Demand for data storage devices has been exponentially increasing with the widespread dissemination of the Internet and cloud computing.

In response to this situation, Toshiba has been developing and supplying all of the main types of storage devices, including hard disk drives (HDDs), optical disc drives (ODDs), and solid-state drives (SSDs) using NAND flash memories. With the ongoing diversification of storage device market needs ranging from personal use to data centers, we are making efforts to accelerate several new technical innovations to meet a wide variety of storage requirements.

Trends in HDD Technologies

Due to the spread of the Internet and cloud computing, in recent years demand for storage devices has been increasing. Figure 1 shows the changes in the volume of data generated worldwide and the capacity of storage devices for storing such data. It is said that the volume of data generated worldwide has been increasing by more than 40% annually, yet hard disk drives (HDDs) are still the dominant storage devices.

HDDs have been able to remain the dominant type of storage device because they have maintained their advantage over the other types through steady improvements in their recording density for more than 40 years. As shown in Figure 2, which details the history of improvements in recording density, not only magnetic heads and magnetic disks but also other technological innovations in various fields have supported improvements in recording density.

Technological innovations that have supported HDDs

Since 1997, the year in which giant magnetoresistive (GMR) heads appeared, recording density improved by 100% annually until dropping to 30% in 2001 due to a slowing in the pace of advancement. The practical application of the perpendicular mag-
In this way, technological innovations in magnetic heads and magnetic disks greatly contributed to improvements in recording density. However, channel technology, error correction technology, servo control technology, and other technologies have also facilitated improvements. For example, recently released storage devices feature a new error correction method that uses low density parity check (LDPC) codes. All storage device makers are adopting these codes quickly as they improve the signal-to-noise ratio (SNR) by 2 dB or more compared with the conventional Reed-Solomon error correction codes (RS-ECCs) (refer to pp. 10–14).

### New technologies to watch

To further improve recording density in the future, we have been developing Thermal Assisted Magnetic Recording (TAMR) or also called Heat Assisted Magnetic Recording (HAMR). This technology induces magnetization reversal using laser-emitted thermal energy to balance the trade-off between ensuring thermal stability and the difficulties in writing to magnetic disks. In these processes, data is written to a magnetic disk by focusing a laser beam on very small spots in order to heat only very specific small sections of the disk. TAMR (HAMR) is gaining attention as a technology capable in theory of achieving a magnetic recording density of 3 T (Tera = 10^{12}) bit/in^2.

Microwaves are considered to be another supplementary measure and are applied in Microwave Assisted Magnetic Recording (MAMR) technology. Here, the spin-torque oscillator—an ultra-small microwave generator—is used to send microwaves to tiny sections of a magnetic disk, eventually lowering the required amount of magnetic energy necessary to write data. In theory this technology can also achieve a magnetic recording density of 3 Tbit/in^2.

Bit Pattern Media (BPM) technology allows for small bit patterns to be physically processed and has also been studied as a magnetic disk technology. Toshiba has been developing these future technologies in collaboration with parts suppliers and its research and development divisions.

In the meantime, Shingled Write Magnetic Recording (SMR) is an approach for improving recording density which differs from traditional approaches. This technology uses existing perpendicular magnetic recording technology and improves recording density by altering the algorithm used to record data to magnetic disks. In this approach, data tracks are not separated when writing data, but a new data track is recorded while layering part of the data track over the previous track. Since this method of writing data resembles the way shingled roofs are installed, this technology is called as shingled write recording. In theory, a recording density approximately 1.5 times that achieved by the perpendicular magnetic recording device, a recording density of 1.5 to 2 Tbit/in^2 can be achieved using this technology.

Servo technology (positioning technology) is also an essential technology supporting improvements in HDD recording density. The most recent HDDs use a track pitch of 100 nm or less, requiring accurate positioning to the target track at a pitch of 10 nm or less. In principle, positioning is performed by the feedback control based on the position information written to the magnetic disk in advance. To achieve this positioning, we have developed technologies related to vibration characteristics, oscillation measures, dual-stage actuators using Piezoelectric elements, and eccentricity correction, among others.

### Information security for the ICT society

As the scope of applications for HDDs expands, additional functions come to be demanded in addition to those ensuring basic performance such as vibration resistance, shock resistance, and low power consumption. Of such functions, encryption is one important technology. Especially recently, the use of encryption technologies to protect data written to HDDs is increasing due to the spread of cloud computing and rising awareness regarding the needs for personal
Trends in ODD Technologies

Acceleration and spread of commoditization

Since DVD drives are now low cost optical disc drives (ODDs), they are regarded as standard equipment in the world of PCs. Tablets, which generally lack DVD drives, are currently spreading rapidly. In response to this increase in the number of PCs without DVD drives, demand for external DVD drives is growing. In the audio-visual (AV) market, although Internet distribution is increasing, DVDs are still the dominant medium for distributing content.

A large capacity optical disc, the Blu-ray disc (Note 1), has been released as the successor to DVDs. In developed countries, the Blu-ray disc market has been gradually growing as flat-screen high-definition (HD) digital TVs and HD broadcasting spread. It is estimated that effective Internet connection speeds will not be able to keep pace with the explosive increase in Internet usage, which will eventually drive the spread of Blu-ray discs (Figure 3).

On the other hand, in emerging countries undergoing rapid economic growth with huge populations, it is expected that distributing content by easy-to-use, less expensive optical discs will establish itself as a method before advanced Internet infrastructure is even developed.

DVD drives

DVD drives for PCs now enjoy sales of 300 million units per year and recording devices account for 80% of that total. In addition, in response to the growth of notebook sales, the percentage of slim models has been increasing (Figure 4). Still, demand for low cost ODDs is becoming stronger as a result of the commoditization of notebooks.

To meet such low cost needs, Toshiba Samsung Storage Technology Corporation, which is engaged in the DVD drive business, has developed slim DVD recording drives with a refreshed design by using the value engineering (VE) (Note 2) technique (refer to pp. 30–33).

(Note 1), (Note 3) Blu-ray Disc™, Blu-ray™, and BDXL™ are trademarks of the Blu-ray Disc Association.
(Note 2) Value Engineering
A technique to achieve the required functionality at minimal cost by analyzing the value of a product or service in terms of the relationship between function and cost.
Blu-ray disk drives

Media for movies and other content is gradually shifting from DVDs to Blu-ray discs as Blu-ray players and recorders spread. However, the difference compared to DVDs in cost of both Blu-ray disc drives and discs is significant because of the large difference in the production volume and structure. Such differences have become barriers to the adoption of Blu-ray technology. Toshiba and Toshiba Samsung Storage Technology Corporation plan to promote Blu-ray by applying the above-mentioned VE technique also to Blu-ray disc drives and producing key components in-house.

At the same time, in order to provide high-value added products, both companies have been developing technologies to record high quality data at high speeds to the new standard three- and four-layer recording discs (BDXL™ (Note 3)) as well as optical pickups for ultra-slim drives (drive height: 9.5 mm).

Next-generation large capacity optical disc technology and its applications

Various technologies to realize the next-generation large capacity optical discs which will succeed Blu-ray discs have been pursued. Research on methods to significantly increase the number of recording layers of discs from the current maximum of four as well as other methods for using discs by stacking many thin discs on top of each other has been conducted in order to increase the recording capacity per disc volume based on Blu-ray disc technology.

In the meantime, as methods to increase recording density and capacity by using recording principles different from the above, other technologies such as hologram recording, which uses the effect of the interference of light, near field recording, in which data is recorded by reducing light spots, and super high resolution recording have also been studied (refer to pp. 24–29).

Some think that as HDDs will be used widely for data backup and other purposes by both individuals and enterprises because of their high capacity, low cost per byte, and high-speed data transfer capabilities, the range of application of large capacity optical discs will narrow. However, the need to save important data securely for the long term is growing due to increases in the amount of data handled in the fields of official documents, legislation, and medicine; a strengthening of regulations; and an increase in the amount of audio and visual data recorded by families for personal use.

In these fields, the advantages of optical discs, including a reduced likelihood of being affected by fluctuations in temperature, humidity, and other environmental factors; portability and ease of use; and resistance to the elements can all be utilized. To this end, Toshiba has also been researching technologies that can guarantee long-term storage of data as well as technologies for recording data in high quality.

Since 3D movies and high resolutions such as 4K2K (4,096 × 2,160 pixels) are expected to prevail in the future, next generation high capacity technologies to realize high capacity content distribution discs will very likely be developed.

Trends in SSD Technologies

In a computer, the data access speed of the main memory (i.e., DRAM) and that of external storage devices (i.e., HDDs) differ in performance by 5 or 6 digits. To eliminate bottlenecks in system performance by reducing this difference, the deployment of Solid State Drives (SSDs), which use NAND flash memory as their recording media, has been increasing.

Storage systems in which many high-speed HDDs are connected in parallel to maintain system performance can significantly reduce the number of HDDs required through tiering technology that combines SSD with low-speed large capacity HDDs. SSDs significantly improve space efficiency, power consumption, and Total Cost of Ownership (TCO) (Note 4) and are essential system components for achieving green ICT (refer to the boxed article on the next page).

(Note 4) TCO
The entire cost of a complete IT system, including installation, operation, facilities, etc.
Prospects of Storage Devices in the Enterprise Market

In servers and storage systems, storage devices have traditionally been layered based on the frequency of information use. As shown in Figure A, the bottleneck in access performance can now be eliminated by installing an SSD in the top tier (Tier-0). In general, it is considered that 80% or more of data access is concentrated on an area accounting for 20% or less of the entire storage capacity. Storage system companies have put the automatic tiering technologies for extracting high access data (alternately, “hot data”) and reallocating such data on SSDs to practical use.

Using SSDs as data caches is a growing trend, and SSDs directly connected to a Peripheral Component Interconnect Express (PCI Express (Note 5)) bus, which has superior access latency, would show promise for the future.

Growth in the enterprise SSD market remains slow. However, with applied technologies including automatic tiering becoming available and resolution of the bottlenecks on the system side that have thus far hindered SSDs’ intrinsic high-speed performance, it is expected that SSDs will rapidly be deployed in the server and storage system markets, which are the main target markets for enterprise SSDs (Figure B).

In HDDs, in addition to high-speed HDDs for the enterprise market, nearline HDDs, which enjoy superior unit price with regard to capacity thanks to tiering technology, are increasingly used as storage devices for low-access data in cases where particularly high performance is not required. Demand for nearline HDDs is increasing. However, total storage capacity has been increasing exponentially as stated above, and the need for low power consumption at data centers is growing, partly as a result of the adoption of anti-global warming measures. Although current mainstream nearline HDDs are 3.5-type models, it is expected that use of 2.5-type models, which have superior power saving performance, will increase in the future.

(Note 5) “PCI Express” is a trademark or registered trademark of PCI-SIG.
SSDs and HDDs

SSDs and HDDs are both major storage devices, each with their respective strengths (Figure 5). Although HDDs are widely used as storage devices that have good balance with respect to capacity, performance, and reliability, they have data access speed limitations due to their mechanical structure. By contrast, although the access performance of SSDs exceeds that of HDDs by a two-digit figure, HDDs are still less expensive in unit price per gigabyte. As demand for data storage grows in terms of capacity and performance, both drives will coexist by complementing each other.

Characteristics and control technology for SSDs

SSDs are quite different than HDDs in their write endurance and data retention times. Regarding write endurance, SSDs adopt wear leveling technique to average write and erase cycles on the NAND cells, a data management technique to efficiently consolidate fragmented data (garbage collection), and Self-Monitoring, Analysis and Reporting Technology (S.M.A.R.T) for life management. Regarding data retention time, data integrity is ensured by the SSDs’ patrol functionality, which is also effective against read disturb (Note 6) and program disturb (Note 7) phenomena, which are unique to NAND flash memory. Further, the data retention time in the power-off state is compliant with JEDEC standards(3) and can meet system requirements in normal use cases.

(Note 6) Read disturb
If a page is read many times, other pages in the same block are affected.

(Note 7) Program disturb
When writing a program, cells other than the program’s target cells are affected.
### Types of SSD products

Existing SSD products can be classified into client SSDs, which are mainly used for personal computers and terminal devices, and enterprise SSDs (refer to pp. 15–19), which are used for servers and storage systems for data centers and corporate systems (Tables 1 and 2).

### Client SSDs

The main advantages of SSDs include high speed data access, short start-up times, low power consumption, and improved reliability (vibration and shock resistance). Current mainstream client SSDs are compatible with 1.8- and 2.5-type HDD sizes. However, more smaller form factors and system-specific implementation are also available in response to the diversification of client and mobile systems (Figure 6). The flexibility of implementation that HDDs cannot realize is also one of the advantages of SSDs.

---

**Tables 1. SSD classifications and requirements**

<table>
<thead>
<tr>
<th>Class</th>
<th>Operating condition (at power-on)</th>
<th>Data retention (at power-off)</th>
<th>UBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>8 hours/day at 40˚C</td>
<td>1 year at 30˚C</td>
<td>≤ 10⁻¹⁵</td>
</tr>
<tr>
<td>Enterprise</td>
<td>24 hours/day at 55˚C</td>
<td>3 months at 40˚C</td>
<td>≤ 10⁻¹⁵</td>
</tr>
</tbody>
</table>

UBER (Uncorrectable Bit Error Rate): Uncorrectable error rate (number of sectors) per total bits read

* Excerpted from JEDEC standard JESD218A

**Tables 2. Comparison of specifications of client SSDs and enterprise SSDs**

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Enterprise SSD</strong></td>
<td><strong>Client SSD</strong></td>
</tr>
<tr>
<td>Application</td>
<td>Servers, storage systems</td>
</tr>
<tr>
<td>Interface</td>
<td>SAS, (PCI Express), (SATA)</td>
</tr>
<tr>
<td>Form Factor: height (mm)</td>
<td>2.5-inch SFF: 15, 2.5-inch: 7</td>
</tr>
<tr>
<td>NAND type</td>
<td>SLC, (MLC)</td>
</tr>
<tr>
<td>Power source (V)</td>
<td>+5/±12</td>
</tr>
<tr>
<td>Performance</td>
<td>Read/write (IOPS)</td>
</tr>
<tr>
<td></td>
<td>Read/write (MB/sec.)</td>
</tr>
<tr>
<td>Endurance</td>
<td>(Bytes)</td>
</tr>
<tr>
<td>Data protection in the event of power failure</td>
<td>Yes</td>
</tr>
<tr>
<td>End-to-end data protection</td>
<td>Yes</td>
</tr>
<tr>
<td>Sector size (Bytes)</td>
<td>512, 520, 528</td>
</tr>
<tr>
<td>Life (Years)</td>
<td>5 (SLC), 3 (MLC)</td>
</tr>
</tbody>
</table>

USB: Universal Serial Bus  
SFF: Small Form Factor  
PB: 10¹⁵ bytes, TB: 10¹² bytes

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**Figure 6. Trends in reduction of form factor of client SSDs** — SSD products were first released as 2.5-inch-HDD-compatible devices. The size of SSDs is decreasing in response to diversification in the size of systems. Such flexibility of form factor cannot be provided by HDDs. The single package SSD containing the controller and NAND flash memory by using stack technologies will be available.
• Enterprise SSDs

SSDs used for mission critical systems must feature higher reliability, higher endurance, high-speed performance, and guaranteed sophisticated data integrity, among other functions, to ensure 24x7 continuous operations in heavy workload environments.

• Use of MLC

For enterprise SSDs, SLC (Single Level Cell) NAND has been used due to the severe requirements for write endurance. However, in order to meet the requirement for lower unit price per gigabyte, the use of MLC (Multi Level Cell) NAND has been promoted. Adoption of MLC NAND requires increased parallel operations of the NAND flash memories to improve read/write performance, optimization of ECC mechanism, digital signal processing and error recovery algorithm to secure effective write endurance and data retention characteristics, and implementation of dynamic write performance throttling mechanism to manage the endurance and product life.

Future Prospects

The amount of information generated worldwide will continue to increase at an accelerated pace, and as such, storage devices will always be required to realize larger capacity, higher performance, higher reliability, and lower prices. To meet these needs, Toshiba will continue to promote the development of cutting-edge technologies and the commercialization of HDDs, ODDs, and SSDs by taking advantage of both its advanced memory technologies as well as its storage device technologies.

References

(2) TECHNO SYSTEMS RESEARCH ODD Long term forecast Data Y10.xls., Tokyo, TECHNO SYSTEMS RESEARCH CO.,LTD, 2011-01-17.

(Note 8), (Note 9) SLC, MLC
In SLC, one-bit data is stored in a single memory cell. On the other hand, in MLC, multi-bit data is stored in the same cell, but the write speed is slower and the writable count is lower than that for SLC.

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