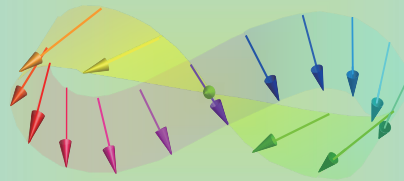


Information Storage and Spintronics

08



Atsufumi Hirohata

Department of Electronic Engineering

THE UNIVERSITY of York



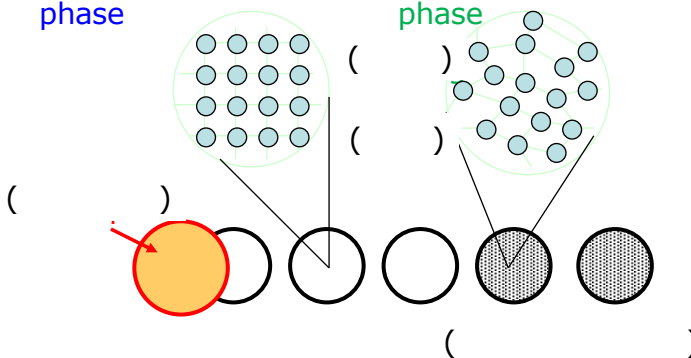
14:00 Monday, 24/October/2022 (SLB 101)



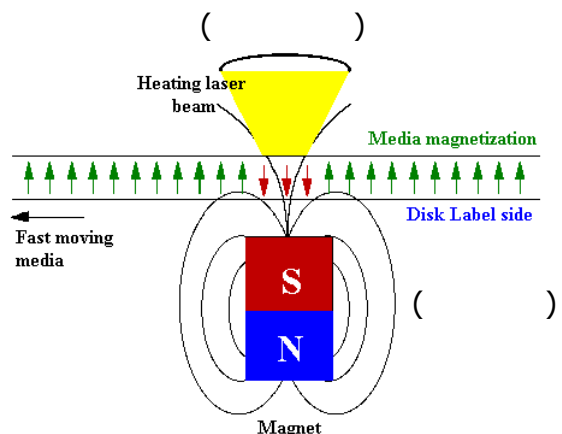
Quick Review over the Last Lecture

Optical recording : *

Initial phase () Written phase ()



Magneto-optical recording : **



* https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiQpNDA-jAhVFoVwKHWGIDssQFjAAegQIARAC&url=http%3A%2F%2Fhome.sato-gallery.com%2Feducation%2Fkouza%2FRyukoku_lecture.ppt&usg=AOvVaw0UTNH3qZH_LSTZ0vsF3Hxx/

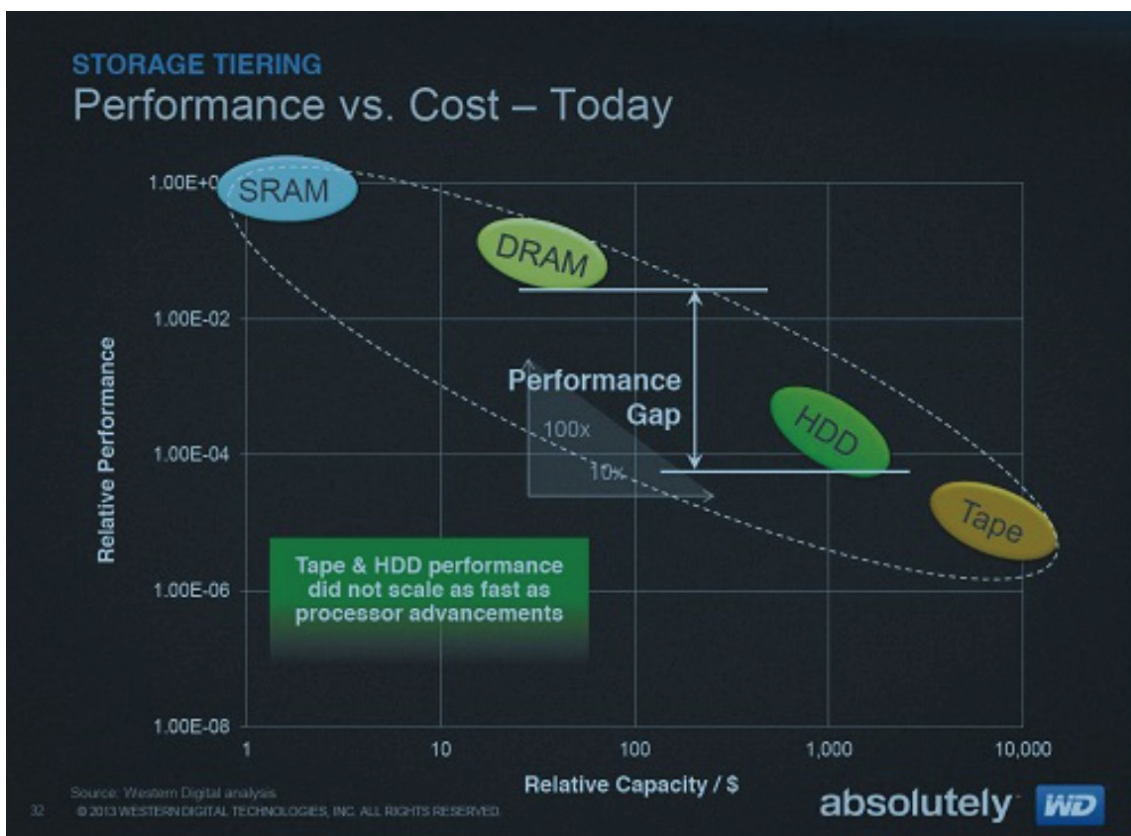
** <http://ffden-2.phys.uaf.edu/211.fall2000.web.projects/J%20Kugler/mo.html>

08 Flash Memory

- NOR flash
- NAND flash
 - TSV
- Multiple value
- SONOS



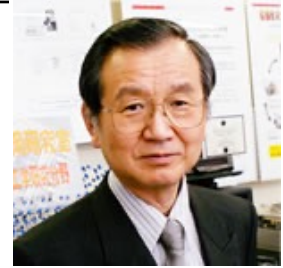
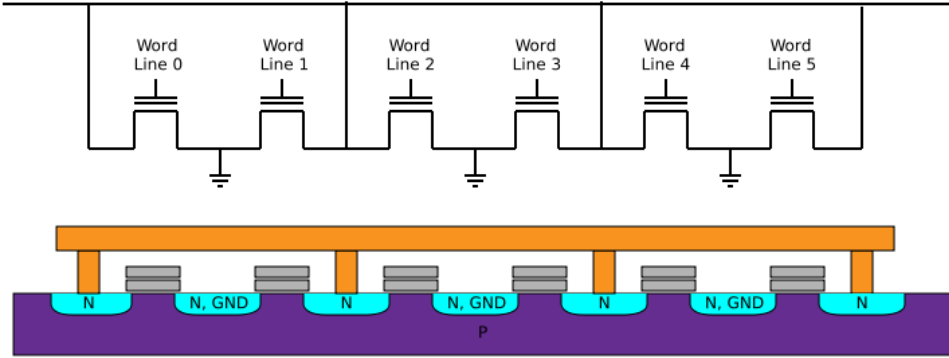
Performance Gap between HDD and DRAM





Flash Memory

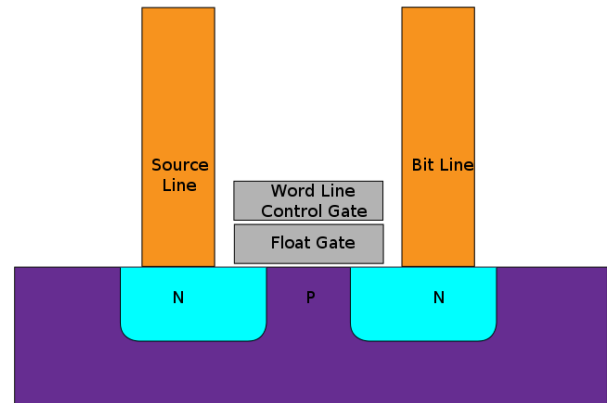
In 1980, Fujio Masuoka invented a NOR-type flash memory :



✓

✗

✗



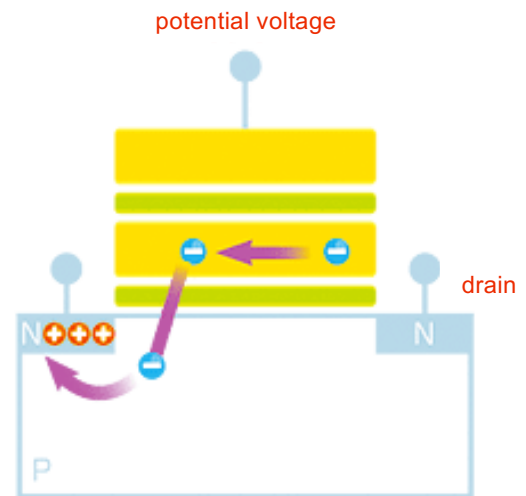
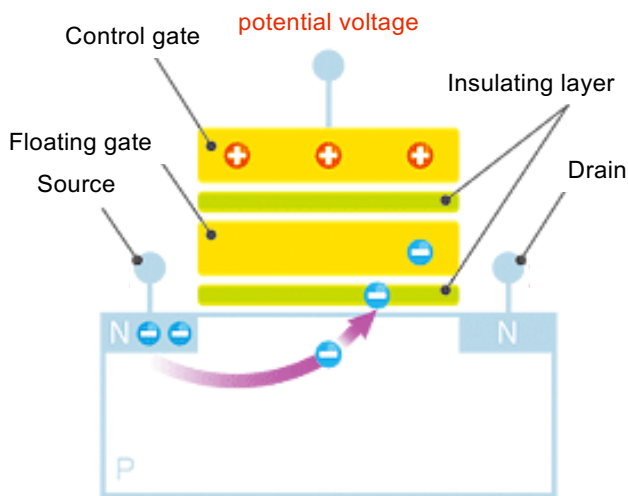
* http://rikunabi-next.yahoo.co.jp/tech/docs/ct_s03600.jsp?p=000500;
 ** <http://www.wikipedia.org/>



NOR-Flash Writing and Erasing Operation

Writing operation :

Erasing operation :

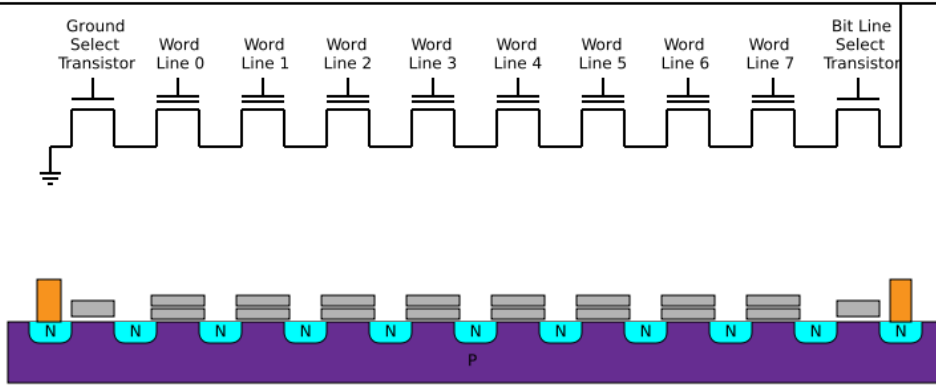


* <http://www.tdk.co.jp/techmag/knowledge/200705/index2.htm>



NAND Flash Memory

In 1986, Fujio Masuoka invented a NAND-type flash memory :



- ×
- ✓
- ✓
- ×

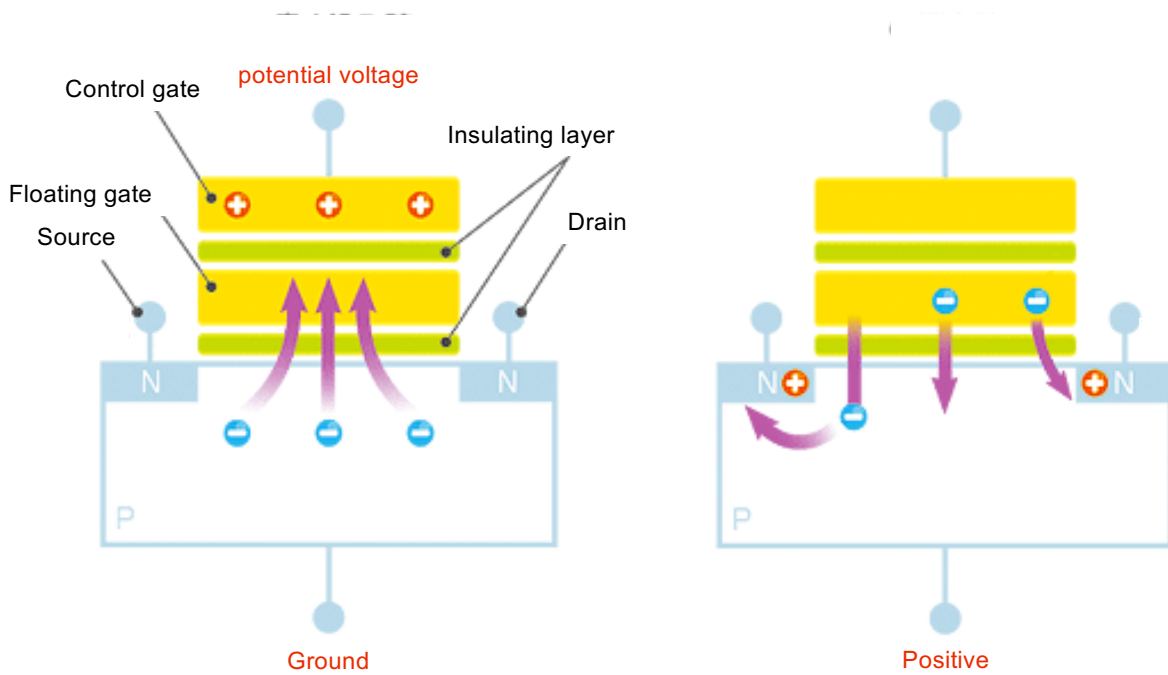
* <http://www.wikipedia.org/>



NAND-Flash Writing and Erasing Operation

Writing operation :

Erasing operation :

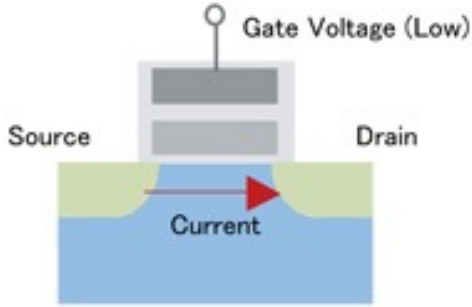


* <http://www.tdk.co.jp/techmag/knowledge/200705/index2.htm>



Reading Operation

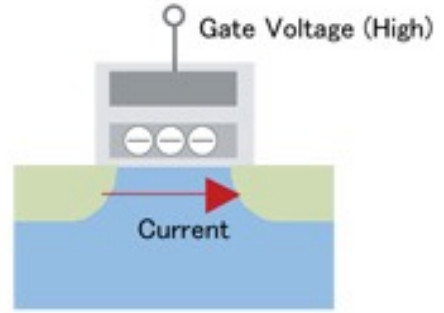
"0" state :



《No electrons have accumulated at floating gate》

- Low resistance between source and drain
- Current flows when gate voltage is low

"1" state :



《Electrons have accumulated at floating gate》

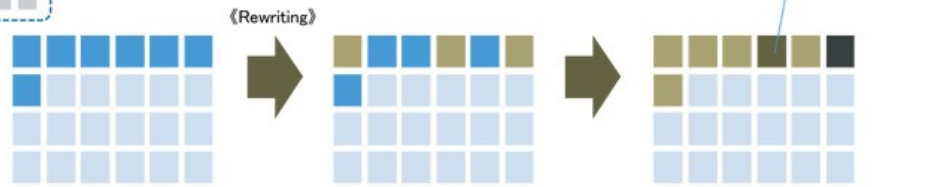
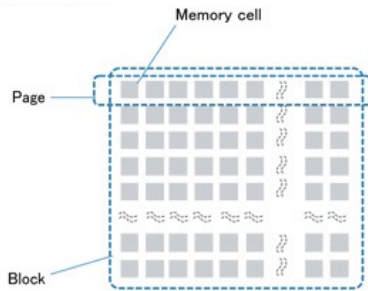
- High resistance between source and drain
- Current flows when gate voltage is high

* http://www.tdk.co.jp/techjournal_e/vol01_ssd/contents05.htm

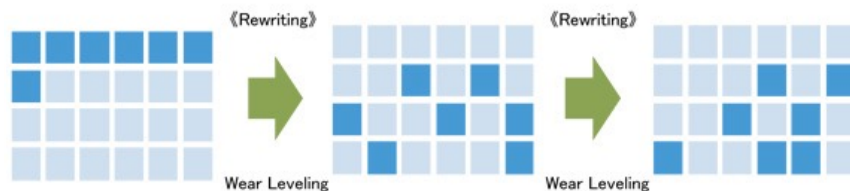


Cells, Pages and Blocks

Flash memory blocks :



When a specific block is rewritten intensively many times, memory cells may degrade and the block becomes unusable (bad block).



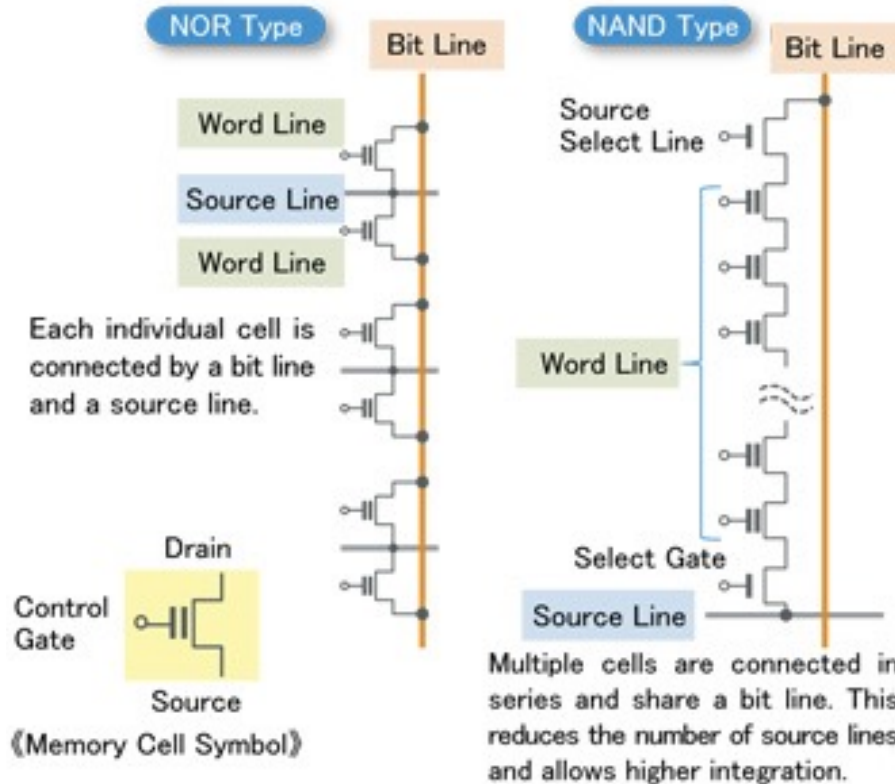
Based on a special algorithm, the controller chip distributes the rewrite operation so that it is not focused on a specific block.

* http://www.tdk.co.jp/techjournal_e/vol01_ssd/contents06.htm



Flash Memory Integration

NOR or NAND ? :



* http://www.tdk.co.jp/techjournal_e/vol01_ssd/contents04.htm



Solid State Drive with Flash Memory

Solid state drive (SSD) started to replace HDD :

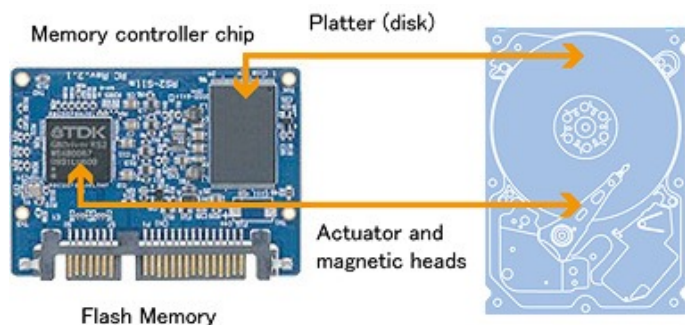
pureSi introduced 2.5" 1-TB SDD in 2009 :



- ✓ Data transfer speed at MB/s
- ✗ write speed

For example, a system with a units of 2kB for read / out and 256 kB for erase :
in order to write 1 bit, the worst case scenario is

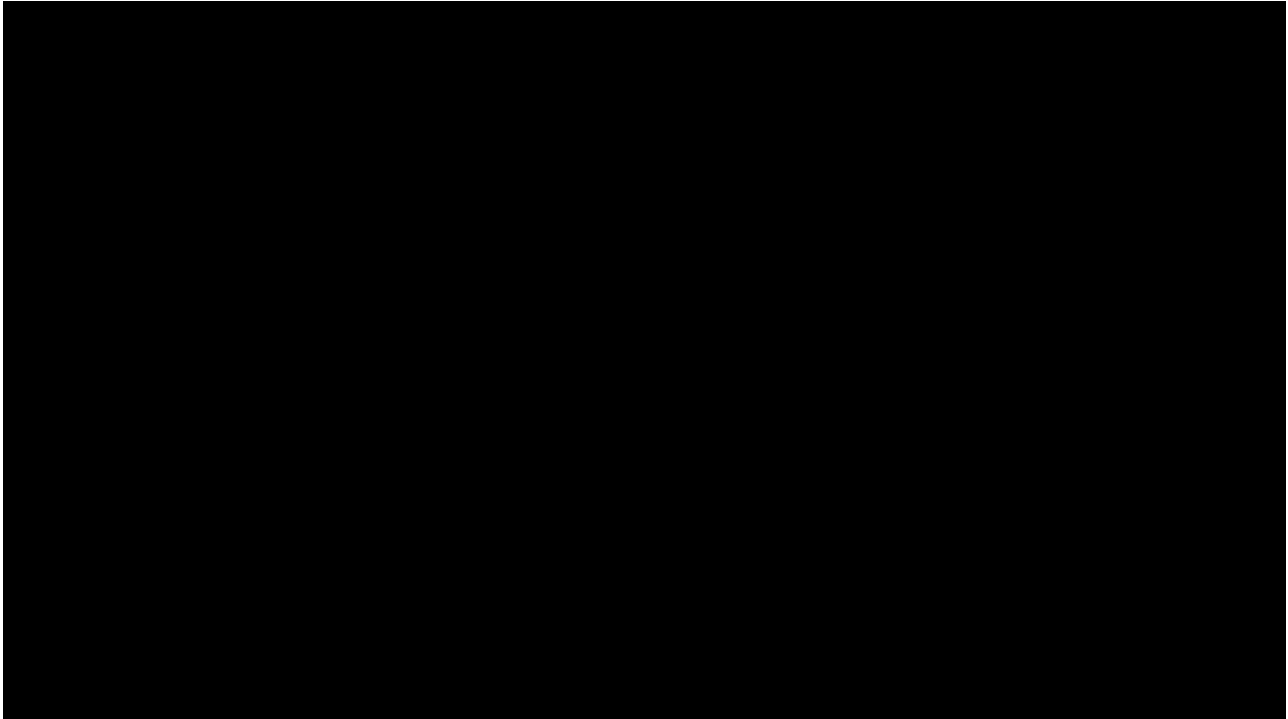
- 128 times read-out
- 1 time flash erase
- 128 times re-write



* http://www.tdk.co.jp/techjournal_e/vol01_ssd/contents02.htm



Fabrication of Flash Memory

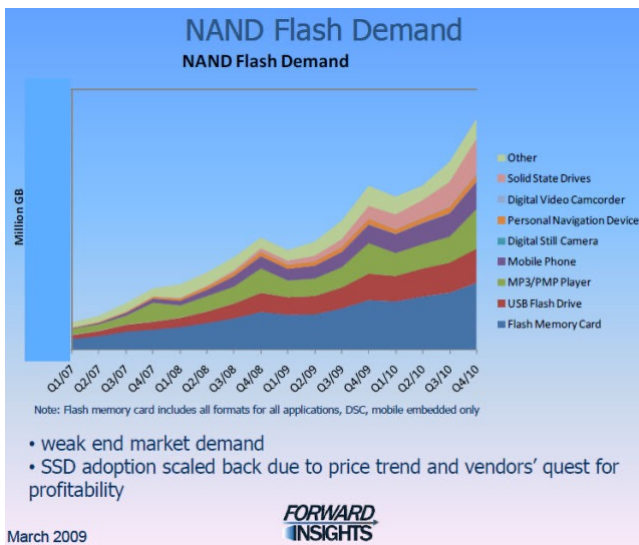


* <https://www.youtube.com/watch?v=M-wNC3Z3ZX4>

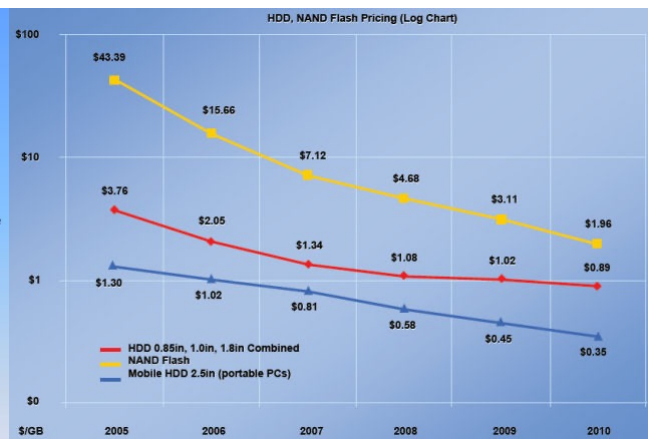


HDD vs Flash Memory

Demand for flash memories :



Price of flash memories :



* http://www.manifest-tech.com/ce_products/flash_revolution.htm



HDD vs Flash Memory

Annualised failure rates for HDD and SSD (Flash) :

Backblaze SSD vs HDD Lifetime AFR through Q2 2022

All Drives Controlled for Average Age by Year

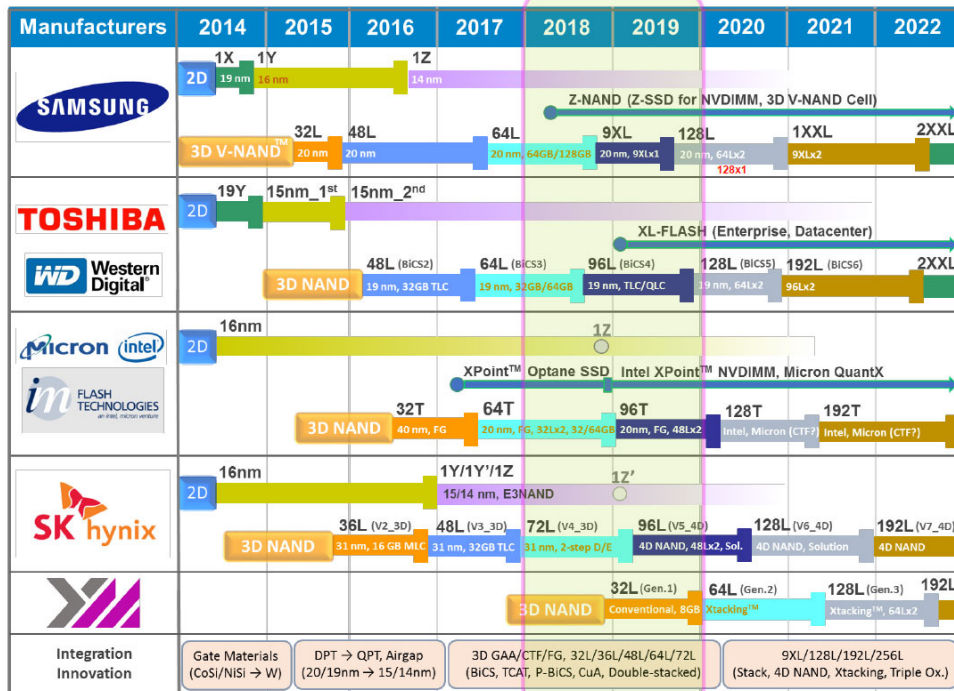


* <https://www.backblaze.com/blog/ssd-drive-stats-mid-2022-review/>



Flash Memory Development

Intel



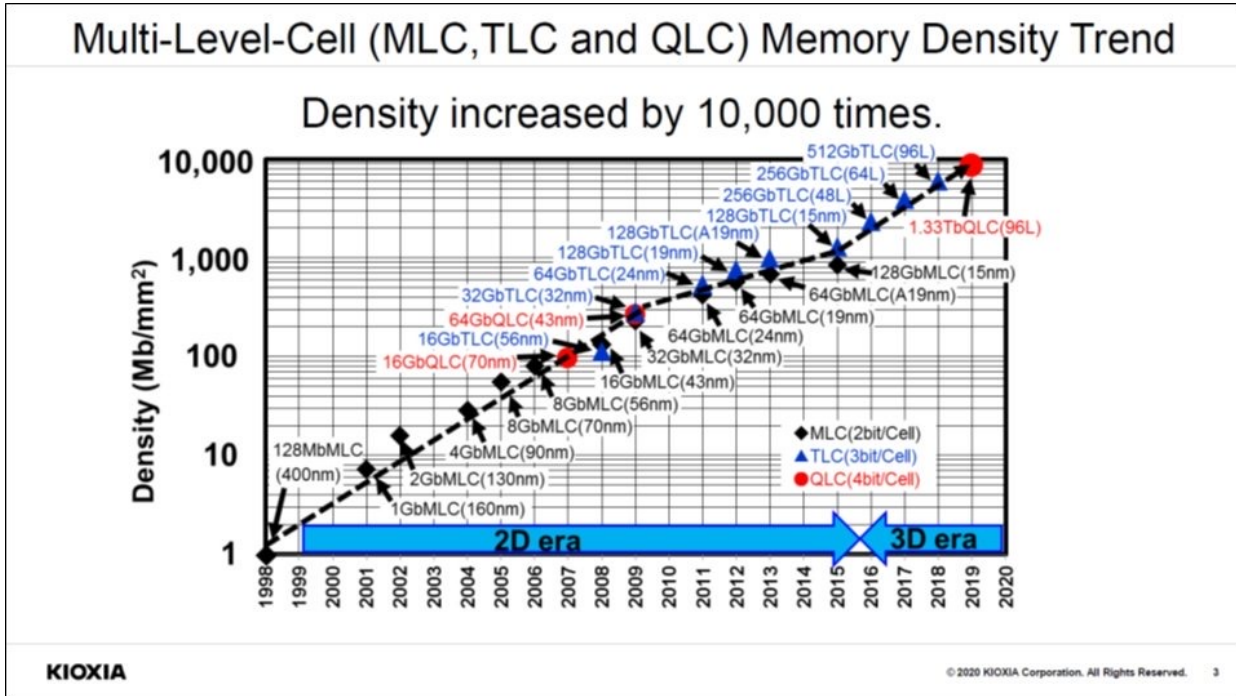
<http://www.pcper.com/reviews/Storage/Inside-Look-Intel-and-Micron-25nm-Flash-Memory-Production/Die-Shrinks-and-You>

* <https://www.techinsights.com/blog/techinsights-memory-technology-update-iedm18>



Recent Development of Flash Memory

Areal density increase : *

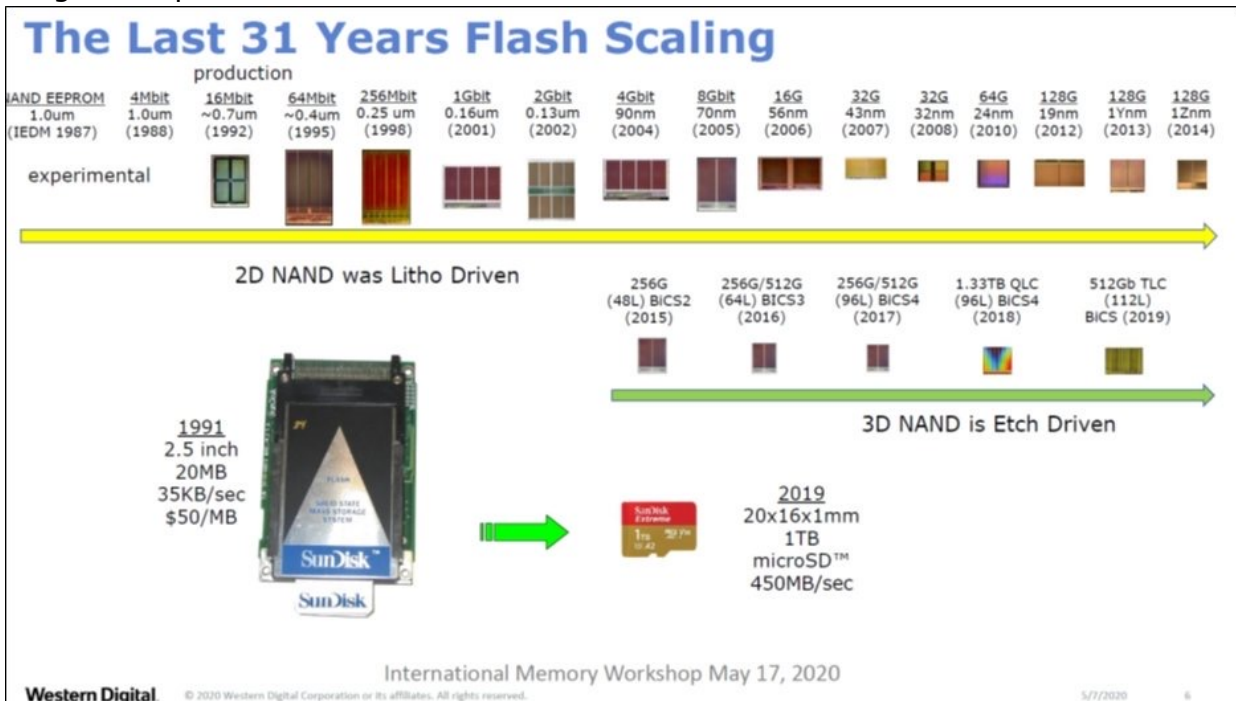


* <https://eetimes.itmedia.co.jp/ee/articles/2006/03/news033.html>



Scaling of Flash Memory

Scaling development : *

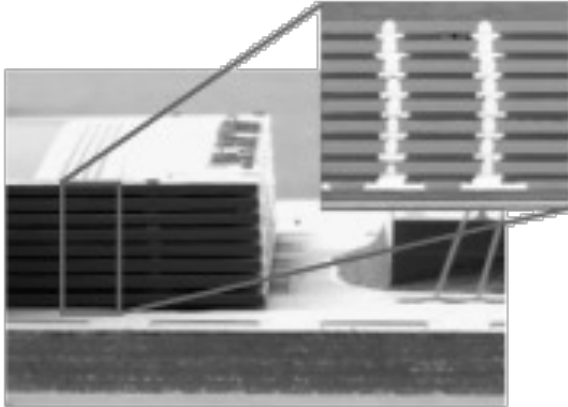


* <https://eetimes.itmedia.co.jp/ee/articles/2006/03/news033.html>



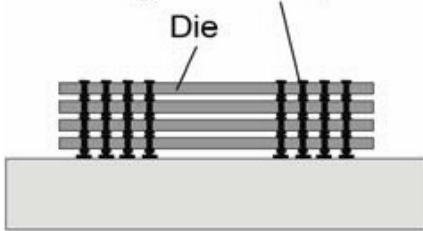
For Higher Recording Density ...

Through Silicon Vias (TSV) :

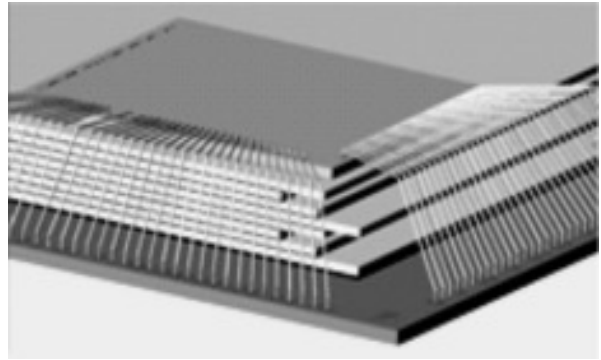


Samsung demonstrated 16 GB flash.

Through silicon via, TSV



Stacked flash :



Toshiba also demonstrated 16 GB flash.

Die attach film, DAF

Die

Bonding wire



** <http://www.intechopen.com/books/advances-in-solid-state-circuit-technologies/dimension-increase-in-metal-oxide-semiconductor-memories-and-transistors>

* <http://www.semiconductorjapan.net/serial/lesson/13.html>;



Latest Flash Memory

32 1-TB flash modules :



V-NAND architecture : 16 layers of flash memories to achieve 512Gb

* <https://news.samsung.com/global/samsung-electronics-begins-mass-production-of-industrys-largest-capacity-ssd-30-72tb-for-next-generation-enterprise-systems>



Latest Flash Memory

Grade 3 : -40°C ~ 85°C

Grade 2 : -40°C ~ 105°C

compatible with 64 layers

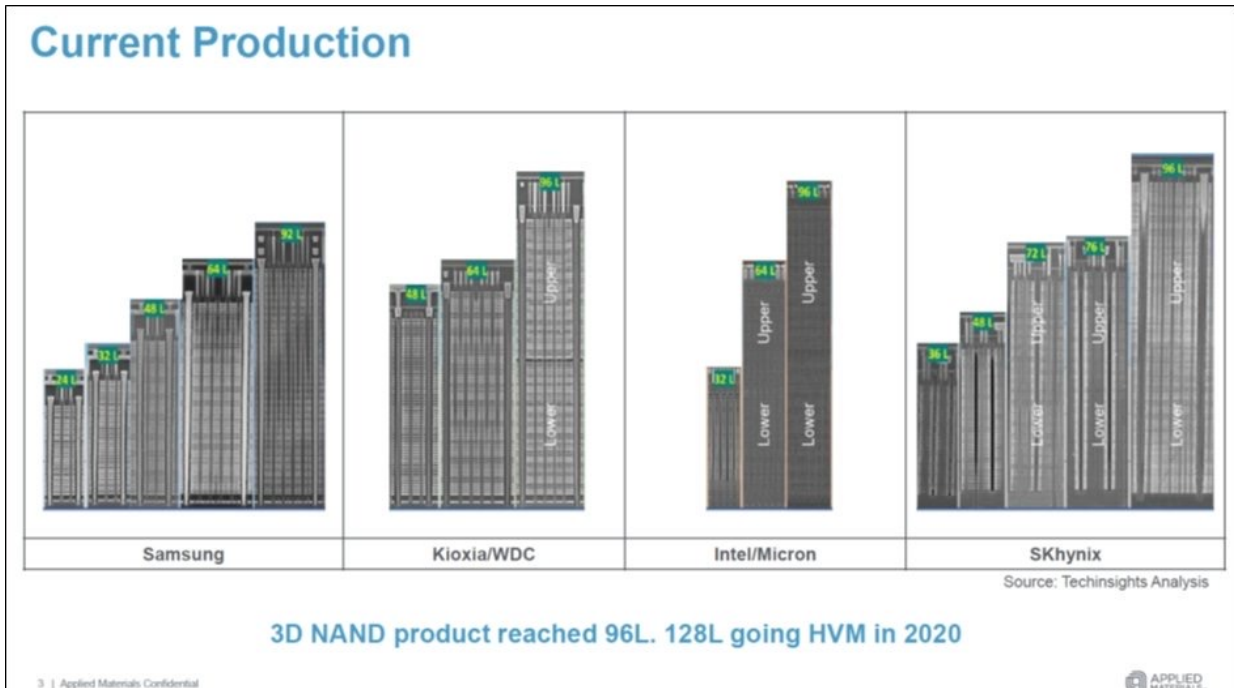


* <https://car.watch.impress.co.jp/docs/news/1148730.html>



Current Flash Memory

High aspect ratio contact (HARC) for high-volume manufacturing (HVM) : *

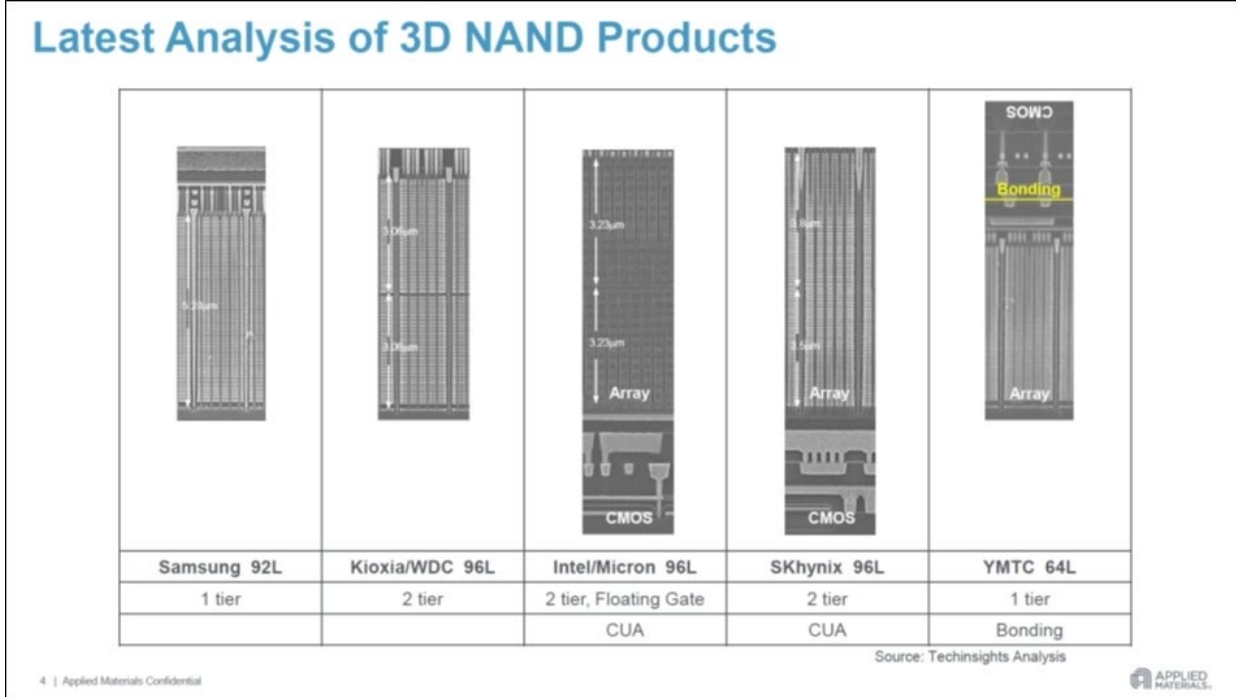


* <https://eetimes.itmedia.co.jp/ee/articles/2006/03/news033.html>



Next-Generation Flash Memory

High aspect ratio contact (HARC) with 1 or 2 tier : *



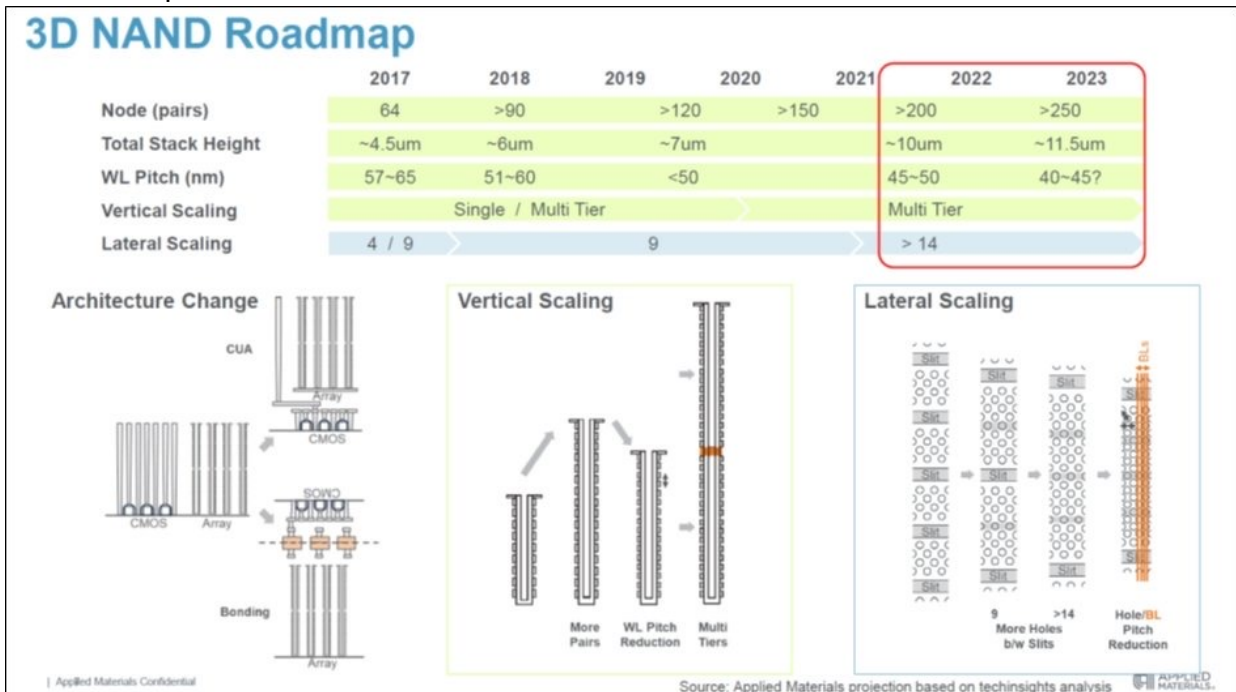
2T vias need to be adjusted for 2 tiers in a 12" wafer.

* <https://eetimes.itmedia.co.jp/ee/articles/2006/03/news033.html>



Further Development

Future development : *

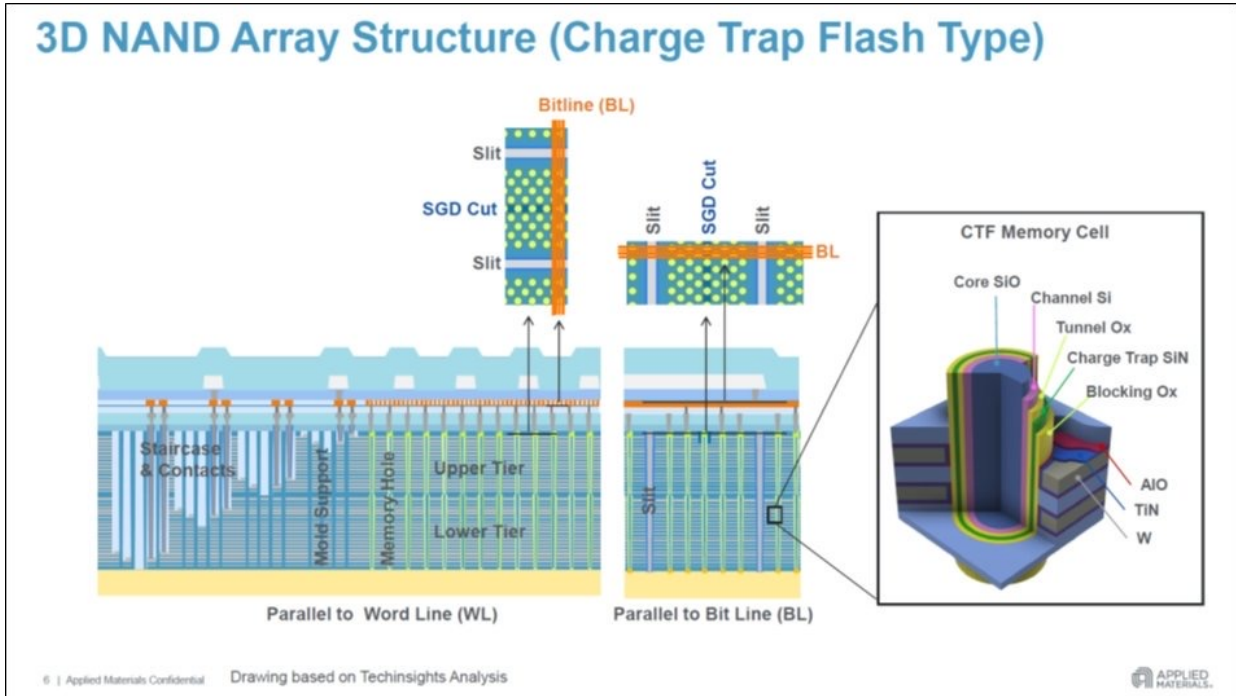


* <https://eetimes.itmedia.co.jp/ee/articles/2006/03/news033.html>



Charge Trap Flash Memory

Charge trap flash memory : *

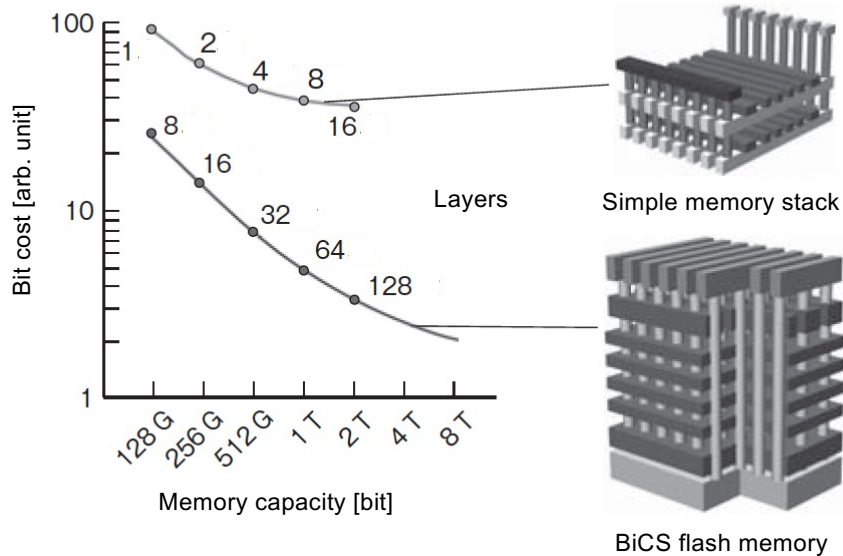


* <https://eetimes.itmedia.co.jp/ee/articles/2006/03/news033.html>



Bit Cost vs Recording Capacity

Simple memory stack and BiCS memory :

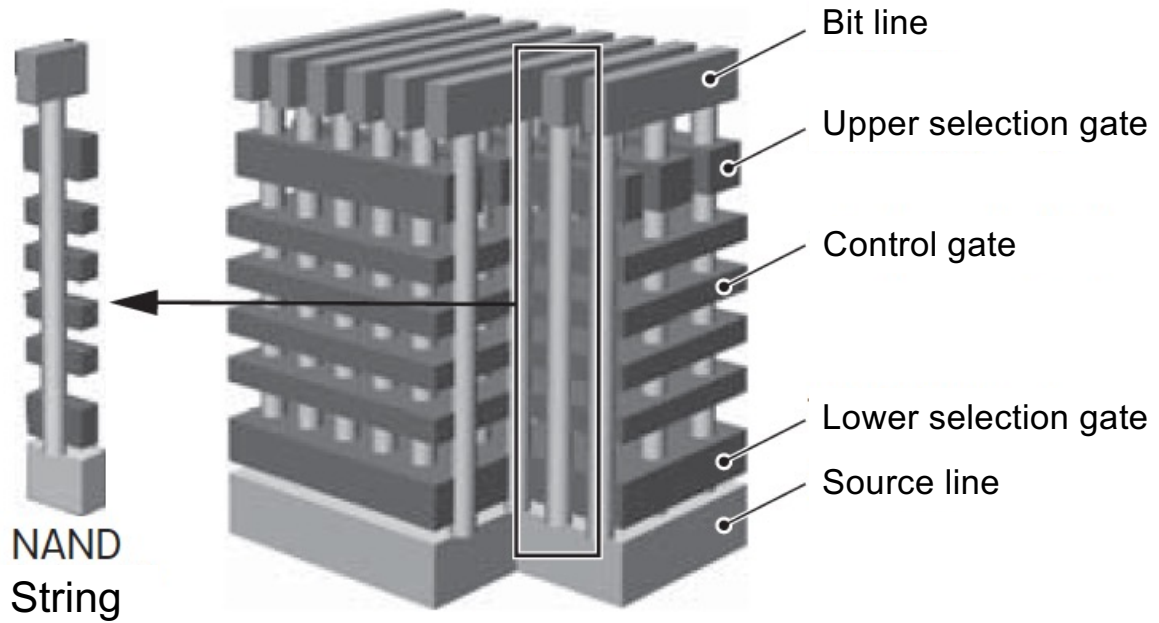


* H. Aochi, R. Katsumata and Y. Fukuzumi, *Toshiba Review* **66**(9), 16 (2011).



Bit Cost Scalable (BiCS)

BiCS memory design :



* H. Aochi, R. Katsumata and Y. Fukuzumi, *Toshiba Review* 66(9), 16 (2011).



Lates 112 Layered Flash Memory

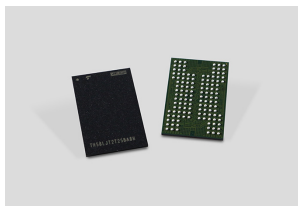
5th generation BiCS : *

The screenshot shows the KIOXIA website header. The KIOXIA logo is on the left, followed by 'KIOXIA Europe GmbH'. To the right are navigation links: 'Corporate Group Information (KIOXIA Holdings Corporation)', 'R&D / Yokkaichi Plant / Company Information (KIOXIA Corporation)', and 'Europe (English)'. A search icon is on the far right. Below the header is a navigation bar with 'Business Products', 'Personal Products', 'News', 'KIOXIA Europe GmbH', and 'Contact Us'.

KIOXIA unveils fifth-generation BiCS FLASH

New generation 3D flash memory adds layers, boosts capacity, broader bandwidth and provides new design flexibility

Düsseldorf, Germany, 31 January 2020



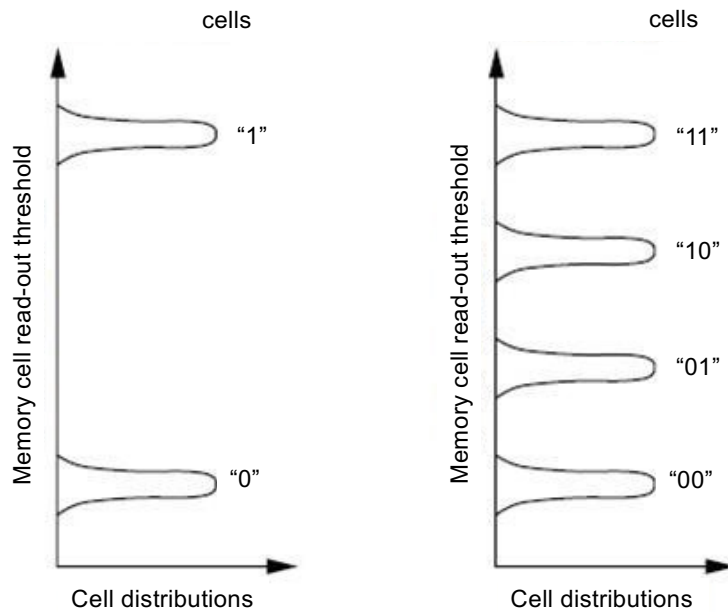
KIOXIA Europe GmbH, the world leader in memory solutions, today announced that it has successfully developed its fifth-generation BiCS FLASH three-dimensional (3D) flash memory with a 112-layer vertically stacked structure. KIOXIA plans to start shipping samples of the new device, which has a 512 gigabit (64 gigabytes) capacity with 3-bit-per-cell (triple-level cell, TLC) technology, for specific applications in the first quarter of the calendar year 2020⁽¹⁾.

* <https://business.kioxia.com/en-emea/news/2020/20200131-1.html>



Multiple-Valued Flash Memory

Multiple electrons can be stored in the floating gate :

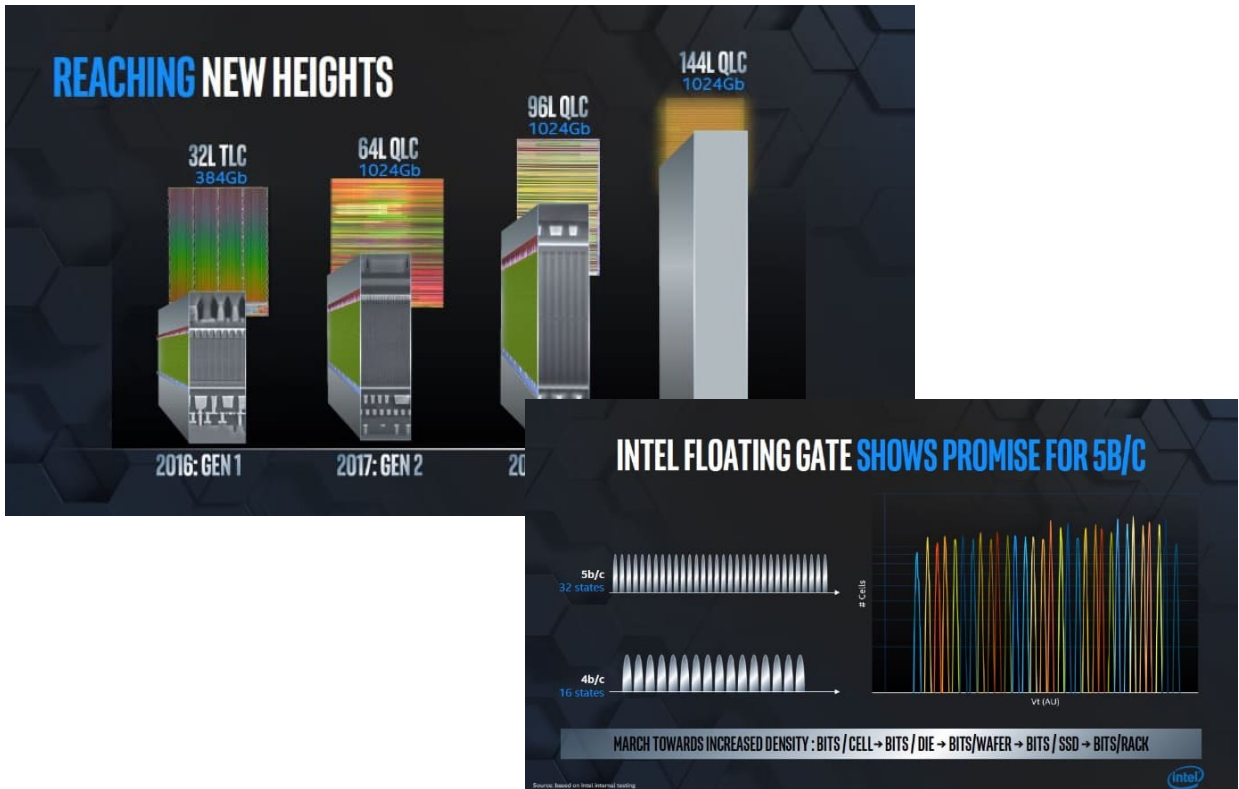


* <http://www.semiconductorjapan.net/serial/lesson/13.html>



Multiple-Valued Flash Memory

Triple / quadruple / penta level cell (TLC / QLC / PLC) :



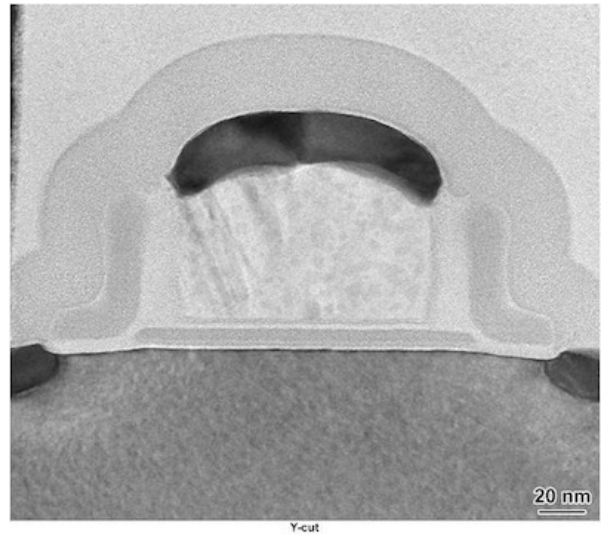
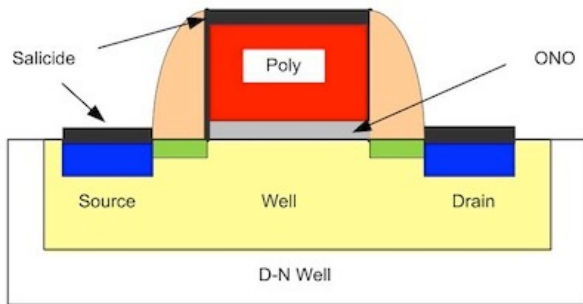
* https://pc.watch.impress.co.jp/docs/column/semicon/1243736.html#photo001_1.jpg

SONOS



Si / SiO₂ / SiN / SiO₂ / poly-Si (SONOS) :

By replacing the poly-Si floating gate with SiN, *i.e.*, Si₃N₄, unbound dangling bonds can trap more electrons.



* http://www.eetimes.com/document.asp?doc_id=1279116

3-Dimensional Integration with Higher Density



Max Shulaker (MIT) proposed monolithic architecture : *

Monolithic 3D Integration

- Massive ILV density > TSV density

TSV (chip stacking)

Through silicon via (TSV)

Monolithic

Nano-scale inter-layer vias (ILVs)

* <https://sense.mit.edu/people/max-shulaker>



Integration of Functionality

3D monolithic can be advantageous over TSV etc. : *

3D NanoSystem

- **First monolithic 3D system**
 - >2 million carbon nanotube FETs
 - 1 Mbit Resistive RAM

← sensing
← logic
← memory
← logic

[Shulaker Nature 17] 12

* <https://sense.mit.edu/people/max-shulaker>



Flash Memory vs DRAM

Comparisons between flash memory and DRAM :

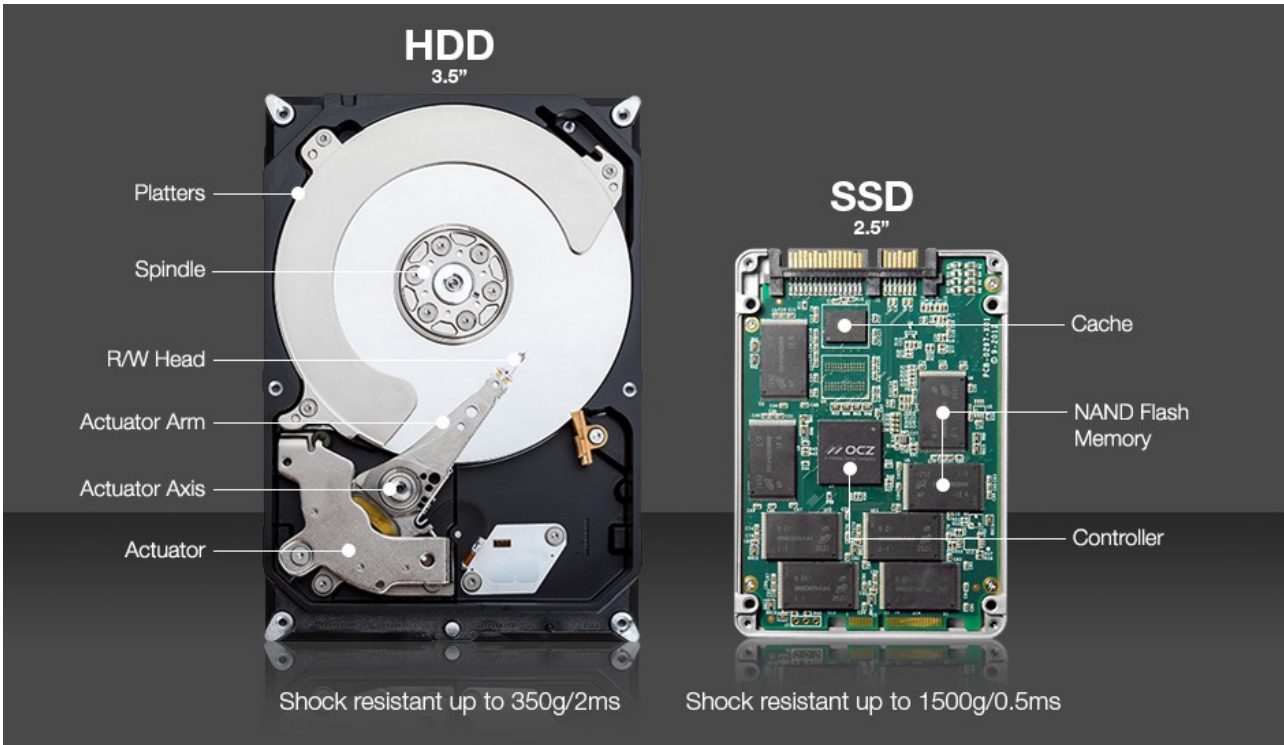
	DRAM	Flash memory
Principles		
Writing operation	<p>Electron charges are stored in the condenser.</p>	<p>Electrons are stored at the floating gate.</p>
Data volatility	<p>Leakage from the condenser.</p>	<p>Electrons cannot tunnel through the barriers.</p>

* <http://pc.nikkeibp.co.jp/article/NPC/20061228/257976/>



Flash Memory vs HDD – Configurations

Comparisons between flash memory and HDD : *





* <https://www.enterprisestorageforum.com/storage-hardware/ssd-vs-hdd.html>



Flash Memory vs HDD - Performance

Comparisons between flash memory and HDD : *

 SSD vs. HDD 		
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	HDDs failure rate fluctuates between 2-5%
SSDs consume between 2 and 5 watts	Energy Savings This means that on a large server, approximately 100 watts are saved	HDDs consume between 6 and 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 remain 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 allow for 3-5 times faster backup for your data	HDD backups take up to 20-24 hours

* <https://www.enterprisestorageforum.com/storage-hardware/ssd-vs-hdd.html>

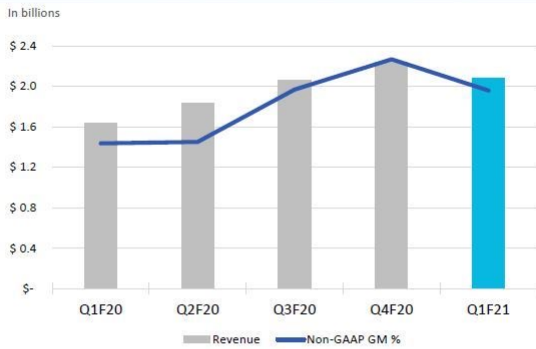


Flash Memory vs HDD - Revenue

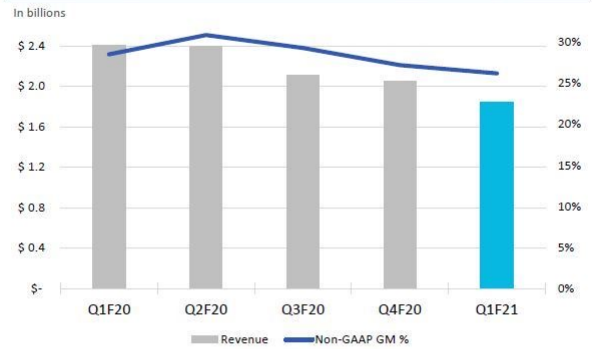
Comparisons between flash memory and HDD : *

Flash and Hard Drive Metrics

Flash Revenue and Non-GAAP Gross Margin



Hard Drive Revenue and Non-GAAP Gross Margin



Flash	
Q1F21 Results	<ul style="list-style-type: none"> Bit shipments: up 1% QoQ ASP/Gigabyte: <ul style="list-style-type: none"> Blended: down 9% QoQ Like-for-like: down 6% QoQ

Hard Drive	
Q1F21 Results	<ul style="list-style-type: none"> Total exabyte shipments: down 7% QoQ ASP per drive: \$79

For reconciliations of GAAP to non-GAAP financial measures, see the Appendix.

* https://eetimes.jp/ee/articles/2011/13/news026_2.html