AFC Media—Extending the Limits of Longitudinal Recording

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Introduction

In May, 2001, the company now called Hitachi Global Storage Technologies announced that it began mass producing hard disk drives based on a new technology that used just a few atoms to push back the data storage industry's most formidable barrier. Research scientists from the former IBM storage division discovered in 1990 that a three-atom-thick layer of the element ruthenium, a precious metal similar to platinum, sandwiched between two magnetic layers, permitted longitudinal recording to achieve data densities over 100 gigabits/inch^2 without suffering from the projected data loss attributed to thermal instabilities. That only a few atoms could have such a dramatic impact caused the research scientists to refer to the ruthenium layer as "pixie dust." The new media, known technically as antiferromagnetically-coupled (AFC) media, delays the impact of superparamagnetism in limiting future areal density increases by several years. AFC media also requires few changes to other aspects of the hard disk drive design. With this discovery, the company postponed the industry's need for more complex techniques to support very high-density magnetic recording including technologies such as perpendicular recording, patterned media and thermally-assisted writing.

Superparamagnetic effect

The superparamagnetic effect originates from the shrinking volume of magnetic grains that compose the storage properties of hard disk media. The magnetic grains represent the data bits that are stored as alternating magnetic orientations. To increase data-storage densities while maintaining acceptable performance, designers have shrunk the media's grain diameters and decreased the thickness of the media. The resulting smaller grain volume makes them increasingly susceptible to thermal fluctuations, which decreases the signal sensed by the drive's read/write head. If the signal reduction is great enough, data could be lost over time to this superparamagnetic effect.

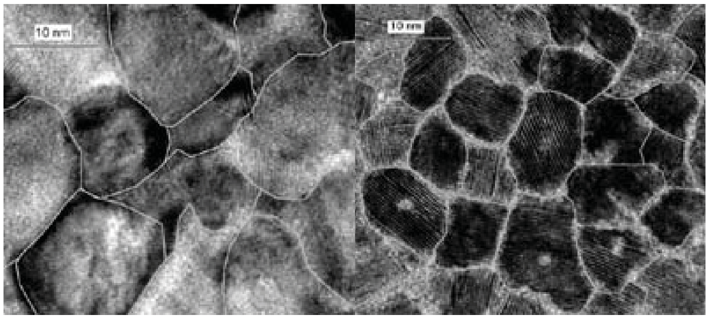

Figure 1. TEM of the grain structures in magnetic media. (magnification = 1 million)

The pictures in Figure 1 are transmission electron micrographs (TEM) of two different disk media which illustrates how the grain structure has evolved over time. The TEM on the left is a magnetic media that supports a data density of about 10 gigabits/inch^2 with an average grain diameter of about 13 nanometers. The magnetic media on the right supports a data density of 25 gigabit/inch^2 with an average grain diameter of about 8.5 nanometers. Historically, disk drive designers have had only two ways to maintain thermal stability as the media's grain volume decreases with increasing areal density: 1) Improve the signal processing and error-correction codes (ECC) so fewer grains are needed per data bit, and 2) develop new magnetic materials that resist more strongly any change to their magnetization, known technically as higher coercivity. The latter is complicated by the laws of physics, as higher coercivity alloys are more difficult to write on. While improvements in coding and ECC are ongoing, Hitachi GST's discovery of AFC media is a major advancement because it allows disk-drive designers to write at very high areal densities on a surface that offers greater stability than conventional media.

How does AFC media work?

Conventional disk media stores data in only one magnetic layer, typically of a complex magnetic alloy (such as cobalt-platinum-chromium-boron, CoPtCrB). AFC media is a multi-layer structure in which two magnetic layers are separated by a three atom layer of ruthenium, a non-magnetic metal. The precise thickness of the ruthenium causes the magnetization in each of the magnetic layers to be coupled in opposite, or anti-parallel, directions which constitutes antiferromagnetic coupling. A schematic representation of this structure is given in Figure 2.

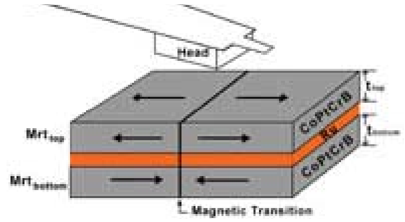

Figure 2. Schematic representation of AFC media with single magnetic transition

When reading data as it flies over the rapidly rotating disk, the recording head in the disk drive senses the magnetic transitions in the magnetic media that coats the disk. The amplitude of this signal is proportional to the media's "magnetic thickness"—the product of the media's remanent magnetic moment density ("Mr") and its physical thickness ("t"). As data densities increase, the media's magnetic thickness (known technically as Mrt) must be decreased proportionately so the closely packed transitions will be sharp enough to be read clearly. For conventional media, this means a decrease in the physical thickness of the media.

The key to AFC media is the anti-parallel alignment of the two magnetic layers across each magnetic transition between two bits. As it flies over a transition, the recording head senses an effective Mrt of the composite structure (Mrteff) that is the difference in Mrt values for each of the two magnetic layers:

Mrteff = Mrttop - Mrtbottom

This property of AFC media permits its overall Mrt to be reduced—and its data density increased—independently of its overall physical thickness. Thus for a given areal density, the Mrt of the top magnetic layer of AFC media can be relatively large compared with single-layer media, permitting inherently more thermally stable larger grain volumes.

Figure 3 compares projections based on measurements of the expected signal amplitude loss after 10 years in conventional single-layer media with that in AFC media. As the Mrt of the conventional media decreases with reduced film thickness and grain diameter, thermal effects rapidly shrink its magnetic amplitude. This dramatic signal loss is at the heart of the superparamagnetic effect. Acceptable levels of signal decay vary depending on system design but typically range between 10 to 20 percent. In comparison, AFC media has the thermal stability of conventional media having about twice its magnetic thickness. AFC media structures are expected to enable thermally stable data storage at densities of 100 gigabits per square inch and beyond.

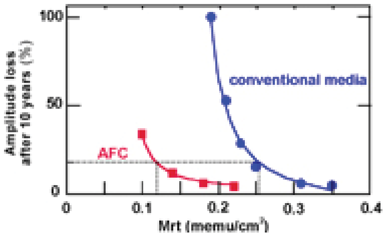

Figure 3. Thermal stability of AFC and conventional media

Two additional advantages of AFC media are that it can be made using existing production equipment at little or no additional cost, and that its writing and read-back characteristics are similar to conventional longitudinal media. The output pulse sensed by the recording head is a superposition of the fields from transitions in both the top and bottom magnetic layers. As with conventional media, this output is detected as a single pulse, so no changes to the disk drive's recording head or electronic data channel components are required.

The invention of AFC media was just the starting point in its development for use in Hitachi GST disk drive products. New physical insights were required to understand how the various properties of the two magnetic layers and the ruthenium layer should be optimized. Definition of a new fabrication process for the multi-layer structures to maintain the proper microcrystalline growth characteristics in each layer was also necessary. Lastly, extensive modifications were implemented to convert existing, conventional, high-volume manufacturing tools to deposit the 6-Å ruthenium layer with suitable uniformity over the entire disk surface.

Hitachi GST pioneered the research, development and manufacture of antiferromagnetically-coupled structures, which have remarkable properties due to the "spintronic" interactions between the materials' electrons and magnetic fields. The 1990 discovery that a thin layer of ruthenium atoms created the strongest anti-parallel coupling between adjacent ferromagnetic layers of any nonmagnetic spacer-layer element changed the history of magnetic recording. The structure was used in the first giant magnetoresistive read element for disk drives, which was introduced by Hitachi GST in hard drive products in that began shipping in 1997. GMR heads are still used in hard drives shipping today.

Summary

The 100 gigabit density milestone was once thought unattainable due to the superparamagnetic effect. Hitachi GST's breakthrough discovery of antiferromagnetically-coupled multi-layers broke this barrier and enabled significant areal density increases while maintaining the thermal stability of recorded data. This advancement permitted magnetic hard disk drive technology to extend far beyond the previously predicted "limits" imposed by the superparamagnetic effect.

Mass production of the first hard drives with AFC media began in May, 2001 with Hitachi GST's 2.5-inch Travelstar® 15GN and 30GN products which featured 15-gigabytes-per-platter and an areal density of 25.7 gigabits/inch^2. Within three years, AFC media enabled the industry's first 400 GB 3.5-inch drive, the Deskstar® 7K400, with the storage capacity equivalent to 400,000 books. One year later, the technology lead to the introduction of the Hitachi Microdrive® 3K6 which provides 6 GB of data or 13 hours of MPEG-4 compressed digital video in the form of eight complete movies.

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Technology Highlights

- AFC media extends density limits by four-fold, to surpass 100 gigabits/inch^2, a level once thought impossible due to the superparamagnetic effect. Based on the usage of a three-atom-thick layer of ruthenium, the technoloogy was discovered in 1990 by research scientists from the former hard drive division of IBM, now Hitachi GST.
- The “spintronic” interaction of antiferromagnetically-coupled structures lead to the application of this technology in GMR heads, another innovation by Hitachi GST.
- AFC media breaks areal density records by employing multiple magnetic layers that act in opposite directions, but “magically” stick together through a thin layer of metal. The result: thick, thermally stable media that facilitates the write process in hard disk drives.
- Hitachi’s Travelstar 2.5-inch hard disk drives were the industry’s first to use antiferromagnetically-coupled (AFC) media, which began shipping in May 2001 and offered storage capacities of 15GB and 30GB.
- Continued growth of data density is crucial to expanding storage needs of information-hungry and Internet-oriented users, and helps hasten the home entertainment transition from passive analog technologies to interactive digital formats.

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Produced in the United States 11/07.