Prospects Concerning Hard-disk Manufacturing Equipment

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OVERVIEW: In recent years, the recording density and capacity of HDDs have been continuously improved. Regarding any production equipment, the odds of accommodating new technologies and attaining mass-production stability are not satisfactory. As examples of these basic technologies, three main developments are continuing: (1) development of a minute-defect detection method using an optical-inspection system, (2) development of simulation analysis of inspection circuitry by using high-frequency circuit technology and a specialized LSI, and (3) development of a precise head carriage using high-precision mechanics technology and a low-vibration spindle. In our efforts to realize highly efficient production, Hitachi High-Technologies Corporation is advancing technological developments in regards to fabrication and inspection of heads and disks (i.e. a recording medium), which are the basic components of HDDs, and expand our line-up of related equipment.

INTRODUCTION

ALTHOUGH the spread of HDDs (hard disk drives)—a magnetic-disk recording device—has been mainly focused on the computer marketplace, they are also rapidly spreading into markets other than computers, such as the field of digital home devices (like HDD recorders and music players).

As the trend towards larger capacity and higher recording density continues, even in the case of fabrication and inspection equipment for basic components like disks (media) and heads, the requirements concerning measurement technology for underpinning recording-density improvement and high-precision mechanics technology are getting even stricter, and further technical advances are thus being desired.

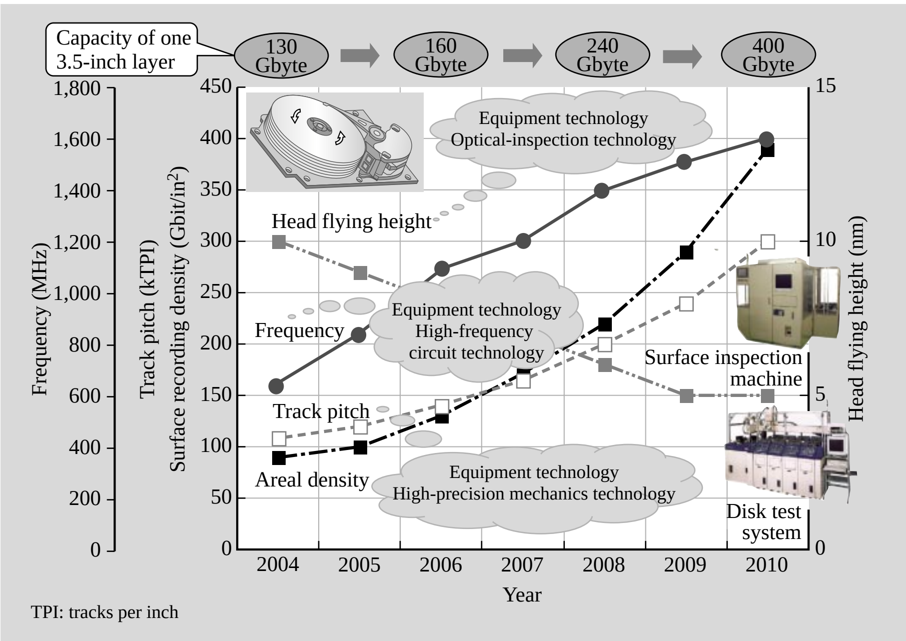

Fig. 1—HDD Technology Roadmap and Facility Technologies.
The main facility technologies for handling measurement of the parameters in the main specifications of HDDs, namely, surface recording density, track pitch, head flying height, and frequency, are shown.

In particular, with the adoption of perpendicular disks and high-density heads for increasing recording density, track pitch for writing and reading data is becoming ever narrower, and frequency is getting higher with the miniaturization of signals and increased precision of head positioning.

Given these circumstances, this paper describes technical shifts and equipment trends and the prospects regarding equipment, processes, and basic technologies for fabricating the disks (media) that will provide the basic components for supporting technical innovations (see Fig. 1).

TRANSITIONS IN HDD TECHNOLOGY AND EQUIPMENT TECHNOLOGY

The history of the HDD is long: it has been 50 years since the announcement of America's IBM (International Business Machines Corporation) of the world's first HDD storage system—namely, RAMAC* (random-access method of accounting and control).

From the viewpoint of capacity, compared to the recording capacity of RAMAC (with 50 stacked layers of 24-inch disks, giving a recording capacity of about 5 Mbyte), current HDD capacity has reached 150 Gbyte on a single 3.5-inch disk; in other words, disk capacity has increased by about 7,500 times since the days of RAMAC.

From the viewpoint of characteristic changes spanning the HDD technology of the last half of the 1990s [e.g. recording method: longitudinal magnetic recording; surface recording density: about 10 Gbit/in^2; head: MIG (metal in gap)/thin film] to the technologies implemented around the year 2000 [e.g. recording method: perpendicular magnetic recording; surface recording density: more than 100 Gbit/in^2; head: GMR (giant magneto-resistance)/TMR (tunnel magneto-resistance); AFC (anti-ferromagnetically coupled)/perpendicular disk], HDD technologies have been adopted one after another (see Fig. 2).

As recording density increases, technological innovations like the already proposed "patterned media" and "heat-assisted technology" proposed as alternative technologies for recording methods are pushing ahead. In the meantime, equipment technology for supporting increases in recording capacity and recording density is also evolving.

In particular, as regards fabrication and inspection equipment, as technologies involved in recording-density improvement, the following five key technologies have been implemented: (1) optical inspection on the disk surface by lowering the head-flying height level, (2) circuit technology for increasing

*RAMAC is a registered trademark of International Business Machines Corporation in the U.S.

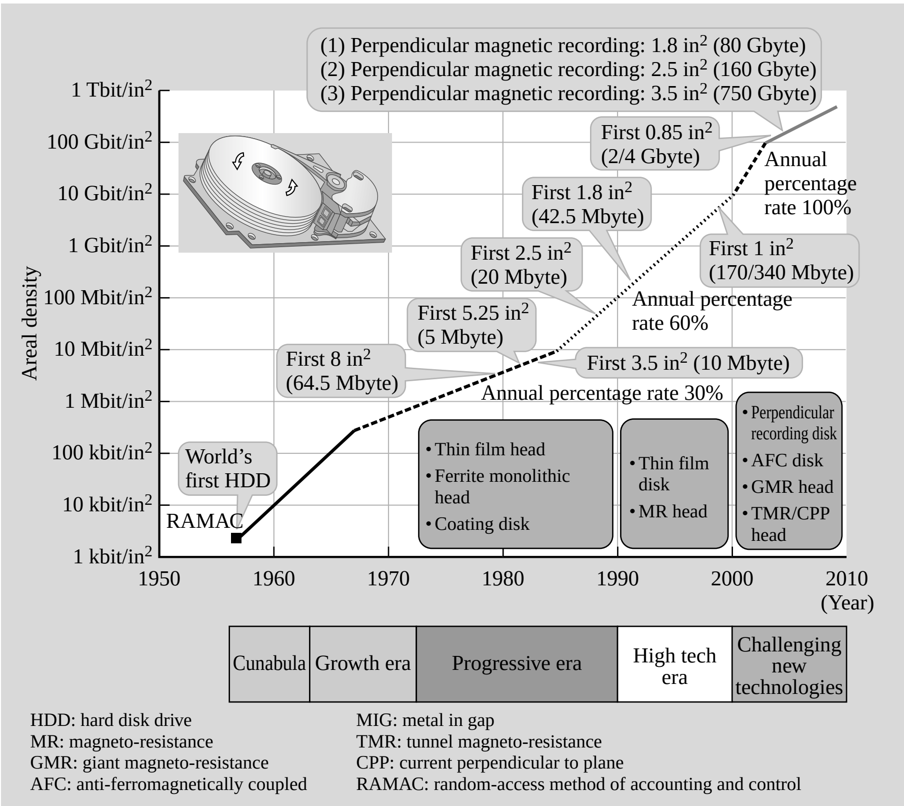

Fig. 2—Transitions in HDD-areal Density and Interent Technologies.
Since the world's first HDD appeared in 1956, improvement of its areal density has continued unabated. Up until 1990, areal density grew annually by 30%, and after that time, it grew even faster, namely, by more than 60% annually. Such growth was accomplished by application of new technologies like MR and GMR head and high-density-storage disks. Likewise, from now onwards, the introduction of new technologies looks likely.

frequency, (3) high-precision mechanics for handling narrow tracks, (4) processing on the disk surface, and (5) minute processing for heads.

EQUIPMENT TRENDS AND FABRICATION PROCESSING

Equipment Trends

Up until now, there have been big changes in regards to fabrication and inspection equipment for the basic components of HDDs—namely, the disk, substrate, and head. As one example change, by significantly reducing both the number of HDD-mounted disks and the number of heads (through increased recording density achieved by innovative technologies), it has been possible to suppress capital investment in production equipment.

As another example, with the introduction of technical innovation and new technologies, the difficulty of mass-production technology and manufacturing techniques has increased while process yields during production have decreased. As a result, there has been significant capital investment in equipment and new technologies for quality management of equipment and processes concerned with process yields.

Since the first half of 2004, on the one hand, recording-density increase through further technical innovations (such as introduction of high-density heads and perpendicular magnetic recording) has proceeded; on the other hand, the demand for increased number of mounted disks and heads has grown stronger with the appearance of applications requiring increased capacity. As a consequence of these changes, construction of new production lines to meet increased demand and capital investments in new technologies are being implemented in quick succession.

From now onwards, as the price of HDDs continues to be cut, it is predicted that demands for high reliability, high efficiency (stable operation), and high throughput in regards to production equipment—while keeping equipment cost low—will get even stronger.

Overview of Equipment for Device-fabrication Processes

A cross-section of a disk is shown schematically in Fig. 3, and an overview of the typical fabrication processes for substrates and disks, and the respective equipment for each process, used at Hitachi High-Technologies Corporation is given in Fig. 4.

Substrate fabrication process

As for the materials used for the substrate of a disk, various materials—such as aluminum, toughened glass, and crystal glass—are adopted, so the fabrication process is different for each. In the following, the

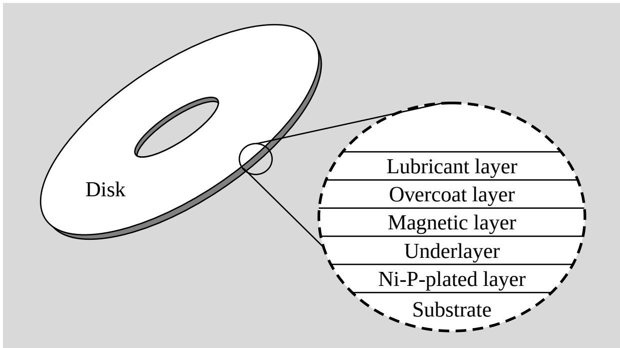

Fig. 3—Disk Cross-sectional Structure (One Side).
Up to the Ni-P-plated layer is referred to as the substrate. On top of that, disk texturing is performed, and lubricant, overcoat, and magnetic layers are formed by sputtering.

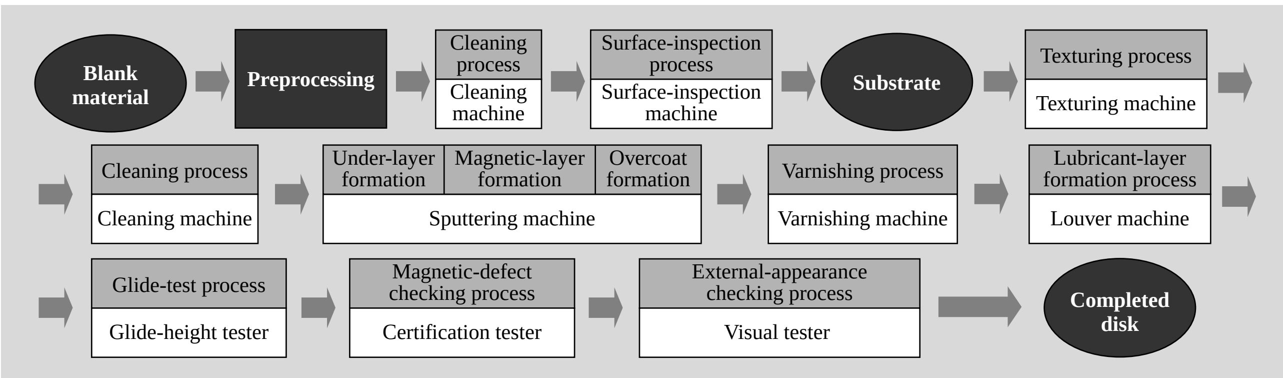

Fig. 4—Substrate and Disk-fabrication Processing.
Fabrication process and related equipment are shown. The process for making a substrate (from introduction of a blank material onwards) and the process for creating a complete disk (through the final inspection process) are shown in order.

fabrication process for an aluminum substrate is presented, and the fabrication and inspection equipment for this process are described.

The aluminum-alloy raw material (called a “blank”) is formed into a substrate by the following processes: grinding, cleaning, nickel-phosphorous coating, polishing, cleaning and inspection.

At Hitachi High-Technologies Corporation, these production processes are performed by equipment such as the “cleaning machine” (used for the final cleaning process and shown in Fig. 5) and the “surface-inspection system” (used for final inspection and shown in Fig. 6). In general, if the recording density continues to increase, the distance between the head and disk (called flying height) becomes even more important, and this distance has been minimized.

As a consequence, the smoothness of the substrate’s surface also becomes more important. Moreover, as the recording domains get smaller, detection of scratches and defects becomes a serious problem.

Along with further increases in recording density from now onwards, the surface-inspection system used for this inspection process will become more and more important as a substitute for visual inspection by eye.

By shining a laser beam (as a light source) on the substrate and receiving the light dispersed by a defect as well as the diffracted light and normally reflected light, it is possible to detect foreign bodies, scratches, etc. on the substrate surface. As HDDs are further miniaturized, anti-shock characteristics of the disk and head become important, and a 2.5-inch glass substrate, which easily increases recording density and has excellent smoothness depending on flying-height reduction, is becoming mainstream.

Fig. 5—Cleaning Machine.
A production-type machine for realizing high cleaning power and space saving by means of compound cleaning.

Fig. 6—Surface-inspection System.
A device for precisely measuring surface defects on the substrate and with a function for discriminating defects.

Fig. 7—Disk-cleaning Machine.
A batch-type, high-speed, high-precision device using precise dry cleaning by a new cleaning module and IPA (isopropyl alcohol) vapor.

Disk-fabrication process

The substrate is formed into a disk by the disk-fabrication processes described below.

(1) Texturing

Texturing is performed to form detailed contours on the substrate surface. Its aim is to improve the orientation of magnetic poles. In general disk processing, abrasive particles (like a sanding tape and slurry) are used, and the substrate is the textured mechanically. To perform this processing, Hitachi developed and commercialized the “texturing machine.”

(2) Cleaning

Cleaning is performed before the sputter processing for forming a magnetic layer. Hitachi manufactures cleaning machines in accord with customers’ specifications. As an example machine, the cleaning system is a module incorporating processes such as scrubbing, ultrasound cleaning, and dry cleaning (see Fig. 7). Regarding the drying method, as well as “dry” drying, IPA (isopropyl alcohol) dry-vapor drying is used.

(3) Sputtering

The underlayer, orientation film, magnetic film, etc. are vapor deposited (i.e. “sputtered”) by the sputtering machine, and a DLC (diamond-like-carbon) film to stop oxidation of these layers and protect them is sputtered in sequence.

(4) Varnishing

In this cleaning process for removing projections from the surface in regard to the sputtered carbon film, the surface is varnished by a sanding tape, and cleaning is performed by a cleaning tape.

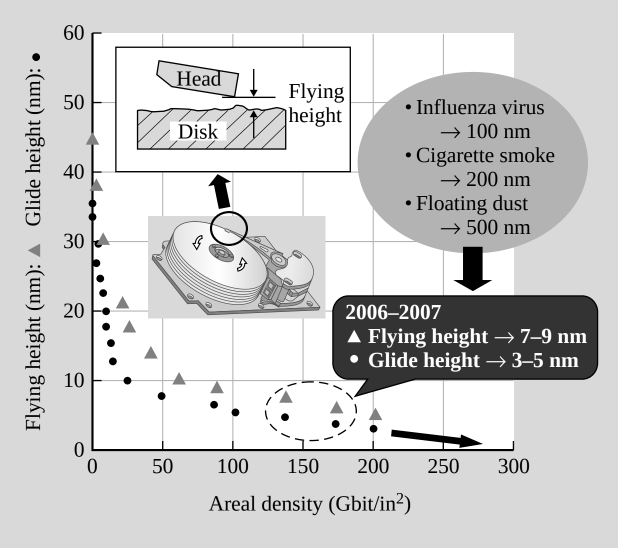

Fig. 8—Glide Height and Flying Height as Function of Surface Recording Density.
With increasing recording density, the gap between the head and disk gets narrower.

Fig. 9—Disk-test System.
A device for automating high-speed processing at the end of disk inspection (i.e. glide-height test, certification test, and parametric test) on one machine.

(5) Louver process

A film that acts as a lubricant between the disk and head is formed by the louver process. As the louver process, many processes—like application by spin coater, a method that rubs a lubricant into a tape so that it infiltrates it, and a dip method—are available, but the "dip coat" method is currently mainstream.

(6) Glide-height test

After the disk is completed from the substrate, the glide-height-test process is carried out as a final inspection process. This test is performed to assure that the head does not hit various protrusions on the disk when it is "flying" above the disk. Normally, when the glide-height test is performed, while the varnishing (depending on the head) is performed, a head for testing glide height is flown at a check height above the disk, and the test is performed on the whole disk area.

Due to increasing recording density in recent years, glide height has been significantly lowered, falling below 10 nm in 2001. Presently, HDDs with glide heights of below 5 nm have become practical (see Fig. 8).

(7) Certification testing

Disks that pass the glide-height check are tested for electrical characteristics and the presence of magnetic defects, and split into classes accordingly. As regards the certification test, a test head is used for recording and reading. The main tests are a parametric test and a defect test.

The parametric test generally measures track position at several places on the disk and electrical properties. It takes time for the defect test to cover the whole disk surface. The increased recording density of disks in recent years has raised various problems in regards to this test method. Increasing track density, i.e. to attain high TPI (track per inch), increases the number of test tracks; thus, the test takes time and productivity falls accordingly. To address this problem, the machine of Hitachi realizes separation of test areas as a result of the move to "multi-head" HDDs and simultaneous testing as a result of the creation of "multi-spindle" HDDs. Testing time is thus reduced accordingly. Moreover, the "disk test system" with a multi-spindle method for executing a magnetic-defect check ("certification test") and a protrusion check (glide-height test) in sequence on the same spindle has been commercialized (see Fig. 9).

BASIC TECHNOLOGY FOR HIGH-PRECISION DISK INSPECTION

In regards to the fabrication processes for disks and heads, inspection plays a key role in assuring high product quality and efficient production. As the miniaturization of recording domains (for increasing recording density) and the reduction of the gap between the head and disk continue, higher performance from inspection equipment is demanded year on year. High-frequency circuit technology and high-precision mechanics technology are two basic technologies involved in inspection equipment, and developments at the vanguard of technological trends in the market are continuing (see Figs. 10 and 11).

High-frequency Circuit Technology

Inspecting characteristics from the quality of a signal readout from a signal written on the disk is one method for inspecting the disk and head. With miniaturization of recording domains, the frequency

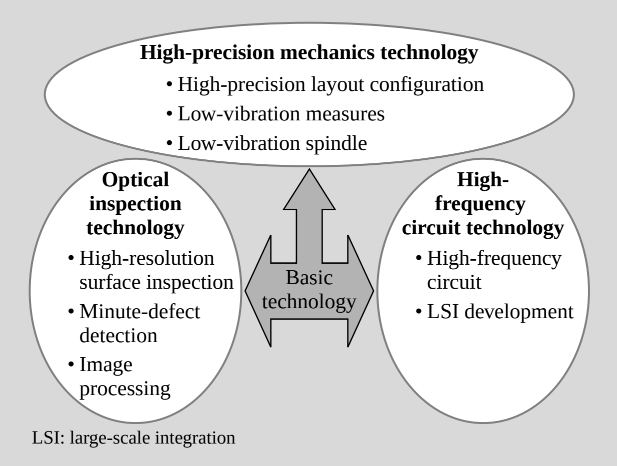

Fig. 10—Basic Technologies.
Basic technologies for high-precision disk inspection are shown.

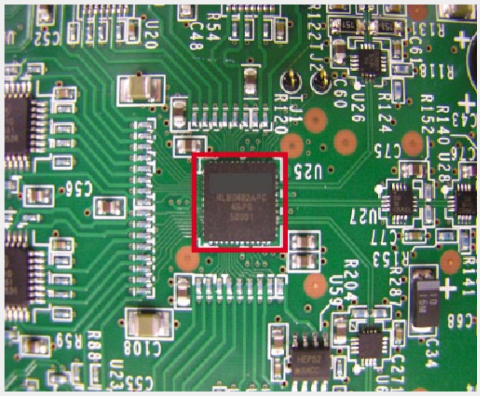

Fig. 12—Multi-function-analog Measurement LSI.
World's highest frequency band and measurement precision are accomplished.

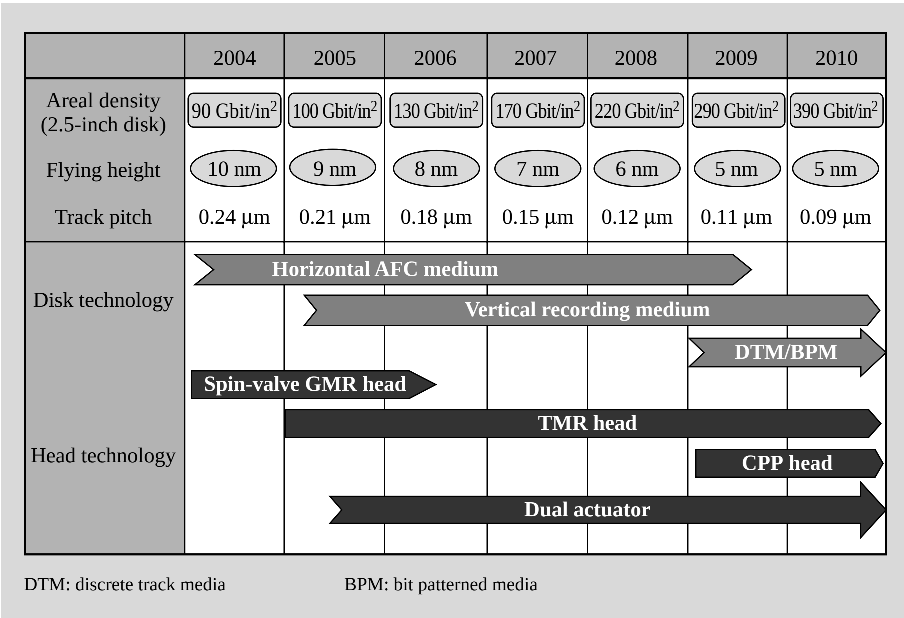

Fig. 11—Forecasted Trends in Specific Technologies.
Forecasted trends in specific technologies are shown.

of the inspection signal is getting higher; consequently, in regards to head-inspection equipment as well, GHz-class signal inspection has become demanded.

As for inspection circuitry, functions such as signal selection, signal amplification, and signal measurement are available, and it is necessary to create high frequency while these functions are being realized. Furthermore, measurement error occurs because of increased wiring loss between the head and circuitry; consequently, circuitry for compensating this loss is needed. In response to this need, during development of the inspection circuitry, analysis by three-dimensional electromagnetic-field simulation taking in wiring and mounted components is performed, and a high-precision equivalent-circuit model is created. By means of simulation evaluation using this model, a multi-function analog measurement LSI (large-scale integration) using a chemical-compound semiconductor process was developed just at the right time (see Fig. 12). Consequently, a world-leading head tester for precision measurement in the high-frequency range was commercialized.

High-precision Mechanics Technology

During the inspection, the head must be accurately placed above the disk, and stable flying of the disk must be maintained. Accordingly, it is necessary to suppress vibration — which disturbs the inspection

Fig. 13—Spindle Motor.
The motor has a static-pressure air bearing with rotation non-repeated fluctuation at the sub-nanometer level.

mechanics — as much as possible.

For example, as regards the head-inspection equipment, track-direction relative displacement between the disk and head is said to be around 1 nm, so extremely high stability is necessary. This characteristic is expressed as a parameter called TMR (track miss-registration) for short. Some of the factors that deteriorate TMR are vibration of the spindle that spins the disks, vibration of the carriage supporting the head, and environmental disturbances such as heat and airflow. Vibration at such levels is, however, difficult to measure in its own right, so vibration analysis is not easy.

An important mechanical factor that influences TMR is the spindle holding the disk. In an HDD, ball bearings and fluid dynamic bearings are used; in contrast, in an inspection machine, static-pressure air bearings are used. The static-pressure air bearings have the characteristics of low friction and low heat generation — ascribable to the pneumatic viscosity of the air bearing being three digits smaller than that of the fluid one. As a result, thermal distortion is lower, more stable spin control is possible, and the range of rotational speed is wider. At the same time, due to static pressure, non-contact is maintained full-time. During start-up and shut-down periods, therefore, wear is not generated, and long-term precision can be maintained.

The inspection system adopts an “extremely low NRRO (non-repeatable run-out)” spindle developed to make TMR especially small (see Fig. 13). NRRO is a spin non-repeated oscillation; therefore, to minimize it, optimization of shaft-bearing design parameters is performed by means of experimental evaluation based on numerical analysis.

OUTLOOK FOR OPTICAL-INSPECTION EQUIPMENT FOR IMPROVING RECORDING DENSITY

To attain high-density recording, the fabrication processes for a disk has become highly controlled, and quality control of each process have become extremely important. Optical-inspection technology has the feature that inspection quality is stable since there is no need to use a head for inspection and no influence on head characteristics is sustained.

Minute-defect Detection for Improving Recording Density

In the case of a disk with a recording density of 170 Gbit/in^2, within an area of 1 μm^2 on the disk surface, recording domains containing 260 bit exist. Consequently, the size of defects that must be detected on the disk is getting finer and finer.

The surface-inspection system is aimed at inspection on production lines used in the fabrication processes for disks or substrates. Utilizing scatterometry optics of a multi-direction illumination system, it can detect minute defects at excellent sensitivity. In this optical system, a minute laser spot (formed from three ellipses) is illuminated on one spot from three directions (forming angles of 120° between each direction). In this way, no sensitivity anisotropy (which depends on defect shape) exists, so inspection precision is assured. In addition, power density is increased three times, so enough sensitivity for detecting polystyrene latex particles with diameter of less than 0.1 μm on the disk surface is obtained.

Discrimination of Defect Contours for Creating Low Flying Height

The surface-inspection system is an inspection device used for evaluation analysis. In addition to the scattering optical system described above, it is fitted with interferometry optics for performing irregularity discrimination and shape analysis of defects, and it provides discrimination of multiple defect types for process control. A feature of this interferometry optics is that it can discriminate roughness of minute defects at high speed—an advantage not available with other companies’ systems (see Fig. 14). The measurement method measures the phase difference between a reference beam and a reflected light from a laser beam shone on the disk by making use of light heterodyne interference, and it converts this measurement into defect height or depth. As for this system, to attain high-speed inspection, a 128-channel parallel processing is performed, and dedicated optics and signal processing were developed for this purpose.

This processing enables the surface inspection system to perform roughness discrimination of minute defects on an entire disk surface in 1 min (in the case

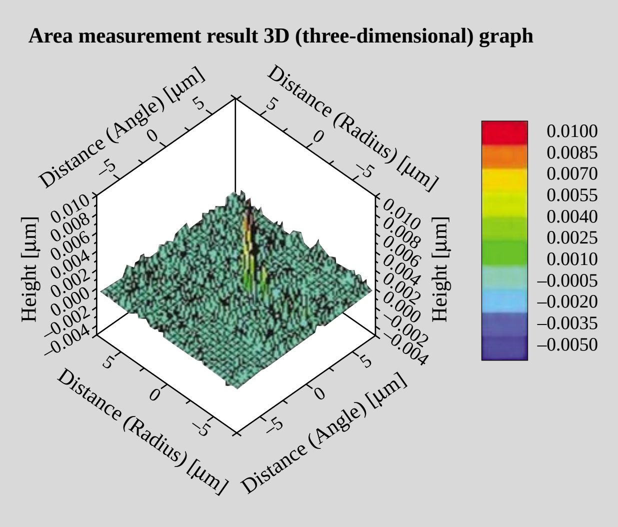

Fig. 14—An Example of Shape Analysis of Minute Defects by Interferometry Optics.
It is shown that sub-micron defects with a height of about 8 nm are present.

of a 2.5-inch disk)—a procedure that takes days with a conventional AFM (atomic force microscope).

Outlook for Inspection Technology

As processes get more and more complicated from now onwards, it is hoped that optical-inspection technology, taking advantage of the above-described features, will be expanded to cover all sorts of process control. Furthermore, integration of the above-described technology with conventional inspection technology will enable more detailed process-management information to be provided at a faster pace. In responding to these needs, we hope to contribute to improving the efficiency of the production processes related to HDDs and to further develop this inspection technology from now onwards.

CONCLUSIONS

This paper described the present status of production and inspection equipment related to HDDs (i.e. production processes and related equipment) as well as the prospects of basic technologies for supporting the increase in recording density of disks. As volumes of information grow more and more, magnetic-disk devices — as external recording media — will be increasingly fitted in devices not only in the field of computers but in the field of home digital appliances as well. As surface recording density has been increased, various new technologies have been introduced. As a result, fabrication and inspection equipment plays an important role in assuring high-quality and high-efficiency production.

Even in regards to the equipment field, technological development for accommodating continual technical innovation and early deployment in the market must be on hand.

While providing equipment for continuing to meet our customers' needs from now onwards, Hitachi will continue trying our utmost regarding leading developments of technologies that look towards the future.

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