Technology Brief 13
Hard Disk Drives (HDD)

Although invented in 1956, the ***hard disk drive*** (HDD) arguably is still the most commonly used data-storage device among nonvolatile storage media available today. It is the availability of vast amounts of relatively inexpensive hard-drive space that has made search engines, webmail, and online games possible. Over the past 40 years, improvements in HDD technology have led to huge increases in storage density, which are simultaneous with the significant reduction in physical size. The term ***hard disk*** or ***hard drive*** evolved from common usage as a means to distinguish these devices from flexible (***floppy***) disk drives.

HDD Operation

Hard drives make use of magnetic material to read and write data. A nonmagnetic disc ranging in diameter from 36 to 146 mm is coated with a thin film of magnetic material, such as an iron or cobalt alloy. When a strong magnetic field is applied across a small area of the disc, it causes the atoms in that area to align along the orientation of the field, providing the mechanism for writing bits of data onto the disc (**Fig. TF13-1**). Conversely, by detecting the aligned field, data can be read back from the disc. The hard drive is equipped with an arm that can be moved across the surface of the disc (**Fig. TF13-2**), and the disc itself is spun around to make all of the magnetic surface accessible to the writing or reading heads. The reading and writing elements are physically moved along the radius of the disk by using a magnet with a coil wrapped around it. When current is driven into the coil, it produces a magnetic force that moves the actuator. Because writing onto or reading from the magnetized surface can be performed very rapidly (fraction of a microsecond), hard drives are spun at very high speeds (5,000 to 15,000 rpm) when directed to record or retrieve information. Amazingly, hard-drive heads usually hover at a height of about 25 nm above the surface of the magnetic disc while the disc is spinning at such high speeds! The extremely small gap between the head and the disc is maintained by having the head "ride" on a thin cushion of air trapped between the head and the surface of the spinning disc. To prevent accidental scratches, the disc is coated with carbon- or Teflon-like materials.

Hard drives are packaged carefully to prevent dust and other airborne particles from interfering with the drive's operation. In combination with the air motion caused by the spinning disc, a very fine air filter is used to keep dust out while maintaining the air pressure necessary to cushion the spinning discs. Hard drives intended for operation at high altitudes (or low air pressure) are sealed hermetically so as to make them airtight.

Modern Drive Technology

Early hard drives performed read and write operations by using an inductor coil placed at the tip of the head. When electric current is made to flow through the coil, the coil induces a magnetic field which in turn aligns the

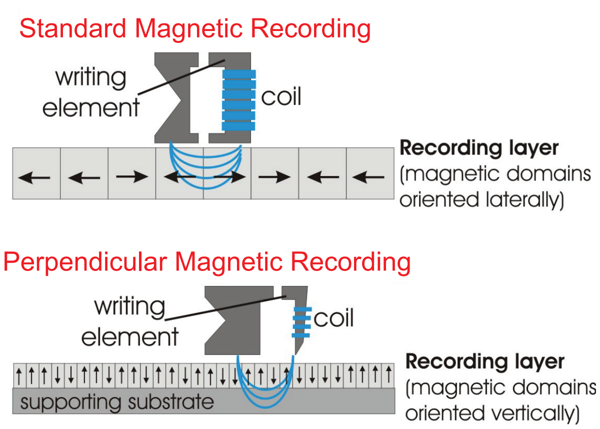


Figure TF13-1: Longitudinal and perpendicular writing techniques.

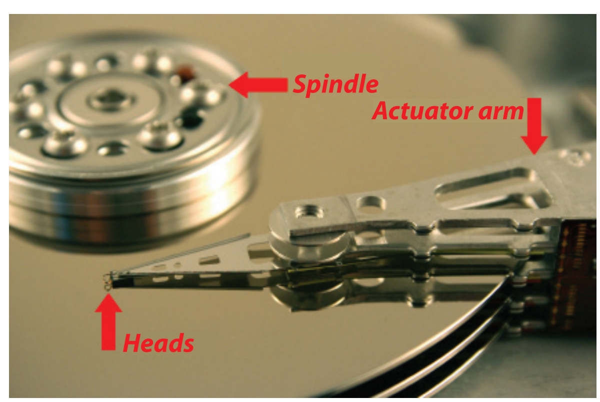
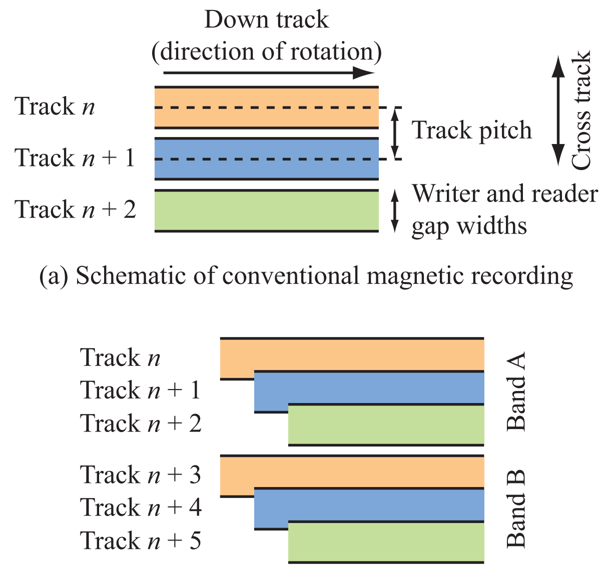


Figure TF13-2: Close-up of a disassembled hard drive showing the magnetic discs mounted on a spindle and an actuator arm. The head sits at the end of the arm and performs the read/write operations as the disc spins.

atoms of the magnetic material (i.e., a ***write*** operation). The same coil also is used to detect the presence of aligned atoms, thereby providing the ***read*** operation. The many major developments that shaped the evolution of read/write heads over the past 50 years have introduced two major differences between the modern hard-drive heads and the original models. Instead of using the same head for both reading and writing, separate heads are now used for the two operations. Furthermore, the writing operation is now carried out with a lithographically defined ***thin-film*** head, thereby reducing the ***feature size*** of the head by several orders of magnitude. The feature size is the area occupied by a single bit on the disc surface, which is determined in part by the size of the write head. Decreasing feature size leads to increased recording density. The read operation—housed separately next to the write head—uses a ***magnetoresistive*** material whose resistance changes when exposed to a magnetic field—even when the field intensity is exceedingly small. In modern hard drives, high magnetoresistive sensitivities are realized through the application of either the ***giant magnetoresistance*** (GMR) phenomena or the ***tunneling magnetoresistance*** (TMR) effect exhibited by certain materials. The 2007 Nobel prize in physics was awarded to Albert Fert and Peter Grünberg for their discovery of GMR. A consequence of the extremely small size of the magnetic bits (each bit in a 100-Gb/in^2 disc is about 40 nm long) is that temperature variations can lead to loss of information over time. One method developed to combat this issue is to use two magnetic layers separated by a thin ($\sim$ 1 nm) insulator, which increases the stability of the stored bit. Another recent innovation that is already in production involves the use of ***perpendicular magnetic recording*** (PMR) as illustrated in **Fig. TF13-1**. PMR makes it possible to align bits more compactly next to each other.

Recent Developments

A new wave of developments is pushing hard drives into the tens of terabytes. Already in commercial use is ***shingled magnetic recording*** (SMR). Conventional drives write bits in parallel rows (**Fig. TF13-3(a)**), usually with a slight gap between them. Making the individual track width smaller is extremely difficult because, as mentioned above, very small magentic grains are not stable (or, conversely, to make very small grains stable makes them very hard to read/write with a magnetic head). The SMR solution (**Fig. TF13-3(b)**) is to lay bits down in overlapping tracks, exactly like roof shingles (where each shingle row



(b) Schematic of shingled magnetic recording

Figure TF13-3: Schematics of (a) conventional magnetic recording and (b) shingled magnetic recording with two 3-track bands.

sits slightly on top of one adjacent row and slightly below the other). The advantage is that the size of the track (and hence, the grain), does not change but the overall density increases. This works because a magnetic head can still read the state of the magentic grain even if it slightly overlapped with a nearby grain. The difficulty of this method is that the writing process slows down since every time we write to one of the overlapped rows, we must also rewrite the neighboring rows. The tracks are organized into bands (**Fig. TF13-3(b)**) and each band is thus rewritten as needed. Coordinating this write activity can be handled in firmware on the drive itself or in the computer's operating system (if it has the appropriate driver to handle such drives).

A variety of other techniques (including the GMR heads discussed above) are being explored to increase areal density; in general, these focus on allowing smaller grains by making them harder to write magnetically (which makes them consequently more temperature stable). Among these are heat-assisted, microwave-assisted and patterning single-grain (or close to single-grain) isolated magnetic islands (instead of a continuous magnetic thin film); this is known as ***bit-patterned media*** (BPM). It is estimated that techniques such as these will enable densities on the order of 1–10 Tb/in^2 in the next decade.