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3D TLC NAND To Beat MLC as Top Flash Storage

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Why will a 3D version of triple level cell flash, notoriously the poor man's flash, replace most higher-end multi-level cell flash?

-- and why this matters to you

The recording and sharing of data is fundamental to the advancement of society and a phenomenon that consumers seem to have embraced with insatiable desire. There is no question that the invention of writing, paper, newsprint, computers, Internet, and now the mobile Internet has resulted in huge leaps in technology. With more connections and users, ultra-fast speeds, and video everywhere, it is forecast that by 2018, 190 exabytes of data will be generated in a single year.[1] To give some context—Eric Schmidt, when he was CEO of Google, stated that “5 exabytes is the total amount of data created between the dawn of civilization and 2003.”

In more recent times, the dawn of social media has triggered a mind-boggling increase in demand to store and share even more information than was anticipated just a few years ago. Popular sites such as YouTube have essentially changed the general population from content consumers to content generators. In fact, more video is uploaded to YouTube in a single month than what the 3 major networks created in 60 years.[2] Correspondingly, the need for IT storage is growing exponentially—forecasted to grow over 20x in the 10 years from 2011 through 2020.

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[1] Cisco VNI: Global Mobile Data Traffic Forecast Update, Feb 2015

[2] YouTube, Mar 2012

Storage medium

With the explosion in information and the relentless growth of information demand, identifying an efficient means of storage has become ever more important. Rotating magnetic media has served as the storage medium for the computing industry for decades, but has become a performance bottleneck as the rest of the computing system has gotten faster. There are three main components that dictate the speed of a computing system: the CPU, memory, and storage. While the CPU and memory are solid-state components that have increased in performance at an exponential rate, digital storage has been hampered by the physical speed of rotating disks. By going to solid-state storage, we are finally closing the gap with the CPU and memory.

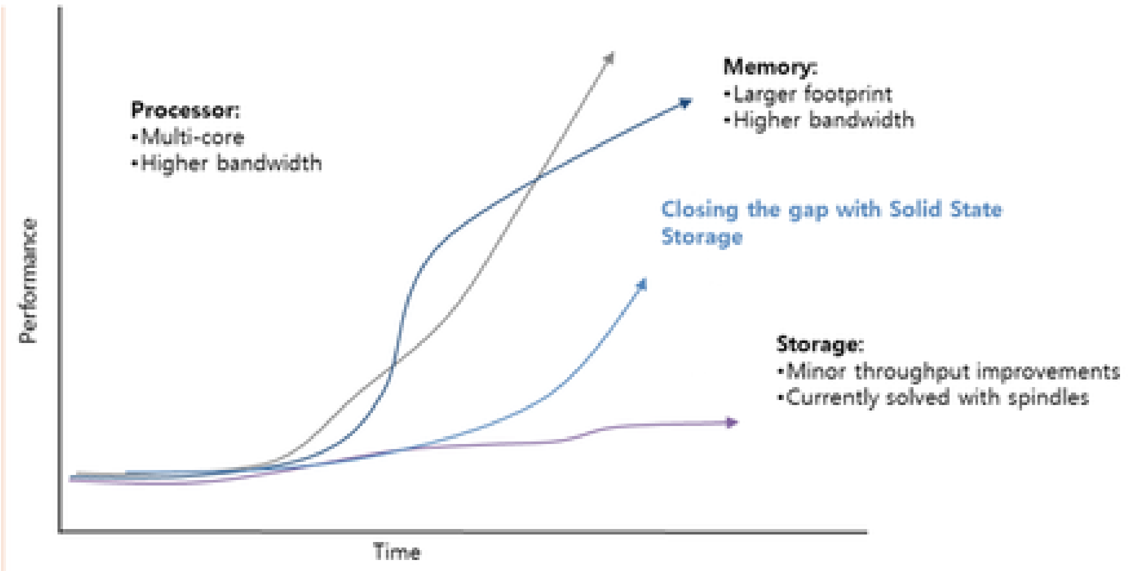

Figure 1.1 Closing the Performance Gap via Solid State Storage.

The last 10 years has seen a spectacular rise in the use of flash-based (NAND) storage, which is now on the threshold of going mainstream in both client-computing and data center applications. This rise in deployment is due to improvements in technology as well as greater cost efficiency. In many cases, the most significant boost you can now give your computer is to upgrade your hard disk to a solid state drive (SSD). PC OEMs have taken notice and are now providing SSD options in many of their notebook offerings. In the data center, flash is increasing its footprint in servers as well as storage arrays. Many companies have been founded with the purpose of offering all-flash arrays.

SSD advantages

So what are the characteristics of solid state drives that give them such an advantage over spinning, magnetic media? The main reason is the lack of moving parts. Magnetic media, whether in the form of removable discs or fixed platters in a hard disk drive, needs rotation to move the area of storage over a read/write head. There is a limitation in how fast you can physically move media, which are orders of magnitude slower than accessing information using electrical signals in solid state devices. Eliminating the rotating disk has a number of advantages, including:

1. Faster, sustained, and more even performance because the file system does not fragment over time
2. Improved reliability—mechanical items have an 'order of magnitude' higher failure rate compared to solid state devices
3. Improved durability—shock rating 4x that of a mechanical system
4. Reduced power consumption—mechanical parts in HDDs require much higher energy to operate
5. Lower heat, hence elimination of cooling fans
6. Smaller physical footprint

So why has solid state storage not completely eliminated magnetic storage? The main barrier is cost. As you can see in Figure 1.2 below, the cost of flash storage has dropped dramatically over the last several years. We are fast approaching a cross-over where SSDs are shown to be more economical than HDDs from a TCO (Total Cost of Ownership) perspective. Figure 1.3, reproduced from Wikibon, indicates that when you factor in considerations such as power, maintenance and space, the 4-year cost of SSDs will be more economical than HDDs in data centers—starting in 2016.

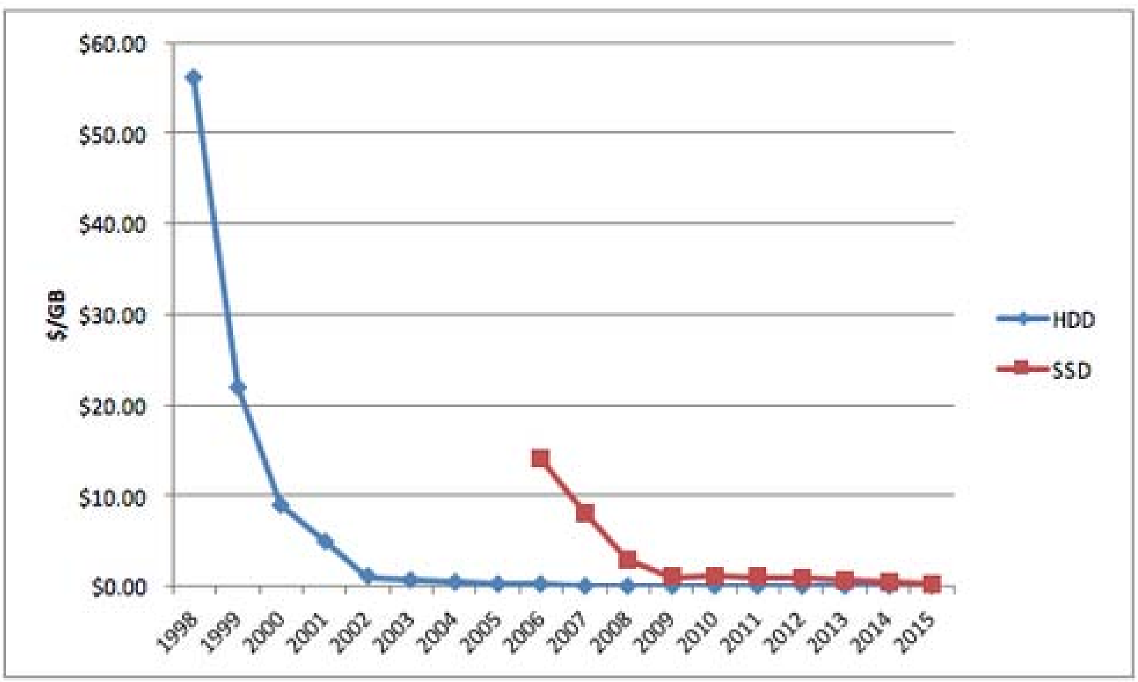

Figure 1.2 Cost per Gigabyte of SSDs vs. HDDs.

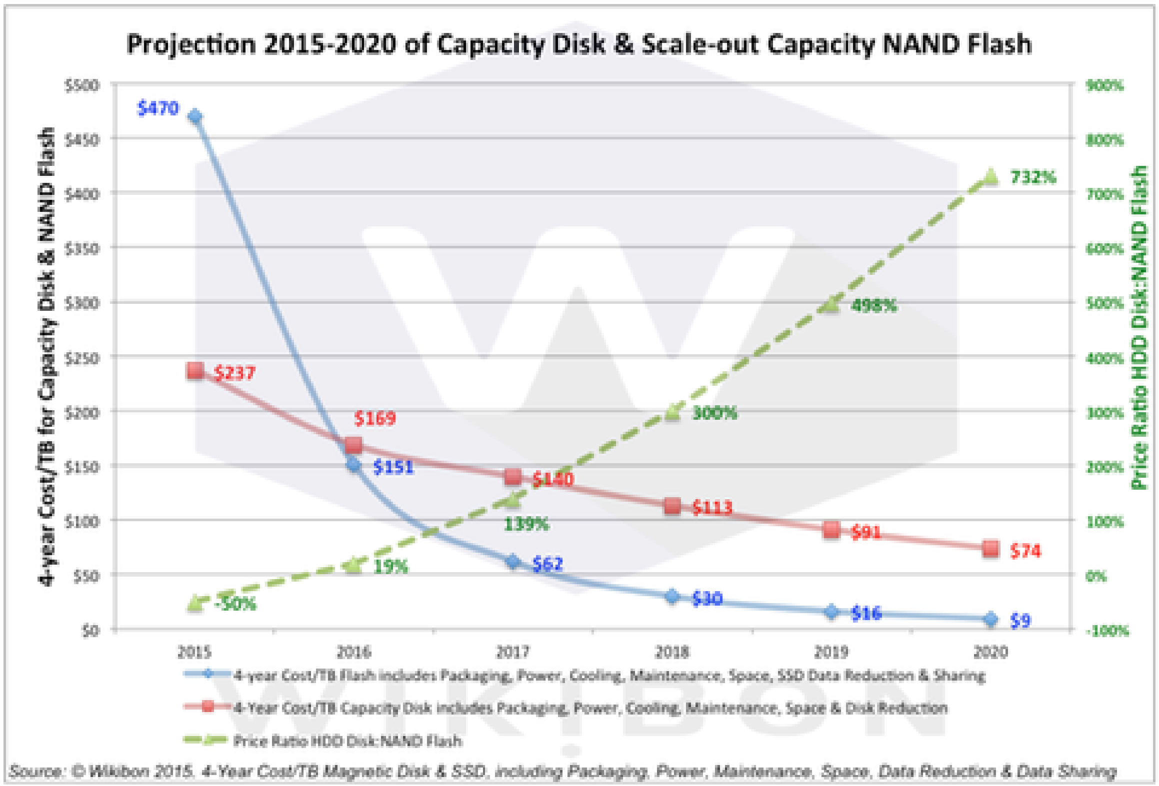

Figure 1.3 Total Cost of Ownership (TCO) of SSDs vs. HDDs

SSD challenges As an industry, flash-based memory has come down in cost due to increasing bit density. The more bits you can fit onto a silicon wafer, the lower the cost per bit. The process geometry has now come down to the mid-10nm-class range. To provide some context, 10nm-class is about 1/1000th the thickness of human hair. However, the closer you squeeze memory cells together, the more cell-to-cell interference occurs. This leads us to take a close look at the main challenge associated with flash-based memory: endurance.

Endurance is a measure of the total number of times a solid state drive can be overwritten. Each time that electrical currents are used to program a memory cell, the structure degrades slightly. The following factors primarily determine endurance:

1. Process geometry—the smaller the process geometry, the less electrons available to hold the charge to determine the data held (as well as more inter-cell interference that can lead to data corruption)
2. Number of bits per memory cell—holding more bits per cell results in greater memory densities, but involves the need to distinguish between finer voltage levels to determine actual data held
3. Flash management firmware
    a. Wear-leveling—effectively spreads program/erase cycles evenly over available NAND in order to extend the life of the drive
    b. Bad block management and Error Correcting Code (ECC)—use of parity bits to compensate for failed bits

As discussed, the industry is at mid teen-nanometer process geometries for NAND memory. We are approaching a physical limit based on inter-cell interference as well as the electrons available to hold a charge at these small geometries. However, every challenge presents opportunities for those that can innovate. In the second segment of this product-to-market storage analysis, we will discuss recent leading-edge approaches to overcoming the challenges facing this increasingly important form of storage.

—Tien Shiah is a product marketing manager for SSDs at Samsung Semiconductor. He serves as a product consultant and market expert, focused on the accelerating migration to SSDs in the client and enterprise marketplaces. He has over 15 years of product marketing experience in the semiconductor and storage industries. He has an MBA from McGill University (Montreal, Canada) and a BSEE from the University of British Columbia.

Part II

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3D TLC NAND To Beat MLC as Top Flash Storage
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Why a 3D version of triple level cell flash--the poor man's flash--can replace most higher-end multi-level cell flash.

-- and why this matters to you [PART II]

In our previous segment, we discussed the advantages and challenges associated with solid state drives (SSDs). The need to reduce cost, as well as increase density, has taken the industry to 10nm-class NAND geometries that are reaching a physical limit in how densely memory cells are packed together. In this segment, we discuss alternate methods to increase density, as well as how a new innovation addresses SSD challenges surprisingly well.

Increasing density via multi-bit cells

An orthogonal approach to geometry shrinks for accommodating increased density is to increase the number of bits per cell. The industry started with what is called SLC (Single-Level Cell) NAND, which holds one bit of information per cell. To increase density, MLC (Multi-Level Cell) NAND was developed that holds two bits of information per cell. Because of the need to now distinguish between 4 voltage levels instead of 2, the cell is more sensitive to physical degradation and as a result, has lower endurance compared to SLC NAND. For example, SLC NAND can withstand approximately 70K

P/E (Program/Erase) cycles before a cell fails. In comparison, MLC NAND endurance is in the 18K P/E range. However, using sophisticated algorithms mentioned above (wear-leveling, bad block management, ECC), SSD vendors are able to mask much of the reduction in NAND P/E cycles at the drive level.

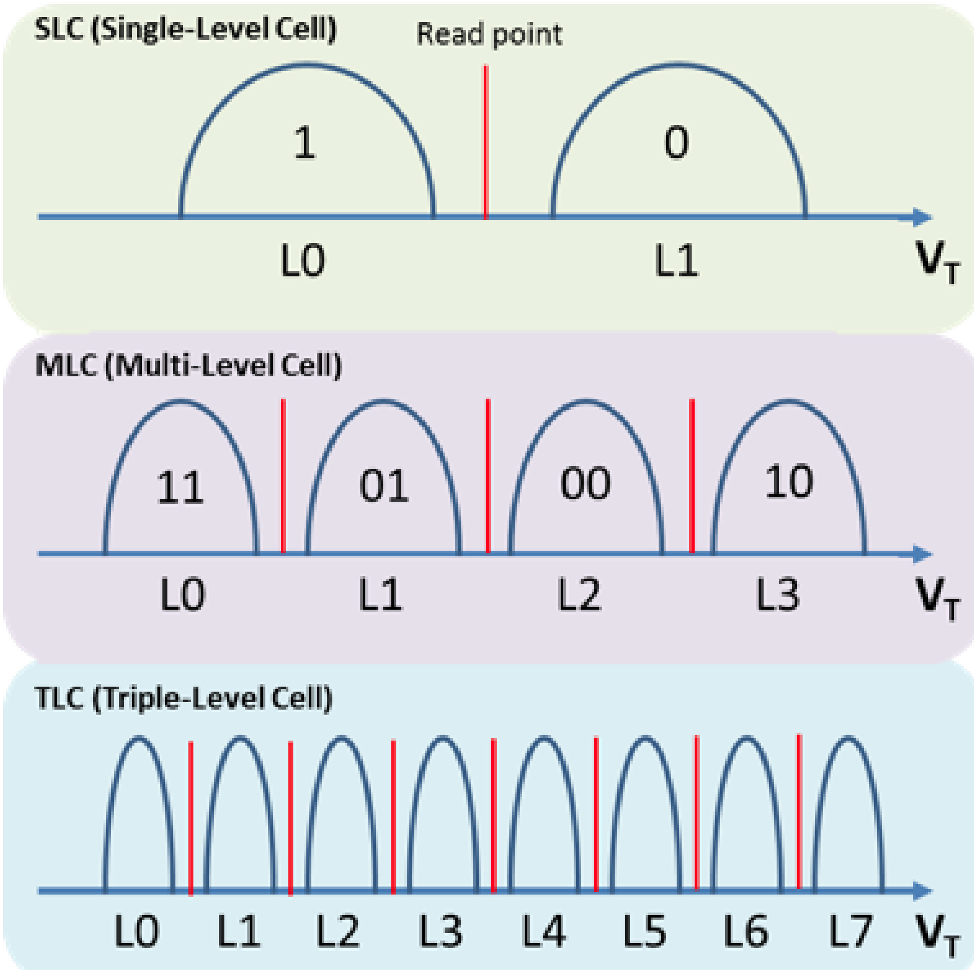

Figure 2.1 Storing Data in SLC, MLC, and TLC NAND.

Another technique, known as Over-Provisioning (OP), can also be used to increase drive endurance. OP sets aside a minimum amount of free space which is inaccessible by the user or Operating System (OS), where the SSD controller can use as "swap space." An SSD is always moving data around to ensure even wear of the drive. The ratio of “drive writes” to actual writes instructed by the host is called the Write Amplification Factor (WAF). Having this extra space reduces the WAF, hence improving drive endurance.

In the past, only SLC NAND was widely considered for enterprise applications. But with the sophisticated techniques available to vendors, SSDs with endurance levels of up to 25 DWPD (drive writes per day, for 5 years) are possible using MLC NAND. Customers are still becoming familiarized with how many DWPD are needed to support what are considered write-intensive, mixed-use, and read-intensive applications. Current trends suggest that the DWPD requirements are converging into three main "swim-lanes": 10DWPD, 3 DWPD, and < 1 DWPD.

Introducing 3D TLC NAND

Because of the need to continue down an aggressive cost-curve, TLC (Triple-Level Cell) NAND-based SSDs were introduced in 2012. TLC NAND holds 3-bits of information per cell. This means there is a need to distinguish between 8 voltage levels to decipher the information held, and as such, endurance is reduced even further. The P/E cycle of planar TLC NAND is in the 1K range, and the technology was met with the same skepticism that faced MLC NAND when it was first introduced in SSDs back in 2008.

At the same time, it was apparent that the NAND industry needed a breakthrough in order to continue down its aggressive cost curve. A physical limit was being reached in terms of being able to shrink the geometry further (inter-cell interference, as well as the reduced number of cells available to hold charge). This is where Samsung led the industry by introducing 3D NAND. With 3D NAND, instead of further squeezing cells closer together, the 3D CTF (Charge Trap Flash) cells are stacked vertically on top of each other to increase density. This is a paradigm shift in terms of scaling density and cell structure, and is what will best allow the industry to continue along the cost efficiency curve.

A key benefit of 3D NAND technology is that it can use a larger process geometry and still get better densities than planar NAND. Larger memory cells have the benefit of yielding faster, more reliable NAND. It also consumes less power, related to the time required to program the flash. 3D NAND is what allows TLC to perform at levels comparable to planar MLC.

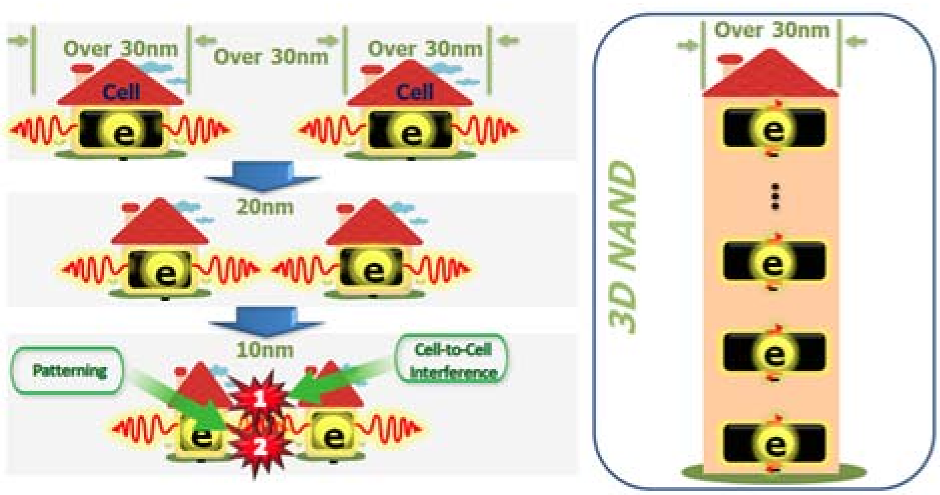

Figure 2.2 Cell-to-cell Interference Mitigated by 3D NAND.

For comparison, Samsung's 2nd-generation 3D TLC NAND is characterized with 20K P/E cycles, an endurance better than planar MLC NAND. Another criticism associated with TLC NAND has been performance. NAND memory writes data in chunks known as Pages, and erases in Blocks. Page program time (tPROG) is a key parameter that determines write performance. For 1x-nm planar NAND, tPROG increased by over 25 percent going from MLC to TLC. However, Samsung's second-generation 3D TLC NAND decreases tPROG by 50% compared to planar TLC NAND, and making it actually faster than planar MLC. Block Erase Time (tBERS) is also reduced to approximately 70% of 1x-nm planar MLC NAND in 3D TLC NAND.

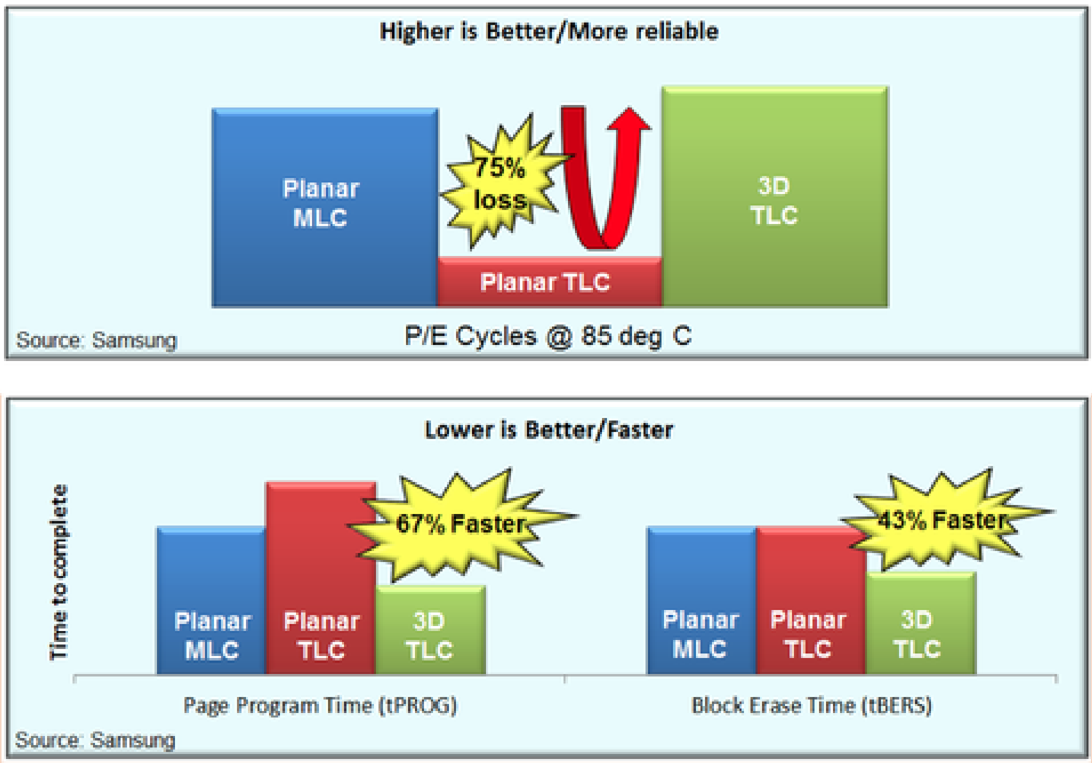

Figure 2.3 3D NAND Gains Back What was Lost Going to TLC.

While there are many factors that can impact endurance, (e.g., controller, firmware, DRAM, NAND), it can be easily shown that 3D TLC NAND-based SSDs can provide the endurance and performance levels that enterprises have come to expect from MLC-based drives.

The charts below illustrate the performance of client and data center SSDs using planar MLC compared to 3D TLC. As can be seen, the 3D TLC SSDs outperform their planar MLC counterparts.

Figure 2.4 Planar MLC vs. 3D TLC SSDs.

3D TLC NAND is the most advanced technology

Table 2.1 summarizes performance and endurance comparisons between 1x-nm planar MLC NAND and second-generation 3D TLC NAND. Table 2.2 compares representative SSDs that use planar versus V-NAND in both client and data center applications. As you can see, *3D NAND brings TLC back to the endurance and performance levels expected by the enterprise*. With 3D TLC NAND's projected continued improvements in scalability we have opened the door to a new era of density, performance and cost benefits.

NAND	10nm-class MLC	10nm-class TLC	3D TLC
Die density (Gb)	64	128	128
Page Size (Byte)	8K + 768	8K + 1024	16K + 2048
Block Size (Byte)	1M + 96K	6M + 768K	6M + 768K
Page Program Time (tPROG, ms)	1.3	1.65	0.8
Block Erase Time (tBERS, ms)	5	5	3.5
P/E Cycles (K) @ 85 deg C	18	4.5	20

Table 2.1 NAND Performance Comparison.

SSD	Client		Data Center	
	10nm-class MLC	3D TLC	10nm-class MLC	3D TLC
Model	SM841n	PM871	SM843Tn	PM863
Sequential read (MB/s)	520	540	530	525
Sequential write (MB/s)	450	500	360	460
Random read (IOPS)	-	-	89K	99K
Random write (IOPS)	-	-	13K	17K

Table 2.2 SSD Performance Comparison.

So why does all of this matter? NAND-based storage has become almost ubiquitous. From the moment a person takes a photo on his/her camera, uploads it into the cloud/data center, and then distributes it to thousands of other users, NAND storage is involved every step of the way. We live in exciting times where a new breed of devices will be enabled as result of continuing advances in NAND technology. To paraphrase a famous line from a classic television series (and soon to be major Hollywood movie) - *"We have the technology. We can make it better than it was. Better...stronger...faster."*

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