Manufacturing Equipment Technologies for Hard Disk's Challenge of Physical Limits

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OVERVIEW: To meet the world's growing demands for volume information, not just with computers but digitalization and video etc. the HDD must continually increase its capacity and meet expectations for reduced power consumption and green IT. Up until now the HDD has undergone many innovative technological developments to achieve higher recording densities. To continue this increase, innovative new technology is again required and is currently being developed at a brisk pace. The key components for areal density improvements, the disk and head, require high levels of performance and reliability from production and inspection equipment for efficient manufacturing and stable quality assurance. To meet this demand, high frequency electronics, servo positioning and optical inspection technology is being developed and equipment provided. Hitachi High-Technologies Corporation is doing its part to meet market needs for increased production and the adoption of next-generation technology by developing the technology and providing disk and head manufacturing/inspection equipment (see Fig. 1).

INTRODUCTION

HDDS (hard disk drives) have long relied on the computer market for growth but in recent years there has been a shift towards cloud computing and consumer electronics etc. along with a rapid expansion of data storage applications (see Fig. 2).

In line with the increasing volumes of information, the HDD requires increases of both capacities and densities. Furthermore, in recent years, data centers controlling massive amounts of information are said to consume hundreds of megawatts of power. From an environmental perspective, low power consumption IT (information technology) must be promoted and is being actively pursued in Japan through the "Green IT Initiative." In this regard, higher efficiency storage, namely higher density HDDs will play a major role.

To increase density, the performance and quality of the HDD's key components, disks (media) and heads have most effect. Therefore further technological advances in manufacturing and inspection equipment are sought to support these.

Increased areal density has caused bit size to get ever smaller, resulting in recent areal densities of something like 650 Gbit/in² or the equivalent of 1,000 bits of data in a 1-micron square. To cope with this Hitachi High-Technologies Corporation has promoted development of high precision head positioning technology along with high frequency electronics for the smaller signals.

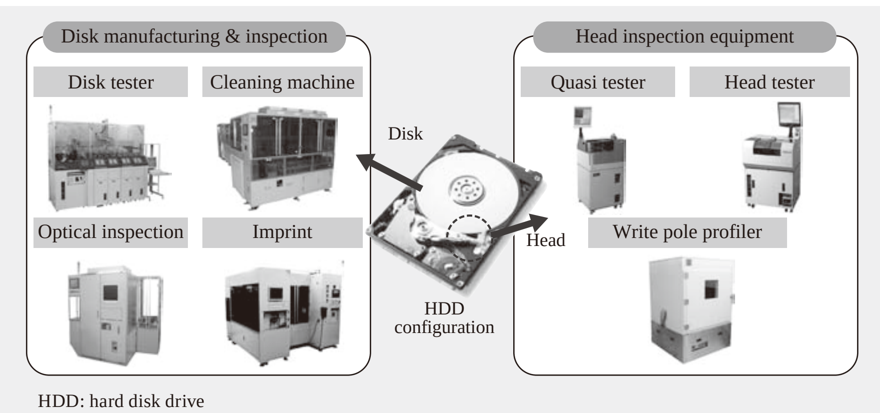

Fig. 1—HDD Manufacturing and Inspection Equipment Products.
The increasing densities of HDDs places high demands on the reliability and quality of the manufacturing and inspection equipment used in their production. These Hitachi High-Technologies Corporation products were designed to meet these demands.

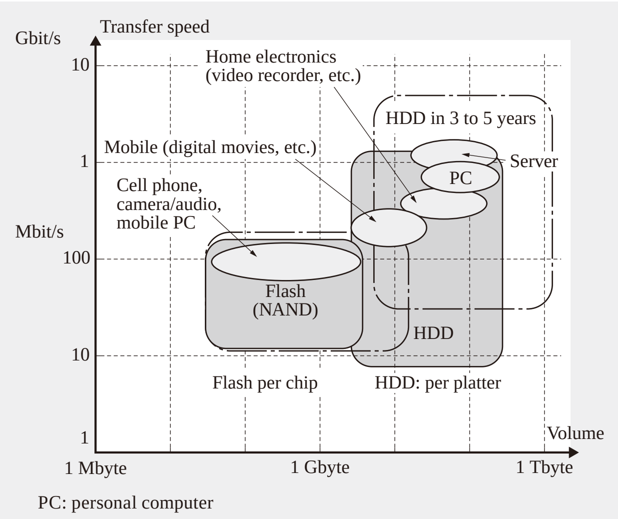

Fig. 2—Storage Technology Adoption.
Whereas past growth in the market for HDDs has been based primarily on their use in computers, new applications such as the cloud and consumer electronics are growing rapidly.

TECHNOLOGY FOR INCREASING HDD DENSITY

HDD Technology Transitions

HDD have a long history dating back to the world's first HDD announced by International Business Machines Corporation (IBM) in 1956. Since then recording density has grown massively, increasing by 8 digits.

To maintain the fast and continuous pace of areal density improvements over the years has taken many technological innovations (see Fig. 3). In the 1990s the read method changed from the electromagnetic induction of thin film heads to a magnetoresistive type and a decade or so later traditional longitudinal recording was surpassed by perpendicular recording.

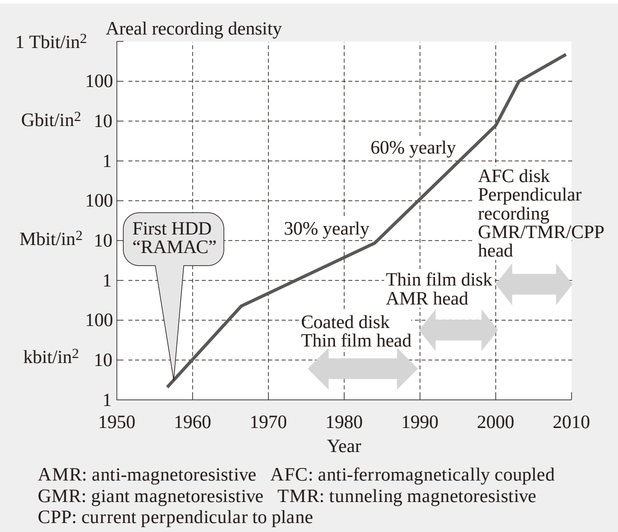

Fig. 3—HDD Areal Density and Technology Transitions.
To satisfy market demand, HDDs have achieved a continuous increase in their areal densities over a span of more than 50 years thanks to numerous technological innovations.

Manufacturing and Inspection Equipment Technology

Inspection equipment plays an important role in trying to maintain highly efficient manufacturing and assure stable quality.

Furthermore, recent areal density increases have been accompanied by miniaturization of the magnetic domains and decreases in the head-disk spacing, warranting ever sophisticated inspection equipment year after year.

Currently, track pitch is being squeezed down to around 70 nm, requiring high precision head positioning servo technology for inspection equipment.

To read the test signals correctly requires track mis-registration of the head to less than 3% of track pitch. Fig. 4 shows the signal on a disk, read as the head is repeatedly scanned sideways across it, plotting the signal strength relative to the distance from the track center. From this we determine that positioning repeatability is of the order of 1 nm, and thus highly stable.

Technical Trends for High Density

Increasing areal density beyond 1 Tbit/in² is said to be extremely difficult with existing technology. In order for the recorded bit to be smaller the grain size of the recording layer must be smaller requiring an

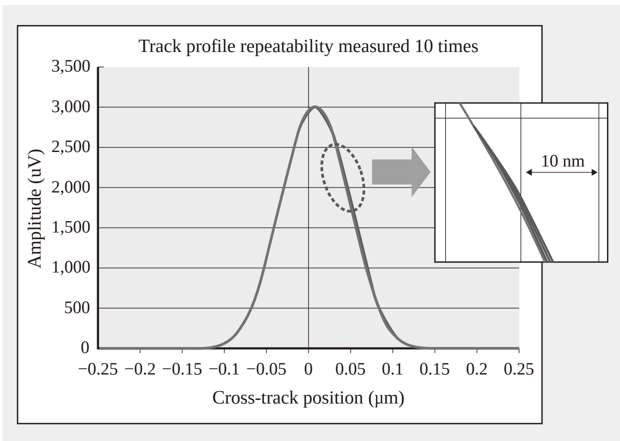

Fig. 4—Head Positioning and Repeatability.
Head inspection requires a relative positioning accuracy between disk and head of 3% or less of track pitch. The graph shows the disk write signal read back from the head and indicates positioning repeatability of about 1 nm.

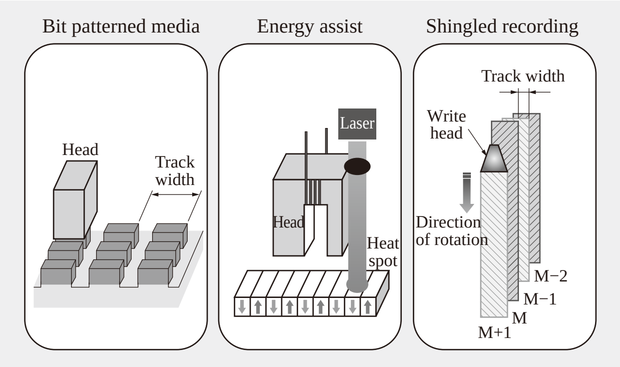

Fig. 5—Technologies for Increasing HDD Density.
While achieving areal densities in excess of 1 Tbit/in² is difficult using conventional technologies, Hitachi has come up with a number of innovative technologies which it is developing to address this challenge.

improvement in SNR (signal-to-noise ratio) to read. Data though would then be vulnerable to decay from the super paramagnetic effect's thermal instability, which in turn would require a high Ku (anisotropy energy) recording layer but the small magnetic field head could no longer write to it and this vicious circle is the so-called "tri-lemma in magnetic recording." Several innovations are proposed to break through this barrier (see Fig. 5).

(1) Shingled recording

Technically there are no great hurdles so this is said to be close to implementation. Large Ku recording layers with large magnetic field heads overwriting part of the previous data leave a narrow remnant to form the track. The drawback is that conventional random access writing will not be possible and must be accounted for with new formatting methods and additional memory.

(2) Energy assisted recording

This is primarily an innovation for the head, when writing a bit of data, additional energy is applied to the area enabling the use of low field strength to switch polarization. Thus, small bits can be recorded in high Ku recording layers. Assist energy solutions in the form of laser light utilizing near-field optics or microwaves from high frequency magnetic field oscillators are being considered. However, focusing of the energy into a minute spot is something that must be built in to a new head.

(3) Bit patterned media

An innovation of the disk sees a move away from the traditional continuous granular recording layer to one of isolated magnetic domains with each one representing a single recorded bit of data. The mutual interference between adjacent bits is minimized so, even for low Ku recording layers, SNR and thermal instability effects are improved. However, the bit location/synchronization not to mention the high volume production of the new disk manufacturing processes still pose problems.

These innovative technologies are being considered but to achieve areal density of 4 Tbit/in² will likely require a combination of both energy assist recording and bit patterned media.

Bit patterned media has servo information pre-embedded on the disk and requires positioning technology to account for eccentricity and otherwise implement track following. To cope with these technology trends, the following equipment technology is being developed:

(a) Non- write-read certify inspection technology
(b) Head inspection technology for early process stage
(c) Patterned media volume manufacturing technology

OPTICAL MEDIA TESTING EQUIPMENT

The last step of the disk manufacturing process is performing a glide test, checking the surface for asperities to assure the fly ability of the head, and a certify inspection to examine magnetic characteristics and defects that influence read and write.

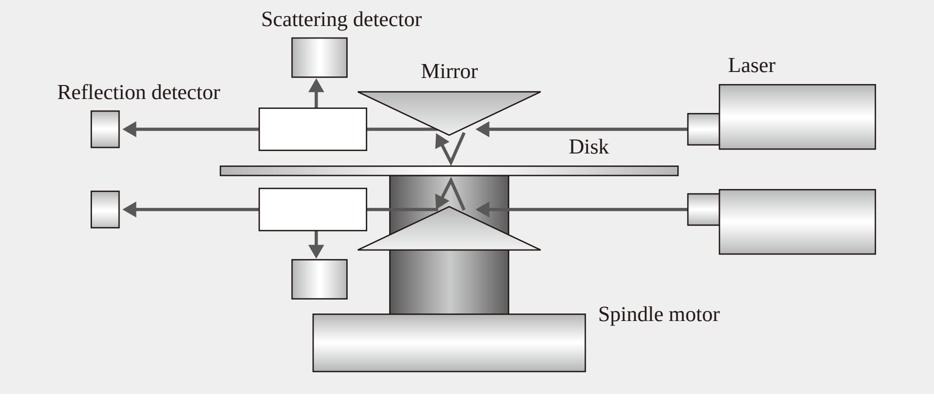

Fig. 6—Optics Configuration.
The machine uses laser light to inspect the disk. This can inspect the entire disk more quickly than the previous method of inspection using heads.

Development Concept

Certify testing involves writing to a disk and judging the quality of the signals read back. With the rise in areal densities, the number of tracks has become immense, so not all the tracks are tested these days.

By adopting an optical method in this system, fast and stable inspection has been achieved (see Fig. 6). Optimization of the optical unit's laser spot size offers simultaneous scanning of multiple tracks enabling full disk surface inspection in a short time. Furthermore, without the need for write and read, it can be applied to high Ku disks intended for energy assist recording.

Performance and Results

The optical system is composed of two sets, top and bottom, so that both sides of a disk can be inspected simultaneously. A regular 2.5" disk with 80 nm track pitch would normally take 20 minutes or so to do a full surface inspection but with this tool it can take just 10 seconds depending on laser spot size and other conditions.

Furthermore, there is no need for regular replacement of heads, calibration etc. leading to superior running costs. Measurement results are as shown in Fig. 7. From this we can see the detection of disk surface defects.

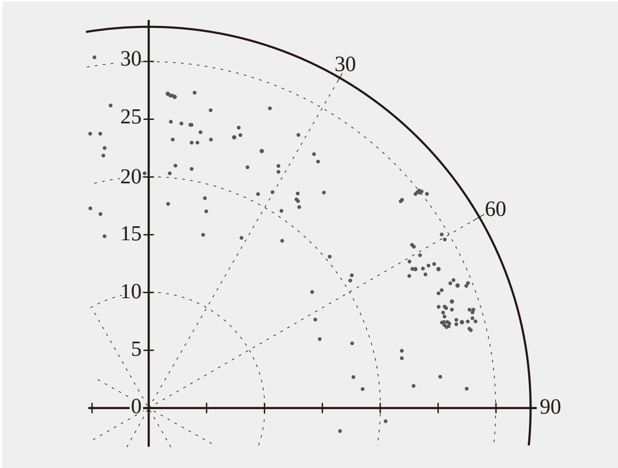

Fig. 7—Measurement Results.
The figure shows results of disk measurement using laser light. The results indicate that defects on the disk surface can be measured.

WRITE POLE PROFILING EQUIPMENT

During the mass production of magnetic heads, measurement of the write pole's track width involves recording a signal onto a disk and scanning the signal read back (see Fig. 8). Consequently, this must be done at the final HGA (head gimbal assembly) stage, when it is fully read-write capable, but there is a strong desire for this inspection at an earlier stage to improve process efficiency.

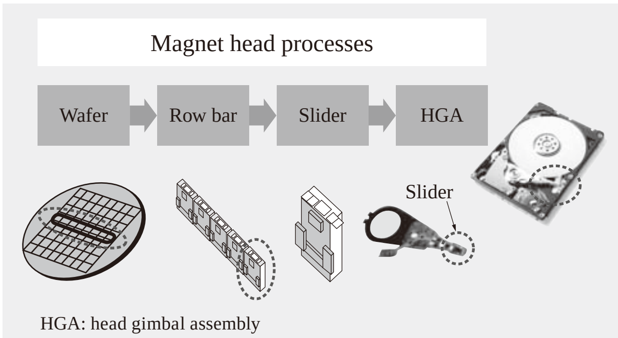

Fig. 8—Magnetic Head Main Production Processes.
The figure shows production process for standard magnetic heads. Although inspection of the write pole track width is currently performed in the HGA stage, it would be very desirable to perform this at an earlier stage to achieve better process efficiency.

Development Concept

In order to inspect the write pole without the need for writing to a disk we have developed a method of directly detecting the minute magnetic field produced from the write pole with a probe. In this method the probe is scanned across the write pole to measure the distribution of magnetic field strength. From the results, data processing yields the required write track width. The measurement of a minute spatial magnetic field to nanometer level is highly susceptible to external vibration, air currents and thermal effects, so careful consideration of the structural design is required to mitigate environmental disturbance.

Performance and Results

This tool measures write pole track width at the rowbar stage enabling early process feedback from which we can expect production efficiency to further reduce costs. In terms of performance, measurement repeatability of 1 nm and cycle time of 8.5 s per slider have been confirmed; with this aiming to offer a head process solution further improvements are being pursued as it is commercialized.

DISK NANO-IMPRINTING EQUIPMENT

In bit patterned media isolated magnetic domains as small as 10 nm are formed over the entire disk surface. It is difficult to manufacture these minute structures with conventional photolithography techniques so it is said that photo cure imprinting technology is essential (see Fig. 9).

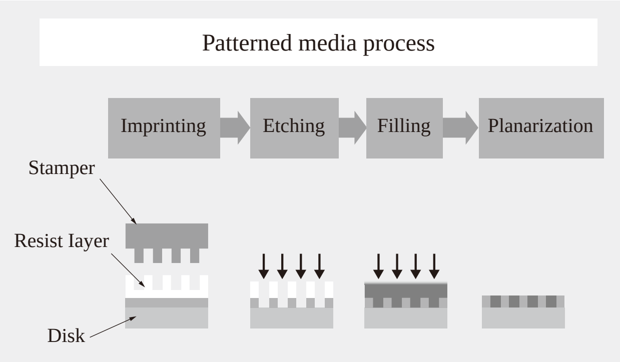

Fig. 9—Patterned Media Production Processes.
The bit patterned media forms isolated magnetic domains 10 nm in size over the entire surface of the disk. It is believed that photo cure imprinting technology will be needed if this technology is to be used for mass production.

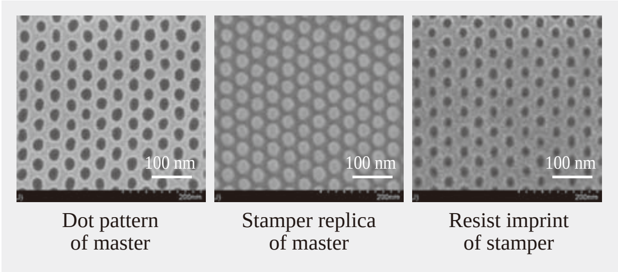

Fig. 10—Fine Pattern Replication.
These photographs show fine patterning produced using photo nano-imprint technology. This shows that the technology can produce fine patterning at a level suitable for patterned media.

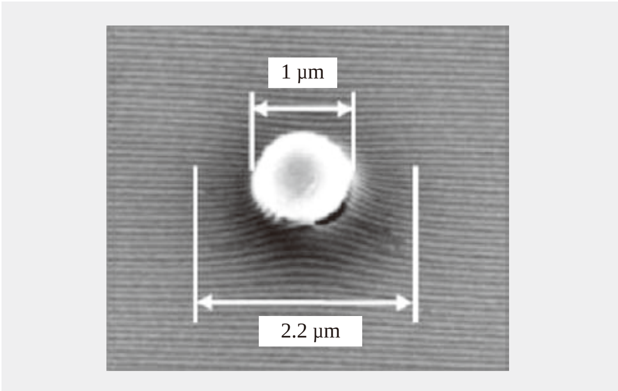

Fig. 11—Defect Area around Contaminant.
1-µm diameter silica beads were sprayed onto a flat disk to investigate their impact on nano-imprinting. The area around the beads where imprinting was defective had a diameter of 2.2 µm.

Development Concept

Photo nano-imprint is a pattern transfer and replication technology whereby the minute structures on the stamper are pressed onto the resist coated surface of a disk. This is basically a low cost process without the miniaturization limitations seen with the exposure wavelength in photolithography technology.

Despite strict contamination controls, however, micronsized foreign material may be found on disk surfaces. While imprinting, the disk and stamper are virtually in contact through just 10 nm or so of resist coating. This pressed condition cannot be maintained in the presence of a foreign body and the surrounding area becomes defective. To minimize the size of defects the stamper needs to be flexible enough to mold itself around the contaminant. To achieve this and to develop a stamper with superior capabilities for continuous replication required the right amount of elasticity. Also, disks have recording surfaces on both sides, so for efficient manufacturing a simultaneous dual-sided imprint process was preferred. In this tool, it was achieved through a unique replication technology. In addition, resist materials development for fast pattern formation and photo curing were included with the overall equipment high speed mass production plans.

Performance and Results

Fig. 10 shows the minute structures achieved with this imprint technology. Using a master arranged with rows of isolated dots of approximately 20 nm, stampers were replicated and used to transfer the pattern to resist coated disks. The suitability of this pattern transfer for patterned media has been confirmed. As for contamination, the stamper's mold ability was assessed from the imprint deformation using a disk sprayed with 1-µm diameter silica beads. As a result, the defective imprint area around the beads had a diameter of 2.2 µm suggesting the stamper molds sufficiently well around the beads (see Fig. 11).

CONCLUSIONS

Herein, we have given an account of the HDD's density improvements in response to market needs and technology trends along with the prospects of production and inspection equipment for manufacturing.

The HDD is no longer driven just by the computer market, from here on the digital consumer electronics market will further accelerate it into the future. As the HDD is continuing to challenge the limits of magnetic miniaturization, Hitachi High-Technologies Corporation will continue to respond to its customers' needs in providing equipment and timely development of future technology.

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