Progress in Manufacture of Chips in South Korea

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Department of Materials Science & Engineering, and
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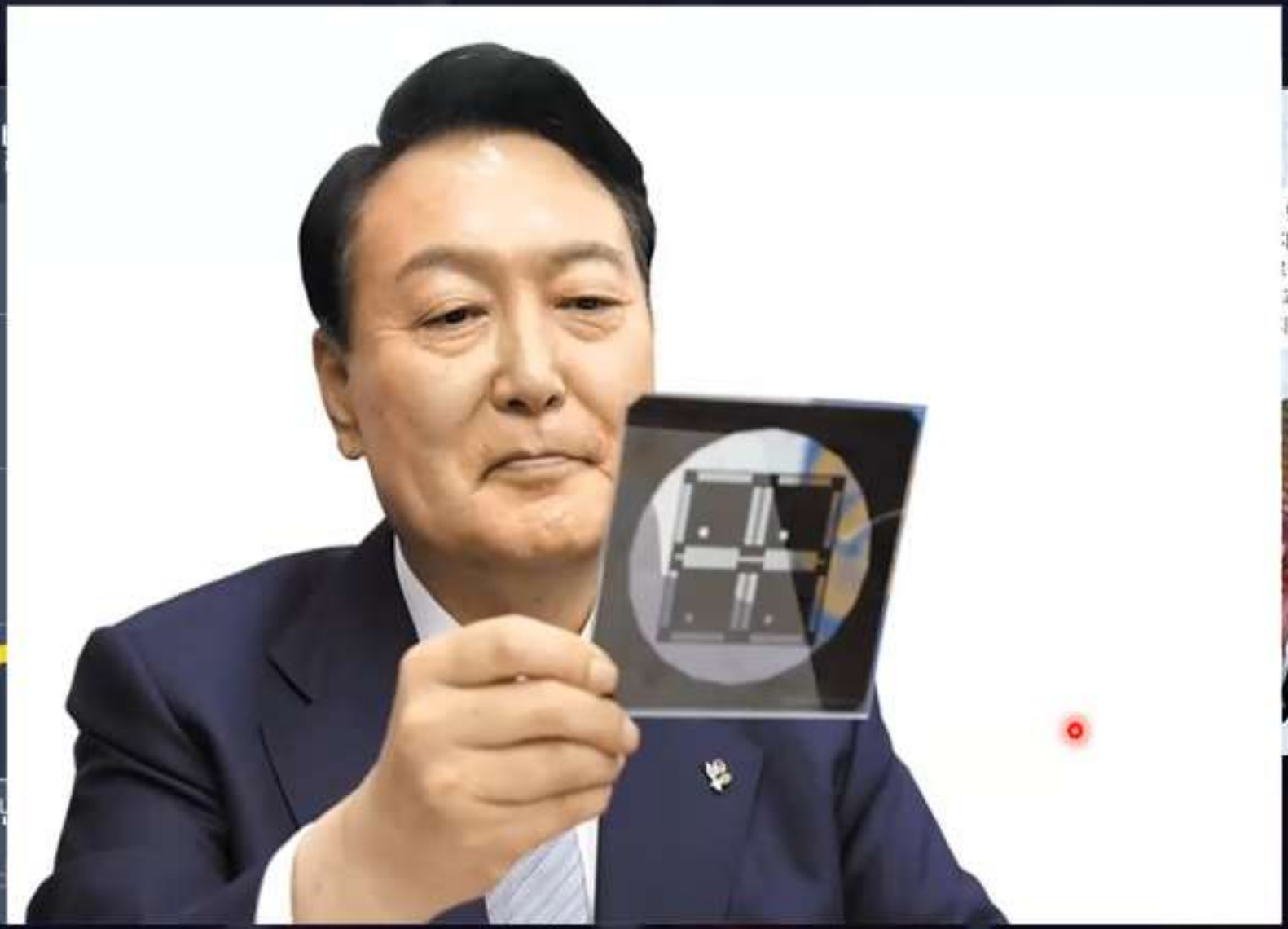
Seoul National University, South Korea

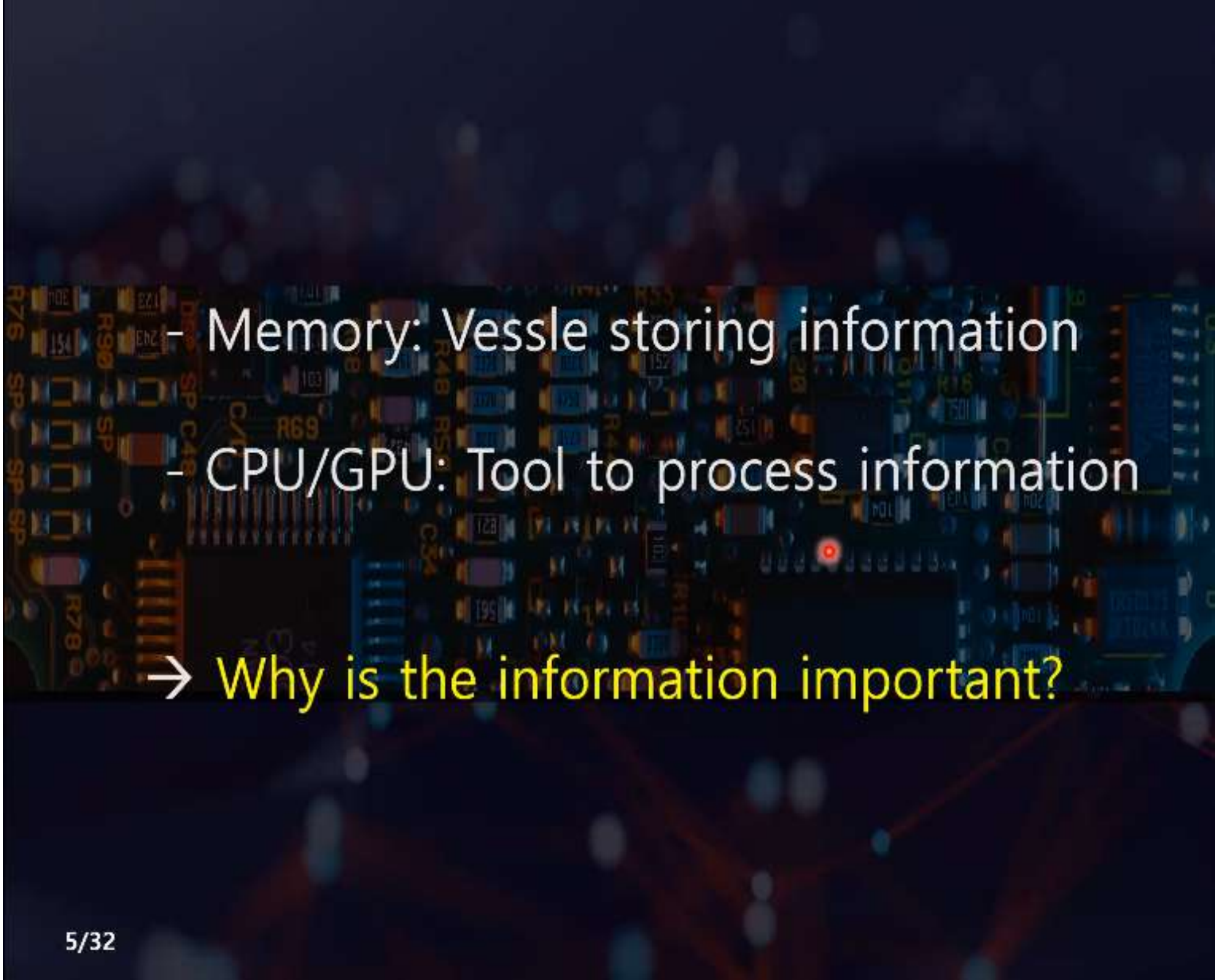

Why is semiconductor so important ?

Security and military issues

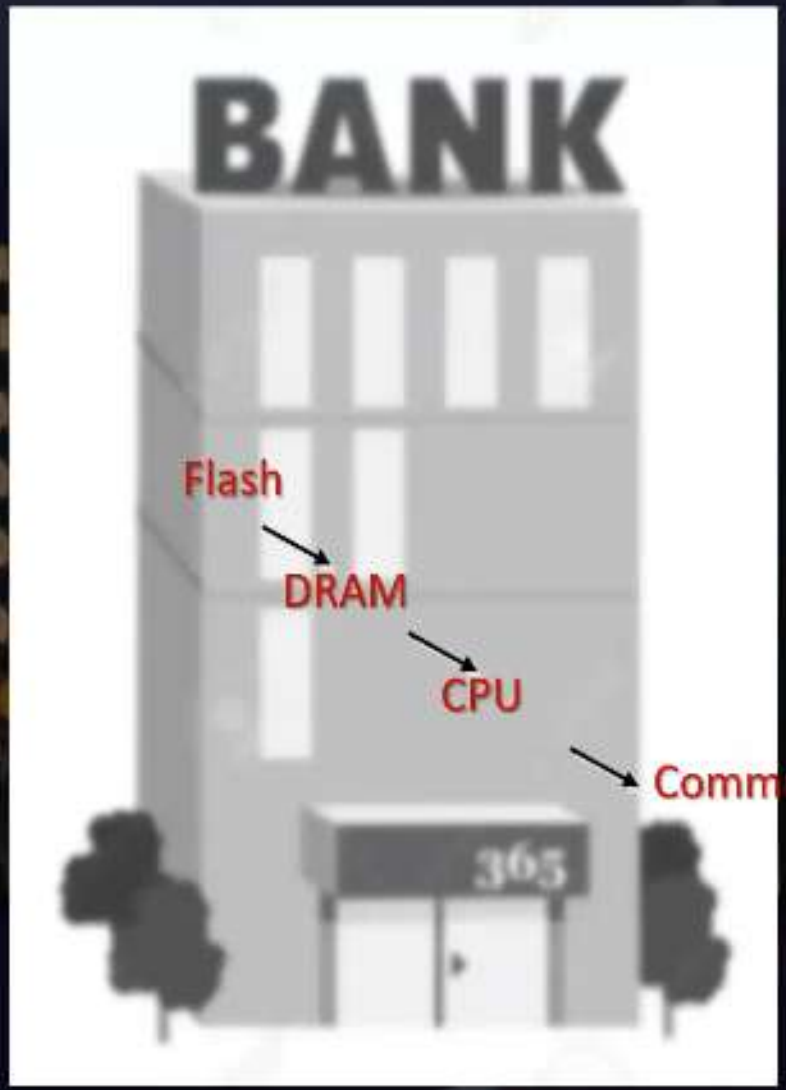
Economical issues

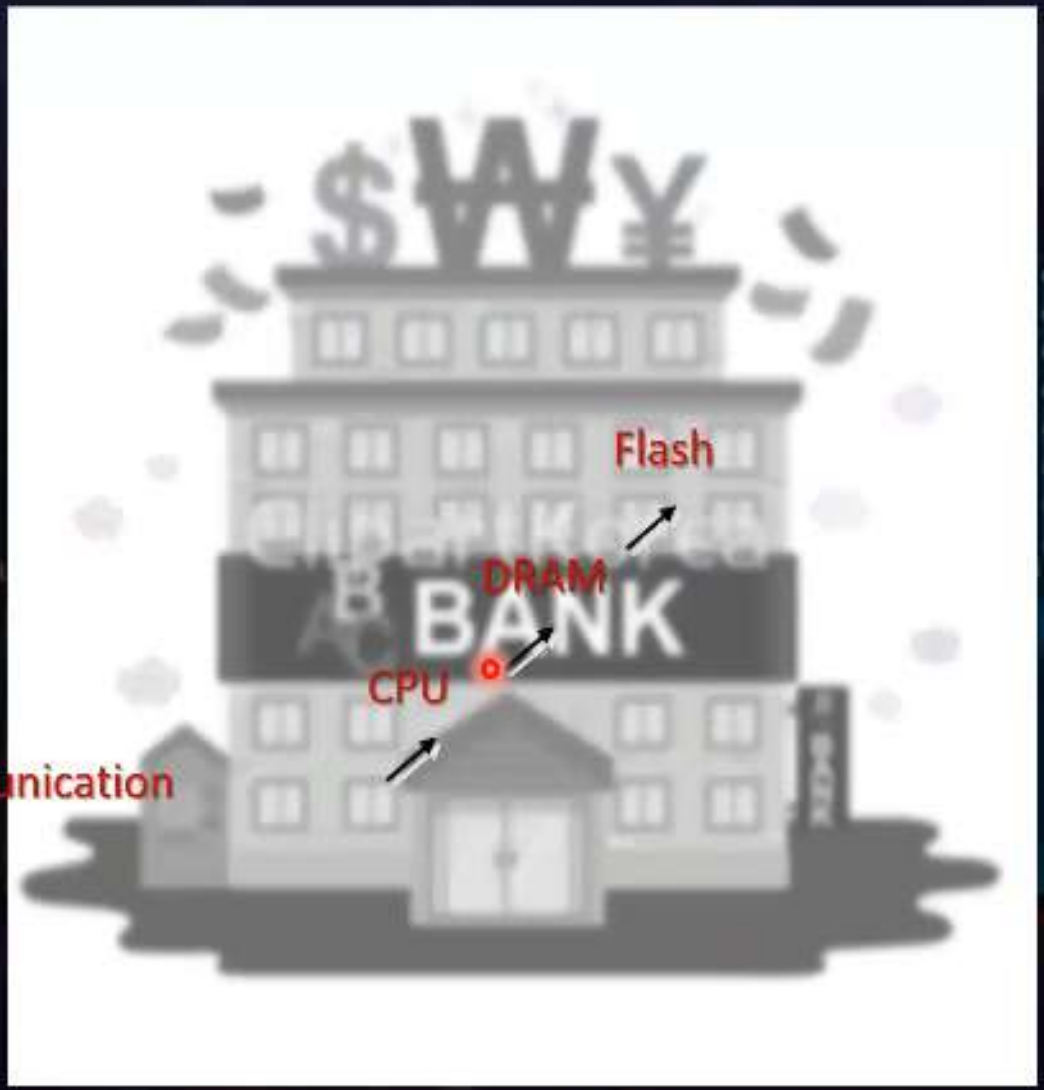
Economical issues




- Memory: Vessle storing information
- CPU/GPU: Tool to process information
→ Why is the information important?

Only information!

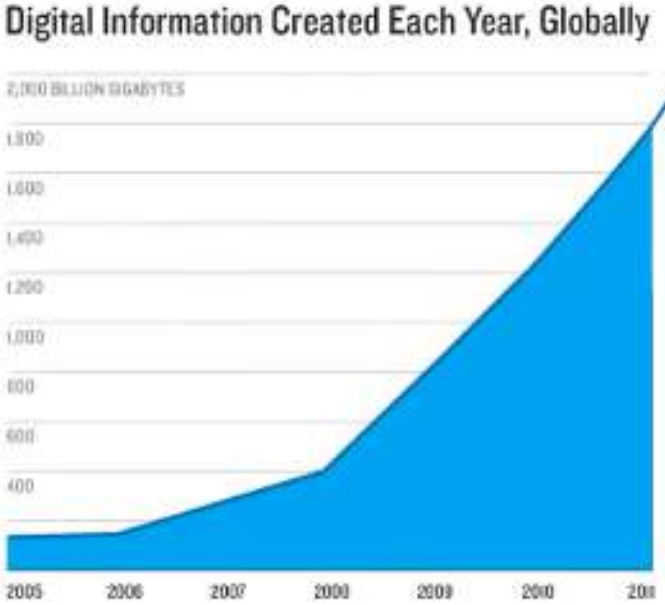

BANK
Flash
DRAM
CPU
Communication
365


Flash
DRAM
BANK
CPU

Energy crisis

~44 zetabytes in 2020

10^{28} bytes by 2040



2,000%
Expected increase in global data by 2020

III Megabytes
Video and photos stored by Facebook, per user

75%
Percentage of all digital data created by consumers

Energy consumption of U.S data centers in 2013 =3.3x10^{17} J

(Annual output of a plant=450MW)
NRDC,Aug.2014

Energy crisis

~44 zetabytes in 2020

By year 2040,

Total binary operation of

10^{40}

$\times 10^{-13}$ J

per one binary operation

Total energy *consumption*

>>

Total energy *production*

10^{25}J

Building a House?

1. Do everything by yourself: design, buying materials, construction, etc.

→ Integrated Device Manufacturer (Intel (CPU) Samsung/SK Hynix (Memory))

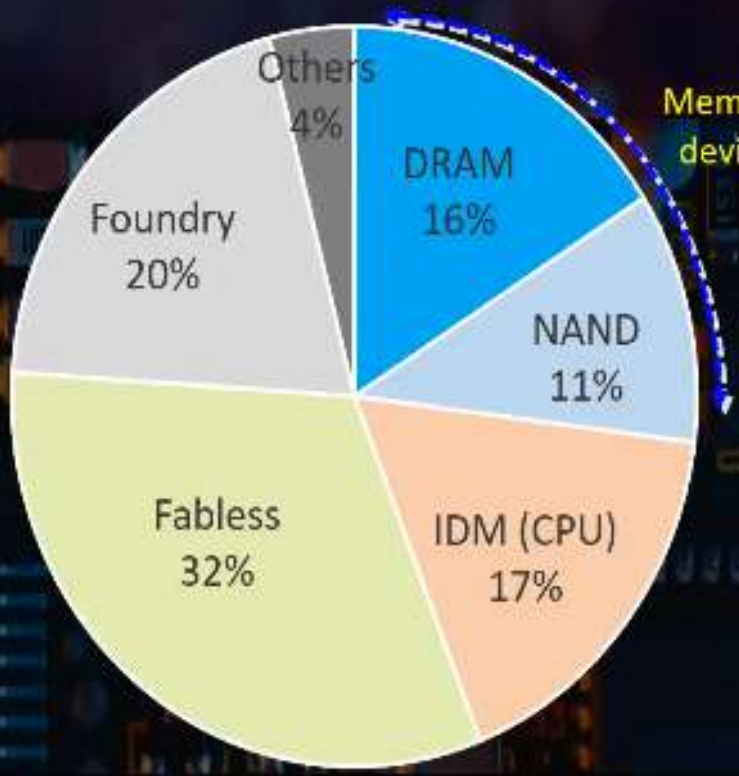
2. Let others do for you while you do what you can do best: I only design and hire others to make them. Or, I do not design but only fabricate what my customers have designed.

→ Fabless: Qualcomm, Nvidia, (Apple)
→ Foundry: TSMC, Samsung foundry, Intel foundry

Global Semiconductor Supply Chain

USA: Design / Software / Fabless
Japan: Material / Tools
Europe: Lithography / Material
Taiwan: Foundry / Fabless → **Double Si shield**
Korea: Memory → **Korea Semiconductor Security shield**
China: Raw material / Fabless
→ Chinese technology excavation (**中國技術挖掘**)
(Foundry/memory)

Total semiconductor market share in 2020

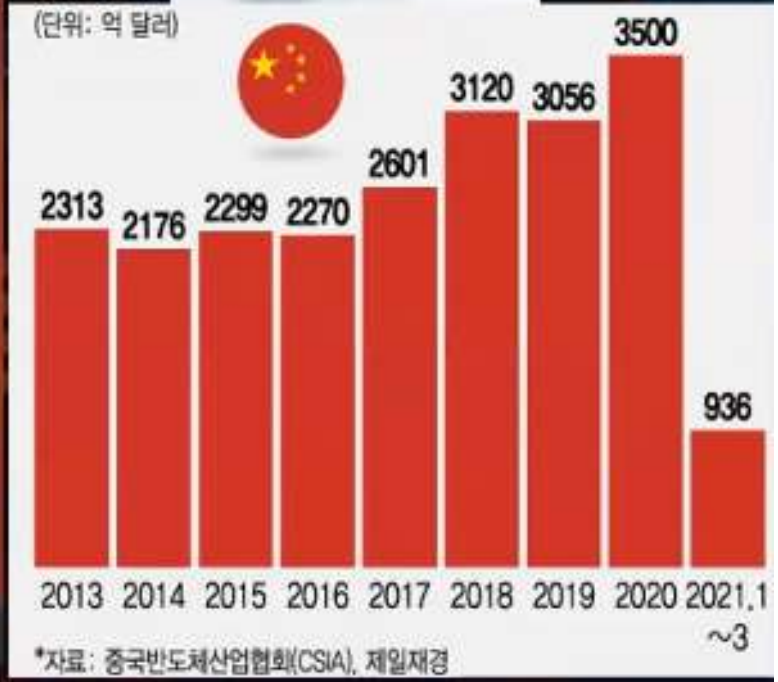


-. **Memory 27%** (DRAM 16%, NAND 11%)
-. **IDM CPU** (Intel), **Fabless** (AMD, NVIDIA, Qualcomm)
-. **Foundry (TSMC, Samsung, GlobalFoundries)**

High barriers to enter

Chinese History Resolution (中國歷史決議)

Chinese History Resolution (中國歷史決議)



REPORT TO THE PRESIDENT

Ensuring Long-Term U.S. Leadership in Semiconductors

Executive Office of the President

President's Council of Advisors on Science and Technology

January 2017

The President's Council of Advisors on Science and Technology

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Final Report

National Security Commission on Artificial Intelligence

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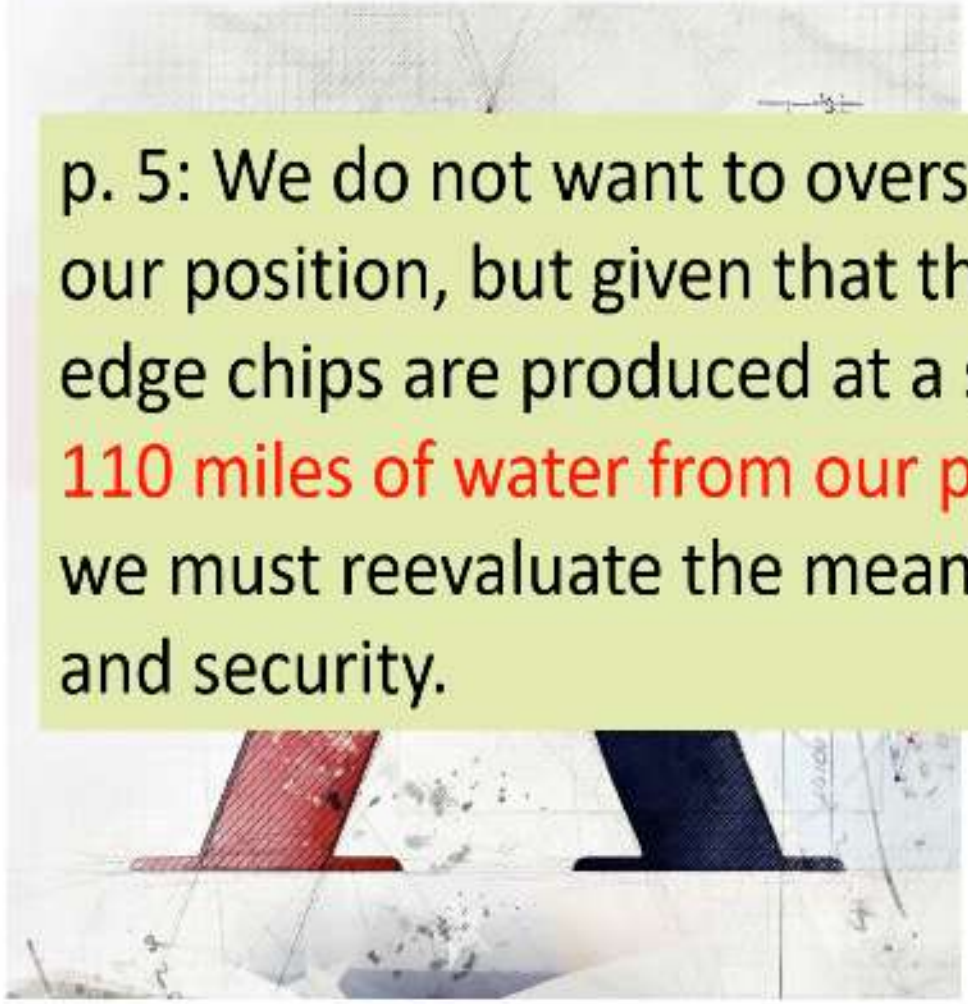
Andrew Moore

Final Report

National Security Commission on Artificial Intelligence



NATIONAL SECURITY COMMISSION ON ARTIFICIAL INTELLIGENCE

COMMISSION MEMBERS

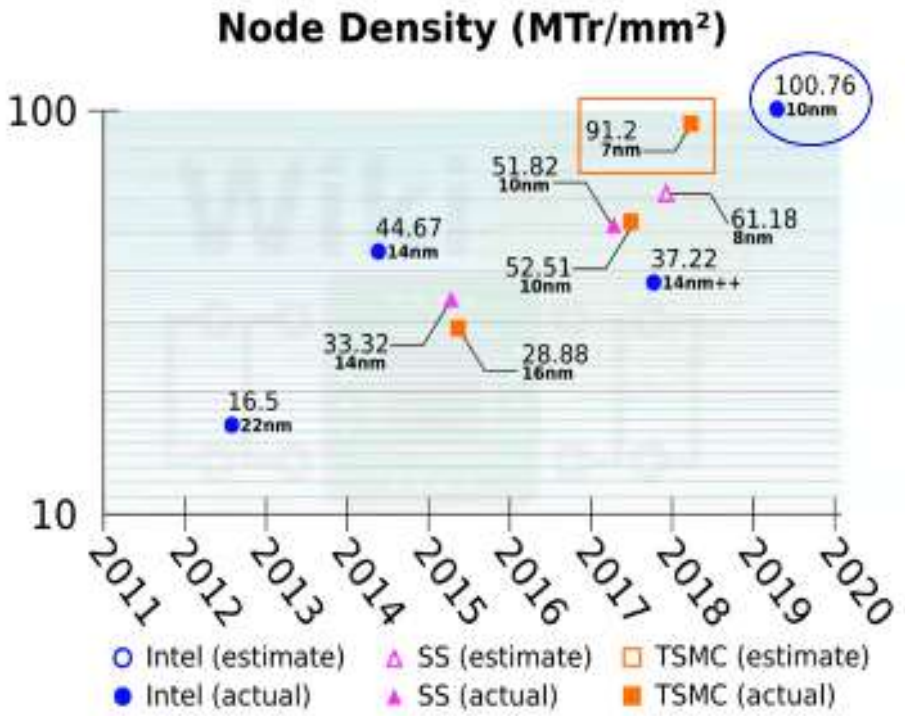
p. 5: We do not want to overstate the precariousness of our position, but given that the vast majority of cutting-edge chips are produced at a single plant separated by just 110 miles of water from our principal strategic competitor, we must reevaluate the meaning of supply chain resilience and security.

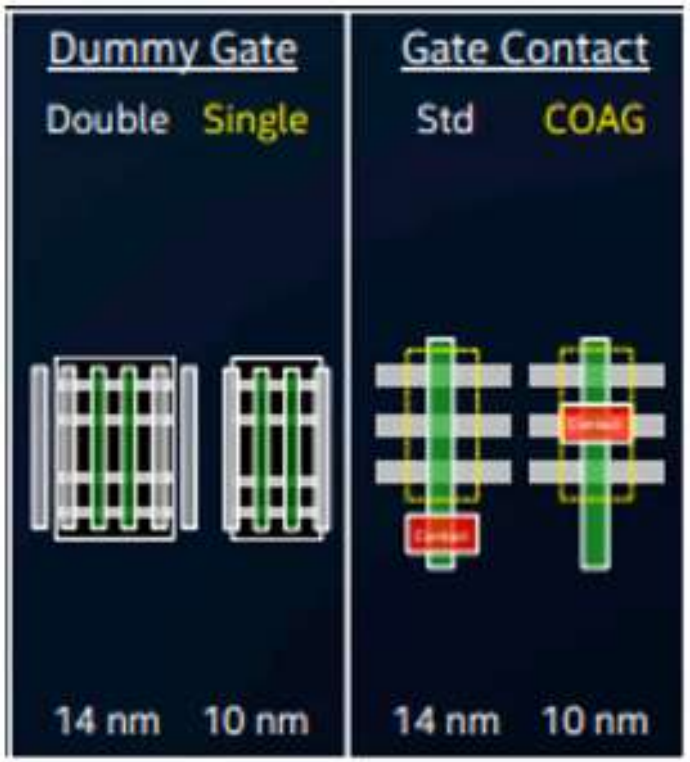
José-Marie Griffiths Katharina McFarland

Andrew Moore

Intel 10 nm vs Qualcomm 7 nm (TSMC)

- Intel: Reduced chip size by hyper scaling





-. By adopting Hyper Scaling (Single Dummy Gate, COAG (contact over active gate)), **Intel 10 nm process accomplished higher transistor density than TSMC 7 nm process.**

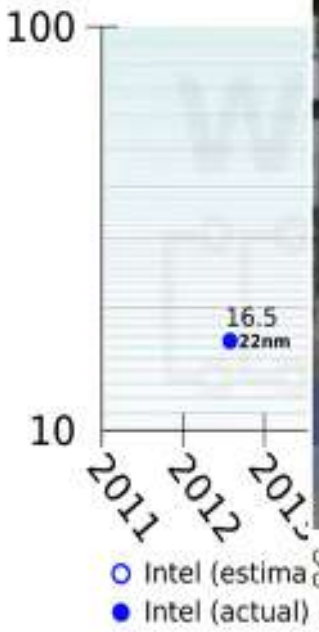
Intel 10 n

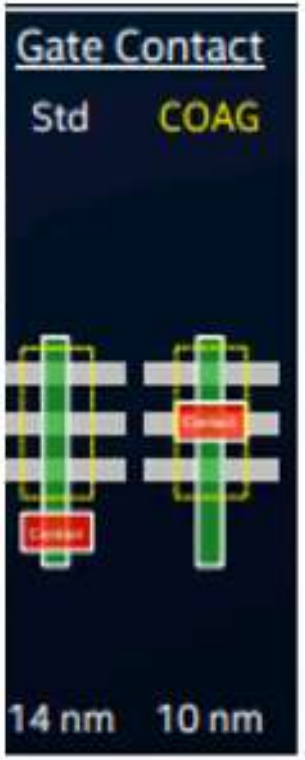
Where does Qualcomm's next CEO fit into the ongoing evolution of the chipmaker?

MC)

- Intel: Reduce

Qualcomm's new CEO Cristiano Amon poses for photos in the lobby at Qualcomm headquarters in San Diego. (Eduardo Contreras/The San Diego Union-Tribune)





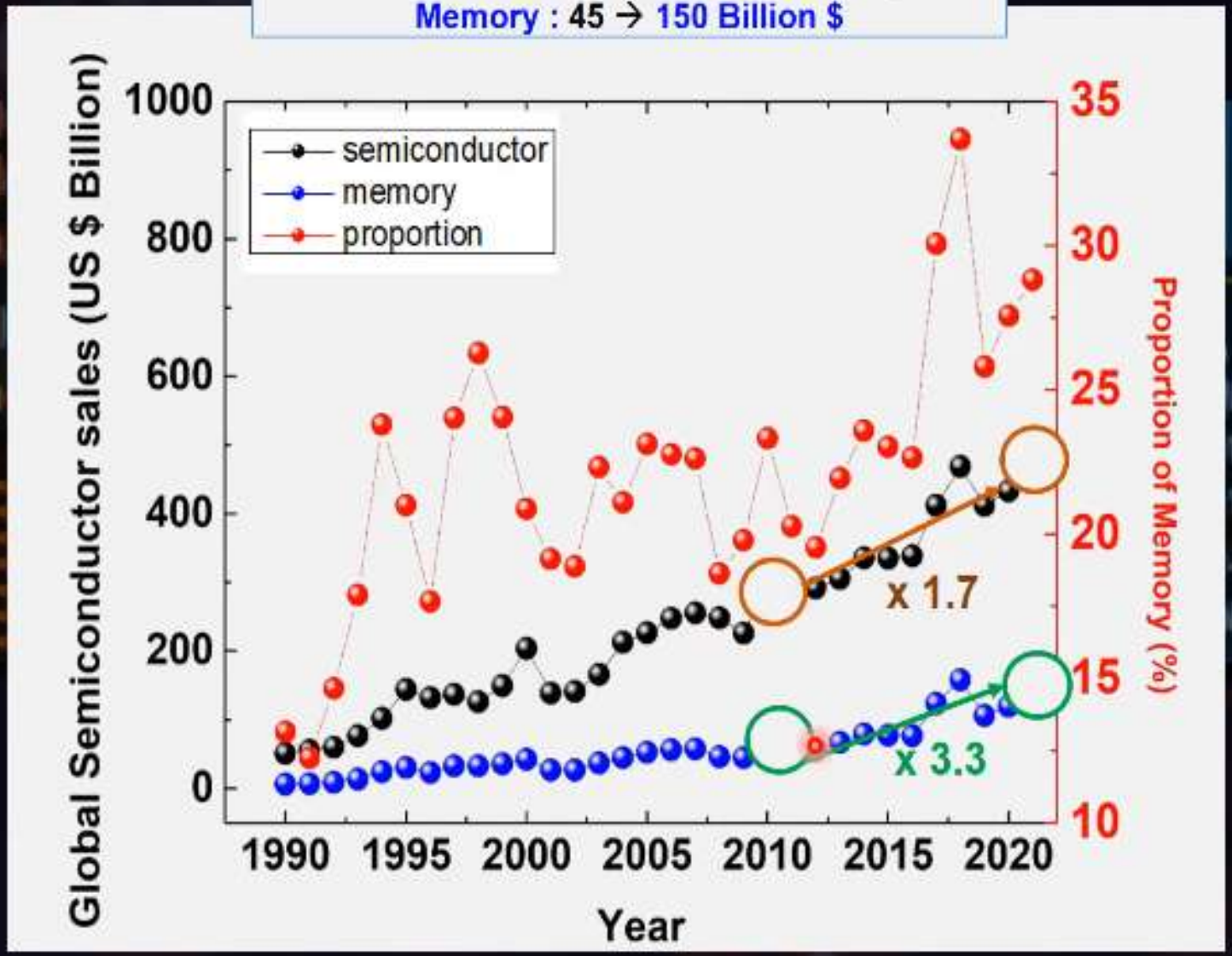
Amon is a proponent of "coopetition," where rivals collaborate on certain things while competing in others. When Intel Chief Executive Pat Gelsinger recently laid out plans for the semiconductor giant to begin manufacturing chips for outside companies at its factories, Qualcomm signed on in support.

-. By adopting H ctive gate)),
Intel 10 nm pro **7 nm process.**

"Like me, Cristiano recognizes the need for a more balanced supply chain and advanced manufacturing operations in the U.S. and Europe to provide geographically diverse capacity at scale for their products," said Gelsinger in an email response to questions. "We are excited to develop a closer relationship with Qualcomm."

Past

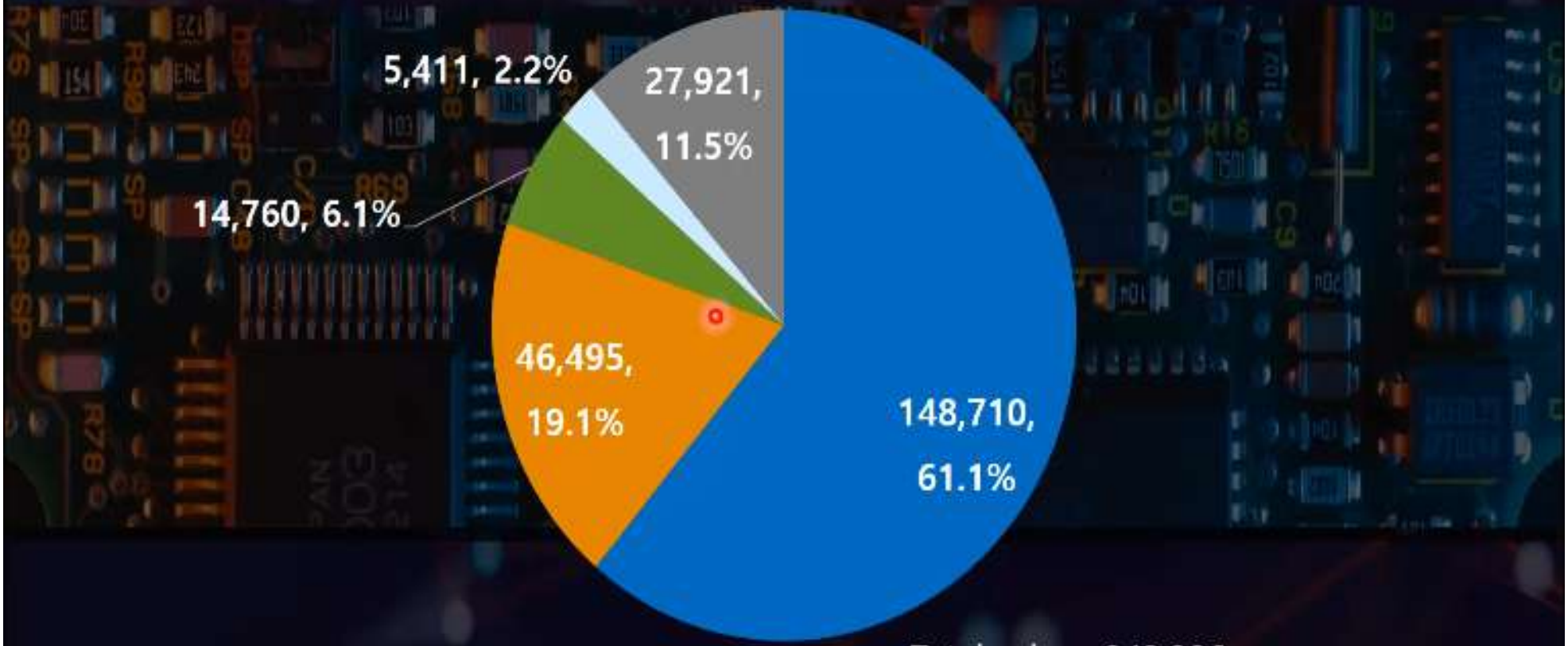
From 2011 to 2021
Semiconductor : 300 → 500 Billion $
Memory : 45 → 150 Billion $



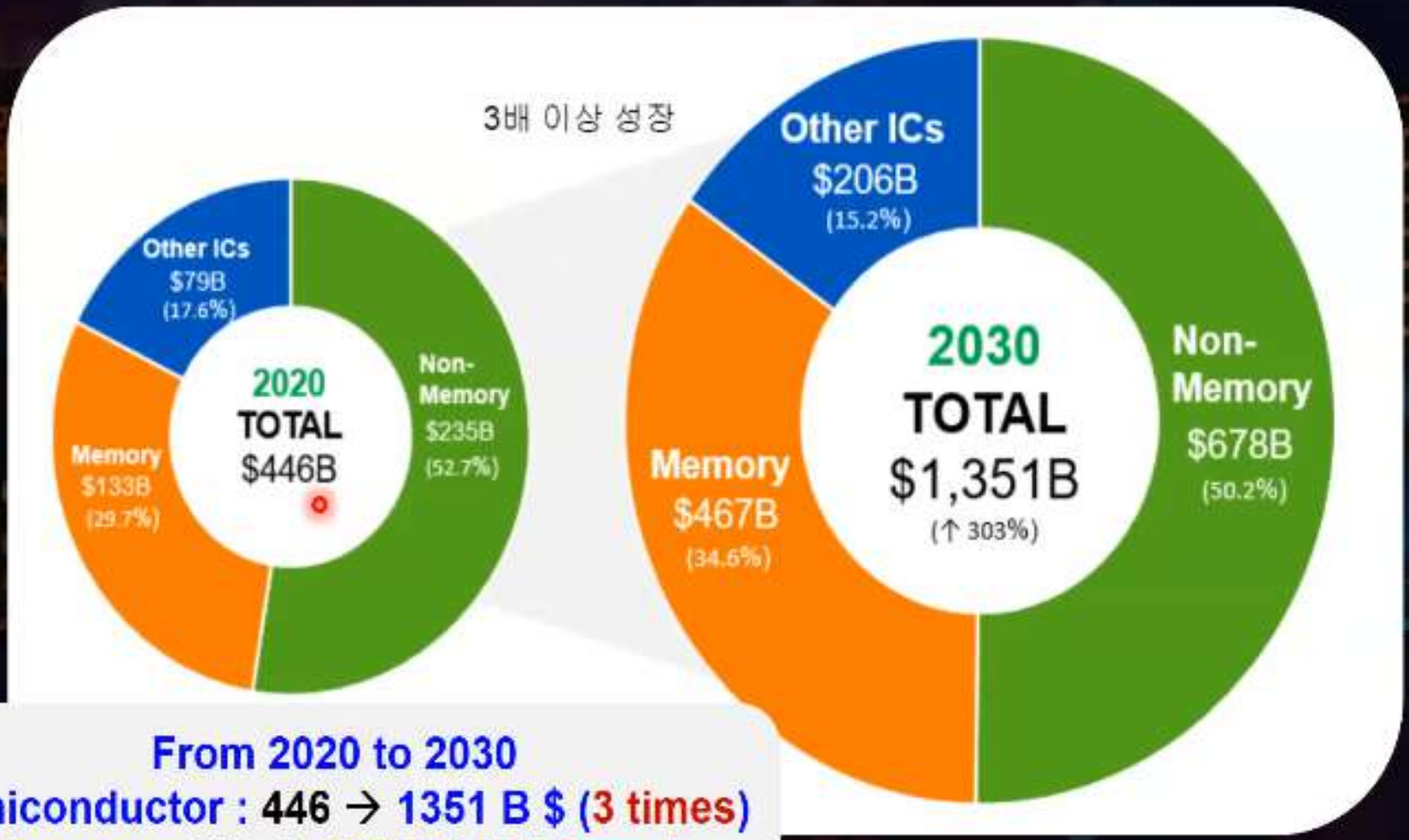
Present

Semiconductor industry sales and share in 2021

(Unit : million $, %)



Future



From 2020 to 2030
Semiconductor : 446 → 1351 B $ (3 times)
Memory : 133 → 467 B $ (3.5 times)

Source: SEMI

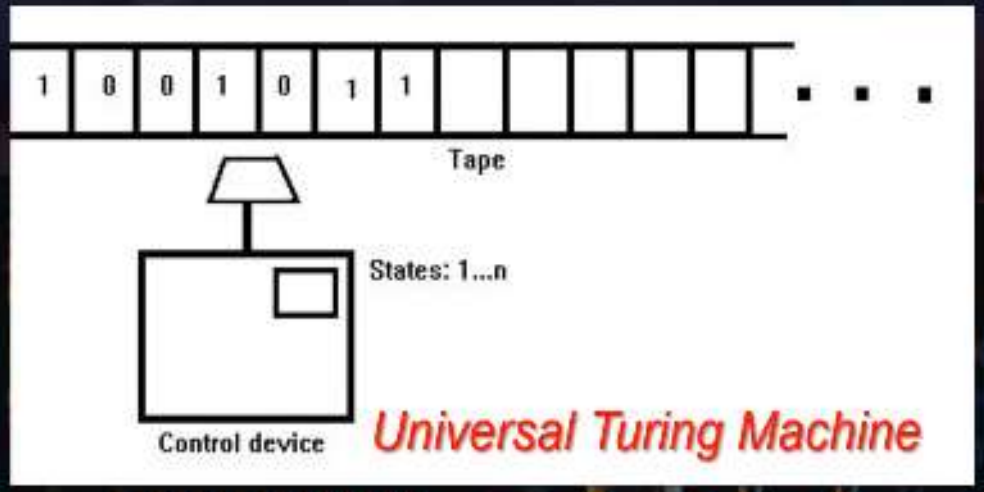
ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM

By A. M. TURING.

[Received 28 May, 1936.—Read 12 November, 1936.]

The "computable" numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means. Although the subject of this paper is ostensibly the computable *numbers*,

How does a computer work ?



Storage

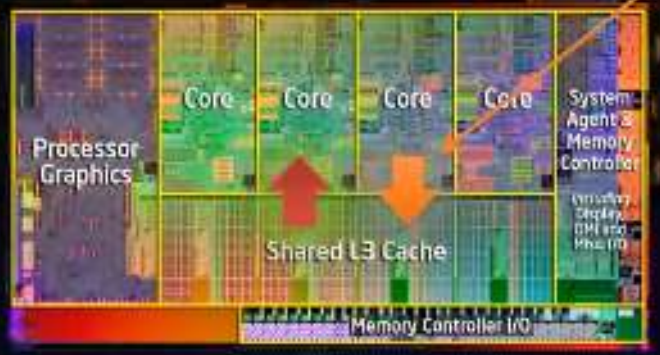
or

Slow

Fast

Fastest

CPU + cache



(Intel Sandy Bridge 2011)

CPU

SRAM (for cache)

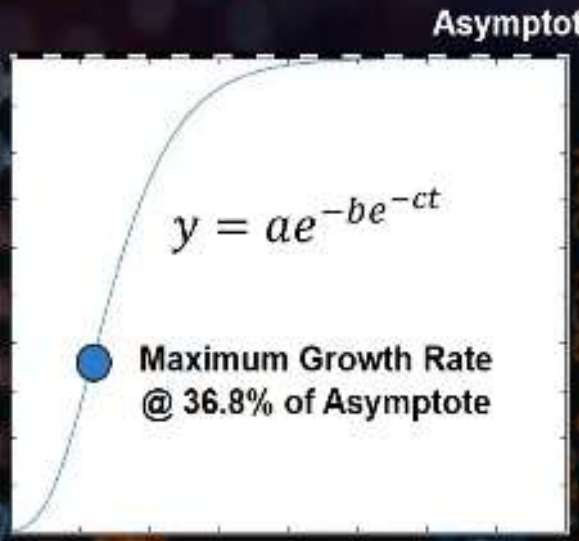
Very fast

Memory

DRAM

Why memory?

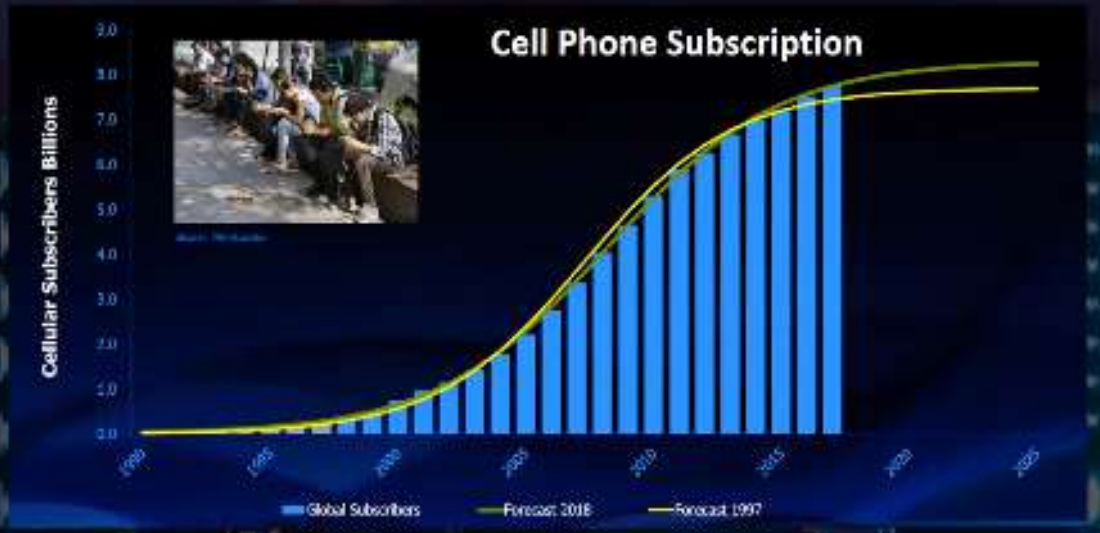
"The Gompertz Curve"



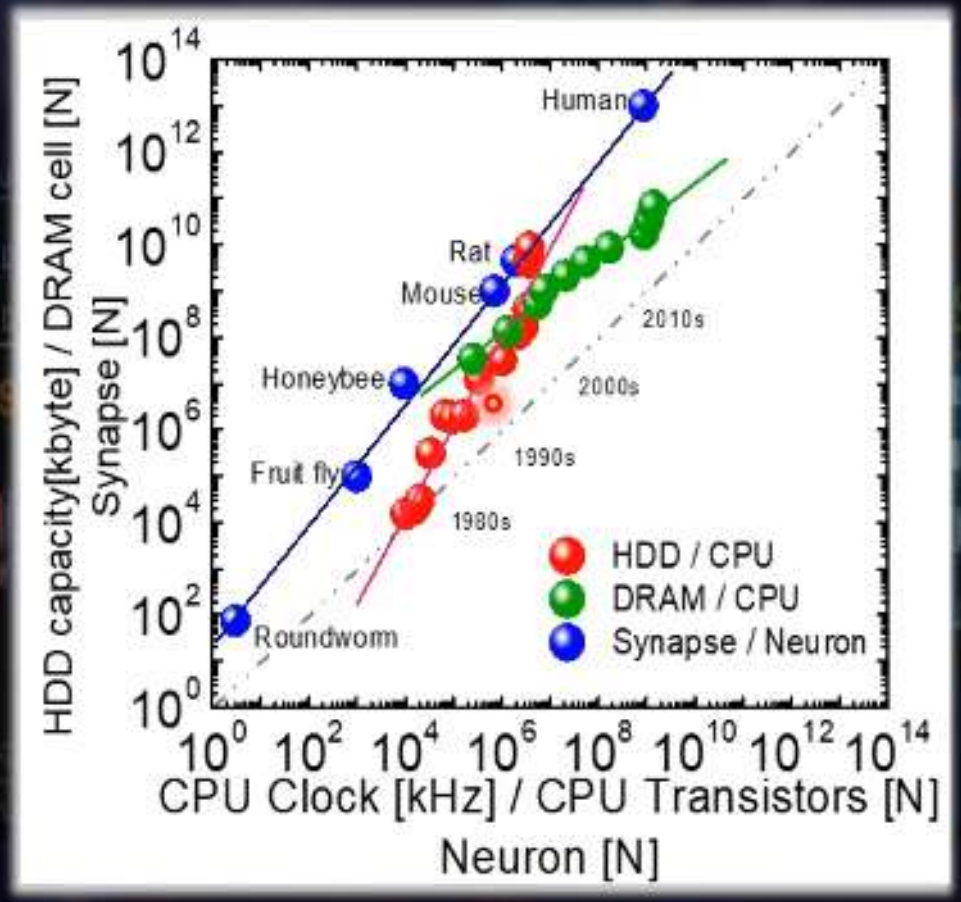
- Mathematical model for time series

➢ 99.9 % of Transistors are in memory!

❖ Prediction by Gompertz Forecast



Computer (find answer) vs. Brain (find best)

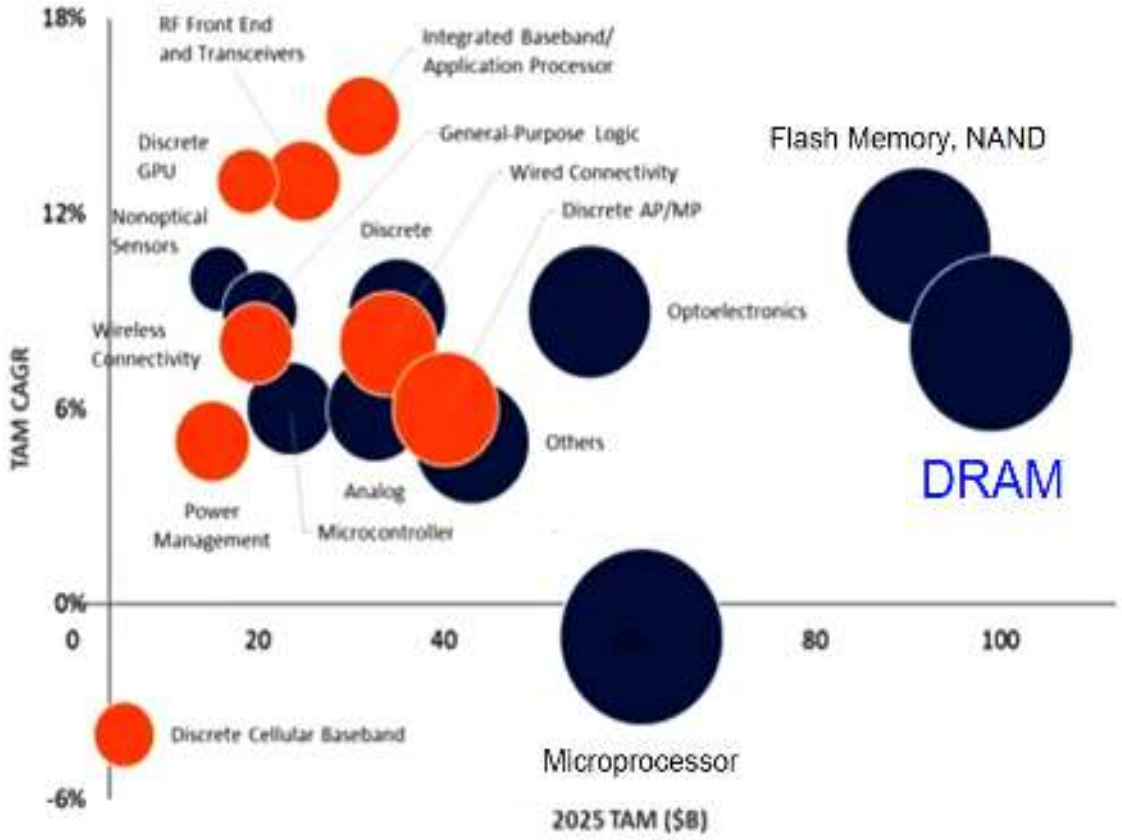


1987 → 2019
CPU clock : ~ 1000 times
Memory : ~ 100,000 times

Synapse/Neuron ~ 10,000
TR in DRAM/CPU ~ 10 - 100

Chip market prospect (up to 2025)

※ Semiconductor Revenue Forecast by Device Type Through 2025 (from Gartner)



Product	Market size	G/R
DRAM	**$100 billion**	**> 6%**
NAND	$90 billion	~10%
Microprocessors	$60 billion	Decaying

* TAM(Total Addressable Market) :
CAGR(Compound Annual Growth Rate)

Business strategies of Semiconductor companies

- IDM, Fabless and Foundry: Dedicate to what they can do best

intel Dedicates to CPU, Sell out flash business to SK Hynix (@20. 11), Extend to Foundry

NVIDIA Try to merge Arm (@20. 9). Dedicates to what they can do well.

tsmc Invest 100B USD$ for next three years for foundry (@21. 4);
do not compete with customers !

SAMSUNG Co-invest Memory, Foundry and system LSI:
120 B USD$ for next three years for memory and fo
but they have to compete with customers!

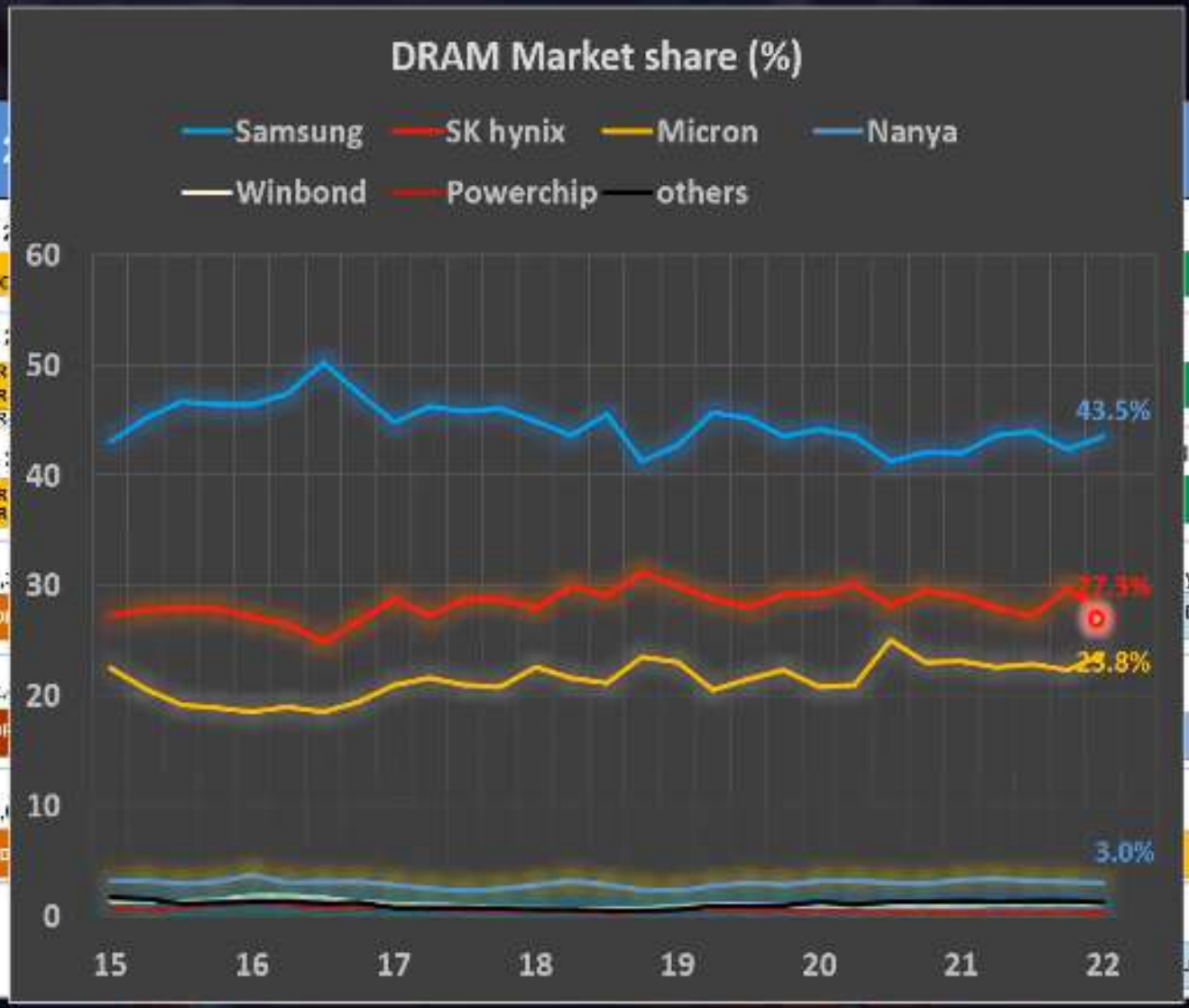
SK hynix Dedicated to Memory. Acquire Intel's Flash → Solidigm
100 B USD$ to build Yongin Semiconductor cluster

Global memory company: DRAM Roadmap

Manufacturers	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2029~
SAMSUNG	2x, 2y (nm) DDR3/LP3 DDR4/LP3/LP4/LPX/GDDR5/GBM2		1x DDR4/LP4X/GDDR6	1y DDR4/LPDDR4/ 4X/LP5/HBM3/GDDR6X		1z DDR5/LPDDR6/6X/GDDR7		1a DDR5/LPDDR5X /GDDR7X	1b	1c	3D DRAM
Micron	3x, 2x, 2y (nm) DDR3/DDR4/LP3/HMC1/HMC2/S DDR3/DDR4/LP3/LP4 DDR4/LP/GDDR5/GDDR6X/GDDR6		1x, 1xs DDR4/LPDDR4/GDDR6X	1y DDR4/LPDDR4	1z DDR4/DDR5/LPDDR5		1α DDR6 /LPDDR5		1β	1γ	
SK hynix	3x, 2x (nm) DDR3/ DDR4/LP4/HBM1	2y, 2z DDR4/LP4/LP4X/GDDR5/HBM2		1x DDR4/LP4/LP4X /HBM2E/GDDR6	1y DDR4/DDR6/LPDDR4 /LPDDR5/5X/GDDR6X	1z DDR5/LPDDR5 LPDDR5X		1α DDR6/LPDDR5X/GDDR7X		1β	
NANYA	4x,3x (nm) DDR3/DDR4/LP3/LP4			2x DDR3/4/LP3/LP4			1x DDR4/DDR5/LP4		1y DDR4/5/LP5	1z	
winbond	6x,4x (nm) DDR2/DDR3/LP1/LP2		3x DDR3/LP3			25 nm DDR3/DDR4/LP3/LP4/LP4X, Auto			1x DDR4/LP4		
PSMC	65,60,40,30 (nm) DDR/DDR2/DDR3/LPDDR2/LPDDR3							20 nm DDR3/DDR4			
CXMT						22 nm DDR4	1x 1G1(DDR4/LPDDR4/4X)	1y	1G2 (DDR5, LP5)	1z 1G3	

Memory Technology 2021 and Beyond – NAND, DRAM, Emerging and Embedded Memory Technology Trends, Techinsights

Global memory company: DRAM Roadmap



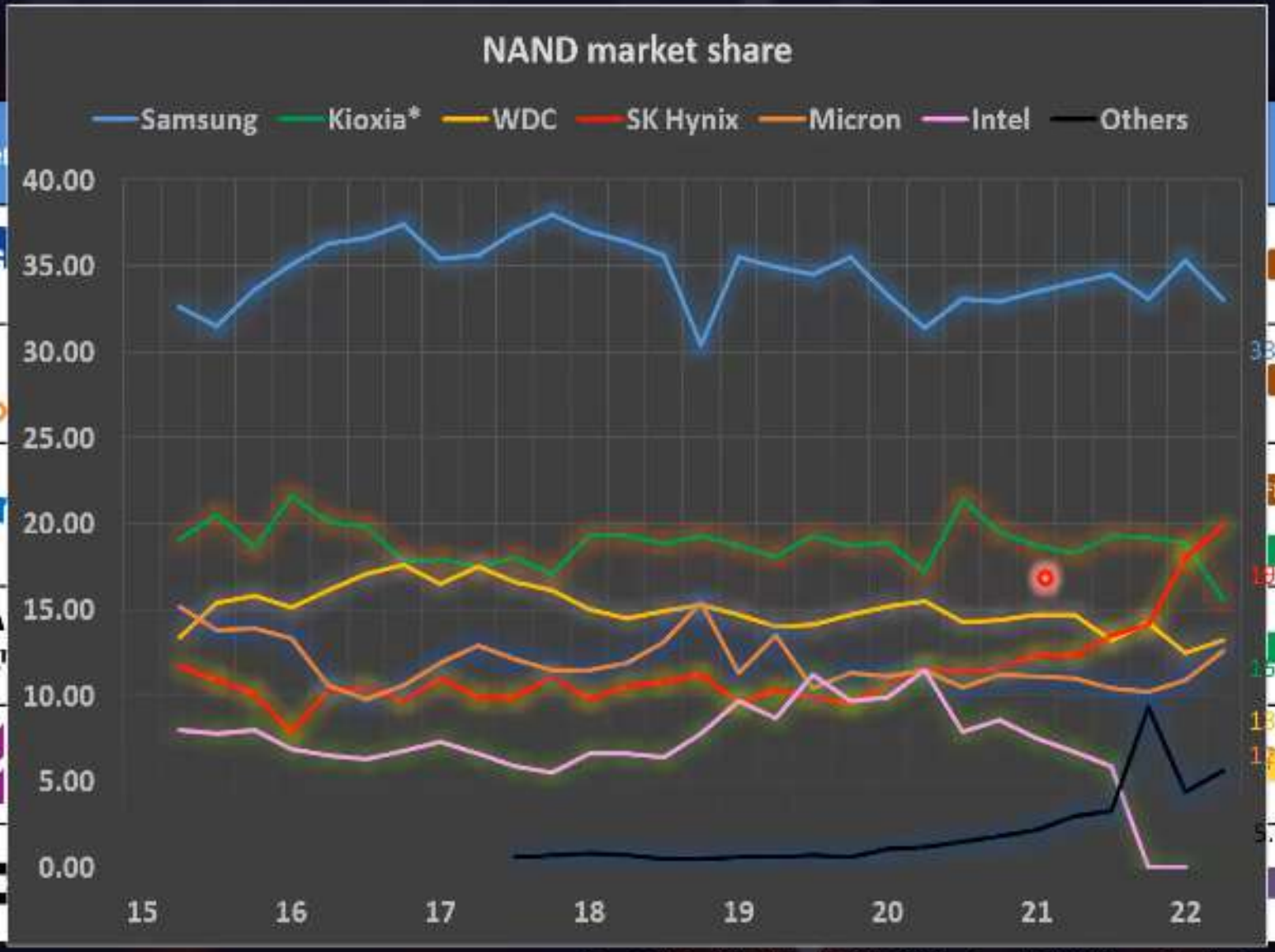
Manu facturers							2024	2029~
SAMSUNG	2x,						1c	3D DRAM
Micron	3x,						1γ	
SK hynix	3x,						1β	
NANYA	4x,						1z	
winbond	6x,							
PSMC	65,							
CXMT							1z	

Memory Technology 2021 and Beyond – NAND, DRAM, Emerging and Embedded Memory Technology Trends, Techinsights

Global memory company: NAND Roadmap

Memory Technology 2020 and Beyond – NAND, DRAM, Emerging and Embedded Memory Technology Trends, Techinsights

Global memory company: NAND Roadmap



Manufacture

2024

3xxL(V9)
3-decks, COP

(V9_4D)
4D NAND PUC

4xxL
Micron (CTF)

3xxL
4-decks

2xxL (Gen.5)
Xtacking 4.0

5.6%

Memory Technology 2020 and Beyond – NAND, DRAM, Emerging and Embedded Memory Technology Trends, Techinsights

4D NAND Flash Memory

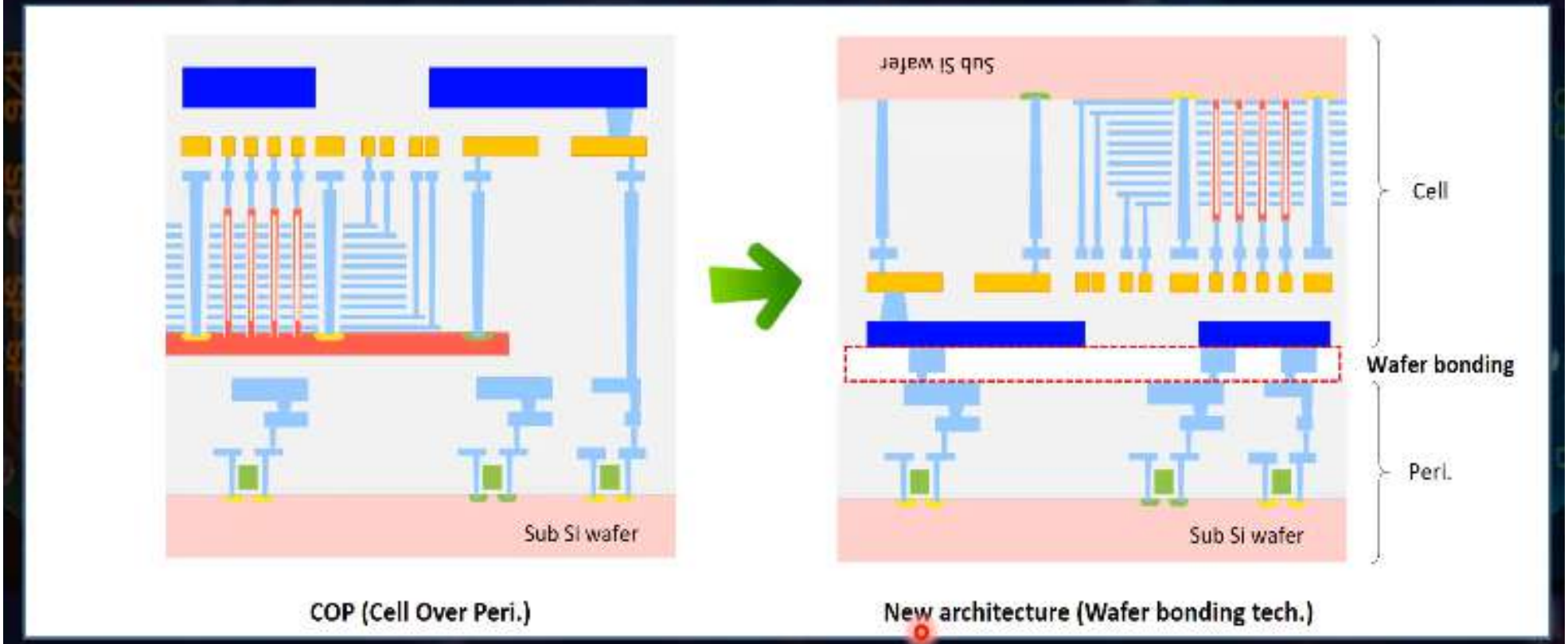
TLC NAND Process Technology Nodes

Company	Layer Count	Density (Gb/mm^2)	Decks	Planes	Shipping[1]
Micron	128	7.76	2	4	Yes
	176	10.27	2	4	Yes
	232	14.60	2	6	Yes
Samsung[2]	128	6.91	1	4	Yes
	176	8.50	2	4	No
	>200	11.55	2	?	No
SK Hynix	128	8.10	2	4	Yes
	176	10.80	2	4	Yes
	238	14.39	2	4	No
Western Digital / Kioxia	112	7.70	2	4	Yes
	162	10.40	2	4	No
	212	?	2	?	No
YMTC	128	8.48	2	4	Yes
	232	15.20	2	6	Yes
Solidigm[3]	144	12.86	3	4	Yes
	196	?	4	4	No

1. In SSDs currently available or sampling from 3rd party SSD/controller firms.
2. 176-layer and >200-layer density disclosed by Samsung at ISSCC.
3. Solidigm density is with QLC not TLC.

Next generation 4D NAND architecture

- **Separation of Cell array & Peri. manufacture process using wafer bonding technology**

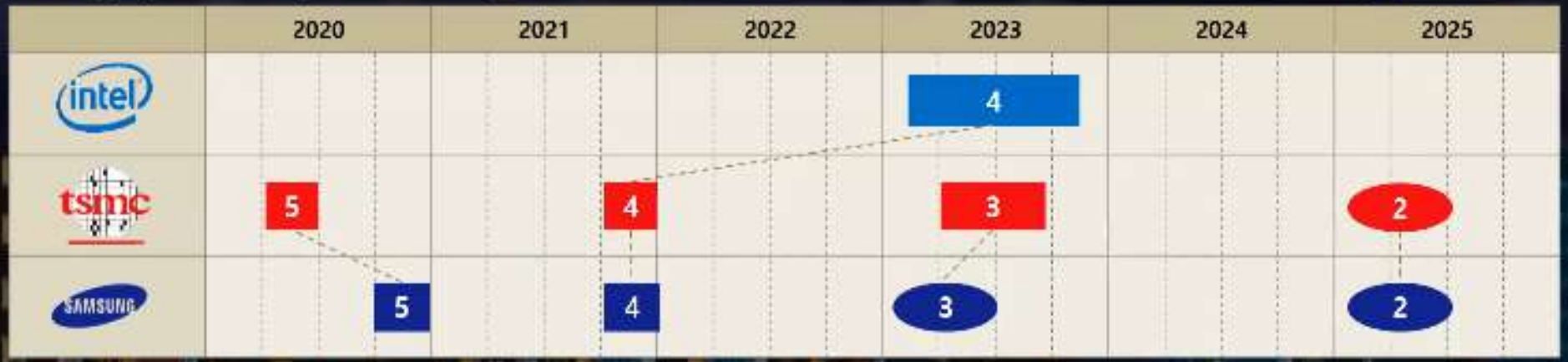


- Enable to use high temperature process (releasing heat budget limitation)
  → Improvement of cell characteristics (reliability and electrical performance)
- Reduce production period (parallel production of cell and peri. wafers)
- *Higher cost by increasing process steps*

Global Foundry Technolgy Roadmap

■ Logic process comparison (mass production)

FinFET GAA

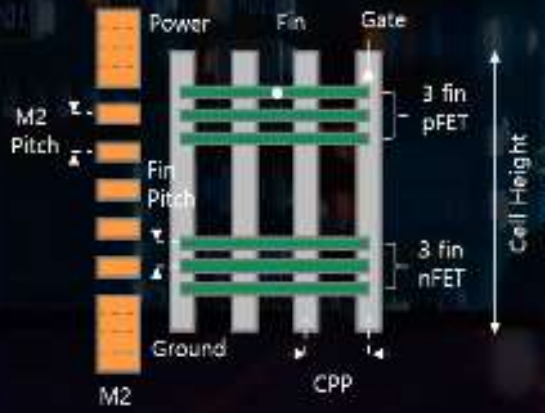


■ Main Logic process comparison

	Samsung	TSMC	Intel	Intel	Samsung	TSMC	TSMC
Node	5 nm		4 nm		3 nm		2 nm
Process Type	FinFET	FinFET	FinFET	FinFET	GAA	FinFET	GAA
CPP (nm) [1]	54	51	50	50	45	45	?
M2P (nm) [2]	36	34	45	45	32	28	?
Tracks [3]	9	9	5.33	9	9	9	?
CH (nm) [4]	324	306	240	405	288	252	?
CPP x CH	17,496	15,606	12,000	20,250	12,960	11,340	?
Mass Product	Q4 2020	Q2 2022	2023		2023	Q2/Q3 2023	H2 2025

** source: IC Knowledge, 삼성증권 반도체 투자 보고서*

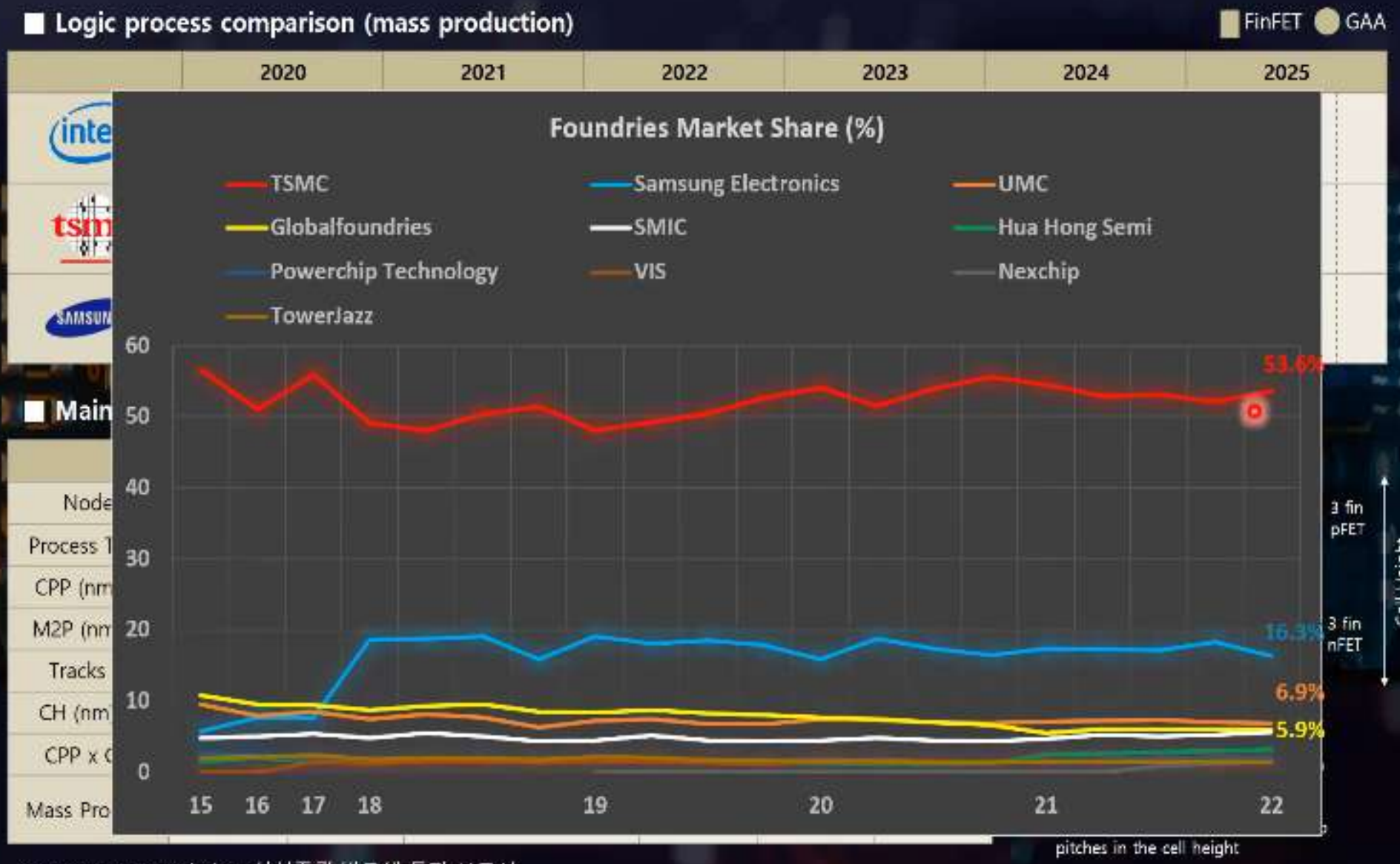
■ 7.5 track logic cell



(1) CPP : Contacted Polysilicon Pitch
(2) M2P : Metal 2 pitch
(3) CH (Cell Height) : M2P x Tracks
(4) Tracks : the number of metal two pitches in the cell height

Global Foundry Technolgy Roadmap

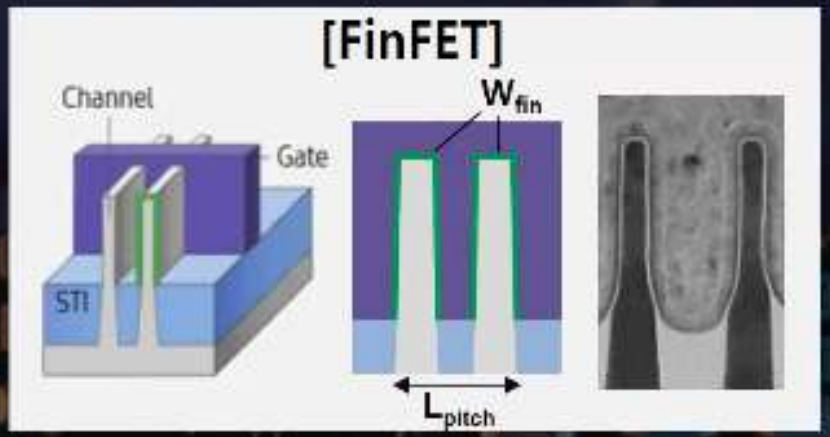
■ Logic process comparison (mass production)

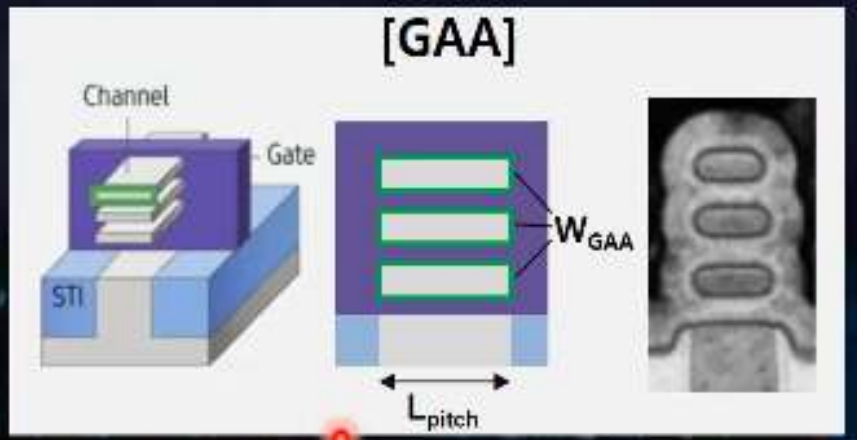


* source: IC Knowledge, 삼성증권 반도체 투자 보고서

FinFET vs GAA (Gate-All-Around)

■ Advantage of GAA

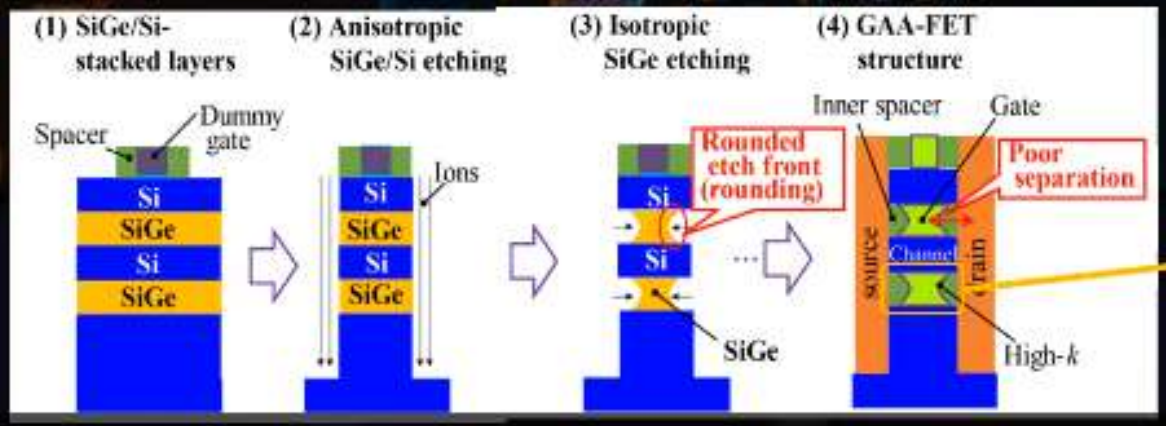


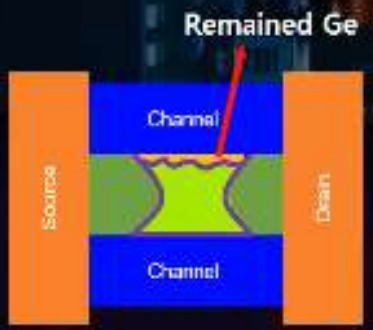


1) GAA has larger channel width relative to FinFET under the same pitch length(L_{pitch}) condition.
2) GAA has flexible control in channel width by changing pitch length(L_{pitch}).

■ Challenge for GAA

※ GAA Process Flow

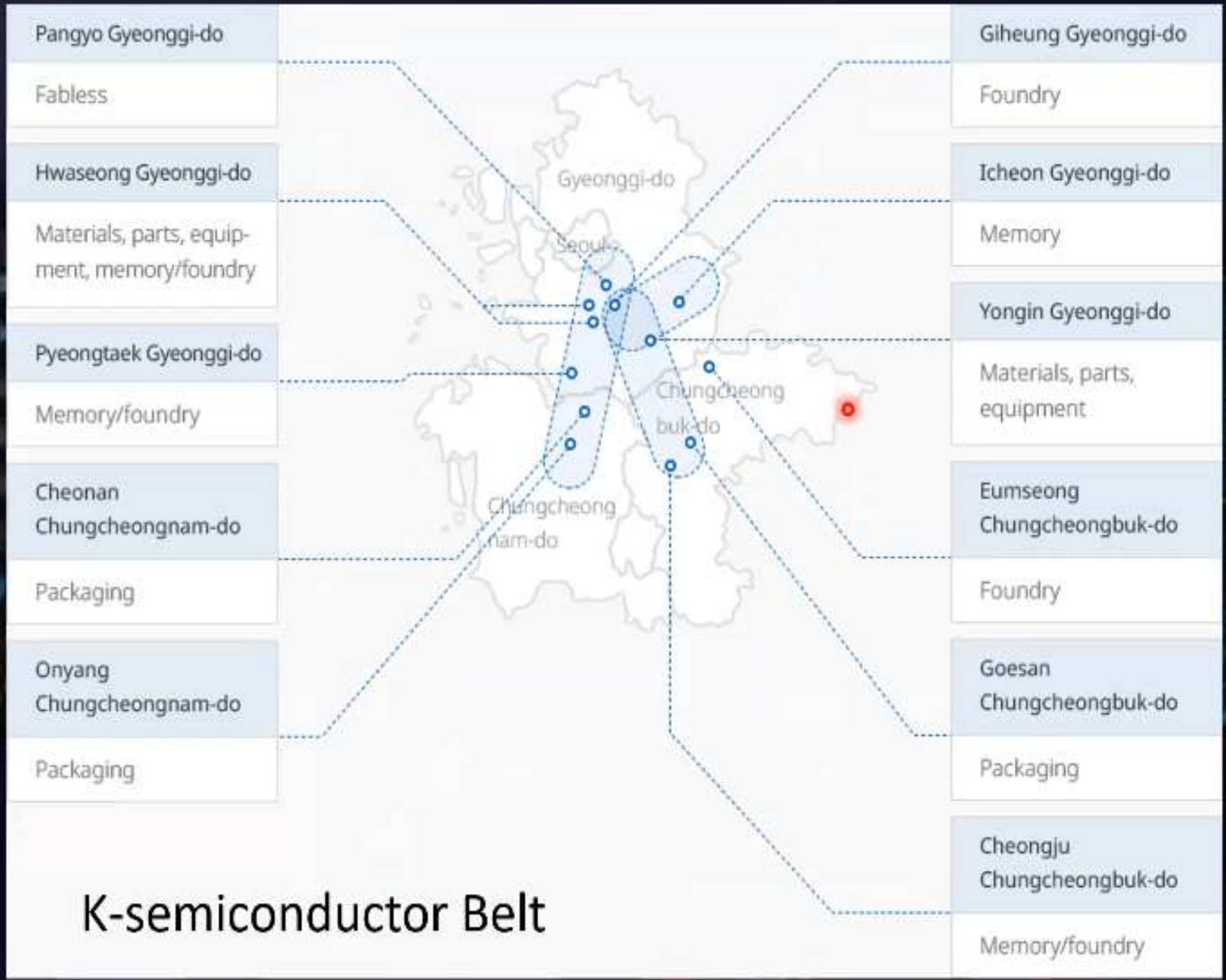




1) Stacking uniform multilayer Si/SiGe is challenging due to lattice mismatch control.
2) Isotropic lateral SiGe etching is also challenging.
   - Rounded etch front can cause poor physical separation between Source/Drain.
   - Remained Ge can degrade uniformity of High-k gate oxide and cause variation of device characteristic.

Source: YU ZHAO, IEEE Journal of the electron devices society, VOLUME 9, 2021


CHIP 4 alliance ?
We have already made the decision!


Pangyo Gyeonggi-do
Fabless
Hwaseong Gyeonggi-do
Materials, parts, equip-ment, memory/foundry
Pyeongtaek Gyeonggi-do
Memory/foundry
Cheonan Chungcheongnam-do
Packaging
Onyang Chungcheongnam-do
Packaging
Giheung Gyeonggi-do
Foundry
Icheon Gyeonggi-do
Memory
Yongin Gyeonggi-do
Materials, parts, equipment
Eumseong Chungcheongbuk-do
Foundry
Goesan Chungcheongbuk-do
Packaging
Cheongju Chungcheongbuk-do
Memory/foundry
Gyeonggi-do
Seoul
Chungcheong buk-do
Chungcheong nam-do
K-semiconductor Belt

G. I. T. E. (Governance, Infra, Technology, Education)

Governance

Inter-ministry control tower

Infra

V-SRF

Virtual Semiconductor Research Facility

Technology

K-SRC

Korea Semiconductor Research Corporation

Education

C-USE

Council for University Semiconductor Education