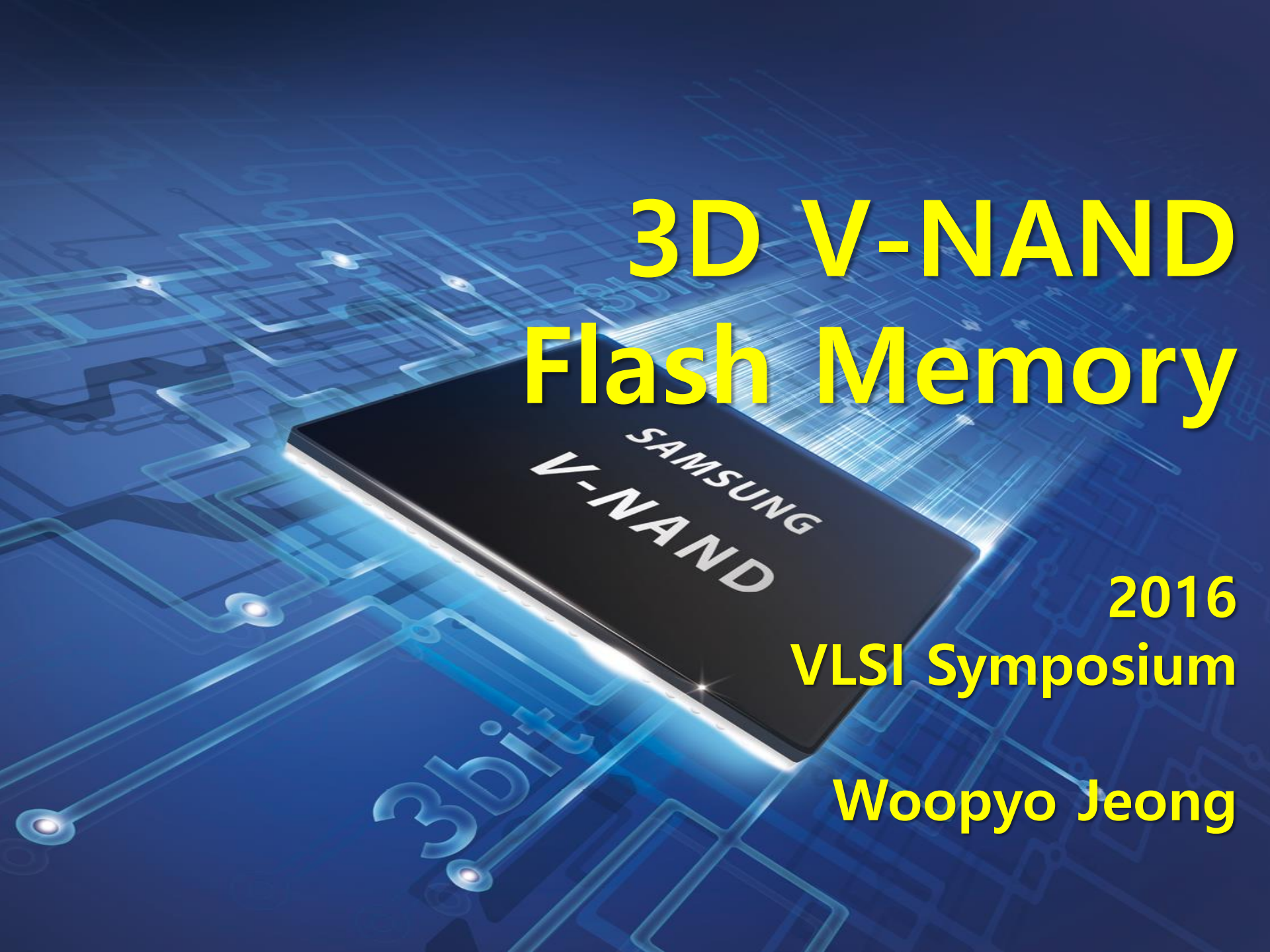


3D V-NAND Flash Memory

2016
VLSI Symposium

Woopyo Jeong

Chapter 1 : Industry Trends

Chapter 2 : Introduction to V-NAND Flash

Chapter 3 : New Era, V-NAND

Chapter 1 : Industry Trends

Chapter 2 : Introduction to V-NAND Flash

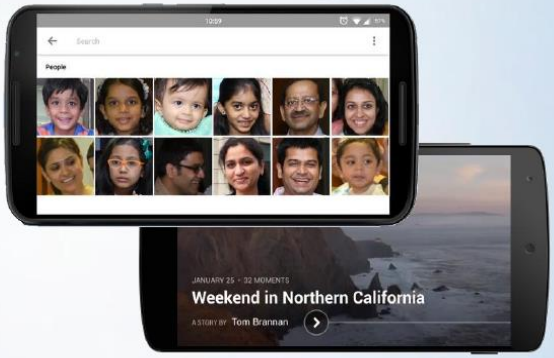
Chapter 3 : New Era, V-NAND

Flash Innovation is Lifestyle Innovation

Photo & Video

Before Flash…

Scattered, fragile, unorganized



Searchable, protected, free

Before Flash…

Bulky & tape-based

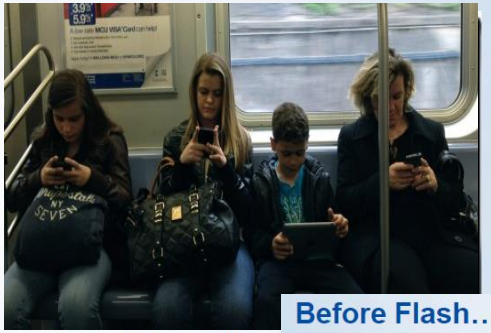
Tiny, rugged & behavior changing

Flash Innovation is Lifestyle Innovation

Media, Entertainment, Shopping etc.

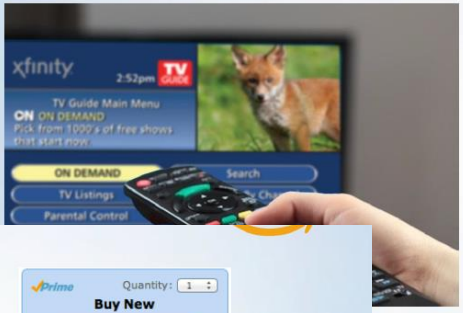
Before Flash…

Day late, eco-hostile



Real-time, targ

Before Flash…



nt

Untethered a la carte

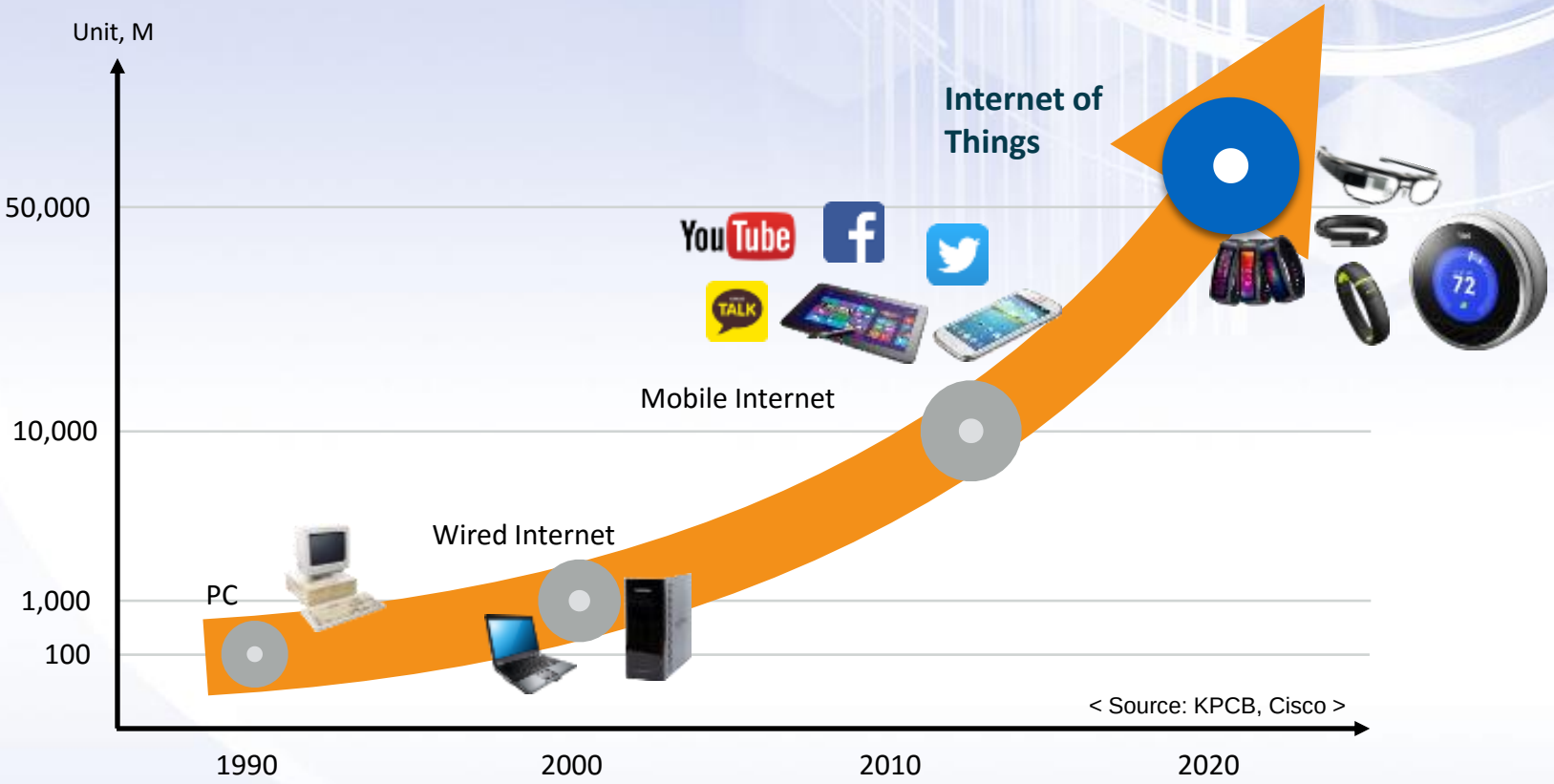
Before Flash…

Long lines, unruly crowds

1-Click™ & boxes arrive

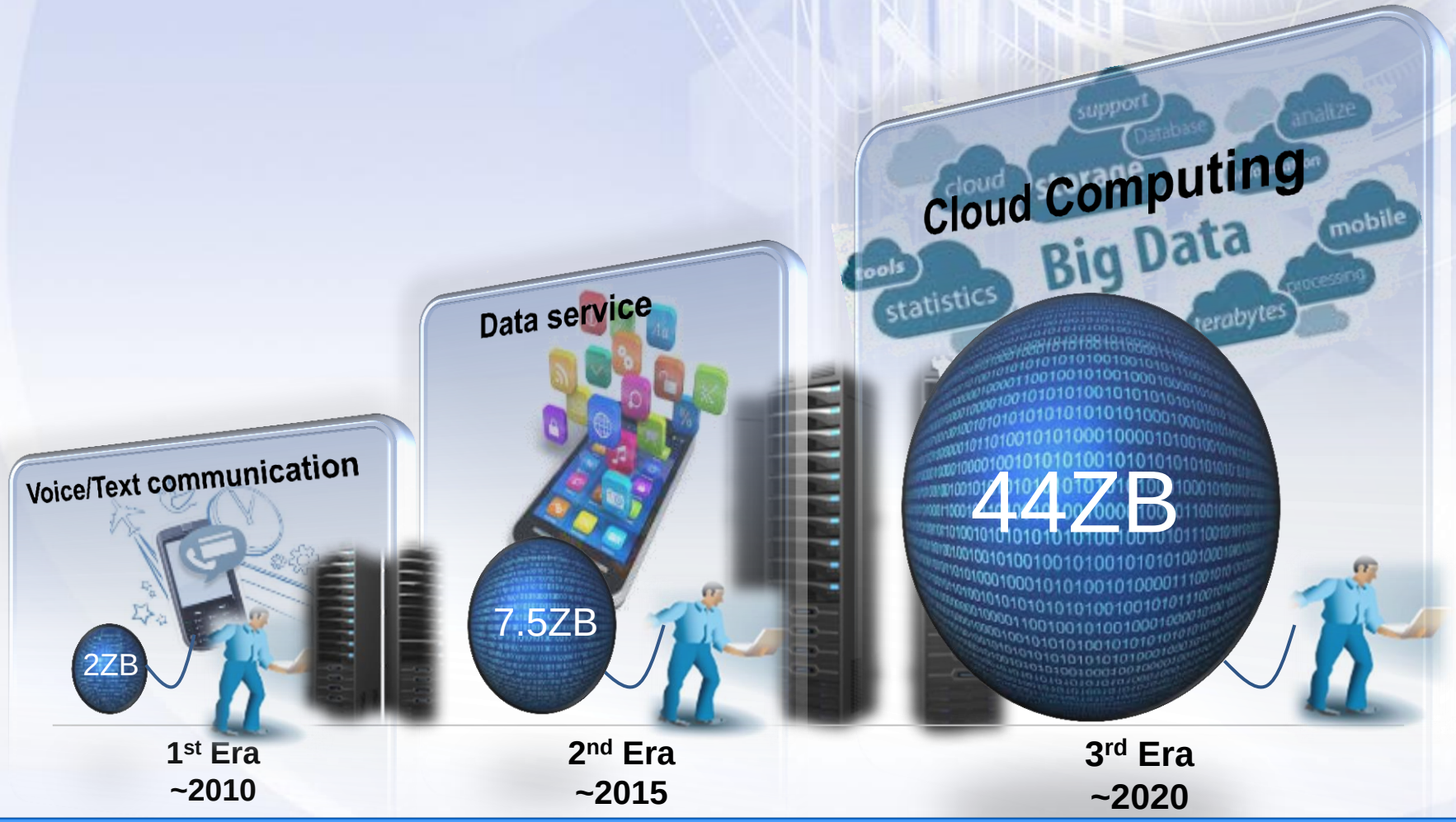
Storage Growth Drivers

PC → Mobile → Cloud & IoT



2012 : Mobile Connected Devices exceeded the World's Population

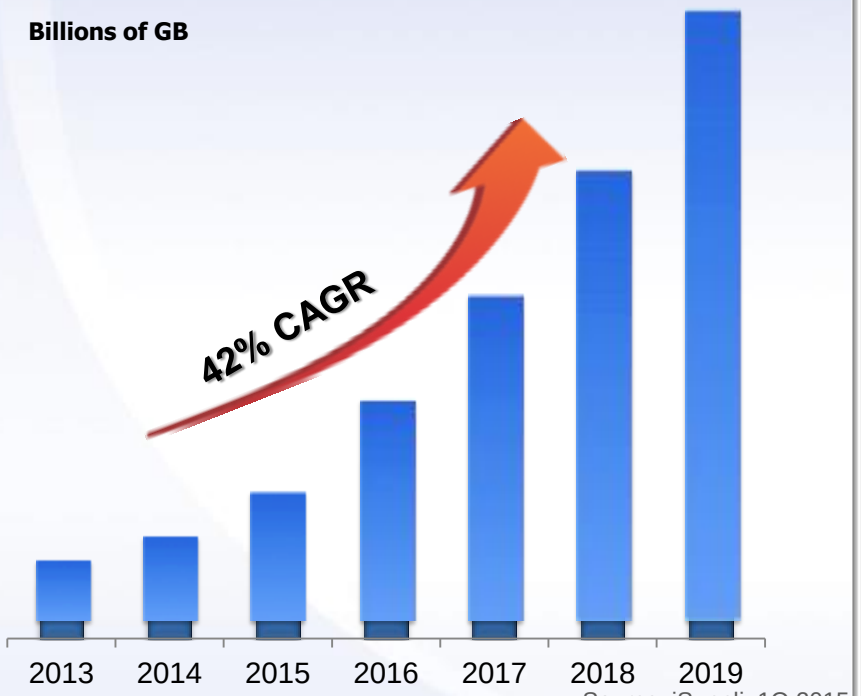
A New Era of "Big Data Creation" is Here



YOU are the New Driving Force for Data Explosion

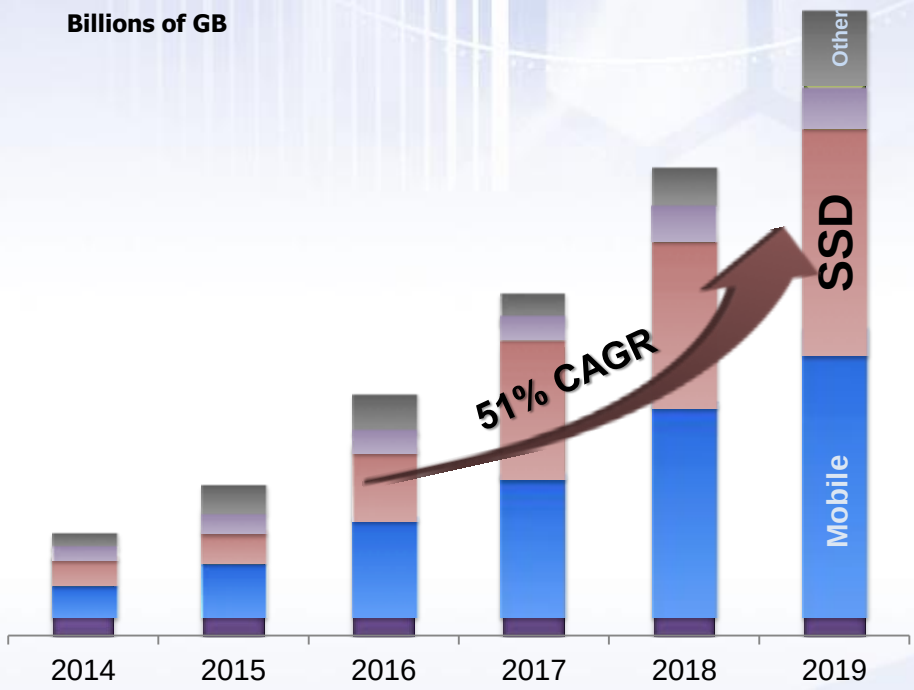
NAND's Exponential Growth Continues

NAND Demand Growth

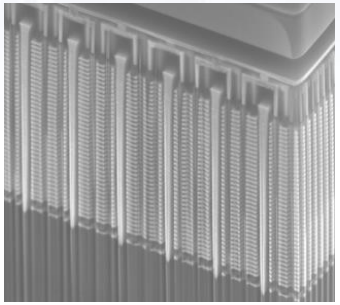


Source: iSuppli, 1Q 2015

Demand by Application

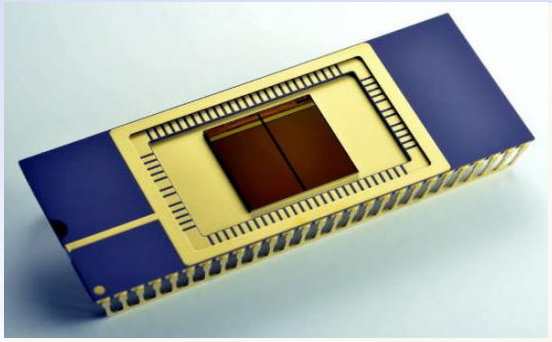


What's Inside of Flash Innovation



Flash Innovation comes near us

3D NAND Market Share Trend



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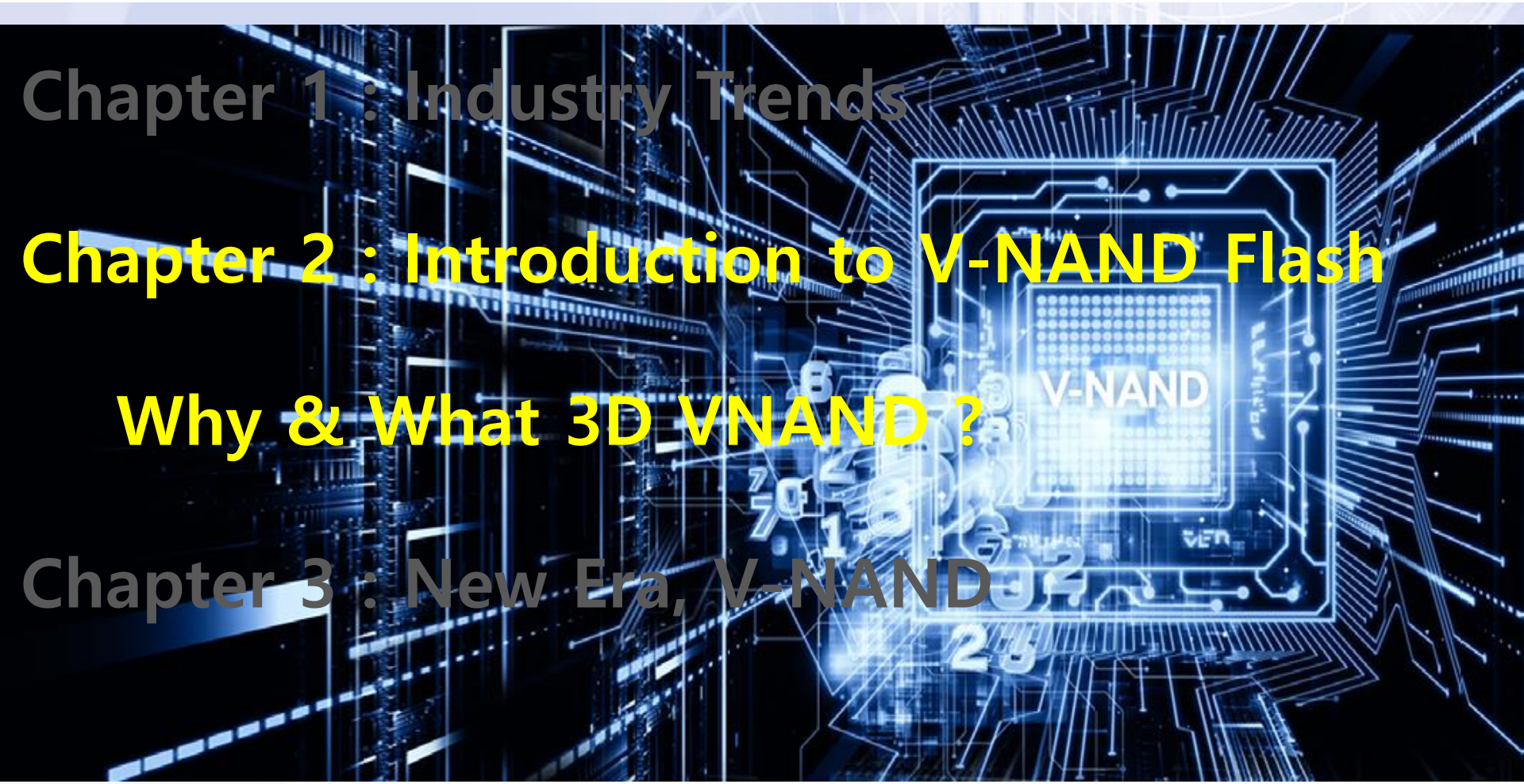


Chapter 1 : Industry Trends

Chapter 2 : Introduction to V-NAND Flash

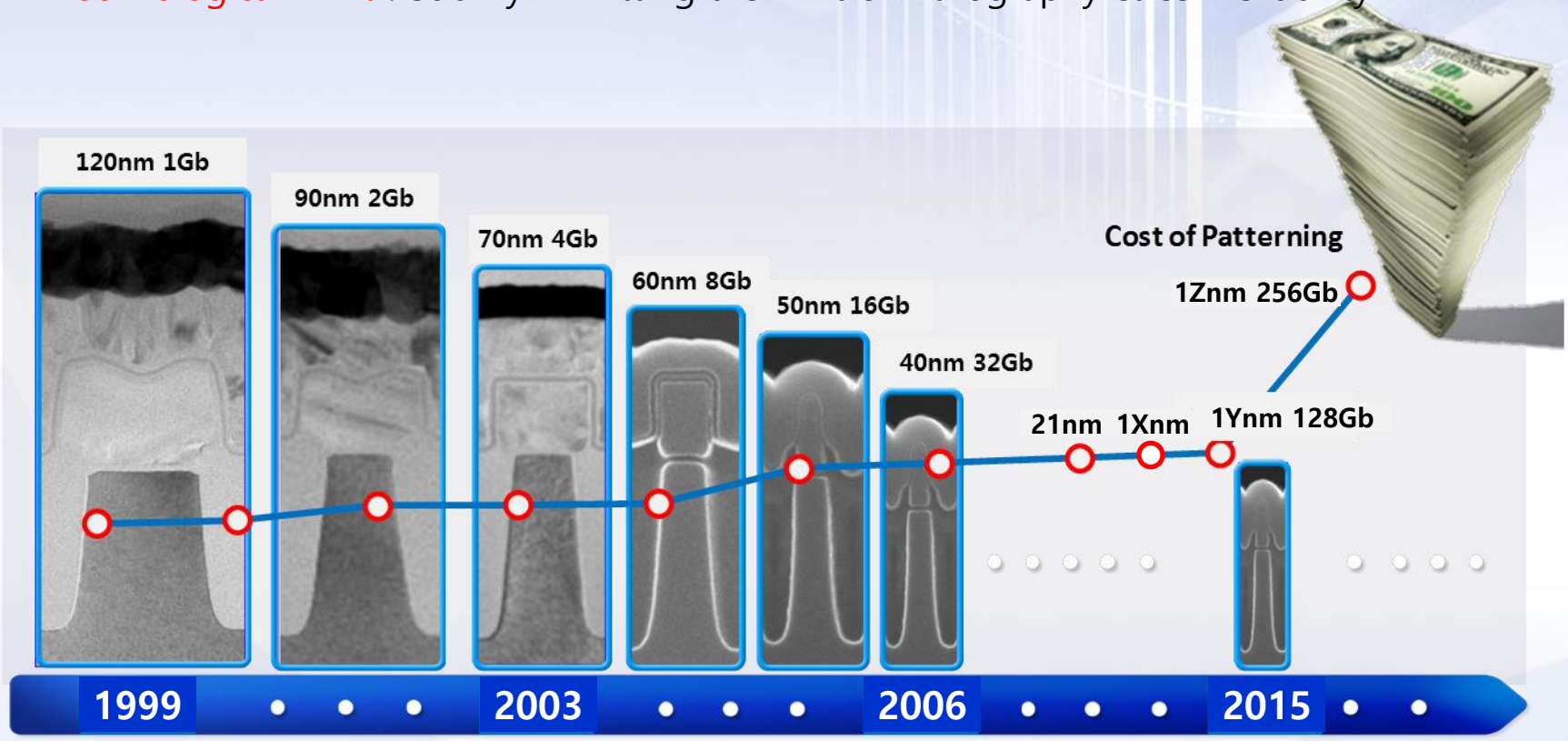
Why & What 3D VNAND ?

Chapter 3 : New Era, V-NAND

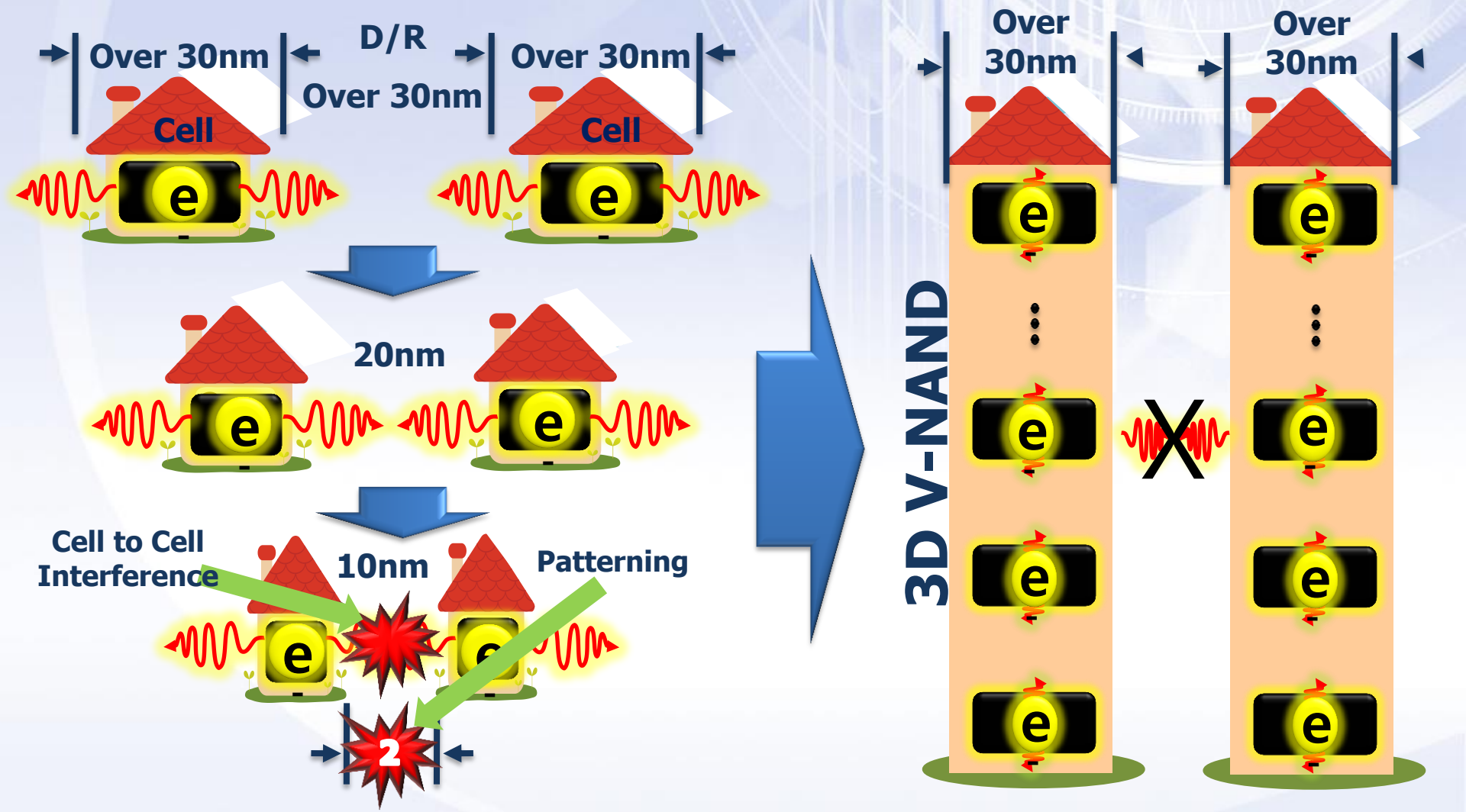
Uncertainty of Future Planar NAND

Scaling is getting difficult (It is true)

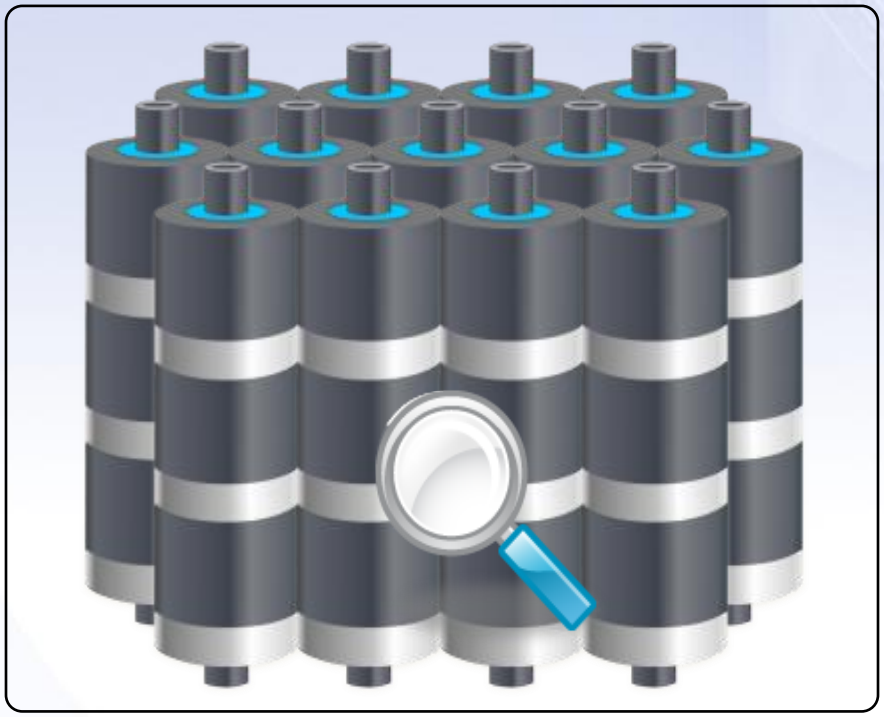
- Economical Limit : Tremendous investment cost
- Technological Limit : Sub-1ynm hitting the limit of Lithography & cell reliability

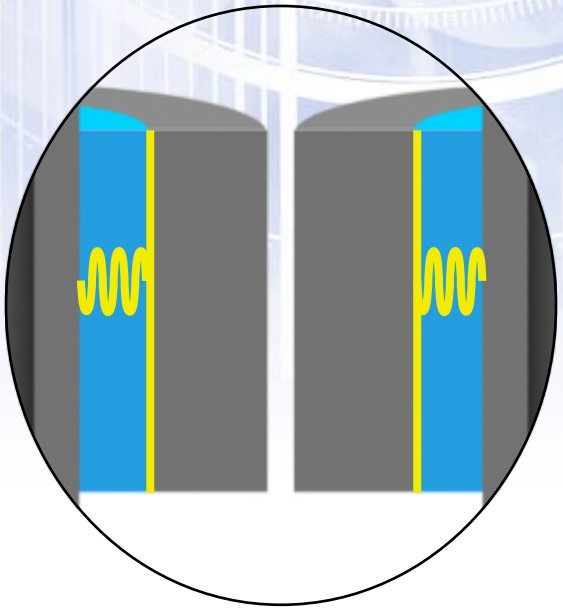


Limits of planar NAND



Cell to Cell Interference-Free Structure

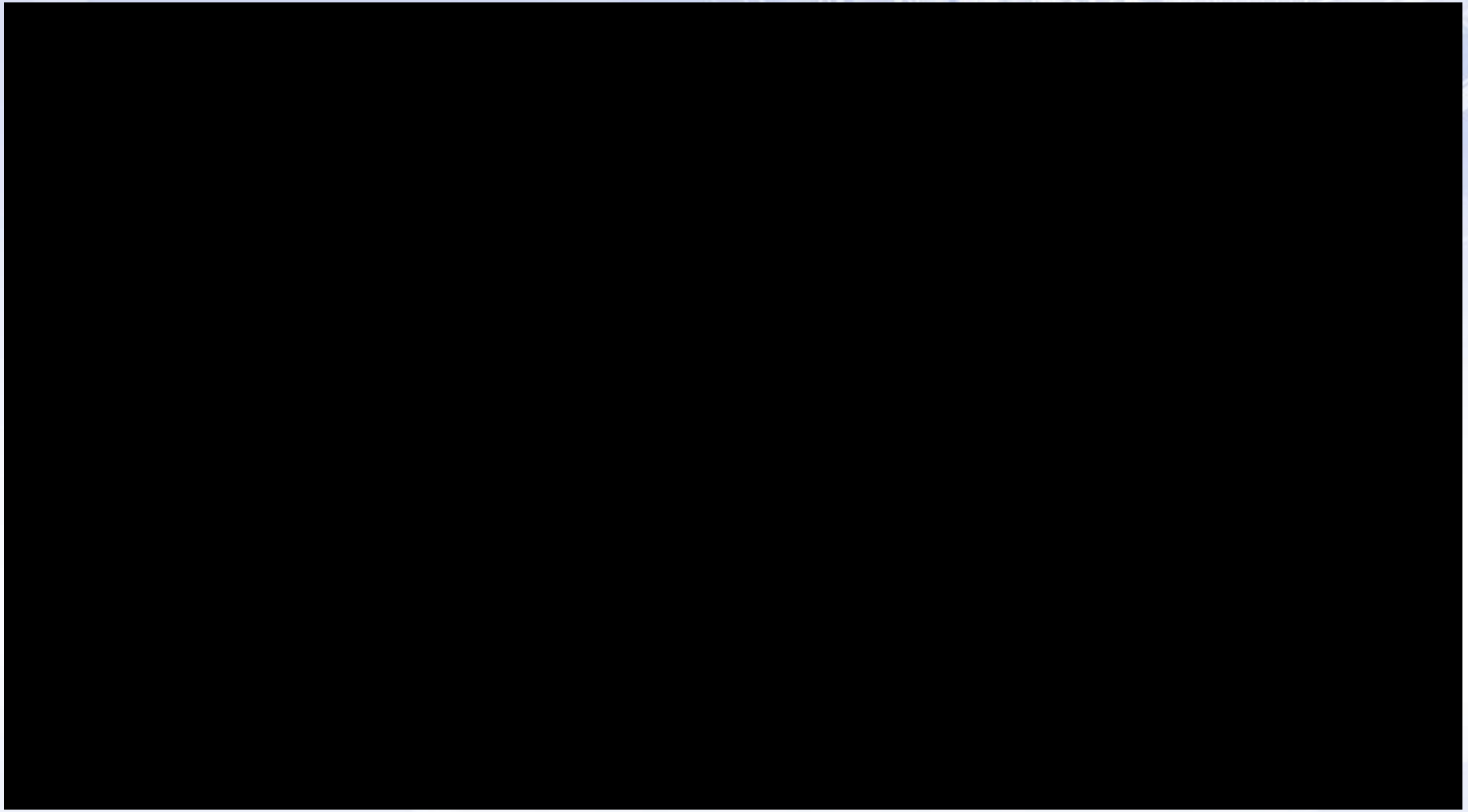




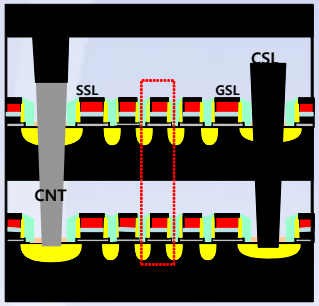
48 Stack = 32 Stack

# of Stacks Increase, but Cell-to-Cell Interference is almost free

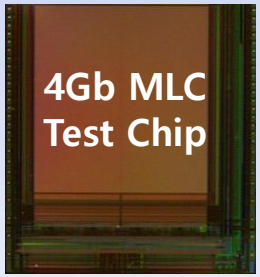
What is 3D V-NAND? (Video)



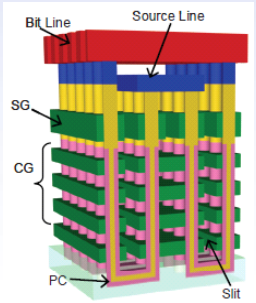
Developing 3D NAND

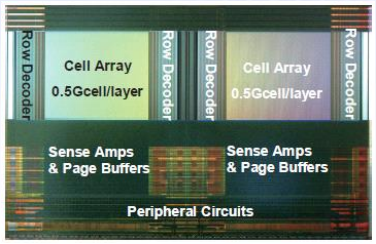


3D Stacked NAND
(IEDM'06, ISSCC'08)

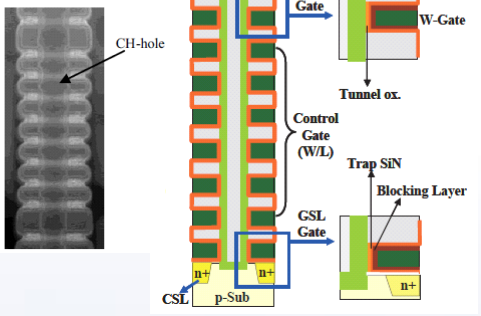


3D Vertical NAND, BiCS
(VLSI'07, VLSI'09)





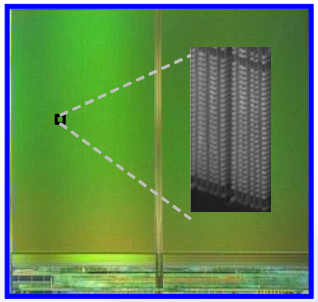
3D Vertical NAND, TCAT
(VLSI'09)



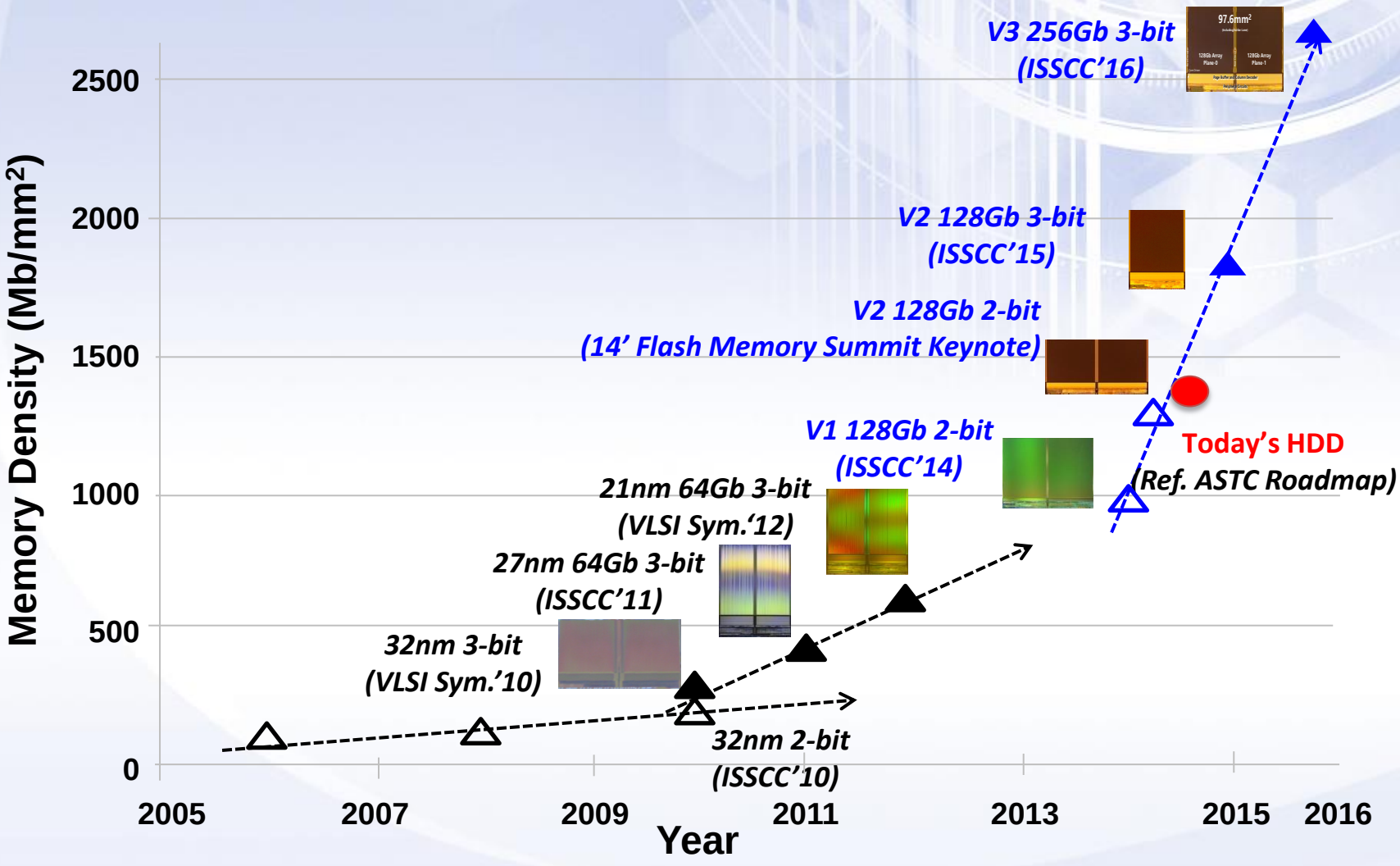
From bottom to top over 10 years

1. Material Innovation
2. Structure Innovation
3. Integration Innovation
4. Design Innovation
5. Managing Innovation

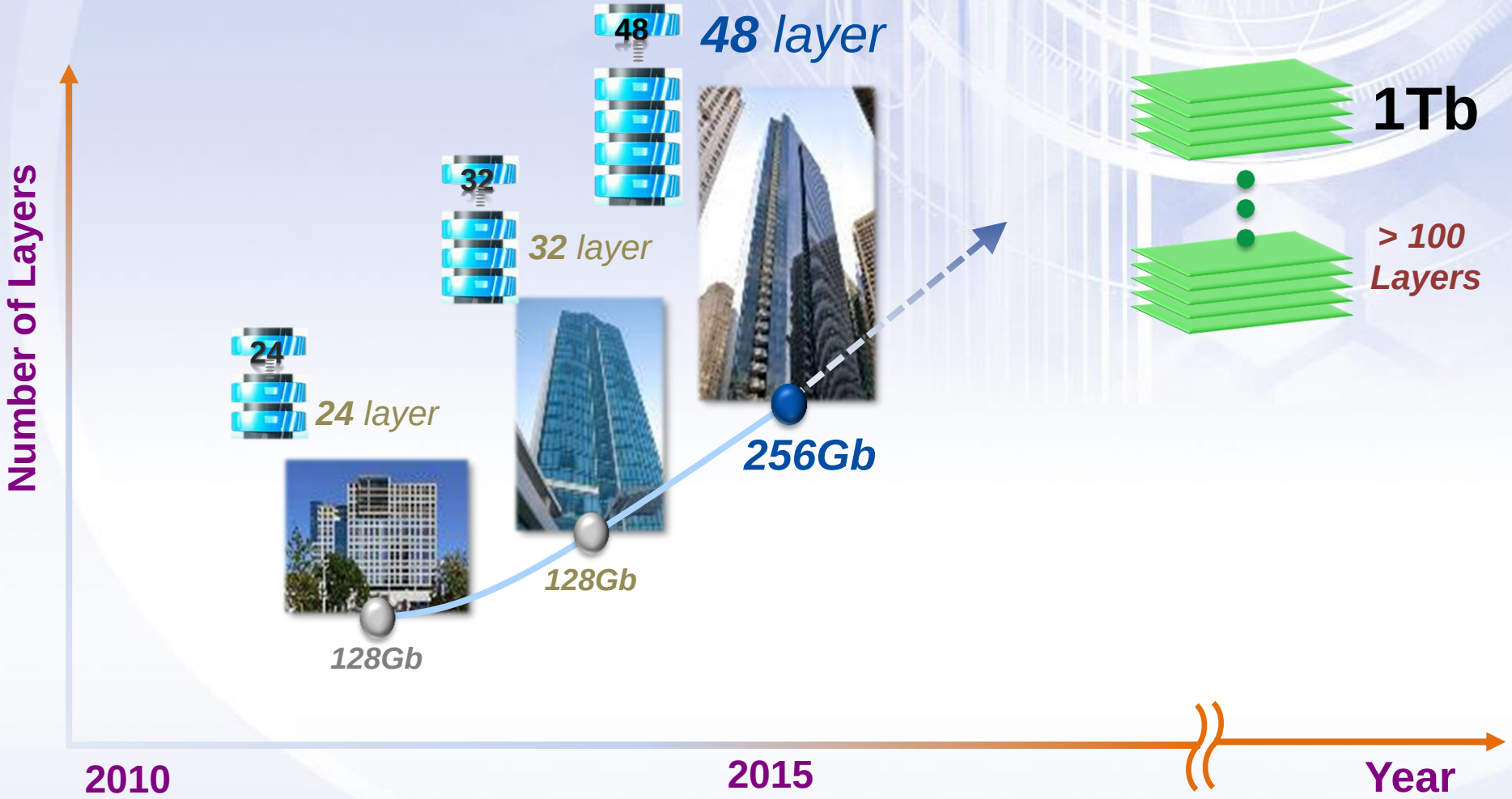
128Gb MLC
3D Vertical NAND
World 1st Product,
(ISSCC'14)



V-NAND : Disruptive Technology



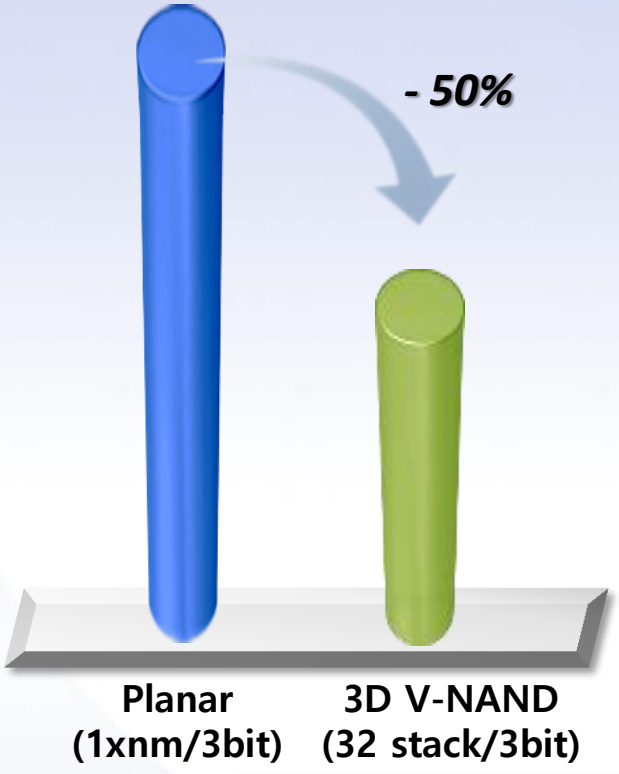
Density Increase of 3D NAND



V-NAND Capacity Breakthrough and Scalability

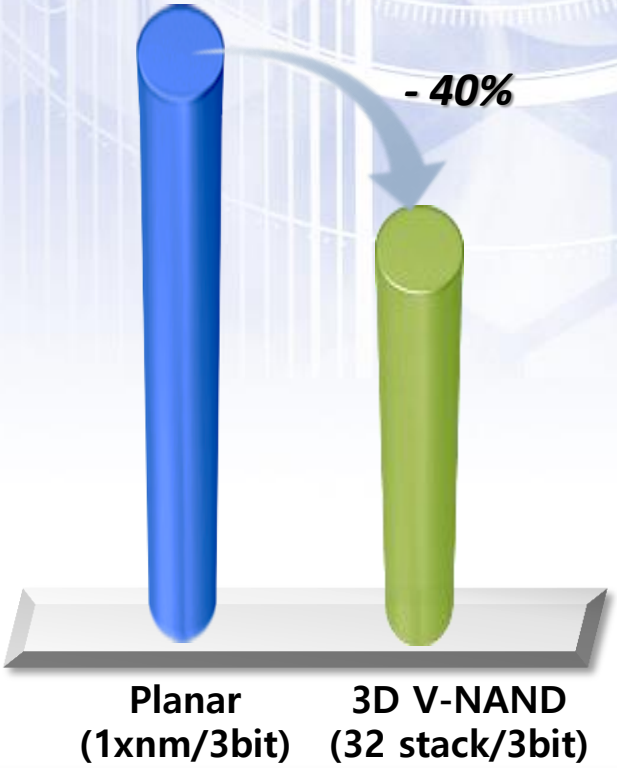
Performance & Power of 3D V-NAND

tPROG



*Lower is better

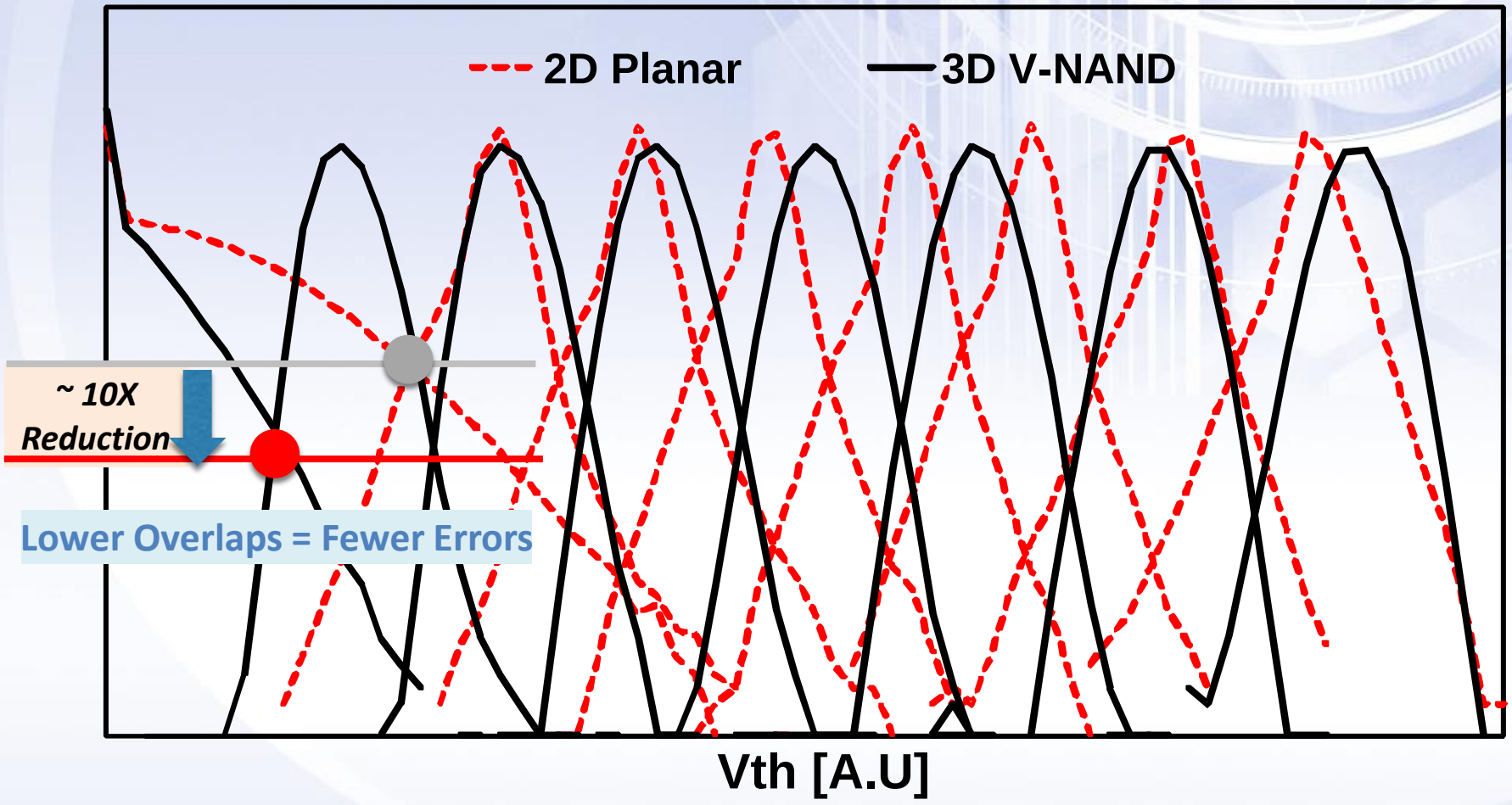
Power Consumption @ PGM



*Lower is better

2X Faster & ~40% Lower Power

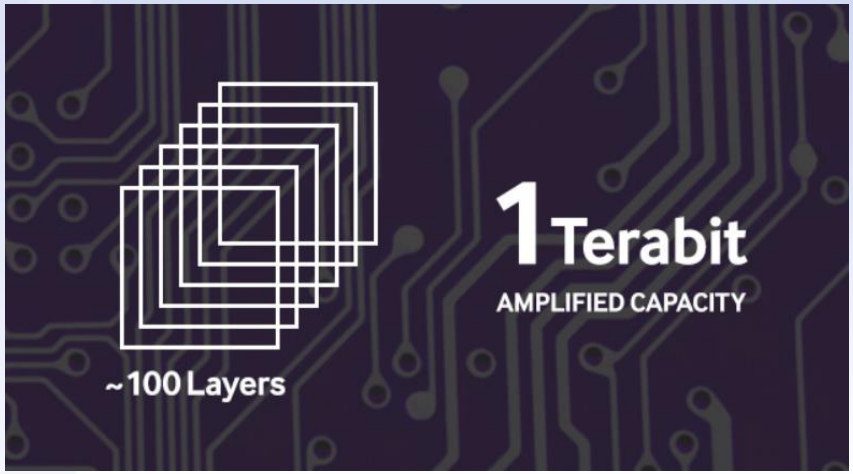
Reliability of 3D V-NAND



3bit V-NAND Improves Bit Error Rate

Vertical Expansion breaks through horizontal limit

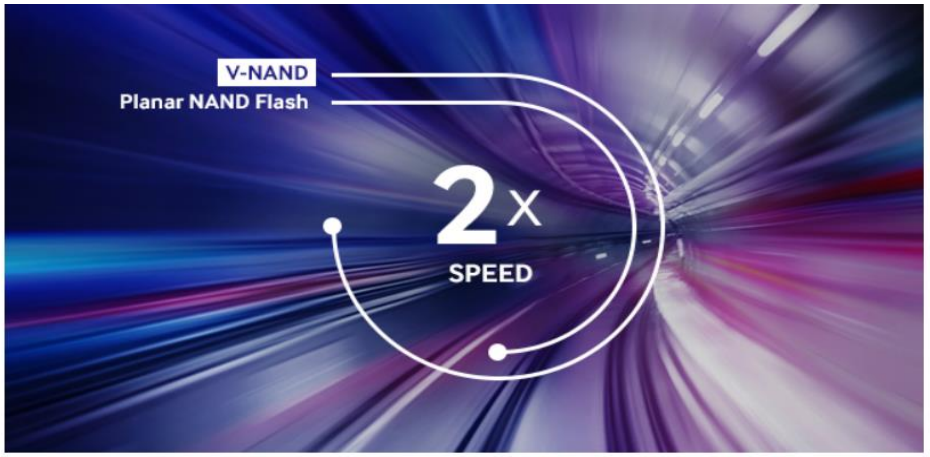
Vertical architecture paves the way for amplified capacity

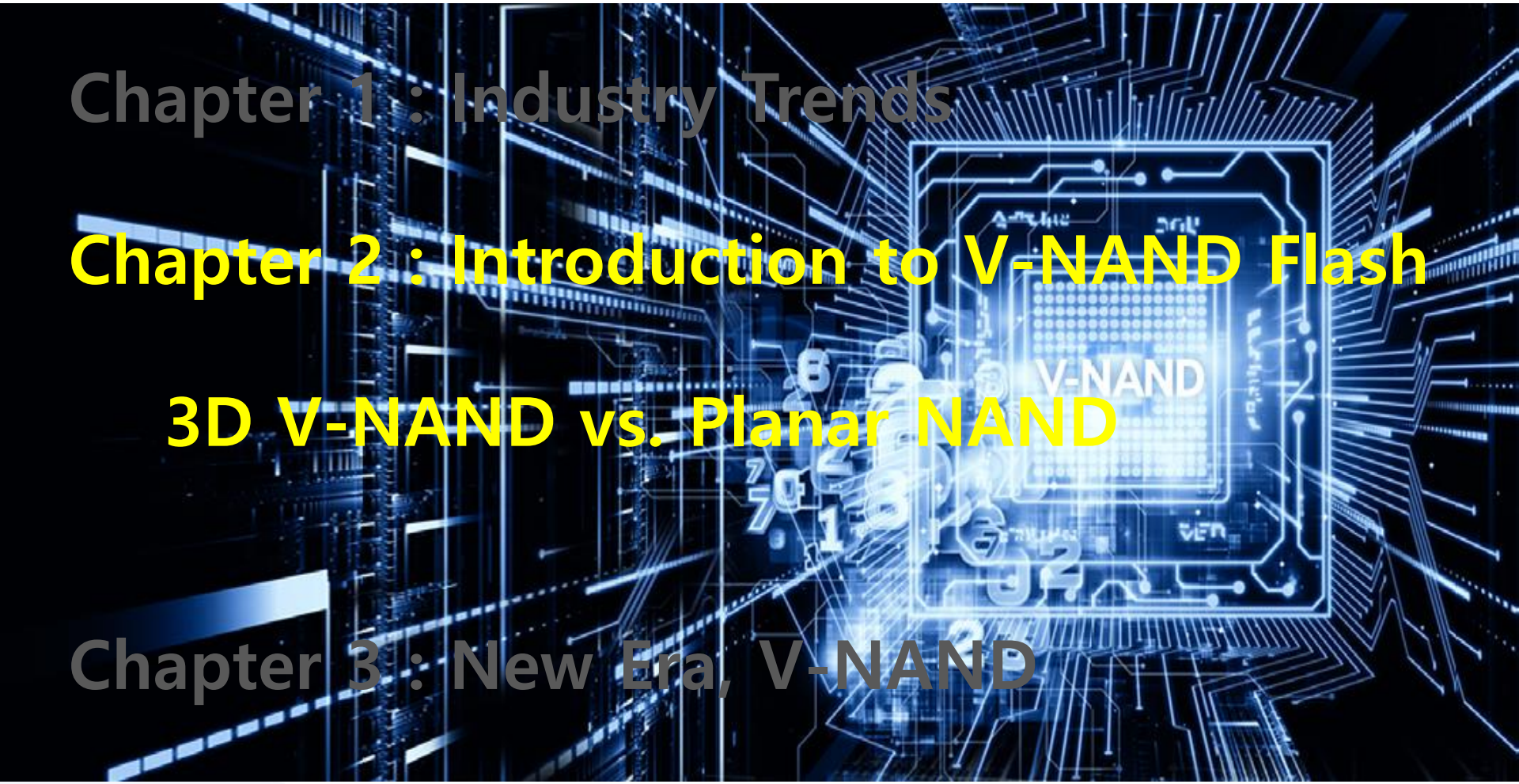


Embedded high endurance to store your valuable data

Unprecedented power efficiency

Innovative algorithm equal faster performance





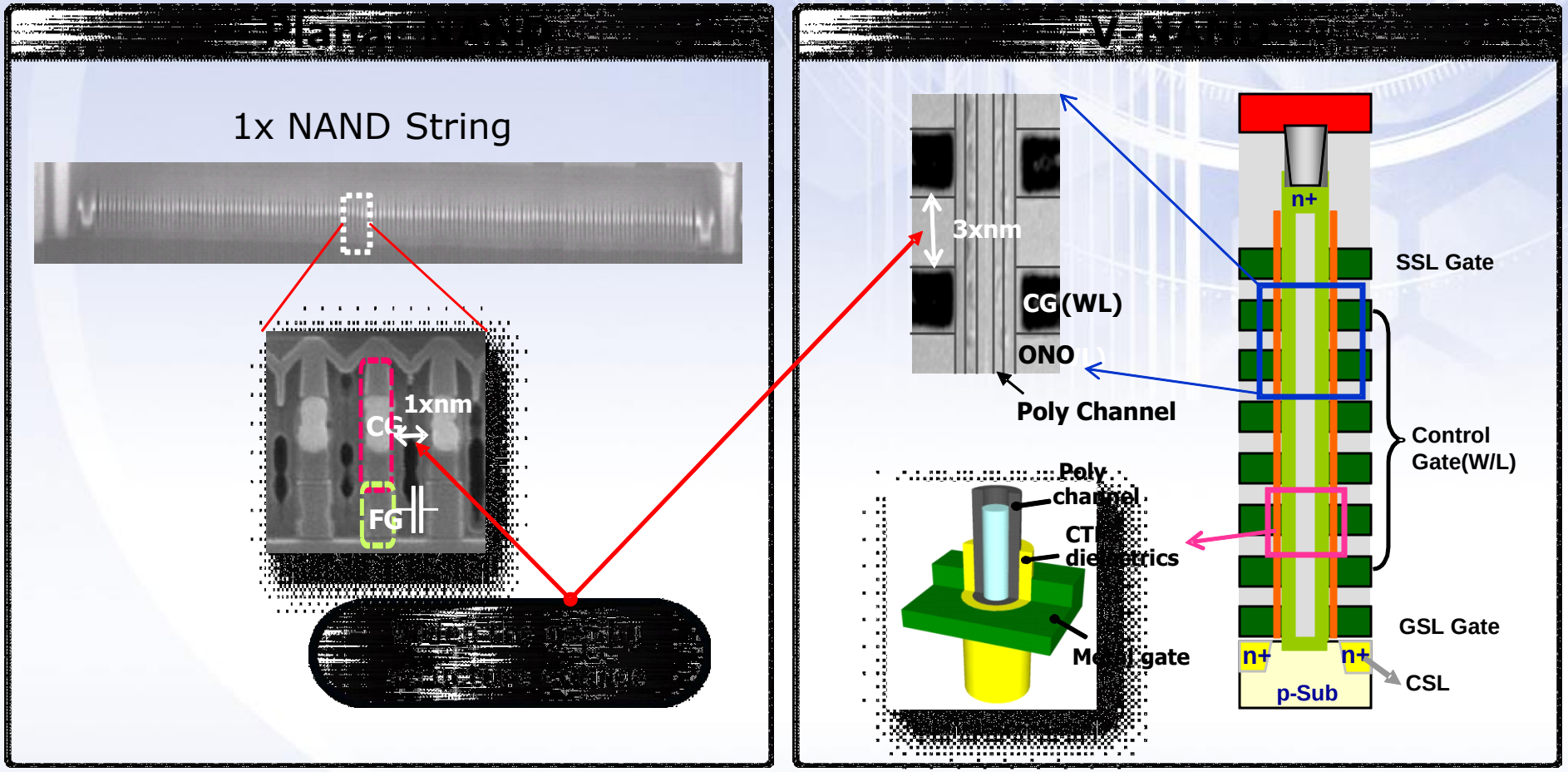
Chapter 1 : Industry Trends

Chapter 2 : Introduction to V-NAND Flash

3D V-NAND vs. Planar NAND

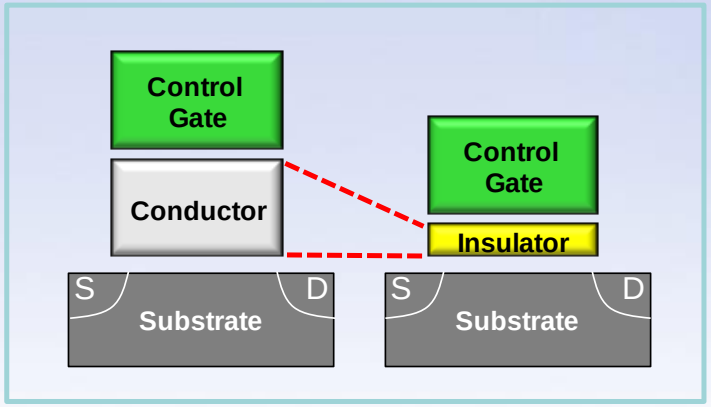
Chapter 3 : New Era, V-NAND

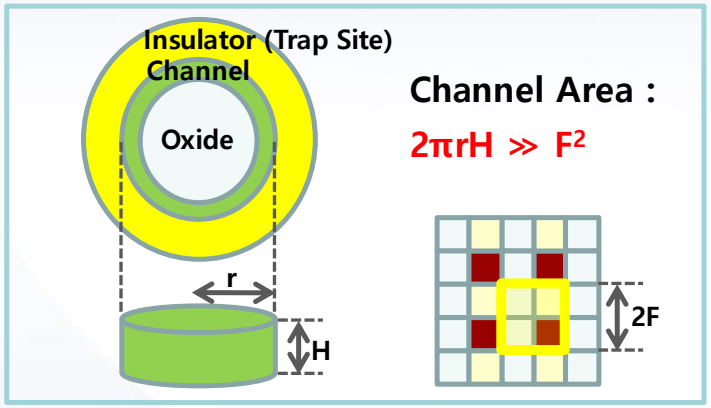
Device Structure Comparison

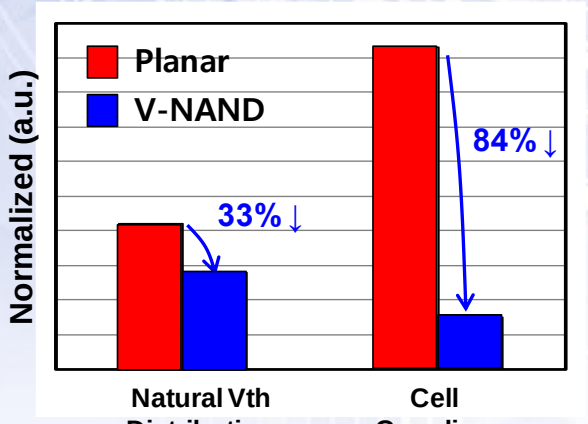


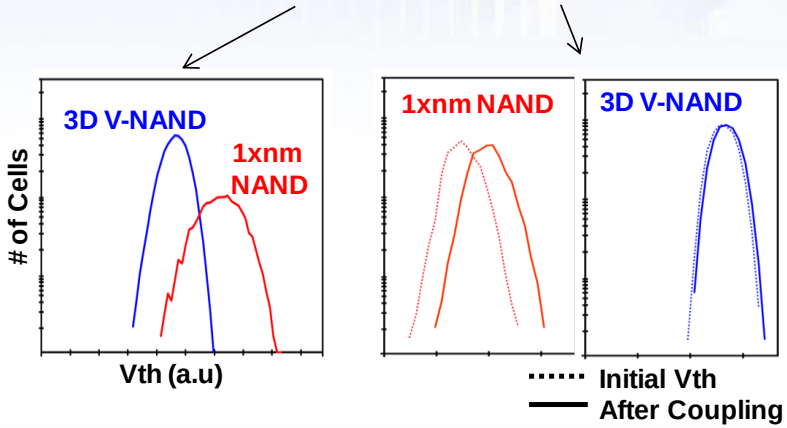
- Overcoming patterning limit
- Reduce BL coupling noise to almost zero by structural changes

Cell Characteristics Comparison



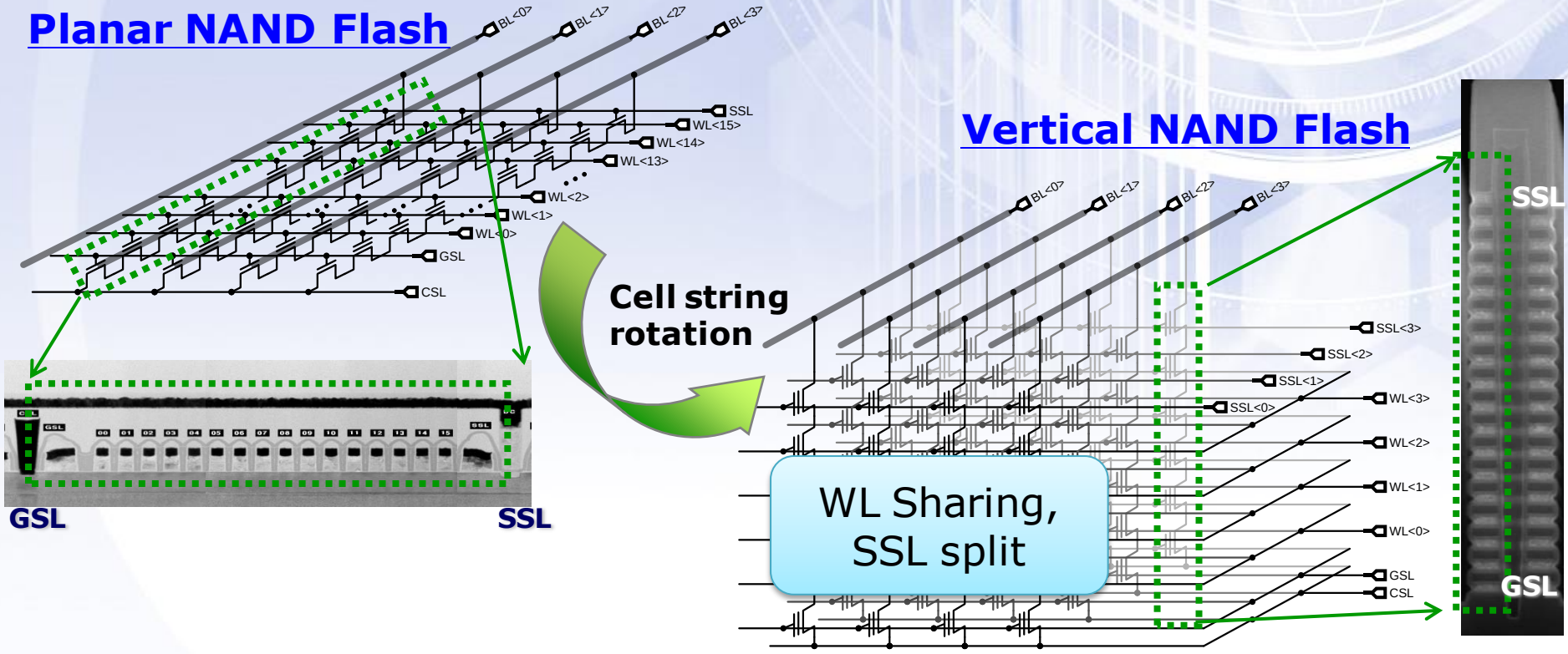






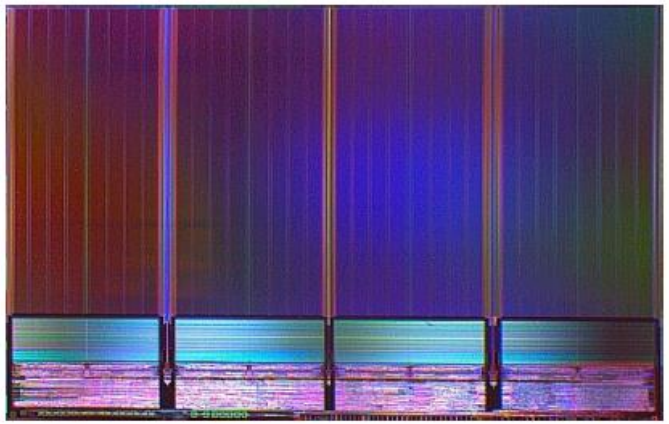
- Advanced CTF(Charge Trap Flash) + Cylinder-Shaped Gate Structure → Superior Cell Characteristics

Cell Array Comparison

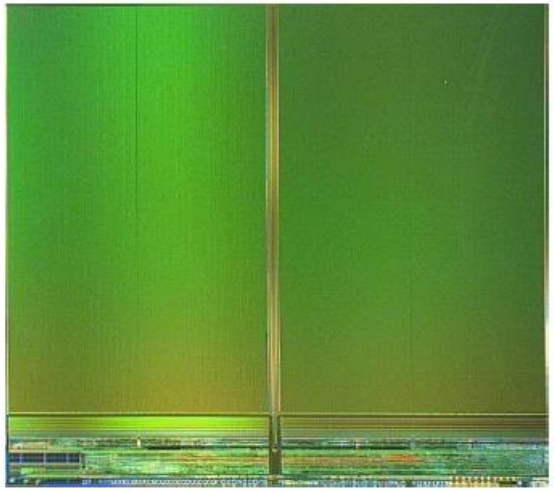


- V-NAND is composed of vertically stacked cell string
- V-NAND operations(Page Operation) is compatible with planar NAND

3D NAND(1st Gen) vs. Planar NAND(1xnm)

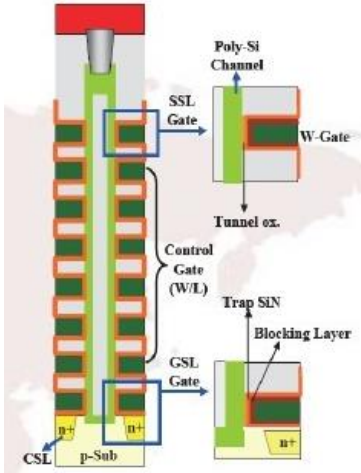
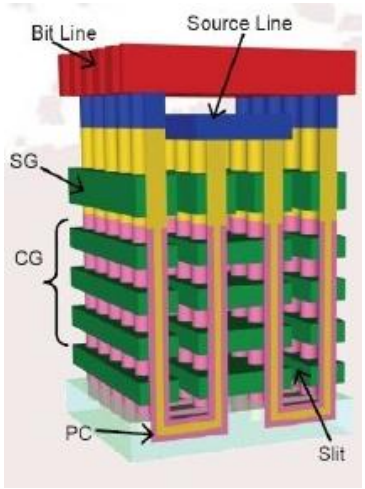
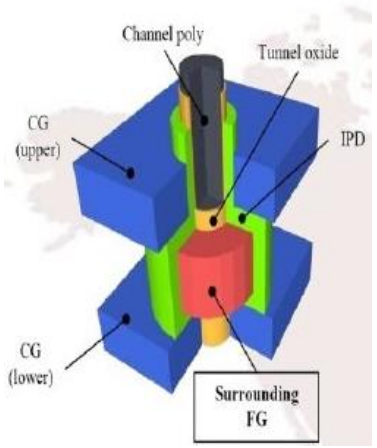
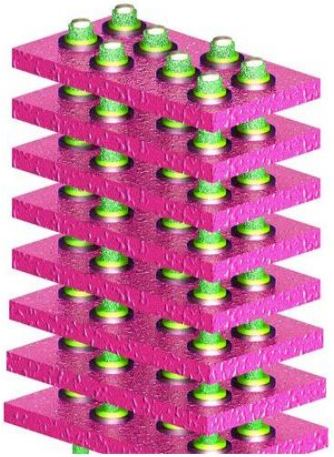


X1.64 Density Increasing



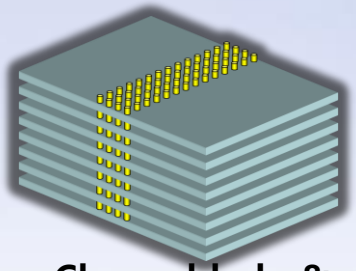
1xnm 64Gb MLC	Features	V1 128Gb MLC
(1M + 80K) Bytes	Block Size	(3M + 336K) Bytes
8KByte x 4Plane	Page Buffer	8KByte x 2Plane
109.5mm^2	Chip Size	133mm^2
0.585Gb/mm^2	Density (X1.64↑)	0.96Gb/mm^2
0.45ms	Page Program Time(tPROG)	**0.33ms**
400Mbps	Data Transfer Rate	**533Mbps**
33MB/s	Write Performance (X1.5↑)	**50MB/s**

3D NAND Flash Architectures

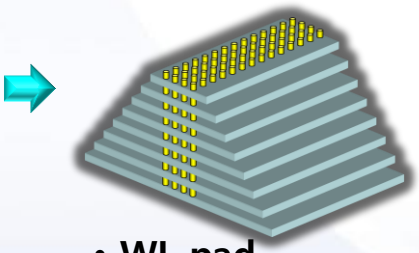
	Samsung	Toshiba	Hynix	Micron
				
Architecture	TCAT	P-BiCS	3D-FG	3D-FG
Cell Type	TANOS GAA	SONOS GAA	FG	FG
Process	Gate Last	Gate First	Gate First	Gate First
	J. Jang, SOVT 2009	R. Katsumata, SOVT 2009	S. Whang, IEDM 2010	

TCAT Process Sequence

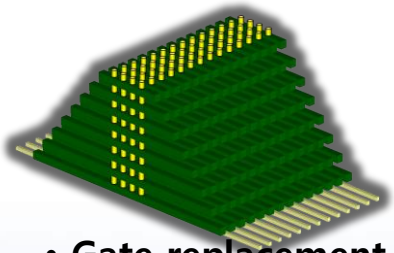
• Ox-SiN stack



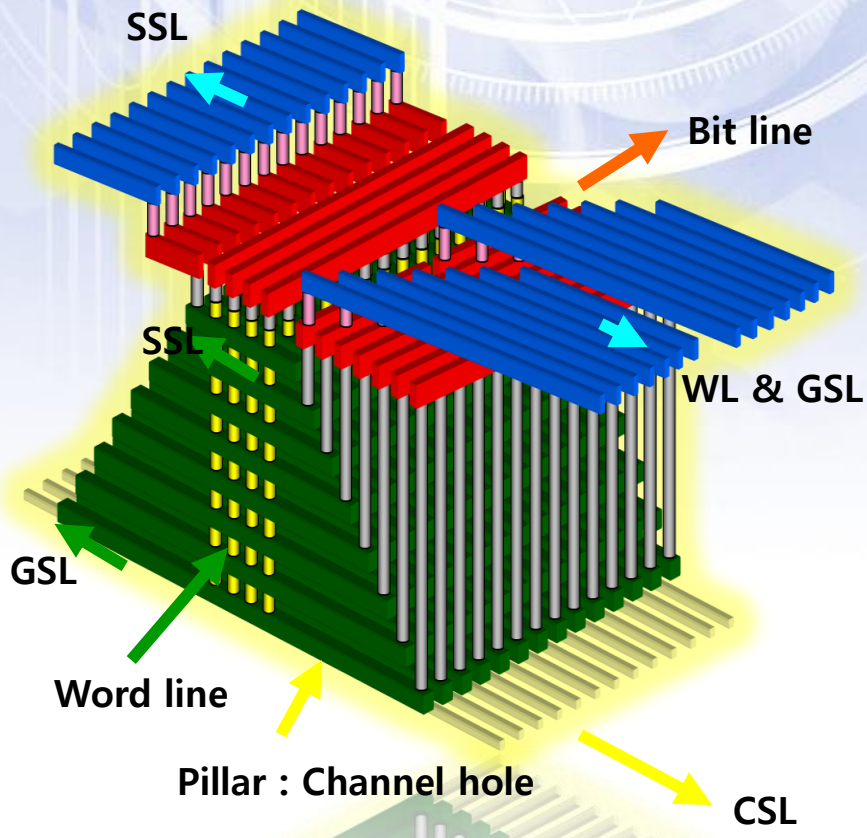
• Channel hole & poly



• WL pad

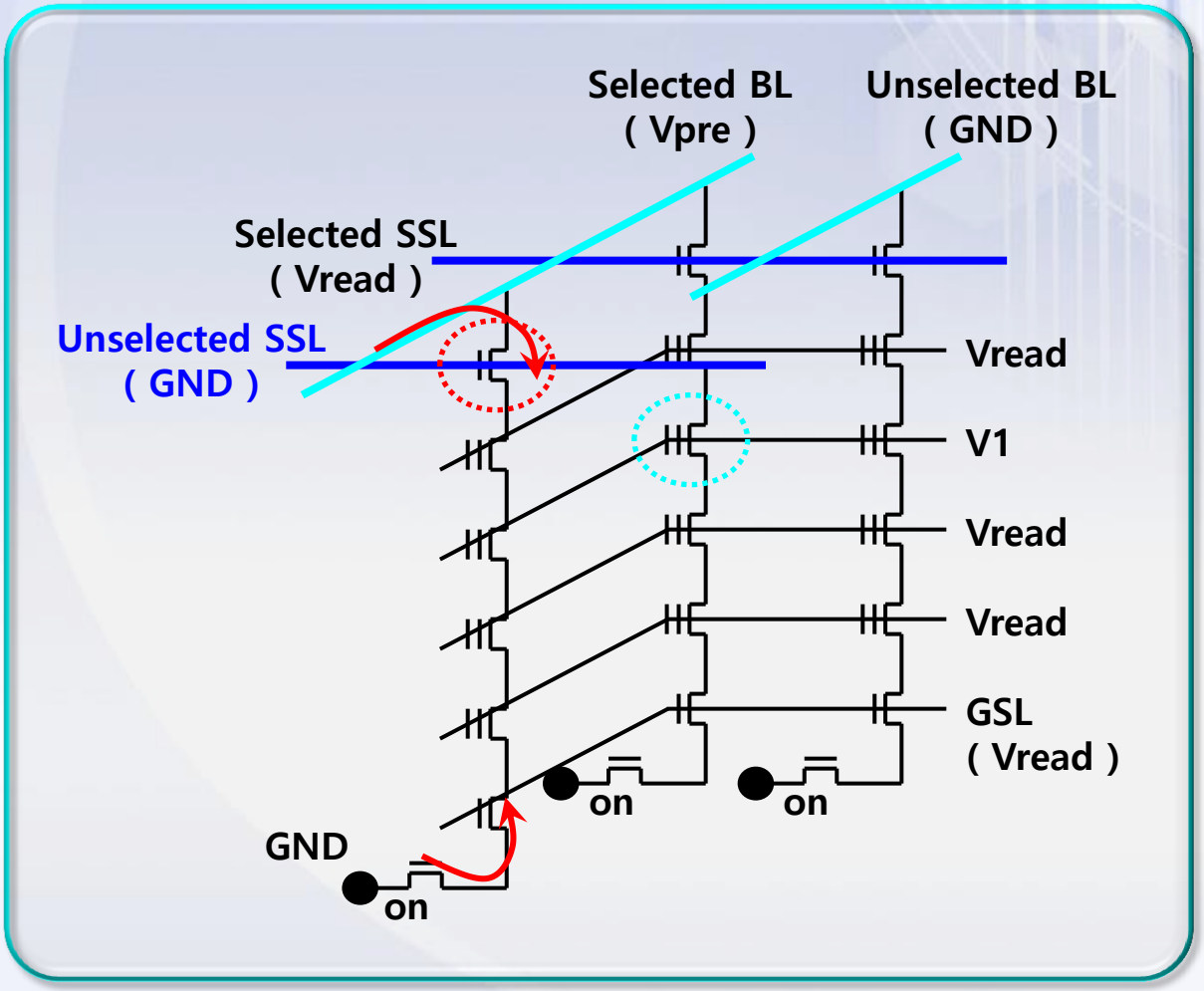


• Gate replacement



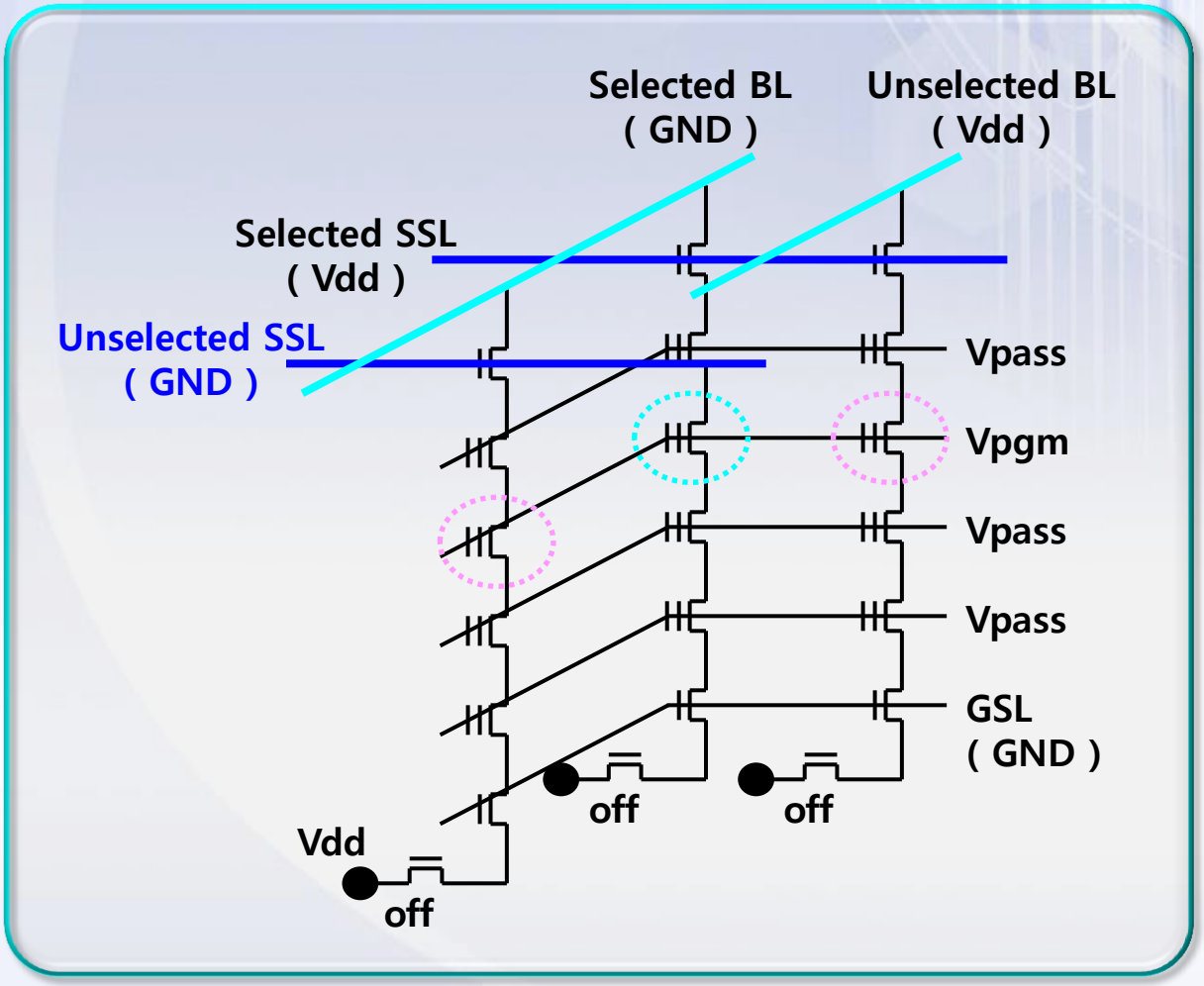
- SSL String Select Line
- GSL Ground Select Line
- CSL Common Source Line

V-NAND Read Operations



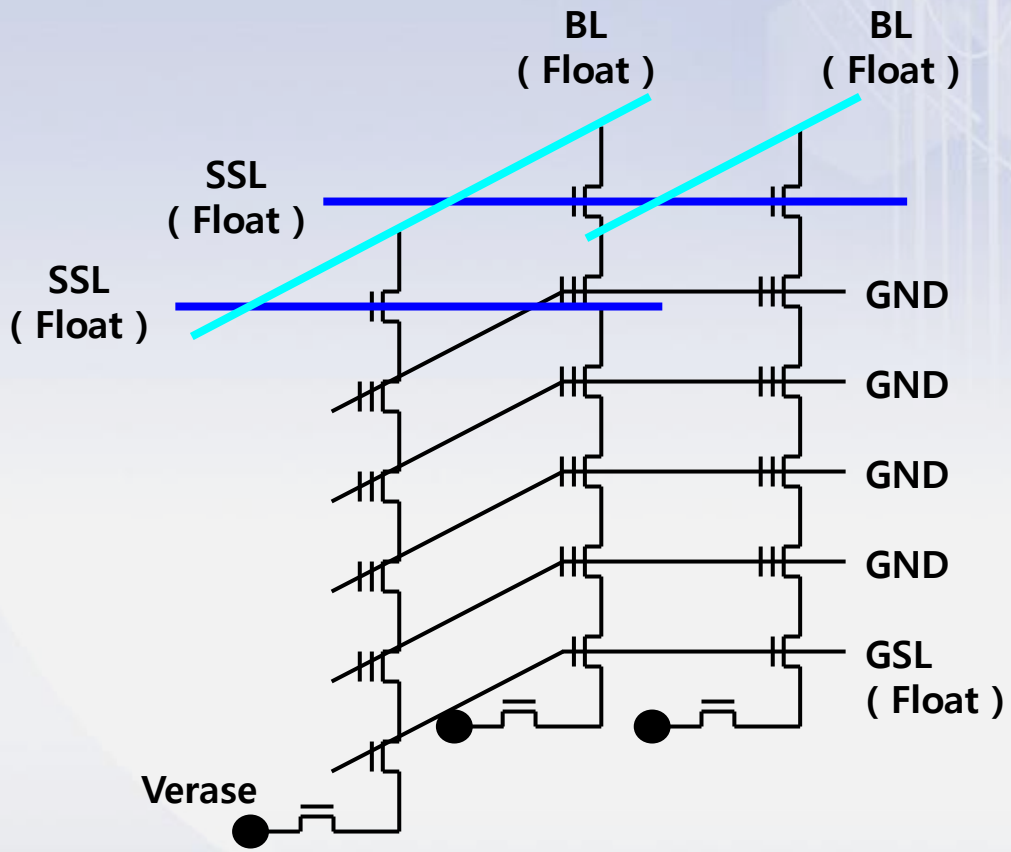
- **Selected String**
  - : SSL – Vread Level
  - : BL – Precharge Level
- **Unselected Strings**
  - : Unselected SSL – GND
  - : Unselected BL – GND

V-NAND Program Operation



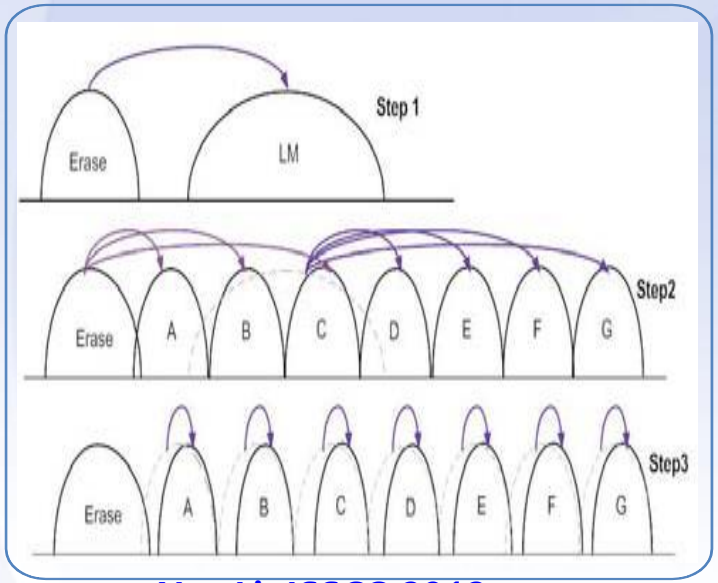
- **Selected String**
  - : SSL – Vdd
  - : BL – GND
- **Unselected Strings**
  - : Unselected SSL – GND
  - : Unselected BL – Vdd

V-NAND Erase Operation

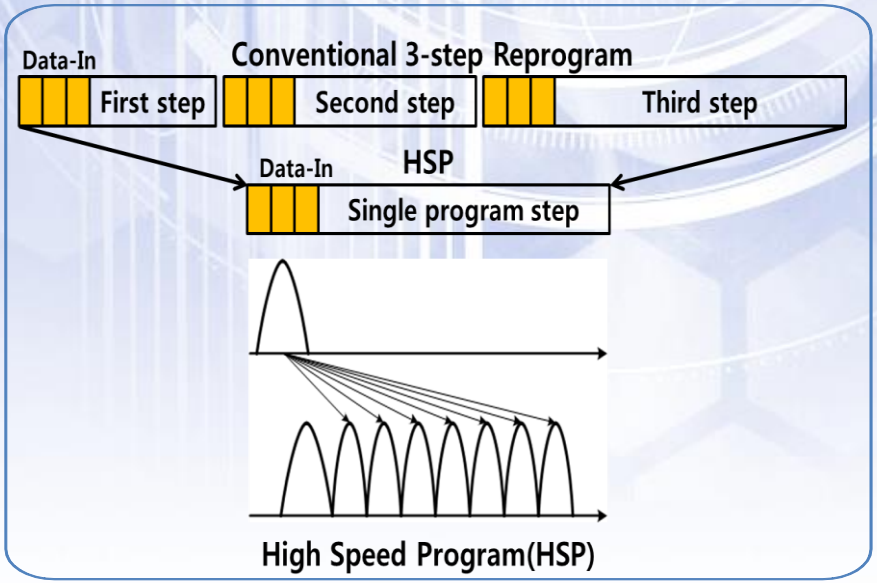


- All Strings
  - : SSL – Floated
  - : BL – Floated
  - : CSL - Verase

High Speed Program Method



< Yan Li, ISSCC 2012>

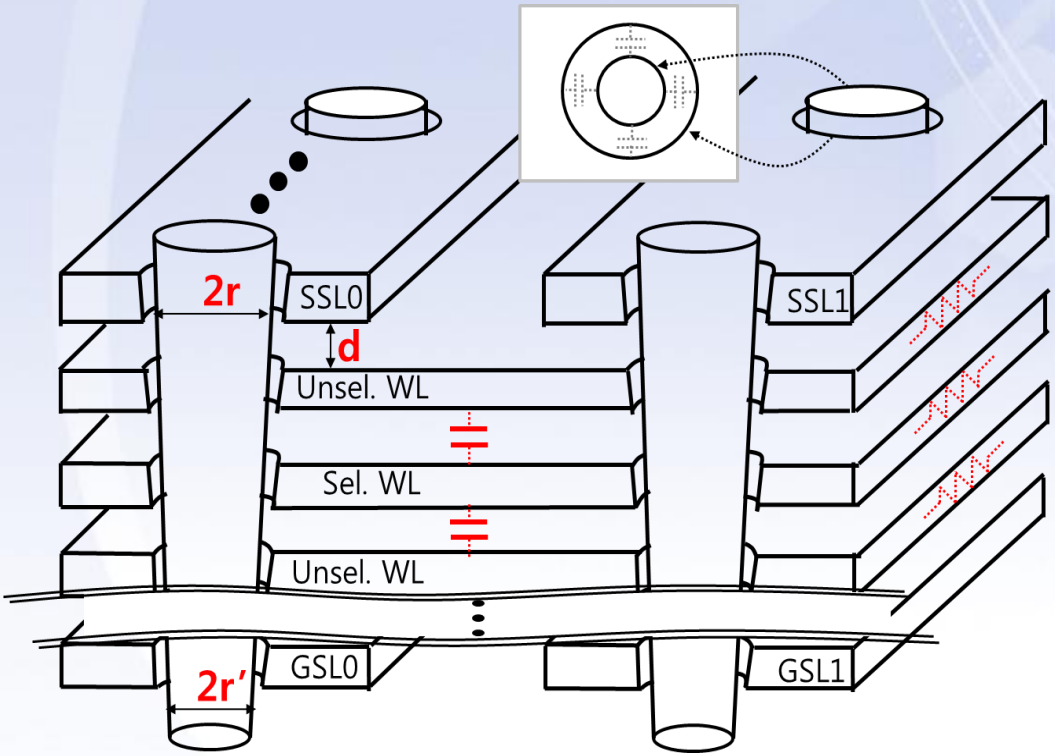


< J. IM, ISSCC 2015>

- **Large Cell to Cell Interference → 3-step reprogram**

- **Small Cell to Cell Interference → HSP as a Program Algorithm.**
- **A WL's programming is completed in a single program step.**

WL Capacitance & Resistance in 3D NAND



CH. Hole increase
→ Easier to fabricate
→ Poor WL resistance

Height shrink
→ Easier to fabricate
→ Space decrease (d)
→ Poor cell char.
→ Poor WL-WL Couple

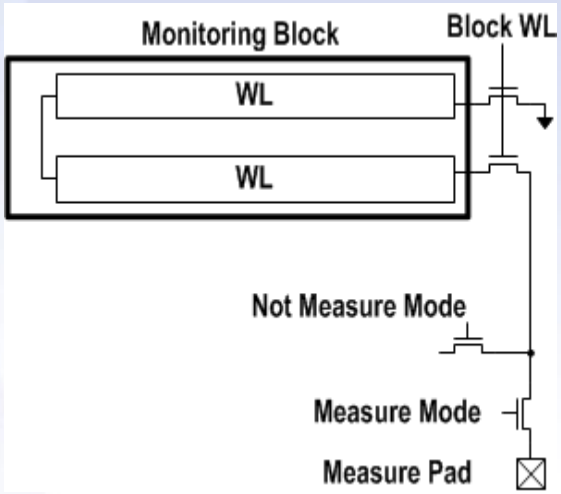
Also,

CH. Hole variation(r > r') is unique characteristic for 3D NAND.

➔ **New Scheme is necessary to overcome WL's large loading & variation**

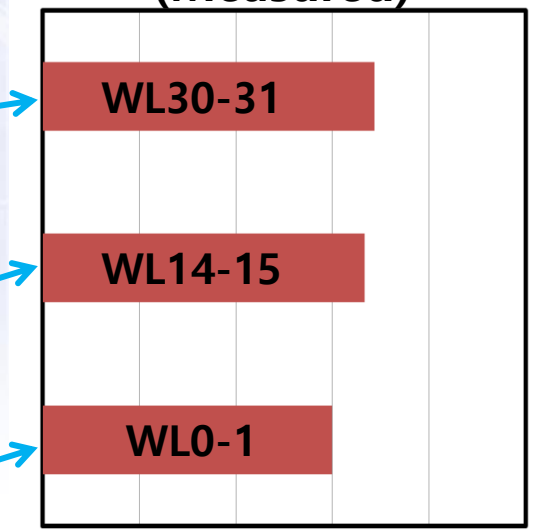
WL Overdrive with Resistance Monitoring

Schematic Diagram of R-Monitoring



Cross Sectional View of Cell Array

WL Resistance (Measured)

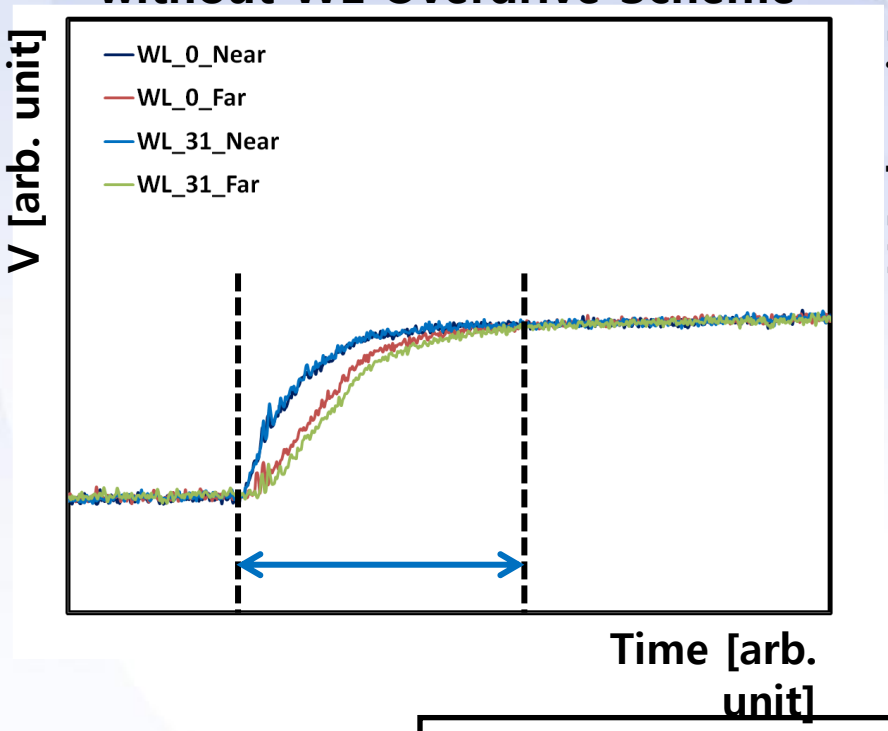


R [arb. unit]

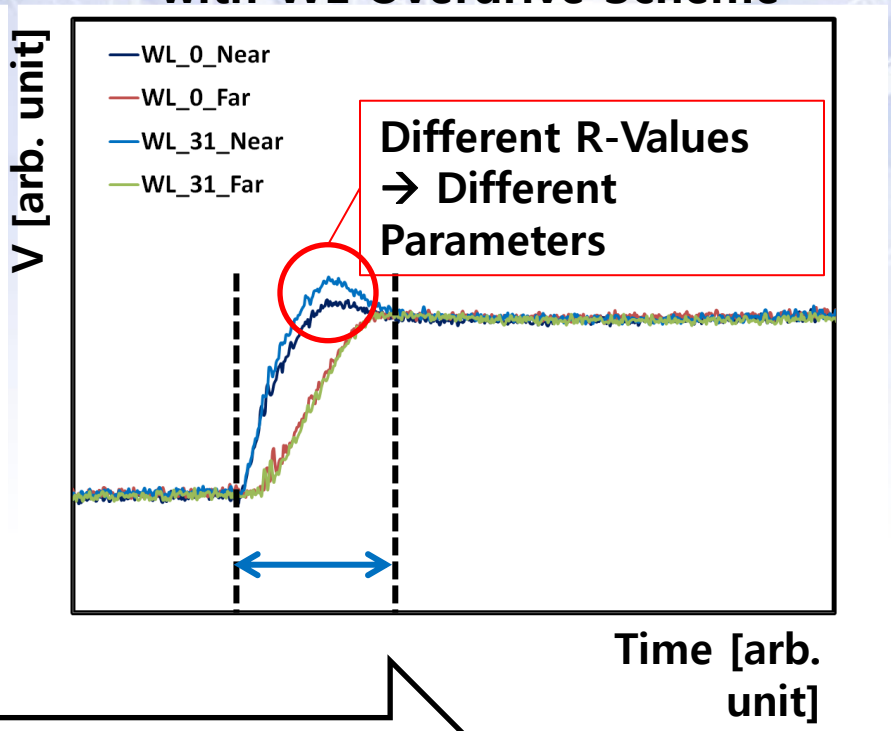
- Resistance Monitoring Scheme
- → Measuring the WL Resistance
- → Utilizing it in EDS Stage to Optimize Overdrive Parameters

WL Overdrive with Resistance Monitoring

Measured Waveform without WL Overdrive Scheme



Measured Waveform with WL Overdrive Scheme

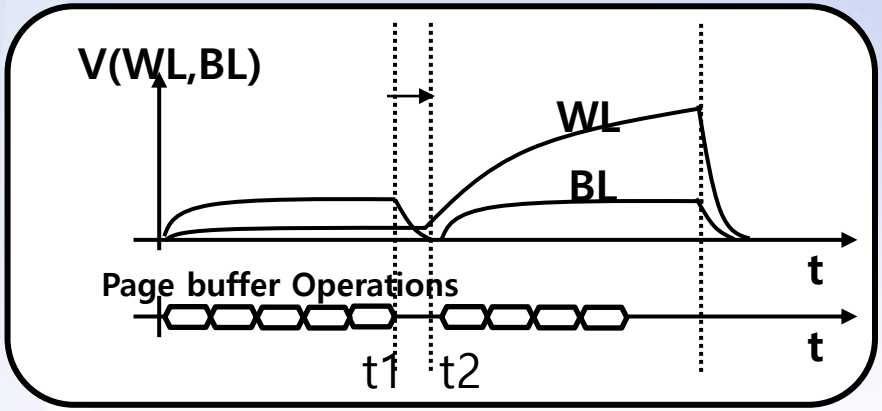


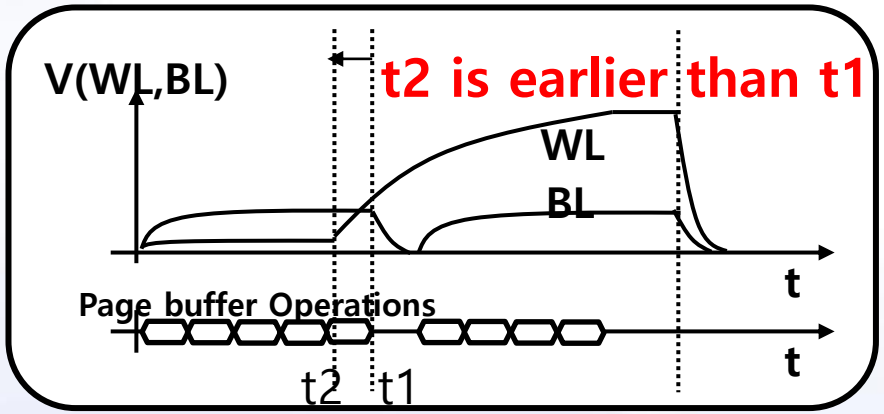
45% Reduction in WL setup time

- According to the measured resistance values, optimal voltage offset values were applied for the WL0 and WL31 each.

WL Timing Control

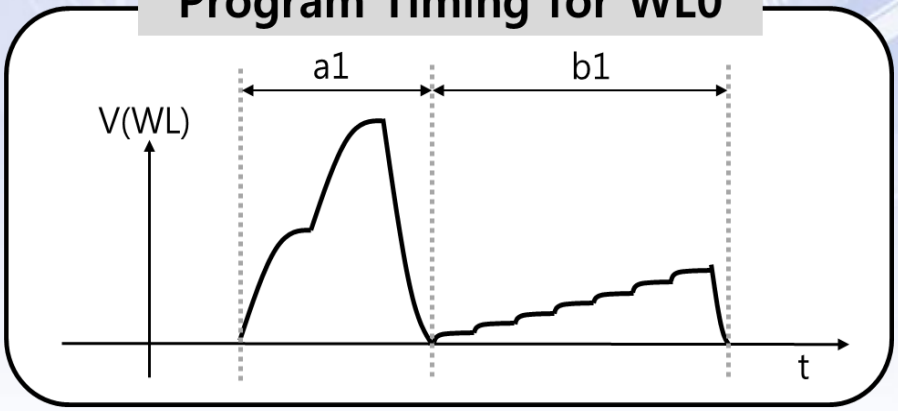
For large Loading of WL





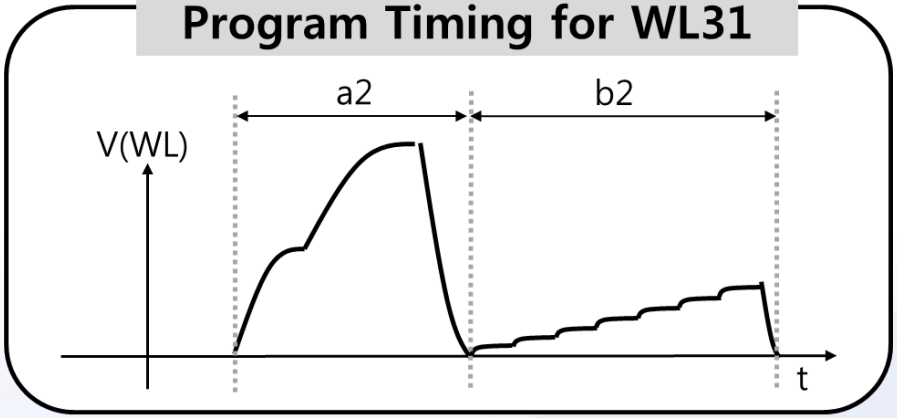
For Loading Variation of WL

Program Timing for WL0



a2 > a1
b2 > b1

Program Timing for WL31



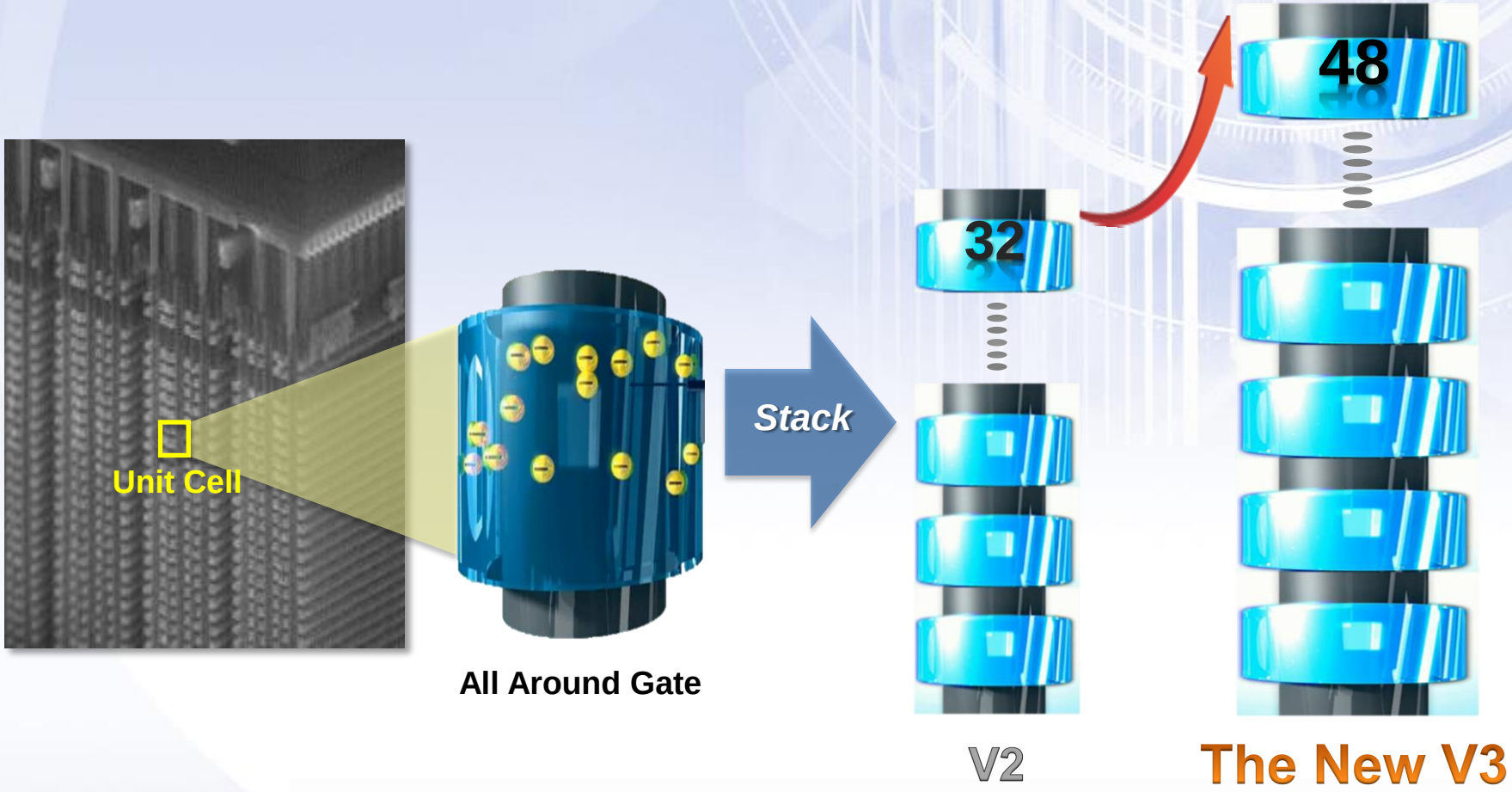
Chapter 1 : Industry Trends

Chapter 2 : Introduction to V-NAND Flash

Chapter 3 : New Era, V-NAND

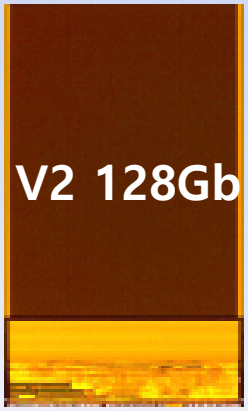
3rd Gen. V-NAND

Disruptive Density, New Era of 3D V-NAND

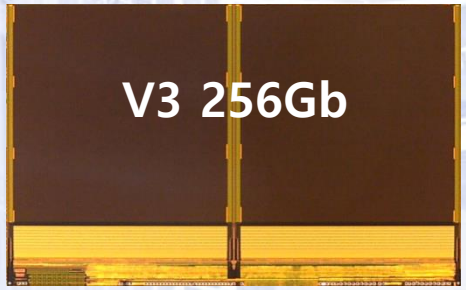


V3 256Gb TLC in Mass Production (Aug. 2015)

V2 vs. V3 3bit VNAND Features



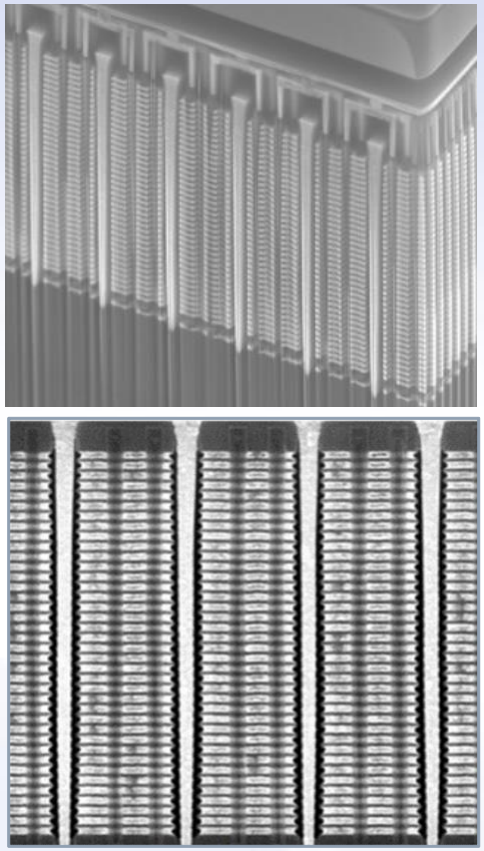
Areal Density
× 1.41 ↑



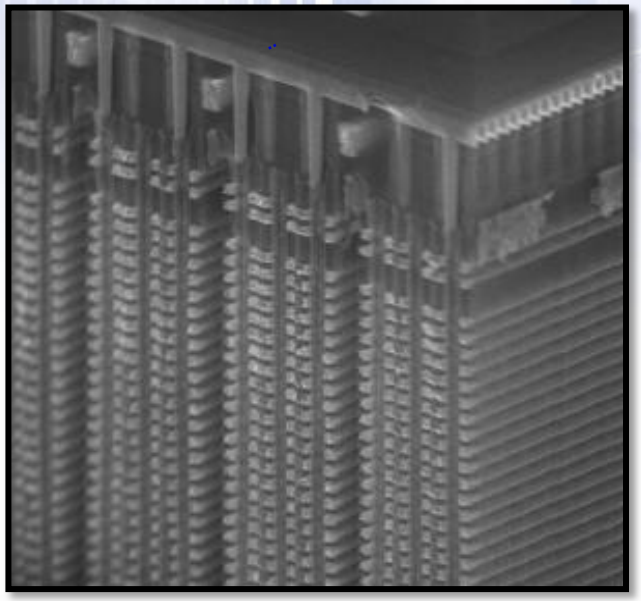
2nd Gen.	Feature	3rd Gen.
128Gb	Density	256Gb
68.9mm²	Chip Size	97.6mm²
1.86Gb/mm²	Density	2.62Gb/mm²
32 stacked WL	Technology	48 stacked WL
16 KB/Page 1Plane	Organization	16 KB/Page 2Plane
Max. 1Gb/s	I/O Bandwidth	Max. 1Gb/s
3.5ms (Typ.)	tBERS	3.5ms (Typ.)
700us	tPROG	660us
45us	tR (4KB)	45us

3rd Gen. 48-stacked V-NAND

2nd Gen. V-NAND
: 32-stacked Layers

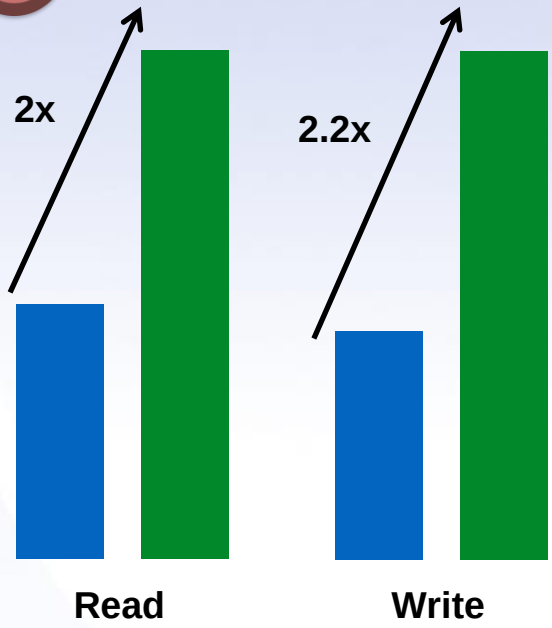


3rd Gen. V-NAND
: 48-stacked Layer



V3: Higher Performance, Lower Power

Faster Performance

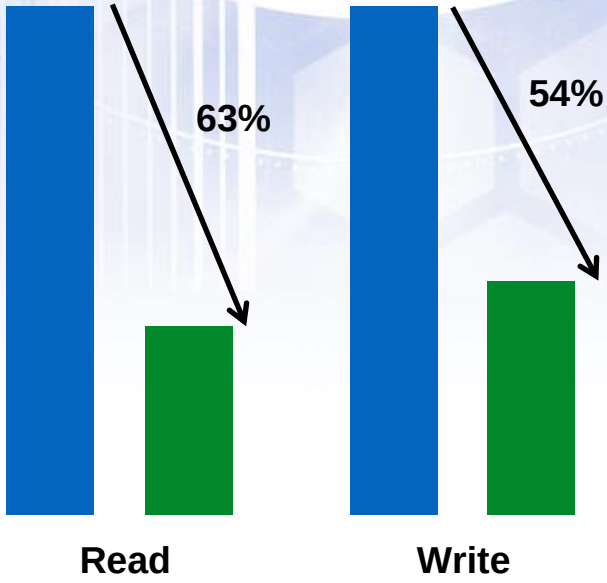


Sequential Operations @ 3bit
*Higher is Better

V3 V-NAND (48stack/3bit)

V2 V-NAND (32stack/3bit)

Better Power Efficiency

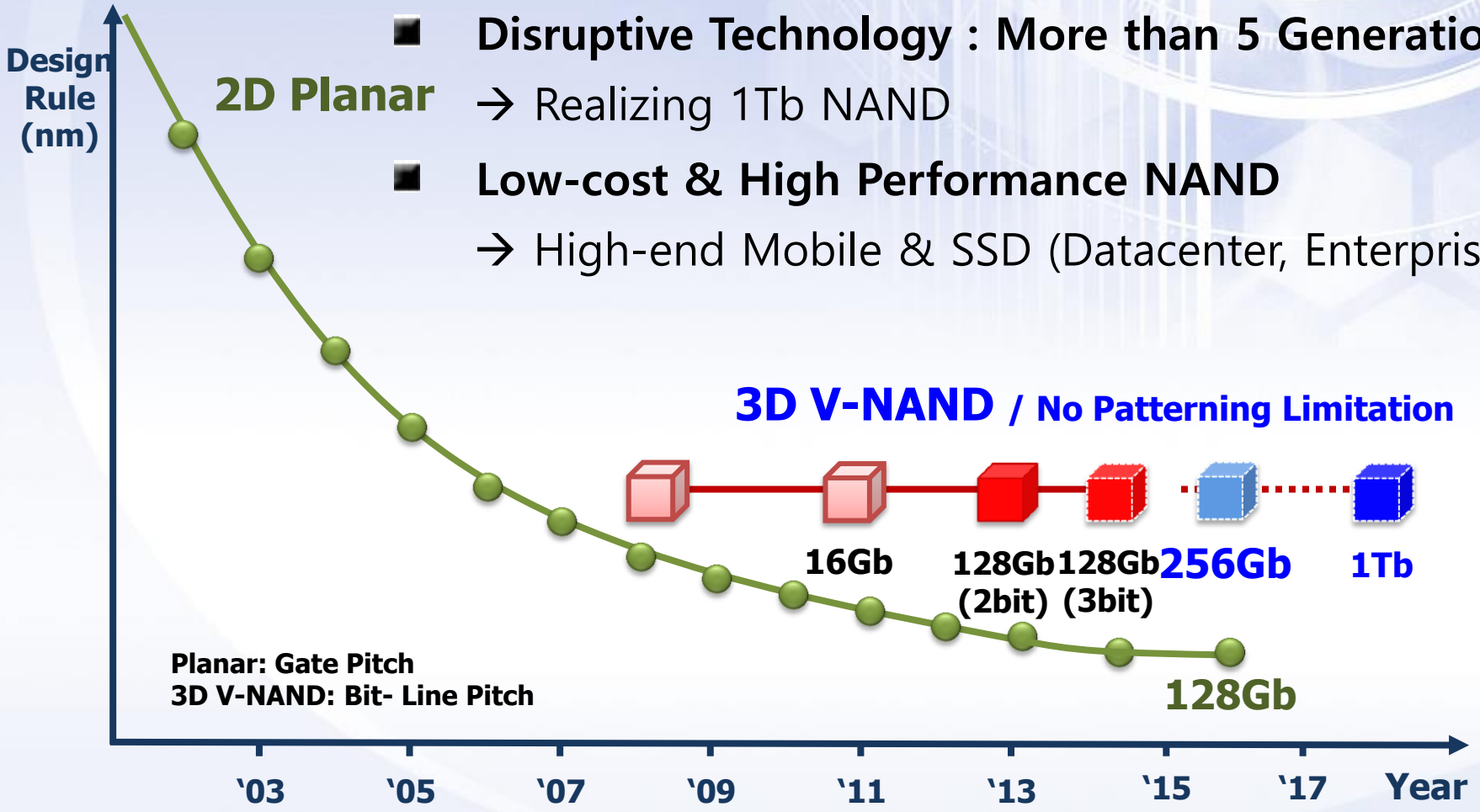


Power Consumption @ 3bit
*Lower is Better

>4x Efficiency

V-NAND Era for the future

- **Disruptive Technology : More than 5 Generations**
  → Realizing 1Tb NAND
- **Low-cost & High Performance NAND**
  → High-end Mobile & SSD (Datacenter, Enterprise)



Chapter 1 : Industry Trends

Chapter 2 : Introduction to V-NAND Flash

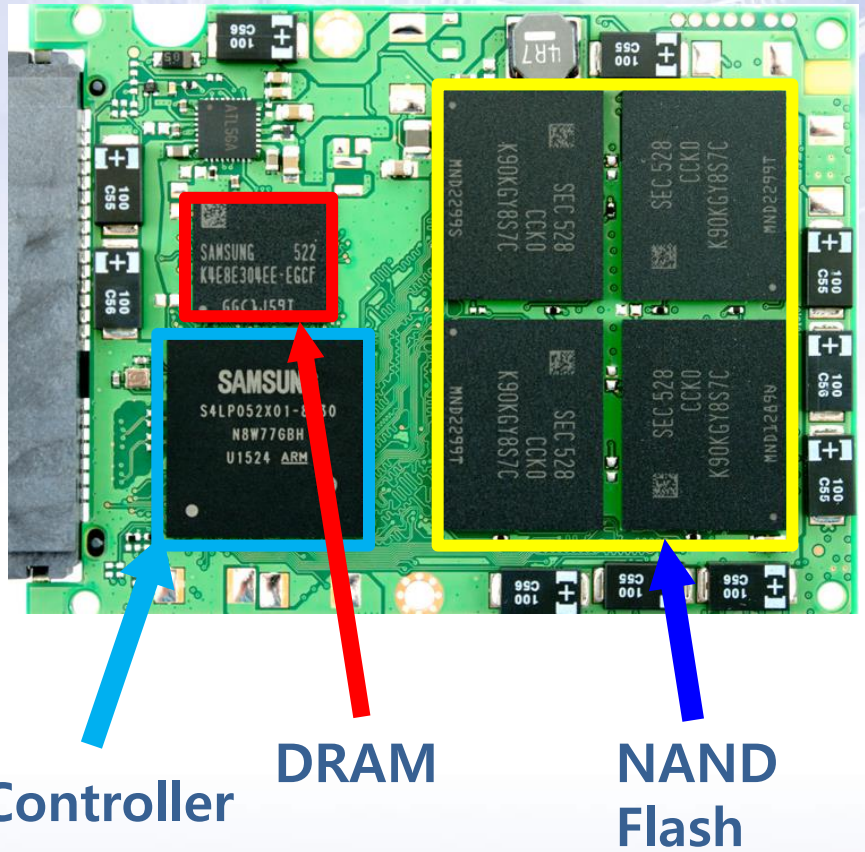
Chapter 3 : New Era, V-NAND Flash

V-NAND based SSD

SSD(Solid State Driver) replaces HDD

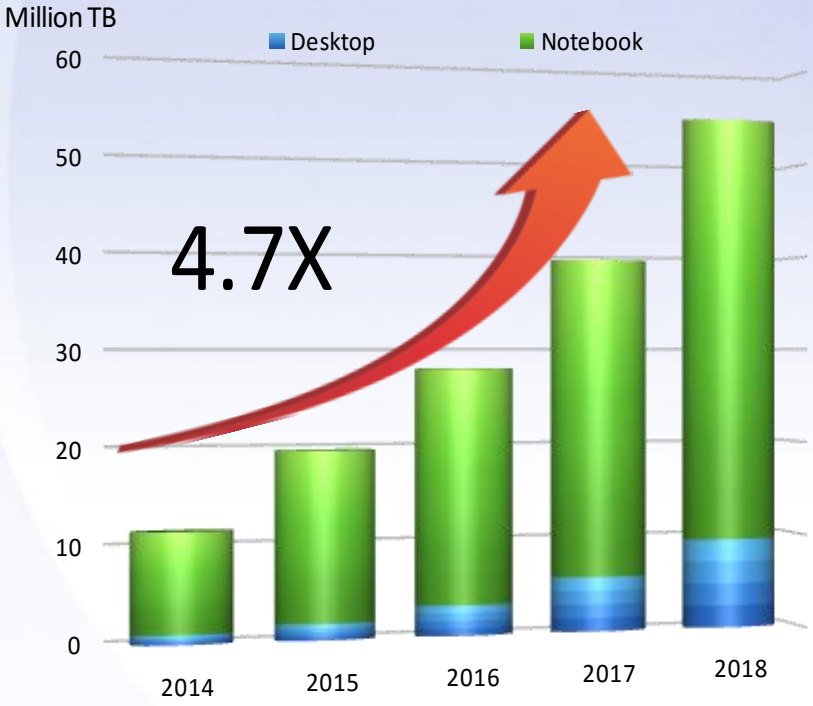
VS

Usually 10 000 or 15 000 rpm SAS drives		
0.1 ms	**Access times** SSDs exhibit virtually no access time	5.5 ~ 8.0 ms
SSDs deliver at least 6000 io/s	**Random I/O Performance** SSDs are at least 15 times faster than HDDs	HDDs reach up to 400 io/s
SSDs have a failure rate of less than 0.5 %	**Reliability** This makes SSDs 4 - 10 times more reliable	HDD"s failure rate fluctuates between 2 ~ 5 %
SSDs consume between 2 & 5 watts	**Energy savings** This means that on a large server like ours, approximately 100 watts are saved	HDDs consume between 6 & 15 watts
SSDs have an average I/O wait of 1 %	**CPU Power** You will have an extra 6% of CPU power for other operations	HDDs' average I/O wait is about 7 %
the average service time for an I/O request while running a backup remains below 20 ms	**Input/Output request times** SSDs allow for much faster data access	the I/O request time with HDDs during backup rises up to 400~500 ms
SSD backups take about 6 hours	**Backup Rates** SSDs allows for 3 - 5 times faster backups for your data	HDD backups take up to 20~24 hours

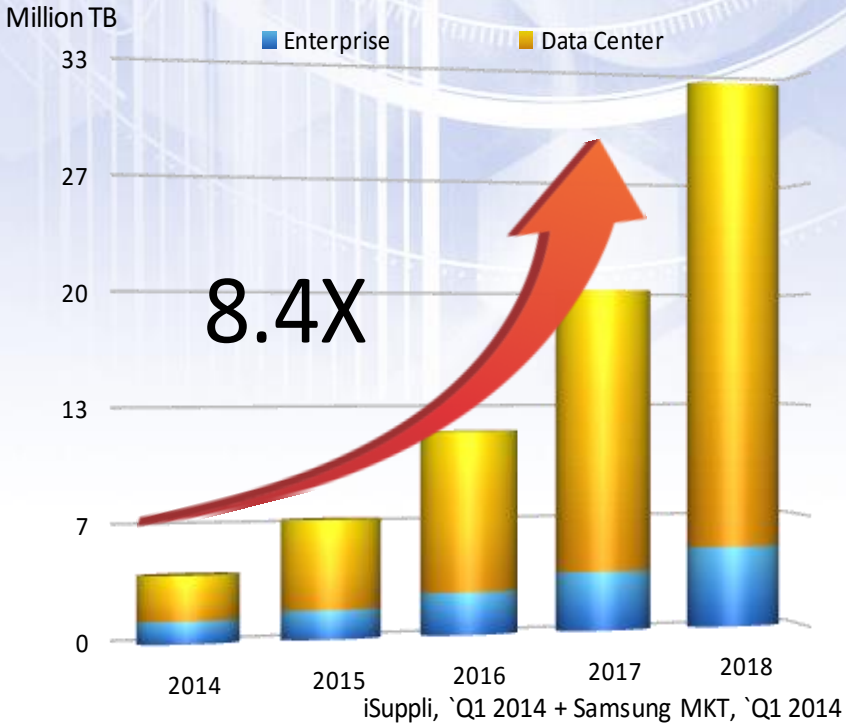


SSD Growth Outlook

PC Market



Data Center / Enterprise Market

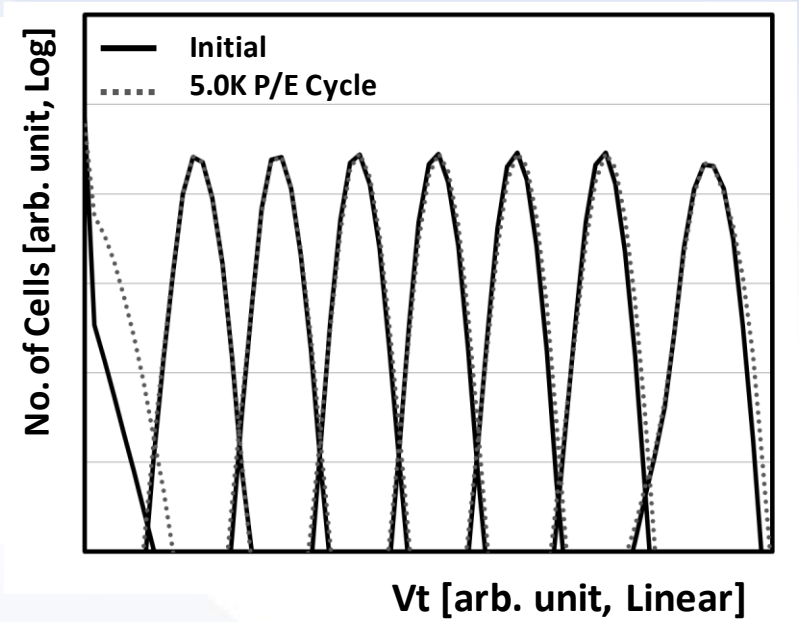


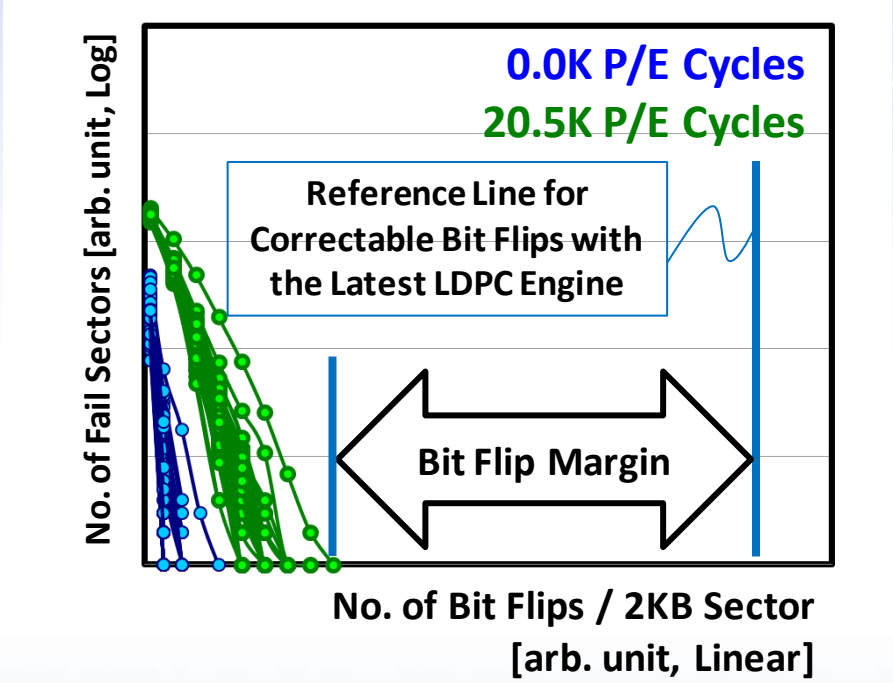
iSuppli, `Q1 2014 + Samsung MKT, `Q1 2014

- **Exponential growth continues**
- **Client & Enterprise SSD market is rapidly increasing**

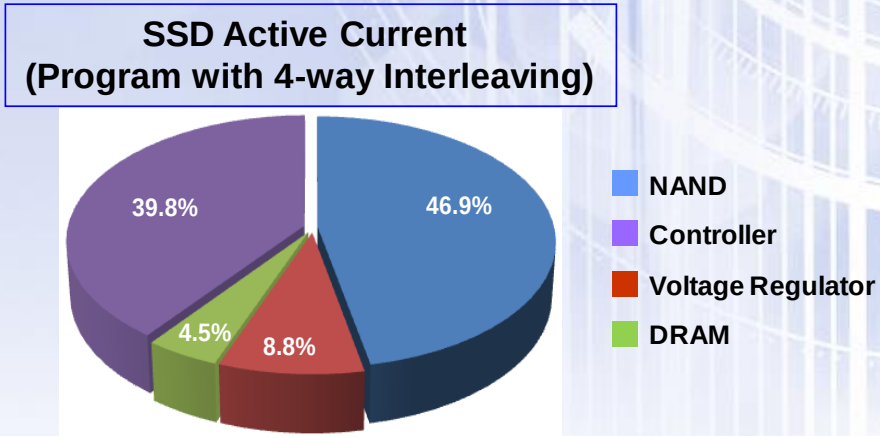
3bit V-NAND is suitable for SSD(@Reliability)

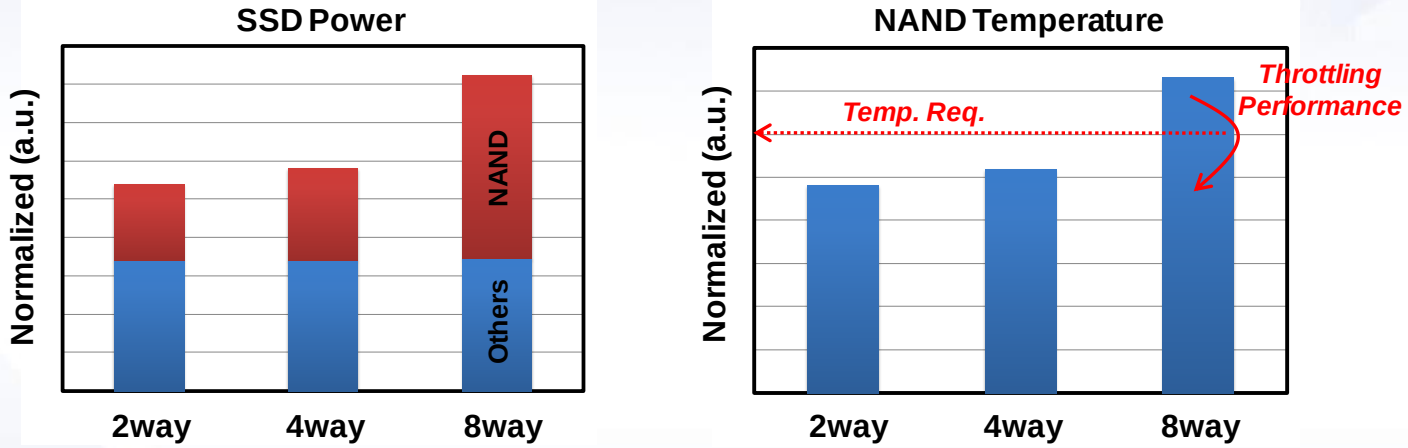
Good Endurance Characteristics





3bit V-NAND is suitable for SSD (@Power)

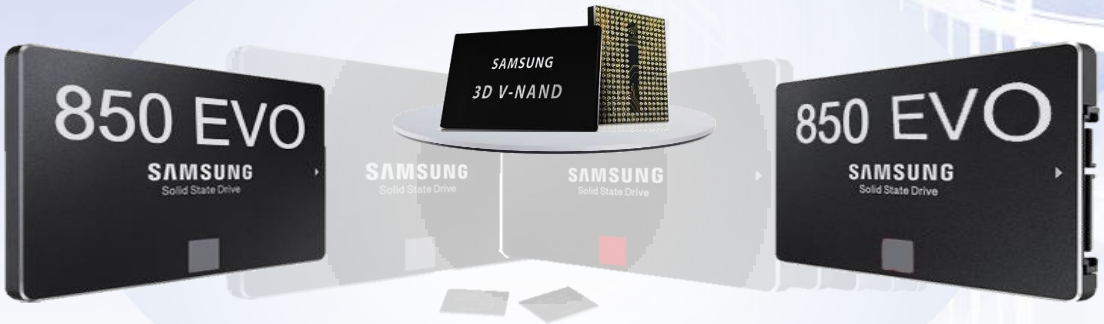




- SSD Power → SSD Temp. → Throttling Performance
- Lowering NAND Power → Increasing SSD Performance

V-NAND based SSD will be everywhere

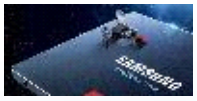
3nd Generation V-NAND
: 48-Stack V-NAND SSD (Samsung)



3D V-NAND | Vertical NAND | 3D V-NAND








2006	2008	2012	2013	2014	2015
1st Samsung SSD	1st 2bit MLC SSD	1st 3bit SSD	1st 3D V-NAND SSD	1st 32 Stack V-NAND SSD	1st 48 Stack 3bit V-NAND

Flash Storage Technology (Client SSD)

Moving Toward Ultra Light, Thin and Low Power

- **SSD has already taken over HDD and is the best storage solution for laptop PC**

Thin & Light

Low Power

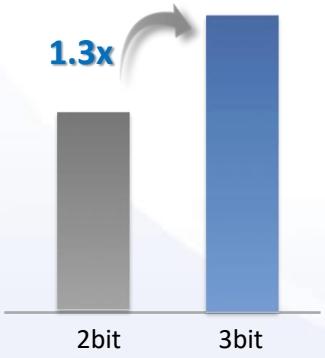
High Capacity

Multi-Tasking

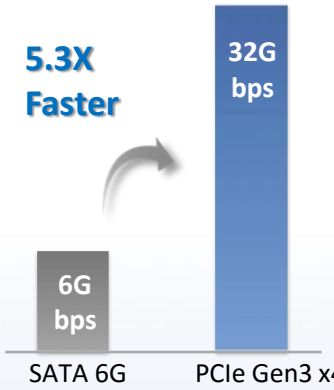
SSD Technical Trend

High Capacity

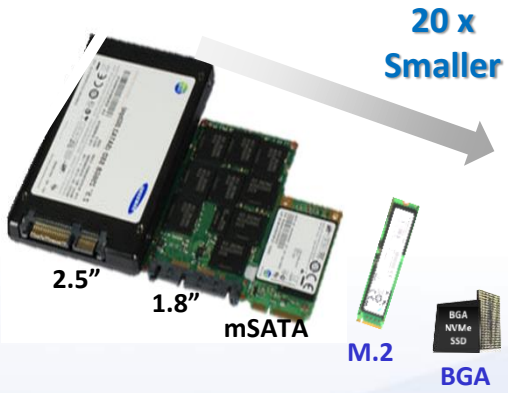
[Capacity / Area]



High Speed I/F



Small Form Factor



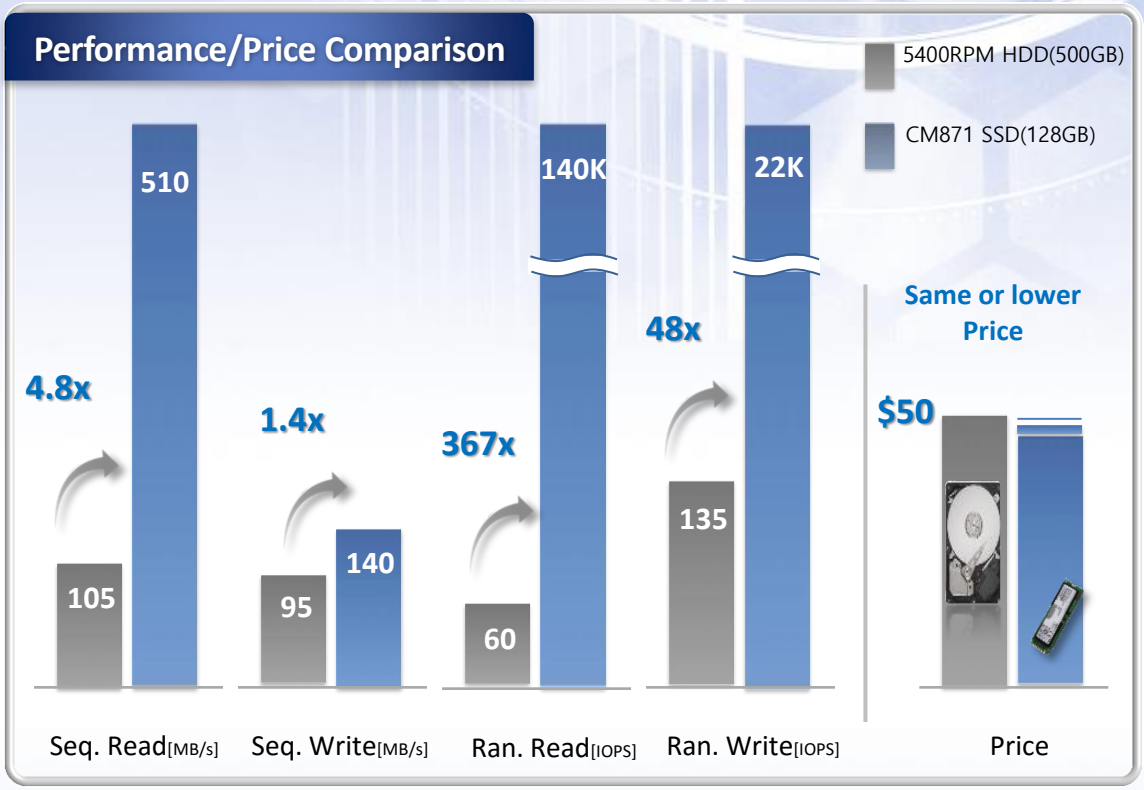
No More HDD: SSD for Entry-level Client PC

- **Providing SSD basic feature at a reasonable price($50↓ @128GB)**

CM871

128/192 GB

- Affordable Endurance by 3bit V-NAND
- Low Power Consumption (DEVSLP <2mW)



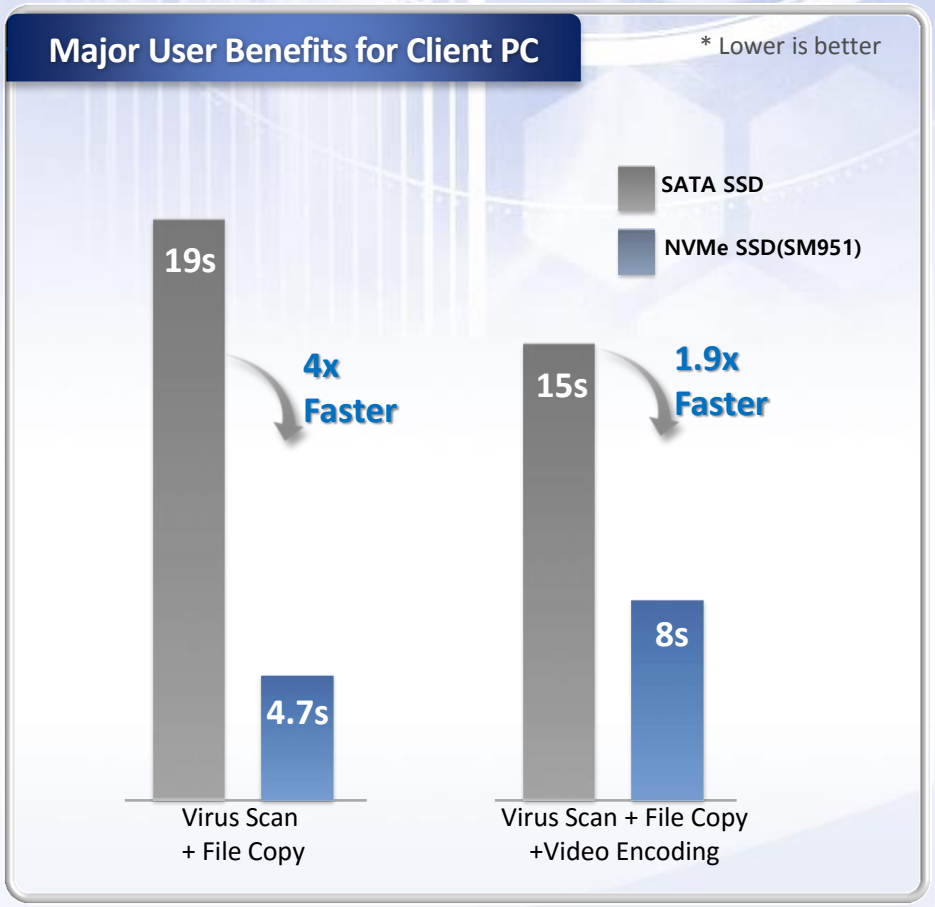
Extreme Performance: Next Gen. SSD for Client PC

- **NVMe SSD will be widely adopted from this year and can offer real UX benefit to end users**

SM951/PM951

128/256/512 GB

0.6GB/s : 10us → 4GB/s : 3us

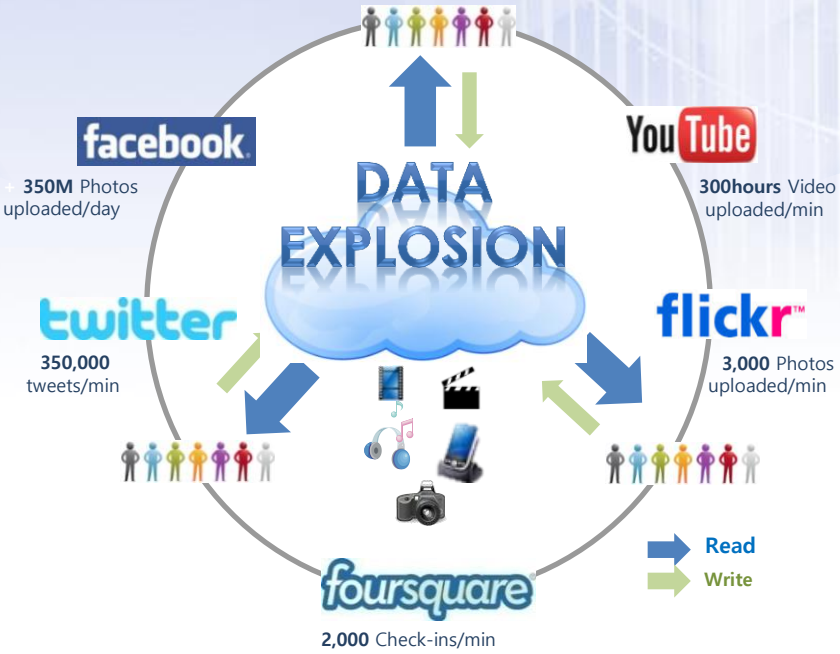


Flash Storage Technology (Data Center)

More Bit and Faster SSD Transition in Data Centers

- **With growth of cloud services and big data analytics, SSD is rapidly adopted in data centers due to high performance, low latency & TCO* benefit**

Hyperscale DC



Enterprise

*TCO: Total Cost of Ownership

Value SSD for Hyperscale Data Centers: SATA SSD

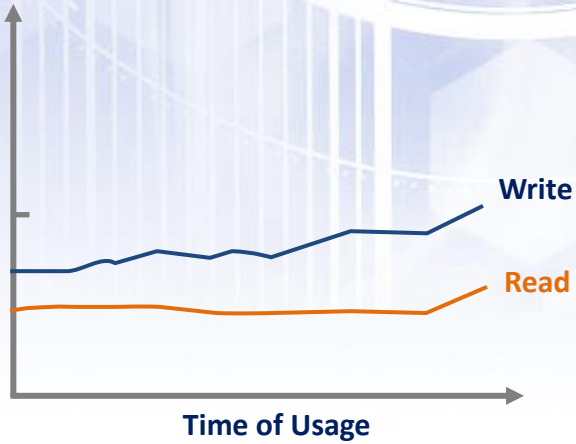
- **Server class SSDs should be fully optimized for consistent QoS**

SM863/PM863

120/240/480/960/1920/3840 GB

- Superior QoS and Low Latency
- Supports Power Loss Protection

QoS 99.9999th(SM863/4K Random)



Superior QoS and Low Latency

Best product for Cloud Service

amazon web services™

Microsoft Azure

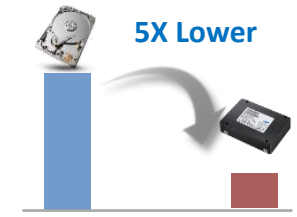
No More 15K HDD: World 1st 3bit SAS SSD for Enterprise

- **SAS SSD can replace traditional 10/15Krpm HDDs due to lower CAPEX/OPEX and better speed/reliability**

PM1633

480/960/1920/3840GB

More Reliable



[Annual Failure Rate]

Smaller Footprint

HDD N:1 Replacement by PT-SAS

• 1.2TB 10Krpm vs. 16TB PT-SAS (13:1) : CAPEX 15% reduction

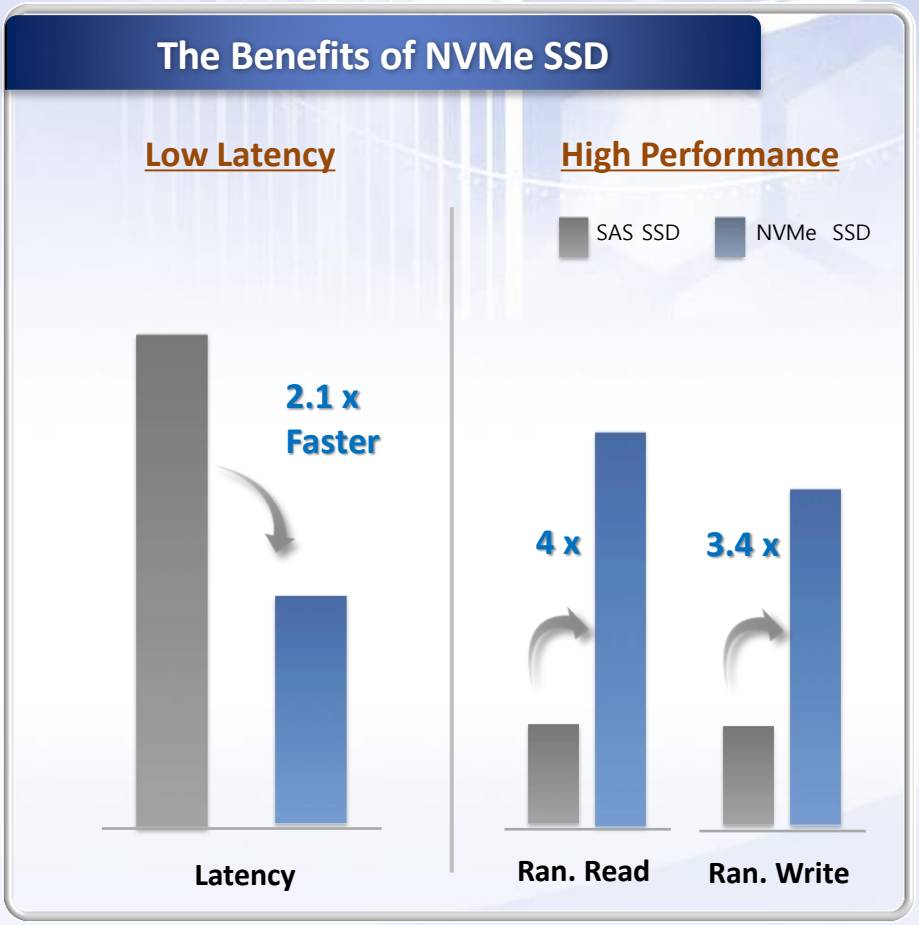
Ultra High-end: Enterprise Class NVMe SSD

- **NVMe SSD demonstrated ultra low latency, ultra high performance**

SM1715/PM1725

1.6/3.2/6.4TB

- High Performance
  (SM1715- Seq. R/W: 3/2.2 GB/s)
- Affordable Endurance by V-NAND




thank you
danke
謝謝
ngiyabonga
teşekkür ederim
спасибо
dank je
gracias
tapadh leat
bedankt
dziękuję
obrigado
sukriya
kop khun krap
go raibh maith agat
terima kasih
grazie
arigato
dakujem
merci
감사합니다
мерси