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WHITE PAPER

MLC Solid State Drives: Accelerating the Adoption of SSDs

Sponsored by: Toshiba

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IN THIS WHITE PAPER

In this IDC white paper, sponsored by Toshiba, IDC explores the opportunity for solid state drives (SSDs); specifically, the advantages multilevel cell (MLC) NAND-based SSDs bring to the market, the market segments most likely to benefit from MLC SSDs, and the opportunity for MLC NAND-based SSDs.

SITUATION OVERVIEW

The computing market is a large, well-established market, but it is by no means static. The way people use their PCs today is different from the way they used them just a few years ago. As this market matured, PCs evolved to suit a wider array of usage models, as evidenced by a number of different dynamics:

- The shift to portable PCs from desktop PCs
- The enormous rise in digital content that touches both our personal lives and our professional lives on a daily basis
- The newer forms of devices, such as ultramobile PCs (UMPCs) or ultra-low-cost PCs (ULCPCs).

Storage and storage requirements are not immune to these dynamics and are evolving as well. Hard disk drive (HDD) technology is over 50 years old and has been a key enabling factor in the rise and success of the computing market through its ability to provide high capacities, good performance, and reliable storage at low prices. However, storage requirements are changing, and it is difficult for one storage technology to satisfy every use scenario related to storage. As markets change, system OEMs insert other requirements into the decision matrix when choosing a storage solution. Price and storage capacity have long been the main requirements of any storage solution; however, form factor, reliability, performance, energy efficiency, and environmental metrics increasingly are becoming more important characteristics in the decision process.

Enter SSDs into the marketplace. An SSD is built using semiconductor memory, typically NAND flash memory, to store data rather than a spinning magnetic platter that is used in a traditional HDD. As a result, SSDs offer a number of advantages over other storage solutions:

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- **Performance.** With no mechanical armature to move, SSDs have virtually no latency time and can provide very fast access to the data stored. As shown in Figure 1, the difference in access times between typical SSD and HDD solutions is rather large and translates into faster performance in certain applications and functions.

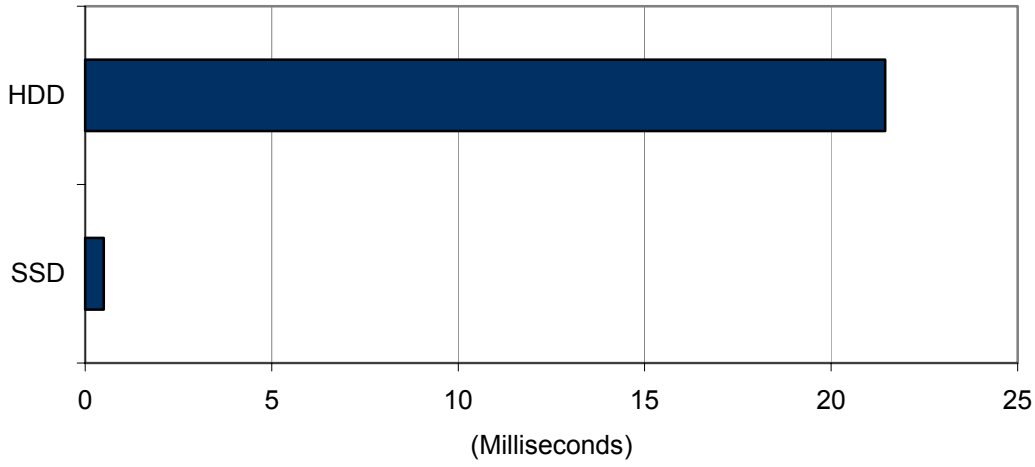
- **Reliability.** Specifications of SSDs on the market indicate that they provide a high mean time between failure (MTBF) and have a low probability of mechanisms that cause an entire SSD to fail. Intuitively, this thesis would seem to be true; however, this metric has yet to be validated in the market with years of historical experience and field data.

- **Energy efficiency.** SSDs should offer lower power consumption, resulting in increased usage time when operating on battery power.

- **Environmental.** SSDs are not restricted to HDD form factors and can offer various capacities in form factors that can be tailored to unique system device design requirements. In addition, SSDs have a high tolerance for wide temperature and humidity ranges and shock/vibration. They also produce no audible noise.

FIGURE 1

SSD and HDD Disk Random Access Time



Source: IDC's Benchmarking Study, 2008

SSDs have garnered the attention of consumers and PC OEMs alike as they seek to take advantage of these benefits. SSD-based laptop PCs have been in the market for some time. Yet, through 2007, SSD adoption was limited. IDC believes a number of factors are on the horizon that should accelerate the adoption of SSDs into PCs.

FUTURE OUTLOOK

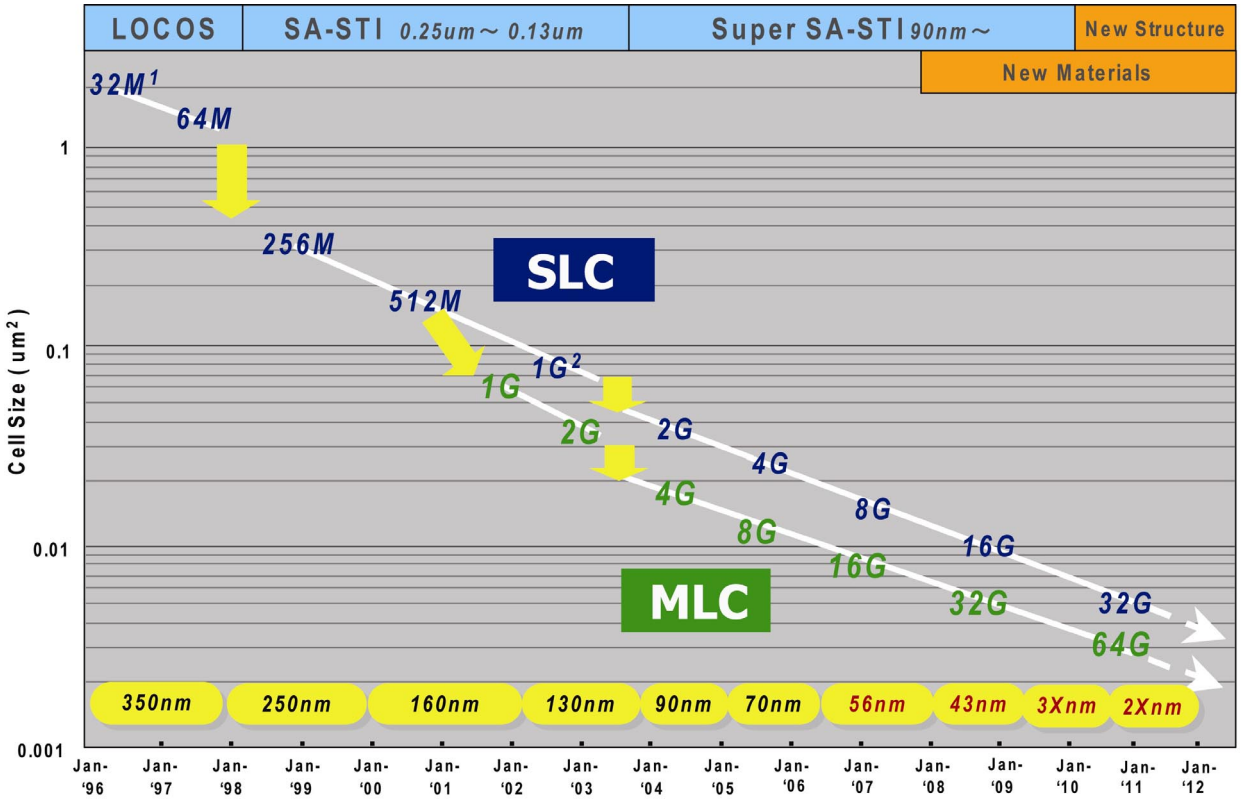
The Opportunity for Solid State Drives

SSD technology does not have the half-century of legacy and experience associated with HDD technology. Nevertheless, the growth and advancements in NAND semiconductors have enabled a significant opportunity for NAND-based SSDs, and there is growing evidence that SSDs are on the cusp of making tangible inroads into markets currently dominated by HDDs as well as enabling new markets.

The semiconductor industry has been able to provide higher capacities at lower prices by aggressively scaling process technology to smaller and smaller dimensions. Toshiba's NAND flash technology roadmap, shown in Figure 2, highlights these dynamics. The result of this scaling translates into higher-capacity and more affordable SSDs. However, while process scaling provides significant advantages, it is only one dimension that helps to accelerate the adoption of SSDs in the market.

FIGURE 2

Toshiba's NAND Product Roadmap



[1] When used herein in relation to memory density, megabit and/or Mb and/or M means 1,024x1,024 = 1,048,576 bits.

[2] When used herein in relation to memory density, gigabyte and/or GB and/or G means 1,024x1,024x1,024 = 1,073,741,824 bytes

Source: Toshiba, 2008

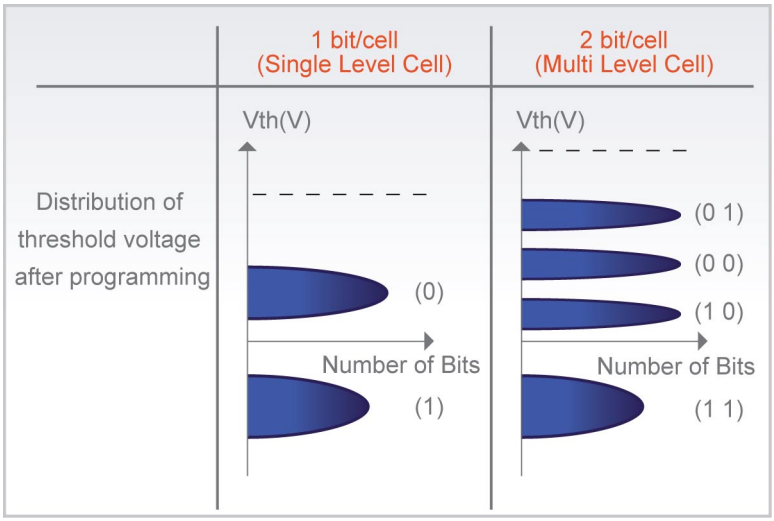
MLC Versus SLC SSD Technology

Another big advancement for NAND technology is the use of MLC technology. Today's NAND flash is based on two types of technologies: single-level cell (SLC) and MLC. Today, MLC NAND stores 2 bits or more in a given cell, whereas SLC NAND stores only 1 bit (see Figure 3). The result is twice the capacity for the devices when using 2-bit MLC technology compared with SLC devices. Thus, MLC offers a higher density and lower cost per bit than its SLC sibling.

As a result, the majority of the NAND flash shipped is MLC because its performance and endurance are more than sufficient for many applications. In fact, these metrics have enabled growth in a number of markets, including MP3 players, portable media players, cell phones, and USB thumb drives. The key to selecting NAND is to match the performance requirements for SLC versus MLC to the right application.

FIGURE 3

MLC and SLC Technology



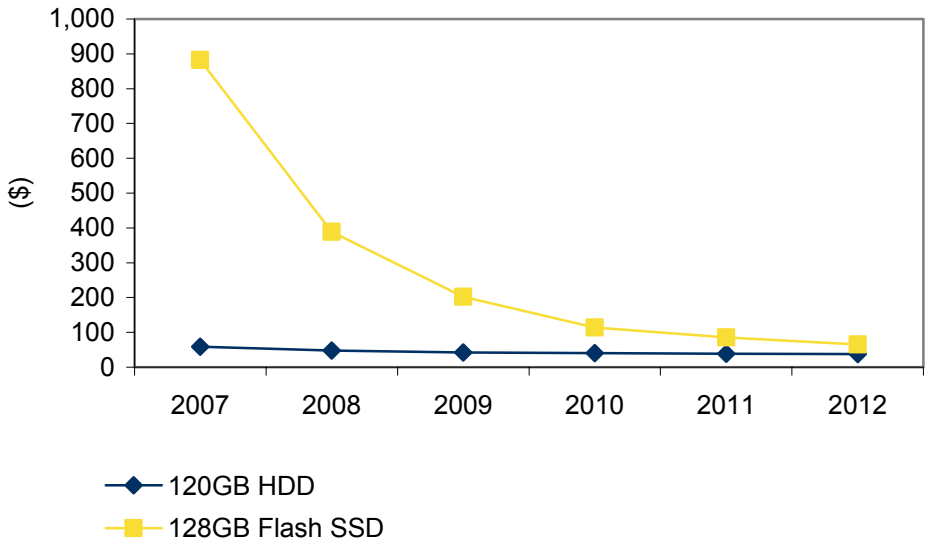
Source: Toshiba, 2008

One notable drawback with MLC NAND is its endurance, considered generally to be one-tenth the endurance of SLC flash (typically specified at 10,000 write/erase cycles for MLC versus 100,000 for SLC). In addition, MLC NAND generally has other aspects, including slower write speeds and higher bit error rates compared with SLC NAND. Consequently, although MLC NAND flash has been available on the market for some time, given the complexity and trade-offs of implementing MLC NAND in SSDs, through 2007, all SSDs were built using SLC technology.

Like it or not, cost has been and will continue to be an important metric that will monopolize the priority list of PC and consumer OEMs. Figure 4 illustrates IDC's expectations of the cost curves associated with 120GB HDD and 128GB SSD devices. The HDD price reflects a blended average of all 2.5in. HDDs (all revolutions per minute [rpm] below 10,000rpm), and the SSD price reflects a blended average as SSDs transition from SLC and MLC technology.

FIGURE 4

ASP Comparison for 120GB HDD Versus 128GB Flash-Based SSD, 2007–2012



Source: IDC, 2008

Ultimately, MLC-based SSDs are necessary to accelerate SSD adoption further. MLC-based SSDs will provide not only a reasonable absolute cost at certain capacity points as shown in Figure 4 but also a competitive price per GB compared with HDDs and the ability to offer higher-capacity SSDs. In addition, MLC NAND has a solid roadmap for the future (shown previously in Figure 2) to provide the right mix of performance requirements. This includes the ability to offer 3 and 4 bits per cell of MLC technology, which augments the bit density and increases the competitiveness of MLC-based SSDs further.

In 2008, MLC-based SSDs became available commercially with significantly more sophisticated controllers than those of previous generations of SSDs. This advancement helped to mitigate some of the key challenges of using MLC NAND and softened many of the concerns relative to performance, endurance, and reliability. Moreover, MLC-based SSDs will enable OEMs to reduce the cost quickly and significantly and lower the average price per gigabyte of an SSD. The result should be an acceleration in the market adoption of SSDs by achieving more acceptable price points in a broad range of devices.

Not All SSDs Are Created Equal

SSDs are more than just NAND flash memory. SSDs are self-contained storage devices that consist of an interface to connect to the host device, an advanced device controller, and the semiconductor memory components packaged in a single device. As such, SSDs contain a number of advanced features that distinguish the technology from just NAND memory in terms of performance and reliability. These advanced features have the potential to make SSDs a compelling storage solution depending on a system OEM's storage and design requirements.

The way SSDs are architected and the way the controller and firmware operate are vitally important to deliver a complete storage solution. Sophisticated controllers and advanced architectures are used to increase the performance and reliability of SSDs. The manner in which the NAND memory is managed, life-cycle management, built-in wear leveling, and error correction codes (ECCs) are some of the key elements in differentiating SSDs in terms of performance and endurance of the device.

Nevertheless, the performance of the MLC NAND component is not a constraining factor in developing an SSD for many applications because the controller and drive architecture can achieve improved performance through techniques such as interleaving multiple banks of memory, caching, and sophisticated wear-leveling algorithms. These enhancements can make it possible to use lower-cost MLC NAND to help balance the cost/performance requirements of SSDs.

Managing Endurance

Recall that NAND memory has an endurance limitation related to the number of write/erase cycles per block. On the surface, this may appear to be a factor limiting SSD adoption. However, by managing NAND effectively and considering the frequency with which data is written in a PC environment, published SSD endurance is likely to be much greater than the underlying NAND memory. In fact, the following strategies and advanced techniques help to overcome this endurance limitation:

- **Large error correction capabilities.** ECC commonly is used in HDDs to guard against bit failures that lead to data corruption. Similar technology is used in SSDs for the same reason.
- **Sophisticated wear-leveling schemes.** To keep a block of cells from being overused, wear-leveling algorithms are integrated into the controller to help ensure that cells are written to in a way that is evenly distributed over all of the resident cells.
- **Overprovisioning capacity.** Additional capacity is included to provide spare blocks to replace those that go bad and room for wear-leveling algorithms to operate. While this spare area enhances the reliability of NAND flash, a 128GB SSD may actually have 156GB, for example, of integrated NAND memory to provide headroom.

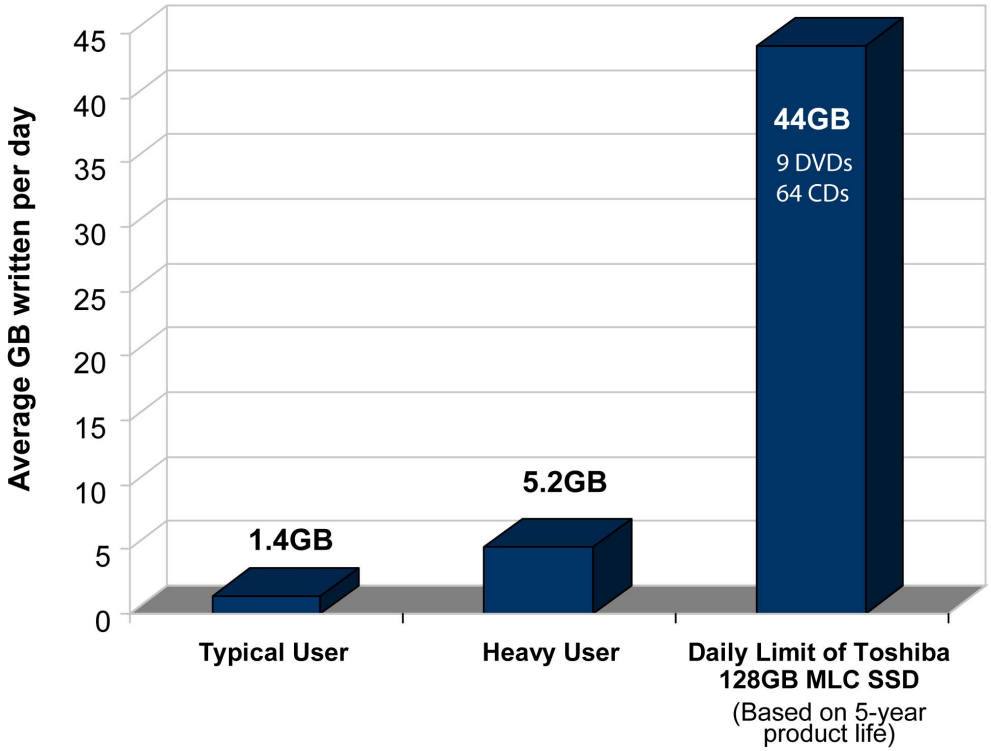
SSD controllers manage these advanced features and help to make SSD solutions suitable for high-capacity storage with the necessary three to five years of expected device life. Depending on the application for which the SSD is intended, the life expectancy could be extended further.

The environment in which SSDs are used or the anticipated usage model is another consideration in managing endurance, and this is an important consideration in matching the performance requirements to the right application. With the lack of any industry-standard usage model for NAND-based SSDs, Toshiba developed an internal model and studied usage patterns for typical and heavy mobile computer users. In the Toshiba usage modeling study, typical users wrote approximately 1.4GB per day, and heavy users wrote about 5.2GB per day. Other studies have identified usage models that also show that the average daily write volume in gigabytes written by PC users is well within the projected MLC write endurance.

To understand how this could translate into SSD endurance for a mobile PC, consider a 64GB MLC NAND-based SSD with wear-leveling technology. A mobile user would have to write approximately 40 terabytes (40 trillion bytes) of data over the expected five-year life of the drive, which equates to approximately 22GB of new data per day, every day, or enough to fill 4.6 DVDs (each with a capacity of 4.7GB), or 32 CDs, daily. With a 128GB drive, the wear would be spread over a larger storage area, effectively doubling the average daily limit to 44GB, or more than 9 DVDs, as seen in Figure 5. This reveals how the endurance limit of MLC-based SSDs could be far beyond the likely usage of a typical mobile computer user.

FIGURE 5

Average Data Written per Day



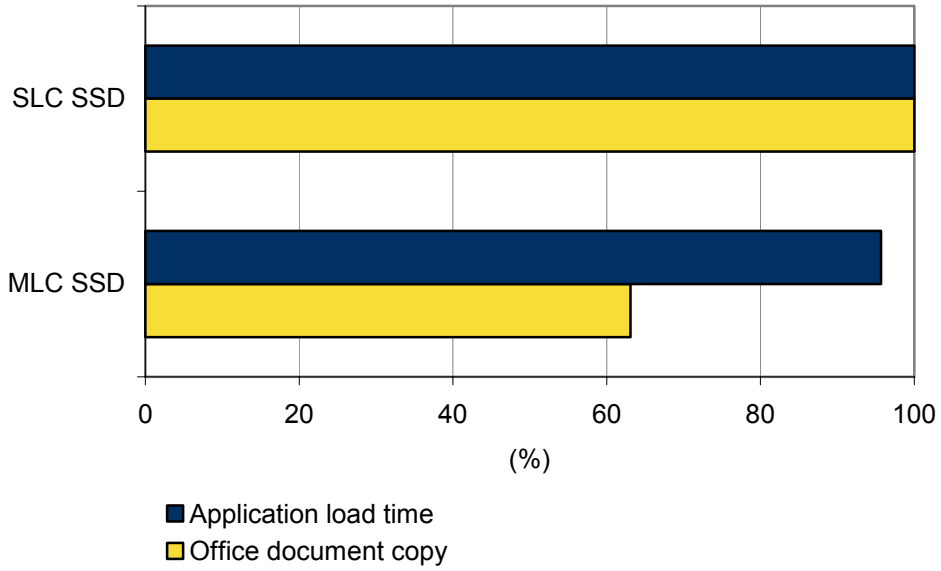
Source: Toshiba's Usage Modeling Study, 2008

Managing Performance

Not all SSDs are created equal on the performance side either. In theory, SLC-based SSDs should outperform MLC-based SSDs in the majority of performance metrics. However, despite all the challenges associated with MLC-based SSDs, IDC found that MLC-based SSDs can indeed outperform SLC-based SSDs. Figure 6 illustrates two tests and the relative performance between SLC and MLC SSDs. These tests, commissioned by IDC, were done by a third-party testing firm. Note that the MLC SSD loaded an application about 5% faster and copied a Microsoft Office Word document nearly 40% faster than the SLC SSD. The results of these and other tests highlight the importance of the SSD architecture and controllers in creating state-of-the-art SSDs suitable for mainstream adoption.

FIGURE 6

SLC and MLC SSD Relative Performance



Source: IDC's Benchmarking Study, 2008

The Opportunities That SSDs Can Enable

SSDs are enabling new usage models and enhancing existing usage models. As we peer into the future, we expect a number of other trends to influence the way PCs are used and to have the potential to increase SSD adoption:

- Increased availability of broadband access and online storage or "cloud computing" has the potential to lessen local storage capacity requirements through increased access to networked storage, applications, and content.

- Increased security concerns or the threat of unauthorized access to sensitive corporate data is another industry dynamic that has the potential to impact capacity requirements. End users and corporations increasingly are focused on exactly what content — especially sensitive corporate data — must be saved, where to store it, and for how long. As such, limiting the amount of storage capacity on notebook PCs is one method to limit the risk of these concerns and could favor SSD adoption.

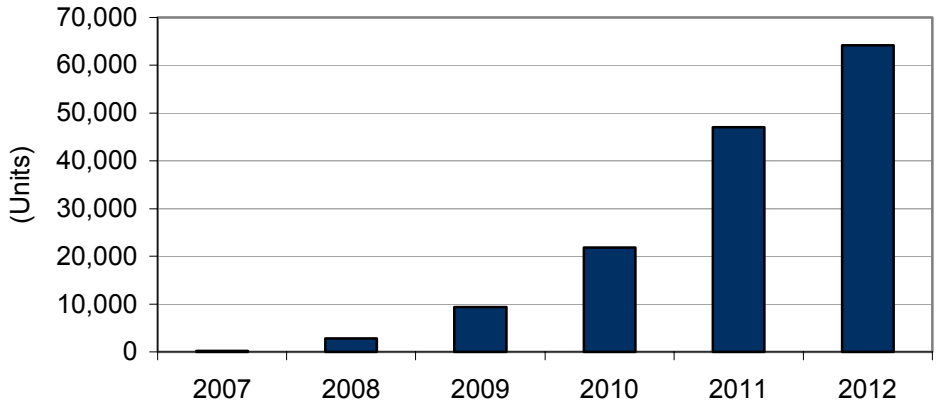
- Increased mobility is changing the storage requirement of devices, such as UMPCs. The PC market is transitioning from a market dominated by desktop shipments to one dominated by notebook shipments as mobility and durability have become increasingly important. These dynamics align well with the benefits of SSDs.

- Emerging PC devices, such as the ultra-low-cost PC (ULCPC), that offer low-capacity points in highly portable devices are an example of a usage model that SSDs help to enable. The early success of some of these devices provides an example of where flash memory in the form of SSDs may provide "good enough" storage capacity and performance for a mobile computing product for its intended application. This represents a near-term opportunity for NAND flash memory and SSDs to showcase the benefit of solid state technology when implemented in an effective manner. Coupled with ubiquitous broadband and cloud computing, this could be a powerful combination and usage model favoring SSDs.

These industry dynamics, as well as the technology and pricing dynamics discussed earlier, showcase the increasing opportunity for SSDs. As these trends converge, the future for SSDs looks very promising. With the industry only in its first generation of MLC-based SSDs, future generations hold the promise of further advancements and improvements to a technology that offers many potential benefits to its users. These dynamics are embedded in IDC's latest forecast on SSD adoption in PCs and consumer electronics (see Figure 7). The forecast assumes significant adoption of MLC technology.

FIGURE 7

PC and Consumer Electronics SSD Unit Shipment Forecast, 2007–2012



Source: IDC, 2008

Toshiba's MLC SSD Solution

For its first SSD product launch, Toshiba integrated an MLC controller and advanced architecture within its SSD product family. Toshiba's first-generation SSDs feature NAND flash memory fabricated with its 56nm process technology, a four-channel parallel controller, DRAM cache, and a 200MHz 32-bit CPU to deliver high performance and fast read-write speeds. To improve reliability, Toshiba used dynamic wear leveling, ECC, and an intelligent architecture to overcome some of the challenges associated with using MLC NAND technology within SSDs for PC applications.

The next generation is expected to have significantly higher performance, with twice the read performance and two to three times the write performance of the initial product. The company is planning for future generations to balance performance and endurance requirements and with a price to meet market requirements. Capacities will also be increased as market demands warrant, with plans for SSDs up to 512GB already announced.

CHALLENGES/OPPORTUNITIES

Many times, the price of storage is the deciding factor when choosing a specific storage device. The high cost of SSDs to date is one of the potent factors hindering SSD adoption. The real key for mainstream adoption of SSDs into traditional PCs is reaching lower price points with acceptable capacity points. The growth of the flash memory market in recent years and the advancements in flash technology have allowed SSD OEMs using NAND flash technology to reach lower price points and offer SSDs as a compelling alternative to rotating magnetic HDDs in various use scenarios. Transitioning to SSDs based on MLC NAND technology will be critical to reaching lower price points since the memory costs are the most significant component of an SSD's bill of material.

The future opportunity for SSDs lies within the forecast decline in NAND component pricing and the commensurate decline in SSD pricing. IDC expects SSD premiums to achieve acceptable levels for broader and increased adoption in 2010. However, SSDs must address the following challenges:

- Today, industry premiums for systems integrating SSDs are too high. When the first SSD in general-purpose notebooks became available, it was not uncommon to pay an additional 50% premium over the cost of the PC for an SSD-based portable PC. Already, these premiums are eroding, and we expect this trend to continue. However, the premiums must be commensurate with the real benefits the end user will experience.

- Some uncertainty remains around SSD performance in an actual system. SSD OEMs need to provide more clarity and real-world benchmark testing to give PC OEMs and end users apples-to-apples comparisons of salient metrics. Thus, there is a clear need for a system to be optimized to take full advantage of the SSD's performance.

- We have decades of history with HDD solutions in the PC environment. While SSDs are not new, their performance under a real-world workload needs some time to prove field viability.

- Much fear, uncertainty, and doubt (FUD) exists around the endurance of SSDs, especially MLC SSDs. SSD vendors must educate their customers about the technology and back up their words with solid field data.

CONCLUSION

Many people believe that NAND memory is all the same and that SSDs are nothing more than NAND memory. Others assume that USB thumb drives are basically the same as SSDs. Yet nothing could be further from the truth. In fact, SSDs utilize far more advanced technology than just memory, and not all SSDs are created equal. As SSD vendors seek to accelerate SSD adoption in portable PC and digital consumer products, these two points are vital.

New technologies, such as SSDs, often are positioned in leading-edge segments, targeted toward high-end users, and priced at a premium. This is the case today with SSDs. However, as the technology evolves and issues are resolved, then volumes increase and price premiums erode and set the stage for more mainstream system applications and segments. Part of the evolution process includes utilizing advanced manufacturing technologies and designs, such as MLC, in an effort to make the technology more attractive and less costly. MLC-based SSDs such as Toshiba's are available today and improve the value/density advantages over SLC SSDs required to accelerate the acceptance of solid state storage in laptops and digital consumer products.

The important consideration when choosing an MLC or SLC SSD is to choose the right technology for the right application and proper system optimization to take full advantage of an SSD's performance. For a specific application, it is important to determine the anticipated usage model to match the capacity, performance, and endurance of the NAND device to the design requirements and thus to achieve an appropriate cost/performance balance. In the end, MLC-based SSDs are a good fit for many mobile computing applications and will be a key in accelerating SSD adoption further in the market.