Solid State Drives
Separating myths from facts

SSD vs HDD? MLC vs SLC? Determine the right technology for the right application. Choose the right performance, endurance and reliability for your mobile computing needs.

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Here's How to Recognize Solid State Drive Myths

There are a lot of myths and misconceptions circulating about solid state drives. As an innovator and industry leader in NAND Flash as well as in 1.8-inch and 2.5-inch hard disk drives for mobile computing, Toshiba would like to provide information to help you separate the reality from the myths.

10 Common SSD Myths

SSD MYTHS

1. Solid state drives are too expensive for mainstream computing ..... Fact
2. SSDs will obsolete hard disk drives ..... Fact
3. There's no clear advantage to SSDs ..... Fact
4. MLC NAND-based SSDs aren't dependable ..... Fact
5. MLC NAND-based SSDs can "wear out" if you write a lot of data ..... Fact
6. Hard drives are more dependable than SSDs because they don't require error correction ..... Fact
7. SSD capacities are too small ..... Fact
8. All SSDs have similar performance ..... Fact
9. Hard disk drives can safely store your data longer than solid state drives ..... Fact
10. SSDs don't reduce power consumption enough to make a difference ..... Fact

Toshiba's SSD products are a collaborative effort developed with expertise from both storage and semiconductor businesses, designed to meet the requirements of the mobile PC OEM and the ultimate end user.

SSD Myth 1

Solid state drives are too expensive for mainstream computing

Fact Like many new technologies, the SSDs that were initially introduced into mainstream computing applications carried a significant price premium in comparison to existing technology, in this case, hard disk drives. The price premium was due in part to their use of Single Level Cell (SLC) NAND technology. Recently, Multi-level Cell (MLC) NAND-based SSDs, which store more than one bit per cell, have become more widely available, enabling high capacities at more competitive prices. Today, Toshiba offers MLC SSDs in capacities up to 512GB. Although today SSDs remain most suitable for those mobile computing users who have a definite need for the increased reliability, ruggedness and performance of a solid state drive, the price premium for SSDs compared to HDDs is decreasing.

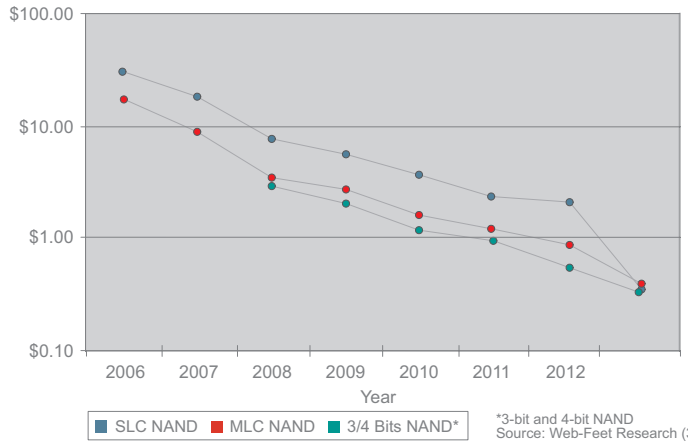
As the price of SSDs continues to decline due to increases in volume, advances in NAND process technology and the expected price curve for semiconductor memory products, more and more users will find the value/performance of a MLC SSD to be attractive. Most market analysts forecast that in 2009 and 2010, the mobile computing market will begin to show significant adoption of SSDs, growing to approximately 25% of the notebook market by 2012. Although SSDs will still carry a price premium over HDDs, as the price difference decreases, many users will find the extra cost to be worth the improved performance, reliability and ruggedness.

The important thing when choosing MLC vs. SLC SSD is to have the right technology for the right application. Based on our usage modeling, Toshiba believes that MLC-based SSDs are a good fit for most mobile computing applications, while SLC-based SSDs may be better suited for high performance enterprise applications.

According to market analyst Web-Feet Research, the evolution of semiconductor technologies and the continuous increase in chip density have contributed to a steady decrease in the relative cost of semiconductor storage. Annual average flash memory per GB price declines of 40 percent are expected to drive down aggregated SSD unit prices by 27 percent per year. This trend is expected to continue throughout the forecast period at a steady pace. By 2012, the price per gigabyte is projected to be approximately 1/26 that of the 2006 price[1].

[1]Web-Feet Research, SSD Markets and Applications Quarterly Series, 1Q 2008.

Semiconductor Memory Price Trend: 2006-2012



*3-bit and 4-bit NAND
Source: Web-Feet Research (3/08)

Performance. Endurance. Reliability.

Compared to hard disk drives, solid state drives offer several advantages for the mobile computing market – performance, ruggedness, and light-weight, compact form factors.

SSD Myth 2

SSDs will obsolete hard disk drives

Fact There is a definite market opportunity for the performance and reliability advantages of SSDs. However, we expect SSDs to coexist with HDDs for the foreseeable future because there is a role for both storage technologies. Toshiba and many market analysts expect SSDs to begin to gain traction in the market in 2009, growing to approximately 10% of the notebook market in 2010/2011. Toshiba expects the value/performance of its MLC NAND-based SSD line-up to help speed the acceptance of solid state storage among early adopters of notebooks and ultra-mobile PCs (UMPCs).

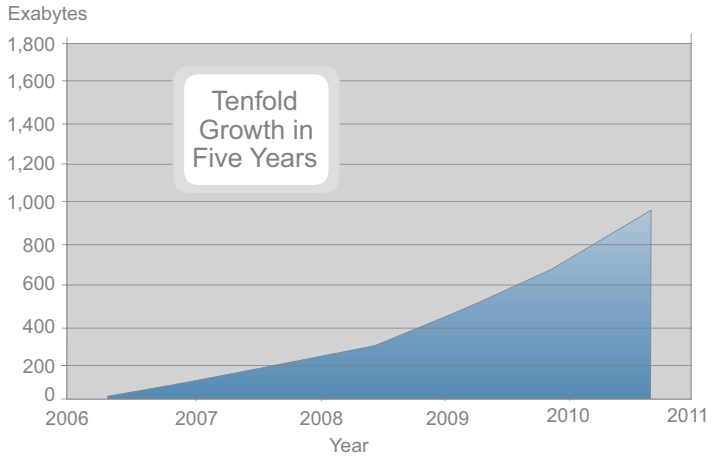
According to IDC, digital storage is growing at a phenomenal pace. In 2006, 161 exabytes (that's 161 billion gigabytes) of digital data was created, captured and replicated, generated by over 1 billion devices including digital cameras, camera phones, medical scanners and surveillance cameras, as well as computers. By 2011, digital data is expected to grow ten-fold to approximately 1,800 exabytes[1]. Major contributors to this growth include film to digital image capture, analog to digital voice, analog to digital TV, Internet, email and IM. In this vast storage market, there's plenty of room for both hard disk drives and SSDs, to provide choices for optimal retrieval of stored data.

Toshiba is an industry leader in both small form factor HDDs and in NAND flash technology, and offers a broad selection of digital media products based on different storage technologies. The breadth of products and markets in which these solutions play shows Toshiba's insight into the requirements, possibilities and future directions of the quickly changing landscape for storage technologies. In the end, we see HDD and NAND Flash as two critical storage solutions which each have long term viability due to their individual attributes and which will be adopted in applications for which each is best suited.

[1]Source: IDC White Paper, "The Diverse and Exploding Digital Universe", sponsored by EMC, March 2008.

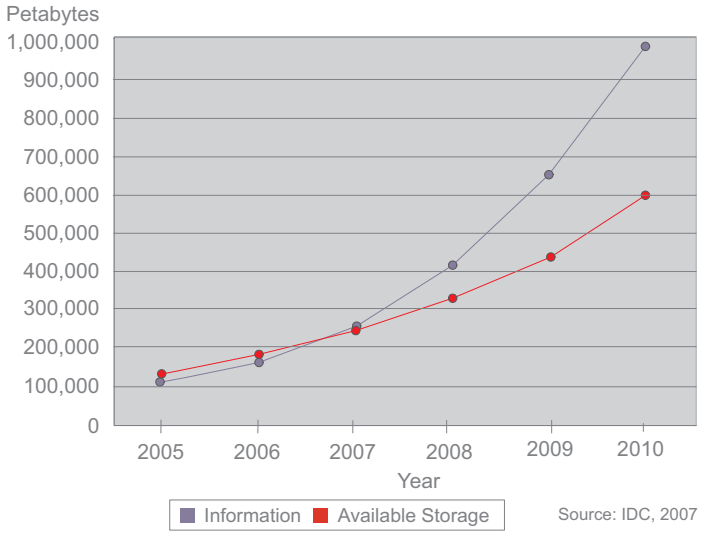
Flying saucers and UFOs have their place, just not in the SSD world.

Digital Information Created, Captured, Replicated Worldwide



Source: IDC, 2008

Information vs. Available Storage



Source: IDC, 2007

SSD Myth 3

There's no clear advantage to SSDs

Fact Compared to hard disk drives, SSDs realize a number of advantages that address needs in the mobile computing market for performance, ruggedness, and lightweight, compact form factors. On the performance side, these advantages include faster boot time and faster random read and random write, which translates to less waiting time at start-up and when opening files. Public demonstrations by SSD manufacturers at various industry conferences and trade shows, including the Consumer Electronics Show have clearly documented faster boot time (typically about half that required for an HDD) and faster file access. The time to find a file on the drive is measured in millionths of a second for SSDs and in thousandths of a second for HDDs, so the difference adds up.

In internal testing[1], Toshiba 56nm MLC NAND SSDs achieved overall PCMark05 benchmark scores nearly comparable to available competitive SATA SLC NAND SSDs and better than 5400 rpm and 7200rpm HDDs. They also excelled in Windows® Vista boot speed, application loading, general usage and virus scan. Toshiba 43nm MLC SSDs, scheduled for mass production in Q1 2009, provide a substantial increase in performance over the previous generation, with a maximum sequential read speed of approximately 240MB/sec. and a maximum sequential write speed of 200MB/sec.

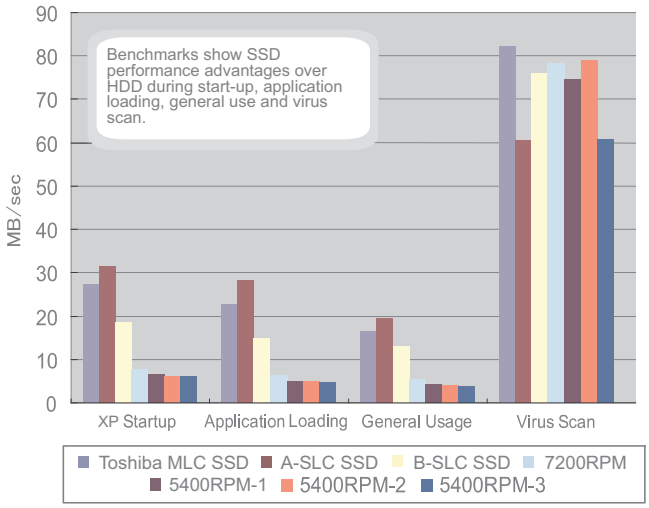
Perhaps even more important to the mobile user are the advantages in terms of higher reliability and ruggedness. Because they have no moving parts, SSDs can withstand greater shock and vibration, and have the added benefit of quieter operation. According to Web-Feet Research[2], 2.5-inch hard drives for computing applications can withstand 350Gs of operating shock and 900Gs of non-operating shock, while MLC and SLC NAND-based SSDs can withstand >1500Gs for both operating and non-operating shock. For vibration resistance, 2.5-inch drives can withstand 0.7Gs vibration, while both MLC and SLC NAND-based SSDs can withstand 20Gs or more.

As an added benefit, SSDs can also be configured to smaller form factors and reduced weight compared to hard drives.

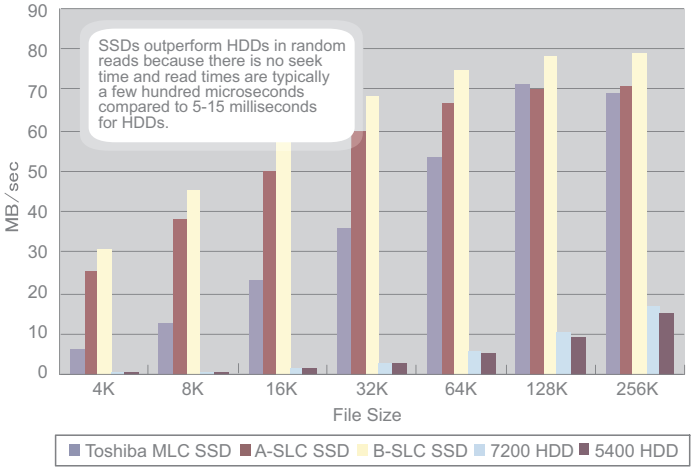
[1]Based on internal tests by Toshiba Corporation. Conditions and configurations: Benchmark tests PCmark, IOmeter and SYSmark, using Intel Core2Duo 2.2GHz E4500 CPU with 2MB L2 cache, 2GB DDR SDRAM with 800MHz FSB, Intel GMA3100 graphics, and Windows® Vista OS.

[2]Market data on SSD and HDD from Web-Feet Research, SSD Markets and Applications Quarterly Series: 1Q 2008, based on average performance of products available as of the date of the report.

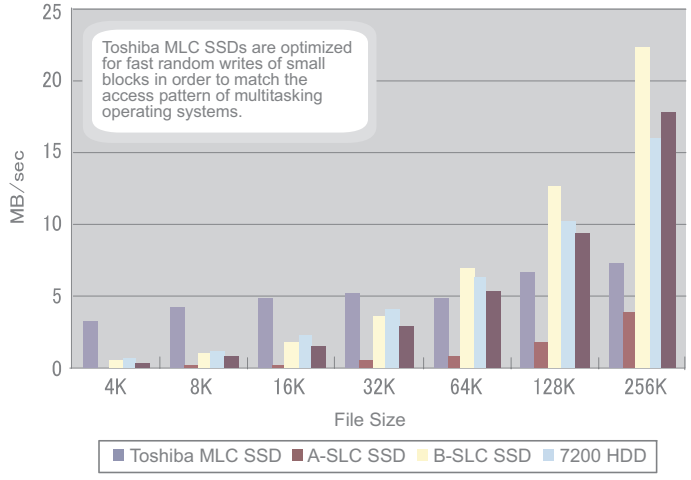
Benchmark by PCmark05



Benchmark by IOmeter Random Read



Benchmark by IOmeter Random Write



SSD Myth 4

MLC NAND-based SSDs aren't dependable

Fact Some commentators have said that MLC NAND based SSDs aren't as dependable as SLC NAND drives, citing a lower number of write cycles and a greater requirement for error correction. Overall, both MLC and SLC types of SSD are more reliable than HDDs because they have no mechanical parts. This additional ruggedness and reliability is the reason flash-based SSDs have been used since the mid-1990's in military and mission-critical applications.

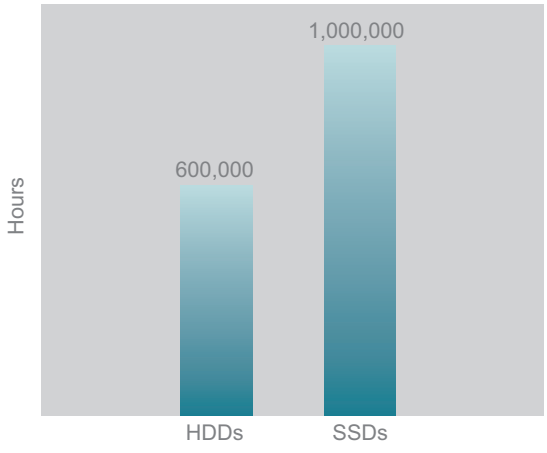
According to Web-Feet Research[1], for PC applications, one may conclude that SSDs are more reliable based on published Mean Time To Failure[2] (MTTF) rates of 1,000,000 hours vs. HDDs in PC applications with MTTF of approximately 600,000 hours.

Both HDDs and SSDs use error correction, and the industry convention for both types of drive is to correct bit errors to one non-recoverable error in 10E14 bits read, or one in approximately 12.5 terabytes. (For more about error correction, please see Myth #6. For more on write cycles, please see Myth #5.)

[1]Web-Feet Research, SSD Markets and Applications Quarterly Series, 1Q 2008, Table 76.

[2]The (MTTF) Mean Time to Failure is not a guarantee or estimate of product life; it is a statistical value related to mean failure rates for a large number of products which may not accurately reflect actual operation. Actual operating life of the product may not resemble the MTTF.

MTTF (Mean Time To Failure)



Source: Web-Feet Research
SSD Markets and Applications
Quarterly Series, IQ 2008, Table 7(

SSD Myth 5

MLC NAND-based SSDs can "wear out" if you write a lot of data

Fact It's true that MLC NAND drives are rated for a smaller number of write cycles than SLC NAND-based drives, but the important thing when choosing MLC vs. SLC is to have the right technology for the right application. Based on our usage modeling, Toshiba believes that MLC-based SSDs are a good fit for most mobile computing applications, while SLC-based SSDs may be better suited for high-performance enterprise applications.

Absent any industry standard usage model, Toshiba developed an internal model and studied usage patterns for normal and heavy users. To even begin to reach a conservative endurance limit of a 64GB[1] MLC NAND-based SSD with wear-leveling technology, a mobile user would have to write approximately 40 Terabytes[2] (forty trillion bytes) of data over the expected five-year life of the drive. That's equal to approximately 22GB of new data per day, every day – or enough to fill 4.6 DVDs, or 32 CDs daily. With a 128GB drive, for example, the wear would be spread over a larger storage area, effectively doubling the average daily write limit to 44GB, or more than 9 DVDs. In the Toshiba usage modeling study*, typical users wrote approximately 1.4GB/day, and heavy users wrote about 5.2GB/day. Further analysis showed that auto-save and hibernate features could increase total data written per day to 2.4GB for the typical user and 9.2GB for heavy users. Although the specifications of Toshiba MLC SSDs exceed the 40 Terabyte example provided, it may help demonstrate that the endurance limit is so far beyond the likely usage of a typical mobile computer user that it isn't a realistic cause for concern.

In comparison, Toshiba also compared the daily write volume for PC-class SSDs using MLC and SLC technology. For a 128GB SLC NAND drive, the daily write volume incrases to approximately 500GB per day over a five year life, while the 256GB and 512GB drives could support write volume of 1 Terabyte and 2 Terabytes per day, respectively.

(continued on next page.)

**Toshiba internal study involving 237 mobile computer users.*

SSD Myth 5 (continued)

Endurance: MLC vs. SLC

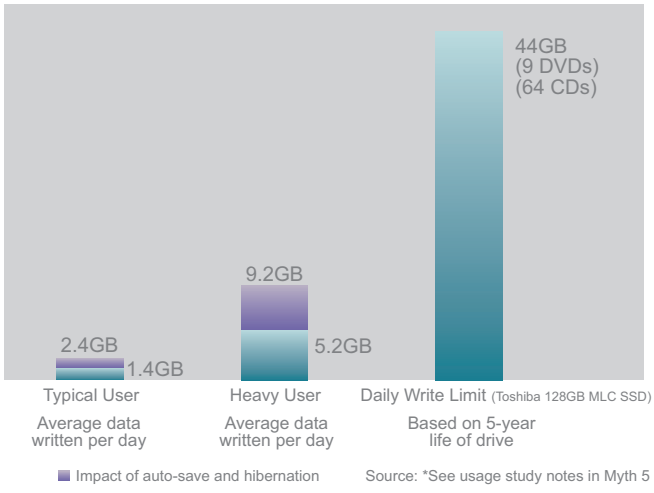
Estimated Average Daily Write Limit

	MLC	SLC	Notes
512GB	176GB[1]	2TB[2]	• Average GB/day write limit based on 5-year product life
256GB	88GB	1TB	• Manufacturers typically warrant HDDs for 3-5 years
128GB	44GB	500GB	• Estimate assumes 1,400 W/E MLC and 50,000 W/E SLC and write amplification factor
64GB	22GB	250GB	

This comparision demonstrates that the endurance limit of an MLC NAND solid state drive is so far beyond the likely usage of a typical mobile computer user that it isn't a realistic cause for concern. Users who write a great deal of data can choose a higher capacity drive.

Toshiba Usage Model Study*

Average Data Written Per Day



[1]When used herein in relation to memory density, gigabyte and/or GB means 1,024x1,024x1,024 = 1,073,741,824 bytes. Usable capacity may be less. For details, please refer to specifications.

[2]When used herein in relation to memory density, terabyte and/or TB means 1,024x1,024x1,024x1024 = 1,099,511,627,776 bytes. Usable capacity may be less.

SSD Myth 6

Hard drives are more dependable than SSDs because they don't require error correction

Fact Both HDD and SSD drives utilize error correction algorithms to ensure that data is stored safely. Just as a hard disk drive is widely accepted with little concern about bad sectors, NAND works in a similar way in that the controller maps around bad memory areas and error correction code (ECC) is used to correct bit errors. Controllers for NAND flash have built-in ECC to automatically correct bit errors. The industry standard is to correct any bit error to a level comparable to that of hard disk drives. System designers have long been aware of using ECC to detect and correct errors. Historically, memory subsystems have used Hamming code, while Reed Solomon ECC is common in hard drives and CD-ROMs.

MLC NAND-based SSDs do require more complex error correction than those using SLC NAND, but this function is taken care of by the integrated controller, and is transparent to the user. The error rate of a Toshiba MLC-based SSD is rated to be equivalent to that of a PC-class SLC SSD or an HDD.

High-Capacity MLC NAND SSD: 512GB

For the SSD market, MLC NAND enables greater capacities in a small form factor. As one of the first companies to enter the solid state drive market with a family of products based on MLC NAND technology, Toshiba has achieved a 256GB drive in both 1.8-inch and 2.5-inch form factors and recently expanded its SSD family to include a 2.5-inch 512GB SSD. In addition, Toshiba offers small size 8GB,16GB, and 32GB Flash modules for Netbooks.

SSD Myth 7

SSD capacities are too small

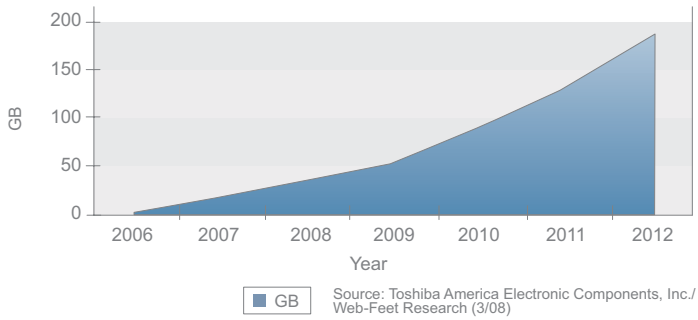
Fact Some of the early SSDs on the market for computing applications have been small, with capacities of 32GB or even less, in an effort to make them more affordable during the early phase of the SSD market in notebook computers.

A 2007 IDC study found that 40GB was the most popular capacity for 2.5-inch HDD in mobile computers from 2005 through 2007. Larger, 80GB drives are now gaining in popularity and are expected to become the sweet spot in early 2008[1].

Toshiba was one of the first companies to enter the solid state drive market with a family of products based on MLC NAND technology. Today, Toshiba has achieved a 512GB in a 2.5-inch form factor, and also offers MLC NAND SSDs in capacities from 64GB to 512GB, in various form facors including 1.8-inch and 2.5-inch drives, and SSD Flash Modules. Toshiba also offers SSD Flash Modules for netbook computers in capacities of 8GB, 16GB and 32GB. Capacities for SSDs are not expected to be a limiting factor as value/performance improves with advances in NAND technology combined with the historical price decline in semiconductor storage.

[1]IDC "Worldwide Hard Disk Drive 2007-2011 Forecast and Analysis: Creating Space for an Expanding Digital Universe," May 2007.

SSD Trend, Average GBs



Source: Toshiba America Electronic Components, Inc./ Web-Feet Research (3/08)

Toshiba MLC SSD Family Capacities

- 1.8" and 2.5", module
- Capacities: 64GB, 128GB and 256GB at 56nm, 64GB to 512GB at 43nm in Q109.
- 256GB at 43nm
- 512GB in Q109, and higher capacities as demand warrants

SSD Myth 8

All SSDs have similar performance

Fact Not all SSDs are created equal. Just taking a controller and NAND and putting it in a drive enclosure does not make a successful SSD. The early market indications that not all SSDs are meeting expectations can be attributed in part to this concern.

We believe that three factors are critical: the design of the controller, proven NAND flash technology and experience with the hard disk drive market. The architecture of the controller can have a significant impact on endurance, wear-leveling and performance, and SSD architectural features such as DRAM cache and parallel design are critical to better performance, but are not apparent to the end user. As an innovator of NAND flash since the 1980's, Toshiba has found that experience plays a significant role in maintaining quality and yield with each process migration as well as in moving to multi-level cell technologies to store more than one bit per cell. Toshiba's SSD products are unique in that industry as they are a collaborative effort developed with expertise from both storage and semiconductor businesses, designed to meet the requirements of the mobile PC OEM and the ultimate end user.

MLC NAND Leadership

- World's most experienced producer of NAND Flash
- World's second largest Flash memory supplier[1]
- Principal innovator of NAND and NOR Flash
- 32Gb[2] NAND chip fabricated with cutting-edge 43nm process
- 32GB[3] NAND and controller in a single package
- Japan's largest 300mm wafer fab
- Consistent semiconductor capital investments of ~$2B annually

INVENTOR OF FLASH MEMORY

[1]iSuppli NAND Flash Supplier Rankings, 2007.

[2]When used herein in relation to memory density, gigabit and/or Gb means 1,024x1,024x1,024 = 1,073,741,824 bits. Usable capacity may be less. For details, please refer to specifications.

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SSD Myth 9

Hard disk drives can safely store your data longer than solid state drives

Fact Although hard disk drives do not have a specified endurance limit in terms of the number of write cycles, they do have higher failure rates, and can fail suddenly. (For a discussion of the SSD endurance limit and why it is so far beyond the likely usage of a typical mobile computer user that it isn't a realistic cause for concern, please see Myth #5.) For both types of drive, best practices for data management will still involve backing up your data.

Industry observers have noted that Total Cost of Ownership may be reduced with SSDs, with savings coming from lower support and replacement costs, as well as reduced costs for recovering data from a failed hard drive, and reduced productivity losses due to time without a PC.

HDDs are generally expected to last three to five years, and Toshiba SSDs are designed to match this level of performance, both in endurance and data retention.

MLC NAND for Mobile Computing
High Density. Cost Effective.

Early solid state drives on the market for notebooks were based on single level cell (SLC) NAND, which stores one bit of data per memory cell. MLC NAND can store two or more bits of data per cell, enabling higher density storage in a small form factor and more cost-effective storage per gigabyte.

MLC technology has helped achieve the increases in capacity and cost/performance that have made NAND flash an attractive storage technology. MLC NAND has been widely accepted in the consumer market in removable storage devices such as memory cards and USB flash drives, as well as in embedded applications in MP3 players, GPS and mobile phones.

SSD Myth 10

SSDs don't reduce power consumption enough to make a difference

Fact There have been articles and blog posts that claim SSDs reduce power significantly compared to HDDs, and can therefore help extend battery life in mobile computing. On the other hand, other commentators have said that the power difference isn't significant.

There are elements of truth to both sides of this argument. According to a study by market analyst firm Web-Feet Research[1], SSD drives with SATA interfaces for PC applications typically consume 0.5W during read and 1.0W during write operations compared to 2.0W during read and 1.8W during write for 5400 rpm 2.5-inch HDDs, and 2.3W during read and 2.1W during write for 7200 rpm 2.5-inch SSDs. This means that for read operations, SSDs consume about 75% less power than HDDs, and for write operations, about 50% less. However, there are very low power 1.8-inch hard drives on the market that reduce these differences.

On a system level basis, which is what the user can most easily observe, the storage system typically uses only 5 to 15% of the total power required by a mobile PC. As a result, the additional battery life may only turn out to be a few additional minutes per charge, depending on the individual notebook, battery and drive. The display and processor account for the largest percentage of the power use.

[1]Web-Feet Research, SSD Markets and Applications, Quarterly Series: Q1 2008.

Storage and Semiconductor Expertise

Products in Every Major Brand of Notebook Computer

Toshiba is an industry leader in both small form factor HDDs and in NAND flash technology, and offers a broad selection of digital media products based on different storage technologies. Toshiba storage products are used by every major brand of notebook computer.

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Toshiba America Electronic Components, Inc.
19900 MacArthur Blvd, Ste 400, Irvine, CA 92612