Present Status and Future Prospects for Magnetic Hard Disks

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1. Introduction

In the early 1980s, when computer use transitioned from main frame computers used in offices to so-called personal computers for private business and applications, hard disk drives (HDDs) as external storage devices achieved a crucial technological breakthrough. Under these circumstances, Fuji Electric succeeded in commercializing thin film magnetic hard disk processed with a sputtering method, and has been successively introducing new products at appropriate times as the recording density of HDDs has been increasing.

In recent years, recording densities have been increasing at an annual rate of 100 %. As a result, the per-bit cost of hard disk has dropped dramatically and has become lower than that of paper recording media. HDDs, also having a high level of processing capability, are expected to extend their applications to fields other than personal computers.

This paper describes the technological trends that support the future expansion of the market for HDDs, and outlines the present status and future prospects of Fuji Electric's technology for magnetic hard disk.

2. Trends in Market and Technology for HDDs

Due to their drastic reduction in per-bit cost, as well as their high capacity and high access rate, HDDs are expected to dominate such new fields as consumer electronics and IT (information technology) through outperforming other storage systems.

Reflecting the continuously increasing recording densities, Fig. 1 shows the trend of HDDs' recording densities as demonstrated by research institutes throughout the world, one or two years ahead of commercialization.

In 2001, HDDs equipped with 30 Gbits/in^2 (40 Gbytes/platter, 95 mm in size) magnetic hard disk developed by Fuji Electric were commercialized. In addition, Fujitsu Ltd. and Seagate Technology successfully demonstrated 100 Gbits/in^2 magnetic hard disk. In 2002, various companies are promoting their development of commercial 60 Gbits/in^2-class HDDs.

The technological development of magnetic heads and magnetic hard disk is crucial for realizing such sophisticated HDDs as mentioned above. Technological challenges facing the development of magnetic hard disk, in which Fuji Electric specializes, are classified into the following:

○ Magnetic characteristics of thermal stability and reduced media noise
○ HDI (head-disk interface) characteristics of low-flying stability and high reliability (high durability and high environmental resistance)

Figure 2 shows a schematic representation of the

Fig.1 Annual trend in recording densities

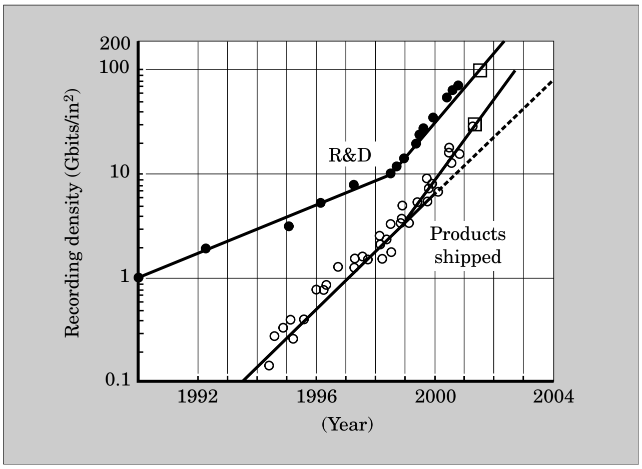
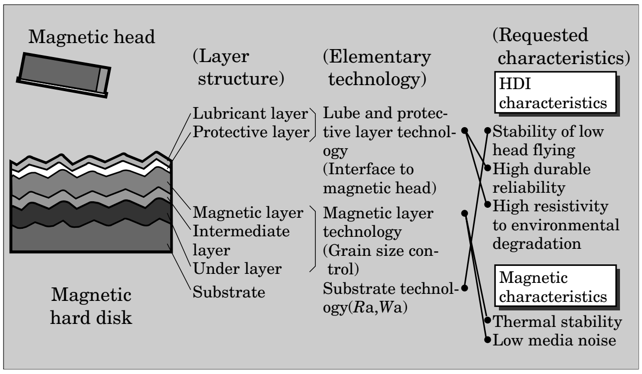


Fig.2 Relationship between elementary technologies and requested characteristics for magnetic hard disk



intricate relationship between elementary technologies and requested characteristics for magnetic hard disk.

The next chapter outlines the progress of these individual elementary technologies.

3. Present Status of Fuji Electric's Technology for Magnetic Hard Disk

3.1 Substrate technology

The performance of currently-used aluminum substrates directly affects the low-flying stability of magnetic heads, which is a primary technology that supports higher recording densities, and plays an important role in reducing physical defects of small recording bits.

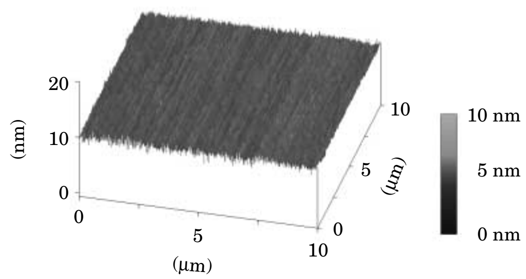
The physical parameters that determine the low-flying stability of magnetic heads are micro-waviness (W_a) and surface roughness (R_a). Reducing W_a requires applying an improved grinding technique to the polished substrates, forming NiP plated film with improved thermal deformation resistance, and applying a highly precise polishing technique. The subsequent texture process greatly affects R_a.

The optimization of processes for the above-mentioned requirements allowed surface properties (R_a = 0.25 nm, W_a = 0.15 nm) as shown in Fig. 3 to be obtained. As a result, the glide avalanche property shown in Fig. 4 was obtained and this almost achieved the low-flying stability required for the 60 Gbits/in^2 magnetic hard disk currently under development.

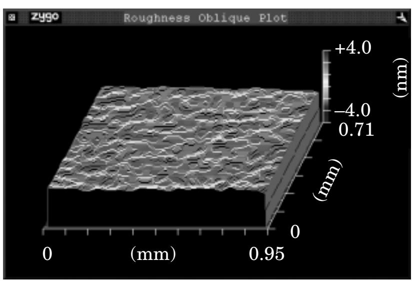
In order to prevent the depletion of recording bits, tolerance for the size of surface defectives is continuously decreasing. The reduction of defects is essential for higher reliability when magnetic disk media are installed in HDDs, as well as for high yields in the media manufacturing processes. When mass production of 30 Gbits/in^2 recording media started in 2001, Fuji Electric reviewed items to be improved and is promoting the advancement of the following:

- ○ Reduction of micro pits and scratches during the substrate polishing process
- ○ Reduction of scratches during texture processing and of micro-contamination during washing

Fig.3 Surface properties of magnetic hard disk



(a) Surface roughness measured with AFM (R_a = 0.25 nm)



(b) Surface micro waviness measured with Zygo (W_a = 0.15 nm)

3.2 Magnetic film technology

To realize high recording density, the extent to which stable recording bits can be made finer is of primary importance. Magnetic films for recording have gone through several changes since the adoption of thin films processed with a sputtering method, and will undergo further change as they are optimized for use in combination with magnetic read/write heads. In the future, it will be important to design magnetic films that correspond with the development of magnetic heads.

This paper introduces a road map for the future development of magnetic films.

The crux of the development of magnetic films for longitudinal recording is to achieve an appropriate balance (tradeoff) between reduced media noise and thermal stability (smaller thermal decay). In addition, the limited writability of magnetic heads keeps the coercivity of magnetic media moderate, particularly in a dynamic range. To be specific, low media noise is realized with magnetically decoupled crystal grains and finer grains in a magnetic recording layer, and through additional measures to secure thermal stability. The importance of thermal stability was recognized during the process of realizing 30 Gbits/in^2 magnetic hard disk, and requires further improvement. This is the reason for interest in the AFC (anti-ferromagnetic coupling) structure[(1)(2)], which was developed in GMR (giant magnetoresistive) elements and is expected to be applied to magnetic disk media. Figure 5 shows the road map for development of magnetic films. As shown in Fig. 5, overlapping the development of conventional-structure 60 Gbits/in^2 longitudinal-recording,

Fig.4 Improvement of glide avalanche properties

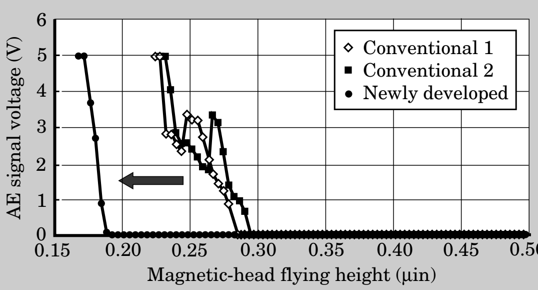


Fig.5 Road map for magnetic film development

Recording density	30 Gbits/in^2	→ 60 Gbits/in^2	→ 120 Gbits/in^2	→ 240 Gbits/in^2
Type of recording layer	<Longitudinal recording> Conventional structure	AFC (anti-ferromagnetic coupling) stucture	<Perpendicular recording> CoCr alloy system	Multi layered film system, hybrid film system
Grain size	8 to 9 nm	→ 7 to 9 nm	→ 5 to 6 nm	→ 4.5 to 5 nm
Coercivity	295 kA/m	→ 334 kA/m	→ 478 kA/m	→ 637 kA/m
Magnetic layer	CCPB system	→ CCPB/AFC	→ CCPB/soft under layer	→ (Co/M)*n*/soft under layer

100 Gbits/in^2 perpendicular-recording is being investigated.

3.3 Lube and protective film technology

In magnetic recording, it is important to minimize clearance between the magnetic recording layer and the magnetic head element, to make the media surface smoother as described in the substrate technology section, and to make the lube and protective film thinner to the extent possible.

Future development, however, faces increasingly difficult challenges for securing flying stability, overcoming interaction between the magnetic head and magnetic disk in an extremely low flying state, for ensuring the required durability in the case that a magnetic head contacts a magnetic disk, and for ensuring corrosion resistance of the magnetic layer, which may be required because the film is very thin.

Figure 6 shows the road map for development of lube and protection films.

Since having established CVD technology for 5nm-thick protective films in 30 Gbits/in^2 magnetic disks, Fuji Electric is developing thinner protective films and expects to be able to realize durable and corrosion resistant 2.5 nm-thick films, through securing further thickness uniformity and higher film hardening. In addition, Fuji Electric is investigating the feasibility of FCA (filtered cathodic arc) films through using a new deposition method, to fabricate extremely thin films in the future.

Fuji Electric is promoting the optimization of lubricant films according to individual HDDs designs. The basic concept for achieving flying stability of a magnetic head lies in forming the lubricant film as thinly as possible on the protective film with surface resistivity controlled by a Fuji Electric proprietary treatment. A thin lubricant film can more easily be designed by adopting a lump load system in place of the previous CSS (contact start stop) system.

In high-rpm HDDs for server applications, self-recovering capability of the lubricant essential for durability and prevention of lubricant depletion caused by spin-off must be balanced in the design of a bonding lubricant. On the other hand, lower flying height of a magnetic head can lead to increased self vibration (instability) of the head itself. This phenomenon is a key factor for magnetic head reliability because it can increase the risk of accidental trouble in actual severe environments. A Fuji Electric study shows that such trouble is related to various properties on the media surface such as micro–surface-waviness and lubricant thickness. Figure 7 shows an evaluation of magnetic-head flying stability with an AE (acoustic emission) sensor.

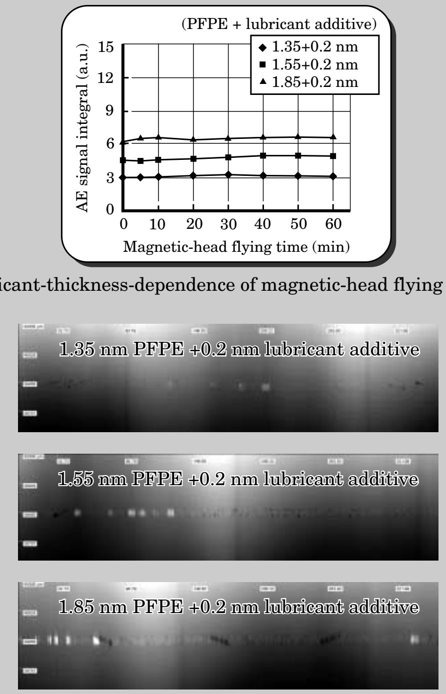
According to measurement with an AE sensor, magnetic-head flying stability becomes worse with increasing lubricant thickness. In addition, moguls are formed on the lubricant surface, and in other words the surface becomes bumpy. A key factor in the future development of lubricant is to prevent moguls from being formed.

Based on these conditions, Fuji Electric has developed a proprietary lubricant refining technology SFE

Fig.6 Road map for development of lube and protective film

Recording density	30 Gbits/in^2	→ 60 Gbits/in^2	→ 120 Gbits/in^2	→ 240 Gbits/in^2
Glide avalanche	6 nm	→ 5 nm	→ 4.5 nm	→ < 4 nm (near contact)
Protective film	<CVD> Surface chemical modification 5 nm	→ 2.5 to 3 nm	→ 2 nm	→ < 2 nm (FCA)
Lubricant film	<PFPE> Improvement of molecular weight distribution	→ Mixture system with additive → Design control of molecular weight		→ New lubrication system → Control of molecular structure

Fig.7 Evaluation of magnetic-head flying stability with an AE sensor



(a) Lubricant-thickness-dependence of magnetic-head flying stability

(b) Observation of lubricant thickness change with OSA (supercritical fluid extraction) to perform detailed molecular weight design according to individual HDD development programs. In addition, based on this technology, Fuji Electric is promoting the study of near-contact-recording and contact-recording systems in their basic research stages.

4. Prospects of Future Technology

As described above, the increase of recording density and cost reduction of recording media are creating new markets for HDDs.

Along this trend, Fuji Electric has been applying its originality to find answers to unsolved issues and to promote developments in new fields for recording media. This paper introduces some new technologies that show potential for success.

4.1 Glass substrate media

With their characteristic advantages of high impact resistance and TMR (track miss registration) resistance, glass substrates are widely used in portable- and server-PCs. Magnetic films formed on glass substrates exhibit, however, isotropic magnetism because of the isotropic surface property of glass substrates. Their magnetic parametric performance is therefore inferior to that of oriented magnetic films formed with Al-substrate media. As a result, future demand will be strong for oriented magnetic films on glass substrates. Although there exists a process to secure oriented magnetism through forming NiP and then performing the same texturing as Al substrates on glass substrates, this process impairs the advantageous characteristics of glass substrates and increases the cost.

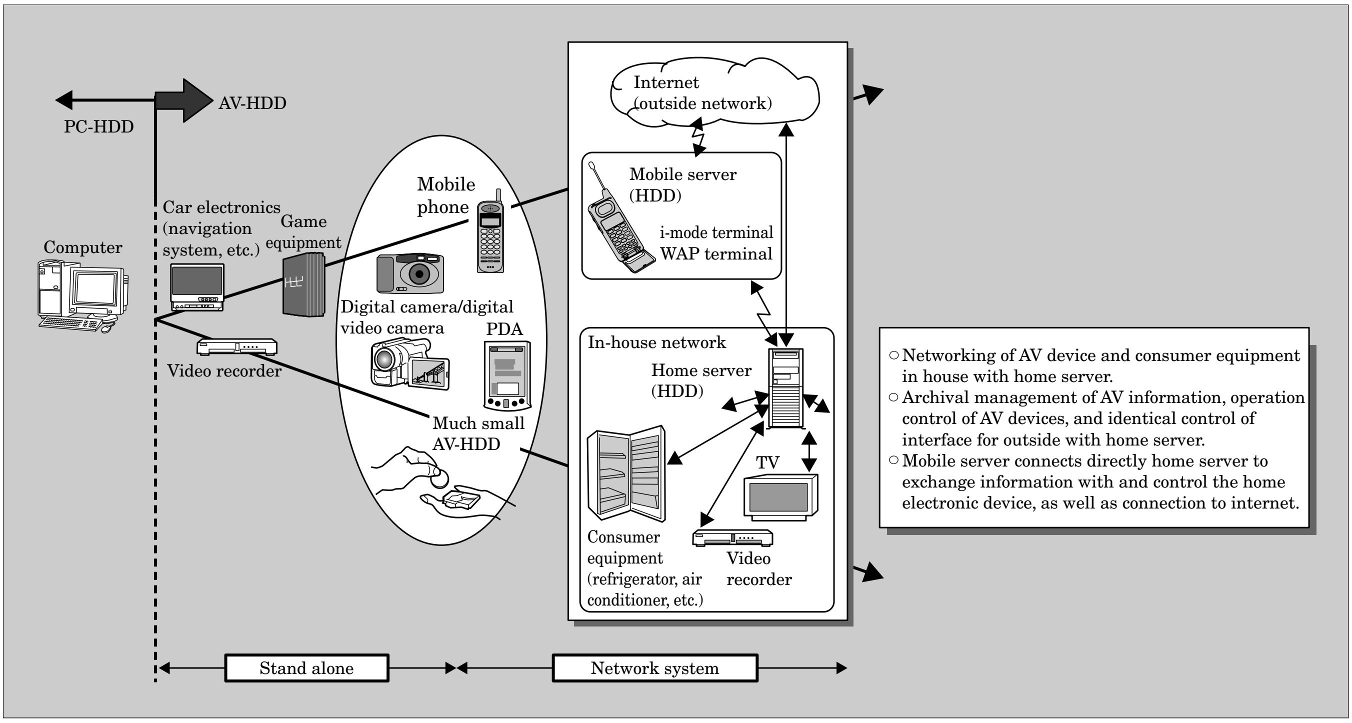
Fuji Electric, having developed a repeatable process to form the same texture lines on glass substrates as on Al-substrates and an original seed layer deposition processes in a vacuum, has optimized the combination of these processes to achieve magnetic-head flying and magnetic parametric performances that compare favorably with Al-substrate magnetic media.

In the future, with its high impact resistance, the newly-developed glass-substrate magnetic media are expected to be used for various mobile HDD applications in addition to PC applications, while smaller size magnetic media are pursued.

4.2 Perpendicular recording media

In recent years, applied research for perpendicular-recording media is increasingly being encouraged because the balance among low media noise, thermal stability and magnetic head writability can be destroyed in higher-density longitudinal recording media. In the future, attention will be given to the feasibility of perpendicular recording media with densities greater than 100 Gbits/in^2. Whether or not any one of the various media layer structures under development is finally chosen depends on technological breakthroughs as well as productivity. Fuji Electric is investigating every possible development and application related to perpendicular recording media. It is also promoting the development of longitudinal and perpendicular recording films simultaneously as shown in the roadmap, through setting the demonstration of 100 Gbits/in^2 magnetic recording films as a first goal. As digital

Fig.8 Usage development of AV-HDD



information technology spreads from PCs to AV (audio-visual) systems, larger-capacity memory will be required, which leads to high hopes for perpendicular recording media and prompts their development and use.

4.3 Magnetic printing media

After magnetic hard disk has been incorporated into an HDD, servo information must be written on the media to control the magnetic head to realize appropriate write and read properties. As recording densities increase, servo writing requires updating of the servo writer and longer times for the servo writing process, resulting in higher cost. With the cooperation of an HDD manufacturer, Fuji Electric has recently established a process for writing pre-servo information through the use of a contact system, and was the first company in the world to realize mass production of 15 Gbits/in^2- and 30 Gbits/in^2-recording media with installed pre-servo information. This technology can be applied to higher-density recording media in the future. It was demonstrated that the servo printing system could effectively be applied to perpendicular recording media. In addition, the servo printing system is expected to be widely applied to HDDs for AV applications as a potential means to write security information to disk media, for which PC development has given little consideration in the past.

Figure 8 shows the development of AV-HDD applications in the future. The technologies described in this chapter will provide specific solutions for issues important to market development, such as low cost, large capacity and security.

5. Conclusion

This paper outlined achievements of Fuji Electric's technological developments and the present status of magnetic hard disk. Technological development to maintain the annual 100 % increase in recording density of recent years is becoming more difficult year after year. Nevertheless, it is expected that 60 Gbits/in^2 hard disk will probably be realized in 2002 through the combined efforts of the concerned parties.

Fuji Electric is determined to lead this technological development and to contribute to the HDD industry in cooperation with other companies as in the case of 30 Gbits/in^2 hard disk. We hope such efforts lead to the expansion of the HDD market.

References

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