Present Status and Future Prospects for Magnetic Hard Disks

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1. Introduction

Since the application of GMR (giant magnetoresistive) technology to the heads of magnetic hard disks, increased density has resulted in an increase of over 60% a year in the capacity of magnetic hard disk drives (HDDs). Previously, the main applications of HDDs were in personal-use desktop or notebook computers. The range of application has expanded to high-end servers that make use of the large capacity, to micro HDDs that utilize the advantages of high density and small size, and recently to audio-visual applications.

Characteristic technologies suitable for each application have been advanced. This paper describes the present status and future prospects of magnetic hard disks (hereinafter referred to as the disk) for personal computer applications.

2. Trends of the Market and Technology

2.1 Increasing capacity

Figure 1 shows the increase in areal recording density per year. Since the application of the GMR head, areal density has increased in capacity over 60% a year, and some product segments are competing for an annual capacity increases of over 100%. The increased capacity was first utilized with 2.5-inch personal computers and then was later applied to the specifications of desktop personal computers. With the increase in density, flying head height has become lower each year as shown in Fig. 2. Recently, a level of 0.4 to 0.5 μ inch, the limit of flying height measurement by the current valuation method, has generally been required. The technology to measure and evaluate low flying heights near contact is also an important technical subject.

2.2 Increasing transfer rate

In addition, the transfer rate for high-end servers has increased, and HDD rotating speed and density are both increasing at the same time. Currently, 5,400 r/min is the standard HDD speed; however, 7,200 and 10,000 r/min speeds have become commonplace and products with speeds on the order of 15,000 r/min are introduced to the market. Figure 3 shows the increase in the transfer rate.

Based on technical demands for higher speed and higher density, it is believed that HDDs mounted with disks using glass substrates of higher rigidity than former aluminum ones will shortly be marketed. Thus

Fig.1 Increase in areal recording density per year

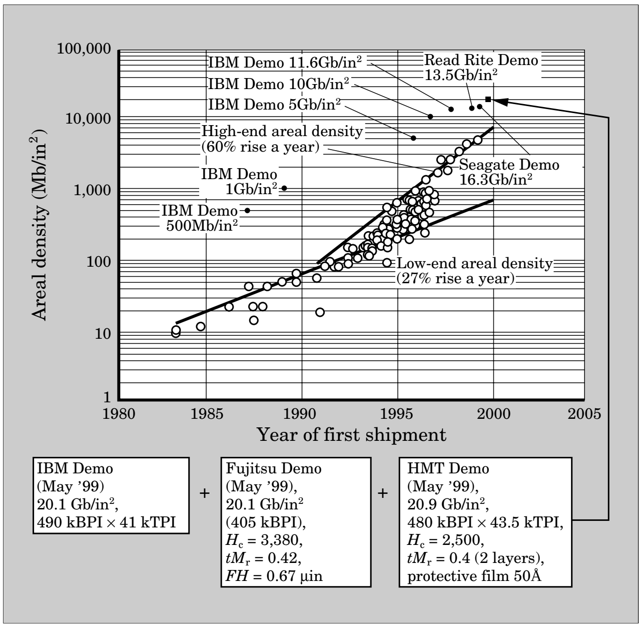


Fig.2 Reduction in flying head height required each year

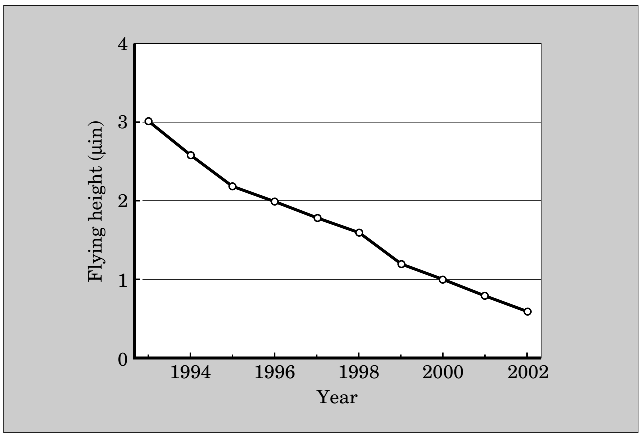


Fig.3 Increase in the transfer rate each year

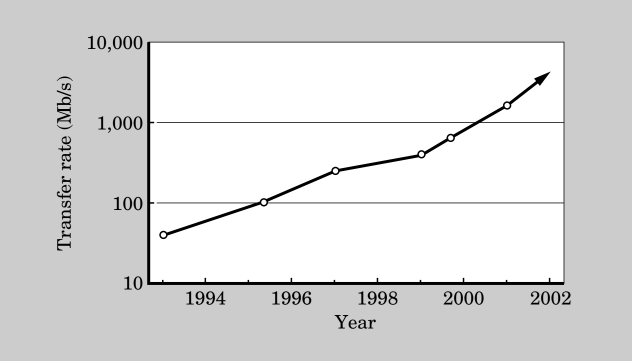


Fig.4 Correlation between disk waviness W_a and flying head characteristics

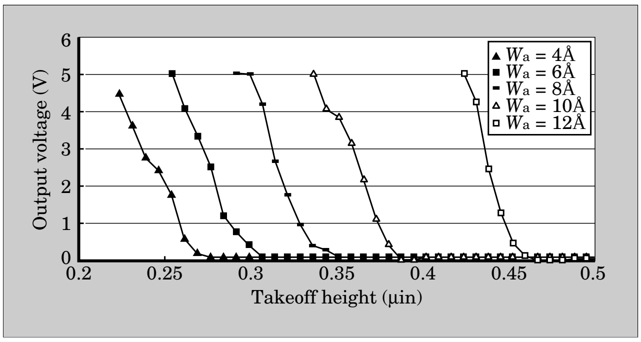


Table 1 Substrate size requirements

Diameter \ Thickness	0.635 mm	0.8 mm	1.0 mm	1.27 mm
2.5 in (65 mm)	○		○	
2.75 in (70 mm)		○	○	
3.0 in (75 mm)		○	○	
3.3 in (84 mm)		○	○	
3.5 in (95 mm)		○	○	○

far, applications of disks with glass substrates have spread only to the limited market of notebook computers that can take advantage of their impact resistance. However, it is predicted that applications will spread to the 3.0 and 3.5-inch HDD field in pursuit of smoothness, flatness, and low waviness.

2.3 Lower cost

There is strong demand for low-priced HDDs in sub-thousand dollar personal computer marketplace. Because performance improvements and price reductions are continuing simultaneously, the review of processes and component materials has become urgent. There is a growing demand for a low-cost one-head/one-disk HDD that is thoroughly economical.

3. Present Status of Magnetic Hard Disks

Only current topics are described here.

3.1 Substrate size, surface quality, and materials

There is a great deal of confusion regarding substrate materials and sizes among recent hard disk technologies. With the aim of reducing non-repeatable run-out (NRRO) to suppress so-called track miss registration (TMR) caused by high-speed rotation, various substrates have been used according to various HDD specifications. Almost all 2.5-inch disks use glass substrates. However, both aluminum and glass substrates are being considered for 3.0-inch or larger disks.

Aluminum and glass substrates have become nearly equal in surface quality, and limitations of characteristics, cost, and mass productivity are becoming key issues. The greatest advantage of glass substrates is their high resistance against impact (head slapping), considered indispensable to HDDs that use a ramp load system. High-end servers require substrate sizes based on consideration of the balance between capacity and airflow loss of the head. Table 1 shows suitable combinations of diameters at intervals of 5 mm and substrate thicknesses.

With the recent increase in capacity, flying head heights have remarkably decreased as low as 0.4 to 0.5 μ inch, near contact.

To attain large capacity, stable flying of the head is absolutely necessary. When examining hard disks only, excluding the HDD mechanism, clamping strain, and motor vibration, it is necessary to consider mechanical characteristics including flatness, smoothness, and rigidity, and physical constants such as the damping constant for resonance. With regard to substrate surface quality, attention must be paid to the influence of substrate micro-waviness on glide height (GH). The mean surface roughness (R_a) of recent hard disks has been reduced to the order of 5 to 6 Å and the flying head height does not depend on R_a at such a level. Instead, as shown in Fig. 4, a correlation between substrate micro-waviness and takeoff height is observed and flying head height has a tendency to improve with reduced micro-waviness.

Further, to suppress the above-mentioned TMR, measures such as increasing the substrate thickness, substrate rigidity, and damping constant are considered. An example of the influence of substrate thickness on NRRO is shown in Fig. 5. Increases to the substrate thickness are limited by the HDD mechanism. A glass substrate is being developed to raise the present substrate rigidity from the 100-GPa level to the 140-GPa level. Because the damping constant is an intrinsic physical constant of the substrate, it is difficult to control freely. Therefore, it is necessary to change the substrate material to a quite different material, or to consider the laminate structures being investigated by some parties.

3.2 Ramp-load systems and padded heads

The ramp load system mentioned above has been

Fig.5 Correlation between substrate rigidity and NRRO

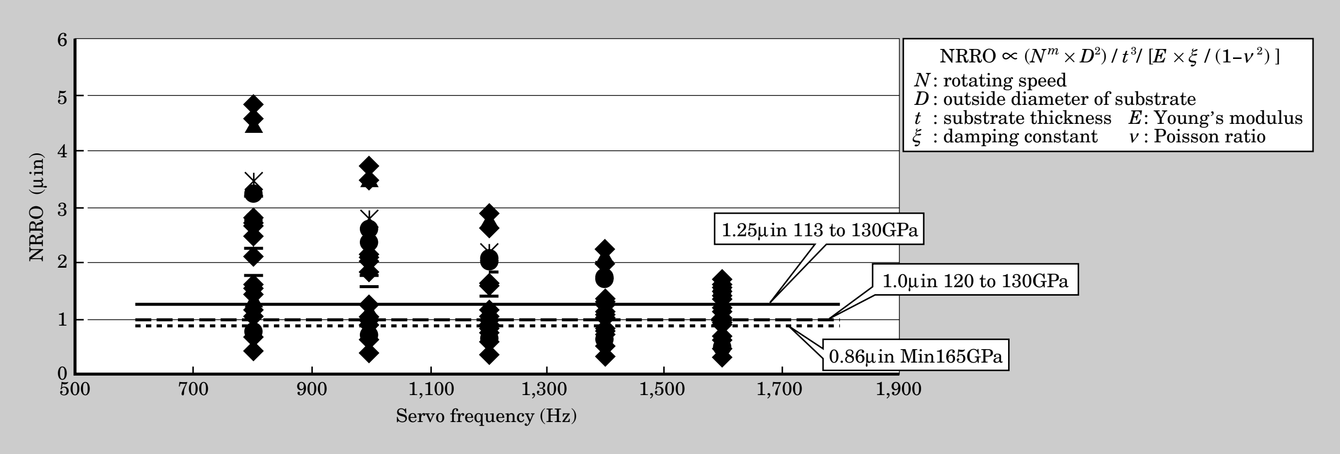


Fig.6 Conceptual sketches of padded head

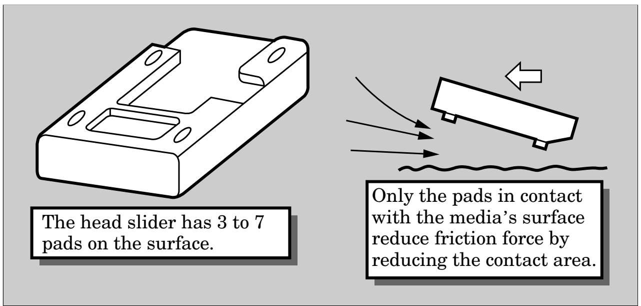
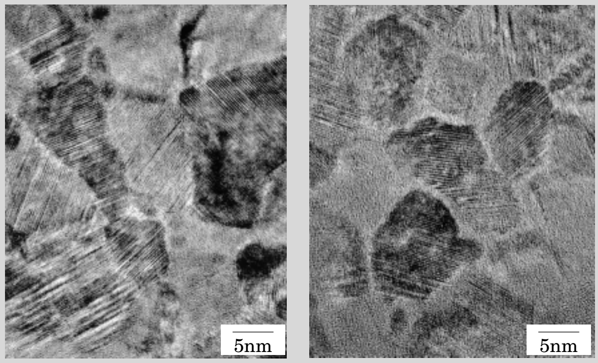


Fig.7 Comparison of TEM images of magnetic grain sizes to different noises



(a) An example of higher noise media (coarse grain size)

(b) An example of lower noise media (fine grain size)

installed in many of IBM's HDD notebook computers and already has been verified technically. However, the HDD speed specification has the comparatively low value of 4,200 r/min, and technology compatible with speeds higher than 7,200 r/min, believed to be the mainstream in the future, has not yet been established. The impact due to head slapping at the time of head loading and unloading is larger than estimated, and there is the danger of serious damage to the head and disk if the mechanism is of poor design or precision.

On the other hand, contact start stop (CSS) systems using a padded head as shown in Fig. 6 are being studied. The style depends upon the HDD manufacture, and there is an infinite variety, but these systems are basically designed to avoid wear with a padded head which has reduced spring force. A smooth head slider surface can be applied with fairly large torque. However, motor torque is minimized in HDDs installed in notebook computers to reduce power consumption and heat generation, and therefore, the possibility of adhesion can not be ruled out and some surface adjustment is required.

3.3 Magnetic characteristics and noise reduction

Although the use of a GMR head enables the reading of feeble signals, how to reduce the media's noise to improve the signal-to-noise ratio (SNR) remains a problem.

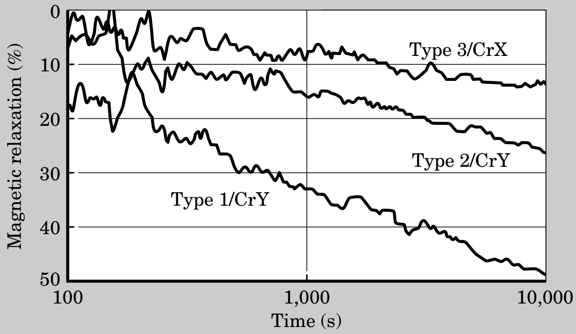
As discussed in various institutes and symposiums, reduction in noise basically depends on how a uniform crystallographic structure of fine magnetic grains can be formed in a high vacuum and under high-speed conveyance (in a short time). Fuji Electric has made continuous efforts to achieve an optimum material, process, and layer configuration.

With regard to the recent increases in density, the characteristic of thermal decay has to be considered. Generally at the current technical level, increases in fineness and uniformity to reduce noise are not compatible with thermal stability. For example, use of multi-layer magnetic media is very effective for noise reduction, but has the drawback of low thermal stability. Figure 7 shows a comparison of TEM images of magnetic grain sizes to different noises, and Fig. 8 shows a comparison of thermal characteristics according to different magnetic materials.

3.4 Hard protective films to reduce magnetic spacing

Until contact recording can be implemented, flying head recording is the mainstream, and magnetic spacing must be minimized to realize high density.

Fig.8 Comparison of thermal characteristics according to different magnetic materials



Applied reverse field = 2,500 Oe

Sample	H_c (Oe)	tM_r (memu/cm^2)
Type 1/CrY	2,894	0.39
Type 2/CrY	3,109	0.41
Type 3/CrX	3,012	0.39

Table 2 Items for reducing magnetic spacing (from Storage Research Consortium documents)

Surface roughness of the head and disk	off 4 nm	off 14 nm in total
Protective film thickness of the head slider	off 3 nm	
Head recess	off 2 nm	
Protective film of the disk	off 5 nm	

Table 3 Typical methods of chemical vapor deposition and features

CVD method	Film quality	Necessity of bias	Continuous operation capability
Filament type ion beam	○	Yes	○
Hollow cathode type ion beam	○	Yes	△
ECR (Electron-Cycrotron-Resonance)	◎	No	△
RF discharge type	○	Yes	◎

Measures for reducing magnetic spacing in the current system are reduction of the disk protective film, the head protective film, and the head recess as shown in Table 2.

The disk protective film has thus far utilized a carbon or diamond-like carbon film by the sputtering method. Because of increasing densities, specifications of protective film thicknesses have changed from the former 100-Å level to become as strict as the 60-Å level. Further, film made by sputtering, intrinsically a porous film, can not satisfy corrosion resistance and durability requirements. Manufacturers are tackling the development and application of chemical vapor deposition (CVD) films, harder and denser films. Table 3 shows typical CVD methods and features. In CVD film formation, the development of a film composition and a film formation method to achieve the desired functionality is of course important, but mass productivity and measures against particles in continuous film formation are more important. Fuji Electric is also striving to develop various CVD films.

3.5 Surface treatment after sputtering

Recent media have had problems with head disk interface (HDI) characteristics that affect reliability. Disk manufacturers have different opinions regarding treatments after sputtering film formation. Fuji Electric is also promoting a review of the work process. The aim is to eliminate irregular projections in film formation, improve surface coverage of the lubricant, and improve the bonding ratio by surface treatment. In addition to the various improvements that were previously implemented, smooth substrates and CVD films have been used on a full-scale for protective films, and a post-treatment process appropriate for the properties of CVD films is considered necessary. To suppress lubricant migration when media are used in high-speed rotating servers, it is necessary to establish polymerization and refinement technologies for the lubricant itself. Figure 9 shows an example of GH characteristics improved by surface treatment after lubricant application.

3.6 Error, defect, and automatic viewer/test system

As densities increase, it is predicted that problems of errors and defects due to each material, process, production schedule, and working environment will become more severe. The recording bit size of 20-Gb/in^2 media, soon to be used in practical applications, is at a level of 0.05 μm × 0.5 μm, and a minute cleaning residue or particle will cause the error characteristics to deteriorate. A defect in the servo signal portion makes read/writing impossible.

Under these circumstances, the quality assurance of magnetic disks requires stricter detection of micro-defects than before. At the same time, to satisfy the current demand for low prices, we must simplify those test systems that require the most labor and equipment investment. Viewed from the manufacturing process, defect and particle inspection just before sputtering and testing is important.

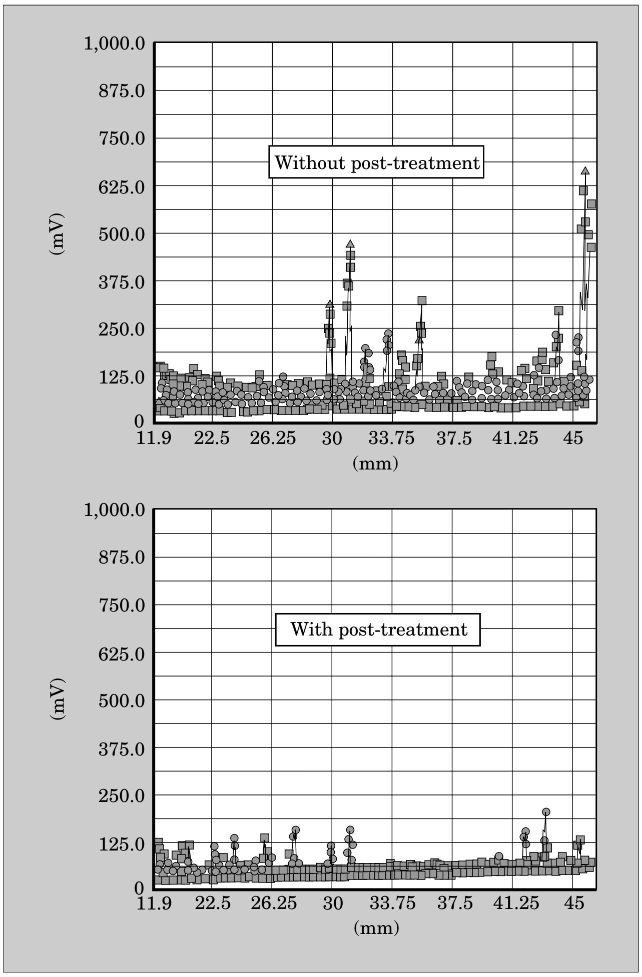
(1) Surface defect inspection before sputtering

Objects for inspection before sputtering are cleaning residues and scratches due to substrate cleaning and surface machining. When glass substrates are used, improved resolution is required because of the transparency.

(2) Surface defect inspection before testing

The objects for inspection are defects in the sputtering process and final tape polish (FTP) scratches. At present, defect sensitivity is 0.8 μm, however

Fig.9 Example of GH characteristic improved by surface treatment after lubricant application



even higher sensitivity is required to meet the rapid increases in density.

(3) Simplification of testing

A defect inspection system that combines a defect inspection system based on an optical method and a statistical processing technique is being studied and is expected to simplify the testing process and reduce the production cost.

4. Future Prospects

Based on the present status as described above, future prospects for magnetic disk technology are discussed below.

4.1 Change of substrate material to glass

Fuji Electric also manufactures aluminum substrates in its factory. Because of rapid technical innovation, it is difficult at present to discriminate between aluminum and glass substrates with regard to the characteristics of smoothness, flatness, and microwaviness. Similarly in the case of server applications requiring rigidity, there is a movement to satisfy immediate needs by using thick aluminum substrates, and on the other hand, there is in fact a demand for glass substrates with high rigidity. Cost reduction is critical for glass substrates to be used for general purposes other than notebook computer and high-speed rotation applications. This requires the preconditions that a supply of thinner blanks is available and a higher-rate polishing technique is established.

4.2 Limit of longitudinal recording and perpendicular recording systems

Manufacturers have different opinions regarding the limit of areal recording density by longitudinal recording. We believe the average opinion is that longitudinal recording can definitely reach 40 Gb/in^2, based on current technical developments.

At INTER.MAG held by IEEE in Korea in 1999, perpendicular magnetic recording system was the topic of conversation. Because the thermal stability of longitudinal recording has been highlighted in the Storage Research Consortium (SRC) and various symposiums, the superiority of perpendicular magnetic recording was brought into the spotlight. However, perpendicular magnetic recording also has some problems and the road is not yet paved for success. First, even perpendicular recording disk needs to be thinner magnetic film, and the problem of thermal stability is not enough eliminated. Secondly, although peripheral technologies are somewhat prepared, a technology with head characteristics comparable to those of longitudinal recording is not yet established. Thirdly, an external magnetic field causes demagnetization, which may be the fate of perpendicular magnetic recording. It will take some time to clear these problems, and therefore, longitudinal recording has the possibility of continuing until 60 to 80 Gb/in^2.

4.3 Lower cost

The most effective methods for the cost reduction of magnetic disks are the simplification of testing systems by combining optical techniques and statistical treatments and the application of plastic material to substrates that account for a large proportion of material costs.

5. Conclusion

For materials and process technology related to increasing densities, HDI technology, production equipment related to reducing errors and defects, and details of cleanness control technology, please refer to separate articles in this special issue. The hard disk will for some time continue to increase in density with a longitudinal recording system and to maintain its position as the major component of external storage devices while extending its range of applications. Fuji Electric will continue to tackle the many technical problems.