



# Western Digital®

## The impact of 3D storage solutions on the next generation of memory systems

*DevelopEX 2017*

*Airport City – Israel*

*Avi Klein*

*Engineering Fellow, Memory Technology Group*

*Western Digital Corp*

October 31, 2017

# Outline

- About Western Digital
- NAND, NVM and the Memory Taxonomy
- From 2D to 3D NAND – Going Vertical
- Key attributes of Western Digital's BICS Technology (3D-NAND)
- Advantage of 3D NAND in various applications
- Summary

# Safe Harbor | Disclaimers

## *Forward-Looking Statements*

This presentation contains forward-looking statements that involve risks and uncertainties, including, but not limited to, statements regarding our market positioning, product development efforts, growth opportunities, business strategy, storage and memory technology, and market trends. Forward-looking statements should not be read as a guarantee of future performance or results, and will not necessarily be accurate indications of the times at, or by, which such performance or results will be achieved, if at all. Forward-looking statements are subject to risks and uncertainties that could cause actual performance or results to differ materially from those expressed in or suggested by the forward-looking statements.

Additional key risks and uncertainties include: volatility in global economic conditions; actions by competitors; difficulties associated with the integration of SanDisk and HGST into our company; business conditions; growth in our markets; and pricing trends and fluctuations in average selling prices. More information about the other risks and uncertainties that could affect our business are listed in our filings with the Securities and Exchange Commission (the "SEC") and available on the SEC's website at [www.sec.gov](http://www.sec.gov), including our most recently filed periodic report, to which your attention is directed. We do not undertake any obligation to publicly update or revise any forward-looking statement, whether as a result of new information, future developments or otherwise, except as otherwise required by law.



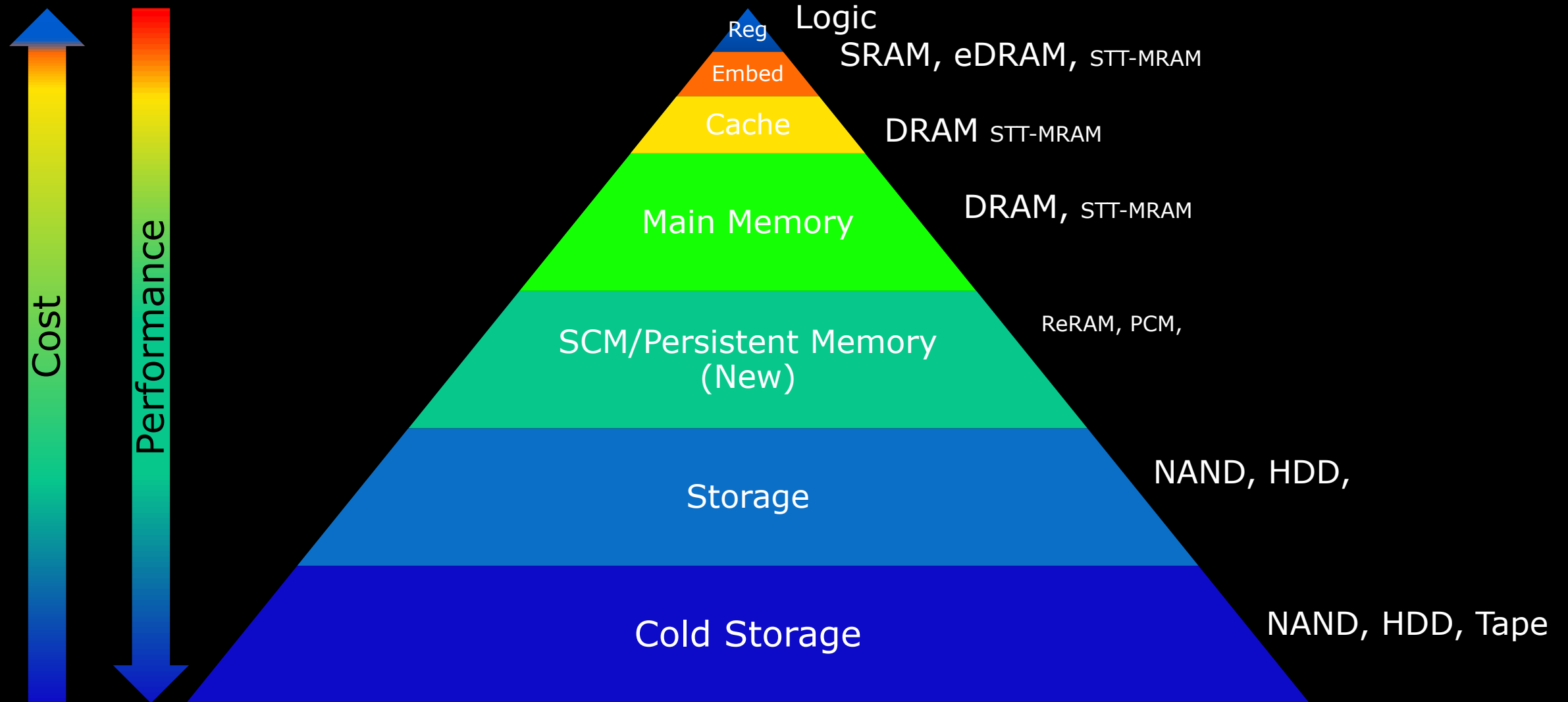
# The Western Digital Family of Brands



SanDisk Western Digital My Passport G S T

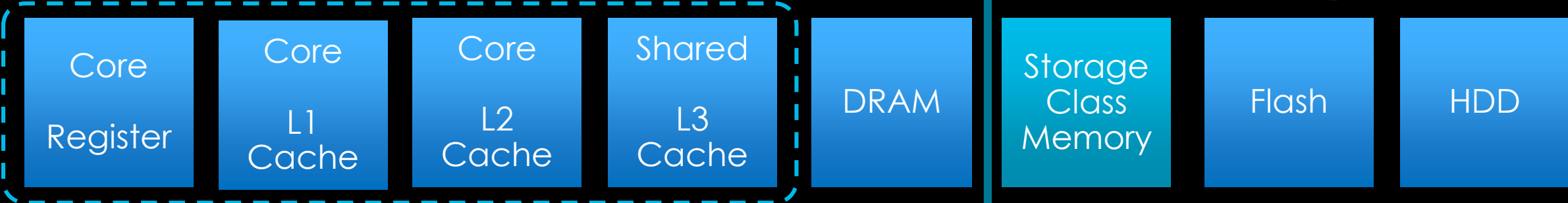
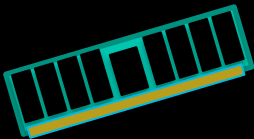
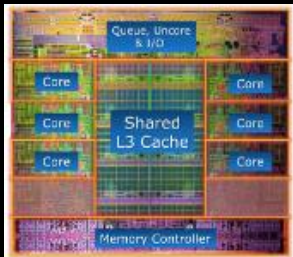
Delivering the Possibilities of Data to Life

# The Memory Taxonomy



# Moving Mountains of Data

Western Digital Technologies



Size	64KB	256KB	2-4MB	16-128GB	128GB-1TB	512GB-4TB	4-16TB
Speed	1ns	3-10ns	10-20ns	50-100ns	250-5,000ns	100,000ns-2,000,000ns	5-10,000,000ns
Cost				100x	20-25x	5x	1x

# Different Tiers of Storage

## DRAM



***Bit has own FET***

**House with own  
Airplane & runway**

## NOR Flash



***Bit has own Contact***

**Expensive Hotel**

## NAND Flash



***128 Bits share Contact***

**No Hallway/door Hotel  
read(sleep)  
disturb problems**

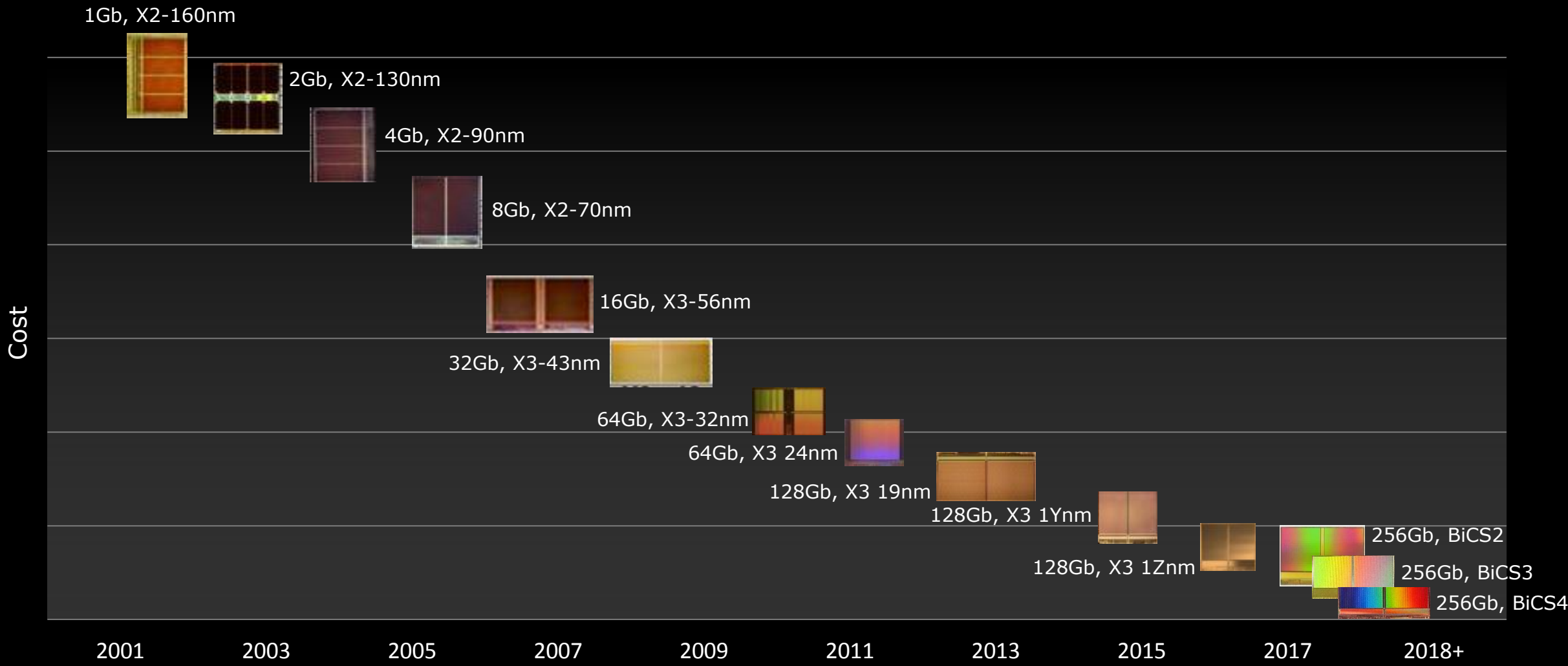
## HDD



***Whole disk share  
one head***

**Chopper to drop guest**

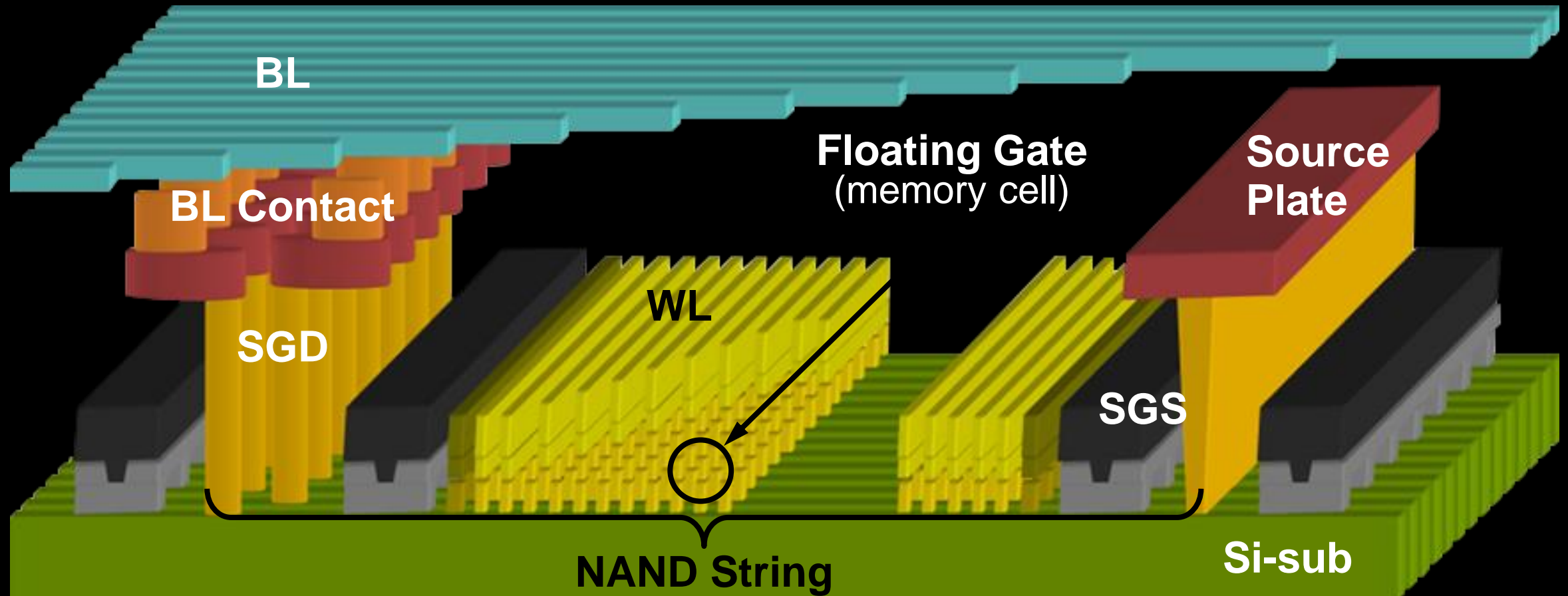
# In NAND We Trust: More than Moore



Note: Images are not to scale \*WDC

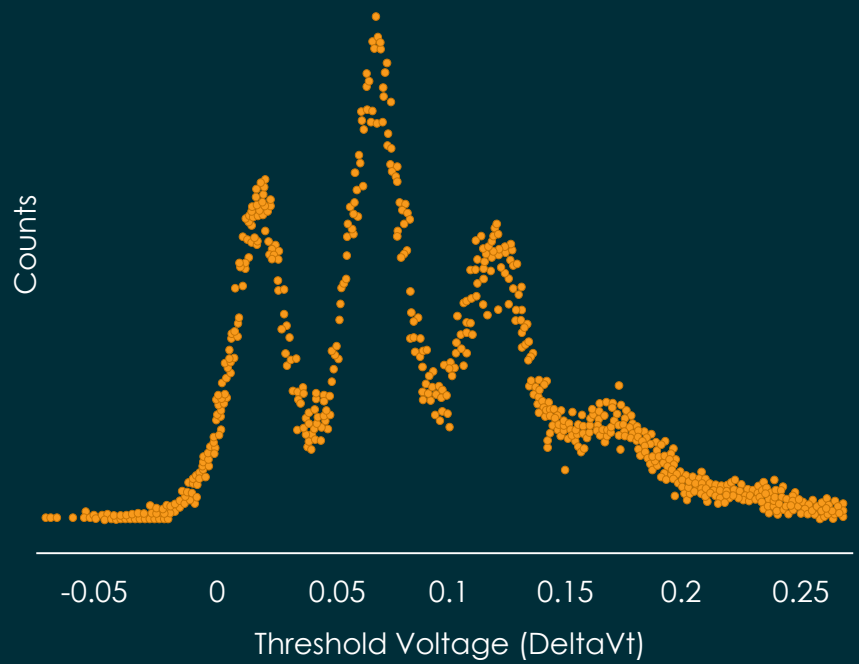


# 2D NAND Architecture

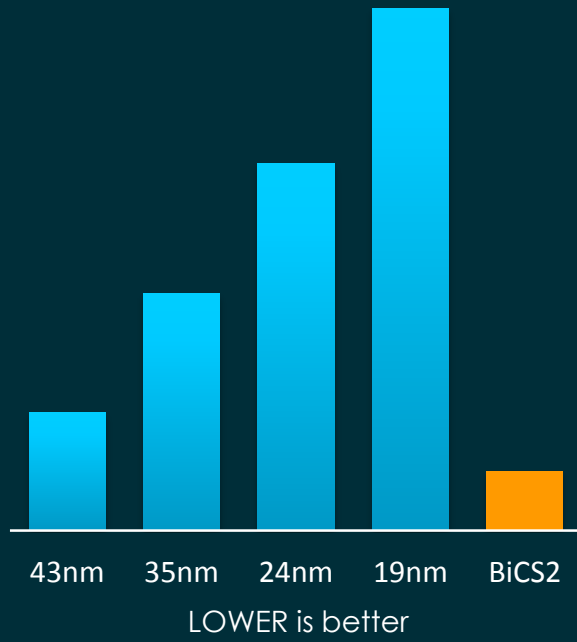


# No Moore: End of Line for 2D NAND Scaling

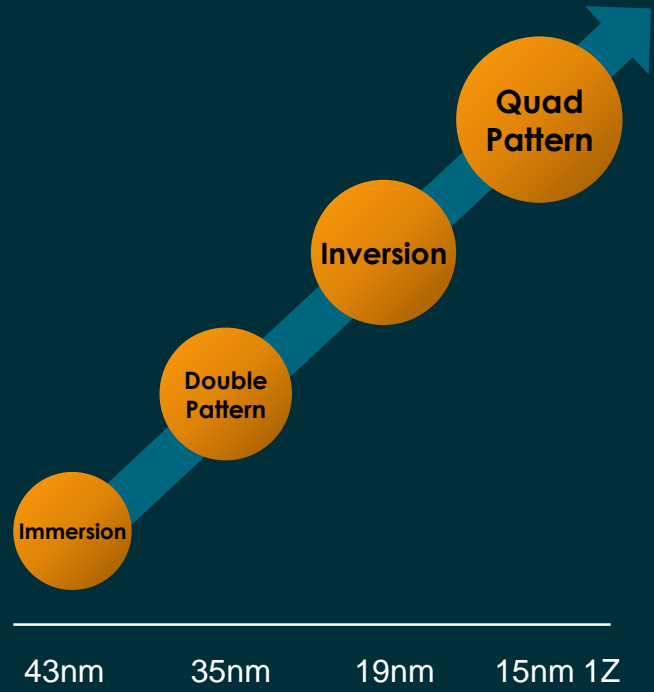
We don't have enough electrons



As cells get closer, proximity effect worsens



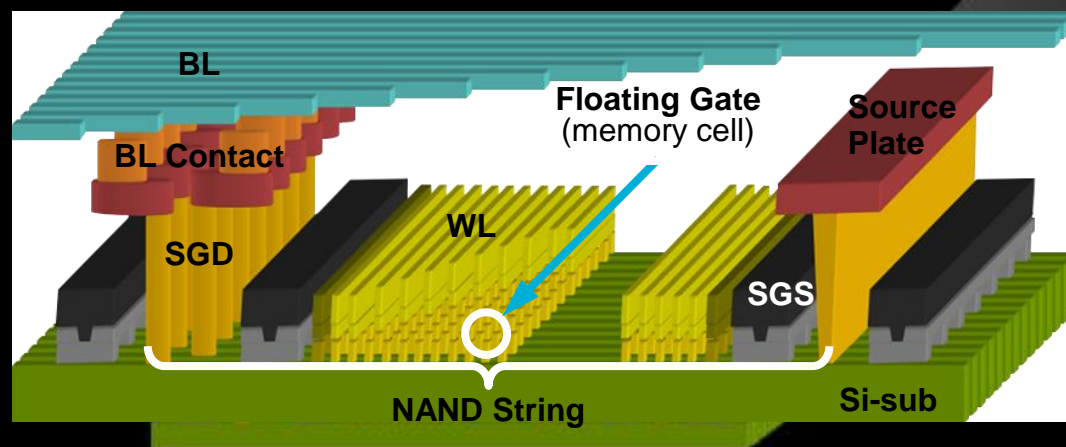
Lithography Process Complexity



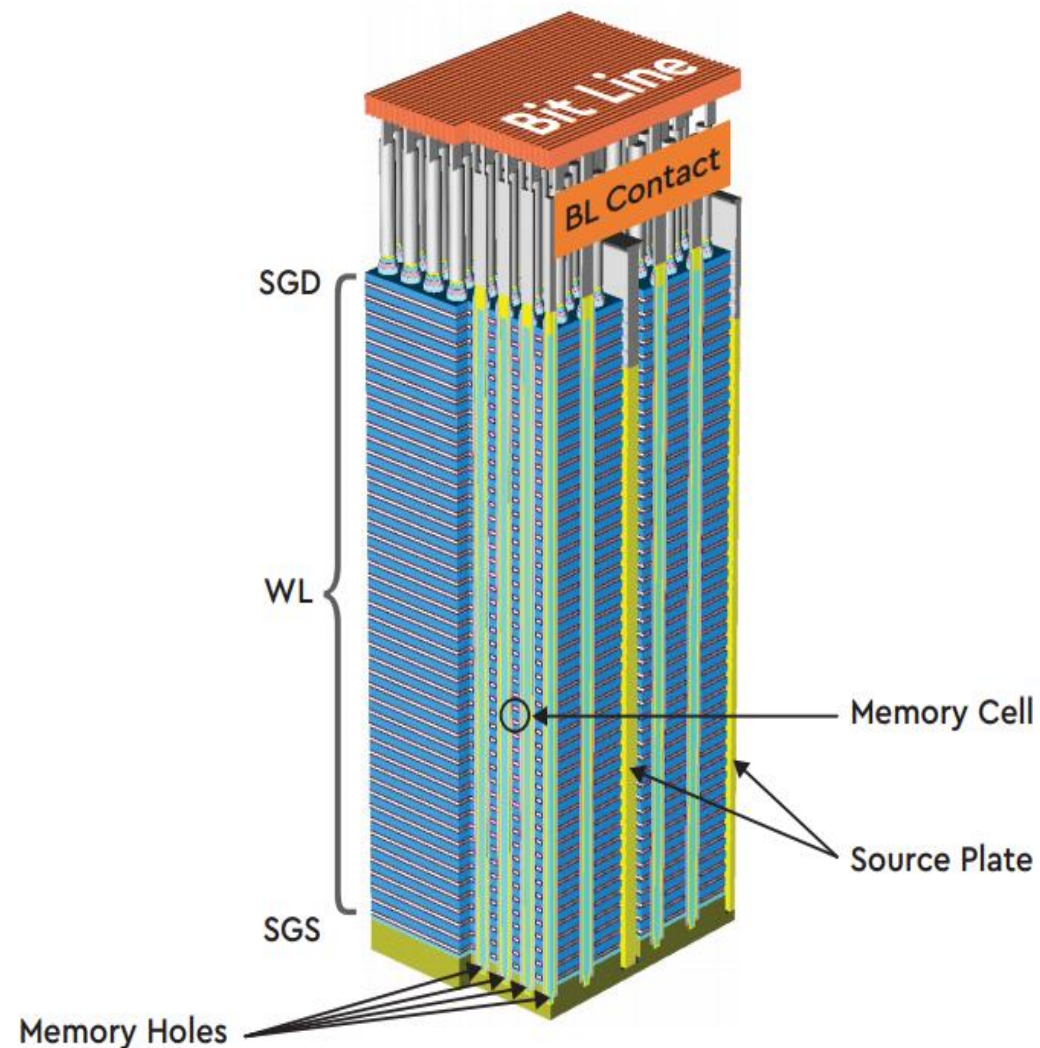
Source: WDC estimates

# Going Vertical

*From 2D to 3D*



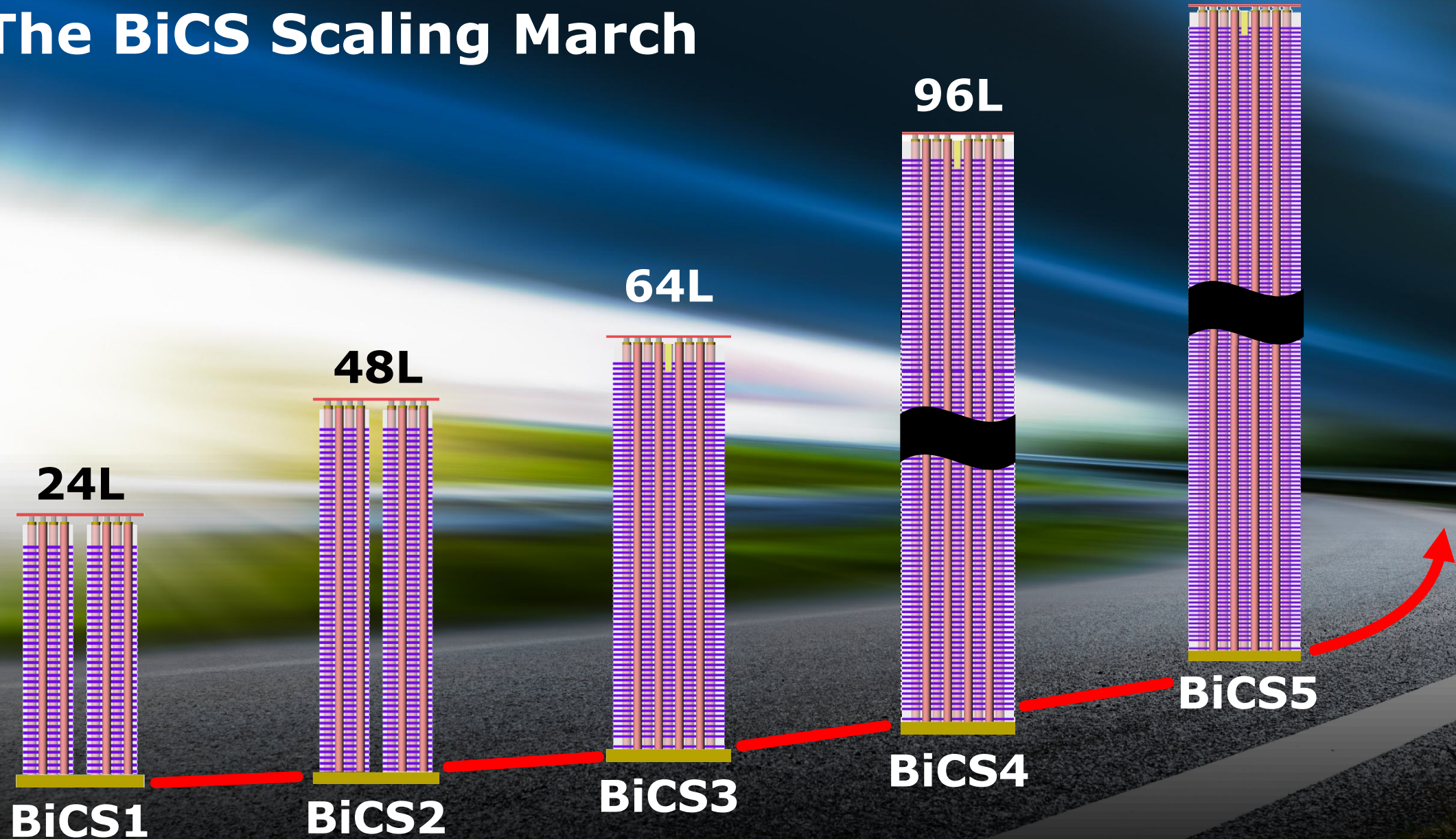
2D NAND Architecture



3D NAND Architecture

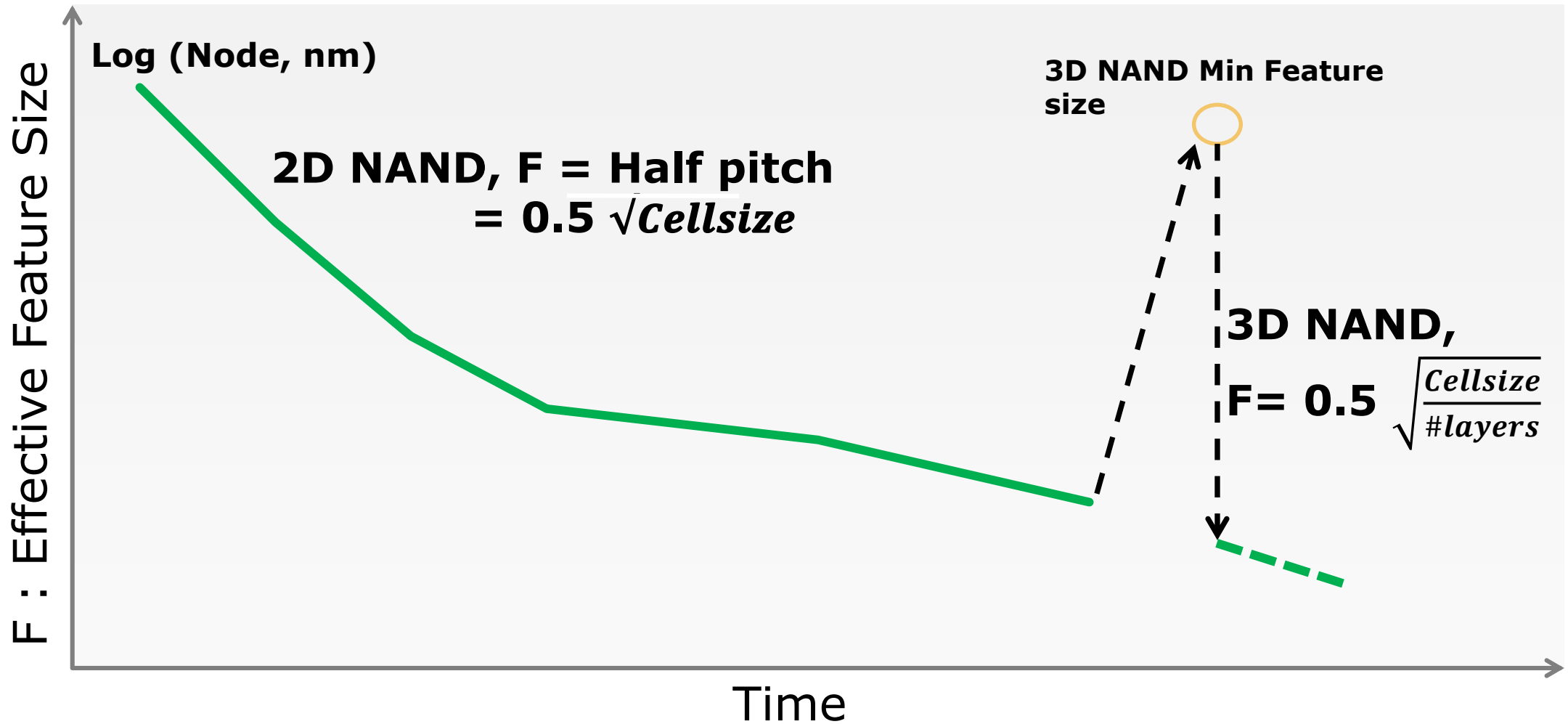


# The BiCS Scaling March





# NAND Technology Scaling: 2D and 3D



# What is BiCS?

*BiCS: Bit Cost Scalable flash technology (3D NAND)*

## 2D NAND: Floating Gate (FG)

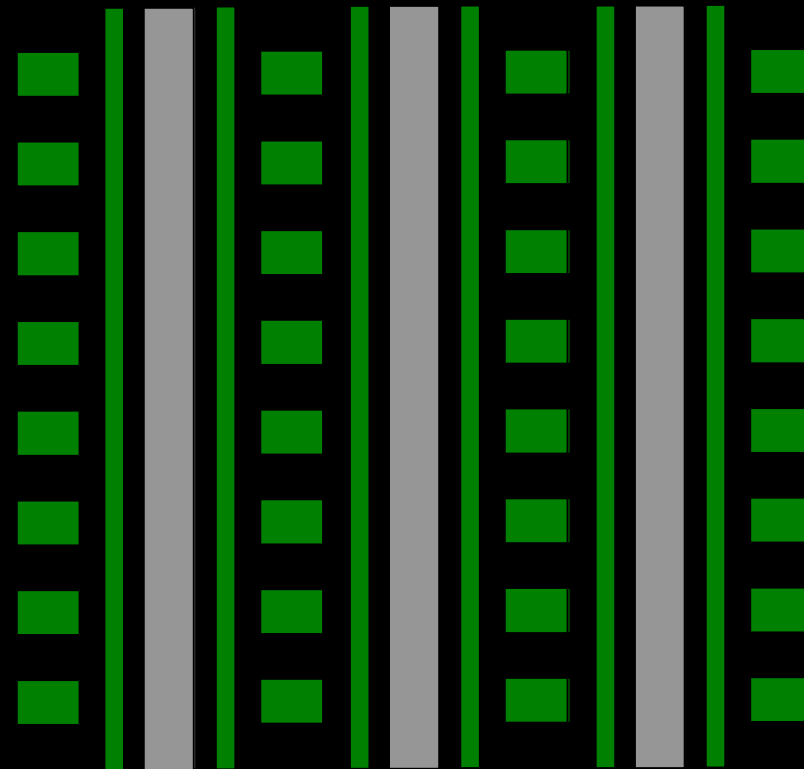


## Replacing FG with Charge Trap Layer (CTL)

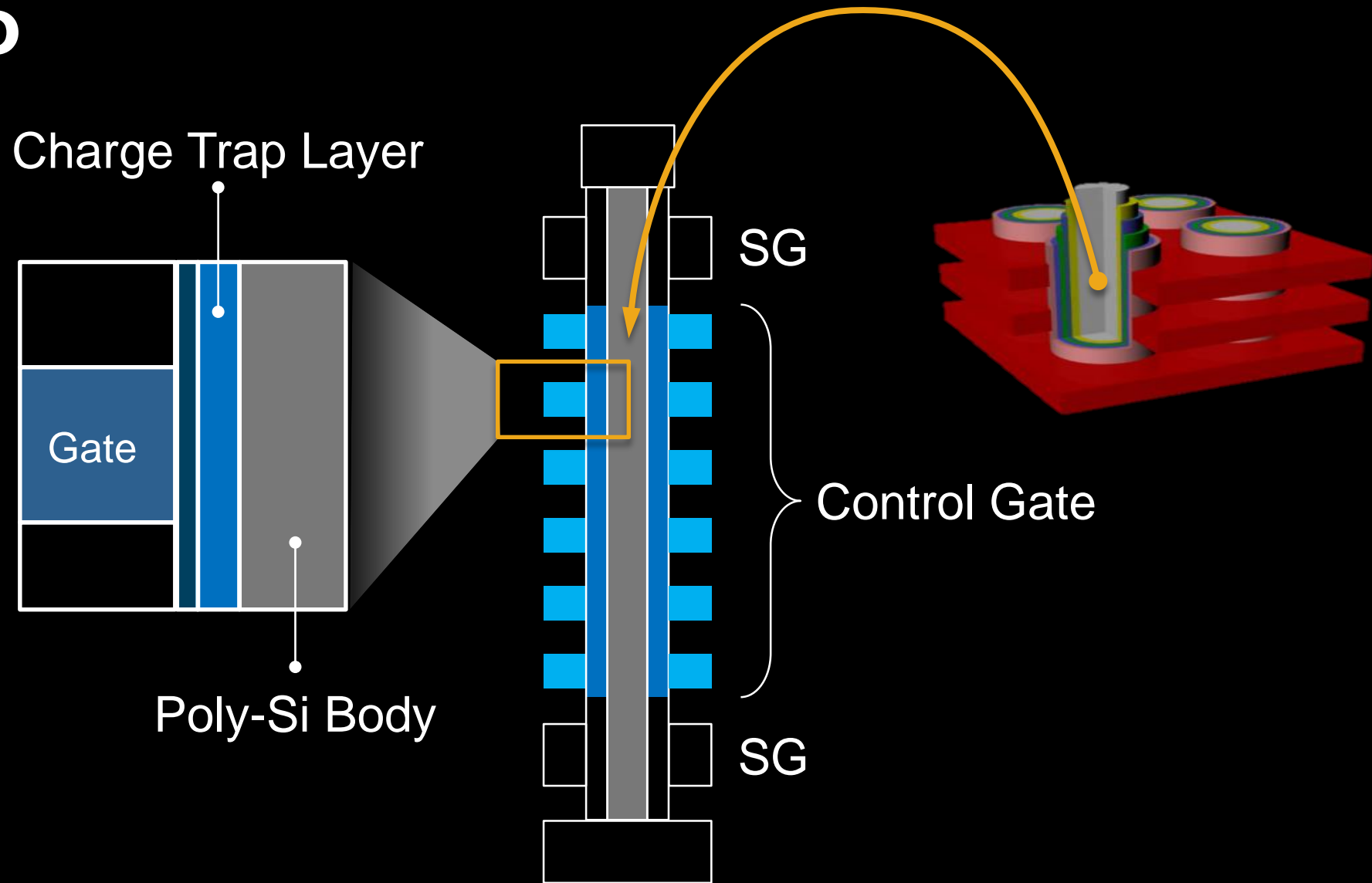


► *Layer stacking w/o adding litho/process steps*

➔ *Effective cell size = lateral cell size / n*

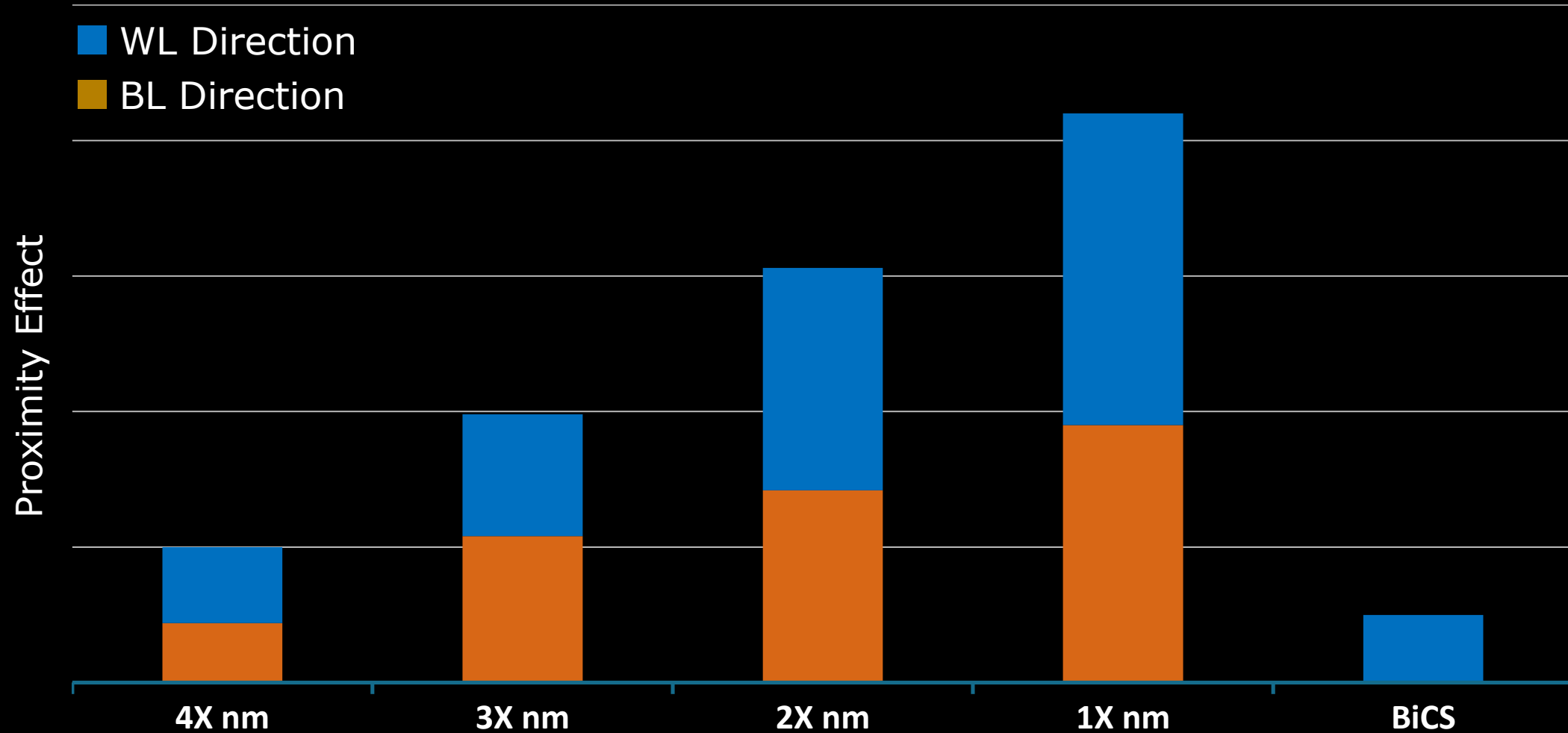


# 3D NAND Cell



# Proximity Effect in BiCS

**Lower is better**





# New opportunities for Scaling in NAND

*Lateral, Vertical, Logical*

**BiCS4**

96-layer  
3D NAND  
technology

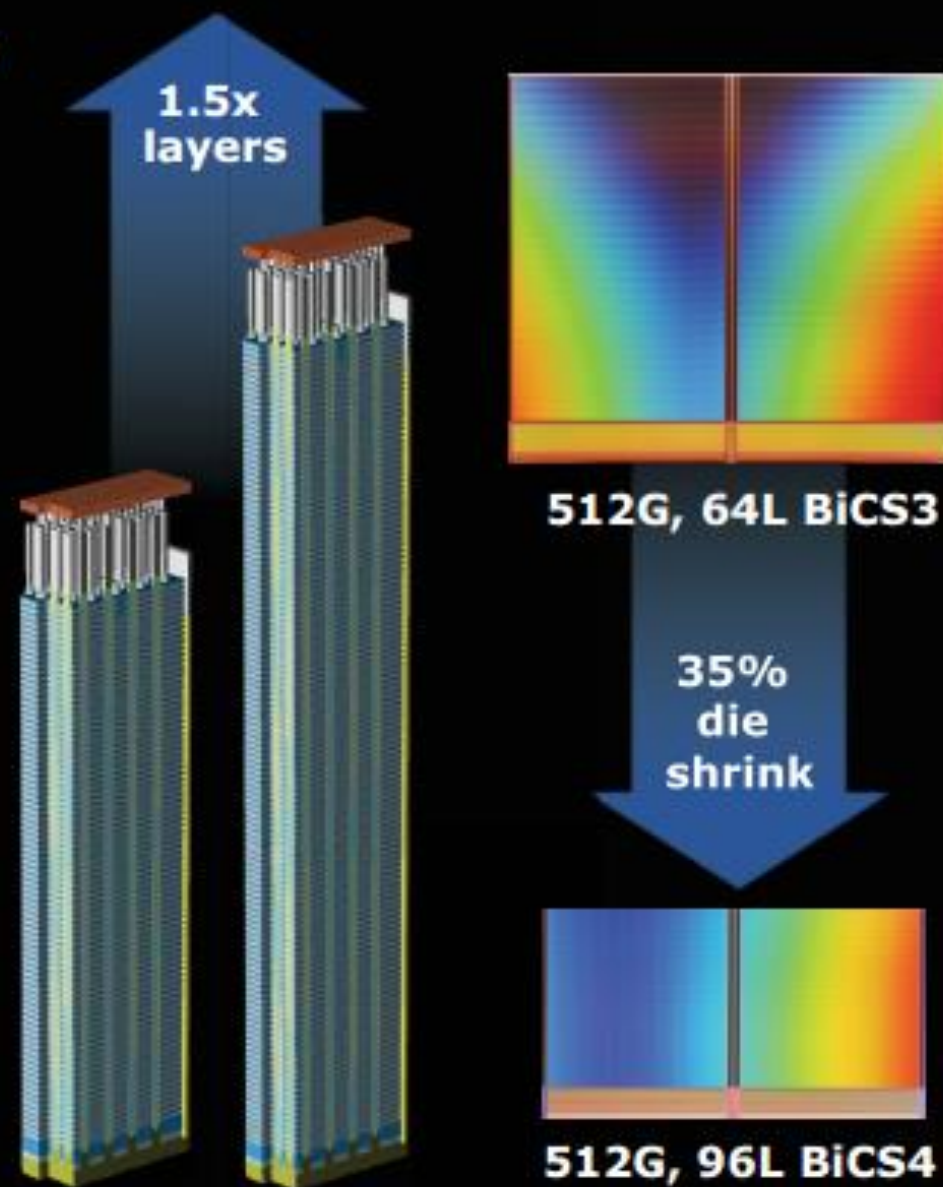
**X4  
Technology**

Four bits  
per cell  
Flash memory

**Western Digital<sup>®</sup>**  
**3D NAND**

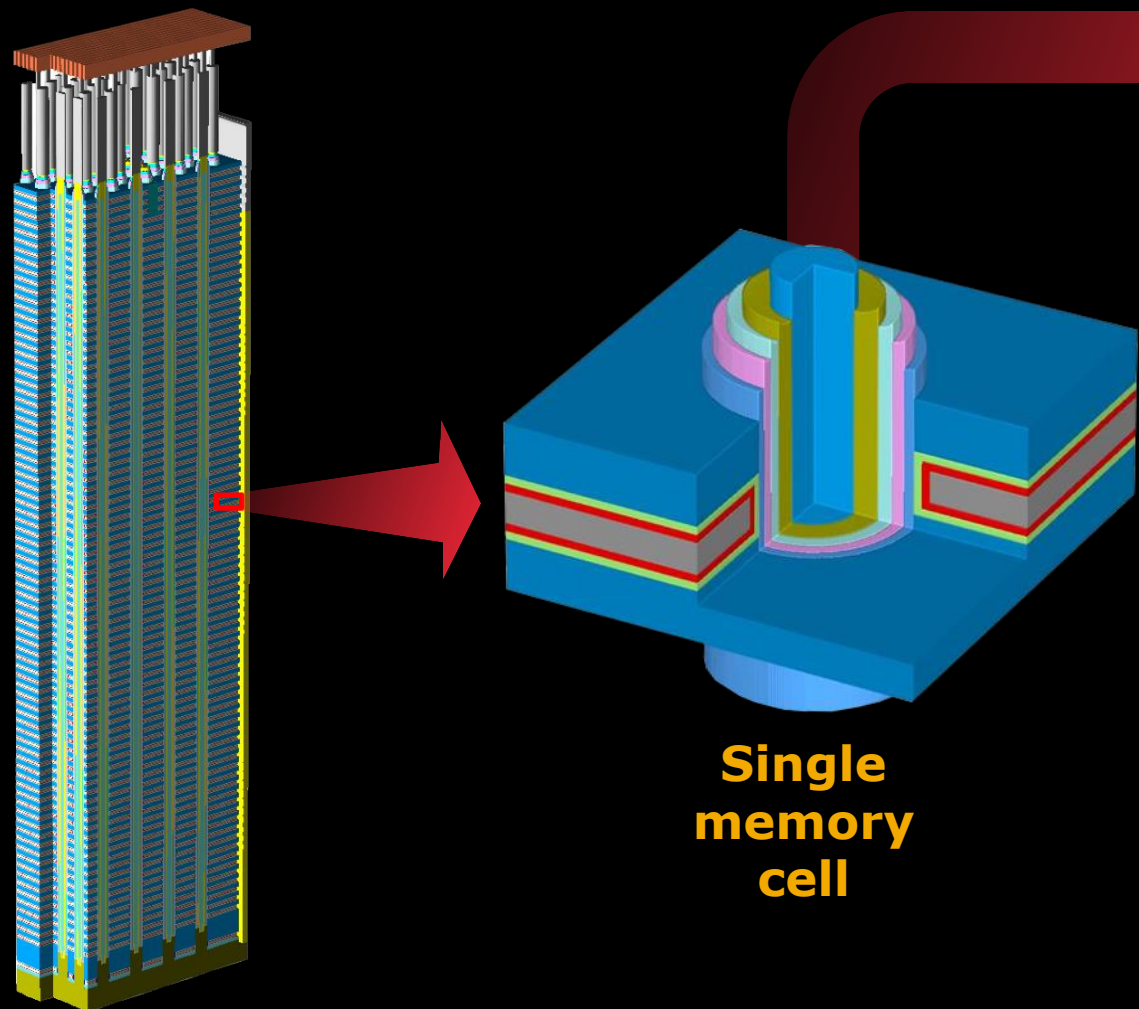
# 96-Layer 3D NAND Technology

- Denser storage, improved scalability at an attractive cost
- Enables up to 1 terabit of storage per die
- Faster IO speed using low power, low voltage IO design



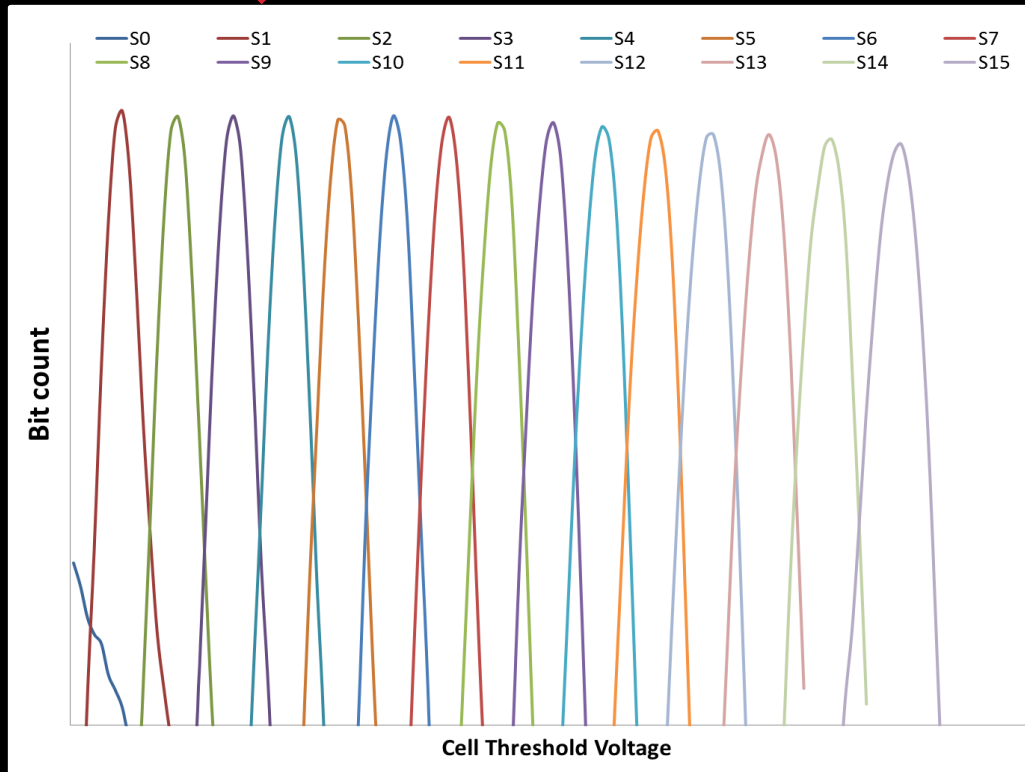


# It is all Quite Logical: 4 Bits per Cell



**Industry-leading  
64-layer 3D NAND**

**16 data levels per cell**



**SSD based on  
768Gb X4**

# Industry Leading Portfolio Breadth

## Client Devices (OEM)



- Notebook / Desktop HDD
- NAS HDD
- Consumer Electronics HDD
- Client SSD
- Embedded, Components

## Client Solutions (Retail)



- Branded HDD
- Branded Flash
- Removable products

## Data Center Devices



- Enterprise HDD
- Enterprise SSD

## Data Center Systems & Platforms



- Integrated Object Storage System
- HDD Platform
- All Flash Platform



# Mobility Markets

The “mobile platform” has evolved to more than handsets – data is at the heart of this revolution!

## Mobile



## Home



## Auto



## Industrial/IoT



# Drivers For The Memory Capacity: Smartphone

**More apps installed – Apps are more user friendly than the website.**

- Social Media
  - Facebook
  - WeChat
  - Snapchat
  - Twitter
- VR/AR
  - Tango
  - VRSE
  - Pokémon Go
  - Orbulus
- Others
  - Maps
  - Music
  - Video
  - Games



# Drivers For The Memory Capacity Increase: Smartphone

## Photo and Video Creations

- Raw Image
- Multi shots
- Panoramic format
- 4K HD video
- Slow motion video





# Drivers for More Performance and Better User Experience

## Consumer Demanded Better User Experience

- **Fast system boot**
- Faster data transfer
- **Launch apps with reduced latency**
- Extended frames of multi-shot
- **Higher frame rate on slow motion video capture**
- Higher resolution burst shots
- **Higher resolution** video – 4K HD

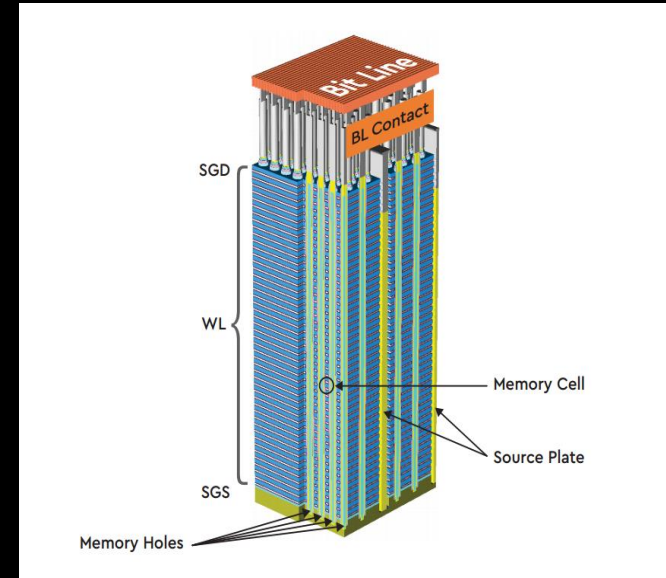




## 3D NAND Summary

3D NAND (BICS) offers:

- Scalability to high memory capacity
- Fast Write Performance
- Long Endurance (TBW)
- Consume less power per GB written



The world's first 64-layer 3D NAND client SSDs are now available, with higher capacities expected in the future.

The world's first 3D NAND technology with 96 layers of vertical storage was introduced at Flash Memory Summit 2017.

The image features the Western Digital logo in white, bold, sans-serif font, centered horizontally. The background is black with a dynamic, abstract pattern of colorful, streaky lines in shades of orange, red, and teal, radiating from the right side towards the center.

**Western Digital®**