

ChipSelect Memory On-Site Seminar

Memory Technology Update

- DRAM

Ver. Feb.-2020

Dr. Jeongdong Choe
Senior Technical Fellow

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Session A. DRAM Roadmap/Technology Update

- Summary on DRAM Technology Update
- Comparison: Samsung 2x / 2y / 1x / 1y
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- Comparison: SK Hynix 2y / 2z / 1x / 1y
- DRAM Transistors: Cell TR & Peripheral TR Structure/Materials
- High Band Width Memory DRAM: HBM2, HMC2
- Graphic DRAM Update: GDDR5/5X & GDDR6
- Camera Module Application Update

Summary on DRAM

- ❑ D1y gen. DRAM released (DDR4/LPDDR4/LPDDR4X)
 - ✓ Samsung D1y: cell $0.0023\mu\text{m}^2$ with 0.24 Gb/mm^2 , cell cap. $\sim 10\text{ fF/cell}$ (expected)
 - ✓ Micron D1y: cell $0.0024\mu\text{m}^2$ with 0.21 Gb/mm^2
 - ✓ SK Hynix D1y: cell $0.0023\mu\text{m}^2$ with 0.23 Gb/mm^2 , cell cap. $\sim 7\text{ fF/cell}$ (expected)
 - ✓ B-WL RCAT, Saddle type bulky FinFET, 6F^2 , QPT active patterning, No BL airgap
- ❑ New Process/Design Technology Innovation on D1x/D1y DRAM
 - ✓ New higher-k dielectric materials: NbO added into ZAZ structure
 - ✓ Physically cylindrical capacitor structure, while electrically pillar capacitor
 - ✓ Recess channel for BL S/A TR, while conventional one for BL precharging/equalizing TR
 - ✓ Dual Gate for cell B-WL RCAT
 - ✓ EUV for 1a/1b, HKMG on peri Gate, 4F^2 1T capacitorless DRAM (R&D)
- ❑ Graphic DRAM and High Bandwidth DRAM
 - ✓ Micron GDDR6 D2y (ex. NVIDIA GeForce RTX2080)
 - ✓ Samsung GDDR6 D1x (ex. NVIDIA Quadro RTX5000)
 - ✓ SK Hynix HBM2 (ex. AMD Vega 10XT), Samsung HBM2 (ex. NVIDIA Tesla P100)
 - ✓ Micron HMC2 with D3x tech node, Controller die fabbed from GF (32nm SOI, IBM markings)
- ❑ Triple Die structure for Camera Module
 - ✓ Sony IMX400/IMX345 with CIS-DRAM-ISP stack (Micron_Elpida D3x, ex. Xperia XZs phone)
 - ✓ Samsung S5K2L3SX & S5K2L4SX with CIS-ISP-DRAM stack (Samsung D2y, ex. Galaxy phone)

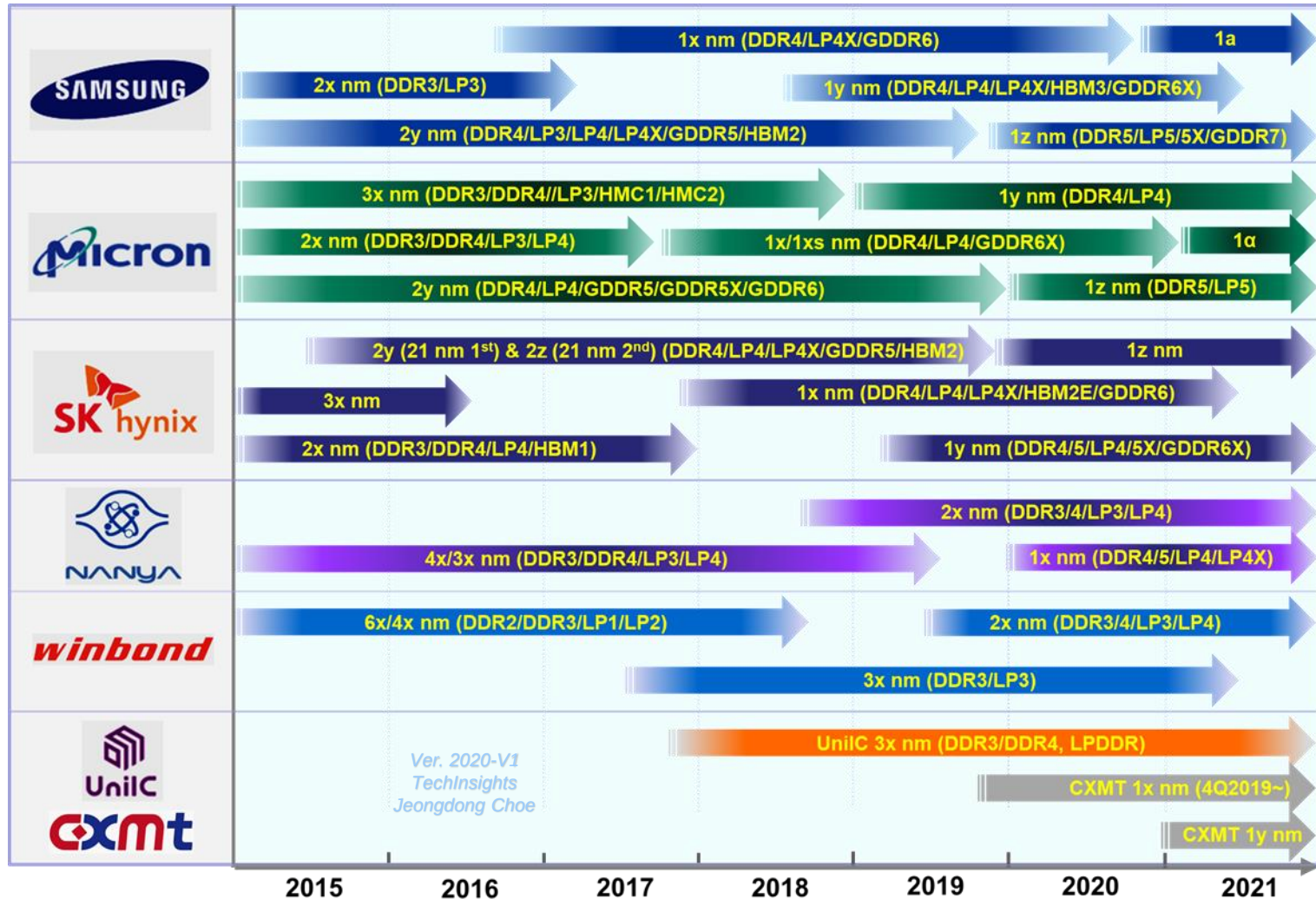
DRAM Memory Analysis Reports released in 2019 (-Feb. 2020)

Die Design & Cost	Structure & Materials	Process Flow		Core/Periphery Design & Circuit	Transistor Characteristics	Circuit (Full)
MFR	AME	PFA	PFF	MDP	TCR	CAR
SK Hynix D1x LP4X 6Gb	SK Hynix D1x	SK Hynix D1x	SK Hynix D1x	Micron D1x DDR4	Micron D1xs DDR4	Micron D1x DDR4
SK Hynix D1x LP4X 8Gb	Samsung D1y	Samsung D1y		SK Hynix D1x LP4X	SK Hynix D1x DDR4	Micron D1x LP4
SK Hynix HBM2 8Gb	Micron D1y			Micron D1y DDR4	SK Hynix D1x LP4X	Samsung D1y DDR4
SK Hynix D1x DDR4 8Gb	SK Hynix D1y			Micron D1y LP4	Samsung D1x LP4X	
Samsung D1y LP4X 8Gb				Samsung D1y DDR4	Samsung D1y LP4X	
Samsung D1y DDR4 8Gb						
Samsung GDDR6 4Gb						
Samsung GDDR6 8Gb						
SK Hynix D1x DDR4 16Gb						
Micron D1x LP4 6Gb						
Micron D1y DDR4 8Gb						
Nanya 20nm DDR4 8Gb						
Micron D1y DDR4 16Gb						
Micron RLDRAM 3 rd gen.						
SK Hynix D1y DDR4 8Gb						

- * MFR: Memory die Functional/Floor plan & cost analysis Report
- * AME: Advanced Memory Essential (Structure & Materials) analysis
- * PFA: Process Flow Analysis report (excel sheet)
- * PFF: Process Flow Full report (3D emulation)
- * MDP: Memory Design on memory core/periphery (layouts, design, circuit)
- * TCR: Transistor Characteristics analysis Report
- * CAR: Circuit Analysis Report

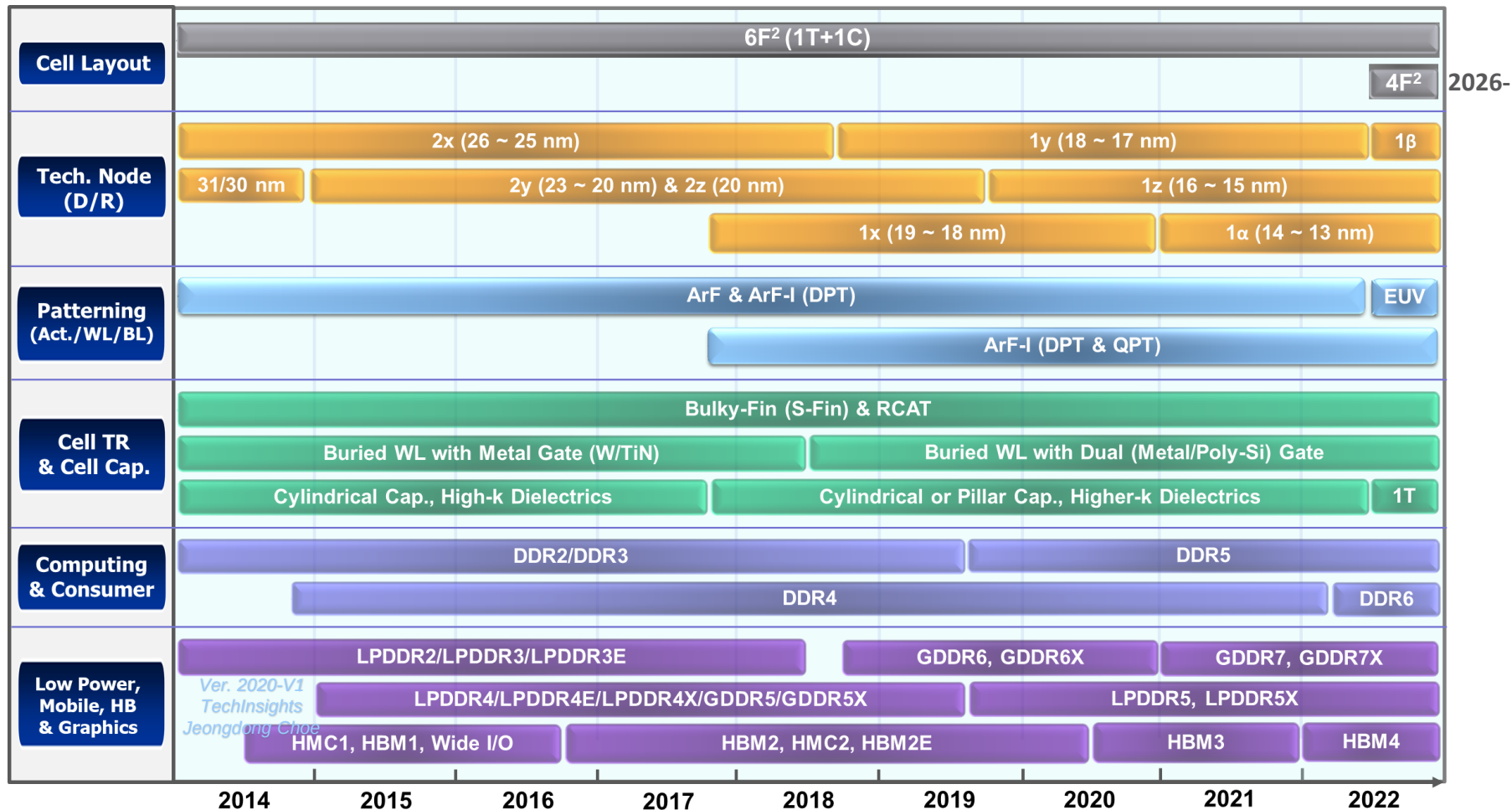
DRAM Roadmap: Technology Node (MP)

* Micron 1xs: Die shrink-ver. of 1x



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DRAM Roadmap: Technology Node (MP)



Mobile DRAM Components: History

□ Apple iPhone vs. Samsung Galaxy

	5	5C, 5S	6, 6+	6S, 6S+	SE, 7, 7+	8, 8+, X	XR, XS/XS Max	11, 11Pro, Max
	• LPDDR2 • 512 MB/die • Elpida • SK Hynix	• LPDDR2, 3 • 512 MB/die • SK Hynix • Micron	• LPDDR3, 4 • 512 MB/die • Samsung • SK Hynix • Micron	• LPDDR4 • 512 MB/die • Samsung	• LPDDR4 • 512 MB/die • 768 MB/die • 1 GB/die • Samsung • SK Hynix	• LPDDR4 • 512 MB/die • 768 MB/die • SK Hynix • Micron • Samsung	• LPDDR4X • 1 GB/die 3 GB (XR) 4 GB (XS/XS Max) • Micron • SK Hynix • Samsung	• LPDDR4X • 1 GB/die - All 4GB • SK Hynix (1x) • Samsung (1y)
	S3, Note 2	S4, Note 3	S5, Note 4	S6, Note 5	S7, S7 E, Note 7	S8, S8+, Note 8	S9, S9+	S10E, S10, S10+
	• LPDDR2 • 512 MB/die • Samsung	• LPDDR2, 3 • 512 MB/die • Samsung	• LPDDR3 • 512 MB/die • 768 MB/die • Samsung	• LPDDR4 • 384 MB/die • 512 MB/die • Samsung	• LPDDR4 • 512 MB/die • 1 GB/die • SK Hynix • Samsung	• LPDDR4X • 1 GB/die • Samsung	• LPDDR4X • 1 GB/die 4 GB/PKG(S9) 6 GB/PKG(S9+) • Samsung	• LPDDR4X • 1 GB/die 8 GB/PKG 12 GB/PKG(S10+) 12 dies/PKG • Samsung
	2012	2013	2014	2015	2016	2017	2018	2019

DRAM Components: iPhone X & 11 Series

Items	iPhone X	iPhone XS, XS Max
Device Model	A1901	A1920, A1921
RAM (Main Board)	3 GB LPDDR4 in A11 PoP PKG	4 GB LPDDR4 in A12 PoP PKG
RAM Details	SK Hynix H9HKNNNDBMAUUR-NEH 4 Dice/PKG H54M6D63M, 21nm_2 nd 6 Gb/die, 0.153 Gb/mm ²	Micron Technology MT53D512M64D4SB-046 4 Dice/PKG 211N 2017, 1X nm 8 Gb/die, 0.152 Gb/mm ²



iPhone 11

SK Hynix 8Gb 1x LP4X Die (US)
Samsung 8Gb 1y LP4X Die (China)



iPhone 11 Pro

SK Hynix 8Gb 1x LP4X Die (US)
Samsung 8Gb 1y LP4X Die (China)



iPhone 11 ProMax

Samsung 8Gb 1y LP4X Die (US)

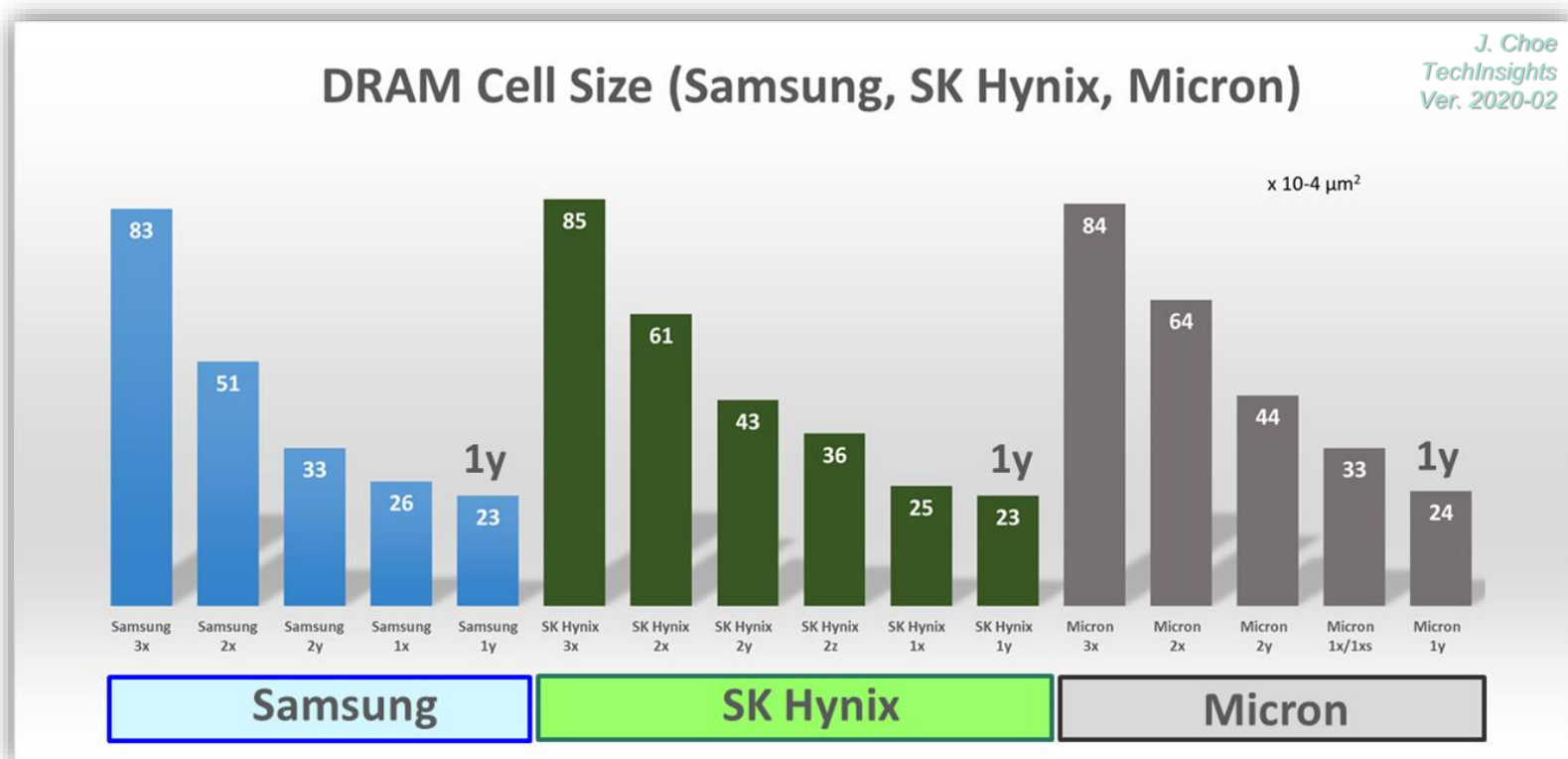
Samsung Galaxy S10/S10+ DRAM Components

Products	S10E (Light)	S10	S10+	S10 5G
Model	SM-G970	SM-G973	SM-G975	SM-G977
Sub-Model	970U, 970F, 970N, 970O, 970W, 9708, 970X	973U, <u>973F</u> , <u>973F/DS</u> , 973N, 9730, 973W, 9738, 973X	975U, <u>975F</u> , <u>975N</u> , 9750, 975W, 9758, 975X, <u>975F/DS</u>	977U, 977F, <u>977N</u> , 977O
NAND Storage	128GB, 256GB	128GB, 256GB	128GB (975F/DS), 512GB (975F), 1TB (975N)	256GB
NAND Components	KLUDG4U1EA	KLUDG4U1EA-B0C1	975N: KLUGGAR1FA-B2C1 (KR) 975F: KLUGG8R1EM-B0C1 (US) 975F/DS: KLUDG4U1EA-B0C1	977N: KLUEG8U1EA-B0C1 (KR)
NAND Die Markings	K9AEGD8H0A	K9AEGD8H0A	975N: K9AHGD8J0A 975F: K9AHGD8J0M 975F/DS: K9AFGD8H0A	977N: K9AFGD8H0A
NAND Die Information	4 Dies+1 Cont./PKG 64L V-NAND 256Gb Die	4 Dies+1 Cont./PKG 64L V-NAND 256Gb Die	975N: 92L V-NAND 512Gb Die 975F: 64L V-NAND 512Gb Die 975F/DS: 64L V-NAND 256Gb Die	64L V-NAND 256Gb Die
Memory DRAM	8GB (6GB)	8GB	12GB (975N), 8GB (975F, F/DS)	8GB
DRAM Components	K3UH6H60BMAGCL	K3UH7H70AMAGCL	975N: K3UHAHA0AMAGCL 975F/DS: K3UH7H70AMAGCL	K3UH7H70AMAGCL
DRAM Details	64 Gb / PKG Samsung 1y LPDDR4X 8Gb Die	64 Gb / PKG Samsung 1y LPDDR4X 8Gb Die	64 Gb or 96 Gb / PKG Samsung 1y LPDDR4X 8Gb Die	64 Gb / PKG Samsung 1y LPDDR4X 8Gb Die

Samsung Galaxy S10+ (SM-G975) DRAM Components

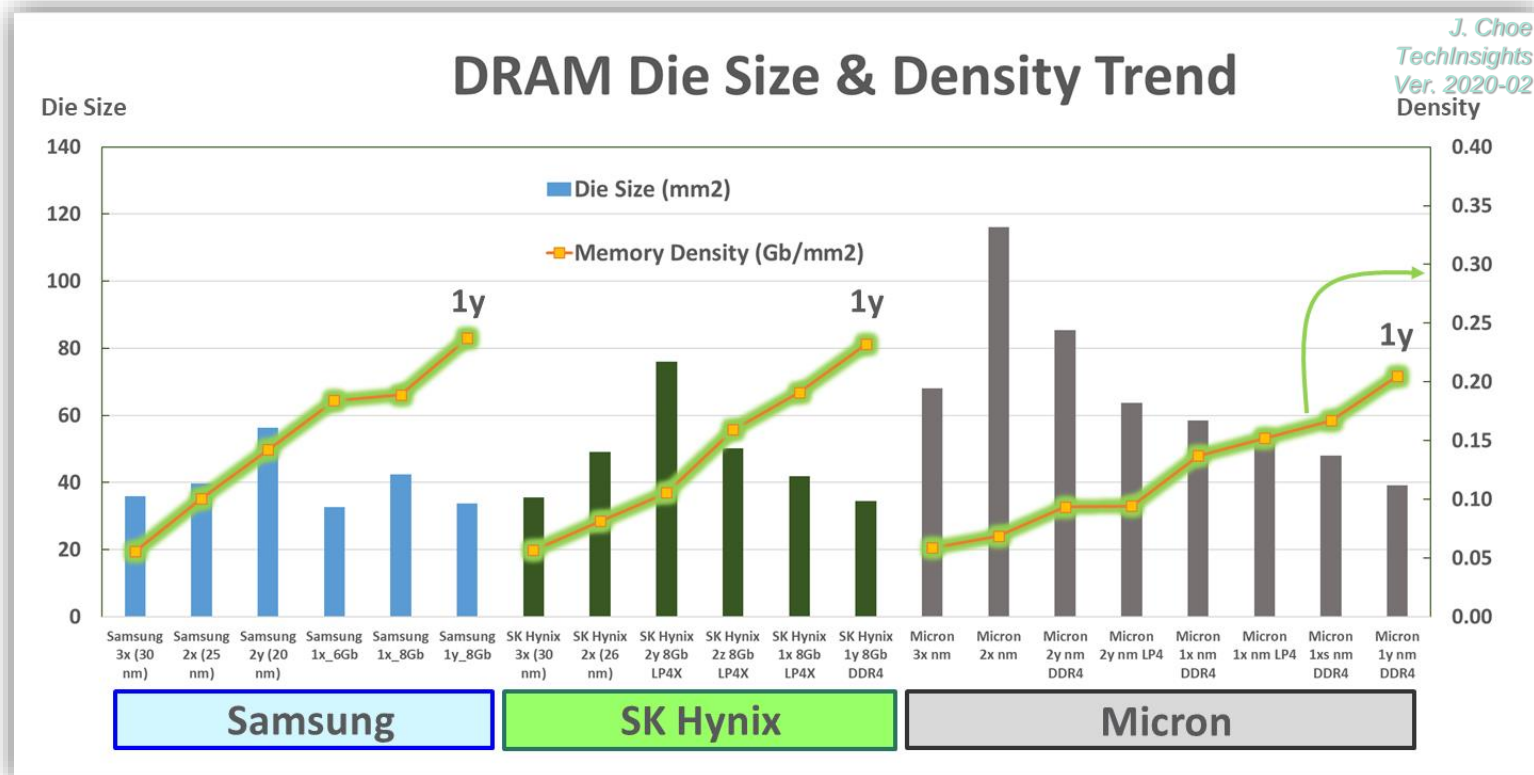
Products Model	S10+ SM-G975NCWFKOO	S10+ SM-G975F/DS	S10+ SM-G975FCKGDBT
Sales Location	Korea	US	US
NAND Storage	1 TB	128 GB	512 GB
NAND Components	KLUGGAR1FA-B2C1	KLUDG4U1EA-B0C1	KLUGG8R1EM-B0C1
NAND Die Markings	K9AHGD8J0A	K9AFGD8H0A	K9AHGD8J0M
NAND Die Details	16 Dies+1 Cont./PKG 92L V-NAND 512Gb Die	4 Dies+1 Cont./PKG 64L V-NAND 256Gb Die	8 Dies+1 Cont./PKG 64L V-NAND 512Gb Die
(D)RAM	12 GB	8 GB	8 GB
DRAM Components	K3UHAHA0AMAGCL	K3UH7H70AMAGCL	K3UH7H70AMAGCL
DRAM Die Markings	No die markings (SEC)	No die markings (SEC)	No die markings (SEC)
DRAM Details	96 Gb/PKG 12 Dies/PKG Samsung 1y LPDDR4X 8Gb Die	64 Gb/PKG 8 Dies/PKG Samsung 1y LPDDR4X 8Gb Die	64 Gb/PKG 8 Dies/PKG Samsung 1y LPDDR4X 8Gb Die
Others	The same die with Renovo Z5 phone		

DRAM Cell Size: Scaling-down Trend (up to D1y)

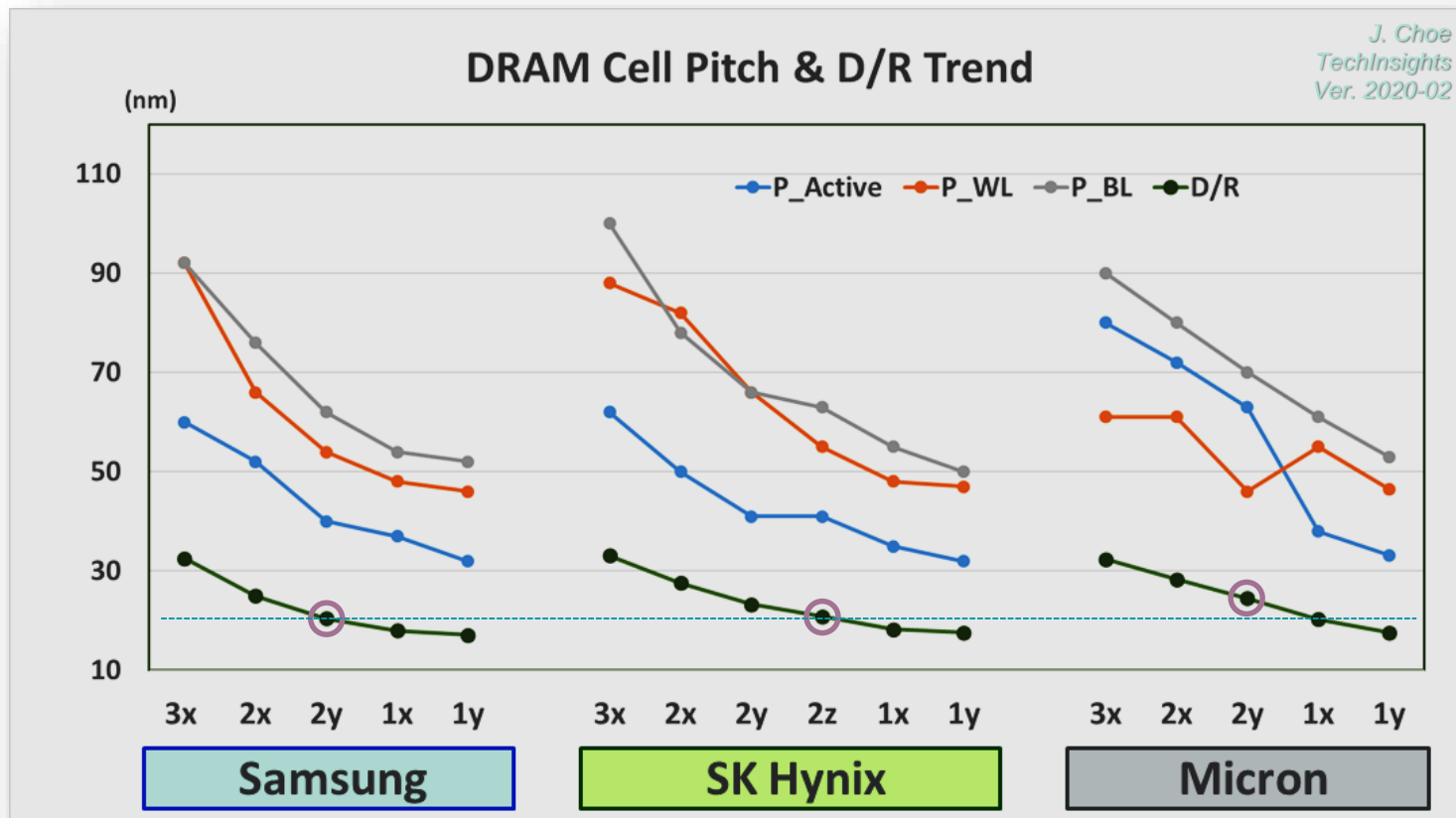


DRAM Die Size & Density Trend (up to D1y)

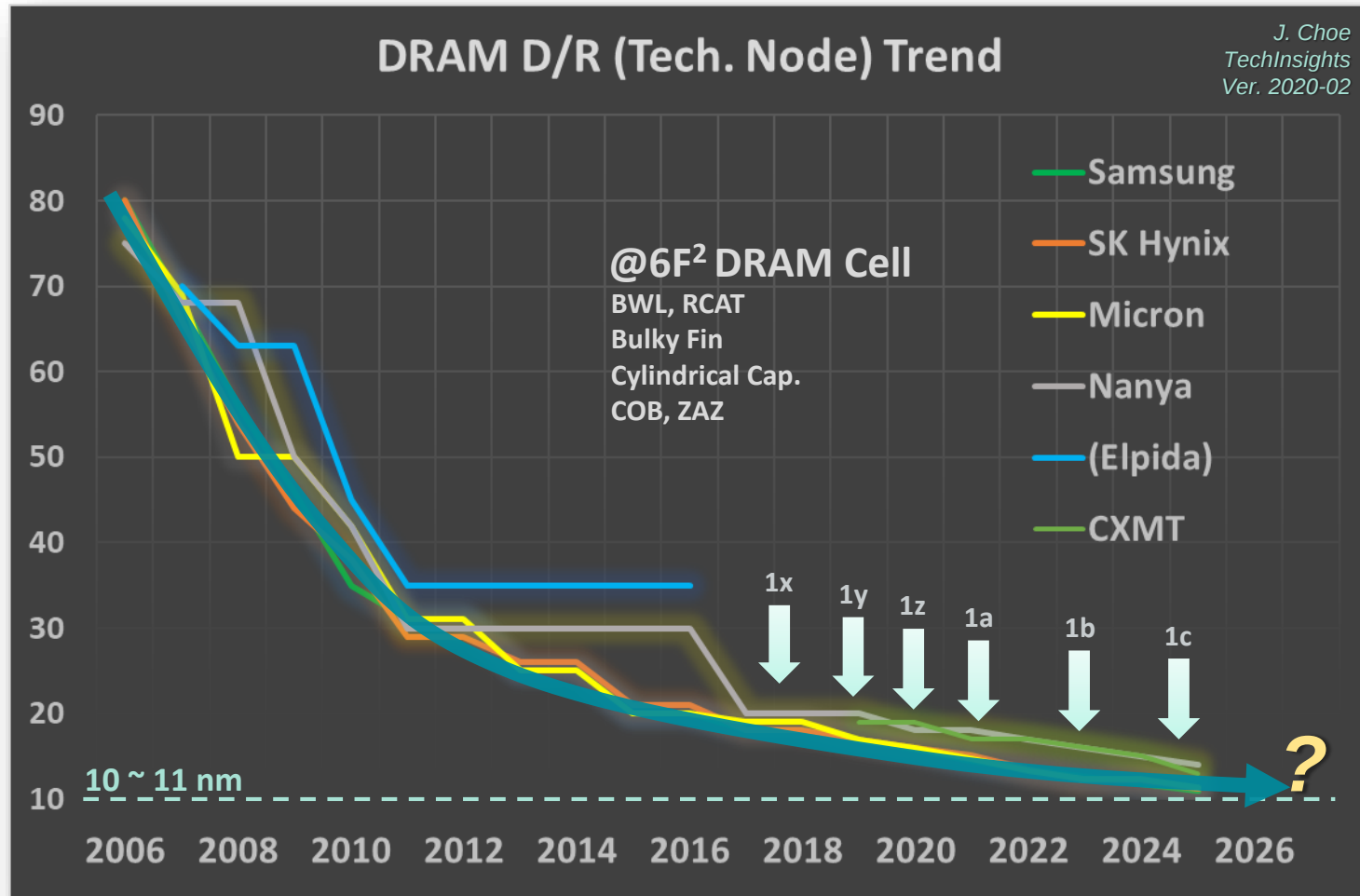
✓ Samsung 1y ~ 0.237 Gb/mm², while Micron 1y ~ 0.205 Gb/mm²



DRAM D/R Trend

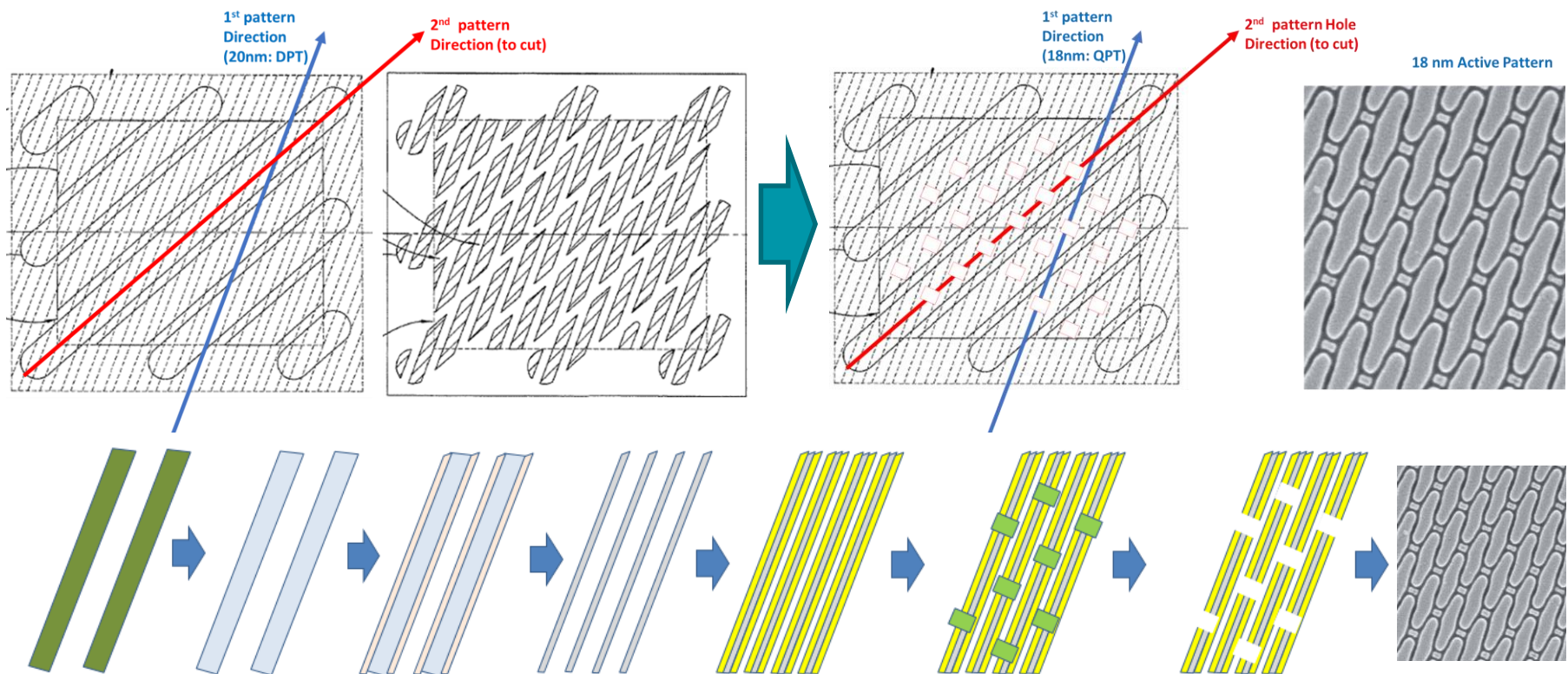


DRAM D/R (Technology Node) Trend



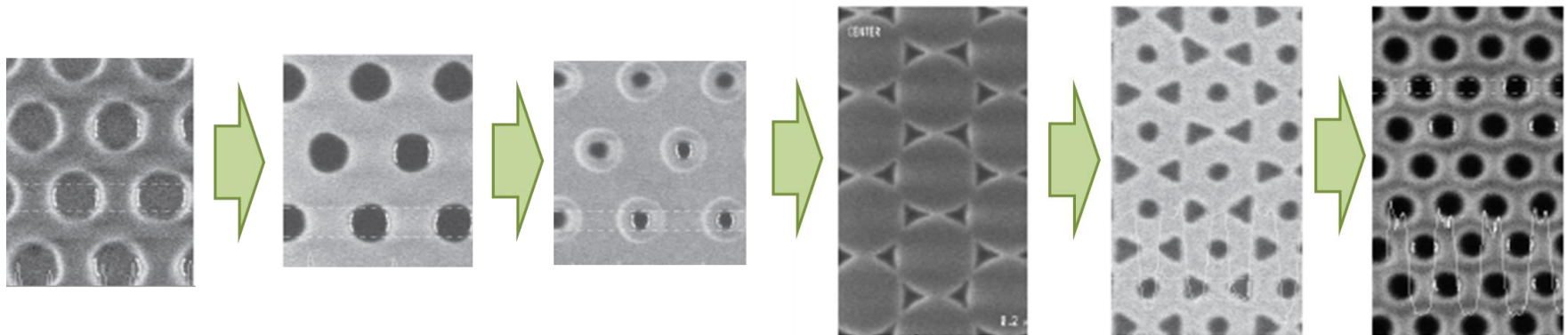
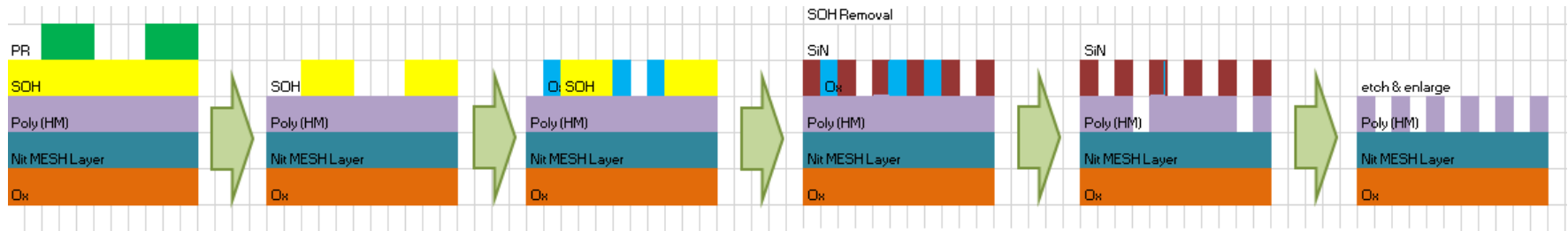
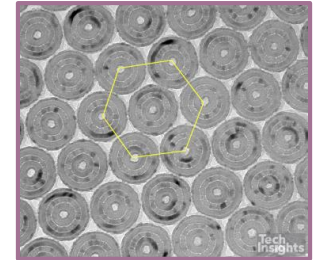
Sub-20nm DRAM Cell Technology: Active Cell Patterning

- ✓ QPT line pattern along a first direction
- ✓ Cutting with hole pattern along a second direction

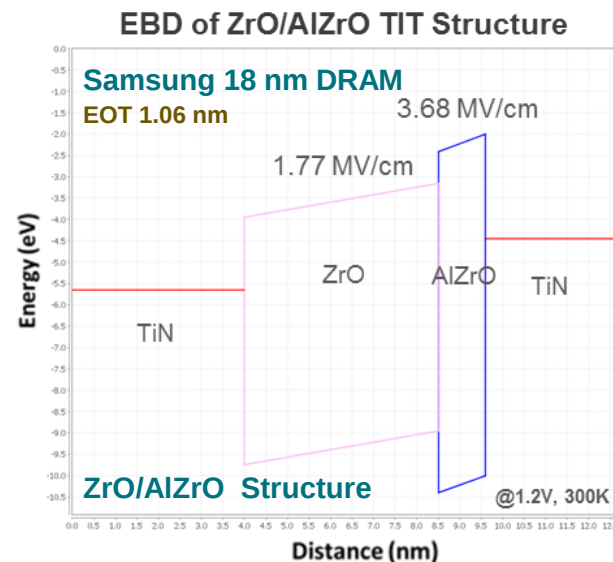
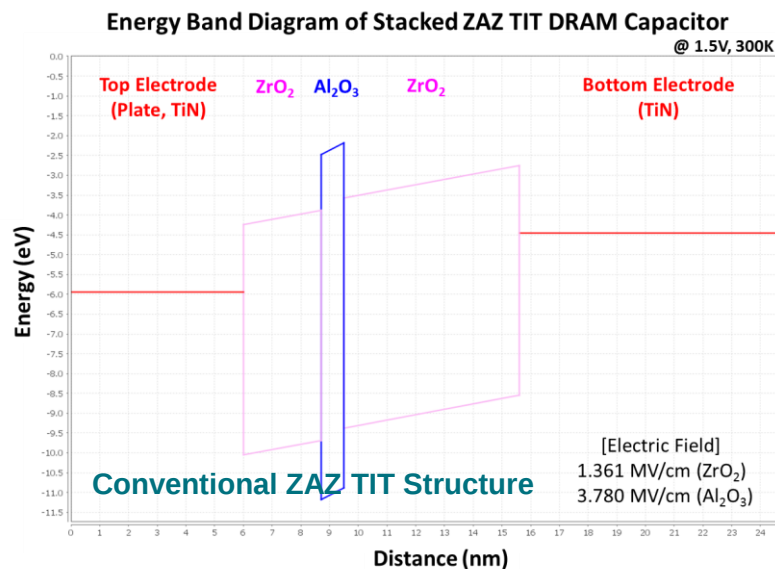


Sub-20nm DRAM Cell Capacitor Patterning

- ✓ Honeycomb Pattern
- ✓ Single photolithography & 2-step spacer deposition used (D2x)
- ✓ 2-step photolithography plus 2 spacers (D2y, D1x, D1y)



DRAM Cell Capacitance

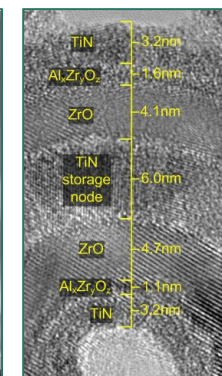
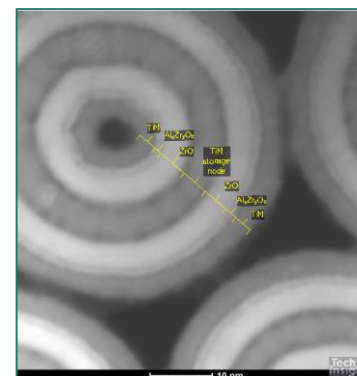


✓ From conventional ZAZ to likely ZrO/AlZrO

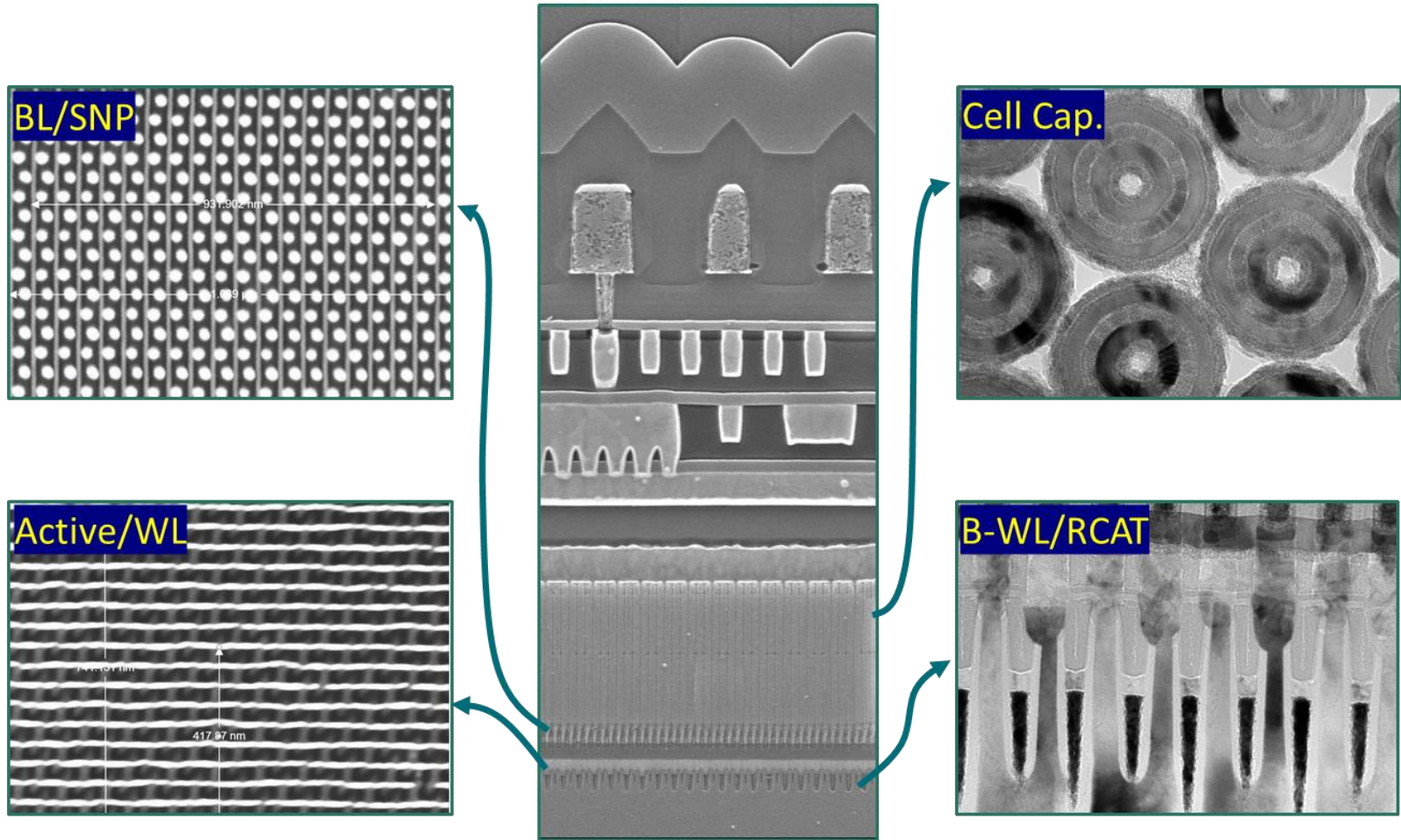
✓ Cell Capacitance (estimated): $C = \frac{\epsilon A}{d}$

2y: 11.8 ~ 13.5 fF/Cell

1x: 10.3 ~ 12.1 fF/Cell

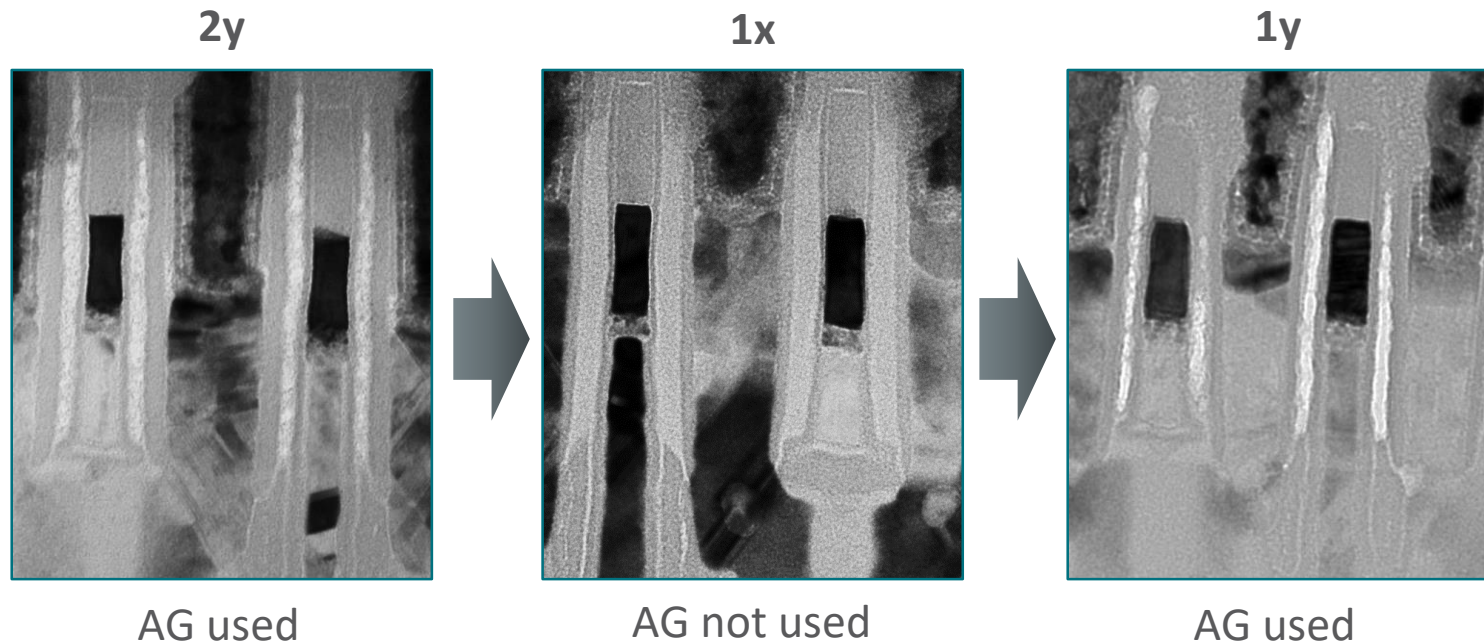


Samsung DRAM Cell Array Process & Structure (ex. D1y)



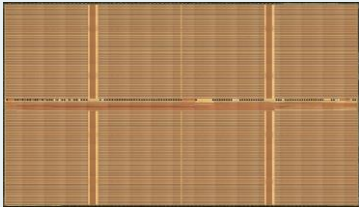
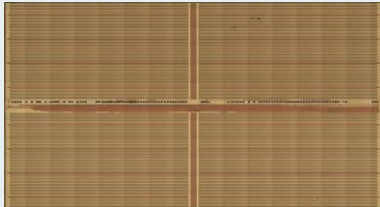
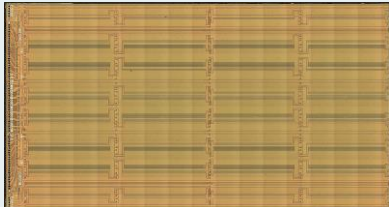
Samsung BL Air-gap Process on DRAM Cell

- ✓ Air-gap spacer used on 2y (20 nm) and 1y (17 nm)



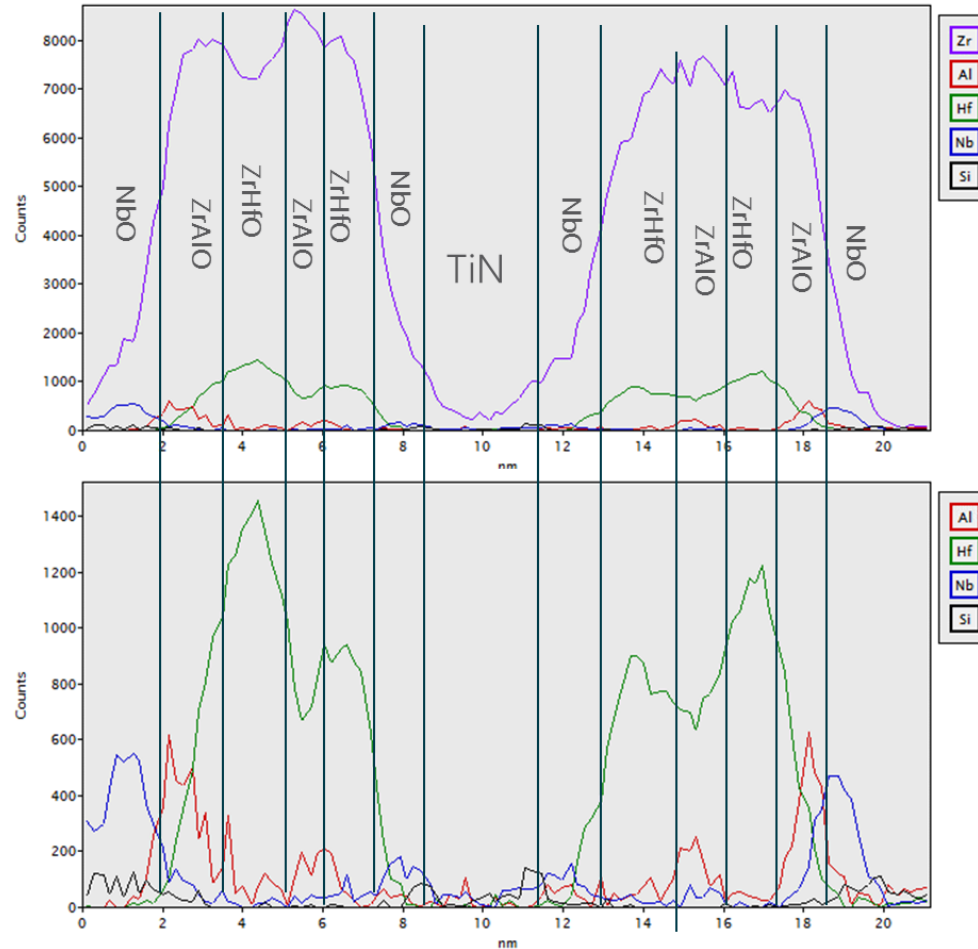
Micron 1x & 1xs DDR4/LPDDR4

's' likely means 'shrink version'

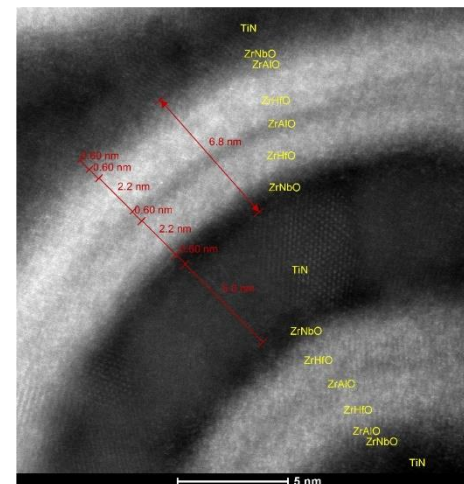
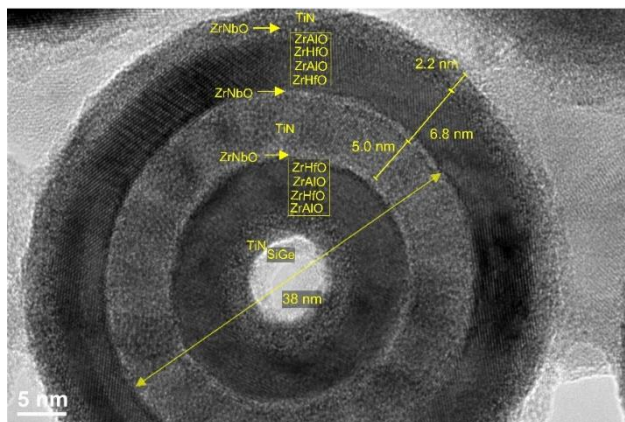
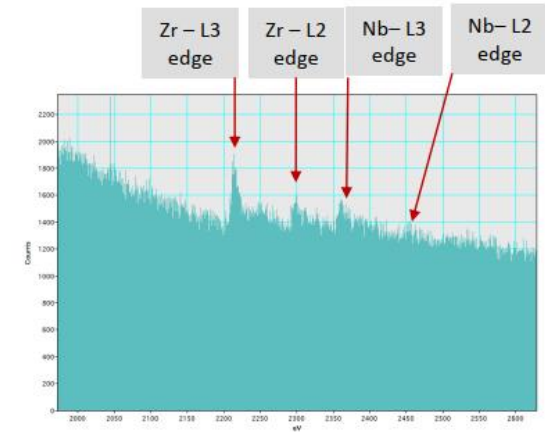
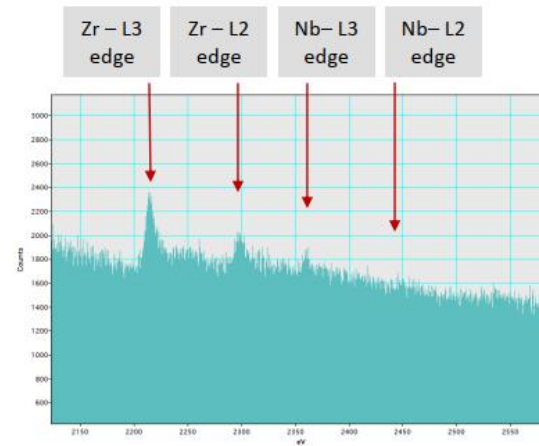
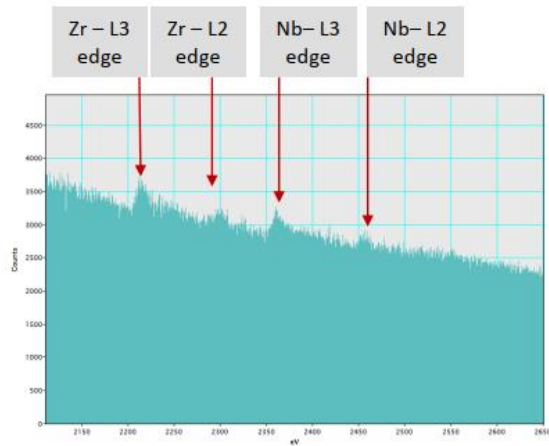
Device	1X DDR4	1XS DDR4	LPDDR4
Parents Products	Micron DIMM MTA8ATF1G64AZ-2G6H1	Micron DIMM MTA8ATF1G64AZ-2G6E1	Huawei Mate 10 HUC-ALP-AL00_PoP
Components	MT40A1G8SA-075:H	MT40A1G8SA-062:E	MT53D512M64D4NZ-053
PKG Markings	7LH75 D9VHP	7VE77 D9WFL	7RD47 D9VQG
Die Markings	Z11C	Z11B	Z11M
Memory Density	8 Gb / Die	8 Gb / Die	8 Gb / Die
Die Size (Seal Die: L x W)	58.48 mm ² (10.1 mm x 5.79 mm)	48.03 mm ² (9.38 mm x 5.12 mm)	52.77 mm ² (9.92 mm x 5.32 mm)
Bit Density	0.137 Gb/mm ²	0.167 Gb/mm ²	0.152 Gb/mm ²
Die Photograph			

Micron Capacitor Dielectrics (D1x)

4th Analysis (Advanced TEM Tool used)



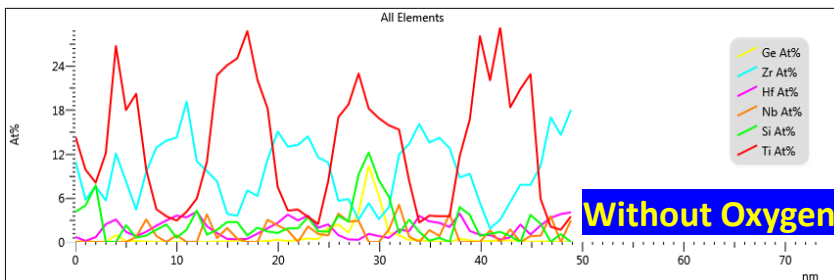
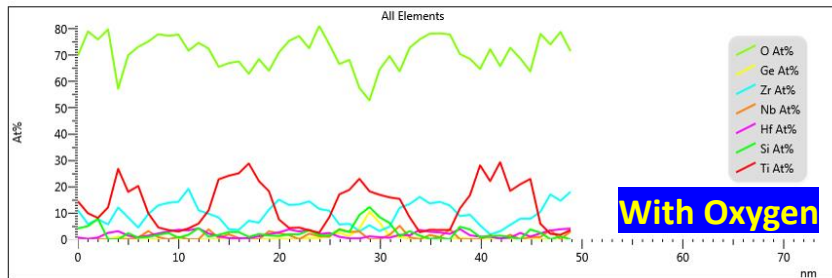
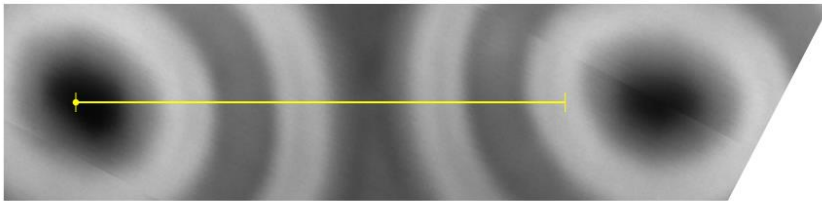
Micron Capacitor Dielectrics (D1x)



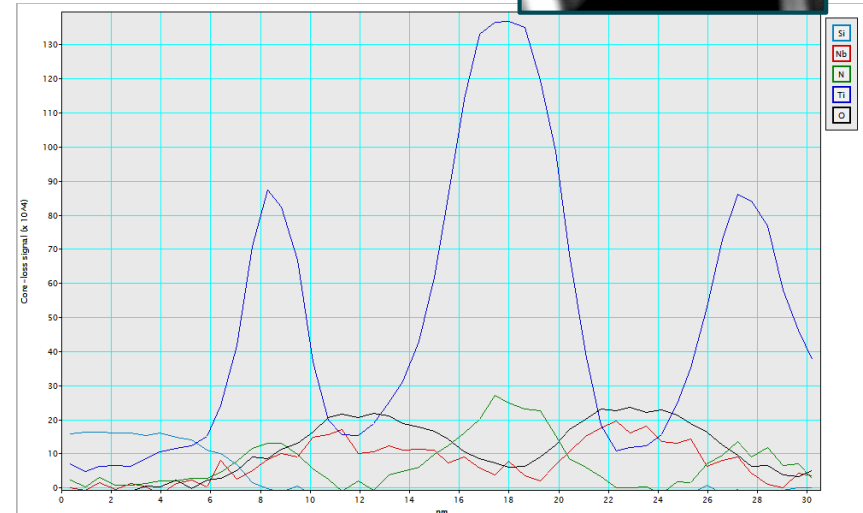
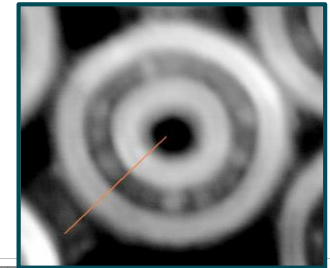
Micron D1y DRAM Cell Capacitor: Materials

- ✓ NbO, HfO and ZrO used for high-k capacitor dielectrics

EDX Analysis



EELS Analysis



Micron 1y nm DDR4

Device	1x DDR4	1xs DDR4	1y DDR4
Components	MT40A1G8SA-075:H	MT40A1G8SA-062:E	MT40A2G4SA-062:J
PKG Markings	7LH75 D9VHP	7VE77 D9WFL	9DJ45 D9WSL
Die Markings	Z11C	Z11B	Z21C
Memory Density	8 Gb / Die	8 Gb / Die	8 Gb / Die
Die Size (Seal Die: L x W)	58.48 mm ² (10.1 mm x 5.79 mm)	48.03 mm ² (9.38 mm x 5.12 mm)	39.11 mm ² (8.52 mm x 4.59 mm)
Bit Density	0.137 Gb/mm ²	0.167 Gb/mm ²	0.205 Gb/mm ²
Pitch (Act/WL/BL)	38 nm / 53 nm / 62 nm	38 nm / 53 nm / 62 nm	33 nm / 46.5 nm / 53 nm
Cell Size	0.0033 μm ²	0.0033 μm ²	0.0025 μm ²

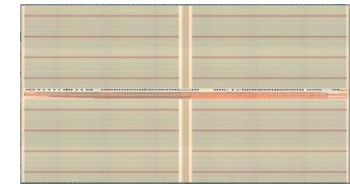
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23% ↑

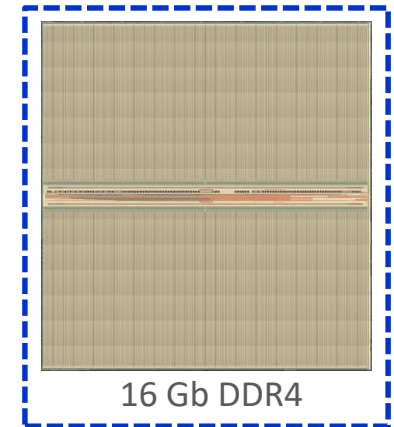
24% ↓

Micron 1y DDR4: 16 Gb die just released

ITEMS	1y DDR4 (8 Gb Die)	1y DDR4 (16 Gb Die)
Memory / Die	8 Gb	16 Gb
Die Markings	Z21C	Z22A
Die Size	39.11 mm ² (8.52 mm x 4.59 mm)	81.52 mm ² (8.59 mm x 9.49 mm)
Bit Density	0.205 Gb/mm ²	0.196 Gb/mm ²
Active Pitch	33 nm	33 nm
WL Pitch	46 nm	46 nm
BL Pitch	53 nm	53 nm
Cell Size	0.0024 μm ²	0.0024 μm ²
Cap. Design	Honeycomb	Honeycomb

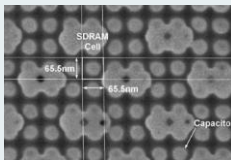
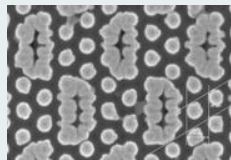


8 Gb DDR4



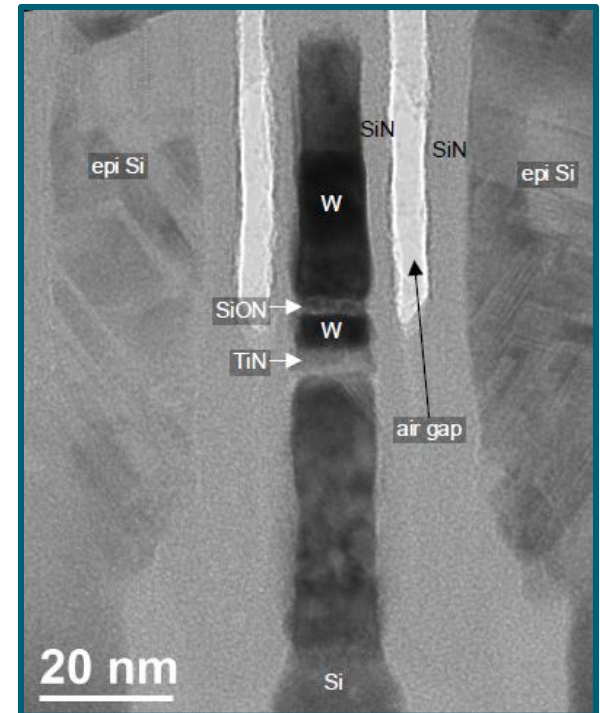
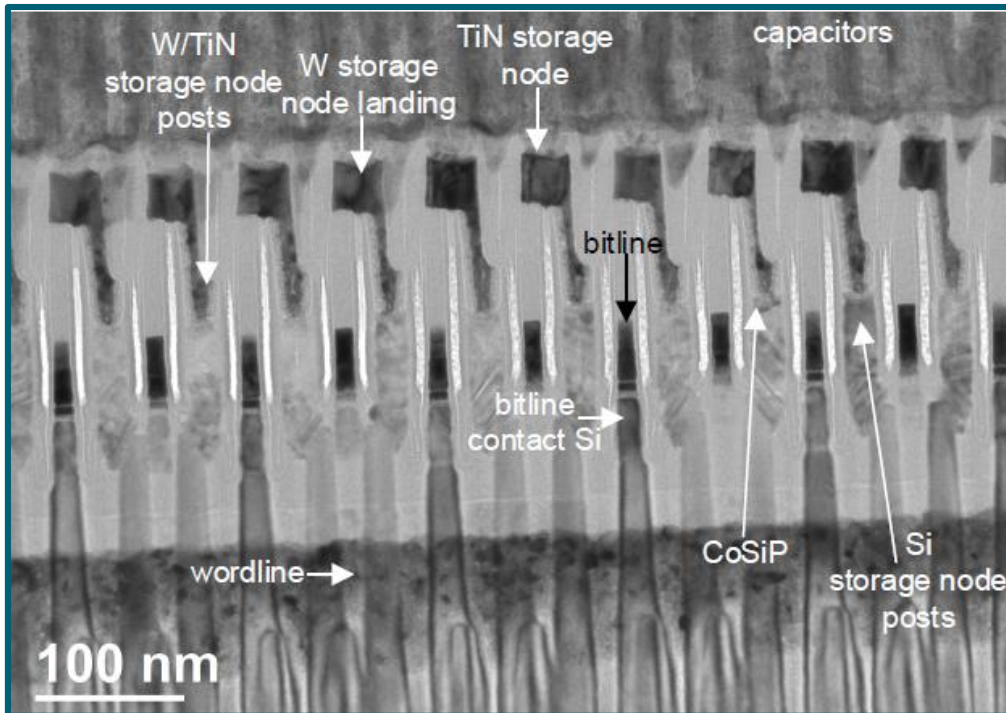
16 Gb DDR4

Comparison: SK Hynix DRAM 2y vs. 2z

Items	21 nm 1 st Gen.	21 nm 2 nd Gen.
Package	H9TQ18ABJTMCP eMCP 16 Gb LPDDR3 + 128 Gb eMMC (2 Dice + 4 Dice)	H5AN8G8NAFR-UHC 8 Gb DDR4 (1 Die)
Die Size	76.0 mm ² (9.50 mm x 8.00 mm)	53.6 mm ² (9.45 mm x 5.67 mm)
Memory/Die (Memory Density)	8 Gb (0.105 Gb/mm ²)	8 Gb (0.149 Gb/mm ²)
Memory Density Increase	-	42 % (from 21 nm 1st Gen.)
Pitch_Measured (Active/WL/BL)	<u>41 nm</u> / 66 nm / 66 nm	<u>41 nm</u> / 55 nm / 63 nm
Cell Size	0.0043 μm ²	0.0036 μm ²
Cell Size Shrink	-	16.3 % ↓
Cap. Design	checker 	honeycomb 

SK Hynix DRAM FEOL: 2z with BL AG

- **Active STI & B-Gate (along WL)**



SK Hynix LPDDR4X: 2z vs. 1x (6 Gb & 8 Gb Die)

ITEMS	21 nm 2 nd Gen. (2Z) LPDDR4_6 Gb	21 nm 2 nd Gen. (2Z) LPDDR4_8 Gb	1X LPDDR4_6 Gb	1X LPDDR4_8 Gb
Application (Examples)	H9HKNNNEBMMU H9HKNNNDBMAU	H9HP52AECMMMD (eMMC BGA)	H9HKNNNEBMBU (Huawei Mate 20)	H9HKNNNCRMMU (iPhone XS A1920)
Memory / Die	6 Gb	8 Gb	6 Gb	8 Gb
Die Size	39.31 mm ² (7.74 mm x 5.08 mm)	50.25 mm ² (9.99 mm x 5.03 mm)	32.52 mm ² (7.04 mm x 4.62 mm)	41.80 mm ² (9.03 mm x 4.62 mm)
Bit Density	0.153 Gb/mm ²	0.159 Gb/mm ²	0.184 Gb/mm ²	0.191 Gb/mm ²
Active Pitch	41 nm	41 nm 15% ↓	35 nm	35 nm
WL Pitch	55 nm	55 nm 15% ↓	47 nm	47 nm
BL Pitch	63 nm	63 nm 14% ↓	54 nm	54 nm
Cell Size	0.0036 μm ²	0.0036 μm ² 30% ↓	0.0025 μm ²	0.0025 μm ²
Cap. Design	Honeycomb	Honeycomb	Honeycomb	Honeycomb

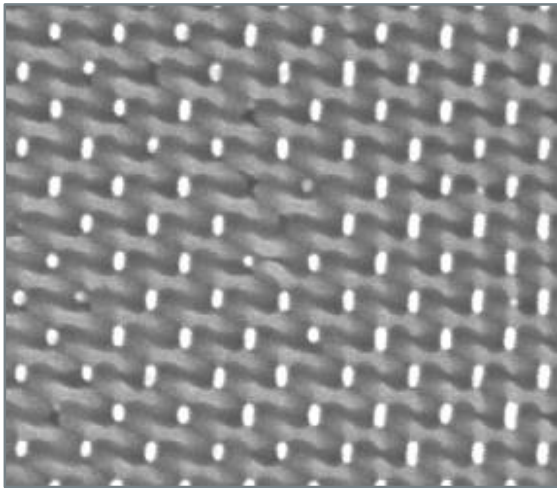
1x nm LP4 Die Design Comparison: Samsung vs. SK Hynix

Items	Area Details	Samsung 1x LPDDR4X die	SK Hynix 1x LPDDR4X die
Parent Product		K3UH6H60AM-AGCJ	H9HKNNNEBMBU-DRNEH
Memory capacity / Die		6 Gb	6 Gb
Die Size (Sealed Area)		32.6 mm ²	33.52 mm ²
Unit Cell Size		0.0026 μm ²	0.0025 μm ²
Area 1	Command, Address, DQ buffer, Voltage generator, I/O, etc.	2.84 mm ² (8.70%)	4.88 mm ² (13.56%)
Area 2	Row/Block Decoder	1.43 mm ² (4.38%)	0.49 mm ² (1.46%)
Area 3	Column Decoder, Data Control, write driver, etc.	1.74 mm ² (5.33%)	0.94 mm ² (2.80%)
Area 4	Memory Cell Array	21.66 mm ² (66.44%)	18.97 mm ² (56.60%)
Area 5	SWD, BL S/A	4.48 mm ² (13.74%)	5.21 mm ² (15.54%)

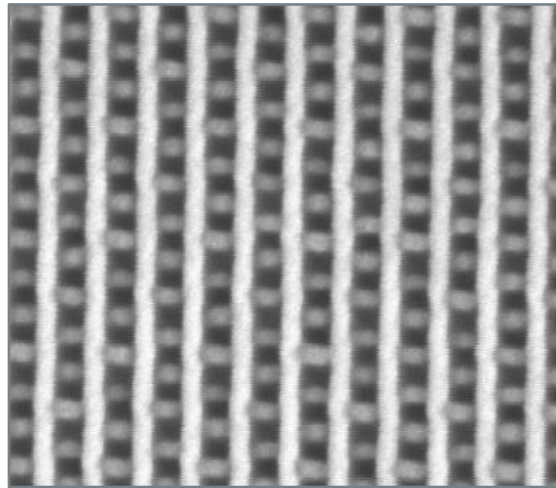
* For more details, please refer to TechInsights' Memory Die Floorplan Analysis Reports (MFR).

SK Hynix 1x DRAM LPDDR4X Cell Array Top Views

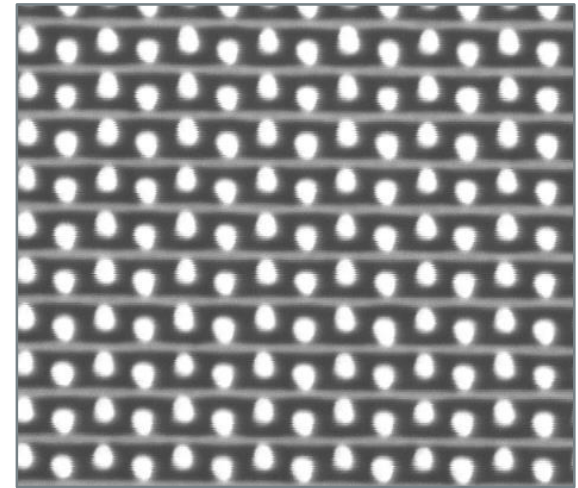
✓ H9HKNNNEBMBU-DRNEH LPDDR4 6GALLPD4E/SK8GLPD4E die



Active Pitch 36 nm



WL Pitch 47 nm



BL Pitch 54 nm

Cell Size 0.0025 μm^2

41 nm (2Z)

55 nm (2Z)

63 nm (2Z)

Cell Size 0.0036 μm^2

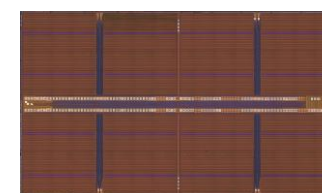
-30%

SK Hynix 1x DRAM: DDR4 & LPDDR4

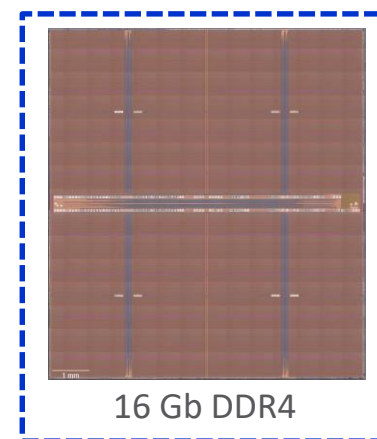
ITEMS	1X LPDDR4X (6 Gb Die)	1X LPDDR4X (8 Gb Die)	1X DDR4 (8 Gb Die)
Application (Examples)	H9HKNNNEBMBU (Huawei Mate 20)	H9HKNNNCRMMU (iPhone XS A1920)	H9HKNNNEBMBU (Huawei Mate 20)
Memory / Die	6 Gb	8 Gb	8 Gb
Die Markings	6GALLPD4E	SK8GLPD4E	8G-ALDDR4B
Die Size	32.52 mm ² (7.04 mm x 4.62 mm)	41.80 mm ² (9.03 mm x 4.62 mm)	40.71 mm ² (8.36 mm x 4.87 mm)
Bit Density	0.184 Gb/mm ²	0.191 Gb/mm ²	0.196 Gb/mm ²
Active Pitch	35 nm	35 nm	35 nm
WL Pitch	47 nm	47 nm	47 nm
BL Pitch	54 nm	54 nm	54 nm
Cell Size	0.0025 μm ²	0.0025 μm ²	0.0025 μm ²
Cap. Design	Honeycomb	Honeycomb	Honeycomb

SK Hynix 1x DDR4: 16 Gb die just released

ITEMS	1X DDR4 (8 Gb Die)	1X DDR4 (16 Gb Die)
Memory / Die	8 Gb	16 Gb
Die Markings	8G-ALDDR4B	16G-ALDDR4
Die Size	40.71 mm ² (8.36 mm x 4.87 mm)	81.52 mm ² (8.59 mm x 9.49 mm)
Bit Density	0.196 Gb/mm ²	0.196 Gb/mm ²
Active Pitch	35 nm	35 nm
WL Pitch	47 nm	47 nm
BL Pitch	54 nm	54 nm
Cell Size	0.0025 μm ²	0.0025 μm ²
Cap. Design	Honeycomb	Honeycomb



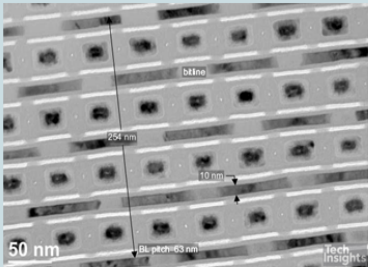
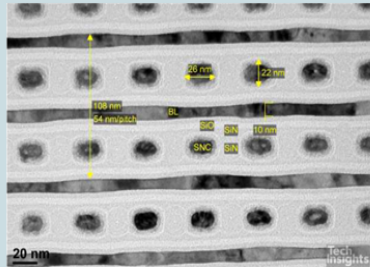
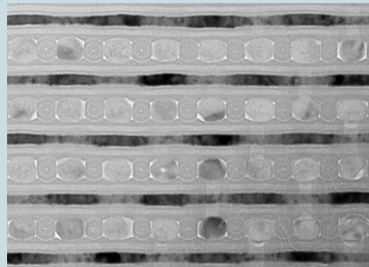
8 Gb DDR4



16 Gb DDR4

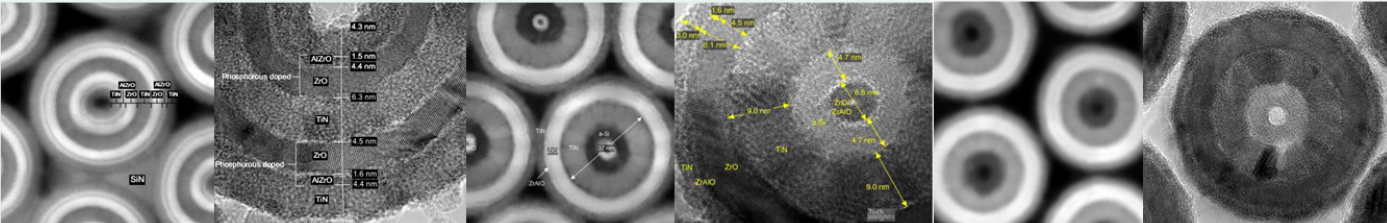
SK Hynix Process Comparison: 2z vs. 1x

❑ BL, BLC & SNP/SNC

Items		2z	1x	1y
BL	Stack	W/SiN/W/TiN/Poly-Si (27nm/1.7nm/5.8nm/3.4nm/ 58nm)	W-DPG W/WSiN/W/TiN/Poly-Si (20nm/2nm/5nm/4nm/40nm)	W-DPG W/WSiN/W/TiN/Poly-Si (20nm/2nm/5nm/4nm/40nm)
	Spacer	SiN/Air-gap	SiN/SiO	SiN/SiO
	Air-Gap	Used	Not Used	Not Used
BLC	BLC Mat.	Poly-Si	Poly-Si	Poly-Si
SN LP	LP Mat.	W M1	W M1	W M1
SNP/SNC	Stack	W/TiN/CoSi/Poly-Si	W/TiN/CoSi/Poly-Si	W/TiN/CoSi/Poly-Si
Top viewed SNC & BL TEM Image				

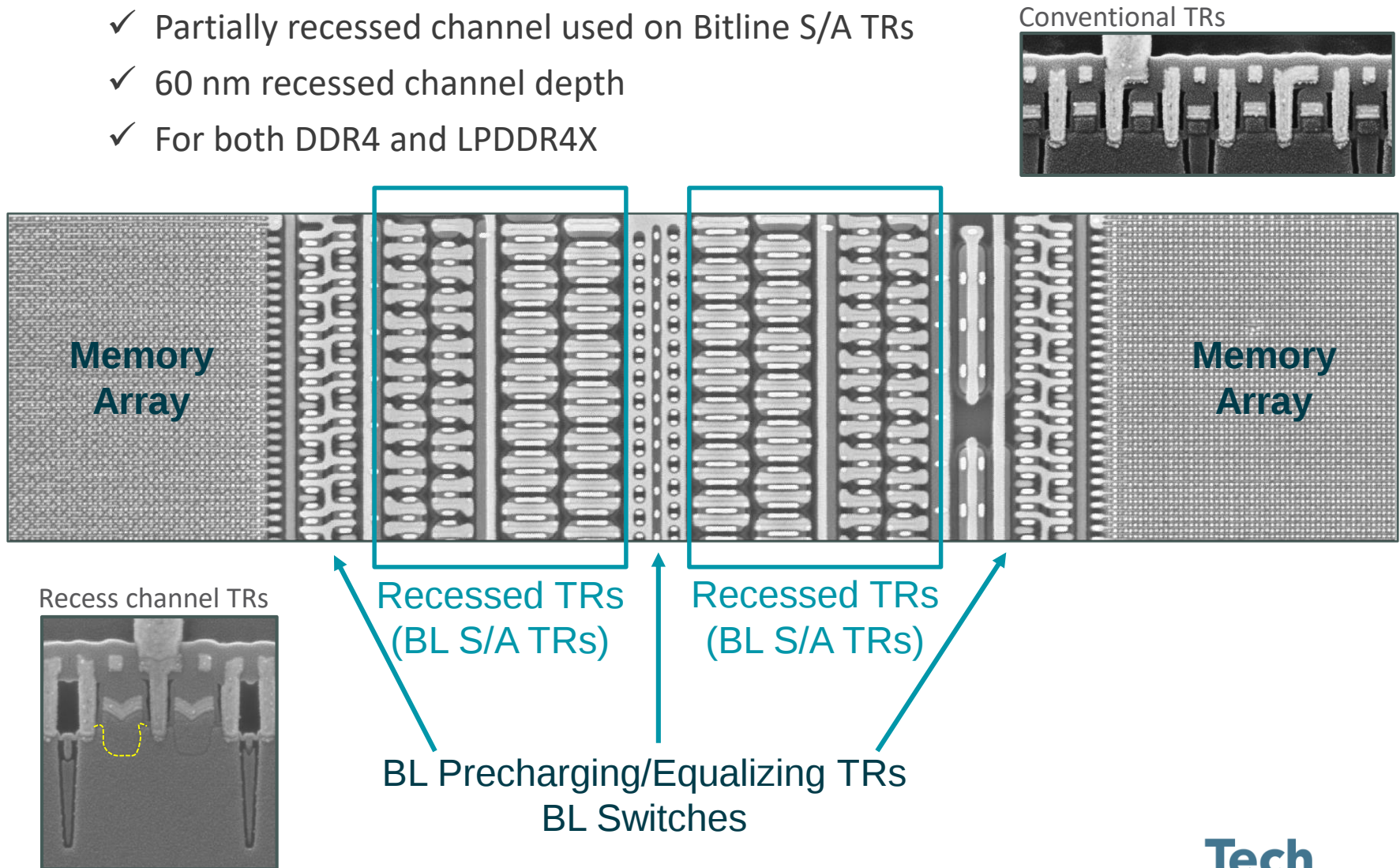
SK Hynix Process Comparison: 2z vs. 1x vs. 1y

Cell Capacitor

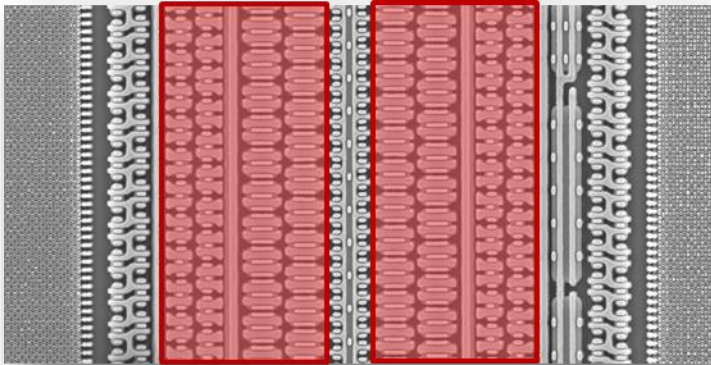
Items	2z	1x	1y
Cell Cap. Height	1.22 μm	1.22 μm	1.22 μm
Capacitor Type	Cylinder	Cylinder (4.7 nm a-Si filled into cylinder)	Cylinder (4.9 nm a-Si filled into cylinder)
Bot. Node	TiN	TiN / (a-Si)	TiN / (a-Si)
High-k Dielectrics	TE/AlZrO/ZrO/BE	TE/AlZrO/ZrO/BE	TE/AlZrO/ZrO/BE
Plate (Top Electrode)	W/SiGe/TiN	W/SiGe/TiN	W/SiGe/TiN
# MESH	2	2	2
1 st / 2 nd MESH Thickness	32 nm / 109 nm	40 nm / 92 nm	18 nm / 110 nm
Top Viewed Cap. & MESH TEM/SEM Images			

SK Hynix 1x nm DRAM: S/A Transistor Structure changed

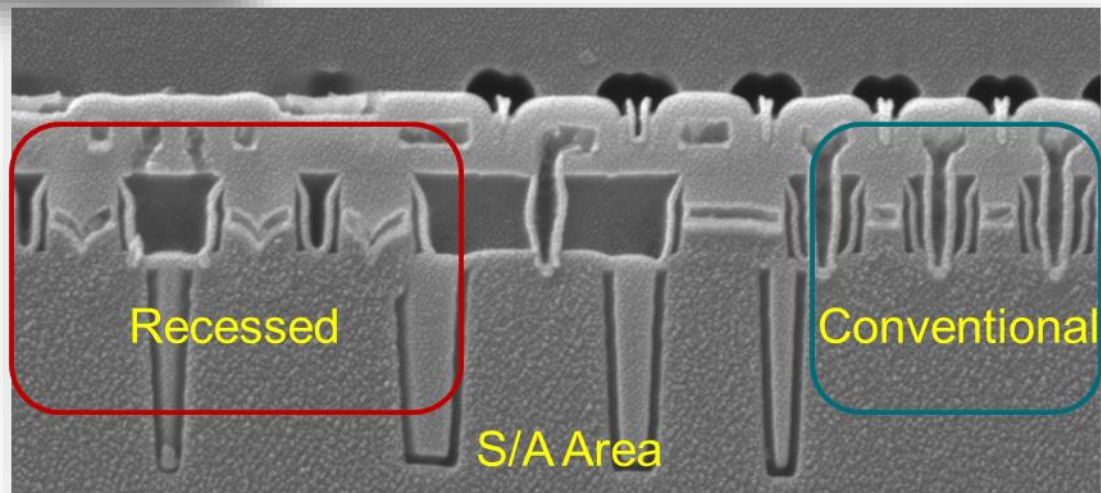
- ✓ Partially recessed channel used on Bitline S/A TRs
- ✓ 60 nm recessed channel depth
- ✓ For both DDR4 and LPDDR4X



SK Hynix 1y nm DRAM: S/A Transistor Structure?



- ✓ Recessed channel used on S/A TRs
- ✓ 60 nm depth, 90 nm Gate Length

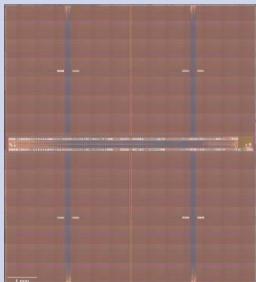


SK Hynix Process Comparison: 2z vs. 1x

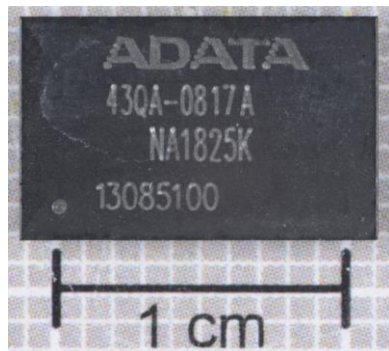
❑ Cell B-WL & Peripheral Gate

Items		2Z	1X
Cell B-WL	Cell STI Depth	270 nm	260 nm
	RCAT Depth	150 nm	140 nm
	B-WL Stack	Poly-Si/W/TiN (36nm/51nm/3.5nm)	Poly-Si/W/TiN (36nm/41nm/3.5nm)
	Gox. (side)	SiO 5.7 nm	SiO 4.5 nm
	HM on WL	SiN Liner	SiN (52 nm)
Peripheral Gate	Stack (From top)	W/SiON/W/TiN/Poly-Si (27nm/1.7nm/5.8nm/3.4nm/ 58nm)	W/W SiN /W/TiN/Poly-Si (20nm/2nm/5nm/4nm/40nm)
	Spacer	b-SiO/SiN/SiO/SiN	b-SiO/SiN/SiN
	LV Ox.	SiON/SiO on Si (2.2 nm thick in total)	SiON/SiO on Si (1.8 nm thick in total)
	HV Ox.	SiON/SiO on Si (5.2 nm thick in total)	SiON/SiO on Si (5.4 nm thick in total)

16 Gb DRAM Die Comparison: SK Hynix vs. Micron

ITEMS	SK Hynix 16 Gb DRAM Die	Micron 16 Gb DRAM Die
Memory / Die	16 Gb	16 Gb
Application	DDR4	DDR4
Die Markings	16G-ALDDR4	Z22A
Die Size	81.52 mm ² (8.59 mm x 9.49 mm)	81.30 mm ² (8.54 mm x 9.52 mm)
Tech. Node	SK Hynix 1x	Micron 1y
Bit Density	0.196 Gb/mm ²	0.197 Gb/mm ²
Cell Size	0.0025 μm ²	0.0024 μm ²
Die Floorplan		

Nanya Technology: 20 nm DRAM DDR4 (2017~2019)



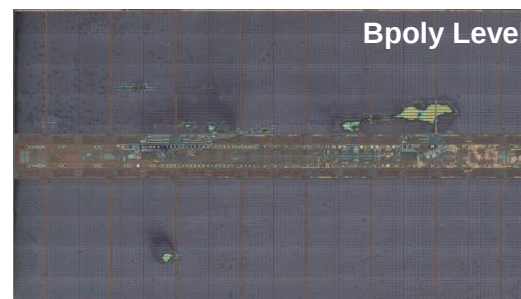
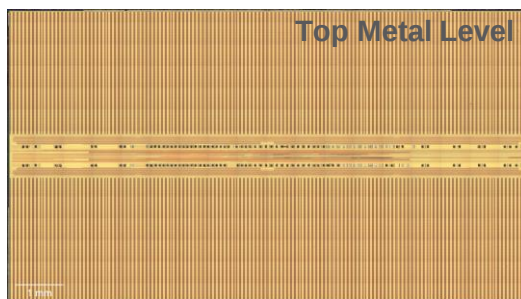
ADATA Technology



Kingston Memory



Nanya Technology



Cell Size: $0.0045 \mu\text{m}^2$

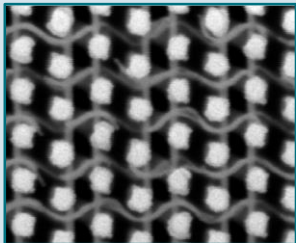
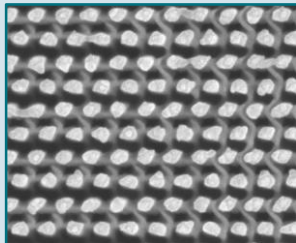
D/R: 20 nm

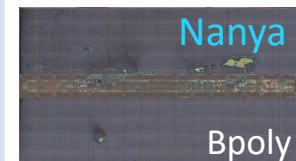
Bit Density: 0.120 Gb/mm^2

20nm DRAM Cell Design: Micron vs. Nanya

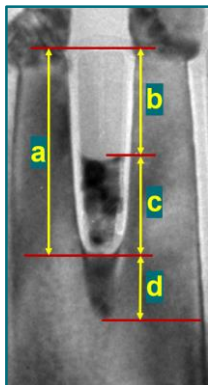
- ✓ Nanya 20nm A-Die is exactly the same cell design as Micron's
- ✓ Nanya 20nm D-Die may will be different from Micron's (on procuring)



Items	Micron 20 nm DRAM (B-Die)	Nanya 20 nm DRAM (A-Die)
Application (Ex. Parts)	DDR4 (MT40A2G4WE-075E:B)	DDR4 (NT5AD512M16A4-HR)
Memory Capacity (/Die)	8 Gb	8 Gb
Die Size (Die Seal)	64.63 mm ² (10.88 mm x 5.94 mm)	66.77 mm ² (10.91 mm x 6.02 mm)
Bit Density	0.124 Gb/mm ²	0.120 Gb/mm ²
Cell Size	0.00446 μm ²	0.00446 μm ²
Pitch (WL(S)/WL(L)/BL)	38nm / 86nm / 72nm	38nm / 86nm / 72nm
BL/Capacitor Pattern	Wavy/Honeycomb	Wavy/Honeycomb
Cell Pattern		
Die Markings		Nothing

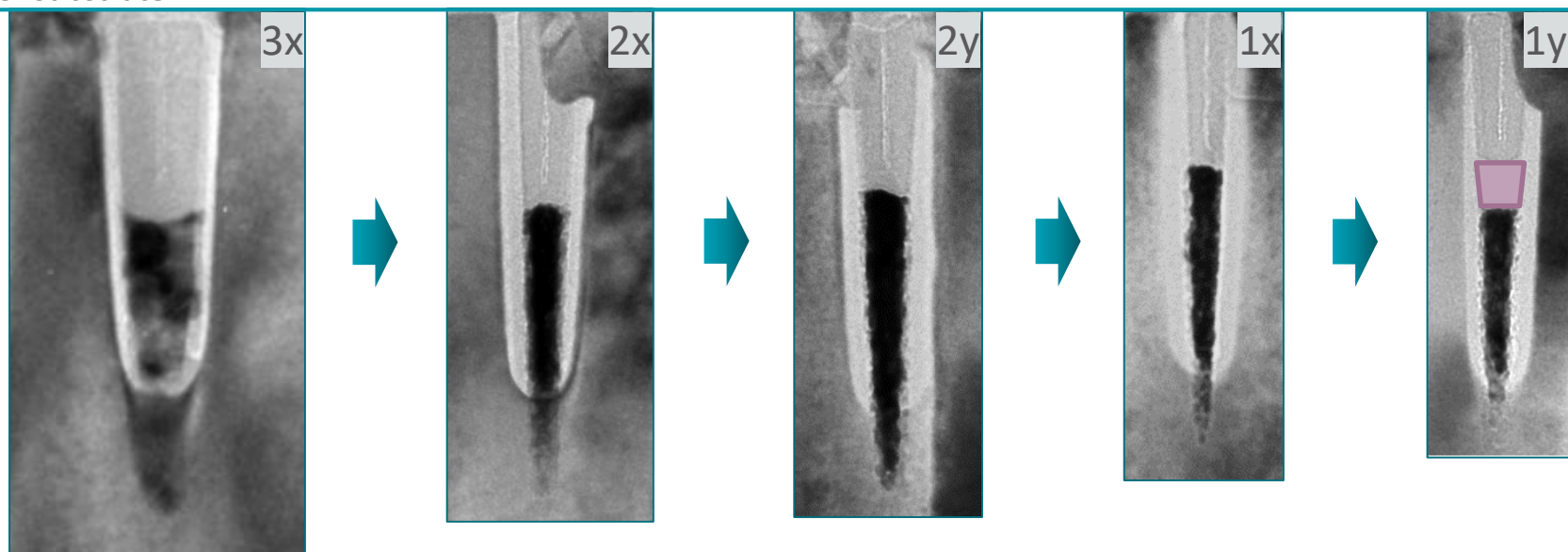


Samsung DRAM Cell Transistor Design (3x/2x/2y/1x/1y) Trend

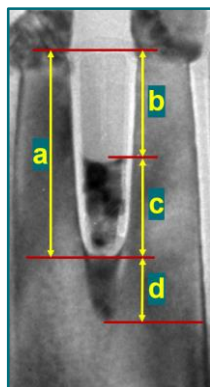


Tech Node	3x	2x	2y	1x	1y
Gate Materials	W/TiN	W/TiN	W/TiN	W/TiN	Poly-Si/W/TiN
RCAT Depth (a)	146.2 nm	145.6 nm	154.0 nm	138.0 nm	142.4 nm
HM Fill (b)	78.0 nm	68.7 nm	70.7 nm	59.1 nm	62.5 nm
Gate Height (c)	68.2 nm	76.9 nm	83.3 nm	78.9 nm	10.8 nm/69.1 nm
Saddle Depth (d)	41.1 nm	37.2 nm	29.5 nm	26.0 nm	16.6 nm

Si-substrate

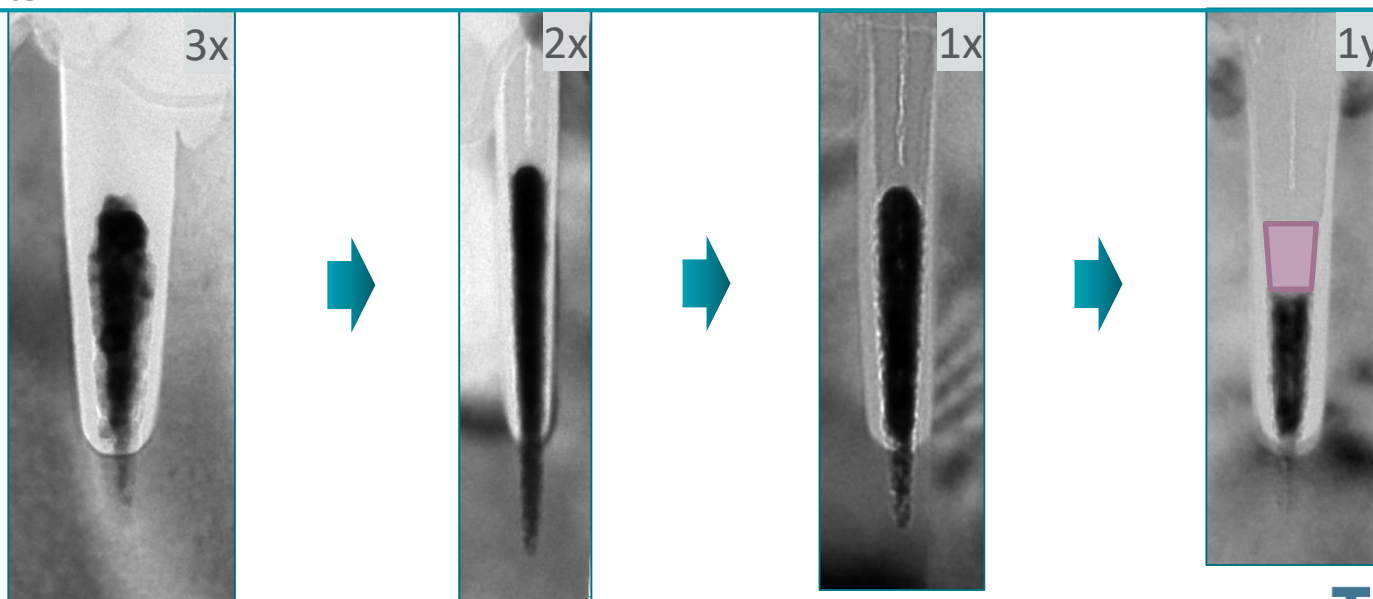


Micron DRAM Cell Transistor Design (30nm/20nm/1x/1y) Trend

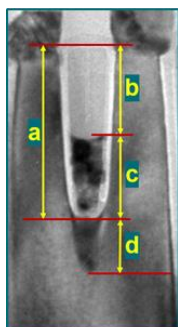


Tech Node	30 nm	20 nm	1x	1y
Gate Materials	W/TiN	W/TiN	W/TiN	Poly-Si/W/TiN
RCAT Depth (a)	158.3 nm	146.1 nm	147.2 nm	148.7 nm
HM Fill (b)	70.7 nm	49.1 nm	56.5 nm	71.2 nm
Gate Height (c)	87.6 nm	97.0 nm	90.7 nm	20.8 nm/56.7 nm
Saddle Depth (d)	26.0 nm	34.4 nm	26.4 nm	19.5 nm

Si-substrate

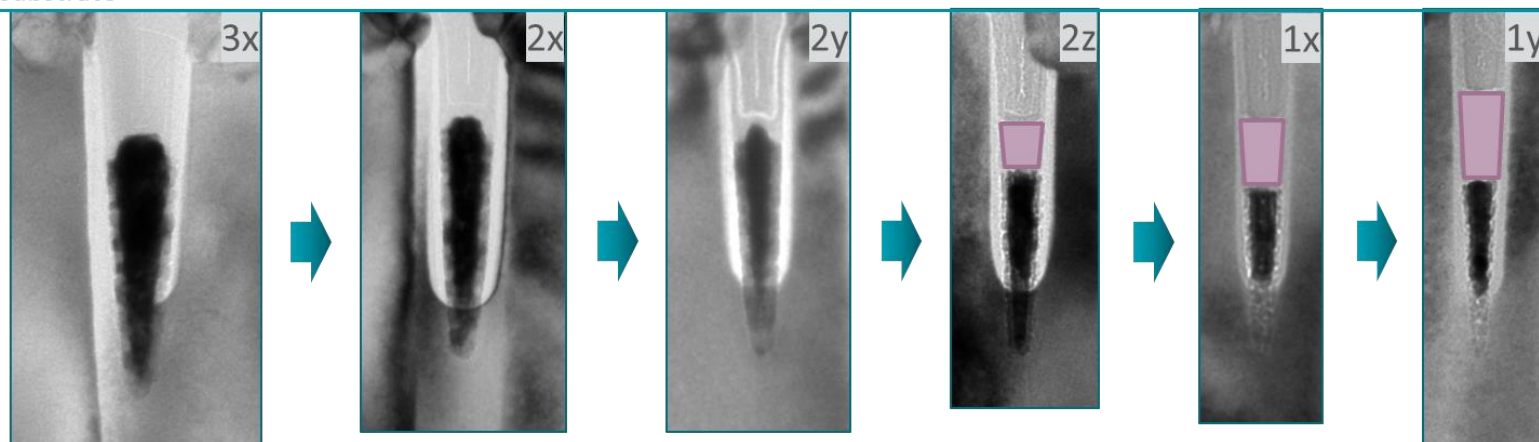


SK Hynix DRAM Cell Transistor Design (3x/2x/2y/2z/1x/1y) Trend



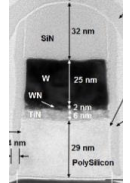
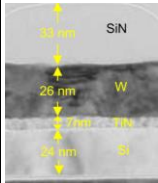
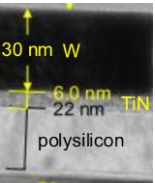
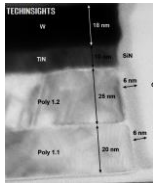
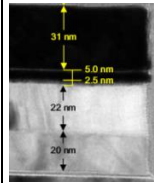
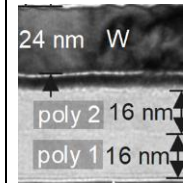
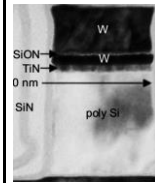
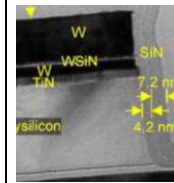
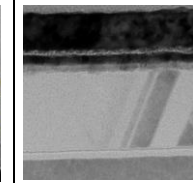
Tech Node	3x	2x	2y	2z	1x	1y
Gate Materials	W/TiN	W/TiN	W/TiN	Poly-Si/W/TiN	Poly-Si/W/TiN	Poly-Si/W/TiN
RCAT Depth (a)	147.8 nm	152.3 nm	132.4 nm	136.5 nm	133.8 nm	141.9 nm
HM Fill (b)	58.5 nm	50.7 nm	55.2 nm	54.7 nm	54.7 nm	47.4 nm
Gate Height (c)	89.3 nm	101.6 nm	77.2 nm	25.1 nm/ 56.7 nm	27.4 nm/51.7 nm	40.8 nm/53.7nm
Saddle Depth (d)	49.2 nm	25.9 nm	32.3 nm	35.2 nm	32.4 nm	27.8 nm

Si-substrate



Comparison DRAM Peripheral Transistors: Structure

- ✓ W based peripheral gate stack
- ✓ Different barrier layers for each device/manufacture
- ✓ S/D Contacts with CoSi
- ✓ Gox with nitrided oxide

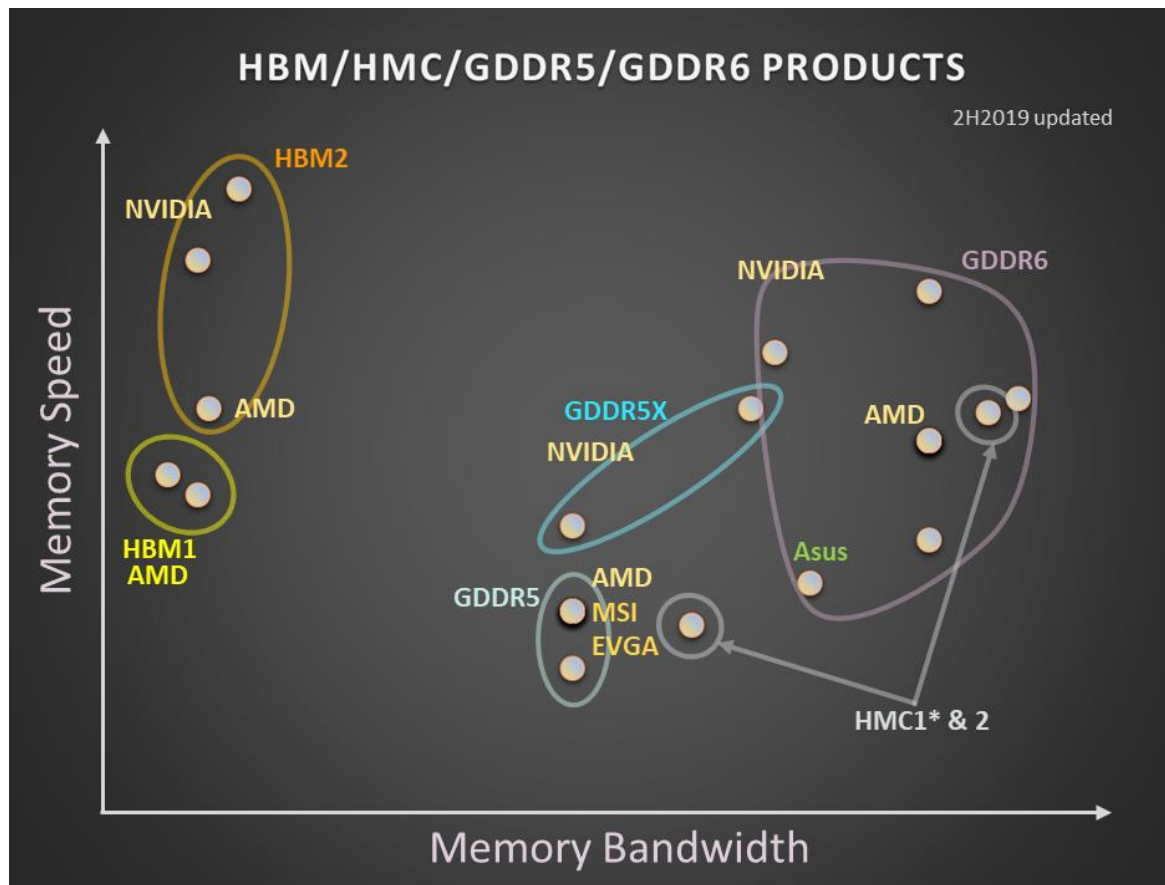
Manufacturer	Samsung			Micron			SK Hynix		
Tech Node	2y (DDR3)	1x	1y	2y	1x	1y	2z	1x	1y
Gate Image (x-section TEM)									
Gate Layer 1	Poly-Si	Poly-Si	Poly-Si	Poly-Si 1	Poly-Si 1	Poly-Si 1	Poly-Si	Poly-Si	Poly-Si
Gate Layer 2	TiN	TiN	TiN	Poly-Si 2	Poly-Si 2	Poly-Si 2	TiN	TiN	TiN
Gate Layer 3	WN	W	W	TiN	TiN	TiN	W	W	W
Gate Layer 4	W			W	WN	WN	SiON	WSiN	WSiN
Gate Layer 5					W	WSiN	W	W	W
Gate Layer 6						W			
Gate Height (Total)	62 nm	57 nm	58 nm	73 nm	80.5 nm	63 nm	98 nm	71 nm	71 nm
Gox Structure	SiO/SiON/SiO	SiON/SiO	SiON/SiO	SiON/SiO	SiON/SiO	SiON/SiO	SiON/SiO	SiON/SiO	SiON/SiO
LV Gox Thickness	2.3 nm	3.0 nm	2.5 nm	2.7 nm	2.3 nm	2.0 nm	2.2 nm	1.8 nm	1.8 nm
HV Gox Thickness	6.0 nm	5.8 nm	5.0 nm	6.4 nm	5.6 nm	5.0 nm	5.2 nm	5.4 nm	4.2 nm
Gate Spacer	SiN liner / SiO SW	SiN liner / SiO SW	SiN liner / SiO SW	SiN liner / SiO SW	SiN liner / SiO SW	SiN liner / SiO Buffer / SiN	SiN liner / SiO SW	SiN double liners / SiO SW	SiN double liners / SiO SW
S/D Materials	CoSi	CoSi	CoSi	CoSi	CoSi	CoSi	CoSi	CoSi	CoSi
Report ID	0315-39040-O-5DM-100	AME-1701-805	AME-1902-802	0716-43012-O-5DM-100	AME-1804-803	AME-1905-801	AME-1703-801	AME-1811-801	AME-1911-801

DRAM

Graphic DRAM, HBM/HMC

AMD & NVIDIA GPU Card Summary

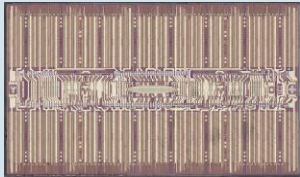
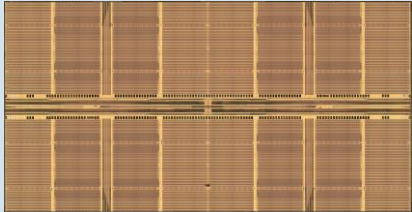
- ✓ GDDR6X & HBM2E, HBM3 in 2020, while no more HMC next gen.

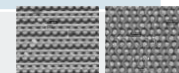


* Fujitsu SPARC64 Xlfx

Comparison GDDR6 Die: Samsung vs. Micron

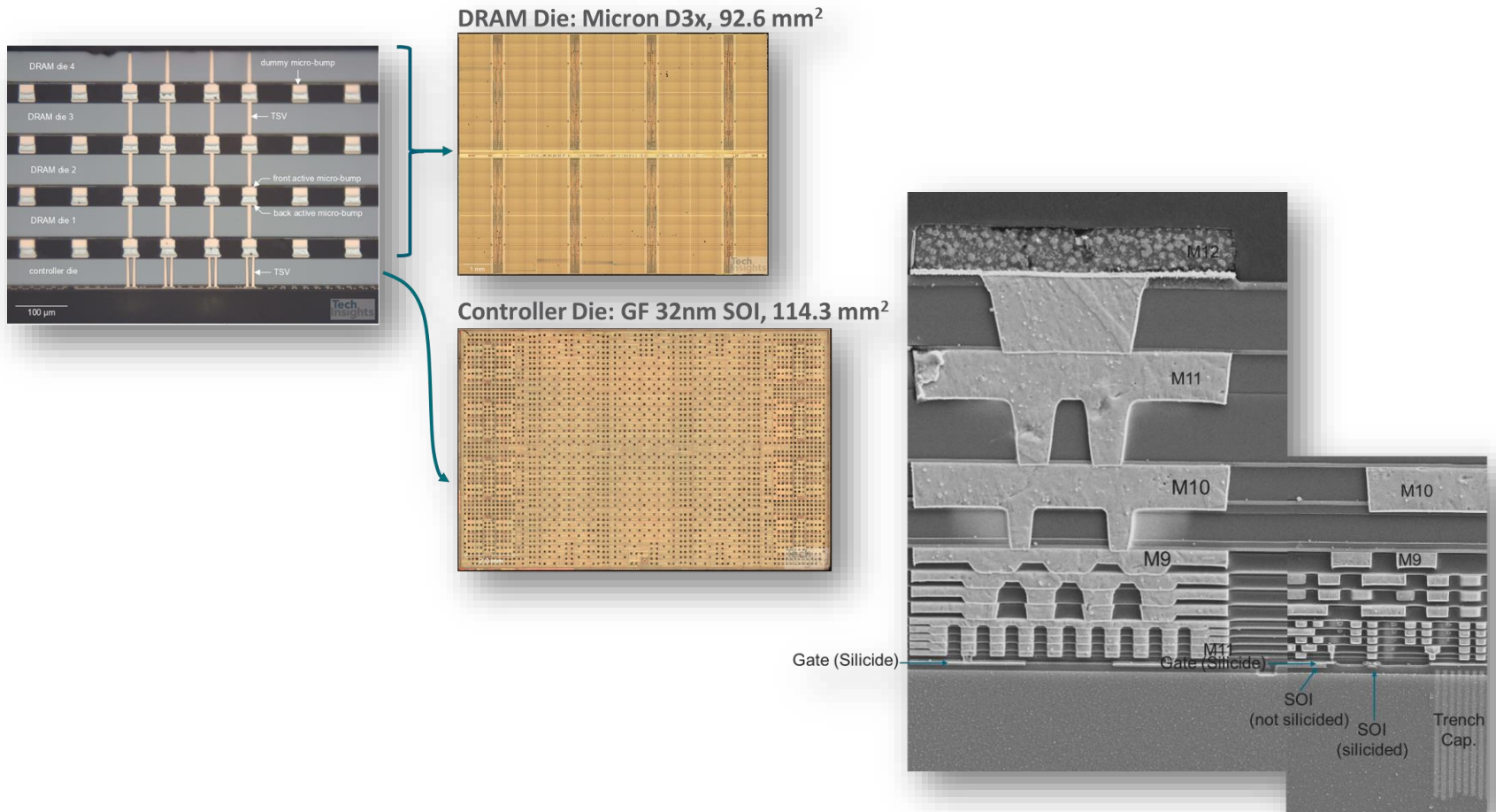


Items	Samsung GDDR6 (4 Gb & 8 Gb Dies)		Micron GDDR6 (8 Gb Die)
Parent Products	NVIDIA GeForce RTX™ 2080 8 GB GDDR6 (8 PKGs)	NVIDIA Quadro RTX™ 5000 16 GB GDDR6	NVIDIA GeForce RTX™ 2080 8 GB GDDR6 (8 PKGs)
GDDR6 Package Markings	K4Z80325BC-HC14	K4ZAF325BM-HC14	8QA77 D9WCW (M)
GDDR6 Device	K4Z80325BC-HC14	K4ZAF325BM-HC14	MT61K256M32JE-14:A
Die Size	26.42 mm ² (5.37 x 4.92 mm ²)	48.12 mm ² (9.08 x 5.30 mm ²)	85.6 mm ² (12.89 mm x 6.64 mm)
Die Markings	K4Z41165BC 2017	K4Z80165BM 2017	Y01G
Memory/Die Bit Density	4 Gb 0.151 Gb/mm²	8 Gb 0.166 Gb/mm²	8 Gb 0.093 Gb/mm²
Technology Node	1x (18 nm)	1x (18 nm)	2y (20 nm)
Cell Size	0.0026 μm ²	0.0026 μm ²	0.0048 μm ²
Die Photograph			

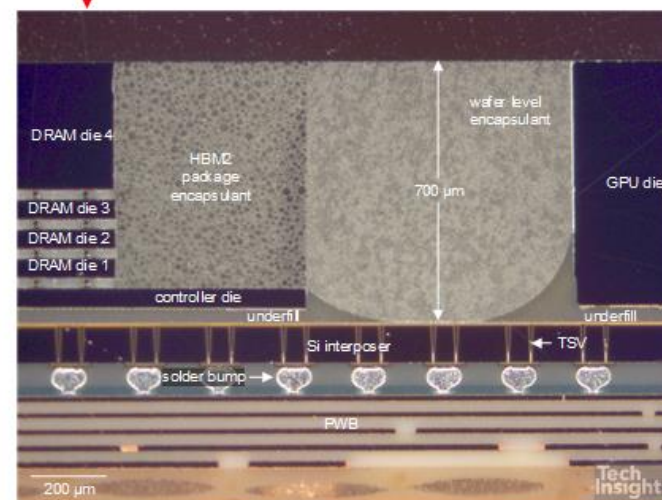


Micron HMC2 Controller Die

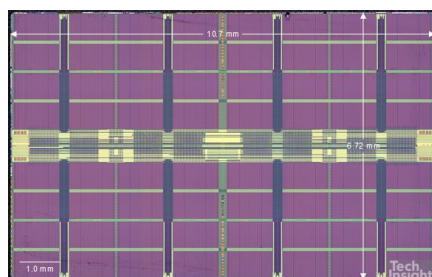
- ✓ IBM die markings, GF fabbed 32nm SOI process, 12 Metal Layers



SK Hynix HBM2: AMD 215-0894144 Vega 10 XT



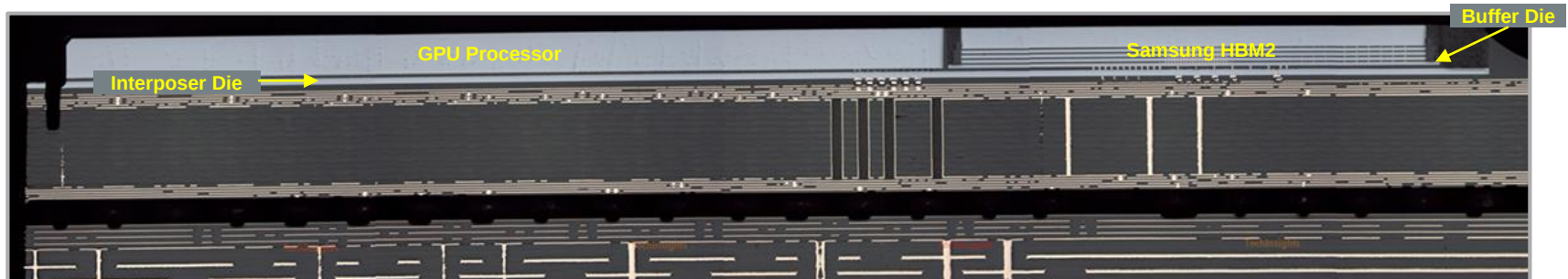
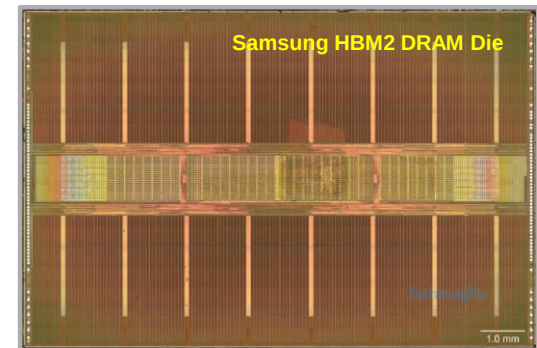
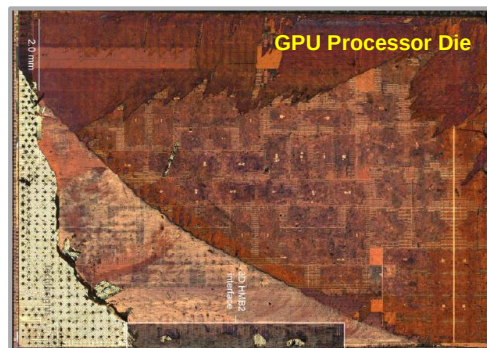
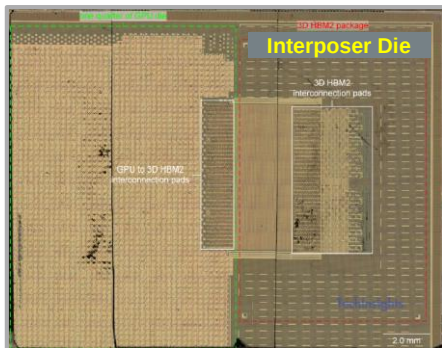
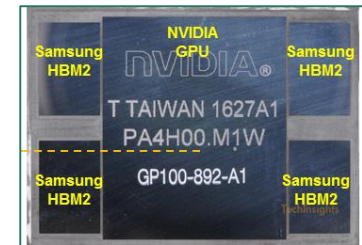
Report ID: EXR-1901-802



SK Hynix HBM2 DRAM Die Floorplan (2z)

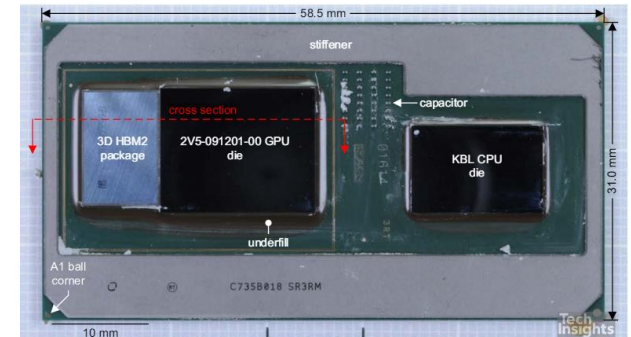
Samsung HBM2 @NVIDIA Tesla P100 PCIe GPU

- ✓ Samsung 4 GB HBM2 DRAM Package (8 Gb/die x 4)
- ✓ NVIDIA GPU Processor Die (TSMC 16 nm FinFET)
- ✓ Si Interposer Die, Buffer Die
- ✓ Same PKG configuration with AMD Radeon R9 Fury X GPU
- ✓ #TSV/Die: ~4830



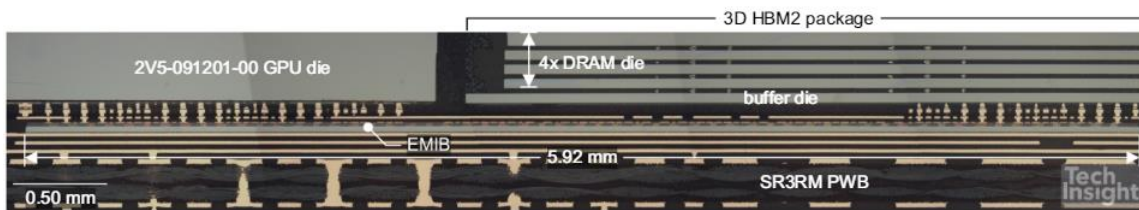
Intel HBM2: SR3RM 8th Gen. Quad Core™ i5-8305G Processor

- ✓ Radeon™ RX Vega M GL GPU die
- ✓ CPU die
- ✓ HBM2 die → Samsung K4C8E1K6MB
- ✓ Buffer Die
- ✓ EMIB* Die



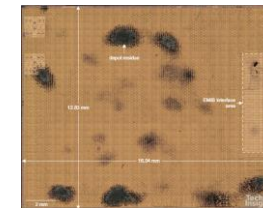
V4 Optical_Cross-section_Images\Mosaic_Alcomplete_mosaic_D_Corrected_305337.png

Package Cross Section – General View

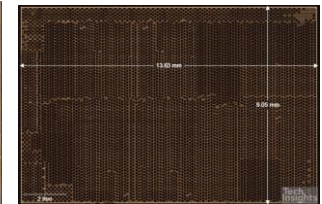


V4 Optical_Cross-section_Images\9_BF_EMIB_mosaic_10x_306500.png

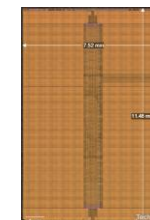
Package Cross Section – EMIB Area



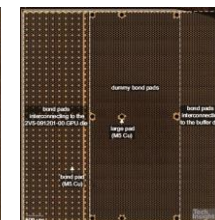
GPU



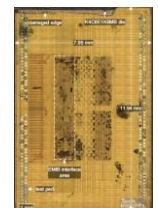
CPU



HBM2



EMIB

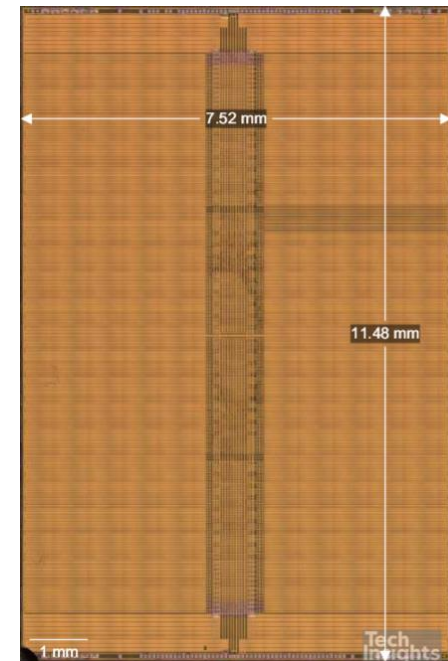


Buffer

* Embedded Multi-die Interconnected Bridge

Intel SR3RM Package with HBM2 DRAM Dies

Items	Intel HBM2
Product	SR3RM 8 th Gen. Quad Core™ i5-8305G with Radeon™ RX Vega M GL GPU
Package Components	1 AMD GPU + 1 KBL CPU 4 HBM2 dice (3 thinner + 1 thicker) 1 Buffer die 1 EMIB die
PKG Size	58.5 mm x 31.0 x 1.5 mm
# Metal Layers (PWB)	12
HBM DRAM Die Size	82.19 mm ² (11.42 mm x 7.46 mm)
HBM density (/die)	8 Gb
HBM DRAM Die Markings	K4C8E1K6MB
HBM DRAM Die density	0.097 Gb/mm ²
HBM DRAM Die Thickness	58 µm, 250 µm
HBM DRAM Cell Technology	Samsung 20 nm (2y) node

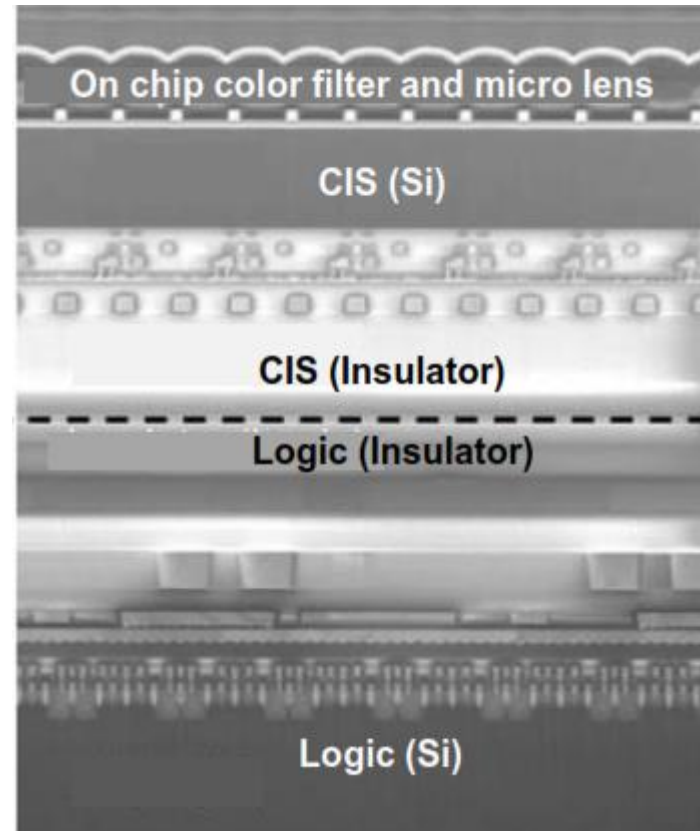
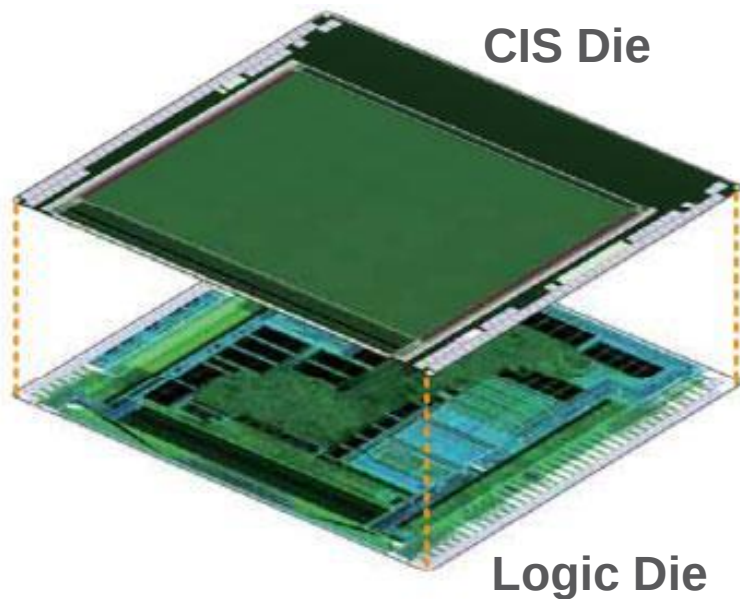


HBM2 DRAM Die
removed from SR3RM

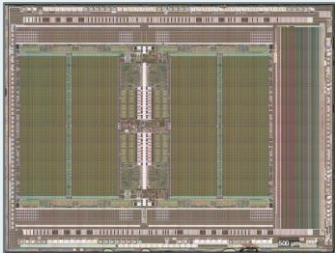
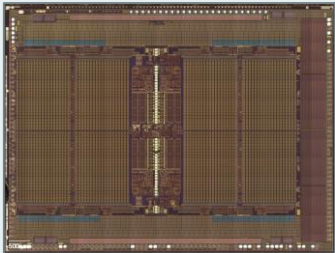
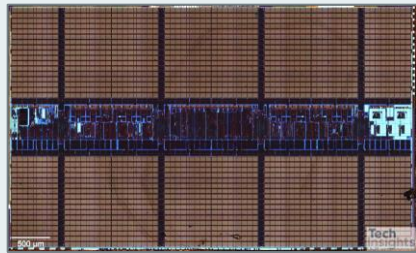
DRAM

DRAM/TSV for Camera Module

Conventional 3D CIS pixel chip and logic IC integration:



DRAM Application for Camera Module: Triple Stack

Component	SONY IMX400	SONY IMX345	Samsung S5K2L3SX & S5K2L4SX
Product	Sony Xperia XZs Smartphone	Samsung Galaxy S9+ SM-G965U	Samsung Galaxy S9+ SM-G965N Samsung Galaxy S10+ SM-G975F
Stack (top to bot.)	CIS DRAM ISP	CIS DRAM ISP	CIS ISP DRAM
DRAM Die Manufacturer	Micron (Elpida Fab.)	Micron (Elpida Fab.)	Samsung (K4F2A164HF)
DRAM Die Photograph (Bpoly)			
Die Size	8.07 x 6.06 mm ²	7.70 x 5.75 mm ²	5.33 x 3.17 mm ²
Tech. Node	3x	3x	2y
Die-to-Die Con.	TSV	TSV	TSV + Micro bump

Selected DRAM Components (Tear Down) Update: 2019

Category	Parent Devices	DRAM Component	Manufacturer	#Dies /PKG	Description
Mobile Phone	Samsung Galaxy S10+	K3UH7H70AM-AGCL	Samsung	8	8 GB LPDDR4X (1y)
	Xiaomi Mi 9 SE	H9HQ53AECMMMDAR-KEM	SK Hynix	10	BGA: 6 GB LPDDR4E (1x)
	Xiaomi Mi 9	K3UHAHA0AM-AGCL	Samsung	12	12 GB LPDDR4X (1y)
	Motorola Moto E Play	KMQE60013M-B318	Samsung	4	eMMC: 2 GB LPDDR3 (2x)
	Huawei Honor V20	K3UH6H60AM-EGCL	Samsung	8	6 GB LPDDR4X (1x)
	LG Stylo 4+	MT29TZZZ7D7DKLAH	Micron	3	eMMC: 3 GB LPDDR3 (2x)
	Samsung S10 5G	H54T2D63M (5G Modem)	SK Hynix	1	2 Gb LPDDR4 20nm
Tablets /Notebook	Dell XPS 13	K4E6E304EC-EGCG (Board) H9CCNNN8JTBL (SSD)	Samsung SK Hynix	2 2	2GB LPDDR3 (2x) 512 MB DDR3 (2x)
	Apple iPad Pro 11	H9HCNNNBRMMLSR-NEH	SK Hynix	4	2 GB LPDDR4X (2z)
	Google Pixelbook COA	K4E6E304EB-EGCF	Samsung	2	2 GB LPDDR3 (2x)
	Microsoft Surface Go	H9CCNNNBKTALBR	SK Hynix	2	2 GB LPDDR3 (2y)
IoT	Amazon Echo Dot	KMFJ20005A-B213	Samsung	2	eMMC: 512 MB LPDDR3
SSD	Samsung Z-SSD 983	K4F2E3S4HA-BGCH	Samsung	2	1.5 GB LPDDR4X (1x)
	Samsung SSD PM983	K4FJE3Q4HA-BGCH	Samsung	8	6 GB LPDDR4X (1x)
	Intel SSD 660p	NT5CC128M16IP-DI	Nanya	1	256 MB DDR3
HBM/HMC	AMD Radeon Pro WX	HBM2 H5VR8GECA	SK Hynix	4	HBM2 (2z)
	Micron HMC2	MT43A4G40200NFA-S15	Micron	4	HMC2 (3x)
	Intel SR3RM HBM2	K4C8E1K6MB	Samsung	4	HBM2 (2y)

Die Floorplan/Functional Blocks/Cost Analysis (-2019)

MFR Report ID	Manufacturer	Device/Comp.	Die Description
MFR-1912-801	SK Hynix	1y 8 Gb DDR4	8 Gb DDR4 (1y node) DRAM Die
MFR-1908-801	Micron	1y 16 Gb DDR4	16 Gb DDR4 (1y node) DRAM Die
MFR-1907-802	Micron	RLDRAM	RLDRAM 3 rd Gen.
MFR-1903-804	Samsung	GDDR6 (8 Gb)	4 Gb GDDR6 DRAM Die
MFR-1903-801	Samsung	GDDR6 (16 Gb)	8 Gb GDDR6 DRAM Die
MFR-1803-801	Samsung	1x 8 Gb LPDDR4X	8 Gb LPDDR4X (1x node) DRAM Die
MFR-1902-801	Samsung	1y 8 Gb LPDDR4X	8 Gb LPDDR4X (1y node) DRAM Die
MFR-1902-802	Samsung	1y 8 Gb DDR4	8 Gb DDR4 (1y node) DRAM Die
MFR-1808-801	SK Hynix	GDDR5 (8 Gb)	8 Gb GDDR5 DRAM Die
MFR-1901-801	SK Hynix	HBM2	HBM2 DRAM Die
MFR-1811-802	SK Hynix	1x 6 Gb LPDDR4X	6 Gb LPDDR4X (1x node) DRAM Die
MFR-1811-803	SK Hynix	1x 8 Gb LPDDR4X	8 Gb LPDDR4X (1x node) DRAM Die
MFR-1901-802	SK Hynix	1x 8 Gb DDR4	8 Gb DDR4 (1x node) DRAM Die
MFR-1905-801	SK Hynix	1x 16 Gb DDR4	16 Gb DDR4 (1x node) DRAM Die
MFR-1809-801	Micron	GDDR6 (8 Gb)	8 Gb GDDR6 DRAM Die
MFR-1810-802	Micron	HMC2	HMC2 DRAM Die
MFR-1906-802	Micron	1x 6 Gb LPDDR4	6 Gb LPDDR4 (1x node) DRAM Die
MFR-1805-802	Micron	1x 8 Gb LPDDR4	8 Gb LPDDR4 (1x node) DRAM Die
MFR-1804-802	Micron	1x 8 Gb DDR4	8 Gb DDR4 (1x node) DRAM Die
MFR-1805-801	Micron	1xs 8 Gb DDR4	8 Gb DDR4 (1xs node) DRAM Die
MFR-1905-802	Micron	1y 8 Gb DDR4	8 Gb DDR4 (1y node) DRAM Die
MFR-1803-801	Nanya	20 nm 8 Gb DDR4	8 Gb DDR4 (20 nm node) DRAM Die
MFR-1808-802	UnilC (China)	3x 2 Gb DDR3	2 Gb DDR3 (3x node) DRAM Die



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Thank You!

For more information, please contact:

Jeongdong Choe: jchoe@techinsights.com