White Paper:

Evaluating MLC vs TLC vs V-NAND

Choosing the Right SSD for Enterprise Applications

SAMSUNG

EVALUATING MLC VS TLC VS V-NAND

Enterprise applications have become much more versatile within the past decade, due to the rise of Internet-connected devices such as smartphones and tablets. As the amount of data that are generated every day is growing and devices are shifting away from high-capacity local storage to cloud storage, the requirements for enterprise storage are changing and cost considerations are becoming more critical.

Today, there are numerous classes of enterprise solid state drives (SSDs) for different applications, each with unique performance and endurance characteristics. One of the most critical differentiators is the underlying NAND technology,

which has been developing rapidly in the past decade with new innovations such as Multi-Level Cell (MLC) and Vertical NAND (V-NAND) technologies.

Choosing the right SSD for the application is not necessarily an easy task given the complexity of the differences between various NAND technologies. This whitepaper explains the fundamental characteristics of two-bit-per-cell (MLC) and three-bit-per-cell (3-bit MLC or TLC) NAND technologies, as well as the inherent scaling limitations of planar NAND and how vertical NAND (V-NAND) technology solves these issues with our innovative vertical structure.

Understanding the basics of NAND is the key to understanding performance, endurance and cost differences between SSDs, which is essential for making an educated purchase for your specific enterprise application.

The Digital Universe by 2020

44
Zettabytes of Data

EMC Digital Universe Study, IDC

HISTORY OF MULTI-LEVEL CELL NAND FLASH

When NAND was invented in the late 1980s, it was only capable of storing one bit per cell. It took nearly two decades of engineering work before the first SSD based on MLC NAND with two bits per cell was introduced by Samsung in 2007. Ever since then, the industry has been moving more and more towards MLC technology and today, SLC only accounts for a few per cents of total NAND flash output. Recently, triple-level-cell (3-bit MLC) NAND has also been gaining popularity, with Samsung being the first manufacturer to introduce it to its client SSDs in 2012 and to enterprise SSDs two years later.

The SSD and NAND industries have been adopting multi-level cell technology due to the increased cost efficiency. NAND cost is dictated primarily by the number of gigabytes each wafer yields and historically there have been two ways to achieve increases. The first is to shrink individual cells through traditional lithography and multi-patterning technologies. By making each cell smaller, it's possible to fit more cells in a wafer, which yields more gigabytes and thus reduces the manufacturing cost of each gigabyte. The whole semiconductor industry relies on lithography shrinks to either provide lower cost by reducing the die size, or by

adding more transistors per die to deliver more functionality or higher performance. While lithography is the cornerstone of semiconductor scaling, it has become less cost effective in recent years.

The second way is to add more bits per cell. NAND flash works by trapping electrons in an insulated floating gate, which creates a charge inside the cell. SLC NAND cells only have two states: charged (0) and non-charged (1), whereas 2-bit MLC NAND has four and 3-bit MLC NAND eight to differentiate all the possible bit outputs that two or three bits can have.

THE DOWNSIDES OF NAND FLASH COST SCALING

Both cost scaling methods have a negative impact on the endurance and performance of NAND. Making cells smaller reduces the number of available electrons that can be used to differentiate between voltage states and additionally, by bringing cells closer to each other and thinning the insulators around the floating gate, the cells become more vulnerable to interference from neighboring cells.

As NAND goes through program and erase (P/E) cycles, the tunnel oxide wears out due to the stress caused by the strong electric field, which is required to tunnel electrons through the insulating oxide to the floating gate. This generates holes inside the oxide structure, which act as escape paths for the electrons in the floating gate. Electrons may also get trapped in the holes during the tunneling process. Because NAND flash differentiates bit values based on the voltage state of the floating gate, electron leakage and trapping may alter the state from the correct one, making the cell unreliable.
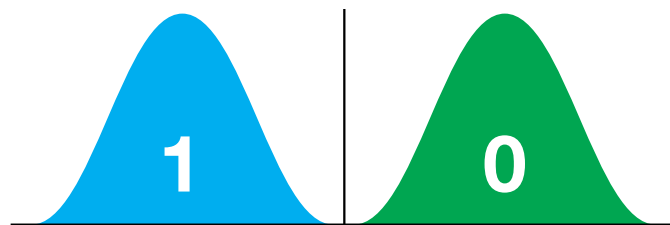
Increasing the number of bits per cell makes matters worse because 3-bit MLC NAND needs to differentiate between eight voltage states, while MLC NAND has only four. That makes 3-bit MLC NAND less tolerant against cell-to-cell interference and electron leakage/trapping, because it takes less interference and fewer electrons to change the state of a cell.

Similarly, 3-bit MLC NAND requires more program-verify iterations than MLC NAND, as every bit is programmed separately and the voltage distribution of each state is much finer, requiring a very specific number of electrons in the floating gate.
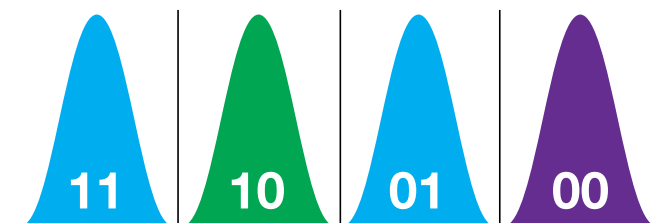
This all leads to 3-bit MLC NAND having lower write endurance and performance compared to MLC NAND, but read endurance and performance are barely affected.

Because reading from NAND works by simply sensing the charge in the cell, the read performance difference between MLC and 3-bit MLC is practically negligible in real-world applications. Similarly, as reading doesn't involve a stressful electron tunneling process, reads induce substantially less strain on cells. Whereas write cycles are measured in thousands or tens of thousands, read cycles run in hundreds of millions even for 3-bit MLC NAND.
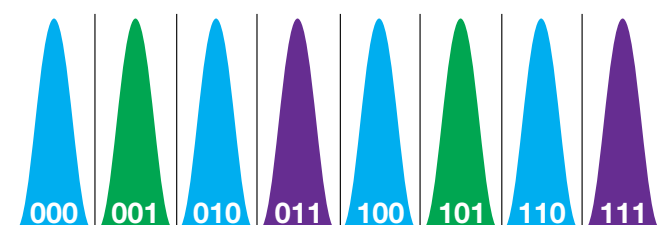
NAND Flash Types

Single Level Cell (SLC) NAND

Multi Level Cell (MLC) NAND

Tri Level Cell (TLC) NAND

V-NAND: ENTER THE THIRD DIMENSION OF SCALING

As explained above, NAND has traditionally been scaled by shrinking the lithography, and in the past decade, multiple bits per cell have been introduced to further scale the cost down, but both methods are now starting to become less effective. These methods are actually counteractive because as cell size and the number of electrons scale down, storing multiple bits per cell becomes even more difficult and creates serious endurance and reliability concerns.

To continue cost scaling in the future, semiconductor manufacturer have introduced 3D or Vertical NAND, stacking multiple cells in layers. Samsung was the first manufacturer to begin production of its V-NAND in 2013, with the first V-NAND-based SSDs released a year later.

V-NAND works by stacking multiple layers in order to create "cell towers." Scaling to the third dimension takes away the lithography stress because instead of making cells smaller, cost reduction can be achieved by increasing the number of layers. Samsung is currently shipping its second generation 32-layer V-NAND, and third generation 48-layer V-NAND is going into production in October 2015.
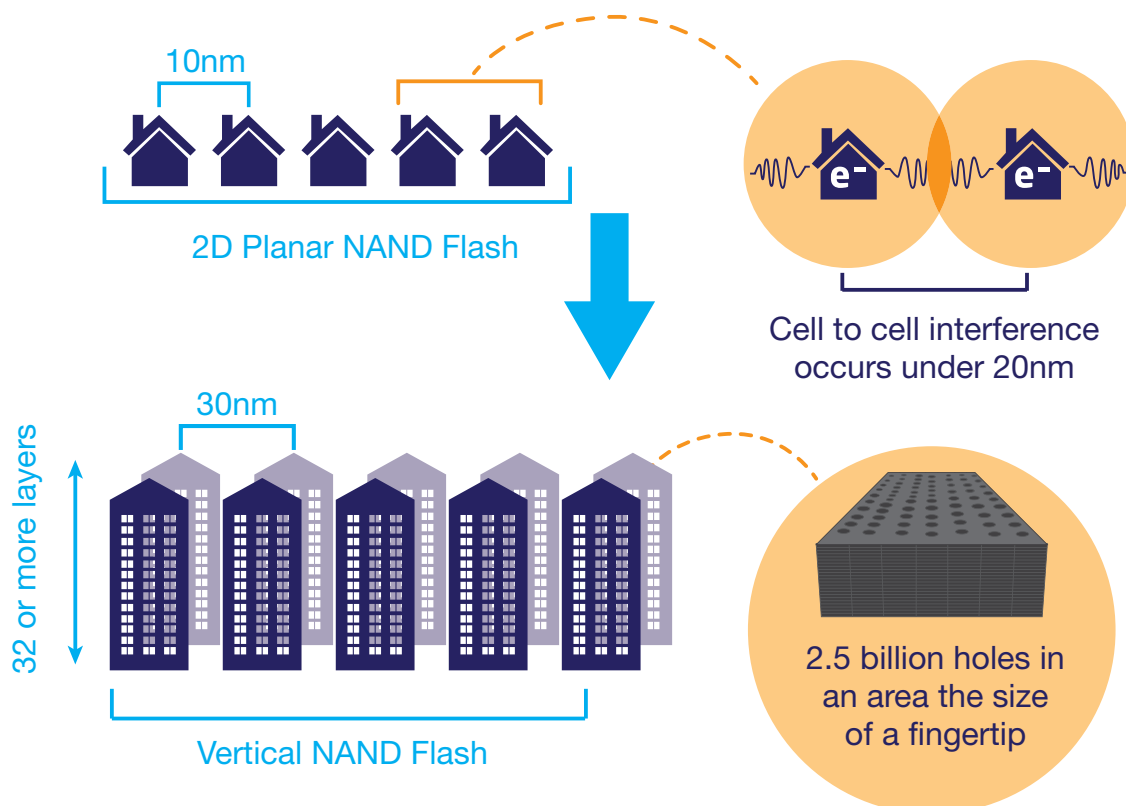
Because the high number of layers brings considerable density improvement, the cells don't have to be packed as closely. Samsung has actually moved to much larger 30nm-class lithography, whereas modern planar NAND is manufactured using 15-20nm lithography. As cells are larger with more available electrons and distance between cells is greater, V-NAND is able to provide tremendous endurance and performance gains over planar NAND.
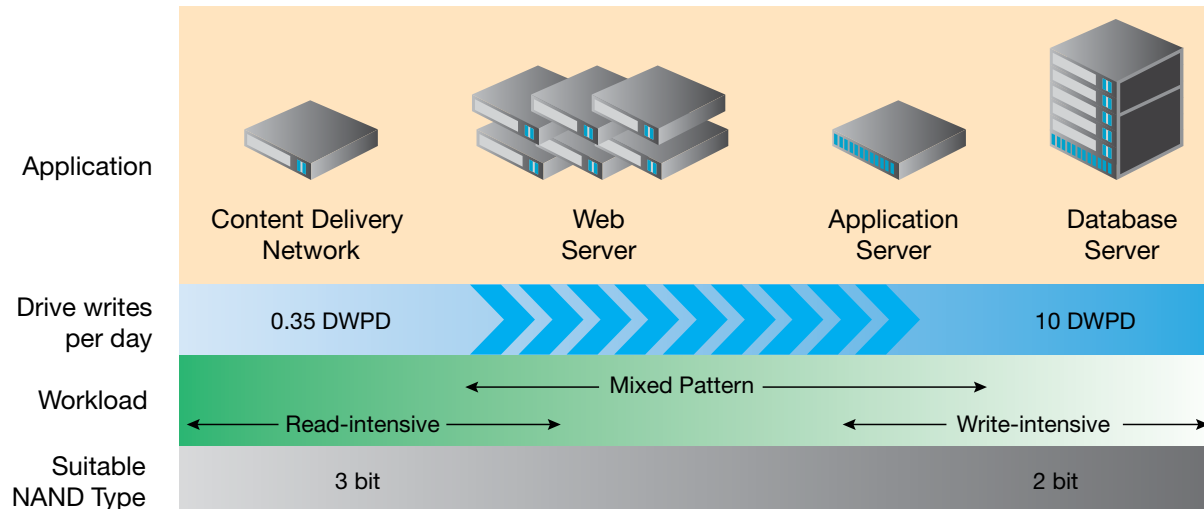
> ▶ LEARN MORE
>
> For more details about V-NAND and how it differs from planar NAND, please refer to this Samsung V-NAND technology whitepaper.

Transforming NAND in an Upward Direction

10nm

2D Planar NAND Flash

Cell to cell interference occurs under 20nm

30nm

32 or more layers

Vertical NAND Flash

2.5 billion holes in an area the size of a fingertip

CHOOSING THE RIGHT NAND FOR ENTERPRISE APPLICATIONS

Application	Content Delivery Network	Web Server	Application Server	Database Server
Drive writes per day	0.35 DWPD			10 DWPD
Workload	Read-intensive	Mixed Pattern		Write-intensive
Suitable NAND Type	3 bit			2 bit

For the majority of client applications, 3-bit MLC NAND provides the necessary write endurance and performance because consumers do not usually write more than 20 gigabytes of data per day and disk activity is based on bursts of IOs. However, enterprise IO workloads are more complicated because there are many different applications, each with unique characteristics. Enterprise workloads can, however, be roughly divided into categories by their write-intensity.

Read-centric workloads include applications such as cloud storage, media streaming and web servers. In these applications, data is written once but is rarely, if ever, modified, yet it may be accessed by millions of people. 3-bit MLC NAND is perfect for such applications because it offers read performance very similar to MLC NAND, but at a substantially lower cost. Many read-intensive applications require very large amounts of storage (consider Netflix and

Facebook as examples), but as the data is mostly read-only, the applications do not usually need more than one drive write per day (DWPD) in endurance, making 3-bit MLC an ideal choice because of its lower cost.

For mixed workloads, the choice of NAND depends on the amount of write activity. Because V-NAND technology offers much higher endurance over planar NAND, 3-bit MLC V-NAND can be used for mixed workloads with low write endurance needs – 1 DWPD or less. For example, desktop virtualization (VDI) is typically not very write-intensive in office environments, and 3-bit MLC V-NAND can meet the endurance needs for such workloads.

On the other hand, applications such as online analytical processing (OLAP) tend to require higher endurance than 1 DWPD and are hence best served by MLC V-NAND, which can scale to up to 10

DWPD with configurable over-provisioning offered in the Samsung SM863 Series.

Use cases such as real-time financial trading and online transaction processing are great examples of very write-intensive and performance-sensitive applications. Because these applications generate a lot of write IOs and even a millisecond of additional latency may result in a lost trade or sale, the higher endurance and write performance of MLC V-NAND is required for such critical applications.

In most enterprise workloads, the path to the lowest total cost of ownership (TCO) is to utilize the benefits of both 3-bit MLC and MLC technologies through tiering. Files that have a lot of write activity can be kept in the more durable MLC-based SSDs, while files that are read-only or accessed more infrequently can be moved to a lower tier that is based on 3-bit MLC SSDs.

CONCLUSION

The choice between 2-bit and 3-bit MLC depends on the application and its performance and endurance requirements. For read-intensive applications, 3-bit MLC is an obvious choice because it delivers the same level of performance at a substantially lower cost per gigabyte. The use of 3-bit MLC V-NAND technology in the Samsung PM863, rated for 1 DWPD, also extends the usability from strictly read-centric applications to some mixed workloads with low write activity.

While V-NAND technology increases write endurance, 3-bit MLC is still inherently slower and less durable than 2-bit MLC, so it is not ideal for write-intensive applications. For mixed and write-intensive workloads, Samsung offers the SM863, which comes standard with 3 DWPD but can be over provisioned to reach endurance of up to 10 DWPD. The lower cost per gigabyte that 3-bit MLC offers may seem alluring, but MLC actually provides a better TCO for write-intensive applications because drives need to be replaced less frequently due to the higher endurance.

	SM863	PM863
MSRP (960GB)	$639.99	$549.99
Endurance (960GB)	6,160 TBW*	1,400 TBW
Price per Gigabyte	$0.67/GB**	$0.57/GB
Price per TBW	$0.10/TBW	$0.39/TBW

*Pricing is as of October, 2015 and subject to change
**TBW = TeraBytes Written
***1 GigaByte = 1 000 000 000 bytes

About the Author

Kristian Vättö is a technical marketing specialist and started his career as a news editor at AnandTech.com in 2011. He later became the site's SSD editor and was responsible for producing highly-detailed and professional SSD reviews. In addition to his work with Samsung, Kristian is currently studying economics at the University of Tampere in Finland.

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