigabits per square inch.

As demand for higher areal densities and data rates increases, more sensitive heads are needed to maintain high quality read-back signals. Newer GMR heads that meet that need are already being shipped in hard drives. Since GMR technology also uses much of the design, production and test experience associated with AMR heads, it will evolve more readily and be shipping in virtually all WD desktop and enterprise drives by the close of 1999.

GMR heads support areal densities greater than 10 gigabits per square inch. Western Digital's EIDE desktop hard drives incorporating GMR heads are currently shipping.

The high areal densities attainable with both AMR and GMR heads enable hard drive products to offer a maximum storage capacity with a minimum number of components—i.e., heads and disks. Fewer components mean higher reliability, lower power requirements and lower storage costs.