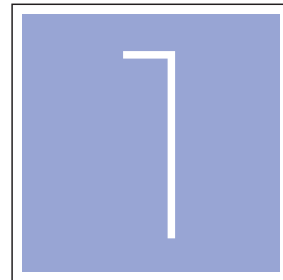


FUJI ELECTRIC REVIEW



2000 VOL.46

Magnetic Hard Disks



Fuji's innovation is at the forefront of technology

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Magnetic hard disks are key components of hard disk drives for computers. Demand for high-performance disks is rising dramatically, driven by increasingly information intensive societies and progress in the multimedia age. Fuji Electric Co., Ltd. has led the world in sputtering technology since 1983, which allowed the manufacture of magnetic

hard disks suitable for high-density recording. In the age of rapid technological development, Fuji Electric has achieved a first-class position in the world market for magnetic hard disks and has earned a strong reputation for quality and reliability from customers worldwide.

FUJI ELECTRIC REVIEW

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7

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Cover Photo:

The personal computer (PC) is now an indispensable tool to offices. The magnetic hard disk is one of key components for computers.

The disk requires extremely high technology. Fuji Electric is making efforts to enhance the capacity of disks for home audio-visual devices as well as for computers.

The cover photo shows an image of the contribution to society with spotlighted disks superposed upon an office worker operating a personal computer which contains a disk storage.

Present Status and Future Prospects for Magnetic Hard Disks

Tomonobu Ogasawara
Kenji Ozawa

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

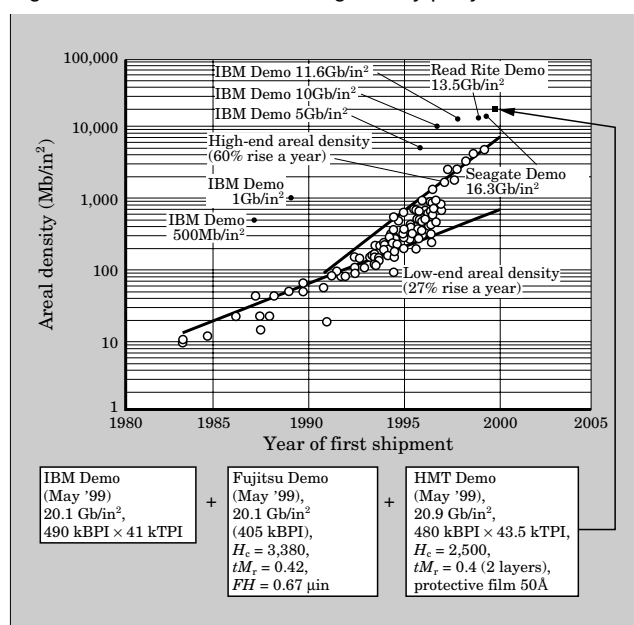


Fig.2 Reduction in flying head height required each year

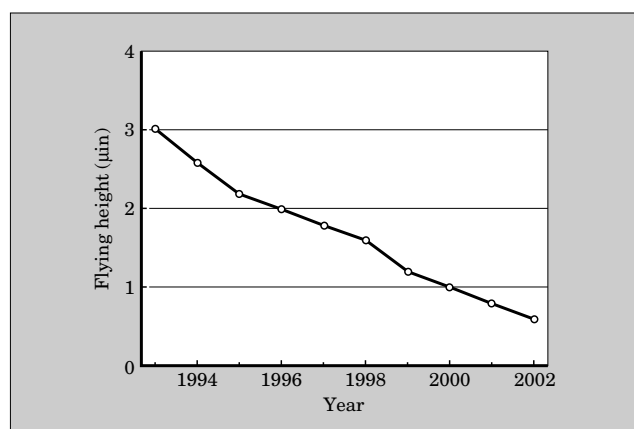


Fig.3 Increase in the transfer rate each year

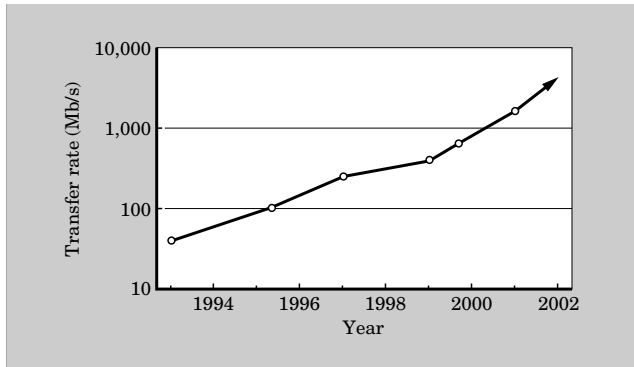


Table 1 Substrate size requirements

Thickness Diameter	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

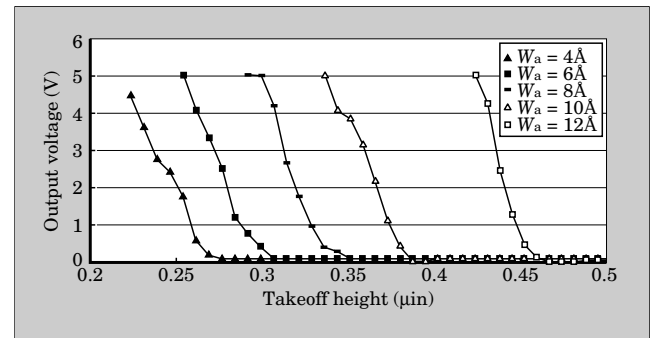
Only current topics are described here.

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

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



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

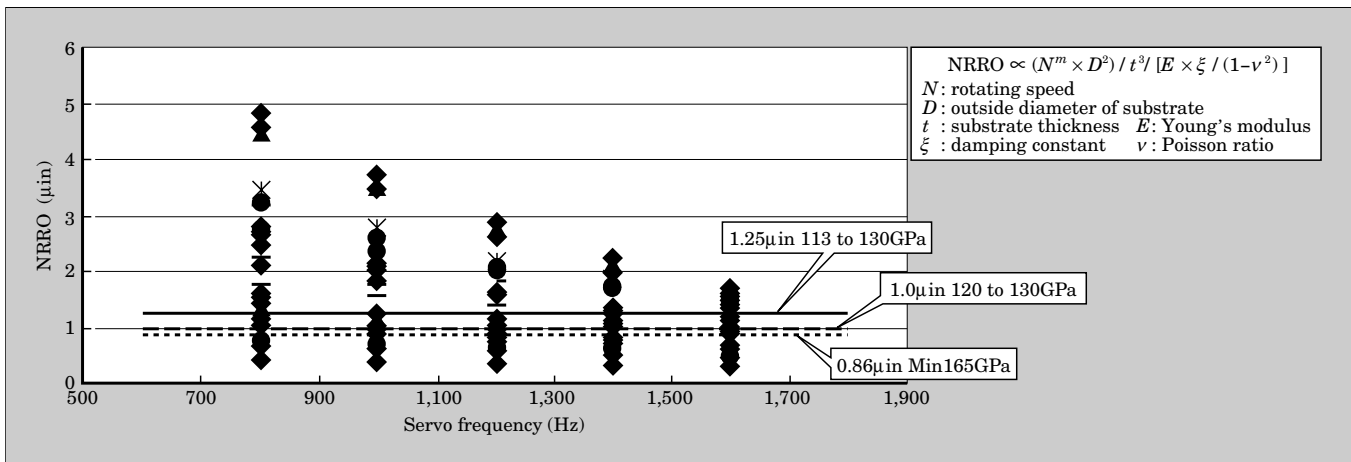
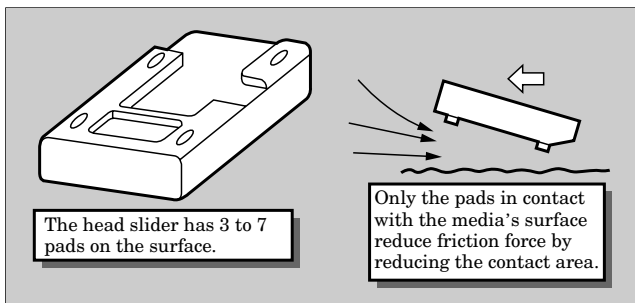


Fig.6 Conceptual sketches of padded head



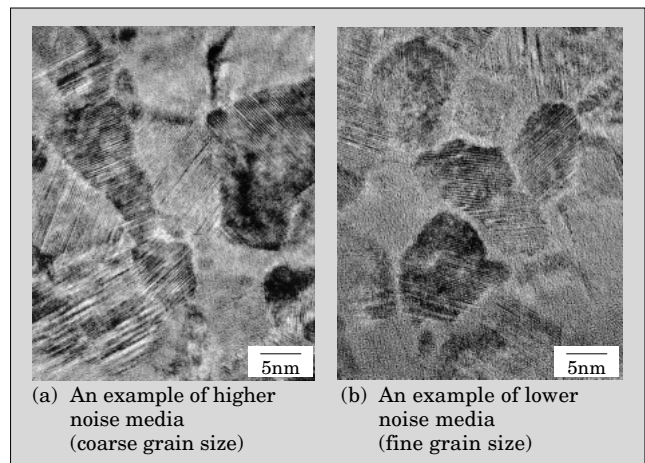
installed in many of IBM's HDD notebook computers and already has been verified technically. However, the HDD speed specification has the comparatively low value of 4,200 r/min, and technology compatible with speeds higher than 7,200 r/min, believed to be the mainstream in the future, has not yet been 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.

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



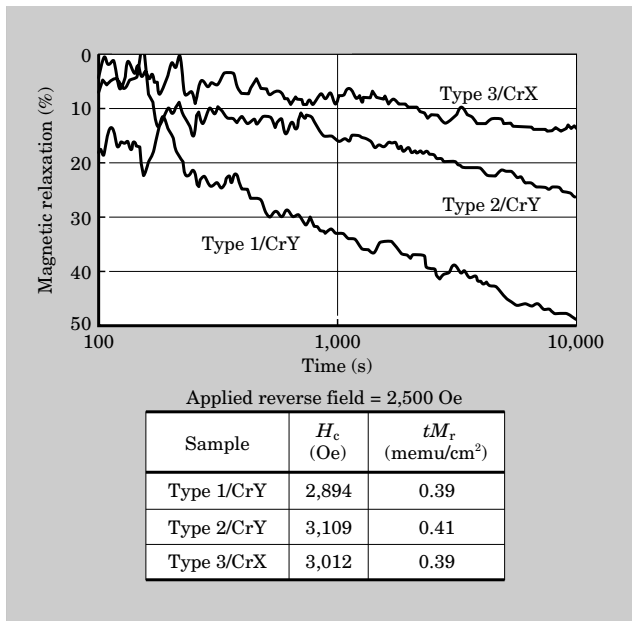
As discussed in various institutes and symposiums, reduction in noise basically depends on how a uniform crystallographic structure of fine magnetic grains can be formed in a high vacuum and under high-speed conveyance (in a short time). Fuji Electric has made continuous efforts to achieve an optimum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



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

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	◎

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/in² 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.

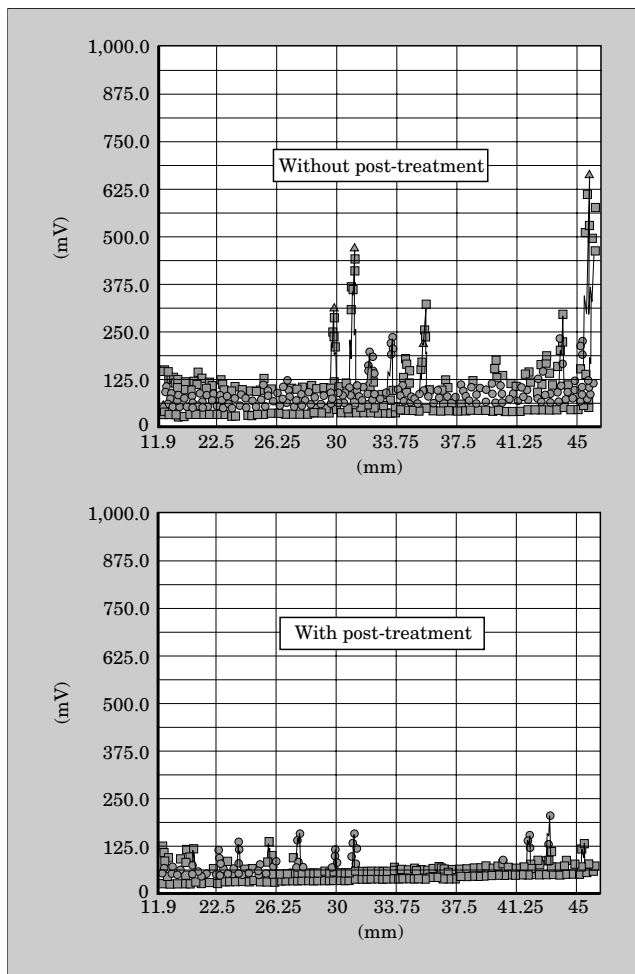
(1) Surface defect inspection before sputtering

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/in², 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/in².

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 cleanliness 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.

Recording Density Enhancement and Material-Process Technologies for Magnetic Hard Disks

Nobuyuki Takahashi
Yoshiharu Kashiwakura
Kazuyoshi Shibata

1. Introduction

Recent magnetic recording media for magnetic hard disk drives (HDDs) have made remarkable technological advancement. When Fuji Electric started manufacturing sputtered thin film magnetic disks in 1985, the recording capacity was 10 to 20 Mbytes per 3.5-in disk. Currently, disks with a capacity of 7 Gbytes are available in the market. Moreover, manufacturers are striving to develop 20-Gbyte disks and bring them to market in the year 2000.

The technology that has supported this recording density enhancement has largely been due to the magnetic head that has developed from a thin film head to a magnetoresistive (MR) head and then to giant magnetoresistive (GMR) head. On the other hand, the technological advancement of the magnetic disk (hereinafter referred to as the disk) itself that maintains the stability of extremely small recording bits should not be overlooked.

This paper describes Fuji Electric's magnetic hard disk technology that has supported recording density enhancement, and in addition, discusses the present status and the problems of future development for this technology.

2. Technological Trends of Recording Density

In the 1980s, thin film technology with sputtering instead of coated disk supported magnetic recording density enhancement at an annual rate exceeding 30%. There is also a history of increasing coercive force and decreasing magnetic recording layer thickness, indexes of important disk characteristics, to realize very small recording bits in the course of increasing magnetic head sensitivity.

In the 1990s, the practical use of MR heads increased recording density by 60% annually. In the meantime, with regard to media characteristics, reduction of media noise was carefully studied and more analytical investigation into magnetic materials and film deposition processes was initiated. Also, to solve the problems of low flying-head height to reduce magnetic spacing and thermal asperity due to contact

with the media, peculiar to MR heads, smooth disk surfaces for the data zone were realized without irregular projections and particles, ensuring that they would be used in practical applications. In addition to the data zone, a contact start-stop (CSS) zone was realized with a laser texturing process to form a newly controlled surface of high-density bumps. This allowed for separate durability characteristics according to the function.

The GMR head, introduced in the middle 1990s, has raised recording density by 100% annually in some fields of HDD application. Bit cost lowered by advances in recording density and new mechanical characteristics such as the ramp load method instead of the CSS method and high rotational speed technology have established HDD with distinctive features for each application field, and the HDD market is showing indications of further expansion. In response to this situation, there is a clear trend to replace conventional Al/NiP substrates with glass substrates in fields that require impact resistance and rigidity against high-speed rotation. A successful recording density of 20 Gb/in² at the research level has been announced⁽¹⁾ and mass production is expected in 2000.

3. Longitudinal Recording System

The details of actual technology for disk used thus far in the longitudinal recording system, classified into the requirements of disk composition and the key formation process, are described below.

3.1 Disk composition

As shown in Fig. 1, disk is composed of a substrate,

Fig.1 Typical layer structure of magnetic hard disks

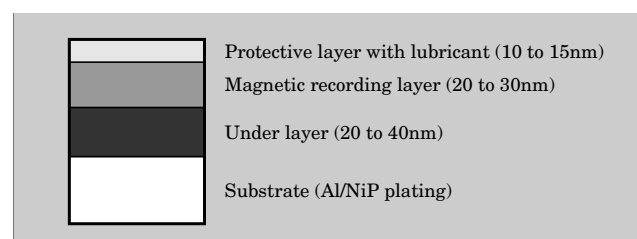
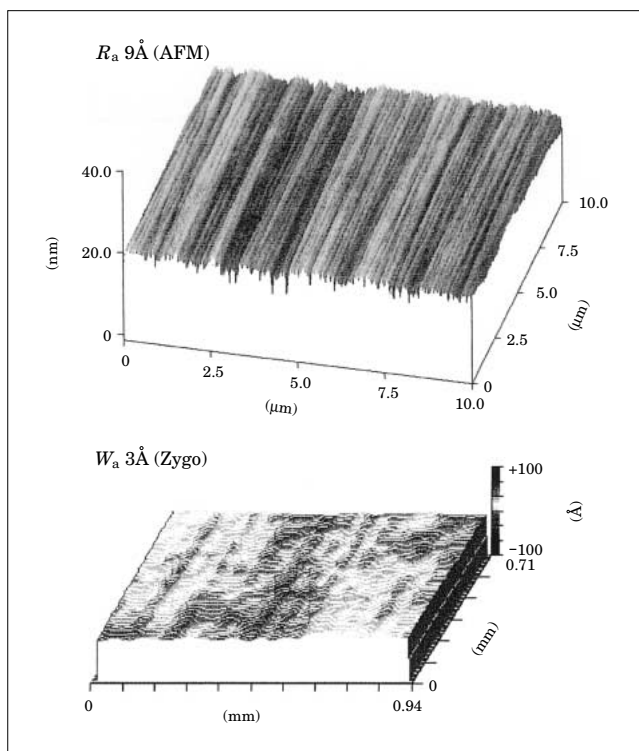


Fig.2 Typical surface texture of a magnetic hard disk (Al substrate)



a magnetic recording layer, and a protective layer with lubricant. Media characteristics required to increase recording density can be examined by considering how the magnetic transition length a , inversely proportional to linear recording density, can be reduced.

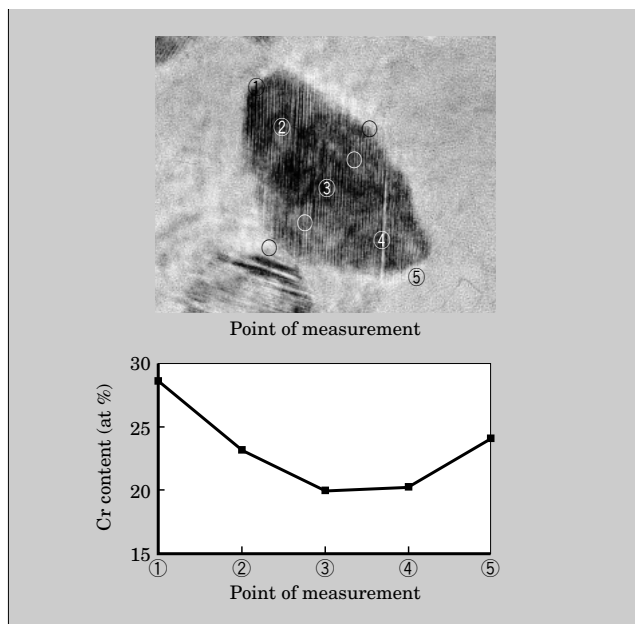
$$a = \left[\frac{4M_r t (d + t/2)}{H_c} \right]^{1/2} \dots \dots \dots (1)$$

where M_r : remanence
 t : magnetic layer thickness
 d : head-disk magnetic spacing

With regard to characteristics required of the substrate, to reduce the head-disk magnetic spacing (d), surface smoothness such as surface roughness (R_a) and micro-waviness (W_a) is most important. As shown in Fig. 2, values below 1nm are in practical use, and further reduction in the values will be required for lower flying-head height or near-contact spacing in the future. To control the circumferential orientation of magnetic characteristics to be discussed later, mechanical texturing is applied within a range that does not effect the flying-head height. The opportunity to expand HDD application fields was made possible by changing the material from conventional Al/NiP to glass. Glass substrates are being used in the market for small, portable personal computers that require impact resistivity, and are accumulating good results. Because of its potential for higher rigidity, the practical use of glass substrates in higher rotational speed applications is expected.

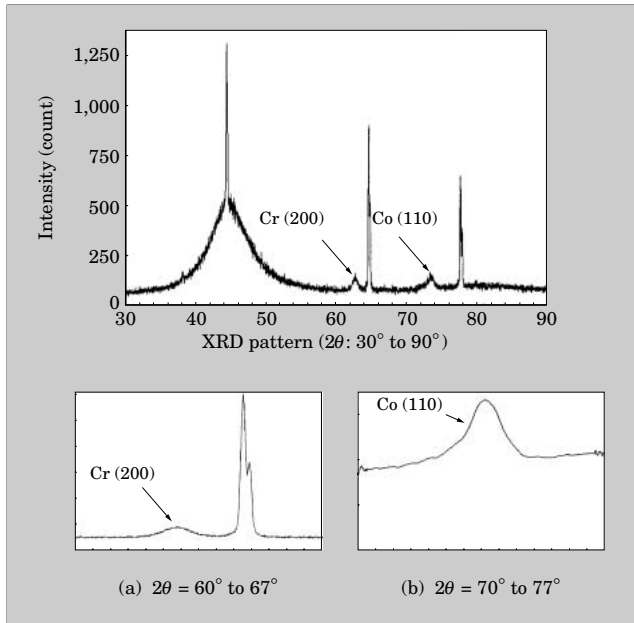
With regard to characteristics required of the magnetic recording layer, maintaining stability of very small recording bits is an important issue from the

Fig.3 Cr segregation structure of a magnetic grain



viewpoints of reading and deterioration with the passage of time. From the above formula, the ratio of the product of remanence and thickness ($B_r \cdot t$) to coercive force (H_c) is a basic magnetic parameter. To support the three digit increase in recording density since thin film magnetic disks were put to practical use until now, H_c has changed from 600Oe to 3,000Oe and $B_r \cdot t$ has changed from 700G·μm to 70G·μm [decrease of one digit in $(M_r \cdot t / H_c)^{1/2}$ during this period]. Co alloys have consistently been used for the magnetic material. However, the composition has greatly changed and an effective composition ratio for optimizing the design of saturated magnetization and for decoupling crystal grains by Cr segregation has been selected from a combination of component elements including Cr, Pt, and Ta. An example of a typical Cr segregation structure currently in practical use is shown in Fig. 3 as examined with a TEM/EDX. Cr segregation can be seen on the grain boundary in the figure. As the layer composition in Fig. 1 shows, the presence of an under layer and a seed layer that realize desirable crystal orientation for the magnetic characteristics of a upper magnetic layer and effect the adjusting of grain size are indispensable prior to magnetic layer formation. Formerly, Cr was used for the under layer; however, a Cr alloy containing W, Mo, and Ti is being commonly used to meet changes in the upper magnetic layer and to optimize conditions. An example X-ray diffraction of a recent typical magnetic layer constructed above an under layer is shown in Fig. 4. The figure shows that the crystal orientation of the Co alloy magnetic layer (110) develops on top of the crystal orientation of the Cr alloy under layer (200), and a desirable in-plane orientation of the c-axis (easy magnetization axis) of the hexagonal close-packed (hcp) structure is realized. Among magnetic characteristics, c-axis alignment with

Fig.4 X-ray diffraction pattern of a magnetic layer

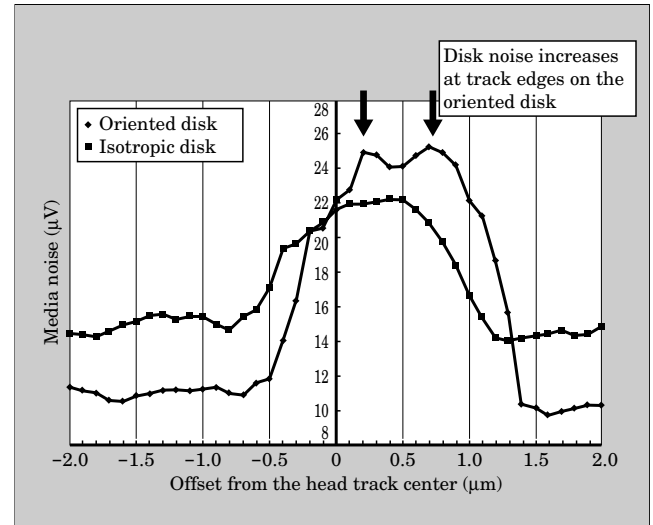


the circumferential direction due to anisotropic film stress along the substrate texture line is characteristic of Al/NiP substrate systems (so-called oriented disk). On the other hand, it has been determined that the formation of a specific seed layer is effective in forming the desired magnetic layer on a glass substrate, and the NiAl alloy layer has already been put to practical use. As a result, proper magnetic grain size and the in-plane orientation of the c-axis of the magnetic layer are realized even on a texture-less, smooth glass substrate. Because of this absence of texture, different from the Al/NiP system, the c-axis is randomly orientated within the plane and an isotropic magnetic property is obtained. At current recording densities, oriented media is generally superior in on-track parametric performance. However, isotropic disk is superior in track-edge noise as shown in Fig. 5, and in order to improve TPI as recording density increases in the future, there is the possibility that isotropic disk will have the advantage. It is necessary to promote further optimization of high density recording areas, including materials.

The development of magnetic layers has been continued with the goal of reducing media noise to realize a high signal-to-noise (SNR) ratio. However, when recording density exceeds 10 Gb/in^2 (for example, $400 \text{ kBPI} \times 25 \text{ kTPI}$), bit size is less than $0.06 \mu\text{m} \times 1 \mu\text{m}$, and only several grains exist in a bit along the direction of magnetic transition. In this case, recorded bits cannot be kept stable due to thermal fluctuation with the passage of time, and the possibility of spontaneously decaying output signals grows with reduction of magnetization.

It is important to keep a parameter, given by (magnetic anisotropy constant: K_u) $\times$ (activation volume: V), above a certain value to prevent this thermal

Fig.5 Edge noise characteristics (oriented and isotropic disk)



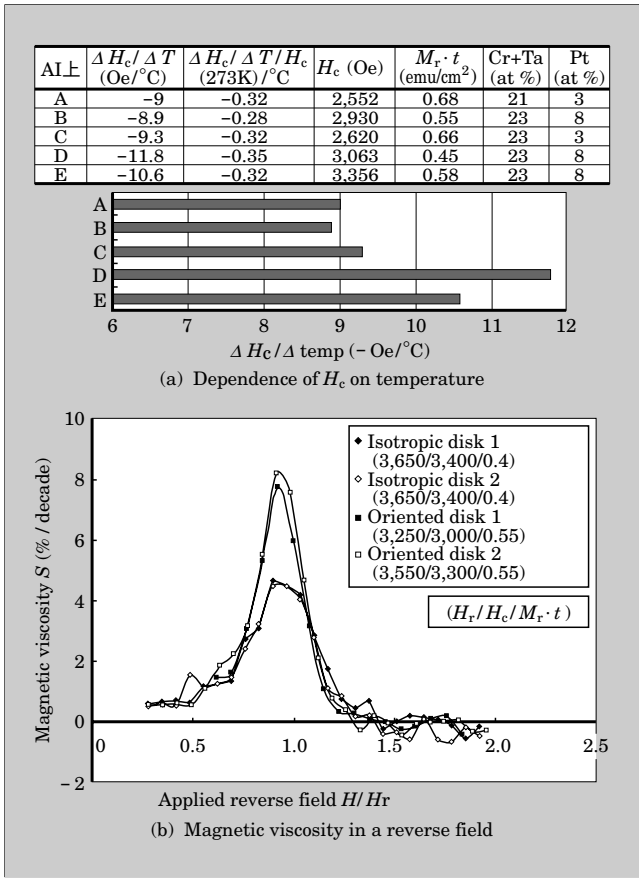
fluctuation phenomenon⁽²⁾. V is related also with the above-mentioned grain size and there is a tradeoff between V and the preferable method for media noise reduction. A solution advantageous to both is to make the distribution of grain sizes as narrow as possible and reduce the proportion of larger and smaller grains. On the other hand, Pt added to the alloy to make small grains thermal-fluctuation-resistant and a segregation structure that diffuses non-magnetic Cr to the grain boundary to raise anisotropy in grains are important. To simply evaluate thermal fluctuation, we applied⁽³⁾ measuring methods for H_c dependence on temperature and magnetization decay in a reverse magnetic field as shown in Fig. 6, and have utilized this method as an evaluation tool. For present disk, the temperature coefficient of the former ($\Delta H_c/H_c/\Delta \text{temp}$) is approximately $-0.3\%/ \text{deg}$, and the latter is approx. $8\%/ \text{decade}$ of time (s). These guidelines will be held for future higher recording density. Regardless, the coexistence of noise and thermal fluctuation will surely become more difficult, and we shall have to reevaluate recording systems.

Lastly, details of the protective layer with lubricant are omitted since it is described separately. With magnetic spacing d (magnetic flying height + protective layer thickness), since linear recording density can increase in proportion to $1/\sqrt{d}$, reduction in protective layer thickness is effective when the head flying height is low. Lubricant on the surface that reduces the coefficient of friction between the head and the disk is important not only from the viewpoint of tribology, but also because flying height instability due to the transference of contamination and lubricant to the head will cause defects in parametric performance.

3.2 Process technology

Actual process technology is described below.

Fig.6 Dependence of H_c on temperature and magnetic viscosity in a reverse field



3.2.1 Substrate process

The correlation between requested characteristics and process parameters in Al/NiP substrates is shown in Fig. 7.

To ensure head stability at a low flying height, local projections or scratches must also be considered in addition to the average smoothness and flatness of the substrate surface, and each step of every machining process requires precise control. In particular, the texturing process that creates the final finish on the substrate surface has to realize extremely low roughness while removing enough stock to eliminate abnormalities (scratches, etc.) on the surface. It is important to select shape-optimized abrasive grids for sufficient stock removal and tape material to fix the grids in place. However, there is a tradeoff between stock removal and surface roughness. To ensure a uniform textured surface with a low rate of stock removal, greater smoothness and flatness at the stage of the polishing process is important. Improvements in Al grinding and NiP plating as well as the utilization of new processing conditions for the polishing process realize very smooth surfaces as shown in Fig. 8. The challenge for future processes will be to realize a surface that ensures stable head flying, assuming that flying-head height is made as low as possible (glide height < 0.3 μ m), requiring much more precision

Fig.7 Correlation between characteristics and processes in Al/NiP substrates

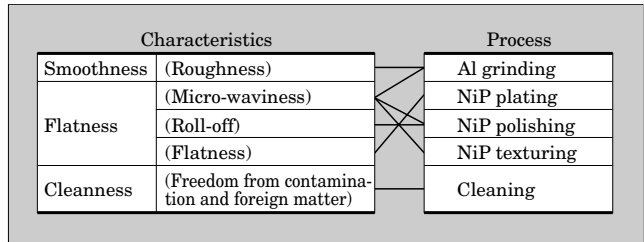


Fig.8 Surface image of a polished substrate (Al/NiP)

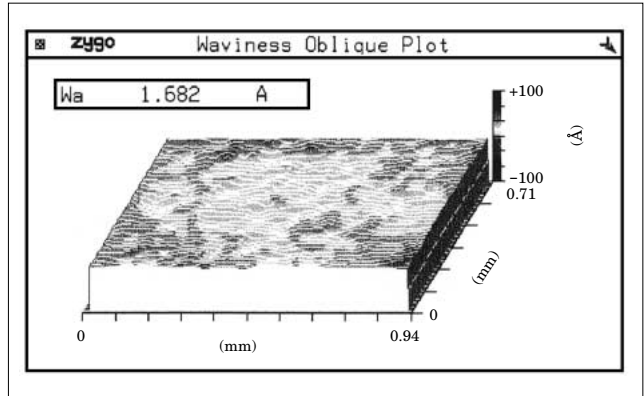


Table 1 Correlation between disk characteristics and deposition processes

Process	Change in media characteristics* due to increase in a process parameter		Remarks
	H_c	Noise	
Degree of vacuum	Increases	Decreases	Higher vacuum necessary
Substrate temperature	There is a maximum value	There is a minimum value	Optimization necessary
Ar gas pressure	Decreases	Decreases	
Under layer thickness (Cr alloy)	Increases	Increases	
Substrate bias	Dependent upon layer structure	Dependent upon layer structure	
Magnetic layer composition	Cr	Decreases	
	Ta	Decreases	
	Pt	Increases	

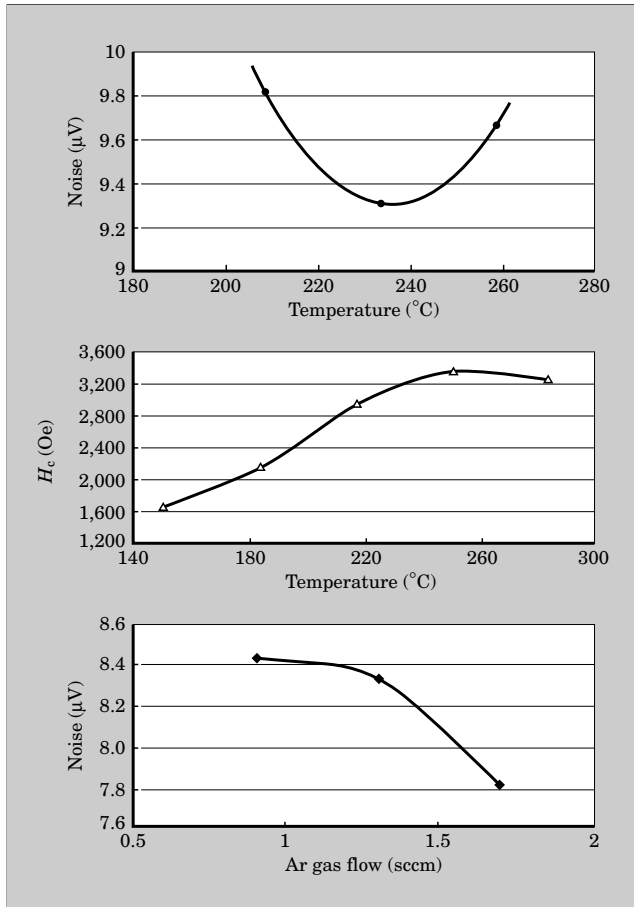
Notes*: Degree of vacuum indicates evacuation to lower pressure.
 Magnetic layer composition indicates increase in the content of a component.

control in each process. Smoothness and flatness requirements for processing glass substrates are similar, however changes in the processes are necessary to comply with special physical property requirements (high hardness and high insulating property).

3.2.2 Magnetic layer deposition process

As mentioned previously, the characteristics required of a magnetic layer to attain high-density recording are high coercive force H_c and low noise. The

Fig.9 Dependence of H_c and noise on several process parameters



relation between these and actual film deposition processes is shown in Table 1. It has already been shown that highly purified operation gas, reduced outgas in the vacuum chamber, and increased vacuum level in the chamber increase effectiveness in principle. Other deposition parameters, such as substrate temperature, gas pressure, under layer thickness, and substrate bias, are related to each other and mutually influence the layer structure and film composition, and therefore, it is necessary to optimize each individually. Figure 9 shows the dependence upon several process parameters of H_c and noise on an Al/NiP substrate. Substrate temperature is an important parameter to increase H_c , but from the viewpoint of reducing noise, the optimum value is a lower temperature than the value for maximum H_c . Increased Ar gas flow and higher gas pressure settings are effective in reducing noise. Actually, the magnetic layer components (Pt, Cr, etc.) are optimized to meet the required H_c and $M_r \cdot t$ values as shown in Table 1. In the course of process optimization, the goal is to realize higher H_c while decreasing the Pt quantity and to prevent H_c from declining while adding as much nonmagnetic elements, such as Cr and Ta, as possible which are effective in reducing noise. Overall, higher Pt and higher Cr and Ta are desirable to increase recording density in the

Fig.10 Dependence of H_c on seed layer thickness

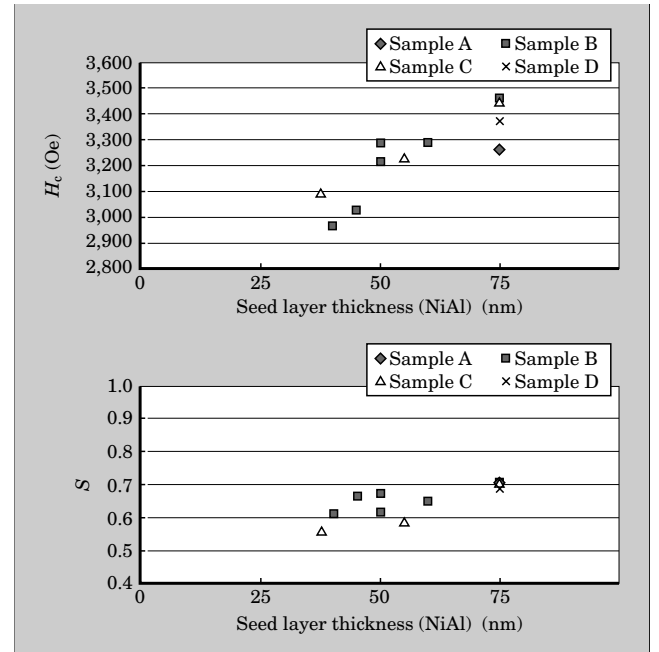
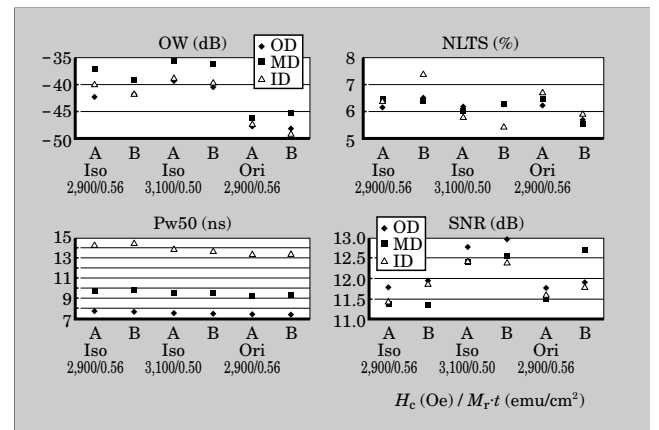


Fig.11 Parametric performances (isotropic and oriented disk)



future. Further, the use of effective nonmagnetic elements in addition to or instead of Cr and Ta is also a subject for further development.

In addition to the above subjects which apply to different substrates, the necessity of a seed layer to realize an isotropic layer, typically utilized with glass substrates, has been described above. By optimizing processing for this seed layer (temperature and film thickness), the desired crystal orientation of a magnetic layer and grain size can be controlled on a glass substrate, and characteristics similar to an oriented magnetic layer on a NiP/Al substrate can be obtained. Examples of experiments are shown in Fig. 10 (process) and Fig. 11 (parametrics). These figures show that seed layer thickness can control H_c , and isotropic disk can have almost the same characteristics (excluding the OW characteristic) as oriented disk by adjusting magnetic characteristics. Irrespective of isotropic or oriented disk, the realization of a magnetic layer for

Table 2 Comparison between longitudinal and perpendicular recording

Classification Item	Longitudinal recording		Perpendicular recording
	Conventional recording	Granular type longitudinal recording	
Thermal stability $K_u V/kT \geq 60$	○ Unstable at high density recording ○ Stable at low recording density	○ Unstable at high density recording ○ Stable at low recording density	○ Unstable at low recording density ○ Stable at high density recording
Magnetic layer thickness	Decreasing	Decreasing	Thinness not strongly required
Increase in K_u	Required	Required	Not strongly required
Reduction in noise	○ Cr segregation to the grain boundary ○ Reduction in grain size	○ Dispersion of magnetic particles such as SiO_2 into the nonmagnetic matrix	○ Cr segregation to the grain boundary ○ Reduction of reverse magnetic domains
Problems	○ Reconciliation between thermal stability and noise reduction	○ Thermal stability	○ Reduction in media noise
Solutions	○ Uniform distribution of grain sizes ○ Increase K_u and H_c	○ Uniform distribution of grain sizes ○ Increase K_u and H_c	○ Reduce interactions among magnetic grains ○ Increase the squareness ratio ○ Increase the magnetic field to form reverse magnetic domain nuclei

Notes: K_u : magnetic anisotropy energy
 k : Boltzmann constant
 V : activation volume
 T : absolute temperature

recording densities greater than 10 Gb/in^2 is a large, challenging subject. To obtain a high SNR while preventing characteristic deterioration due to thermal fluctuation as mentioned above, more precise process control as well as fine adjustment of the optimal material composition is required.

4. Future Recording Systems

In the previous chapter, examination focused on the longitudinal system. However, there is a common perception in the industry that the current disk configuration will limit enhancement of recording density in the near future. In the longitudinal recording system, the so-called granular structure has been proposed as a method of reducing noise to make the grain boundary more definite using oxides such as SiO_2 from Cr segregation in order to decouple the magnetic grains. Further, to increase areal recording density effectively, the importance of lowering the conventional aspect ratio (BPI/TPI), i.e. raising track density (TPI) rather than linear recording density (BPI), is recognized and is being implemented. Eventually, the problem of thermal fluctuation has to be solved. Factors that have an effect on the SNR in a high density recording area are given by Bertram et al⁽⁴⁾ as follows:

$$\text{SNR} \propto 1/[\text{Density}^{3/2} (W/B)^{1/2} D^3]$$

where

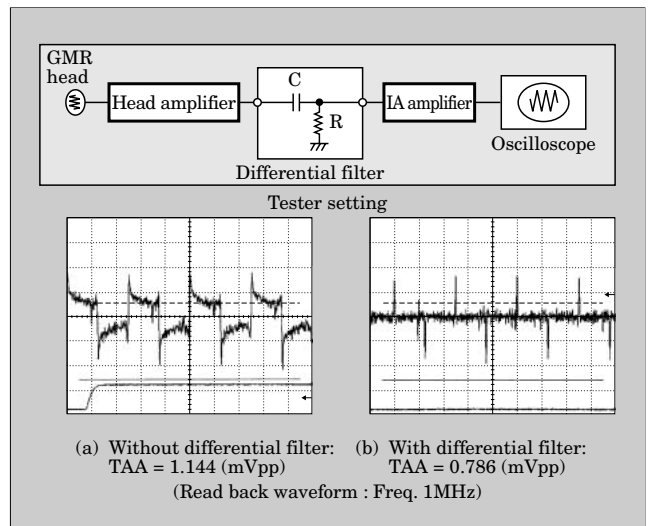
B : bit spacing

W : read track width

D : grain diameter

As discussed before, this formula supports reducing the micro-grain size and aspect ratio to raise the SNR. Because thermal fluctuation is directly related to grain volume $D^3 t$ (t : magnetic layer thickness) and a comparatively thicker magnetic layer is desirable for

Fig.12 Measuring system for perpendicular recording disk



the perpendicular recording system to stabilize magnetization, the perpendicular recording system is superior with respect to the limit of SNR restricted by thermal fluctuation because it can take advantage of film thickness.

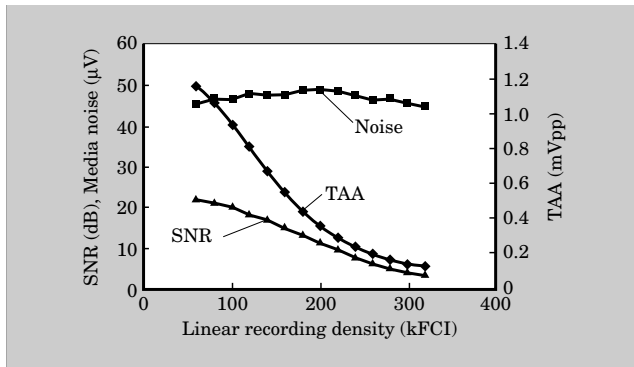
Simplified features of the above-mentioned technologies are listed in Table 2. Although Fuji Electric has just started development, examples of its experiments are presented below. The perpendicular coercivity obtained with a configuration of NiFe/TiCr/CoCr-TaPt on an Al/NiP substrate was 2,000 Oe. This was evaluated with a GMR head in the setup shown in Fig. 12. Noise reduction was observed to depend on the thickness of the intermediate layer TiCr, and typically, the frequency characteristics were as shown in Fig. 13. This proved that the noise characteristics lag those of the longitudinal recording system.

Perpendicular recording media has thus far faced a

Table 3 Promising new technologies for high density recording

New technology	Content	Features	Problems
Granular disk	Magnetic particles such as Co and Pt scattered in the nonmagnetic matrix	Low noise and high thermal stability	○ Increase in coercivity
Perpendicular recording	Magnetization in the direction of the C-axis of Co alloy crystals perpendicular to the film	High thermal stability	○ Reduction in noise ○ Thermal stability in low recording density ○ Stabilization of stray fields
Square bit	The ratio of width to length of bit domain is nearly 1 (currently 10 or more) with a small demagnetized field.	High thermal stability	○ Reduction in the track pitch ○ Increase in precision of track servo
Patterned disk	Magnetic domains of several tens of nm in size arranged in a lattice pattern, having little interaction. Can be used for longitudinal and perpendicular media.	Low noise and high thermal stability	○ Increase in writing and reading speed ○ Reduction in cost
Near field recording	Writes and reads with a collimated sub-micron size light beam based on near field optics theory. The solid immersion lens system under development by Tera Store, the same as a magneto-optical disk	High thermal stability	○ Dust control ○ Strict tolerance to optical configuration ○ Low efficiency in light utilization
Optically assisted Winchester	Writes bits with the help of light-induced heat, the same as a magneto-optical disk. Light transmitted to the HDD head through optical fiber is irradiated on the media by micro-mirror and lens to write and read with the magnetic domain. Being developed by Quita/Seagate.	High thermal stability	○ Noise caused by optical fibers ○ Dust control

Fig.13 Example frequency characteristics of perpendicular disk



great problem in media noise reduction. However, the direction of the solution has been clarified in a recent institute paper⁽⁵⁾. It is desired that through further process development in the future, performance superior than that of longitudinal recording in applications above 20 Gb/in² will be ensured.

As shown in Table 3, various new recording principles and concepts other than current longitudinal recording have been proposed, and their application to HDDs is expected in the future.

5. Conclusion

Details of the recent technological development of magnetic hard disks for HDDs have been examined, focusing on materials and processes. Recently, the

development of conventional longitudinal recording has reached a more difficult technological phase. This paper has proposed important subjects for expanding those boundaries. On the other hand, new recording systems are under development in various locations as replacements to longitudinal recording. It is expected that these new systems will expand the role of HDDs in the future memory market and further widen the main fields of application. Fuji Electric will also support development of the HDD industry through continuous contribution to the technical development of magnetic hard disks.

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Next Generation HDI Technologies for Magnetic Hard Disks

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Akiyasu Kumagai

1. Introduction

With enhanced recording density of magnetic hard disk drives (HDDs), requirements for reducing the “magnetic spacing”, the distance between the read-write head and the magnetic layer, are becoming more and more critical. In order to reduce magnetic spacing, the most effective means is to reduce flying height of the head. Following current trends, the flying height will decrease below 20nm and various demands are being placed on the hard disk (hereinafter referred to as the disk) (Fig. 1).

From this viewpoint, development in various fields is being actively promoted in order to define the phenomena involved in the head disk interface (HDI), that is, interactions between the head and disk. Problems with HDI technology have become increasingly important together with reliability improvement of a hard disk drive.

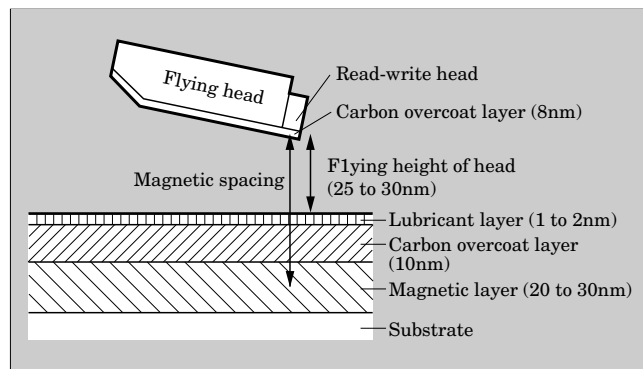
2. Problems of HDI Technology Related to the Disk

Firstly, to reduce substantially the magnetic spacing, it is strongly required that the disk has both a thinner carbon overcoat layer, covering the surface of the magnetic layer, and a thinner lubricant layer on top. Furthermore, the surface roughness (R_a) and the surface undulation (waviness) (W_a) of the disk must be made small so that the surface will not come in contact with the head, even if the head flying height is reduced. Precise substrate processing techniques to obtain a flat and smooth surface have become more critical.

Secondly, another problem is the contact of the head and disk that necessarily occurs during starts and stops. In the current CSS (contact start stop) system broadly used, the laser bump system is applied as means to make the contact area as small as possible. The development of design and processing techniques for a laser bumps of smaller diameter and high density has been accelerated, keeping pace with the reduction in magnetic spacing.

On the other hand, there is a demand for a disk

Fig.1 Cross section of flying head and hard disk



design able to withstand temporary contact of the head in a load-unload system, which will broadly be used in future.

In this paper, we suggest a fabrication method for the CVD (chemical vapor deposition) carbon overcoat layer, and discuss the analysis technology to microscopically observe this layer and the distribution of the lubricant used.

3. CVD Overcoat Layer

3.1 CVD and carbon layer characteristics

At present, the carbon overcoat layer is deposited by sputtering a graphite target. If the layer is not more than 10nm thick, it is likely to be defective with regard to durability or corrosion-resistance for protection. A layer formed by CVD has superior coverage characteristics and protective performance for under layers because the layer formation is accompanied by a surface chemical reaction. Because the layer material of carbon can be controlled with ion energy, compared with a sputtered layer, a finer and more rigid layer can be formed. Accordingly, fabrication of the carbon overcoat layer will employ the CVD method in the future.

Among CVD applications, filament type ion beam deposition (IBD), hollow cathode type ion beam deposition, ECR (electron cyclotron resonance)-CVD and RF (radio frequency)-CVD are currently suggested for applications to disk. The carbon overcoat layer and

Fig.2 Principle of ECR-CVD

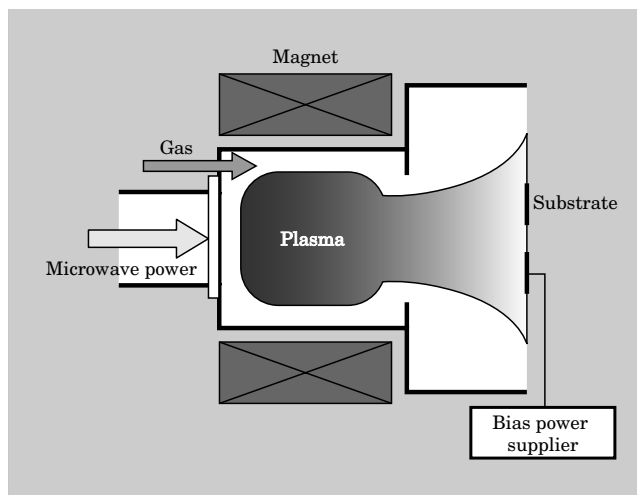
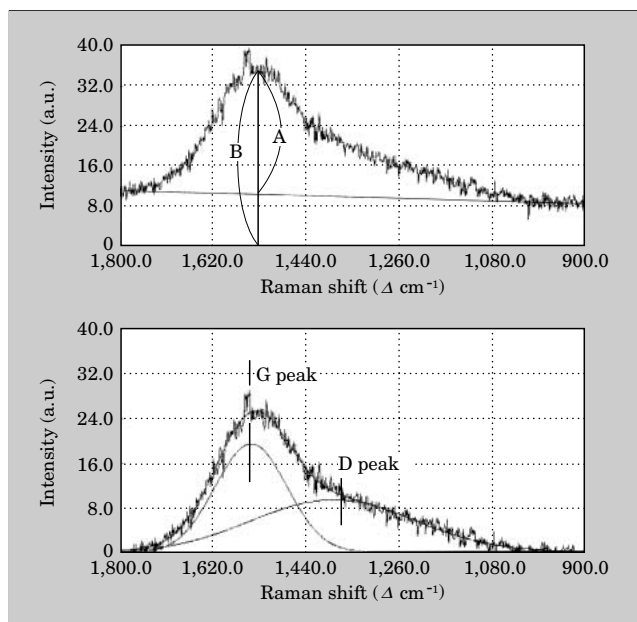


Fig.3 Result of Raman spectroscopy measurement



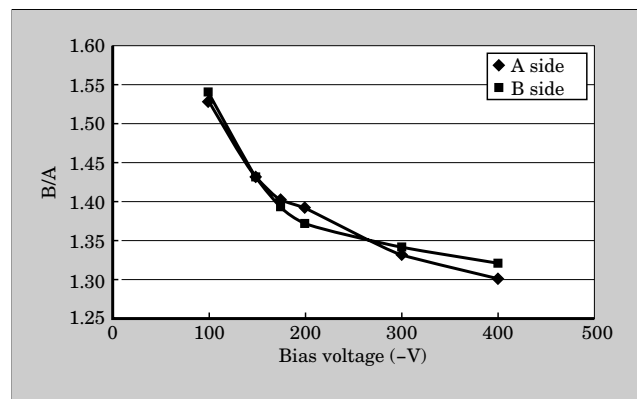
related equipment of ECR-CVD, IBD and RF-CVD have already been evaluated. Hollow cathode type ion beam deposition will be evaluated in the future. This paper describes layer deposited by ECR-CVD and IBD in particular.

3.2 Carbon overcoat layer by ECR-CVD

When microwaves of 2.45GHz are introduced into a magnetic field of 875 G, electron cyclotron resonance occurs, converting the microwave energy into kinetic energy with high efficiency, and high-density plasma is formed. ECR-CVD utilizes this principle as shown in Fig. 2. The same structure is arranged also on the opposite side of substrate and microwaves are introduced differing in phase angle by 90° so as to prevent interference.

Raman scattering spectroscopy is generally used to evaluate the carbon layer material. Figure 3 shows a

Fig.4 Process dependence of B/A characteristic (ECR-CVD)



Raman spectrum for the case where a carbon layer has been deposited with C_2H_4 of 0.03 SLM, microwave power of 70W, and a bias voltage of -200V . We observed the carbon layer, exciting it with an Ar laser light of 514nm. A peak known as the D-peak appears near $1,350\text{cm}^{-1}$, possibly inherent in the carbon on the border of a graphite crystallite. Another peak known as the G-peak appears near $1,570\text{cm}^{-1}$, inherent in the planar vibration of the graphite. Both peaks superimpose on the broadband fluorescent component having a peak at approximately $3,000\text{cm}^{-1}$. As shown in Fig. 3, we assume the total intensity of G-peak to be B. Subtracting the intensity of the fluorescent component from B, we assume this intensity to be A. The intensity ratio B/A correlates with the hydrogen concentration in the carbon layer. We know that if the ratio B/A increases, the hydrogen concentration in the carbon layer becomes higher.

Among the deposition parameters such as microwave power, flow rate of raw material gas (ethylene: C_2H_4), bias voltage applied on the substrate, etc., the parameter most influential on the layer material is the bias voltage applied on the substrate. Figure 4 shows the bias voltage dependence of the ratio B/A characteristic obtained by Raman scattering spectroscopy measurement. As the negative bias voltage increases, the ratio B/A becomes smaller, the hydrogen concentration in the layer decreases, and the layer goes finer. It is believed that the impact energy of ions becomes larger with increasing bias voltage, and as a result, weakly combined hydrogen atoms are separated and carbon atoms are rearranged in the layer.

3.3 Carbon layer by IBD

The principle of IBD equipment is shown in Fig. 5. Thermoelectrons are emitted from a heated filament and attracted to an anode electrode. They collide with raw material gas flowing from the anode side and ionize. The ionized gas is repelled by the anode voltage and attracted by the negative bias voltage applied on the substrate. The ionized gas arrives at the substrate to form the layer. Similar to ECR, IBD controls the carbon layer material with a voltage applied on the

Fig.5 Principle of IBD-CVD

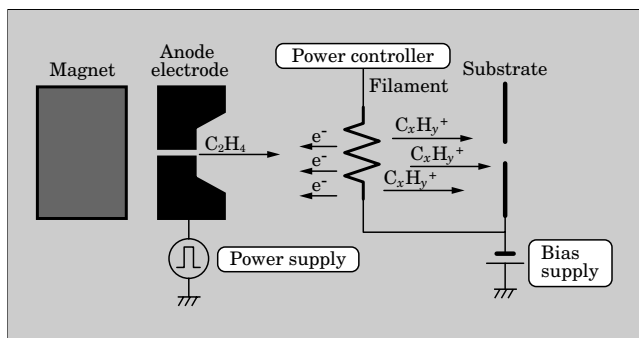
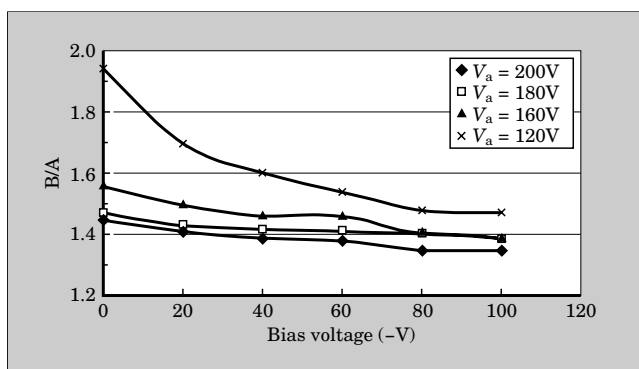


Fig.6 Process dependence of B/A characteristic



substrate.

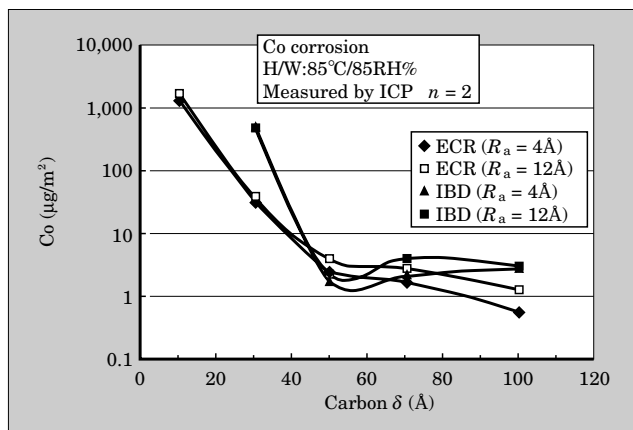
IBD in particular controls the layer material with the sum of the absolute values of the anode voltage and bias voltage. With the anode voltage (V_a) as a parameter, the dependency of the ratio B/A upon the bias voltage applied on the substrate is shown in Fig. 6. As in the case of ECR, the ratio B/A decreases as the bias voltage increases. However, as the anode voltage becomes higher, its effect on the bias voltage becomes smaller and the ratio B/A converges to approximately 1.4. If the anode voltage is higher, the initial energy of the ions becomes larger and therefore the effect of the bias voltage is barely noticeable.

At first, we thought it possible to develop a method to deposit a layer on an insulating substrate without applying a bias voltage and increasing the anode voltage. However, unless a bias voltage is applied, the ions repelled by the anode voltage spring toward the space around the substrate. In other words, the same material as deposited on the substrate is deposited on many places in the chamber. This deposited material has a relatively high internal stress, and if made thick, will exfoliate to create particles. We determined that this process could not be applied to mass production. By lowering the anode voltage and applying a bias voltage on the substrate, we utilized a fabrication process capable of suppressing particle scatter by attracting the ions to the substrate.

3.4 Characteristics of the CVD layer

We evaluated the durability of the carbon overcoat

Fig.7 Co separation versus carbon layer thickness



layer by a CSS test that repeats starts and stops. In addition to the CSS test, we investigated the performance of the carbon overcoat layer and the resistance of the layer surface against gas adsorption in order to secure high reliability.

For the coating performance, we applied a method to investigate the amount of cobalt (Co), the main material of the magnetic layer, that corrodes the disk in a high temperature and humidity environment. According to the result shown in Fig. 7, ECR and IBD do not differ much in coating performance for layer thicknesses of 5nm or more, but ECR seems superior for layer thicknesses of 5nm or less. Supposedly, IBD deposits the layer mainly by ions, but ECR forms the layer with a surface reaction of neutral radicals.

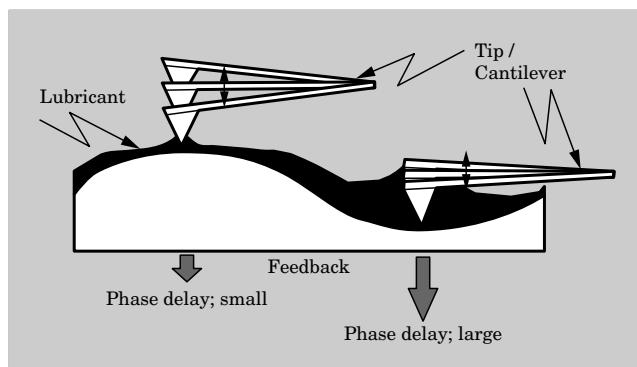
In addition, we measured and evaluated the resistance of the layer surface against gas contamination with time-of-flight secondary ion mass spectroscopy (TOF-SIMS) after leaving it for 24 hours in atmospheres of SO_2 gas of 0.1ppm concentration and NH_3 gas of 1ppm concentration. When acid gas SO_2 is adsorbed, the ions of sulfuric acid cause Co corrosion of the magnetic layer. When alkaline gas NH_3 is adsorbed, the ammonium ions cause the head to become dirty.

CVD carbon layers will become, without a doubt, the mainstream of protective overcoats in the future due to their superior performance in fineness and surface coating. However, many unresolved issues such as long term stability of the fabrication equipment, particle scattering and related suppressing methods need to find solutions as quickly as possible. We will aggressively promote further development aiming at the highest technical levels.

4. Observation Techniques of High Space Resolution for Liquid Lubricant

Analysis techniques that provide much chemical information, such as Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS) and time-of-flight secondary ion mass spectrom-

Fig.8 Principle of liquid lubricant thickness evaluation by SPM



etry (TOF-SIMS), are utilized to investigate extremely thin layers (several nm or less) of a liquid lubricant placed on the disk media. It is not easy, however, for the aforementioned techniques to evaluate the distribution of lubricant at high spatial resolutions that do not exceed the sub-micron level.

The tribology between the head and disk should naturally be discussed from a microscopic viewpoint. Therefore, we have developed a new method to evaluate liquid lubricant distribution utilizing a scanning probe microscope (SPM) that sensitively evaluates the sample surface at a high spatial resolution.

4.1 Principles

SPM is the general term for analysis techniques to investigate the surface state of a sample by detecting interactions between the surface and a sharpened tip.

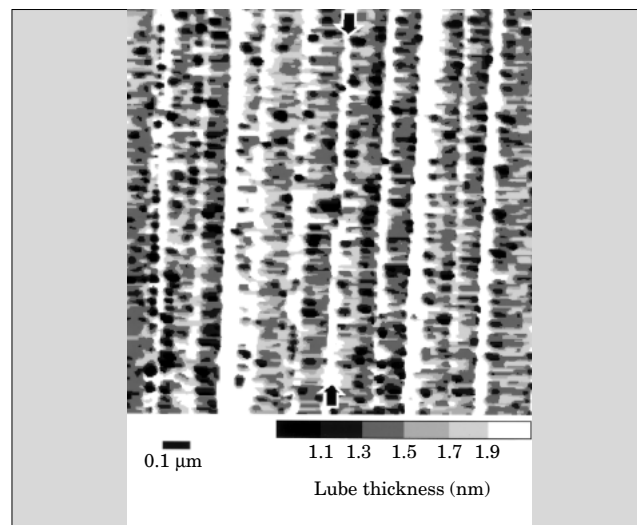
The probe used is fabricated by silicon micro-machining and is integrated into the edge of a cantilever. While vibrating the cantilever at a frequency near the resonance frequency, the sample of the disk media surface is brought close to the probe. At the position where it touches the probe, the vibration amplitude of the probe decreases due to the meniscus force of lubricant. Then, SPM works by feedback to move the sample away from the probe until the original vibration amplitude is restored. When the probe is peeled away from the lubricant, a phase delay occurs in the vibration of the cantilever due to viscosity of the lubricant. We can observe the thickness distribution of the lubricant layer by monitoring this phase delay (see Fig. 8).

The phase imaging mode itself is a well-known method to detect phase. We applied this technique to the lubricant of the disk and developed a new evaluation method that could quantitatively measure thickness distribution of the liquid lubricant layer at high space resolution.

4.2 Results

When we observed the lubricant layer of the disk with the above-mentioned method, we found that the phase delay did not continuously change with the local distribution of lubricant layer thickness. In the local

Fig.9 Distribution of liquid lubricant on disk



area of observation, where the lubricant layer thickness exceeds a certain threshold value, the probe becomes suddenly trapped in the lubricant layer and produces a large phase delay.

In other words, the phase image is displayed as a binary figure, clearly separating the thick and thin parts of the lubricant layer. We also found that we could control the threshold value with the vibration amplitude of the cantilever. By superimposing phase images of different vibration amplitudes, we can obtain a topological image of the liquid lubricant layer's thickness.

Based on the data thus provided, we can calculate the volume of the liquid lubricant in the area of observation. The calculated volume is only a relative quantity of lubricant, because thickness of the lubricant layer is given by the vibration amplitude of the cantilever as a quantity proportional to the layer thickness. However, the volume has a close correlation with the average quantity of lubricant evaluated by other techniques (FTIR, etc.) and we consider that this method can quantitatively evaluate the distribution of liquid lubricant.

By comparing the relative quantity of lubricant obtained by this method with the average quantity of lubricant measured by the other techniques, we can convert the vibration amplitude of the cantilever into the thickness of the lubricant layer.

Figure 9 shows a distribution of liquid lubricant on Al substrate disk evaluated by the above-mentioned method (overcoat layer; a-C:H:N). A brighter color indicates a thicker lubricant layer.

In this technique, the vibration amplitude of the cantilever is gradually increased until finally the probe becomes untrapped in the area of observation, and the shape of the disk itself can be seen by using atomic force microscope mode. In other words, the disk surface image can be compared with the lubricant distribution.

In Fig. 9, the area between two arrows is a textured groove. We understand that, in this disk, lubricant is thick at the bottom of the groove and thin at the slope of the groove. Definition of correct spatial resolution may be difficult, but lubricant structures on the order of approximately 10nm can be observed. The spatial resolution that can be observed is enhanced by approximately two digits compared with conventional techniques.

We will be able to use this technique as an analysis tool for microscopic phenomena involved in the head and disk interface in future.

5. Conclusions

As examples of HDI technology, we described the latest fabrication methods of the CVD carbon overcoat layer and observation techniques of the CVD carbon overcoat layer and related lubricant distribution. HDI technology involves a wide range of technical fields. To enhance the level of these important techniques in securing reliable HDDs, we will continue to tackle further development in these fields.



Magnetic Hard Disks for Audio-Visual Applications

Youichi Tei
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Hiroyuki Uwazumi

1. Introduction

Since about three years ago, it has been expected (mainly in the United States) that a new home-oriented service, in which communications, computers and consumers converge, will grow to become a gigantic market in the 21st century along with the development of digital broadcasting (see Fig. 1). The “convergence” of this service will create a trend of global cooperation, absorption and mergers to overcome business or national barriers and existing industrial structures will evolve to reintegrate their overall associated infrastructures (see Fig. 2).

More specifically, this trend will, for example, develop at homes in the following way.

A set top box (STB) capable of temporarily storing audio-visual (AV) information such as a digital broadcast will be set up at input and output points that interface between users and society. The STB will be connected with home AV equipment such as digital TVs through an IEEE 1394 high-speed communication system. Needless to say, handheld AV equipment can also be connected to the STB. Home AV equipment will be controllable by a home server equipped with a man-machine interface that is superior than that of today’s personal computers (PCs). In the 21st century, consumers will be able to freely edit and distribute musical or pictorial data or personal AV information.

The “convergence” will tend to popularize the above home information service in the short-term and data broadcasting service in the mid-term. In the long-term, it will lead to a future system that guarantees consumer comfort with regard to electronic commerce (EC) and security control.

More accurately, the “convergence” is expected to spread throughout homes and society in the following three stages. In the first stage, the diffusion of data broadcasting after the year 2000 will become a turning point, and individual AV equipment and associated networks will come into wide use responding to increasing information volume. In the second stage, utilizing the opportunity provided by the world cup soccer games, home servers with higher functions will spread into homes as broadcasting stations. In the

Fig.1 Flow of “convergence” advancing in the 21st century

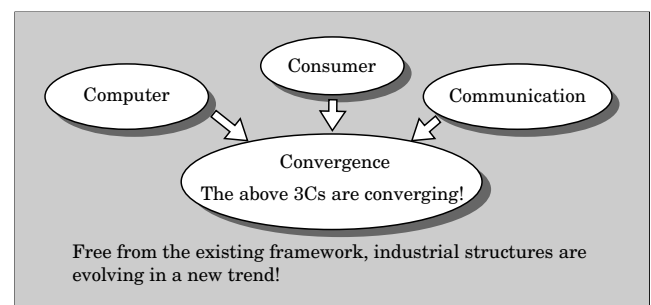
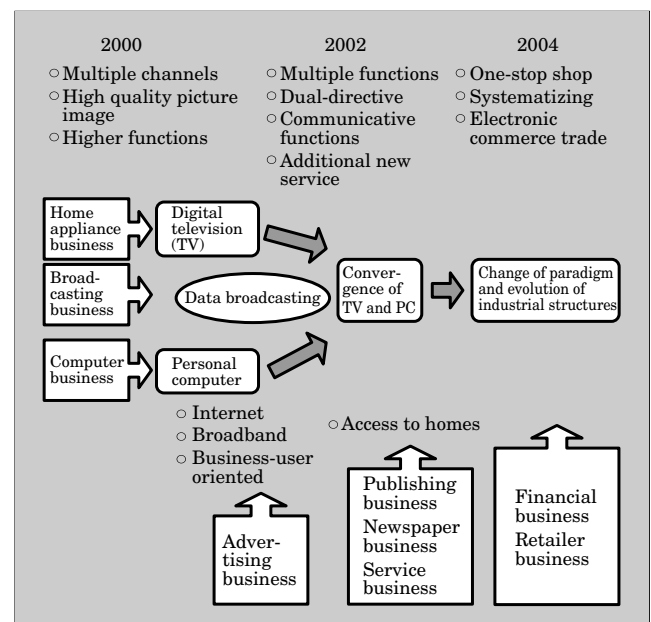


Fig.2 Evolution of industrial structures with “convergence”



third stage, from the year 2004 or 2005 and thereafter, new on-demand service will burgeon for EC and security control.

The key technology for achieving “convergence” is to develop an “AV information cash memory” capable of handling quality AV information with a fast, versatile and cost-effective means. As shown in Table 1, among the candidates for external memory devices, those having all of the above features are unexpectedly few (see Table 1). The hard disk drive (HDD), having

Table 1 Performance comparison of main external memories

Category Item	Flash memory		HDD	Magnetooptical disk drive
Product	SanDisk Corp. Compact Flash	Toshiba Smart Media	Quantum Corp. Eagle	Sony MD data
Memory size	48 MB	16 MB	25 GB	650 MB
Data transfer velocity	24 Mbit/s	8 Mbit/s	288 Mbit/s	4.6 Mbit/s
Access time	10 μ s	7 μ s	12ms	500ms

Example from products on sale

been an indispensable device for PCs, is once again in the spotlight.

These trends will finally lead to use of various AV-HDDs (custom HDDs for the AV equipment) having different specifications and shapes in the STB, digital TV, home server and handheld AV devices. The era when consumers can readily walk around with handheld AV information will arrive very soon.

In consideration of the future aspects of 3-D televisions and handheld devices for personal use, AV-HDDs as well as their core elements, that is, magnetic hard disk (hereinafter referred to as the disk) for AV use, will be most promising.

This paper describes the development of the latest AV magnetic hard disk that Fuji Electric is focusing on.

2. Plastic Disks

An HDD uses magnetic heads flying above its disk surfaces for fast read-out and write-in. Therefore, aluminum or glass substrate has mainly been utilized to create a super smooth surface. On the other hand, optronical devices such as CDs, MDs, PDs and DVDs use injection-molded plastics, because their optical heads do not require high surface precision for reading and writing, but only need groove formation. Therefore, plastics are most advantageous in cost since

plastic disks can be fabricated by injection molding. Recently, injection-molding techniques have advanced to fabricate plastic substrates having surface precision that is suitable for the flying head of HDDs.

Moreover, digitalization in the AV field has been advancing. It is expected that the start of digital broadcasting will accelerate expansion of the digital AV market, and HDDs that can quickly handle large volumes of data will play an essential role. This market necessarily demands large-capacity and price-effective HDDs.

Plastic disks completely match these needs. Plastic disks not only have inexpensive material costs but also require few fabricating processes, and therefore offer lower cost, because substrates can be formed simply by injection molding. Their light weight lowers the energy consumption and reduces acoustic noise caused by rotation. These features are optimal for AV recording devices. Elasticity of the plastic disk absorbs mechanical shocks from the head, and therefore makes it possible to design damage-resistant disk for the ramp load mechanism.

Different from the case of ordinary processing of computers, defective bits of AV data are not as serious a problem as long as people cannot sense the defect in pictorial images or musical sounds. However, it causes serious problems when the pictorial images are blacked out or the music does not sound smooth.

HDDs are sometimes handled by people not familiar with mechanics, or are exposed to direct sunlight or mechanical impacts. The data processing of computers and AVs is different as summarized in Table 2. In view of this table, HDDs for AV applications demand another kind of reliability, not as computers but as home appliances.

Let us imagine, for instance, the situation when digital broadcasting gets started in the future.

You have a handheld set with an HDD and an image display device. Before leaving home, you can record the news of the day from an STB in an instant, and watch it on the way to work. During the recess after lunch, you can also watch the drama that you

Table 2 Comparison of the hard disk drives for PC and AV applications

Category Item	PC applications	AV applications			
	PC	Home server	Set top box	Handheld drive	Handheld media
Use	Data processing	Video editor Home TV Internet data	Image data Digital TV	Video camera Cellular phone Navigator	Video camera Portable video set Music distribution
Error rate	10^{-10}	10^{-10}	10^{-3} to 10^{-4}	10^{-3} to 10^{-4}	10^{-3} to 10^{-4}
Environment	33°C, 80%RH	80°C, 80%RH	80°C, 80%RH	80°C, 80%RH	80°C, 80%RH
Data preservation term	2 to 3 years	3 to 5 years	1 to 7 days	1 to 2 weeks	1 to 2 weeks
Frequency of operations	A few times per day	A few times per day	Continuous operation	A few times per day	A few times per day
Access speed	High speed rotation Low speed seek	Medium speed rotation High speed seek	Low speed rotation High speed seek	Low speed rotation Low speed seek	Low speed rotation Low speed seek
Media	Al, glass	Al, glass	Glass, plastics	Glass	Plastics

Table 3 Comparison of material performance

Item \ Category	Resin A	Resin B	Poly-carbonate
Longitudinal expansion coefficient (1/°C)	$< 5 \times 10^{-5}$	6×10^{-5}	8×10^{-5}
Temperature of thermal decomposition (°C)	420	400	360
Water contents (ppm)	5	5	150

missed on the day before. Or, you can record distributed music and listen to it at any time you want.

The HDD you use should be compact, lightweight, shock-resistant, low in acoustic noise, and energy consumption. Above all, it should be low in price. Only the plastic disk can achieve these features.

To form the plastic disk, we have to solve three major problems:

- Technology of plastic materials
 - Precision molding technology for plastic substrates
 - Low temperature deposition of the magnetic layer on the disk surface for high recording density use
- Since plastics are weak at high temperature, low temperature deposition is required.

2.1 Technology of plastic materials

Application of conventional plastic substrates for MDs, DVDs, etc. to magnetic disk substrates that usually demand precise surface characteristics result in difficulties in reading and writing due to the insufficient head flying-height caused by undulation (waviness) of the substrate surface. Even if the surface characteristics are sufficient, ordinary plastic substrates such as those made of polycarbonate resin are mechanically weak, thermally transformable and humidity-absorbent, and therefore cause deformation of the substrates in hot or humid environmental conditions.

The performance required of plastic substrate materials for magnetic disks are as follows:

- (1) Extremely small residual stress on the molded substrate and preservation of stable shape under hot and humid environmental conditions
- (2) Preservation of low roughness, no defects and precision of the substrate surface
- (3) Cleanliness with controlled outgas and contaminants

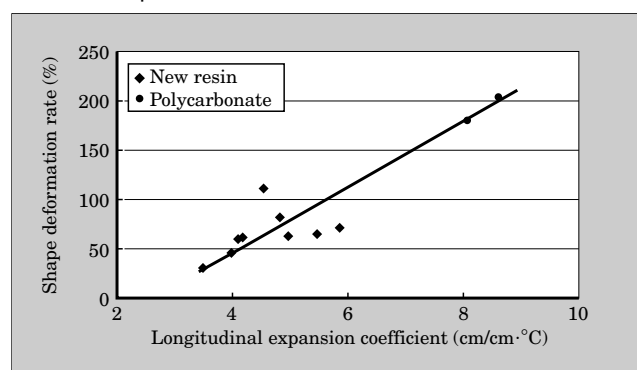
Conventional resin materials such as polycarbonates or polyacrilates cannot attain the above level of performance. We are currently promoting development of new resins and their applications.

Required performance characteristics are higher rigidity, three-dimensionally combined molecular structure, high mechanical strength, creep-resistance and small thermal expansion.

Table 3 shows a comparison of the main characteristics of the resin materials.

The new resin is superior to polycarbonate in

Fig.3 Comparison of shape deformation rate versus longitudinal expansion coefficient



mechanical strength, heat-resistance, creep characteristic and thermal expansion. From the viewpoint of molecular structures having high rigidity, resin is copolymerized with more three-dimensionally combined and heat-resistant monomer units.

The above-mentioned shape stability is the most important requirement. Shape deformation is considered to take place by the following mechanism.

Upon filling resin into the molding die, the hot resin in the cavity center flows in a radial direction with a small gradient of temperature and velocity, and orientates the substrate bulk in this direction. On the other hand, the hot resin cools and solidifies at the inside surface of the die. The gradient temperature and velocity between the boundary of the above two resin fluids generates shearing stress, and therefore the entangled molecules solidify without orientation. The larger the difference in the molecule orientations at the surface and bulk of the substrate, the stronger the residual stress will be near the substrate surface. A molded substrate with large residual stress will undergo a large transformation of shape while left under hot and humid environmental conditions. Moreover, accelerated by the humidity-absorbent characteristic inherent in the resin, a substrate with larger residual stress deforms so much that it cannot preserve its original shape.

The degree of deformation and residual stress of the substrate depends upon the creep and thermal expansion characteristics inherent in the resin structures.

Figure 3 shows the relation of the longitudinal expansion coefficient and the shape deformation ratio of substrates under various molding conditions of resin A, B and polycarbonates. In these experiments, the substrates were left for 500 hours under 60°C and 80% relative humidity.

The longitudinal expansion coefficients decrease in order of polycarbonate, resin B and then resin A. After these materials are left under hot and humid environmental conditions, their shape deformation ratios are also smaller in this order. However, the longitudinal expansion coefficient and the shape deformation ratio

of resin A varies in a wide range depending upon the molding conditions.

The following investigations are necessary to obtain plastic substrates with smaller shape deformation ratios.

- Investigation of excellent precision molding technology attaining smaller residual stresses and longitudinal expansion coefficient ($< 4 \times 10^{-5}$)
- Application of new heat-resistant materials having a more rigid three-dimensional structure with better creep characteristics and mechanical strength

On the other hand, in order to attain “precise surface characteristics”, it is necessary to lower the viscosity of the molten resin and use clean resin. We must inject and mold resin in a better fluid state. As discussed below in section 2.2, we must remove as many contaminants as possible such as outgas components and particles causing surface defects.

- (1) Upgrade of resin fluidity
 - (a) Control of molecular weight distribution to lower the viscosity of melting resin
 - (b) Application of heat-resistant resin to mold at high temperature and speed
- (2) Prevention of surface defects
 - (a) Preservation of a clean environment during fabrication and conveyance process to reduce particle contamination

The HDDs for PC applications have become more complex due to the explosive increase in recording density. On the other hand, HDDs for AV applications are required to be less expensive than before, while preserving their high performance. Plastic disks are most promising to solve the above contradictory problem.

Regardless of the common conception of conventional plastic substrates, it is most important to enhance the technology of plastic materials as well as that of molding and dies. It is necessary not only to positively improve performance and quality of the current plastic materials but also to actively promote development of new materials of higher performance.

2.2 Precision molding technology

Additionally, magnetic disk substrates for AV applications have the following quality requirements:

- (1) Precise surface characteristics

Surface roughness and surface undulation (waviness)
- (2) Good mechanical characteristics

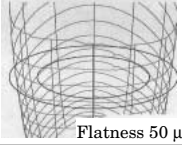
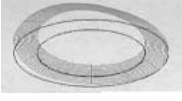
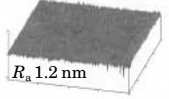
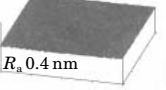
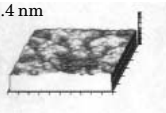
Flatness, total index runout and surface acceleration
- (3) Few surface defects

Abnormal bumps, pits, scratches and particles
- (4) Heat-resistance stability

Material physical property and after treatment

Plastic substrates for conventional optical disks are controlled for the performance of pattern copying

Fig.4 Comparison of surface characteristics

Item	Magnetooptical disk (PC)	Hard disk (Al)
Shape	 Flatness 50 μm	 Flatness 3 μm
Surface flatness (AFM)	 R_a 1.2 nm	 R_a 0.4 nm
Undulation (ZYGO)	 W_a 3.2 nm	 W_a 0.4 nm

and light refraction in addition to the above items (2), (3) and (4). Item (1), “precise surface characteristics”, of the optical disks is controlled above a certain level but not more than necessary. Therefore, actual surface characteristics of optical disks are quite different from those of current magnetic disks (see Fig. 4).

The important factors that affect molding of magnet disk substrates are as follows:

- Pellet materials
- Accuracy of dies
- Molding conditions
- Atmospheric conditions
- Fabrication facilities

In this paper, we discuss the molding conditions and the results of their study.

Important factors related to precision injection molding and the mold shape are assumed as follows:

- Die temperature
- Resin temperature (nozzle temperature)
- Injection speed
- Molding pressure
- Cooling time (molding cycle)

We assessed the effects of these five factors on the shape figures by varying them parametrically. In addition, we have found that annealing after molding releases internal stress caused by the molding process and annealing is also another influential factor in the fabrication of precision plastic substrates. At the same time, we have also confirmed the actual effects of annealing (see Fig. 5).

The resin property is closely related to the appropriate die temperature, the die temperature should be higher for resins with higher glass transition temperatures (T_g). Regarding die temperature settings, the temperature of the movable die should be different from that of the fixed die, as this is also an important factor affecting surface characteristics.

The larger the temperature difference, the better the surface flatness before annealing. After annealing,

Fig.5 Flatness of the substrate versus die temperature difference

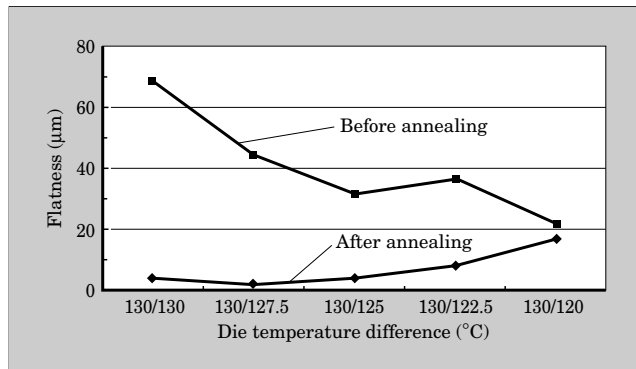
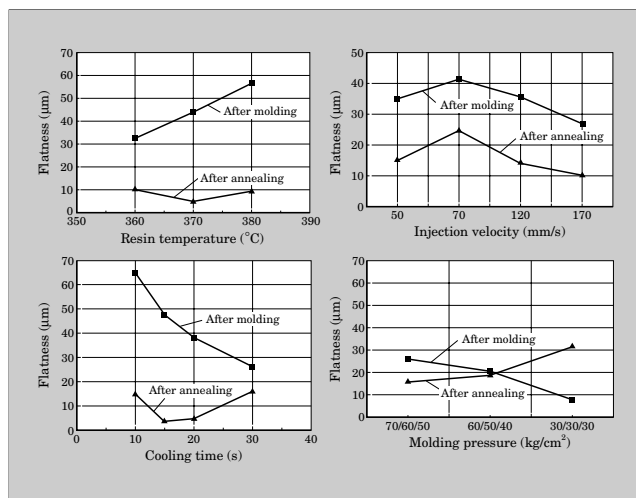


Fig.6 Flatness versus important factors for molding



however, the surface flatness worsens. The stored stresses after molding differ in the outermost surface layer and the internal bulk. These stresses are released by annealing. However, residual stress may strain the substrate at a side where final residual stresses remain. Analysis demonstrates that the longitudinal expansion coefficients are not equal at both sides of the substrate. This phenomenon has been verified as the relation between shape deformation by annealing and stress.

As shown in Fig.6, each other important factor affecting the shape has its own optimum range. It is necessary to ultimately set up the molding conditions in view of the mutual influence of these factors.

Figure 7 shows the shape and surface characteristics of plastic substrates fabricated under optimum molding conditions currently available.

A microscopic assessment demonstrates that it is possible to fabricate substrates that exceed the Al disks in precision surface characteristics.

When we observe the overall surface of the substrate, we will find some partial molding defects such as surface roughness, silver streaks, pits, etc.

However, the problems of these defects are currently unresolved and solutions must be found in the

Fig.7 Substrate shape and related surface characteristics under optimal molding conditions

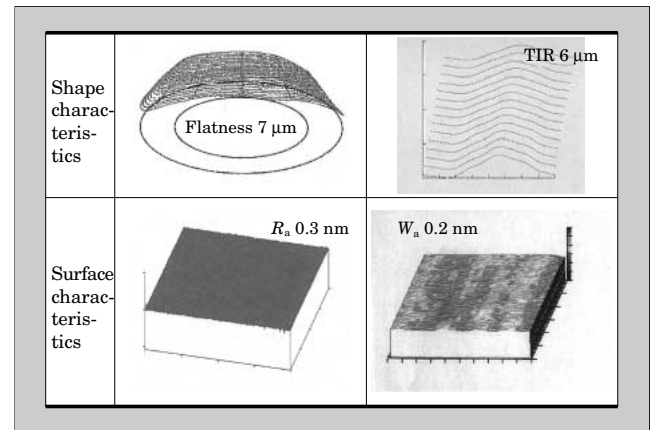
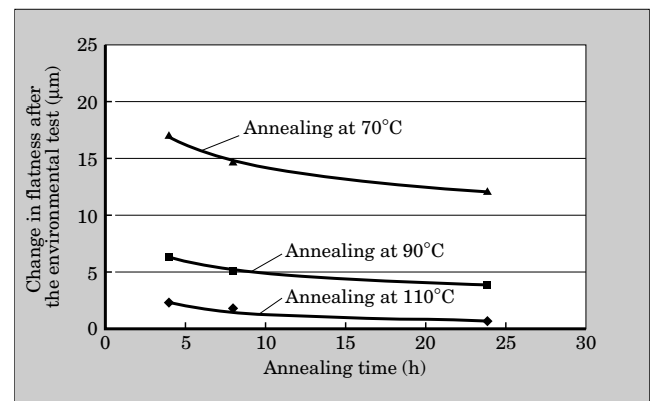


Fig.8 Change in flatness versus annealing time



future.

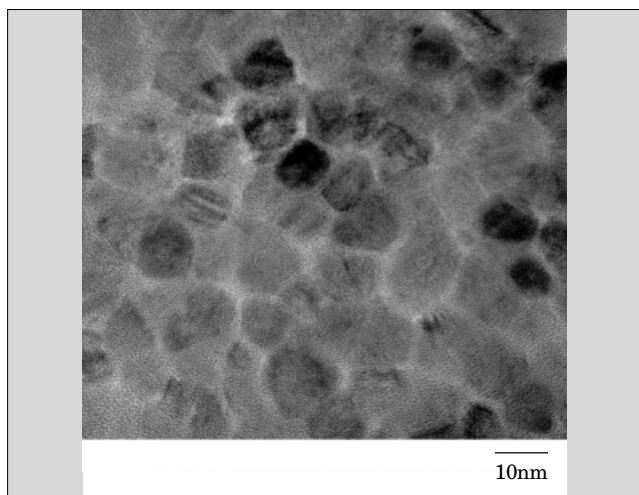
About heat-resistance stability, it is necessary to control fluidity inherent in the resin after molding by measures that suppress changes of the physical property and shape of the substrates due to heat. The essential points are how to make rigid molecular structures and uniformly distributed internal stresses. It is necessary, for the former, to develop new resin materials as discussed in section 2.1, and for the latter, to investigate post-molding treatments.

After investigating the post-treatments, we have found that “heat processing; annealing” can suppress shape deformation to some extent.

More accurately, the two factors of “temperature and time” are capable of controlling both shape quality and heat-resistance stability of the substrate. Figure 5 refers to the surface characteristics of the substrate versus thermal conditions of the die. The result of the environmental test (60°C-80%RH-500h) for heat-resistance stability is shown in Fig. 8. If optimal annealing conditions to release internal stresses are found, it is possible to suppress deformation of the substrate shape after the environmental test and to offer more stabilized substrates fabricated by plastic molding.

In order to produce precision moldings of stable

Fig.9 TEM image of granular magnetic layer



quality in a quick and inexpensive way, it is essential to systematize overall processes involving product design, die work, injection molding, release of stress and verification as well as to shorten these processing times. Most molding techniques have been established by trial and error. Accumulation of the data thus obtained and its effective use as a database will lead to enhancement of the precision molding techniques.

2.3 Low temperature deposition technology for magnetic layers

Conventional magnetic hard disks are generally produced at high temperature in the following manner.

After heating the substrate up to approximately 300°C, a Cr-alloy is sputtered onto a substrate as an under layer, and then a CoCrPtTa-alloy is sputtered onto the top surface as a magnetic layer. The high substrate temperature accelerates the Cr in the magnetic layer to segregate towards the grain boundary of the Co-alloy grains, and therefore to reduce the magnetic interactions between the Co-alloy grains. This process helps create a disk of high magnetic coercive force H_c and low noise. These features are desirable for high recording density.

On the other hand, plastic substrates are heat-resistant only up to approximately 100°C. Therefore, it was necessary to develop a significantly new deposition technology for the magnetic layer, which the magnetic layer was deposited at low temperature so that Co-alloy grains could be isolated from each other and their magnetic interactions could be reduced. Because oxide additives such as SiO_2 are almost insoluble in a Co-alloy solid at equilibrium, they were added to help isolate Co-alloy grains in the magnetic layer. This layer is called the granular magnetic layer. Instead of the conventional DC magnetron sputtering method, we introduced the RF sputtering method capable of depositing insulation additives such as oxides.

Fig.10 TEM image of granular magnetic layer with modified outermost surface

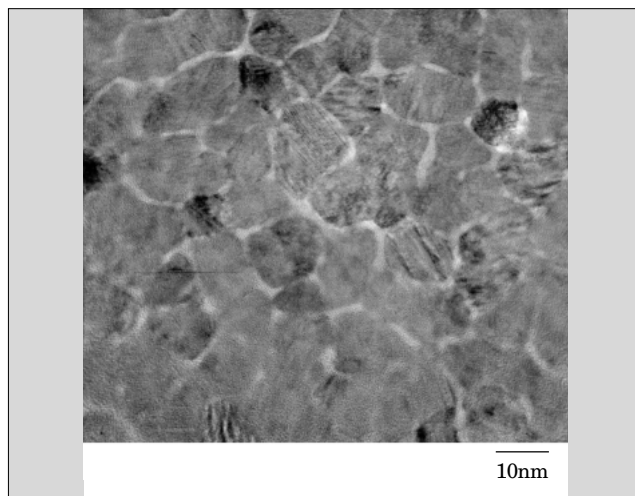


Figure 9 demonstrates a TEM planar image of the granular magnetic layer. As the under layer, the Cr-alloy was deposited onto the plastic substrate, and then RF deposition was performed using the composite target of a CoCrPt-alloy and an additive of 5 mol% SiO_2 . We can observe that the grain boundary phase (whitish area) surrounding the magnetic alloy grain forms the so-called granular structure. The magnetic properties and noise of the disk are superior to those of the low temperature-deposited CoCrPt disk without oxide additives. We consider that boundary segregation by oxide additives has the favorable effect of reducing the magnetic interactions between the magnetic alloy grains and the granular disk, resulting in excellent characteristics even for a low temperature-deposited magnetic layer.

However, the characteristics of the granular disk are inferior to those of the conventional high temperature-deposited disk. Therefore, it is important to enhance grain segregation with oxide additives and to lower transition noises. It is believed that the microstructure of the grains and their related boundary segregation and grain size distributions depend upon the method with which the deposited layer is grown initially. Therefore, we changed the conditions for depositing the outermost surface of the Cr-alloy under layer, to control the physical conditions bordering the magnetic layer and finally control the initial growth of this layer. As the result, we have enhanced the granular structure and have found that its magnetic property and electromagnetic conversion characteristics can greatly be improved.

Figure 10 shows a TEM image of the magnetic layer of the disk, which is sequentially composed of a plastic substrate, a Cr-alloy under layer, a modified outermost surface of the under layer and a CoCrPt- SiO_2 granular magnetic layer. Only the depositing conditions of the outermost surface of the under layer differ from those of Fig. 9. Comparing Fig. 9 and

Table 4 Comparison of main figures with or without modified outermost surface

Modified layer	H_{cr} (Oe)	$M_r t$ (memu/cm ²)	O/W (dB)	SNR (dB)
Without modified outermost layer	2,200	0.77	36.7	26.6
With modified outermost layer	2,500	0.73	38.3	32.5

Fig. 10, we can clearly identify the grain boundary areas in Fig. 10, and understand that grain boundary segregation is greatly enhanced with a SiO₂ additive.

Table 4 compares the above two disks with regard to magnetic coercive force H_c , $M_r t$ (product of remanence magnetization and layer thickness), O/W value and SNR. An AMR head with recording density of 200kFCI is used to measure the O/W value and SNR.

We have changed the depositing conditions of the outermost surface of the under layer to control the physical conditions that border the magnetic layer. Under the low temperature-deposited conditions, we finally have achieved better performance of the new disk comparable with that of the conventional one.

The conventional CoCrTaPt high temperature-deposited magnetic layer has encountered the other difficulty of "thermal decay of magnetism" which causes loss of the recording bits under normal ambient temperature. In order to suppress noise, the high temperature-deposited magnetic layer increases its Cr

contents for the grain boundary segregation. At the same time, however, the level of saturating magnetic moment is reduced and thermal energy becomes greater than magnetic energy. On the other hand, the oxide additive promotes the grain boundary segregation for the granular magnetic layer, without reducing the level of saturating magnetic moment. Therefore, an excellent magnetic hard disk of high recording density, high thermal stability and low noise can be fabricated. Low temperature-deposited magnetic layer technology can also be applied to Al or glass substrates without difficulties.

We are currently promoting development of higher performance disk media in this way.

3. Conclusion

In the 21st century, the information revolution that personal computers and the Internet have brought about will also extend into homes, and everyone will have the ability to handle images, music and information as desired. In this situation, one of the indispensable devices will be a capable but inexpensive hard disk drive. We have been promoting the development of magnetic hard disk for this drive.

In the future, society will demand a variety of HDDs in applications not only for computers but also for audio-visual devices, and will encourage further expansion of these devices. To respond to the impending demand and supply of versatile magnetic hard disk, we will successively improve hard disk so that it is optimized for each application.



Automation of Magnetic Hard Disk Production Lines

Hiroshi Hashida
Eiichi Fujisawa
Motonori Nakazawa

1. Introduction

In industry, the main aim of production line automation is to reduce the workforce. However in the magnetic hard disk (hereinafter referred to as the disk) industry, the aim is to improve quality and to enhance stability of the disk through a cleaner working environment as well as to reduce the workforce.

The surface area of the disk per bit ($0.8 \times 0.07 \mu\text{m}$ at present) and the size of particles and defects under consideration are decreasing year by year as the storage capacity of disks increases. To cope with this, automation of the disk production line can prevent damage to the disk caused by manual transfer and can prevent dust from adhering to the disk in the case of a clean transfer.

Ever-increasing demand for higher-quality disk, however, cannot be satisfied only by automation of the disk production line, resulting in the necessity of an automated transfer system integrated with clean room design.

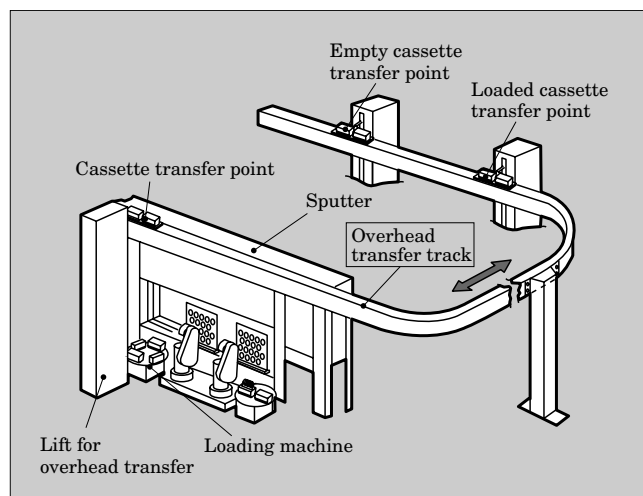
Since an automated transfer system equipped with a cleaning function for a disk production line is highly specialized, there are very few dedicated systems compared with other industries. Thus, transfer systems for this purpose have mainly been developed jointly with transfer system manufacturers based on their existing systems.

This paper describes examples of the introduction of an automated transfer system into an existing production line, replacing a previous manual transfer system, and introduction into a newly built production line. Also described is an example of an automated transfer system as a total system for integrating clean room design to meet the requirements of a cleaner work environment.

2. Introduction of an Automated Transfer System into an Existing Production Line

Figure 1 shows a schematic diagram of an automated transfer system introduced between processes where disk cassettes have traditionally been manually transferred. This automated transfer system aims to

Fig.1 Schematic diagram of an automated transfer system



improve cleanliness of the disk.

2.1 Space savings in the clean room

Automated transfer systems within a single process or between several processes require a rather large amount of space in a clean room for installation. Especially when installed on the floor, such a system can obstruct passage and reduce workspace, resulting in increased cost of the clean room.

As for the introduction of an automated transfer system into an existing production line, it is difficult to secure space for its installation. Thus, we designed an overhead-transfer system that saves space by utilizing the space near the clean room ceiling.

Consequently, the space under the transfer system could be used for the existing passage and workspace. This has enabled the introduction of a clean transfer system without requiring expansion of the clean room.

2.2 Purification due to the overhead-transfer system

Since the transfer system was installed close to the ceiling, the clean area directly underneath the fan filter unit has become a transfer route for disk cassettes. This separates the disk from the workers, a source of particles.

Automation can also reduce the quantity of goods-in-process between operations and the time during which disk is left exposed.

The above measures were implemented to realize clean media transfer that prevents particles from adhering to the disk.

2.3 Considerations regarding the automation of an existing line

In the above example of the automation of an existing line, the transfer system could not be suspended from the ceiling of the clean room due to insufficient strength, but was instead supported by standalone posts and by using existing facilities. However, the locations of supporting posts and the transfer route were restricted to secure space for the existing production line.

In this manner, installation of the automated transfer system in the clean room was subjected to various constraints due to the construction of the clean room and the facilities layout.

Thus, it has become important to design an integrated production line and clean room that incorporates the concept of an automated transfer system in the early stages of the clean room design.

Based on this overhead transfer system, we have developed subsequent automated transfer systems.

3. Introduction of an Automated Transfer System into a New Production Line

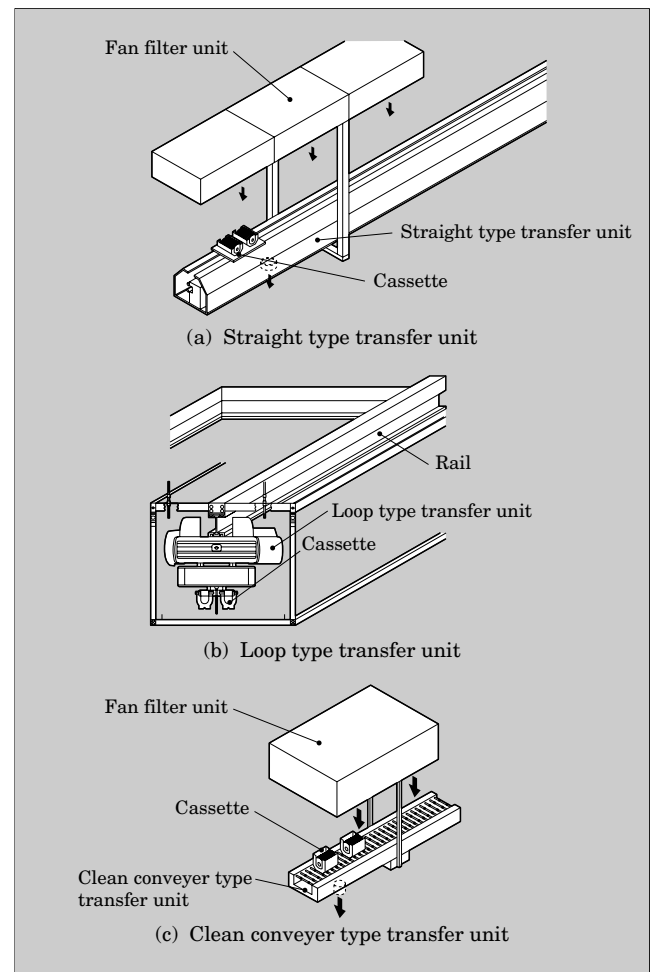
3.1 Selection of a transfer system in accordance with its uses

Figure 2 shows a schematic diagram of an overhead automated transfer system introduced between processes of a new production line. The system, jointly developed in collaboration with a transfer system manufacturer, is based on the overhead disk cassette transfer system that has been introduced into existing production lines.

- (1) Straight type transfer system (linear transfer system)
Applicable to a high-class clean area where transfer distance is short, buffers between processes are not required, and high transfer speed is required
- (2) Loop type transfer system (track feed system)
Applicable to a middle- or low-class clean area where multiple input and output devices are installed to transfer multiple transfer cassettes
- (3) Clean conveyer type transfer system
Applicable to a high- or middle-class clean area where a buffer function for disk cassettes is required between processes

An automated transfer system that complies with high quality requirements was realized by choosing from among the above-mentioned systems according to the use and operating environment of the transfer system.

Fig.2 Schematic diagram of an overhead automated transfer system introduced in a new production line



3.2 Automated production line integrated with clean room design

In the introduction of a transfer system, the design and installation of the transfer system along with the design of the clean room take into consideration, from the outset, the required transfer area, attachment of hanging bolts to the ceiling, ceiling strength, arrangement within the clean room and air flow in the clean room due to cover mounting.

Consequently, an automated transfer system can be introduced smoothly without impairing the function of a clean room and resulting in reduced installation cost.

After the installation, minor changes such as alterations of floor openings and the addition of covers were performed to improve the cleanliness in the room based on the results of investigation and analysis of particles and airflow in the clean room.

If even higher quality is required, it is necessary to design a clean room and automated transfer systems between processes as a total system, including the placement of peripheral equipment of the transfer system and clean room construction.

Fig.3 Schematic diagram of a total system

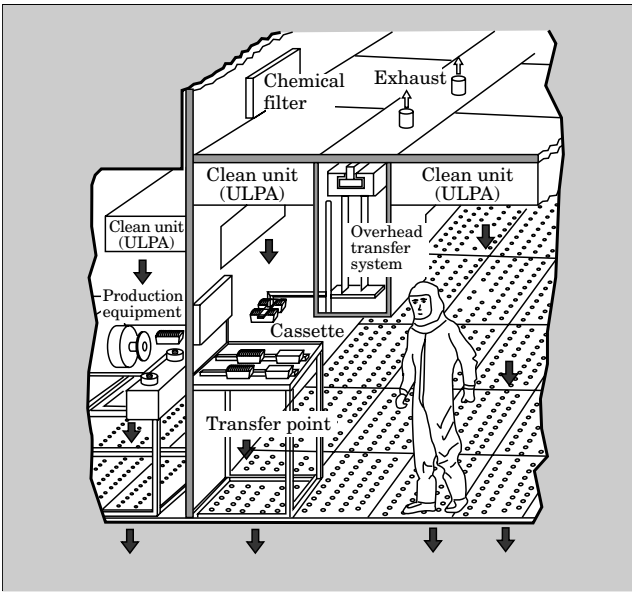
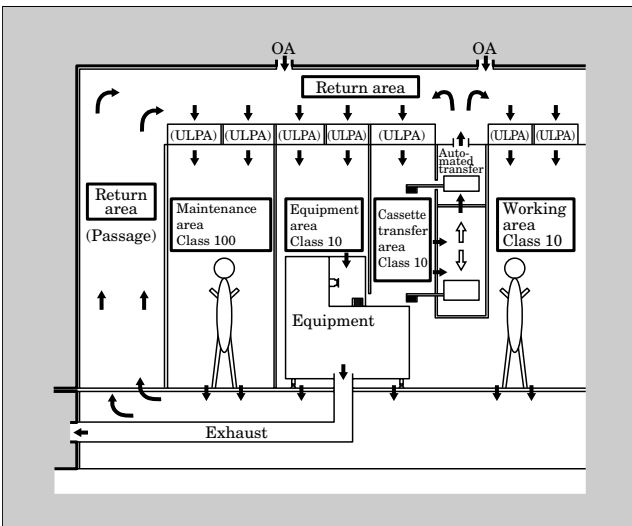


Fig.4 Schematic diagram of area separation



4. Design as a Total System

To cope with higher quality requirements for the disk, an example of an automated transfer system introduced between processes will be described.

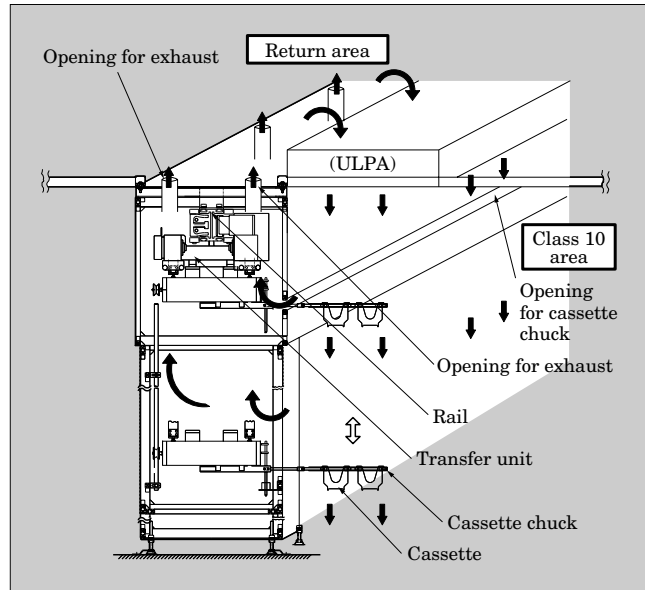
Figure 3 shows a schematic diagram of the total system.

4.1 Area separation

In designing an automated transfer system, areas in and between processes were separated from each other in accordance with the required cleanliness.

Due to economical and technical limitations, it is impossible to make dust source free of the system. Therefore, disk cassette transfer routes, facilities installation areas, and maintenance and working areas were completely separated to isolate the disk and dust

Fig.5 Schematic diagram of low cost clean transfer system



sources. In addition, no shielding materials were used over the disk cassette transfer routes in order to secure a laminar flow of air. Figure 4 shows a schematic diagram of the area separation.

Thus, dust sources and the disk were completely isolated in the clean room to create a clean environment that maintained the required cleanliness in each area even if there was dust from human bodies and facilities.

4.2 Development of a transfer system for improving cleanliness

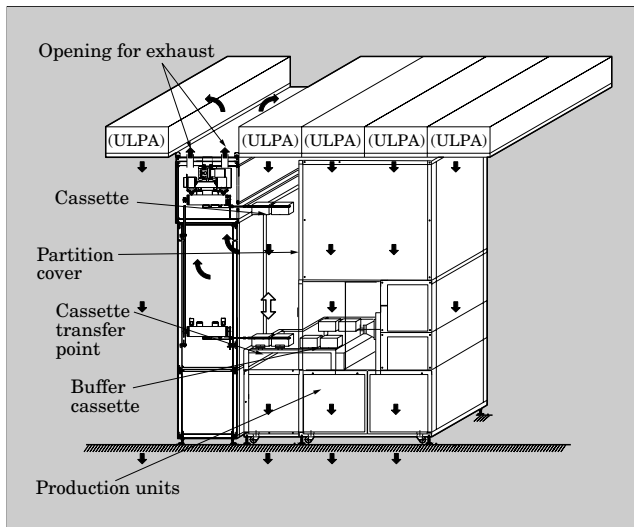
Traditionally, transfer systems in areas requiring a high level of cleanliness were not popular because of their high cost.

By improving the track feed system (the loop type transfer system mentioned above) and integrating it with a clean room, Fuji Electric has developed a low-cost clean transfer system which can be used in an ultra high-class clean area. Previously, track feed systems could only be applied to medium- and low-class clean areas. Figure 5 shows a schematic diagram of the newly developed low-cost clean transfer system.

In the previous type of transfer systems, disk cassette chucks were provided under the transfer system body. In the new system, the chucks were removed from the system and placed outside the body cover to separate them from dust sources. In addition, to provide a clean power supply system to the transfer system body, an induction type feed system (non-contact type) was developed to replace the brush type feed system (contact type) because the latter emits a relatively large amount of dust.

The transfer system was developed as part of the total system, integrating a clean room design around the transfer system.

Fig.6 Configuration of an automated transfer system and peripheral equipment



4.3 Improvement of exhaust routes

The exhaust of air from facilities and dust sources is important in maintaining cleanliness of the clean room. The exhaust of a large amount air required for automated transfer systems within a single process or between several processes also requires a large amount of intake air, resulting in increased cost.

Realizing that exhaust air does not contain hazardous gases but only particles, Fuji Electric has developed a system that, utilizing pressure differences in the clean room to reduce the amount of intake air, directly exhausts dust sources to a return area and then removes particles from the exhaust. Figure 5 shows a schematic diagram of a low cost clean transfer system.

More specifically, exhaust pipes are attached to the top of the main body of the transfer system that is installed close to the ceiling. Usually these pipes are connected to exhaust ducts, but instead they pass exhaust air to the return area. In addition, since disk cassette chucks are provided outside the cover, slits are needed. An exhaust system was constructed to allow the exhaust air to be drawn into and to flow inside the cover and to directly return to the return area utilizing the pressure in the clean room.

Since media cassettes are transferred in an area outside the cover, which is installed immediately below clean units (ULPA) where a laminar flow of air flows, the clean transfer of disk was realized.

This type of transfer system was employed in other ceiling transfer systems [items (1) and (3) of section 3.1 above].

The driving unit of the transfer system was placed below disk cassettes and shielded with covers to separate it from the cassettes. The covers were provided with openings so that the exhaust air would directly return to the return area.

These measures can reduce costs in the exhaust system of an automated transfer system.

4.4 Configuration of peripheral equipment

Figure 6 shows the configuration of an automated transfer system and peripheral equipment that, as a total system, aim at improving cleanliness.

As a total system, measures for improving cleanliness were implemented for production facilities as well as for the automated transfer system. Particular attention was paid to the cassette transfer points of the automated transfer system, areas where cassettes and the disk passed, and their surrounding areas.

As higher quality products are required, special attention must be paid to the residence period between processes, and thus the buffer function was improved.

4.4.1 Areas where cassettes and the disk pass

To secure a laminar flow of air from the ceiling, measures were implemented in the facility at areas where cassettes and the disk passed.

Partition covers are attached to the ceiling to separate areas for cassettes and the disk from the areas for facilities. Disk cassettes were placed on a framework construction to allow the laminar flow of air to and under the floor bottom.

Since cassettes and the disk are placed on transfer units at the transfer points, and robots for chucking are operated from the side, there are no shielding materials over the cassettes and the disk while they travel, preventing clean-air flow turbulence and securing a laminar flow of air.

4.4.2 Buffer function of cassettes

To cope with higher quality requirements for the disk, the residence period between processes should be shortened to reduce the quantity of adhered particles and ion contamination. In some cases, there are limitations on the residence period for products between processes. An automated transfer system was designed taking into consideration not only tact time but also the residence period of disk cassettes.

In addition, a buffer function for disk cassettes is required for short time stoppage of the facilities. The number of buffer cassettes is designated in the production specifications for each unit, taking into consideration the number of units in each process, unit reliability and tact time at the time of total system design.

Buffer areas for disk cassettes were constructed in the same manner as cassette transfer points to secure a laminar flow of air from the ceiling. Utilizing the advantage of an overhead transfer system, the buffer function was incorporated into the design of overhead transfer routes.

Specifically, an area for receiving disk cassettes was secured on the overhead transfer routes. Although that area is not normally used, during operation of the production line it provides functions to remove and buffer all of the disk cassettes from the

previous process in the event of a short stop of the production line when disk cassettes being transferred to the next process.

Since disk cassettes are buffered directly below the overhead clean units, they are shielded from other dust sources, and particles are prevented from adhering to the disk cassettes even if the buffer time is short.

5. Conclusion

In order to construct automated transfer systems within a single process or between several processes, it is necessary to design as a total system all facilities including the transfer systems, clean room and each area.

Cost and technical limitations in improving cleanliness can be overcome by total system design, leading to a substantial cost reduction.

As the drive toward lower cost has intensified much faster than expected, cost reduction of the

production line and transfer systems has become imperative. On the other hand, total automation of the production line is required to meet the demands of higher quality disk.

To satisfy these mutually contradictory requirements, it is necessary to shorten the residence period to prevent contamination, to reduce the quantity of goods in process and simplify production management, to reduce the cost of the transfer system and to save space, and as a result, to provide a production line with a minimized transfer system.

Minimization of the transfer system can be realized by connecting processes, eliminating distances between several processes, and improving the reliability of facilities.

Fuji Electric will continue to develop total systems in which the transfer function is incorporated into production facilities, beginning from the early stage of production specification determination.



Ultra-Clean Technology for High Density Magnetic Hard Disks

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1. Introduction

With the dramatic proliferation and higher performance of personal computers, higher quality is increasingly demanded of magnetic hard disks (hereinafter referred to as the disk) mounted on hard disk drives.

One of the factors affecting the trend mentioned above is the widespread use of hermetically sealed drives without any openings for air intake. As the use of drives become more widespread, applications in adverse environments coupled with mobile usage will disrupt the humidity and temperature balance in the drives, leading to dew condensation on the surface of the disks. Adsorbed water due to dew condensation reacts with ionic contaminants, and can corrode and dissolve thin film magnetic materials and lubricant.

Another factor is the challenge of higher recording density. In recent years, the size of the recording bit of disk platters where digital data is recorded has become extremely small, $0.8\ \mu\text{m} \times 0.07\ \mu\text{m}$ in currently mass-produced types. If there are defects of approximately the same size as mentioned above, some reproduced data will be missing. On the other hand, since the gap between a disk and a recording head (flying height of the head) is small ($0.03\ \mu\text{m}$), dust on the surface of the disk will scratch the surfaces of the recording head and disk, and in the worst case, recorded data will be lost. The size of the recording bit and flying height have been exponentially decreasing as shown in Fig. 1, and this trend will continue in the future.

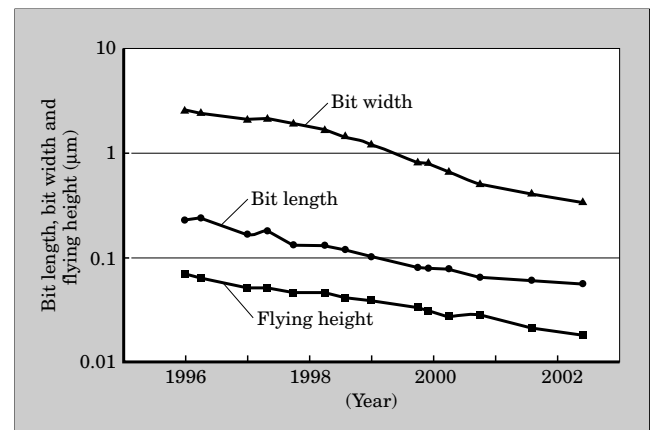
With higher recording density, contamination of disk surfaces during processing must be kept to a minimum, necessitating a total control of environment, materials and equipment in a clean room, (refer to Table 1).

This paper presents an overview of contamination control in a clean room and contamination prevention of disk surfaces and countermeasures against electrostatic hazards.

2. Contamination Control in a Clean Room

Contaminants in a clean room are divided into two major categories: particle contaminants, and gaseous

Fig.1 Transition of bit size and head flying height versus year



chemical contaminants that cannot be removed with a dust removal filter. The recent development of high efficiency filters such as HEPA (high efficiency particulate air-filter) and ULPA (ultra low penetration air-filter) has made it possible to control dust contaminants. Thus, the control of gaseous chemical contaminants has become commonplace within a clean room.

Chemical contaminants are acids, alkalis and organic gases, that come from equipment, workers, construction materials, cassette materials and outside air. The contaminants are selectively adsorbed by the surfaces of a disk and recording head, exerting an adverse effect on product quality.

Chemical contaminant control can be broadly classified into three methods: “do not bring in,” “do not generate,” and “removal.” The “do not bring in” and “do not generate” methods use construction materials and cassette materials in the clean room having a low amount of outgassing. The “removal” method is implemented by installing a chemical filter and an air washer. Figure 2 shows a schematic diagram of an air conditioning system in a clean room.

2.1 Chemical contaminant control in a clean room

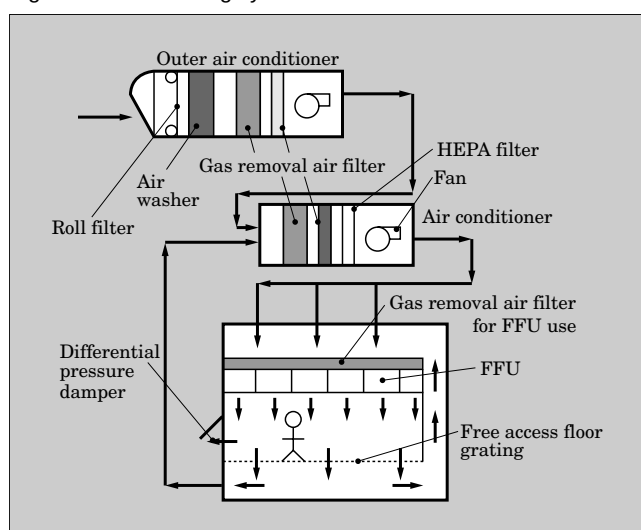
2.1.1 Contamination control due to air flow control

If dust contaminants are adsorbed by products in a clean room, they exert an adverse effect on product

Table 1 Summary of cleaning items and their evaluation

Item		Object	Evaluation	Measurement frequency
Clean room environment	Air flow control	Air flow	Air flow visualization system	Whenever necessary
	Monitoring	Dust in the air	Automatic particle counter	Continuously
		Temperature, humidity, room atmospheric pressure	Automatic monitor	
		Ion components in the air	Impinger collection → IC	Every week
			Witness disk → IC	
		Organic components in the air	Adsorption by the disk when left standing → FTIR	Whenever necessary
			Adsorption by activated carbon → GC-MS	
	Selection of construction materials	Ion components	Ultra pure water extraction → IC	When constructing or reconstructing the clean room
Organic components		Concentrated collection → GS-MS		
Filtration	Filter	Ion components	Impinger collection → IC	Every month
		Organic components	Adsorption by activated carbon → GC-MS	Whenever necessary
	Air washer	Water	Electrical conductivity sensor	Continuously
		Ion component in the water	Impinger collection → IC	Every month
Contamination check of finished products		Ion components	Ultra pure water extraction → IC	Every week
		Corrosion	Ultra pure water extraction → ICP	
		Organic components	Ultra pure water extraction → FTIR	
Materials, utility	Lubricant, solvent	Ion components	IC	Every week
		Organic components	FTIR	
	Ultra pure water	Particles, ion components	Particle counter, IC	Continuously
	Cassette, bag	Ion components	Ultra pure water extraction → IC	Every week
		Organic components	Ultra pure water extraction → FTIR	
		Concentrated collection → GS-MS	When selected	
		Particles	Particle counter	Every week

Fig.2 Air conditioning system in a clean room



quality. Although a dust removal filter is generally used for this purpose, that by itself is insufficient. Air flow control is necessary to exhaust dust contaminants generated in the clean room out of a production process without contaminating products.

Air flow control requires that parameters such as

the positions of air inlet and outlet openings, air flow rate and the layout of equipment in the room be adjusted to prevent turbulence, including the consideration of a push-pull construction for air inlet and outlet openings. At present, design of air flow control is mainly based on a simulation conducted at the time of construction. Special attention must be paid to the fact that even if there was no trouble in air flow control at the beginning, turbulence caused by changes to the layout of line equipment or other factors could contaminate products as time goes by.

Therefore, after layout, air flow in the clean room must regularly be monitored by an air flow visualization system. Points that are detected as causing turbulence are altered. Figure 3 shows the verification of air flow with an air flow visualization system.

2.1.2 Monitoring of dust contaminants

Maintaining cleanliness in a clean room requires regular monitoring based on control criteria. A centralized supervisory system is constructed to simultaneously monitor in real-time the dust suspended in the air, dust suspended in liquids, temperature and humidity in the clean room so that countermeasures can be implemented against sudden abnormalities.

Fig.3 Verification of air flow with a visualization system



2.2 Countermeasures against chemical contaminants in a clean room

2.2.1 Contamination control due to selection of construction materials in a clean room

Organic gases from chemical contaminants are mainly emitted by construction materials used for the clean room's interior and cassette materials. To cope with this, construction and cassette materials that only emit a small amount of outgas were selected to construct a clean room having few organic gases.

(1) Selection of construction materials

Construction materials used in a clean room include paint, adhesive, wall and floor materials, resin mold, tape and other materials.

First, materials emitting low aggregate amounts of organic gases and specific components with low amounts of outgases were selected from among potential construction materials using a gas chromatograph-mass spectrometer (GC-MS). Specific components include siloxane and dioctyl phthalate (DOP), possibly harmful to the quality of products.

Secondly, construction materials with ionic components below reference values were selected by analyzing them with an ion chromatograph (IC). Figure 4 shows sealant analysis results as an example of the analysis of construction materials. It was determined from the results that sealant A emitted a small amount of gases and their ion components were below reference values. On the other hand, sealant B emitted a rather large amount of gases, and gases such as DOP were identified, and the material was judged as improper.

(2) Confirmation of effect of selection of construction materials

To confirm the effect of the selection, organic gas concentration was verified for clean rooms A (CR-A) and B (CR-B), which were constructed in different times. CR-B contains the latest high-tech equipment and was constructed 18 months after the installation of CR-A. CR-B was provided with construction materials

Fig.4 Sealant analysis results with a GC-MS

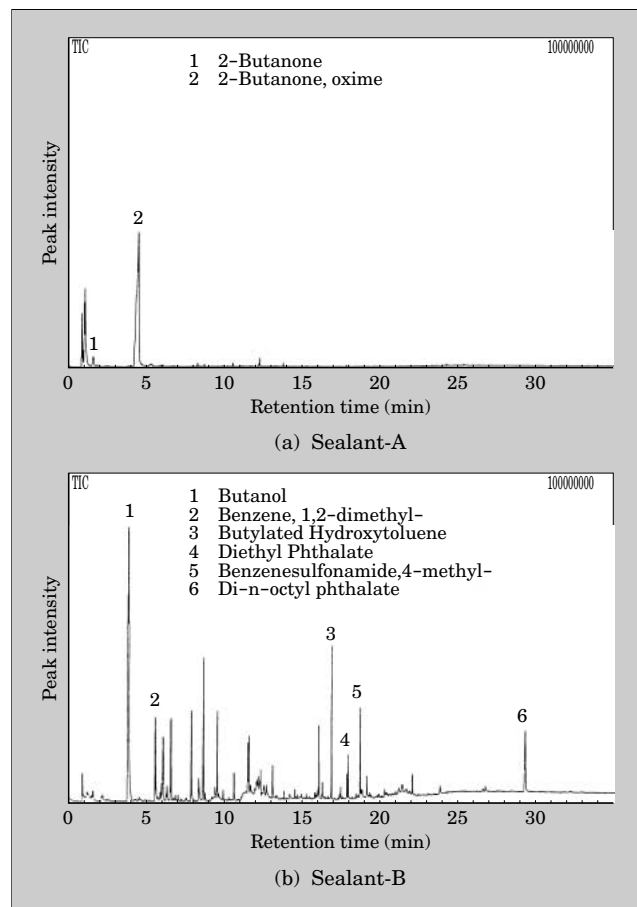
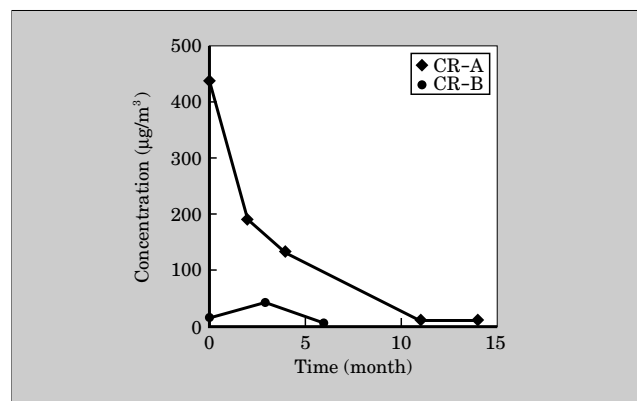


Fig.5 Transition of organic gas concentration



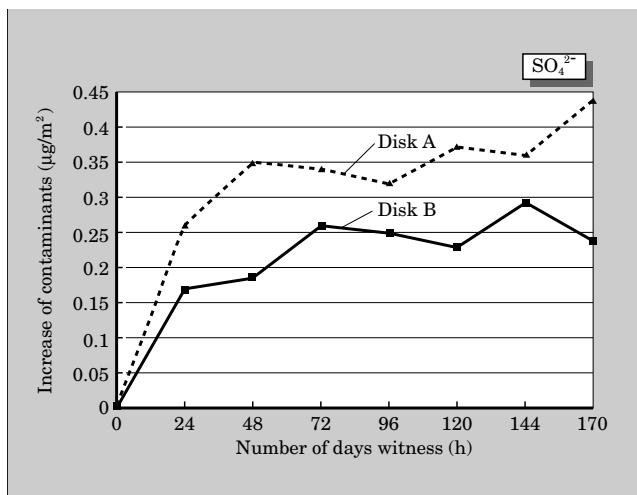
selected for their low outgassing.

Figure 5 shows the transition of the organic gas concentration of CR-A and CR-B. It was confirmed that CR-B had much lower organic gas concentration immediately after and since its construction, compared with CR-A. This demonstrated the effect and importance of material selection.

2.2.2 Contamination control due to installation of a chemical filter and other devices

Chemical contaminants enter a clean room from equipment and workers in the clean room and from outside air, in addition to construction and cassette

Fig.6 Witness of the disk



materials. Countermeasures only against construction and cassette materials are insufficient. Thus, a chemical filter and an air washer are used to reduce or remove harmful gases.

(1) Contamination control with a chemical filter

Various types of chemical filters have been developed and an appropriate filter for the gas components should be used. At present, an ion exchange filter is used for alkaline gases, a chemical adsorption filter for acidic gases, and an activated carbon filter for organic gases. When required, filters are installed in the air circulation system and in an outer air conditioner. The number of filters installed varies with gas concentration settings.

(2) Contamination control with an air washer

Chemical contaminants also enter a clean room from outside air entering a circulating system. The outer air contains SO_x, NO_x, etc., and their concentration varies with meteorological conditions and the direction of a wind, affecting gas concentration in the air circulation of the clean room. An air washer is used together with a filter to remove the gases, because providing the outer air conditioner with only a filter is neither sufficient nor cost-effective.

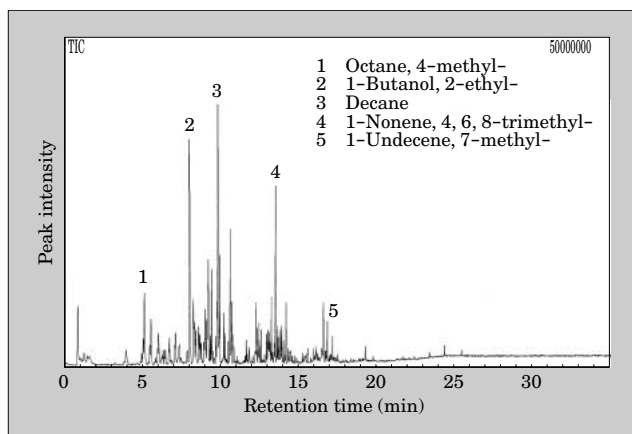
An air washer is a system intended to remove chemical contaminants in the outer air by absorbing them with water. This system passes the air through a spray of pure water before taking the air into the clean room circulation system.

Special care must be taken because the contaminant removal rate decreases when the contaminant concentration in the water increases. Pure water used for the air washer is automatically controlled with an electrical conductivity sensor to maintain a specified removal rate.

2.2.3 Monitoring of chemical contaminants

Chemical contaminants are monitored based on established methods of sample collection and analysis. At present SO_x, NO_x and ammonium are automatically monitored with a sulfur oxide meter and others.

Fig.7 Analysis of a PP cassette cover before implementing measures against outgassing



Detection limits can be circumvented and a large amount of information can be processed by combining sample collection with analysis. Sample collection includes collection with an impinger and activated-carbon tube. Analysis is conducted with IC and GC-MS. Automatic monitoring with IC is being considered by some manufacturers.

3. Contamination Control of Disk Surfaces

Contamination control of disk surfaces requires a comprehensive control of environment, processes, packing materials and workpiece materials to be surface-processed. As mentioned before, with the increase of packing density, stricter contamination control is required. The present challenge is how to achieve an effective contamination control. Contamination control currently in use for disk surfaces is presented below.

3.1 Control of residence time in the process

In the processes following sputtering, control of the environment during the lubricant coating process and residence time during disk processing is important for contamination control of disk surfaces. Carbon layers closest to the disk surface are, in general, sensitive to contamination until they are coated with lubricant. As shown in Fig. 6, the amount of contaminants adsorbed by the disk increases with residence time.

Based on the findings, strict control of residence time during processing is conducted to minimize the adsorption of contaminants. Time control is conducted using a production control system and the disk quality is verified through analysis using IC of pure water extracted from the disk.

3.2 Control of disk contamination due to cassettes and packing

Since disk loaded on cassettes for a long time is subject to outgas from the cassettes, examination of

Fig.8 Analysis of a PP cassette cover after having implemented measures against outgassing

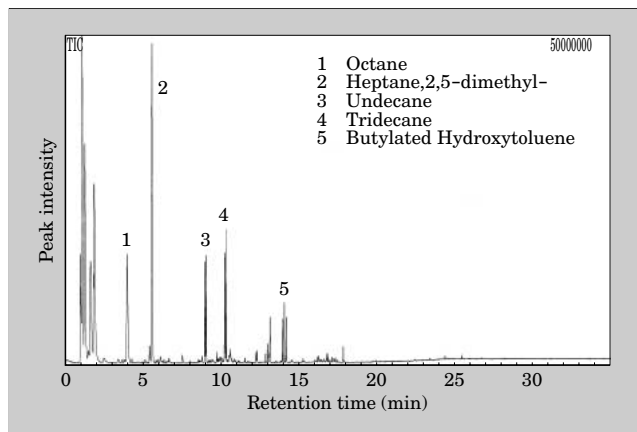
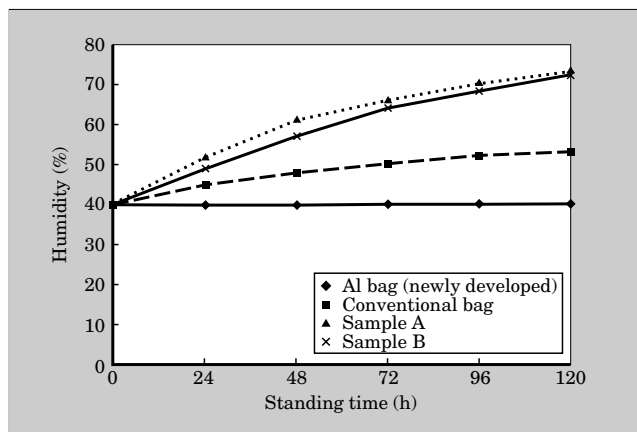


Fig.9 Water vapor permeability characteristics versus time



resins used for cassettes and confirmation of cleaning quality are very important.

Today, the dominant cassettes to be antistatic finished consist of a body made of polycarbonate (PC) and upper and lower covers of polypropylene (PP). Both PC and PP must fully be checked for dust generation and outgassing. Quantitative control must regularly be made to check if the cassettes contain a large quantity of plasticizer and sizing materials, contaminants easily adsorbed by the disk surface. In particular, special attention must be paid to specific polymeric compounds such as BHP, DBP, DEP and siloxane, contaminants requiring extra caution, because they were claimed to be responsible for some accidents in the past. Analysis is regularly performed to check the quality of the disk by an FTIR (Fourier transform infrared spectrophotometer), extracting solvent from the disk, and by a high sensitivity concentration method based on GC-MS purges and traps.

3.2.1 Improvement in the quality of cassette materials

Outgassing from cassette materials can be substantially reduced by joint efforts with the cassette manufacturer, resulting in simplification of the cassette cleaning process.

Figures 7 and 8 show an example of improvement in the quality of cassette materials. Due to this improvement, the gas cure process during cleaning can be omitted.

3.2.2 Improvement in the quality of packing materials

Contamination control against packing materials and enhancement of environmental barrier characteristics are also important topics in the prevention of disk surface contamination.

(1) Outgassing

Materials having a low amount of outgassing were examined and selected with a GC-MS as is the case with cassettes.

(2) Environmental barrier characteristics (water vapor permeability)

Figure 9 shows an example of the improvement from implementing measures against humidity during transportation. Fuji Electric, in collaboration with a packing material manufacturer, has developed and put to practical use a new four-layer bag using aluminum and new-generation packing materials. This bag is provided with measures against static electricity and features enhanced strength.

3.3 Monitoring of contaminants (workpiece materials, clean room, process, finished goods)

Surface contamination of the disk and its environment are continuously monitored with regard to the items listed in Table 1. These items are regularly measured by week, by month and by lot. A database is created from these results and necessary data is fed back to production processes for the purpose of contamination control and improving product quality.

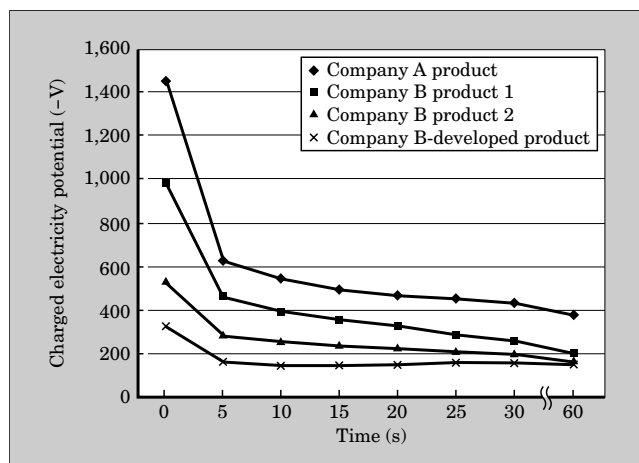
In the future, Fuji Electric will clarify the relationship between disk reliability evaluation items and contamination control items and will reconstruct an efficient quality assurance system to meet the needs of next-generation disk.

4. Static Electricity

Static electricity causes contamination due to dust deposition and electrostatic discharge failure in workpiece materials.

- (1) Countermeasures against static electricity are the last to be implemented against contamination due to dust deposition. Charged electric potential must be 50V or less to prevent the deposition of dust particles of 0.5 μm or more in diameter. In a disk production process, grounding of the product transfer system and use of conductive materials for cassettes and humidity control are implemented as countermeasures against contamination due to dust deposition.
- (2) As for the breakdown of workpiece materials, countermeasures against electrostatic discharge failure are implemented on the GMR (giant magnetoresistive) head during testing. The counter-

Fig.10 Charged electricity potential characteristic of clean garments versus time



measures include ① grounding, ② use of conductive materials, ③ humidity control and ④ use of an ionizer.

- ① A testing machine and workbench for exchanging GMR(giant magneto-resistive) heads were grounded. The charged electric potential of a human body can be reduced from 1,500V to 3V or less by the use of a wristband.
- ② Use of conductive materials permitted the charged electric potential of substrates in the cassettes to be reduced from 2,310V to 5V or less, covers to be reduced from 2,200V to 3V or less and chairs from 7,910V to 5V or less.
- ③ Humidity is controlled and maintained at greater than 45%.

- ④ An ionizer with an AC special-type fan which can control the ion balance within a range of $\pm 5V$ was selected and used for GMR head exchange on the workbench.

Fuji Electric has asked a manufacturer to develop clean garments equipped with countermeasures against static electricity. Changing the fibers in clean garments from hydrophobic to hydrophilic reduced the charged electric potential from 350-470V to 10V or less when wearing the garments on a conductive floor, and from 600-1,500V maximum to 300V when wearing them on an insulated material. These results are shown in Fig. 10, illustrating the advantage of changing fibers. Fuji Electric is also considering the development of gloves.

5. Conclusion

This paper has presented improvements to the clean room environment and management, and methods to verify the products. These procedures must continuously be improved as higher performance hard disks are required.

On the other hand, within several years revolutionary changes in the concepts for magnetic hard disks will possibly be needed, particularly when production processes are substantially changed due to the introduction of a perpendicular magnetic recording system and an optically assisted recording system, and alternative substrates are utilized to meet cost reduction goals. To satisfy these needs, the development and enhancement of clean technology will be required.

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