



Flash Memory

2D NAND vs. 3D NAND

White Paper F-WP002

Table of Contents

Introduction	3
2D NAND vs. 3D NAND Technology Overview	4
3D NAND Advantages and Limitations	5
SMART Modular Technologies' 3D NAND Migration Plan	5
Conclusion	6

Introduction

NAND Flash memory has been on the market since the early 2000s and is a non-volatile memory with planar 2D technology. It is also known as Floating-Gate (FG) NAND, since electrons placed on the FG are trapped and removed to indicate the cell is programmed or erased. In order to increase the density of 2D NAND, the only way is to shrink the die size smaller and smaller in the X-Y dimensions. However, a 2D NAND cell can't be so small. It has to have sufficient space to store enough number of electrons to ensure the cell function correctly. The key is that when 2D NAND cell size is reduced too much, the adjacent cell interference effect is uncontrollably increased, causing the reliability and endurance on 2D NAND Flash to deteriorate. Improving on these factors is the main reasons 3D NAND Flash technology was created.

2D NAND vs. 3D NAND Technology Overview

2D NAND memory is based on FG technology, while the majority of 3D NAND memory is based on Charge-Trapping (CT) technology, where the vertical silicon nitride layer stores charges. With the technology improvement, 2D NAND is shrunk in the x-y dimension while 3D NAND is stacked up by numbers of layers. Up to now, 15nm or 16nm is the final development stage of 2D NAND technology, although some research and development papers claims that 2D NAND can be smaller than 15nm, no one has proven it yet. 2D NAND development currently offers SLC (Single Level Cell) with 100K P/E (Program/Erase) cycles, MLC (Multi Level Cell) with 3K-10K P/E cycles, and TLC (Triple Level Cell) with 300 to 1K P/E cycles.

3D NAND starts with 32 layer technology and is now upgraded to 48, 64 and 96 layers. The majority of NAND vendors are currently in mass production with their 64-layer 3D NAND. 128 layer technology is under R&D (Research and Development) now. 3D NAND provides a higher density die than 2D NAND. The current technology can support a 256Gb/die and 512Gb/die, which is a significant advantage for building a much higher capacity SSD.

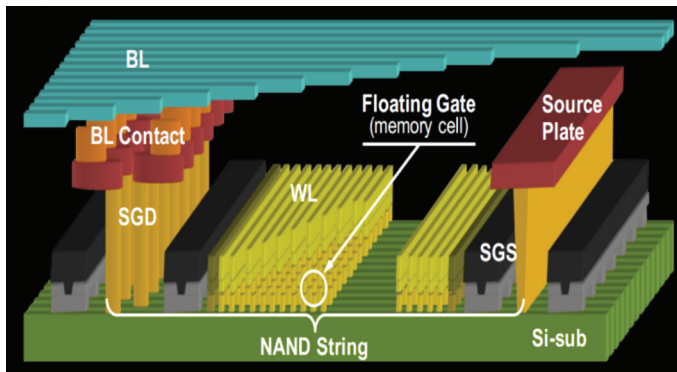


Figure 1 - 2D-NAND Architecture

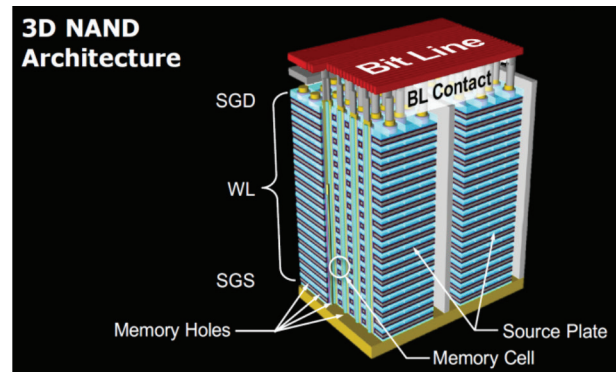


Figure 2 – 3D-NAND Architecture

Source: Western Digital Corp.

With CT technology and bigger cell size, 3D NAND provides better endurance than 2D NAND. A TLC, 3-bit per cell, on 3D NAND can provide more than 3,000 (P/E) cycle endurance, in contrast to approximately 300 P/E on TLC 2D NAND. The latest 3D NAND offers QLC (Quad Level Cell), 4 bits per cell, which can provide a similar P/E cycle endurance as TLC of 2D NAND.

Below are the summary tables reflecting the difference between the two technologies:

3D NAND Advantages and Limitations

2D Flash Technology	Bit(s) of Data per Memory Cell	Write Endurance P/E Cycles)
SLC	1	~100K
MLC	2	~3K
TLC	3	~300

3D Flash Technology	Bit(s) of Data per Memory Cell	Write Endurance P/E Cycles)
TLC	3	~3K
QLC	4	~300

Although 3D NAND has many advantages over 2D NAND, there are still some limitations that NAND vendors are putting in an effort to improve. Below is the summary of the advantages:

3D NAND Advantages

- 4bits/cell (QLC), good for high density mass storage
- QLC 3D NAND is a huge advantage for high density mass storage application, while TLC 3D NAND is a replacement for MLC 2D NAND
- Like 2D NAND, 3D NAND also has an option to make pSLC (Psuedo SLC) or pMLC (Psuedo MLC) to achieve higher endurance specification
- 1-pass programming of 3D NAND (based on most of NAND vendors' design) provides better speed (higher read/write bandwidth, I/O speed), while using less power compared to 2D NAND
- The number of bits per cell is increased compared to 2D NAND and helps to produce reduced cost per GB

3D NAND Limitations

- Complexity in LDPC ECC requirements and Flash management on 3D NAND requires powerful error correction and data management algorithms from controllers
- Non-homogeneity in 3D NAND architecture from manufacturer to manufacturer
- Not suitable for very high endurance and long life cycle applications (100K P/E cycle requirement)
- High manufacturing cost and complexity
- Charge trap technology has its own set of reliability issues, especially at high temperature

3D NAND provides both advantages and disadvantages in density compared to 2D NAND. The minimum density that a 3D Flash drive should be is 32GB. This is a disadvantage for end users who only need a few GB density drives, especially on cards such as SD, CF, eUSB, etc. Moreover, some controllers may require more than 1x 3D NAND on a drive, in order for it to appropriately operate. On the other hand, the advantages of high density 3D NAND not only helps to reduce cost per GB, but also to provide a huge-density Flash drive.

SMART Modular Technologies' 3D NAND Migration Plan

SMART is proactively engaging with NAND technology. SMART is vigorously developing SATA and PCIe NVMe products using 3D NAND, and is currently working with different NAND vendors and controller vendors to provide the best state-of-the-art 3D NAND drives.

SMART expects to launch the first series of qualified 3D NAND products, including M.2 2280 SATA III, M.2 2242 SATA III, Slim SATA III, mSATA and 2.5" SATA III at the end of 2018. Some of these products offer PLP (Power Loss Protection), which combines unique power loss detection and hold-up circuitries, and advanced controller firmware algorithm to flush in-flight data from volatile cache to Flash memory which safeguards data against data corruption. Other customized 3D NAND products, requested by many customers are also in SMART development timeline.

Conclusion

There is no doubt that 3D NAND is a future storage technology and will definitely soon replace 2D NAND. It is predicted that 3D NAND will dominate SSD market over 2D NAND by 2019. Although there are still some limitations to 3D NAND, its advantages over 2D NAND are clearly proven through the third or fourth generation of 3D. SMART is a pioneer on migrating to 3D NAND technology on its future products line-up. Check with SMART Modular Technologies at <https://www.smartm.com> for upcoming information.

Corporate Headquarters: 39870 Eureka Dr., Newark, CA 94560, USA • Tel: (510) 623-1231 • Fax: (510) 623-1434 • E-mail: info@smartm.com

Customer Service: Tel: (+1) 978-303-8500 • Email: customers@smartm.com

Latin America: Tel: (+55) 11 4417-7200 • Email: sac@smartm.com

Europe: Tel: (+44) 7825-084427 • Email: euro.sales@smartm.com

Asia/Pacific: Tel: (+65) 6232-2858 • Email: infoasia@smartm.com