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PRISMARK PRESENTATION

December 8, 2021

PREPARED FOR:

INTEL

- Market Outlook: Systems, Semiconductor and Packaging, including OSAT and Foundry Financials
- FCBGA Shortage and Investments
- Advanced Package Technologies and Investments/Direction

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ELECTRONICS INDUSTRY: SUMMARY

- 2021 has been a tremendous growth year in electronics and related components. Year-on-year revenue growth of the first nine months from top players by segment is as follows:
  - OEM and ODM/EMS: +17%
  - Semiconductor: +25%
  - OSAT: +25%
  - Foundries: +30%
  - Package Substrates: +38%
- This value growth has been driven by strong unit demand across all product sectors and continues to be supported by:
  - Continued x-from-home trends, including changed consumer spending habits
  - Supportive fiscal and monetary policy and economies reopening
- Shortages, rising prices, and supply chain issues driving “just in case” purchase strategies
  - Much of supply chain (fab, packaging, components, assembly) is capacity constrained
  - Despite some of these constraints, electronics hardware and component growth on track for a record year
- Prismark expects slowing systems growth in 2022 (+2%), and the semiconductor outlook for 2022 remains positive, with 6% value growth over 2021 (higher for non-memory)

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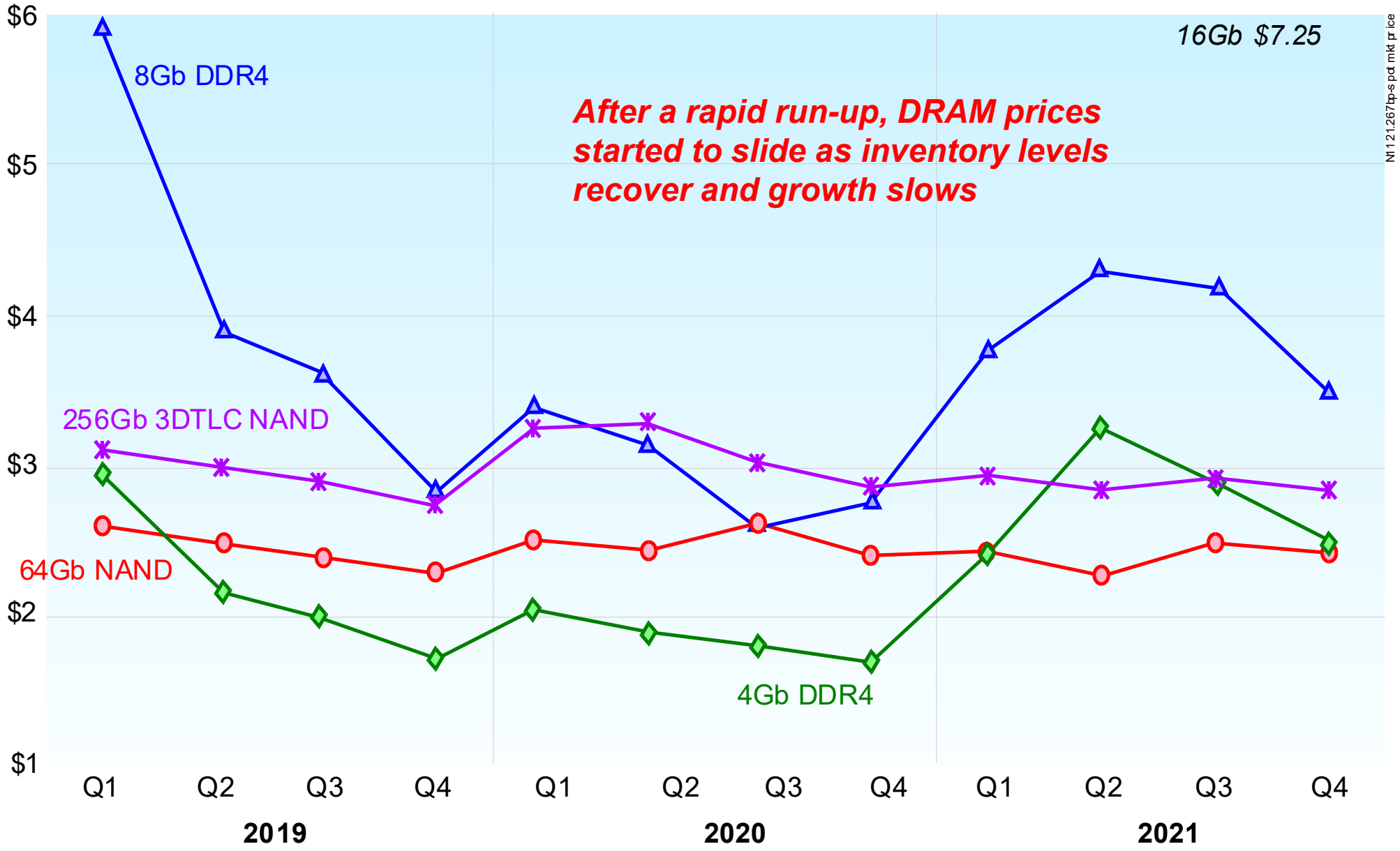
MEMORY SPOT MARKET PRICING



Source: DRAMeXchange

OEM REVENUES (1 OF 2)

($Bn)	2020	2020/2019	Q3 2021	Q1-Q3 2021/ Q1-Q3 2020	2021E / 2020
Apple	$237.3	8%	$65.1	42%	27%
Huawei	$135.3	11%	$20.9	-27%	-29%
Samsung	$114.7	-1%	$33.6	17%	17%
Dell	$69.9	-1%	$21.5	18%	14%
Panasonic	$62.1	-12%	$15.8	11%	9%
HP	$57.7	-2%	$16.7	14%	11%
LG Electronics	$53.9	1%	$16.2	30%	21%
Lenovo	$55.7	7%	$17.9	31%	24%
Cisco	$34.6	-10%	$9.5	9%	9%
Canon	$29.7	-10%	$7.6	15%	10%
Xiaomi	$32.19	20%	$10.2	52%	45%
NEC	$27.7	-1%	$6.5	2%	2%
Ericsson	$25.5	6%	$6.5	9%	1%
Nokia	$25.0	-4%	$6.4	10%	4%
HP Enterprise	$24.3	-3%	$6.5	0%	3%
BYD	$22.8	23%	$8.4	49%	33%
Ricoh	$16.8	-9%	$3.9	5%	4%
ZTE	$14.7	12%	$4.8	22%	19%
Asus	$13.5	24%	$5.0	48%	39%
TCL	$11.2	108%	$7.2	168%	128%

With few exceptions, OEM revenues experiencing tremendous growth/recovery in past 12 months

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OEM REVENUES (2 OF 2)

($Bn)	2020	2020/2019	Q3 2021	Q1-Q3 2021/ Q1-Q3 2020	2021E / 2020
Haier Smart Home	$10.4	19%	$2.7	0%	3%
Acer	$9.4	25%	$2.9	27%	21%
Inspur	$9.1	23%	$2.7	10%	11%
Motorola Solutions	$7.5	-4%	$2.1	11%	10%
IBM	$7.0	-8%	$1.1	-6%	-20%
Microsoft (PC)	$6.7	15%	$1.3	-9%	-15%
Skyworth Group	$5.8	9%	$2.1	44%	29%
Oracle	$3.4	-5%	$0.8	-4%	-4%
Siemens***	$61.7	0%	$19.3	21%	17%
Lockheed Martin***	$54.9	10%	$13.5	2%	1%
Denso***	$44.9	-7%	$11.1	18%	12%
Mitsubishi Electric***	$39.0	-6%	$9.7	8%	7%
Hyundai Mobis***	$31.2	-4%	$8.6	23%	16%
Medtronic***	$27.9	-10%	$7.5	17%	11%
Continental***	$25.5	-14%	$6.3	16%	10%
Honeywell***	$24.7	-10%	$6.2	8%	4%
Valeo***	$18.9	-14%	$4.7	20%	7%
L3Harris***	$18.2	-1%	$4.2	-1%	-2%
Aptiv***	$13.1	-9%	$3.7	30%	17%
TOTAL	$1,484	2%	$401.9	17%	12%
Automotive Total	$134	-9%	$34.4	20%	12%
Total (excl Automotive)	$1,351	3%	$367.4	17%	12%

*** *Total sales, electronics+other*

Overall 12% growth in 2021

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EMS/ODM REVENUES

($Bn)	2020	2020/ 2019	Q3 2021	Q3 2021/ Q2 2021	Q1-Q3 2021/ Q1-Q3 2020	2021E / 2020
Hon Hai	$182.9	6%	$50.4	4%	31%	21%
Pegatron	$47.4	7%	$11.6	19%	-7%	-7%
Quanta	$37.1	11%	$9.4	1%	7%	6%
Compal	$35.7	12%	$12.1	30%	30%	25%
Wistron	$28.8	1%	$7.9	10%	4%	4%
Jabil	$27.6	5%	$7.4	3%	9%	7%
Flex	$23.3	-6%	$6.2	-2%	13%	8%
Inventec	$17.3	6%	$5.2	27%	4%	8%
USI	$7.0	31%	$2.2	26%	34%	21%
Sanmina	$6.9	-13%	$1.6	-1%	-2%	-3%
Celestica	$5.7	-2%	$1.5	3%	-5%	-2%
Plexus	$3.4	4%	$0.8	4%	0%	2%
Total	**$423.1**	**6%**	$116.5	8%	17%	13%

After 6% growth in 2020, expect 13% growth in 2021

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SEMICONDUCTOR SUPPLIER REVENUES

$Bn	2020	2020/ 2019	Q3 2021	Q3 2021/ Q2 2021	Q4F 2021/ Q3 2021	2021E/ 2020
Intel	$77.9	8%	$19.2	-2%	0%	0%
Samsung	$61.9	11%	$22.8	12%	1%	34%
SKHynix	$27.1	16%	$10.2	11%	3%	39%
Micron	$22.1	7%	$8.3	11%	-8%	34%
Qualcomm	$19.4	34%	$7.7	19%	11%	50%
Broadcom^	$18.0	5%	$5.4^	8%	2%	15%
Nvidia (incl Mellanox)	$17.1	40%	$7.1	9%	4%	56%
TI	$14.5	1%	$4.6	1%	-5%	24%
Infineon	$12.1	-9%	$3.5	8%	0%	12%
MediaTek	$11.0	38%	$4.7	5%	-5%	58%
Kioxia	$10.9	25%	$3.6	21%	-1%	19%
STMicro	$10.2	7%	$3.2	7%	6%	23%
AMD	$9.8	45%	$4.3	12%	4%	65%
Sony	$9.5	0%	$2.5	27%	-3%	-3%
NXP	$8.6	-3%	$2.9	10%	5%	28%
WD Flash	$7.5	14%	$2.4	0%	-5%	11%
Renesas	$6.7	-1%	$2.3	18%	15%	34%
Analog Devices	$5.9	2%	$1.8	1%	-2%	19%
Microchip	$5.4	4%	$1.7	5%	6%	19%
ON Semiconductor	$5.3	-5%	$1.7	4%	3%	27%
Xilinx	$3.1	-6%	$0.9	6%	1%	18%
Maxim	$2.4	8%	$0.7	3%	0%	22%
Total	**$367.0**	**11%**	**$121.8**	**8%**	**1%**	**25%**
Memory	$115.1	13%	$42.5	12%	-1%	34%
Total (excl memory)	**$251.8**	**10%**	**$79.3**	**7%**	**2%**	**21%**

^Estimated Q3 data

Non-Memory growth of 10% in 2020 and expect 21% growth in 2021

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PC MARKET FORECAST

Work From Home

Back to the Office Impact?

M Units

N1221.360rd-changes pc

	2019	2020	2021E	2022F	2025F
Total	437M	495M	543M	520M	535M
Tablet	150	172	177	170	185
Notebook	184	229	270	255	260
Desktop	103	94	96	95	90

xFH driven growth in 2020/2021 tapers in 2022

2025 market outlook 25% above earlier forecasts

QUARTERLY SERVER SHIPMENTS

	Quarterly Shipments								Annual Shipments			
	2020				2021							
M Units	Q1	Q2	Q3	Q4	Q1	Q2	Q3F	Q4F	2019	2020	2021F	2025F
Servers	3.5	3.7	3.8	4.0	3.6	3.9	4.2	4.4	14.0	15.0	16.1	19.6

- Server 2020 market of 15M units reflects addition of edge servers
  - 2021 outlook for servers of 7% growth to 16.1M units
  - Server players expect significant pick up from Q3 2021 through 2022

- Demand for server substrates (54M in 2021) is significantly higher, due to:
  - Use of 2, 4, 8, or higher number of CPU per server
  - Use of Xeon/EPYC branded CPU in non-server applications (e.g. workstation)
  - Replacement CPU and build of inventory

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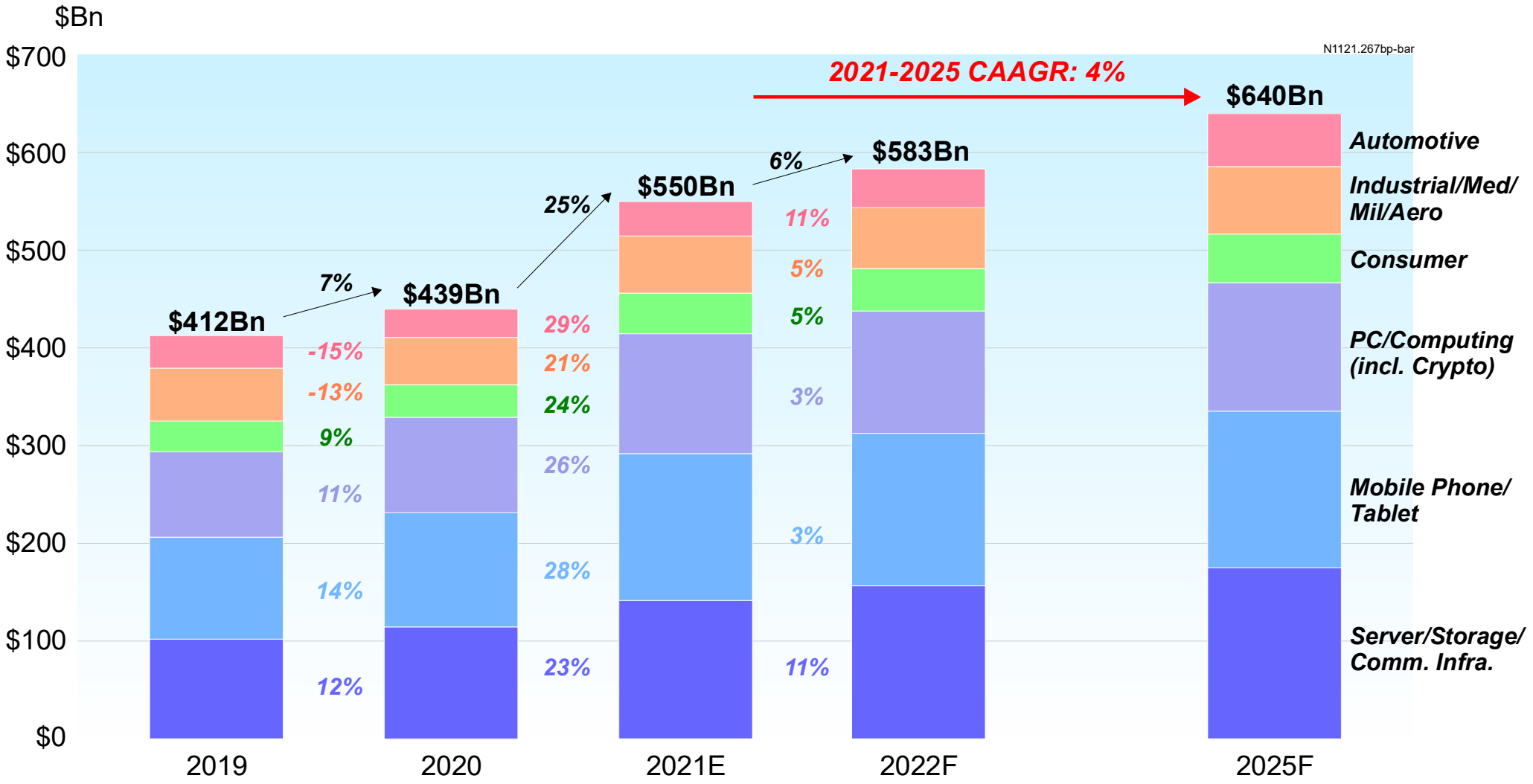
SEMICONDUCTOR REVENUES



SEMICONDUCTOR MARKET BY APPLICATION

($Bn)	2019	2020	Growth	2021F	Growth*	Comments on 2022 Outlook
Server, Storage, and Communication Infrastructure	$103	$115	12%	$142	23%	Data center expansion slowed from 2H 2020, but resumes in 2H 2021 and into 2022
Mobile Phone / Tablet	$103	$117	14%	$150	28%	5G semiconductor content bump continues to drive >10% growth in 2022
Traditional PC and Other Computer	$87	$97	11%	$122	26%	2022 PC market turns negative in units, but semi value continues to grow <10%
Consumer	$32	$34	6%	$42	24%	Slowing systems and semiconductor growth from 2022
Industrial, Medical, Military/Aerospace	$54	$48	-11%	$58	21%	Recovery and strong growth through end of 2022
Automotive	$33	$28	-15%	$36	29%	Strong growth through 2022
Total	**$412**	**$439**	7%	**$550**	25%	System demand + higher semi content enables 12% CAAGR 2019-2022

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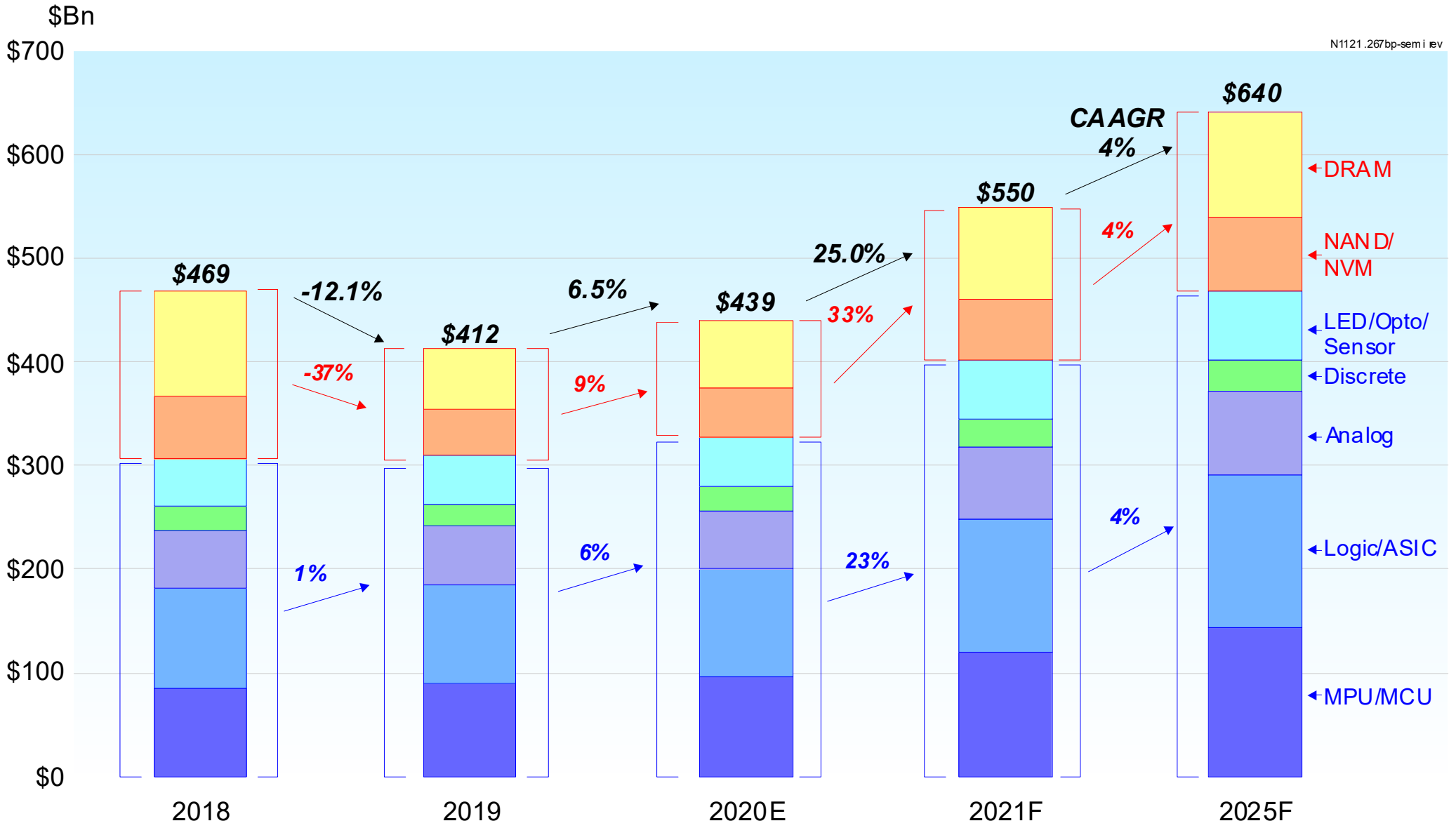
SEMICONDUCTOR REVENUES BY DEVICE TYPE



WAFER FOUNDRY REVENUES

($Bn)	2020	2020 / 2019	Q3 2021	Q3 2021 / Q2 2021	Q4F 2021 / Q3 2021	2021E / 2020
TSMC	$45.54	31%	$14.9	12%	3%	24%
GlobalFoundries	$4.85	-13%	$1.7	11%	7%	35%
UMC	$6.01	25%	$2.0	11%	3%	26%
SMIC	$3.91	25%	$1.4	5%	12%	39%
TowerJazz	$1.27	3%	$0.4	7%	6%	19%
Vanguard	$1.13	23%	$0.4	16%	3%	39%
Total	$62.70	25%	$20.8	11%	4%	26%

Sustained 25-26% YoY Growth

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MAJOR FAB EXPANSION PLANS AND INCENTIVES

	Amount $Bn	Timing	Location	Purpose
Direct Investments				
TSMC	$100	2021-2023	Taiwan, US (AZ)	Advanced packing capacity and R&D
TSMC	$12 (some overlap)	2021-2026	USA (AZ)	New 5nm fab
TSMC	NA	2021-2023	Japan	NA
Global Foundries	$6.3	2021-2022	EU/NY/Singapore	Fab Expansions
Intel	$20	2021-2024	AZ, USA	Two new fabs <7nm
Intel	$3.5	2021-2025	NM, USA	Fab upgrade advanced packaging
Intel	$12	2022-2023	EU	Two new fabs
Infineon	$1.3	-	EU	Power Semiconductors
Samsung	$150	2021-2030	KO/CN/US	Foundry <3nm and advanced memory
SK Hynix	$200	2020-2030	KO/CN	Advanced memory and capacity expansion
SMIC	$2.4	2021	CN	Foundry 28nm
SMIC	$8.9	2022-2024	CN	Foundry 28nm
Government Incentives				
USA	$52	2021-2026	USA	Semi capacity and R&D, yet to be funded
EU	$35	2021-2025	EU	Semi capacity and R&D. ESG
Korea	$100	2021-2025	KO	Semi manufacturing incentives
Japan (Sony/TSMC)	$9.2	2021-2023	JP	<20nm fab

Source: Prismark, VLSI, and company reports

LEADING FABS AND NEW INVESTMENTS IN CHINA

Company	Fab Location	Technology	Total Investment ($Bn)	Capacity/Month	Production Date
TSMC	Nanjing (Phase I)	12-inch	$3.0	20,000	October 2018
	Nanjing (Phase II)		NA	40,000	2022-2023
UMC/United Semi(Xiamen)	Xiamen (Phase I)	12-inch	$1.2	25,000	2016
SMIC	Shanghai	12-inch	NA	120,000	NA
	Beijing (2 plants)	12-inch			
	Shenzhen	12-inch	NA	20,000	2H 2022
Intel	Dalian	12-inch	$2.5	70,000	2010
Shanghai Huahong Group	Wuxi (Phase I)	12-inch	$2.5	65,000	September 2019
CanSemi	Guangzhou (Phase I)	12-inch	$1.9	40,000	September 2019
	Guangzhou (Phase II)		0.9	20,000	Q1 2022
	Guangzhou (Phase III and IV)	12-inch		60,000	By 2025
Hefei CXMT	Hefei (Phase I)		$3.6	20,000	Late 2019
Hangzhou Silan	Xiamen (Phase I)	12-inch	$1.0	35,000	2020
	Xiamen (Phase II)		$1.5	25,000	Late 2022
ASMC/GTA Semiconductor	Shanghai (Phase I)	6, 8, & 12-inch	$5.2	68,000	March 2020
Samsung	Xi'an Plant 2 (Phase I)	12-inch	$7.0	65,000	March 2020
	Xi'an Plant 2 (Phase II)	12-inch	$8.0	70,000	2H 2021
SiEn (Qingdao)	Qingdao (Phase I)	8 & 12-inch	$2.7	33,000	Q3 2021
	Qingdao (Phase II)	12-inch		17,000	
Galaxycore	Shanghai (Phase I)	12-inch CIS	$2.2	60,000	2022
Nextchip Semiconductor	Hefei	12-inch	NA	25,000	End of 2019
YMTC	Wuhan (Phase I)	12-inch	NA	100,000	End of 2020
	Wuhan (Phase II)			100,000	2022
China Resources Micro. (CRM)	Chongqing	12-inch	NA	30,000	2022
SK Hynix	Wuxi	8-inch	$1.4	115,000	Late 2020

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IC PACKAGE ASSEMBLY VALUE (EXCLUDES TEST)

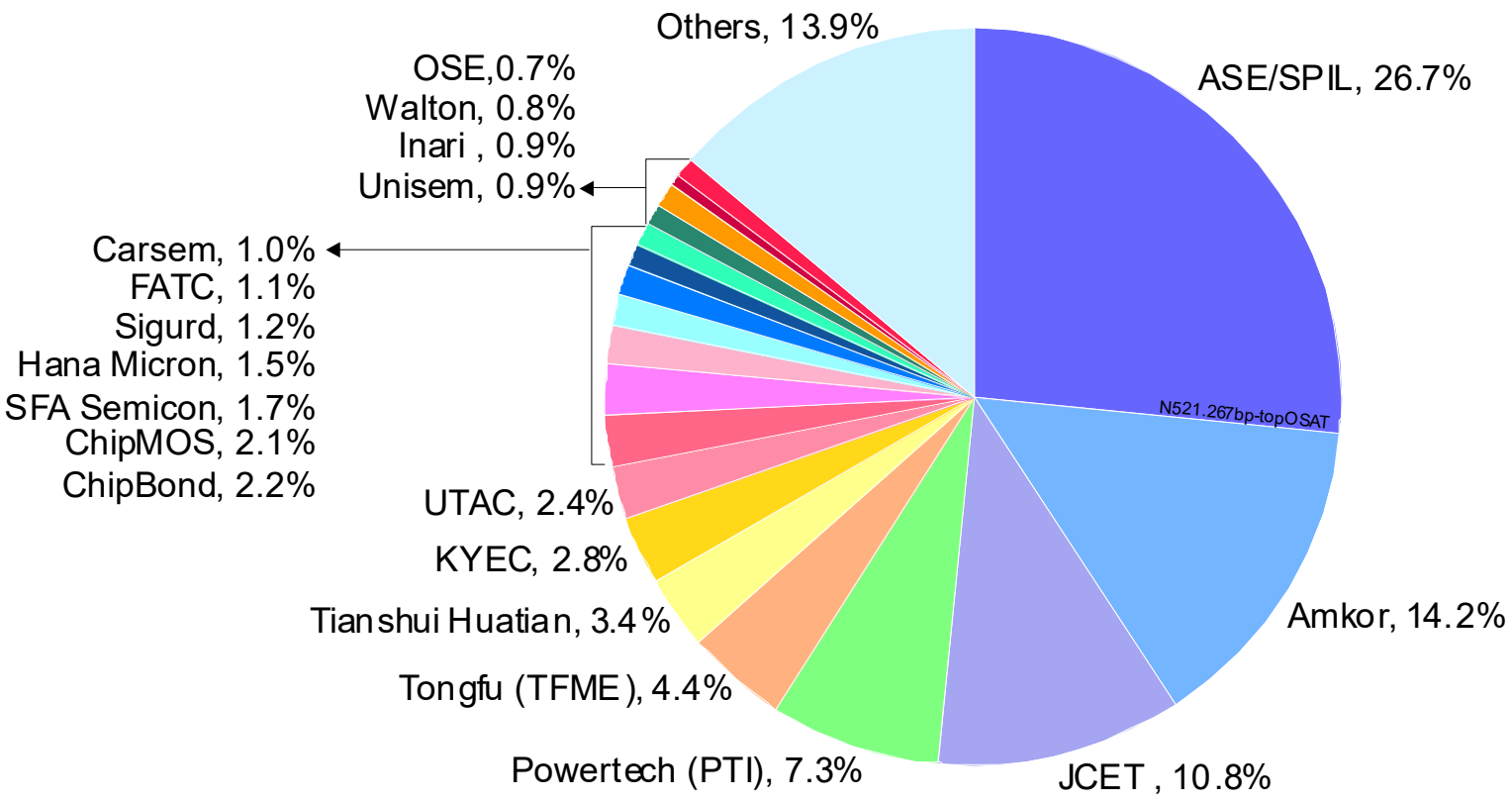
$Bn	2019	2020	2021E	2025F	YoY 2020/2019	YoY 2021/2020	CAAGR 2020-2025
Leadframe	$10.2	$10.7	$13.5	$14.0	5%	26%	6%
Wire Bond BGA/CSP	$6.8	$7.1	$8.5	$9.0	4%	20%	5%
Stacked CSP	$5.2	$5.8	$7.0	$7.4	13%	21%	5%
Wire Bond SiP	$1.4	$1.4	$1.8	$1.8	4%	29%	5%
Flip Chip SiP	$1.3	$1.7	$2.4	$3.6	36%	41%	16%
FCCSP	$4.4	$5.4	$6.7	$7.9	23%	24%	8%
FCCSP/DRAM	$1.1	$1.3	$1.7	$2.2	18%	31%	11%
FCBGA/LGA	**$5.5**	**$6.5**	**$8.8**	**$13.4**	**18%**	**35%**	**16%**
WLCSP	$3.2	$3.2	$4.0	$5.3	0%	25%	11%
FOWLP/PLP	$0.8	$0.9	$1.1	$1.7	13%	22%	14%
HD-FO/2.5D*	**$0.7**	**$1.0**	**$1.5**	**$3.3**	**54%**	**50%**	**27%**
COF/COG	$1.6	$1.8	$2.2	$2.9	13%	22%	10%
Total	**$42.0**	**$46.8**	**$59.3**	**$72.5**	**11%**	**27%**	**9%**

*HD-FO and 2.5D also use FCBGA substrate/assembly

Long-term 9% CAAGR of package value concentrated on QFN, SiP, flip chip, and related advanced packages

TOP OSAT PLAYERS

2020



TOTAL: $35.5Bn

OSAT REVENUES: STILL CLIMBING

$Bn	2020	2020/ 2019	Q3 2021	Q3 2021/ Q2 2021	Q4F 2021/ Q3 2021	2021E/ 2020
ASE	$6.01	19%	$2.16	18%	0%	32%
Amkor	$5.05	25%	$1.68	19%	-2%	20%
JCET	$3.85	13%	$1.25	14%	4%	22%
SPIL	$3.47	12%	$1.04	12%	0%	12%
Powertech	$2.59	20%	$0.80	9%	3%	17%
Tongfu	$1.57	31%	$0.64	7%	2%	52%
Huatian	$1.22	4%	$0.50	7%	6%	56%
King Yuan	$0.98	19%	$0.32	19%	7%	23%
UTAC	$0.86	21%	$0.42	30%	-4%	65%
ChipBond	$0.76	15%	$0.26	2%	4%	32%
ChipMOS	$0.78	18%	$0.26	4%	2%	29%
Carsem	$0.34	13%	$0.12	-4%	3%	40%
Unisem	$0.31	1%	$0.09	-10%	9%	22%
OSE	$0.25	-14%	$0.08	4%	2%	25%
Total	**$28.03**	**17%**	**$9.61**	**14%**	**1%**	**27%**

For 2021, growth coming from both wirebond and advanced (flip chip / wafer level) packages
After 17% growth in 2020, expect 27% growth in 2021, with Q4 likely to be peak of cycle

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PROFITABILITY AND CAPEX OF LEADING OSAT COMPANIES

	2019			2020			1H 2021		
Company	Sales ($M)	Operating Margin %	Capex ($M)	Sales ($M)	Operating Margin %	Capex ($M)	Sales ($M)	Operating Margin %	Capex ($M)
ASE	$5,217	9.5%	$1,038	$6,149	11.0%	$1,197	$3,709	14.6%	$824
SPIL	$3,097	10.2%	$698	$3,466	12.1%	$750	$1,797	17.7%	$267
Amkor	$4,053	5.8%	$472	$5,051	9.1%	$553	$2,733	11.0%	$274
JCET	$3,394	0.5%	$406	$3,847	5.5%	$483	$2,136	10.5%	$255
Tongfu	$1,195	-0.2%	$306	$1,567	3.4%	$526	$1,096	5.6%	$416
Huatian	$1,172	4.4%	$283	$1,219	10.8%	$441	$869	16.0%	$368
Powertech	$2,266	13.1%	$282	$2,588	14.1%	$609	$1,394	16.7%	$227
King Yuan	$860	15.8%	$376	$984	16.1%	$371	$543	16.0%	$310
Chipbond	$710	26.5%	$169	$758	21.7%	$84	$478	24.6%	$100
ChipMOS	$659	12.1%	$176	$782	15.5%	$135	$480	20.1%	$109
Subtotal	**$22,622**	**—**	**$4,208**	**$26,410**	**—**	**$5,149**	**$15,236**	**—**	**$3,149**

After two years of strong growth, and near 100% utilization across all products in 2021, OSATS have been expanding capacity for both wirebond and advanced packages.
Capex for full year 2021 in aggregate will be up >25% after 22% growth in 2020
Even with increased capex, operating margins are well above typical for past 5-10 years

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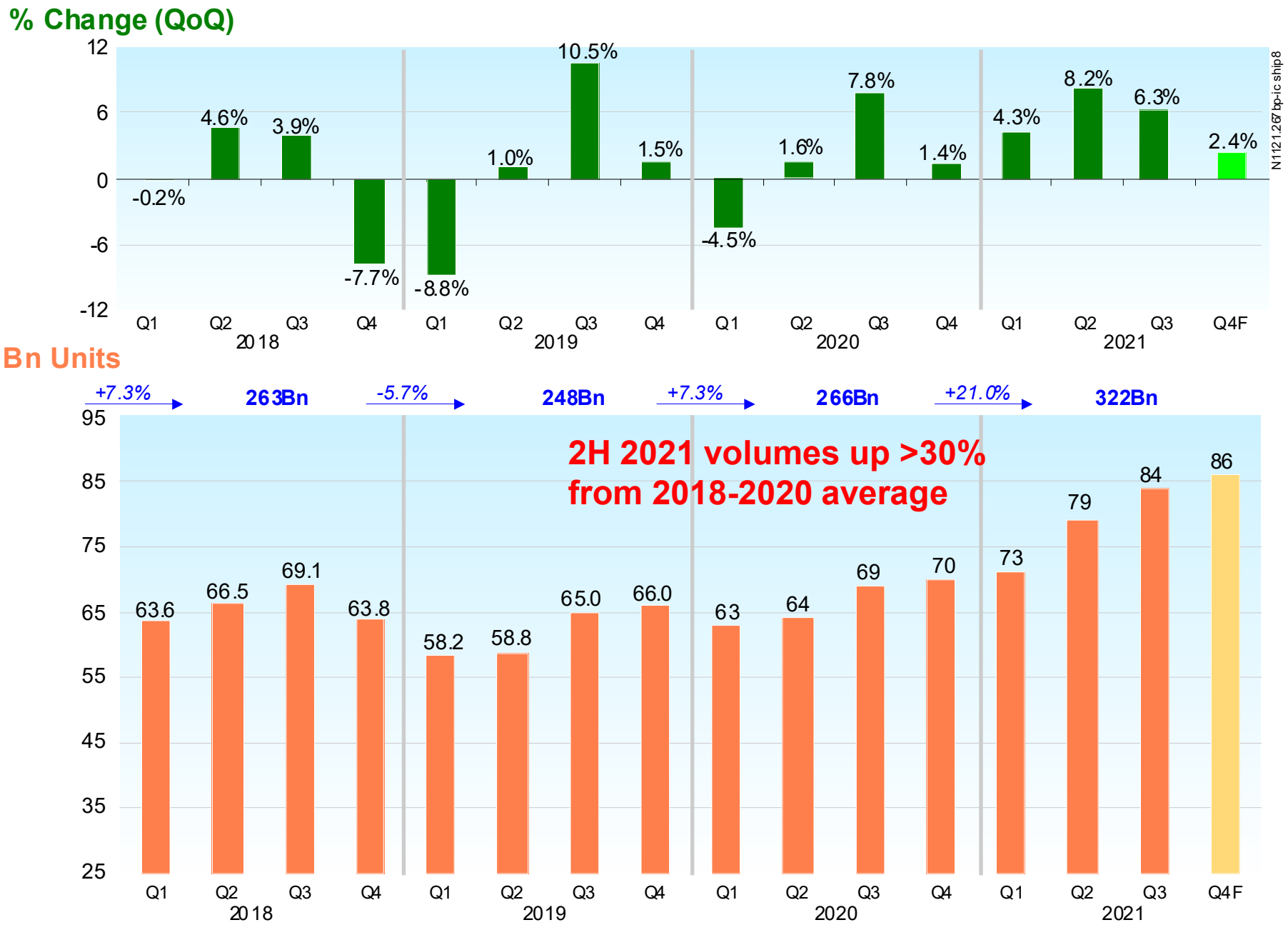
QUARTERLY IC UNIT SHIPMENTS



Source: SIA for historic data

SUPPLY CHAIN FORECAST AND 2022 OUTLOOK

	2020/2019 Revenue Growth	2021F/2020 Revenue Growth	Comments and 2022 Outlook
OEM	2%	12%	2021 growth in all sectors, with supply chain concerns curbing higher growth. **2022 slowdown to ~2% growth**
ODM/EMS	6%	13%	Limited impact from declining automotive/industrial/aerospace in 2020. **2022 5% growth**
Semiconductor	7%	25%	Strong growth from all sectors and increased semiconductor content. **2022 6% growth (higher for non-memory)**
OSAT	17%	27%	OSAT benefit from SiP, complex packages, and fabless customer growth. **2022 growth of >8%**
Package Substrates	*25%*	*38%*	*Growth fueled by strong PC / HPC combined with increasing complexity/ASP* ***2022 growth of 11%***

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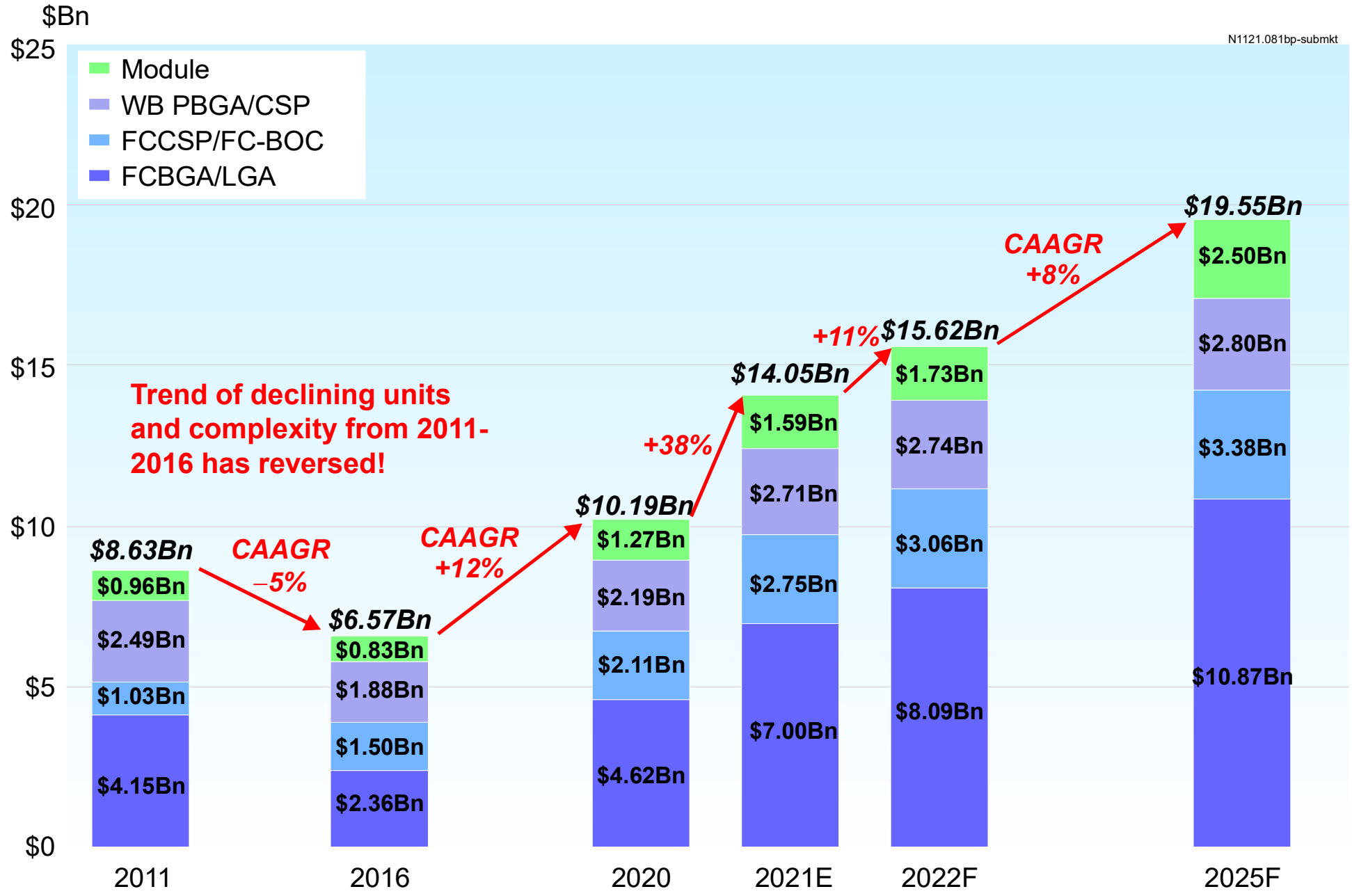
WHEN WILL THE SEMICONDUCTOR BOOM (SHORTAGE?) END

- Most electronics companies experiencing tremendous growth compared to last year
  - OEM, ODM/EMS, PCB, Semiconductor, Foundry, OSAT, Materials, and Equipment
- The absolute growth (vs. 2019 baseline) is stronger across some segments
  - PC, consumer, cryptomining up 20-300% YoY
  - Other segments (industrial, automotive, medical) have recovered to previous levels or better
- Concerns about double booking exist, however:
  - The underlying demand is there, as shown by OEM and ODM/EMS consumption
- Supply chain shortages for many components are expected to relax by the Mid-2022
- Further inventory rebuilding for bottleneck components is likely, but some components are likely over supplied into the channel
- Excess inventory will get utilized in 2H 2022, suggesting a flattening of the growth curve experienced since Q3 2020

FCBGA SUBSTRATES: SHORTAGE AND INVESTMENTS

PACKAGE SUBSTRATE MARKET



SUBSTRATE MARKET: WHAT CHANGED?

- Several factors lead to strong growth in 2020, and will continue in 2021-2025
  - Increased system unit demand
  - Larger and more complex packages
  - Higher selling prices (for the same product)

- Increased System Demand near and long term
  - 2021 PC shipments reached 550M units vs. 425M originally forecast (30% higher)
  - Strong GPU demand for enthusiast / gaming PCs as well as cryptomining
  - Server/Accelerator Cards: Rapid transition to large / complex FCBGA since 2019

- Larger and More Complex Packages
  - Example: excluding data center, Nvidia GPU devices have increased ~30% in X-Y size during 2020/2021
  - Both Intel and AMD have seen a shift toward demand for the >70mm server CPU socket platforms. These typically require 8-2-8 or higher layercount substrates
  - At least a dozen other players now using large and high layercount FCBGA/LGA

- Selling prices for all substrates, but notably FCBGA have increased
  - Prices paid for same substrate last year can be 20-30% higher
  - Customers have been rumored to offer paying higher prices just to secure capacity

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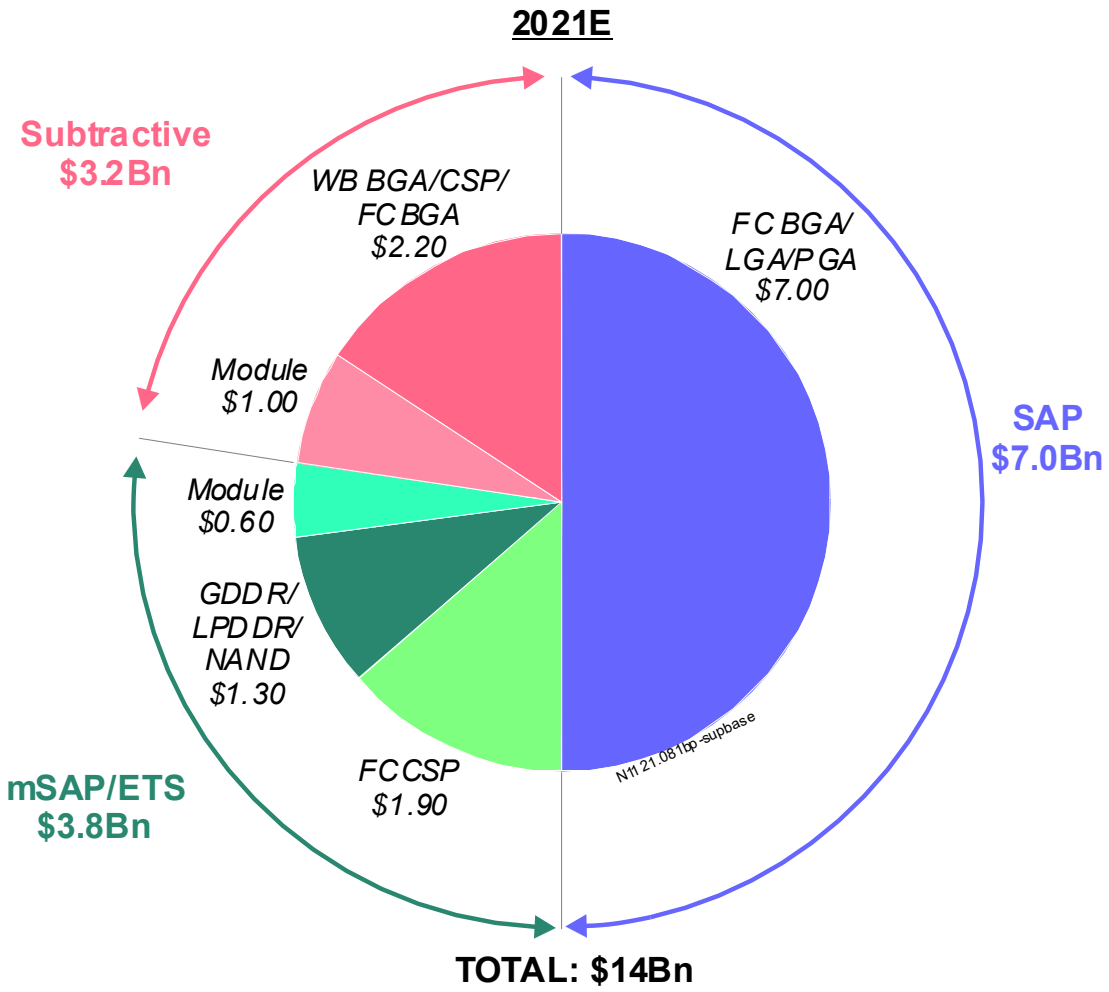
PACKAGE SUBSTRATE SUPPLY BASE



SAP Share	
Ibiden	24%
Unimicron	20%
Shinko	16%
Nan Ya PCB	13%
AT&S	7%
Kinsus	6%
SEMCO	5%
Kyocera	5%
Toppan Printing	2%

mSAP/ETS Share	
SEMCO	22%
Simmtech	15%
Unimicron	14%
LG Innotek	13%
Daeduck Group	11%
Kinsus	10%
Others	15%

Subtractive Share	
ASE Material, Nan Ya, Unimicron, Shennan	10-12% each
SIMMTECH, Daeduck, SEMCO Korea Circuit, Kinsus	5-10% each
Others	25%

PACKAGE SUBSTRATE SUPPLIER REVENUES

Company ($M)	2020	Q3 2021	Q3 2021 / Q2 2021	Q3 2021 / Q3 2020	2021F	2021F / 2020
Unimicron	**$1,635**	**$604**	**18%**	**40%**	**$2,196**	**34%**
Ibiden	**$1,240**	**$508**	**19%**	**61%**	**$1,845**	**49%**
SEMCO	**$1,092**	**$376**	**7%**	**35%**	**$1,434**	**31%**
Nan Ya PCB	**$945**	**$384**	**13%**	**48%**	**$1,399**	**48%**
Shinko	**$876**	**$329**	**21%**	**50%**	**$1,185**	**35%**
Kinsus	**$669**	**$263**	**12%**	**53%**	**$957**	**43%**
Simmtech	$720	$196	-8%	9%	$806	12%
Daeduck Group	$449	$151	9%	27%	$570	27%
LG Innotek	$382	$140	16%	41%	$525	37%
AT&S	**$315**	**$149**	**38%**	**68%**	**$515**	**63%**
Shennan Circuit	$274	$111	23%	54%	$395	44%
ASE Material	$282	$94	9%	31%	$353	25%
Kyocera	**$281**	**$95**	**17%**	**35%**	**$354**	**26%**
Korea Circuits	$159	$58	7%	13%	$216	36%
Zhen Ding	$92	$48	12%	63%	$173	88%
AKM Meadville	$67	$54	34%	177%	$175	161%
Toppan Printing	**$136**	**$37**	**9%**	**6%**	**$144**	**6%**
Shenzhen Fastprint	$43	$21	7%	110%	$79	83%
Fujitsu	**$46**	**$20**	**12%**	**39%**	**$71**	**53%**
Top 19 Total (95% of Market)	**$9,703**	**$3,639**	**14% (QoQ)**	**44% (YoY)**	**$13,391**	**38%**

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SUBSTRATE MARKET BY TECHNOLOGY

Package Types	Process Technology	Typical L/S (µm)	Layer Count	Market Size($Bn) 2020	2021E	2022F	2020-2022 CAAGR
FCBGA/LGA	**SAP**	**8-12**	**6-20+**	**$4.62**	**$7.00**	**$8.09**	**32%**
FCCSP	ETS/mSAP	6-15	2-4	$1.53	$2.02	$2.06	15%
FCCSP/WB CSP for GDDR/LPDDR/NAND, Modules	mSAP	15-25	3-4	$1.40	$1.81	$2.09	22%
FCCSP, WB BGA/CSP, Modules	Subtractive	25-35	2	$2.65	$3.22	$3.38	13%
TOTAL				**$10.19**	**$14.05**	**$15.62**	**24%**

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2021 FCBGA MARKET: CONTINUED GROWTH

- Prismark expects total substrate market to grow another 38% in 2021
  - Continued demand for advanced FCBGA substrates for server, high-performance computing, high-speed networking, and AI applications
  - New FCBGA supply capacities by Ibiden, Unimicron, Shinko, Nan Ya, and AT&S combined with higher pricing for the same products will enable revenue growth as much as 50% in 2021 from the entire market

- "Supply Shortage" has been a frequently used term in semiconductors throughout 2021
  - Starting from 2019, larger and more complex packages using chiplets have pushed the limits or current substrate capabilities, resulting in low yields
  - These low yield, high layer, large packages require significant capacity allocation
  - Package substrate equipment such as imaging (Ushio), via drilling (Hitachi), and advanced plating tools (ASM NEXX) have had long lead times since 2020, and today are extended beyond 18 months
  - Substrate lead times to major customers have been reported as long as 18 months in Q3 2021. In many cases, capacity allocations are starting to extend into years
  - The number of companies that can supply mid- to high-end FCBGA will grow from 10 to 15 or more by 2025

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FCBGA UNITS BY APPLICATION

M Units	2020	2021E	2022F	2025F	2020-2025 CAAGR
Server MPU	45	54	60	70	9%
Desktop/Notebook MPU	415	480	470	520	5%
GPU (Computing/Gaming/Crypto)	195	240	250	270	7%
ASIC/FPGA/AI	125	145	160	190	9%
Computing Chipset	260	290	285	280	1%
Networking/Consumer	220	260	265	320	8%
Automotive (GPU, ASIC/FPGA/Logic)	50	81	110	250	38%
Total	1310	1550	1600	1900	8%

Unit growth of 18% 2021 expected to slow to ~5% CAAGR
Mainly due to slowing PC market and shift to CSP within some platforms

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FCBGA SUBSTRATE VALUE BY APPLICATION

$M	2020	2021E	2022F	2025F	2020-2025 CAAGR
Server MPU	$850	$1,360	$1,730	$2,520	24%
Desktop/Notebook MPU	$1,400	$1,920	$2,170	$2,650	14%
GPU for Computing/Gaming/Crypto	$940	$1,450	$1,690	$2,080	17%
ASIC/FPGA/AI	$450	$800	$950	$1,420	26%
Computing Chipset	$440	$580	$570	$590	6%
Networking/Consumer	$365	$520	$500	$560	9%
Automotive (incl. GPU, ASIC/FPGA/Logic)	$175	$370	$480	$1,050	43%
Total	**$4,620**	**$7,000**	**$8,090**	**$10,870**	**19%**

After 12% CAAGR from 2016-2019, market accelerated to 39% growth in 2020 and 50% growth in 2021
Forecasted to grow another 16% in 2022, before returning to 10% growth
Note value CAAGR of 19% vs. 8% for units

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LARGE/COMPLEX FCBGA SUBSTRATES

- In 2020 and 201, FCBGA packages had strongest unit growth in a decade
  - More critically, trend toward adoption of larger and higher layercount packages continued within this segment; several designs with 75-100mm body size

- FCBGA substrate suppliers expect ~50% growth in 2021 over 2020
  - All major substrate players see capacity booked through end of 2023
  - Some already talking about reserving capacity to 2025/2026!

- Large/complex FCBGA substrates (55mm+ and 5-x-5+) to grow to 70M units by 2025
  - 5-2-5 and above expected to represent 80% of the absolute growth of FCBGA processed area from 2020 to 2025

- Intel and AMD remain dominant end users of large/complex FCBGA
  - Second-tier includes: HiSilicon, Xilinx (now AMD), Nvidia, and Broadcom
  - Third-tier includes: Marvell, Google, Microsemi, Mellanox (now Nvidia), Centec, Innovium, Amazon, Ampere, and likely more

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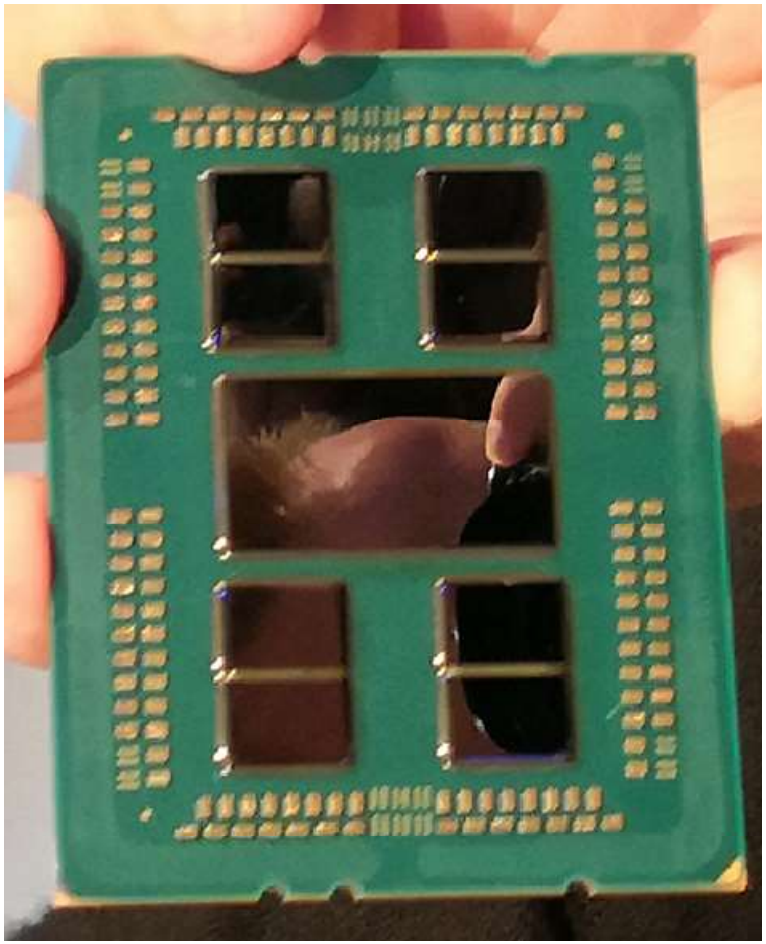
LARGE BODY-SIZE SUBSTRATES: DRIVING DEMAND

- Large body-size substrates include BGA/LGA that are:
  - 55 x 55mm package body size and larger
  - 5-2-5 construction and above

- In 2021, this segment will grow to $1.3Bn
  - 19% of FCBGA substrate value
  - ~2% of market size in units
  - In 2022, will represent >20% of value

- Large-body-size substrate suppliers by value:
  - Ibiden: 35% share
  - Shinko: 25% share
  - Unimicron: 20% share
  - Nan Ya: 10% Share
  - Others: Kyocera, Toppan, Kinsus, AT&S, SEMCO, FICT: 3-5% each

- FCBGA substrate suppliers are upgrading/expanding
  - $15Bn collective investment from 2019-2024
  - Average of $2.5Bn/year (up 7X from 2013-2016)



AMD Server CPU Package
75.4 x 58.5mm
20 Layer Substrate (9-2-9)
Eight 7nm Chiplet CPU + I/O Die

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SUPPORTING LARGE FCBGA/LGA PACKAGES

- The following companies are leaders in capability (not necessarily capacity or production volume) and experience of FCBGA/LGA substrates >65x65mm and 8-2-8 layers or more:
  - Ibiden: Largest player, with focus to support Intel, AMD, and now Nvidia and TSMC
  - Shinko: Long standing player, focus on Intel and AMD
  - Unimicron: Becoming leading player in capacity and technology, supporting nearly all customers, with heavy R&D effort with Intel and Apple/TSMC
  - Nan Ya: Second-tier in technology, with top name customers
  - Kyocera: Long standing supplier of large packages, but limited investment focus
  - Toppan: Long standing supplier of large packages, but limited investment focus
  - Fujitsu Interconnect Technologies: Long standing supplier of large packages
  - AT&S: Mainly supporting Intel
- The following companies are capable and in production/prototyping of such substrates:
  - Kinsus, SEMCO
- The following companies are in low-volume production of FCBGA substrates, but not likely candidates to produce complex substrates before 2023
  - Daeduck, Korea Circuits, ACCESS
- The following are looking to develop FCBGA, with production not likely until 2022
  - SIMMTECH, LG, Xin AI and ZDT
  - ZDT likely to have sizable investment, pending customers/partner commitment levels

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AMD SUBSTRATE DEMAND

- AMD total revenues have gone from $6.5Bn in 2018 to $9.8Bn in 2020, and may reach $16Bn in 2021
  - Total substrate procurement will have grown from $100M/quarter to over $250/quarter by end of 2021
  - Growth has been across all platforms, but notably GPU, high-end desktop, and server products

- Product / Substrate Line Up
  - GPU packages were typically <45 x 45mm in 2020, and historical trend to smaller size has reversed
  - More recent GPU for gaming and other are 52.5x52.5 with 6-2-6 constructions
  - High-end desktop and low end server CPUs are ~50 x 50mm BGA and volumes of 10M/yr
  - “Enthusiast/gaming” desktop (Threadripper) and high-end server are 75.4 x 58.5mm and are 9-2-9. Volumes for DT+server approaching 5M/year run rate
  - Notebook CPU and chipset are typically 25x35mm and can be 2-2-2 (Chipset) to 4-2-4 (CPU)

- Suppliers and Managing Capacity
  - Substrates supply is from Shinko (25%+), Ibiden (25%+), Nan Ya (15-20%), Unimicron (15%), and Toppan (10%)
  - In the process of long-term agreements with above as well as new suppliers Kinsus and AT&S
  - Priority for procurement has been to focus on higher margin products, which includes specific server CPU, enthusiast PC (CPU, chipset, and GPU)

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NVIDIA SUBSTRATE DEMAND

- Nvidia total revenues have grown from $12.8Bn in 2018 to $17.1Bn in 2020, and may reach $26Bn in 2021
  - Substrate procurement has grown from <$100M /quarter in 2019 to over $200M/quarter today
  - Growth has been driven by increasing units, larger package sizes, and growth of high-end products

- Product / Substrate Line Up
  - Gaming GPU have shifted from <45 x 45mm up to 47.5mm and larger for the latest RTX products
  - Both 55 x 55mm and 60x60mm GPU with HBM using CoWoS has been used for data center and automotive applications. Larger packages are coming. Single-digit million units per year so far, but expect >10M in five-year horizon
  - Future growth of large-size FCBGA driven by data center and eventually automotive

- Suppliers and Managing Capacity
  - Substrates supply is from Ibiden (20%+), Nan Ya (~30%), Unimicron (~30%), Kinsus (5%), and also adding Toppan and Kyocera for lower volume products from Mellanox acquisition
  - While Nvidia prepared suppliers for strong growth, this remains a top concern in order to manage current and future demand
  - Went from considering reducing from 4 to 3 suppliers back in Q1 2019, to now seeing that their current 6-7 suppliers cannot support ongoing demand
  - Current focus is to maintain close ties with current suppliers and work to encourage further investment via what has become normal practice: longer term contracts, higher prices
  - Nvidia also has ongoing initiative to address limitations of design rules and yields with suppliers

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SEMICONDUCTOR COMPANY STRATEGIES

- Leading users of FCBGA such as Intel, AMD, and Nvidia have nearly always directly procured substrates
  - Nvidia only for last ten years or so
  - Intel has always been initiator and developer of new substrate technologies

- Suppliers and Managing Capacity
  - Most leaders had attempted to limit major suppliers to 3-4 companies, but each have expanded due to acquisitions as well as current shortage
  - All have long-term agreements, which have expanded in scope and length in the past 6 months
  - Priority for procurement has been to focus on higher margin products
  - To date, only Intel has been engaging in up front investment with suppliers, but others are now doing as well, including smaller end users

- Select Blind Anecdotes
  - “Went from considering reducing suppliers back in Q1 2019, to now having twice as many different suppliers, and even they cannot support ongoing demand”
  - “Current focus is to maintain close ties with current suppliers and work to encourage further investment via what has become normal practice: longer term contracts, higher prices”
  - “Ongoing initiatives to address limitations of design rules and yields with suppliers”
  - “Using OSAT to manage assembly and substrate procurement, but now engaging directly with substrate suppliers to assure capacity”
  - “OSATs currently handle substrate procurement, and will continue to do so outside automotive applications”

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SUBSTRATE SUPPLY / CAPACITY OUTLOOK (1)

- Flip chip package substrates are expected to remain in short supply through the end of 2022, and possibly into 2023
  - Lead time for wire bond, SiP, and FCCSP substrates remains around 15 to 20 weeks
  - FCBGA substrates lead times, though quoted at 6-18 months, has become a bit muddled with companies making agreements out many years.
  - There has been some minor concern about materials, particularly core/laminate products. The supply of ABF or alternatives remains sufficient based on another 20% ramp from current demand level
  - The level of investment should alleviate shortages within the coming 12 months, the concern will be ability of leading equipment companies to deliver upon orders. Most have already increased their deliveries by 50% or more compared to 2020
  - Concerns over shipping and ongoing pandemic-related shutdowns also need to be taken into account

- FCBGA substrates have had significant capacity come online in 2021, with much more to follow in 2022 and 2023
  - Several vendors have added significant capacity for EMIB substrates. This production capability did not ramp as fast as expected (by Prismark) during Q2, but is now ramping

SUBSTRATE SUPPLY / CAPACITY OUTLOOK (2)

- FCBGA extended lead times and price increases identify the market as supply constrained
  - Though most FCBGA suppliers have committed to add more capacity in the next few years, the under supply situation is likely to extend through 2022
  - Substrate suppliers that engage with customers to make longer term contracts (out 2 years+) have cited 1-2 instances where major players have missed opportunities by not acting fast enough

- The growth in electronics will slow, and this will eventually slow down growth of FCBGA substrates
  - Most notably, slowing notebook PC, plus migration to FCCSP will have significant impact from 2022 onward
  - The move to larger size substrates for Server CPU, GPU, and ASIC/FPGA/AI will eventually slow, or even reverse for some segments
  - Yields for larger and high layercount package substrates should improve

- Although all above will take months to years to have impact, combined with sizable investments made to date, and planned in coming 6-18 months, Prismark expects supply/demand balance to restore sometime in late-2022, with a more reasonable, but still high capacity of >90% in 1H 2023

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FCBGA SUBSTRATE EXPANSION

Company	Production Location	Investment Plan
Ibiden	Ogaki Central, Ogaki, and Gama, Japan	$1.2Bn in Ogaki Central, started production in late 2020. $1.6Bn investment in Gama by 2023. New land in Gifu for expansion in 2023
Unimicron	Shanying, Yangmei, and Hsinfeng, Taiwan; and Suzhou, China	>$1.5Bn in 4 years, Yangmei by end 2021, Shangying expansion in 2021. Suzhou, Hsinfeng, and other factories to strengthen non-Intel products
Shinko	Takaoka, Wakaho, and Arai, Japan	Invested $500M and started FCBGA production at Takaoka in 1H 2021 Further $1.3Bn investment within Takaoka site from 2022-2025
Nan Ya PCB	Luchu and Shulin, Taiwan; and Kunshan, China	Investing $500M for FCBGA substrate and SLP products
Kyocera	Ayabe and Sendai, Japan	Ayabe No.3 factory to expand FCBGA substrate production
SEMCO	Daejeon and Busan, Korea	>$380M CAPEX to add 20 to 30% of FCCSP, FCBGA, and AiP $950M investment in Vietnam for FCBGA
Kinsus	Tsinghua, Shihlei, and Hsinfeng, Taiwan; and Suzhou, China	Investing $220M to expand FCCSP and FCBGA substrates
AT&S	Chongqing No.1/No.3, China, and Malaysia	Additional $2.0Bn investment in Malaysia
Toppan Printing	Niigata, Japan	$110M to expand FCBGA substrates for GPU and other
Fujitsu (FICT)	Nagano, Japan	Large size FCBGA substrates as expansion plan for FY2021
Korea Circuit	Ansan, Korea	Expand from 1,000 to 4,000m^2/month capacity in 2021
Daeduck	Ansan, Korea	$140M to expand FCBGA capacity to 5,000m^2/month
Access	Zhuhai, Nantong, China	Invest and expand FCBGA production in Nantong
Shennan Circuit	Kuangzhou, China	$1.0Bn to establish FCBGA production capacity with 200M units annual capacity
Xin Ai / Aalto Semi	Nanjing, China	Total substrate investment plan is $1.5Bn (FCBGA and/or other)
Zhen Ding Technology	Shenzhen No.2 and Qinhuangdao	$1.5Bn to add FCCSP, FCBGA, and AiP substrate capacity

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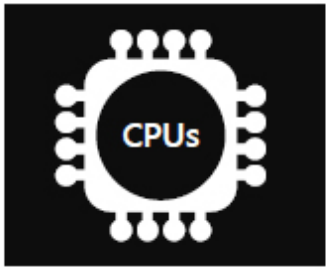
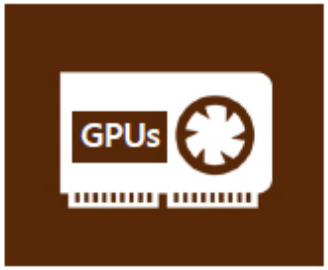
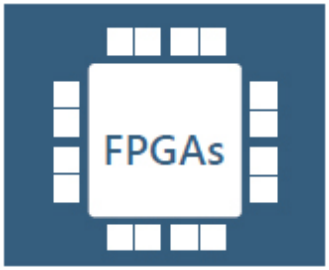
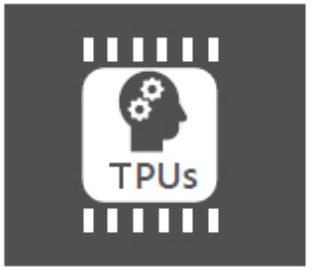
ADVANCED PACKAGE TECHNOLOGIES AND INVESTMENTS

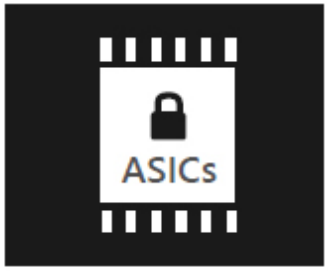
SEMICONDUCTOR OPTIONS FOR MACHINE LEARNING



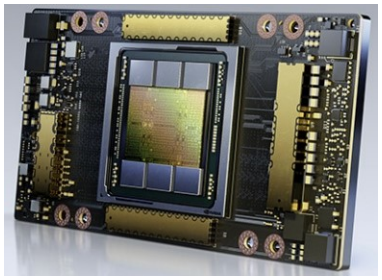




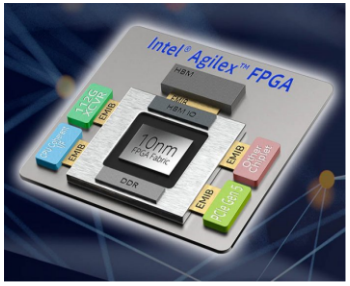




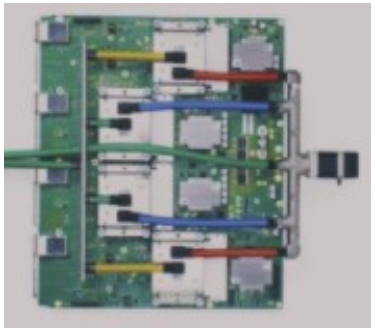
AMD ZEN 3



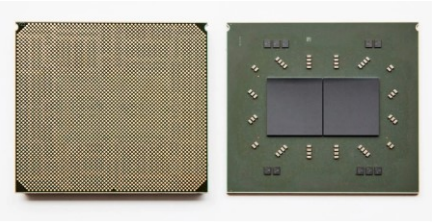
NVIDIA A100



Intel Agilex



Google TPU V4

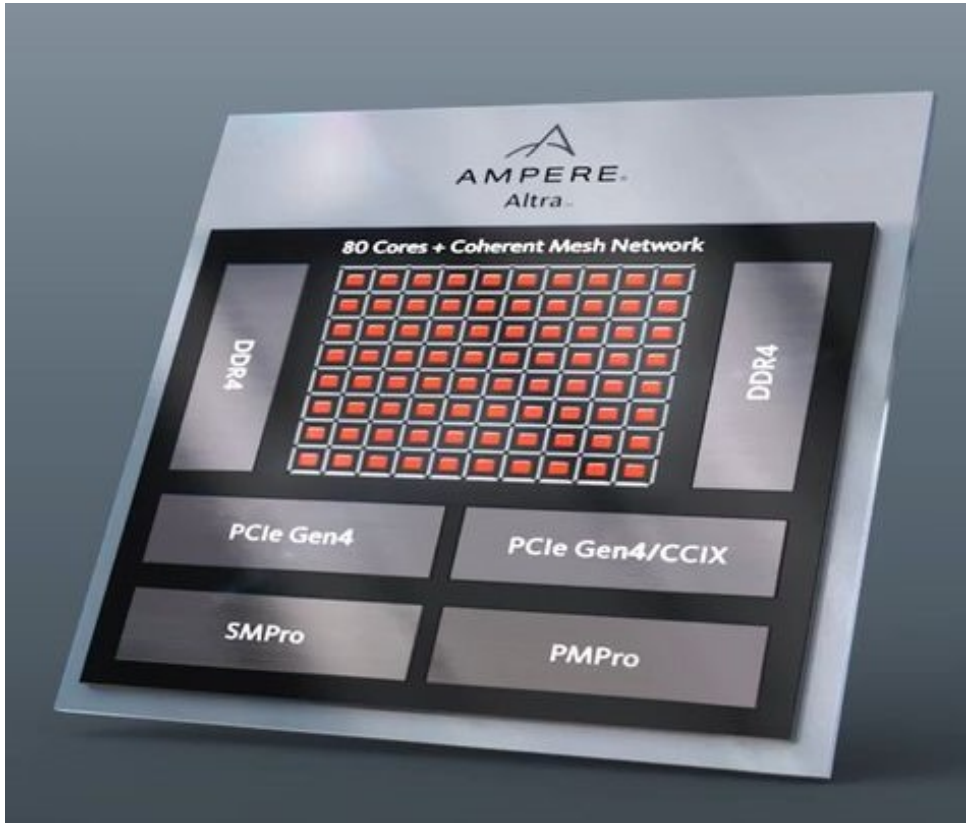


IBM Telum

Source: Prismark, AMD, NVIDIA, Intel, Google, IBM

AMPERE COMPUTING – ALTRA AND ALTRA MAX

- **80-128 ARM v8.2 cores on single die**
  - Up to 3.3 GHz, 200-250W TDP
  - TSMC 7nm FINFET
- ECC protected SRAM cache on die
  - 64KB L1 and 1MB L2 cache per core
  - Additional 32MB system level cache
- Supports DDR4 3200 (no HBM)
  - Up to 4TB per socket with 8 72-bit memory channels
- Single Chip FCLGA with 4926 LGA pads
  - 67x77mm
  - Lidded package



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GROQ TENSOR STREAMING PROCESSING (TSP)

- 14nm die with 26.8Bn transistors
  - Single Core CPU
  - All memory access on die
  - FCBGA package
- PCIe Gen4x 16
- 220 MB on-die SRAM
  - 80TB / s on –die memory bandwidth across 20 lanes
  - Each memory unit contains 5.5MB of SRAM divided into 44 slices (banks) of 128KB each
  - The memory unit can perform two 16-byte reads and two 16-byte writes per cycle

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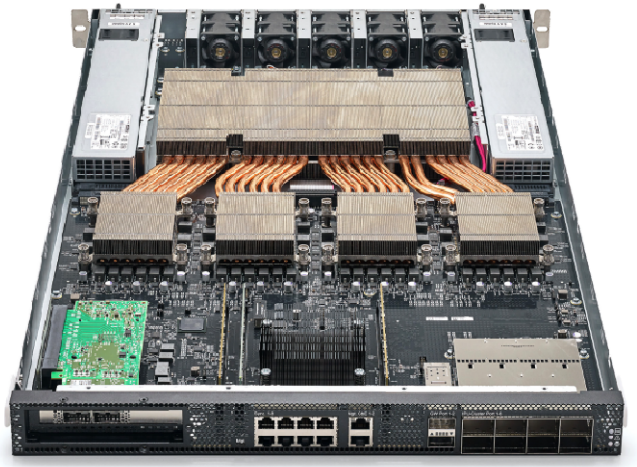
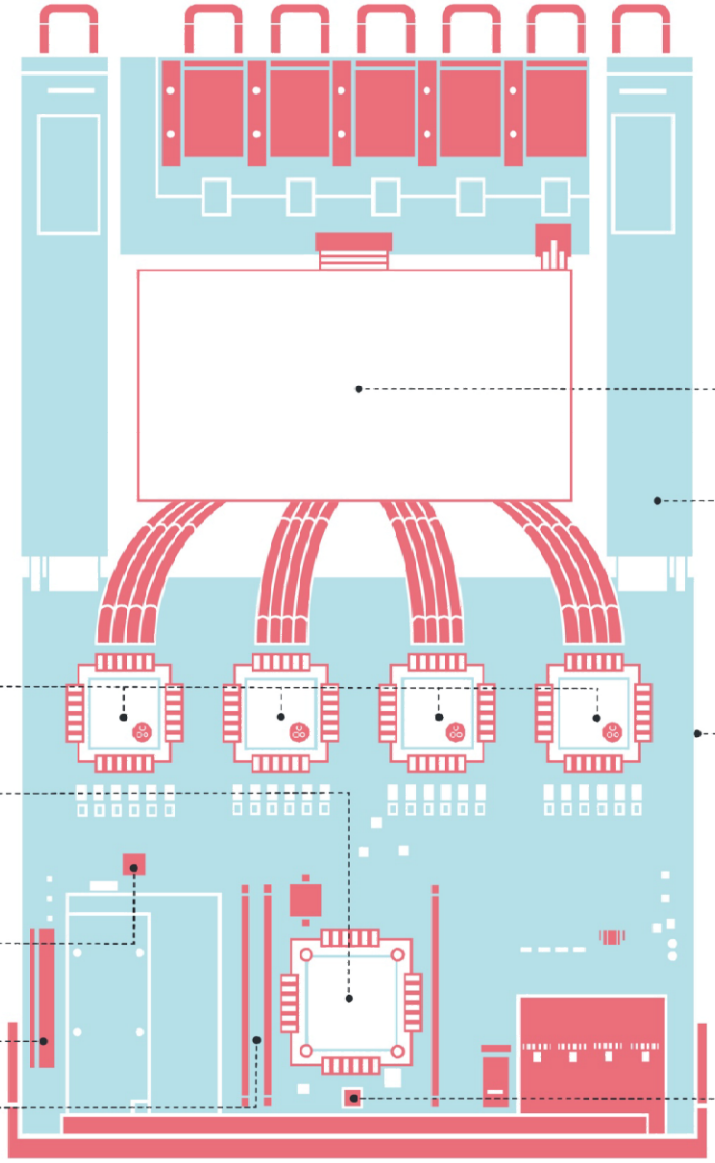
GRAPHCORE M2000 ACCELERATOR

IPU-Machine: M2000

4 x Colossus™ GC200 IPU
1 petaFLOPS AI compute
Up to 450GB Exchange Memory™
2.8Tbps IPU-Fabric™





Each Colossus™ GC200 IPU

59.4Bn transistors, TSMC 7nm @ 823mm2
250 teraFLOPS AI compute
1472 independent processor cores
8832 separate parallel threads

Advanced air cooling system

Power Supply Unit (x2)

Ultra compact 1U server chassis

IPU-Gateway SoC

Arm Cortex-A quad-core SoC
Super low latency IPU-Fabric™ interconnect

Board Management Controller

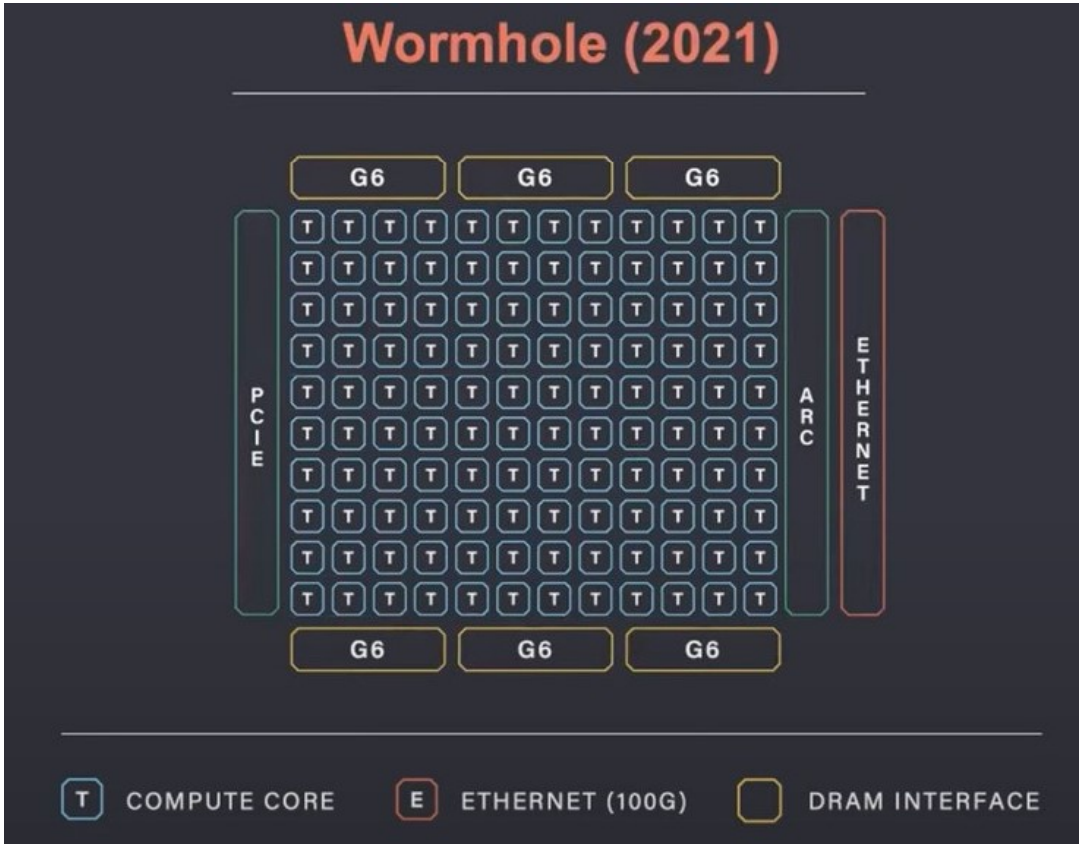
RoCEv2/SmartNIC Connector

DDR4 DIMM DRAM x 2

SSD Connector

TENSTORRENT – AI PROCESSOR

- 150W PCIE gen4 card: 16 ports of 100G for 1.6Tbps
- 6 Channels of GDDR6 to get 384GB/s
- 12nm die from Global Foundries
  - ~25x27mm die, lidded FCBGA
- Configurable in 4U server with 32 processors and 384GB of GDDR6



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ADVANCED PACKAGING – 2.5D AND 3D PACKAGING

- IDMs and foundries play a leading role in advanced packaging technology development
- Intel
  - EMIB for FPGA for last several years, with client CPU ramping for Q4 release. Data center GPU and server volumes ramping expected in Q2 2022
  - FOVEROS 3D packaging for CPU and GPU devices, low volume GPU by end of 2021 and increase production by 2023/2024.
- TSMC
  - InFO: Single-die packaging in volume production. InFO-R or InFO-L in future
  - CoWoS: CoWoS-S in production. CoWoS-R and CoWoS-L under development
  - SoIC: Low volumes now, likely to reach production stage in 2023/2024
- Samsung
  - 2.5D, high density Fan-Out (development), continued PLP program
- OSAT companies such as ASE, SPIL, Amkor, JCET, and now others (TFME, Huatian)
  - Focus on high density fan-out, chip-first, and/or chip-last
  - Continue to support substrate based chiplet and 2.5D

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FLIP CHIP BGA ASSEMBLY

- Total volumes of FCBGA have grown to over 1.5Bn in 2021
  - Most assembly is done by Intel and OSATs
  - Increasing but small share by TSMC for very large packages (CoWoS)

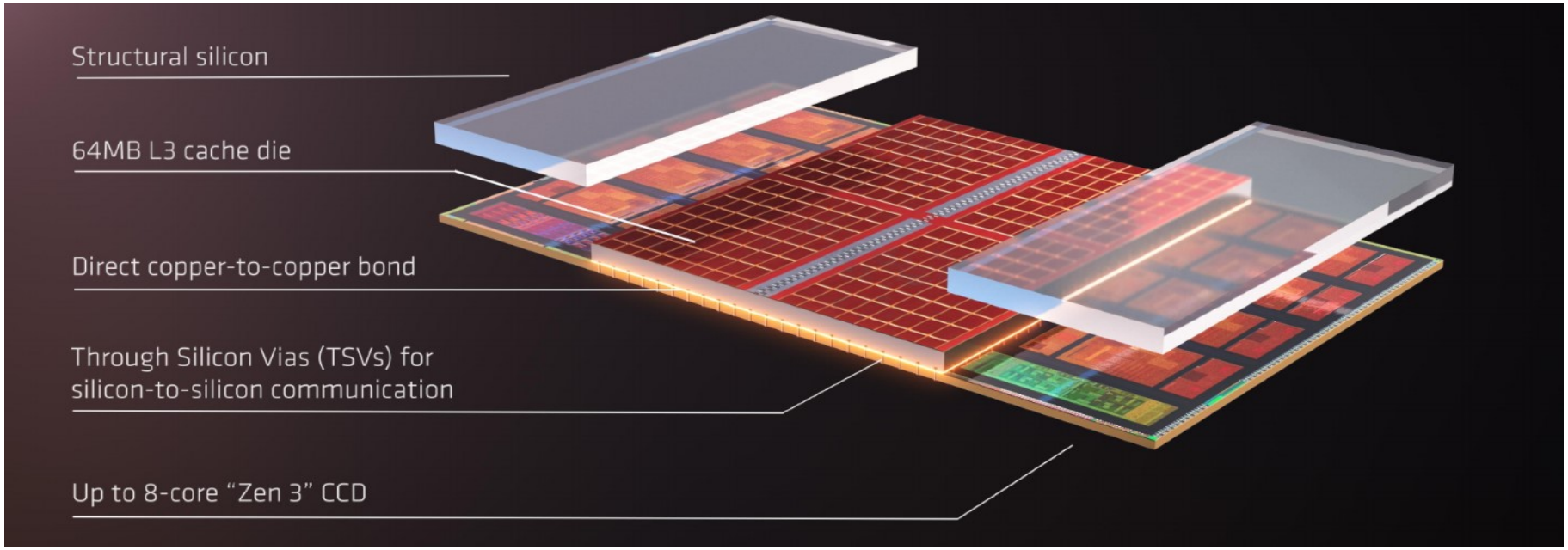
- Estimated regional split by units
  - Taiwan (ASE, SPIL, Amkor): 25%
  - China (Intel, Amkor, JCET, TFME): 15%
  - Korea (Amkor, JCET, Samsung):15%
  - Malaysia (Intel, TFME): 30%
  - All other (Vietnam, Japan/Americas/Rest of Asia): 15%

- Intel is largest user and assembler for server and PC CPU
  - AMD is second largest, with assembly by TFME in Malaysia
  - Nvidia and Broadcom are the third/fourth largest users, with assembly by Amkor Taiwan, ASE, SPIL and others
  - HiSilicon had gained significant share, mainly supported by SPIL and JCET, but now in decline
  - Other users mainly supported by OSAT: MediaTek, Xilinx, Samsung, STMicro, NXP, Marvell, Fujitsu, Renesas, NEC, Centec, Innovium, MicroSemi, etc.

621.081bp

AMD AND TSMC – HYBRID BONDING

- AMD announced use of Cu-Cu hybrid bonding with TSV for next generation Ryzen CPU
  - “Direct Copper-Copper Bond with L3 Cache stacked over L2 on die cache”
  - "TSV for chip to chip communication" TSV to access back/top of logic die to the memory (F2B)
- AMD is working with TSMC with SoIC process
  - Adapted for 3 EPYC CPU part numbers priced $5K-$12K each
  - Targeted for niche applications: weather forecasting, fluid dynamics, AI: 100K>few million per year
  - 15% performance improvement will cost 1.5-2X to end user
  - Eventually goes to more CPU/GPU products, but not anytime soon.



Source: AMD

HYBRID BONDING – EQUIPMENT AND PROCESSING

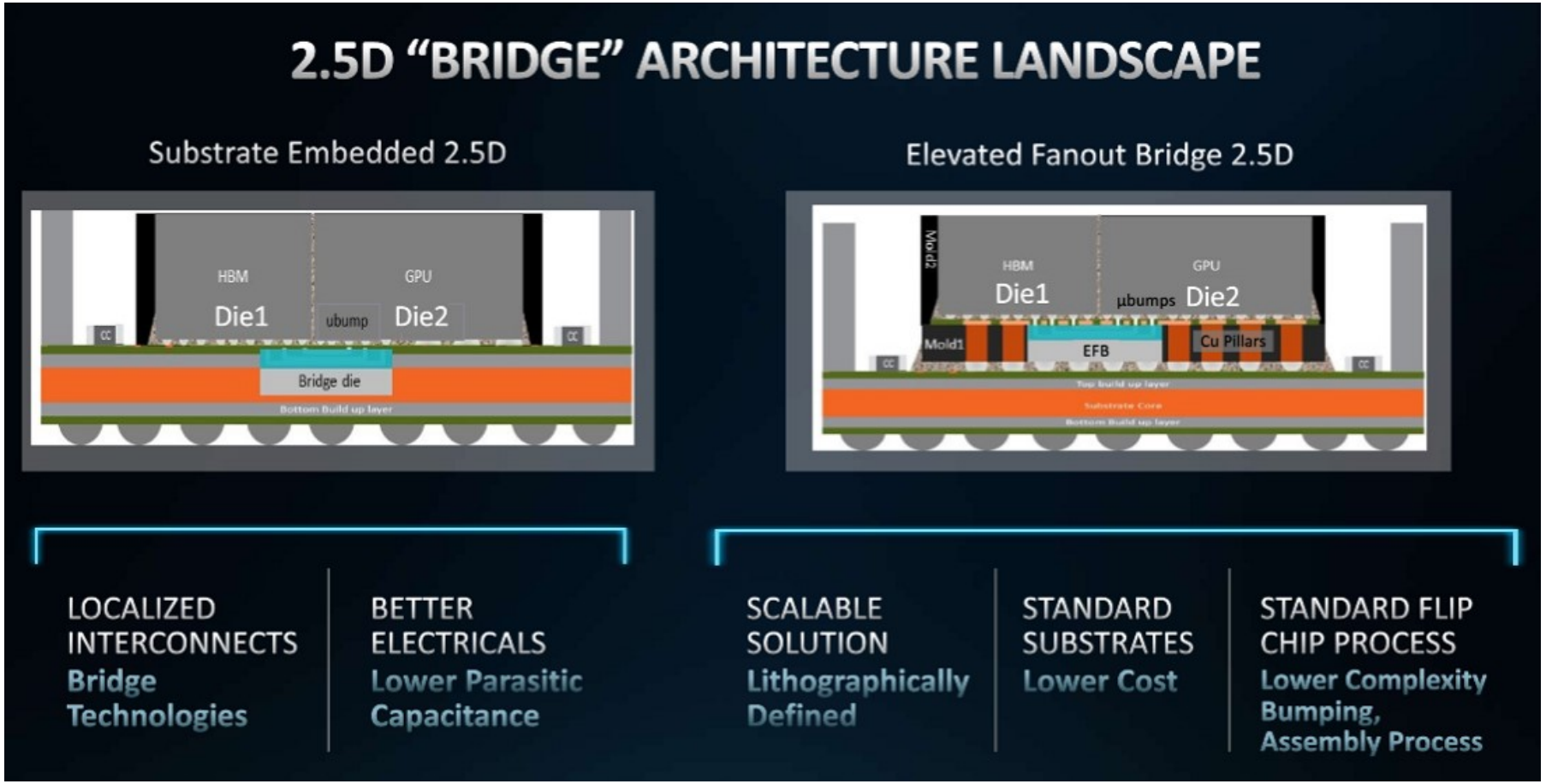
- Equipment Solutions
  - EVG is already entrenched with Xperi DBI process used in volume for image sensors. EVG provides equipment for die preparation and bonding
  - EVG and ASMPT announced joint development to co-develop equipment and process for next generation (e.g. logic and/or memory) hybrid bonding
  - BESI and Applied Materials with recent partnership
  - Suss and SET development partnerships

- Processing challenges to consider
  - RDL and Bump
  - Wafer / Die preparation: CMP, plasma, and other
  - Bonding: Die-to-wafer, wafer-to-wafer
  - Underfill / Encapsulation
  - Other critical process steps: Metal/dielectric deposition, cleaning, etch, planarization, metrology/inspection, annealing

721.294bp

AMD ELEVATED FAN-OUT BRIDGE (EFB)

- AMD announced use of EFB as alternative to 2.5D technology for its forthcoming MI200 Accelerator
  - MI200 integrates 2 GPU + 8HBM stacks onto a single package
  - Uses 2 “FO-MCM” with 1 GPU + 4HBM: Total of 8 bridge chips
- Likely partner with SPIL (FO-EB) and/or ASE (S-FOCoS)
  - Eventually goes to more CPU/GPU products, but not anytime soon



Source: AMD

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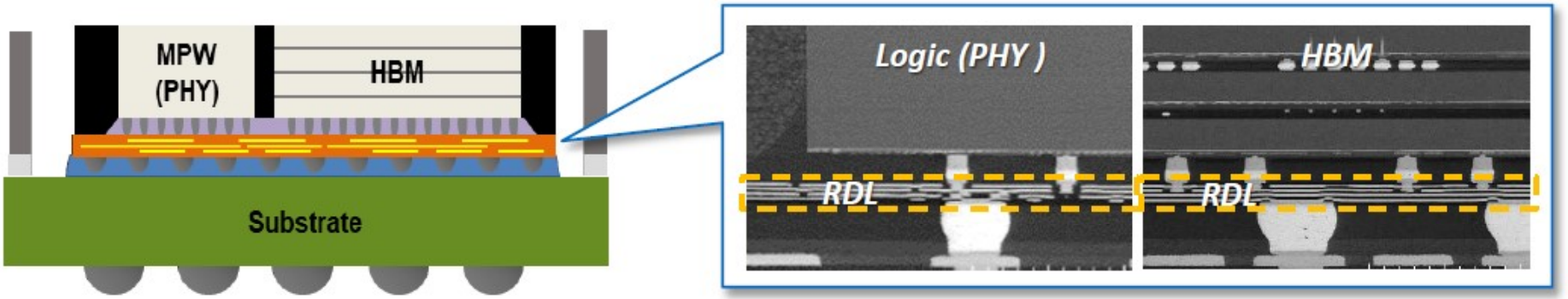
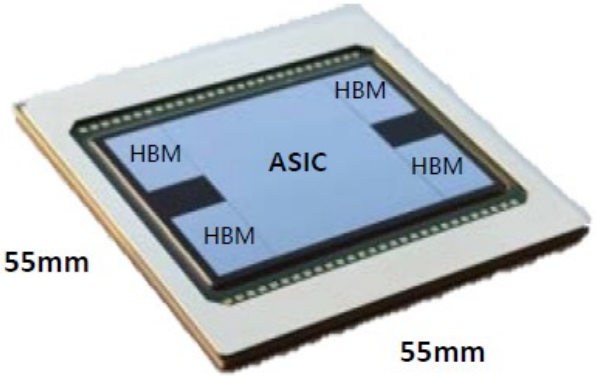
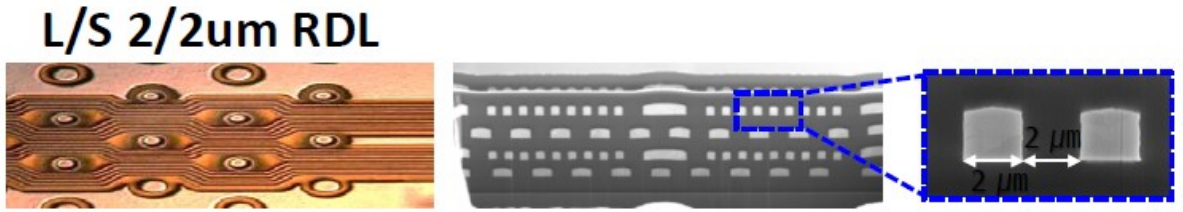
SAMSUNG 2.5D RDL INTERPOSER PACKAGE

- Chip's last FO-MCM approach
- Shorter development cycle and lower cost vs. Si Interposer
- Functionally verified with logic and HBM2E
- Down to 2µm L/S using RDL, and sub-2µm in development with Cu damascene







Source: Samsung

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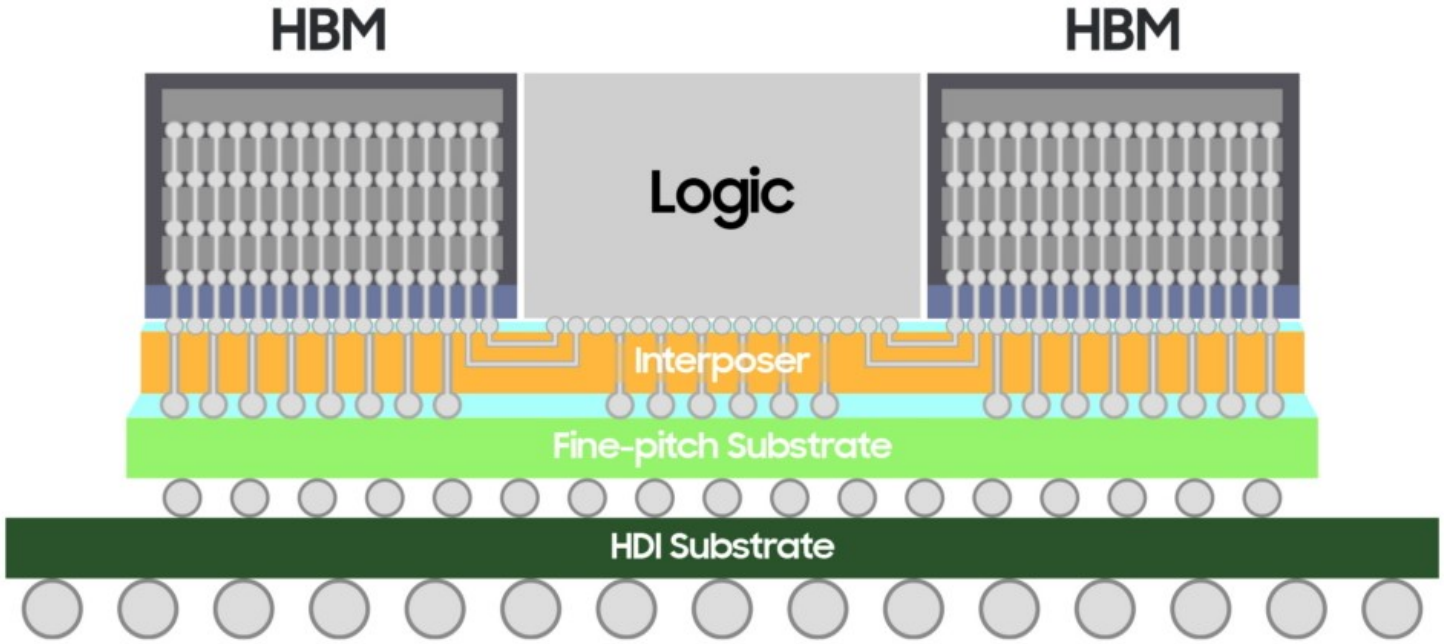
HYBRID SUBSTRATE – DEVELOPMENT AND ADOPTION

- Combining higher density substrate with lower density module is a concept that has been considered in many formats
  - Package substrate on CPU module (Intel Itanium from pre-2000)
  - Intel Patch on Interposer (PoINT)
  - 2.1, 2.3 (substrate/RDL) such as Shinko iTHOP
  - Aside from Intel PoINT (now discontinued) no known design wins at this time

- In 2021, seeing some further interest coming from select customers asking substrate suppliers to propose concepts, such as H Cube™ below from Samsung/SEMCO/Amkor



Source: Samsung

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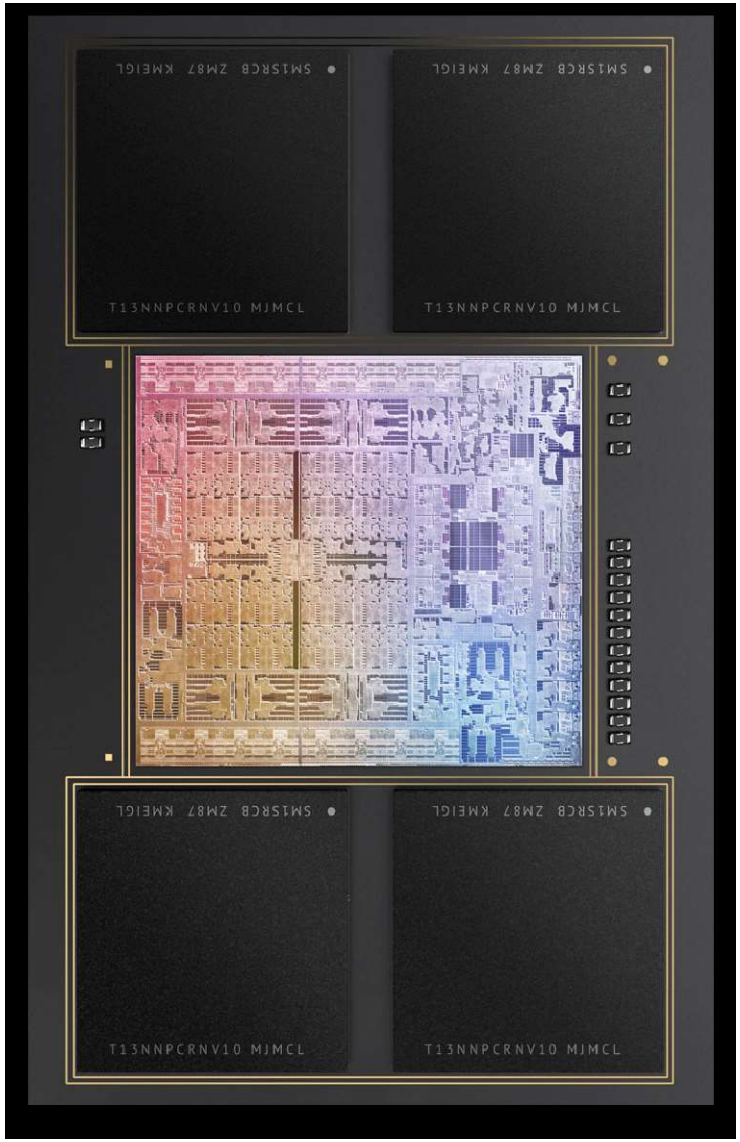
APPLE M1 PROCESSORS

	M1	M1 Pro	M1 Max
Node/ Transistors	5nm / 16Bn	5nm / 33.7Bn	5nm / 57Bn
CPU Cores GPU Cores	8 7 or 8	8 or 10 14 or 16	10 24 or 32
Memory Bandwidth	68 GB/s	200GB/s	400GB/s
Packaged Memory on FCBGA	16GB	32GB	64GB

M1: 23x27mm FCBGA

M1 Pro

M1 Max



Artist renditions from Apple, not necessarily to scale

APPLE SILICON PACKAGING

Planned Production	End 2020	2021	2022*
Target System	Notebook and Mini PC	MacBook Pro	Performance PC
CPU Name	M1	M1Max / M1Pro	“M1Max Duo / Quad?”
Package Structure	CPU + Packaged Memory on FCBGA	CPU + Packaged Memory on FCBGA	InFO-R or similar*
Substrate Suppliers	Unimicron	Unimicron / SEMCO	Unimicron
OSAT Partners	Amkor	Amkor + ASE or JCET?	TSMC

*Future Apple Silicon are speculated to utilize advanced packages

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TSMC – ADVANCED PACKAGING

- Wafer bumping and WLCSP
  - 200K wafer per month
  - Support for all advanced node customers
- InFO_PoP
  - 160K wafer / month capacity; Apple was 100% of sales in 2020
  - Look for MediaTek to adopt in late 2021, with numerous others in consideration
- CoWoS
  - Supports up to 5M units of CoW for 2.5D assembly. Some final assembly done by OSAT partners
  - Known customers include AMD, Nvidia , Xilinx, Google, Intel, Broadcom, HiSilicon, Fujitsu, and NEC
- InFO-R (InFO_oS)
  - Supported <0.2M units in 2020, continues to expand capacity but new customers slow to qualify
  - Known customers was MediaTek, with Apple being speculated for the future
- InFO-L
  - Development, with qualification planned in 2021
  - Possible customers include Apple, AMD, Nvidia, Broadcom, and others currently using CoWoS
- 2021 expansion added 15-18% capacity to its existing capacity
  - Was ready for HVM in June to enable additional 20-25K wafers/month (assuming 3-4 RDL)

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TSMC 3DFabric™

- 3DFabric™ is TSMC's latest terminology covering most of their advanced packaging developments and offerings
  - SOIC: "Front-End 3D" Chip-on-Wafer and Wafer-on-Wafer
  - Advanced versions of InFO: multi-die and embedded bridge (LSI)
  - CoWoS: 2.5D, with latest versions using RDL and/or embedded bridge (LSI)
  - CoWoS-S replaces CoWoS / 2.5D and InFO-R replaces former InFO_oS

Source: TSMC

SoIC: System on Integrated Chips

InFO: Integrated Fan-Out
CoWoS: Chip on Wafer on Substrate
RDL: Redistribution Layer
LSI: Local Si Interconnect

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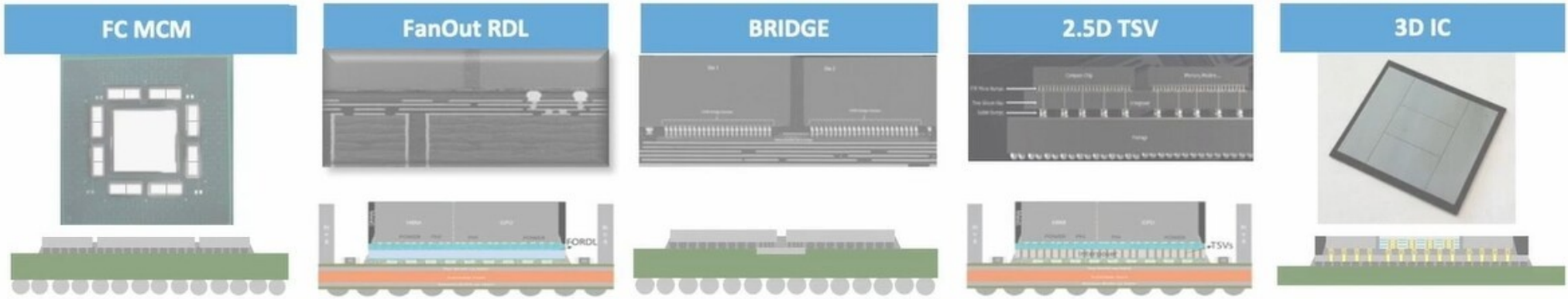
ASE VIEW OF ADVANCED PACKAGING OPTIONS

- ASE Group remains the largest OSAT with a broad range of advanced packaging capabilities
  - Close ties with TSMC and most major fabless players
  - Remains a leading supporter of Fan-out (M-Series, HD-FO/FOCoS, and 2.5D)
- Continues to invest significantly through 2021, but also recognizes limitations of OSAT within 2.5/3D



FC MCM	FanOut RDL	BRIDGE	2.5D TSV	3D IC
• Organic substrate ($) • Low/med density D2D • > 10um line/space • > 100um bump pitch • > 50um D2D spacing • Chip last process • Cost effective	• Post fab RDL ($$) • FC to organic subs. • Med/high density D2D • > 1um line/space • > 40um bump pitch • 100um D2D spacing • Chip first / last • No TSV – lower loss	• Embed Si die ($$$) • Med/high density D2D interconnect • < 0.5um line/space • > 40um bump pitch • High bandwidth • 100um D2D spacing • Chip last process • No TSV – lower loss	• Si Interposer ($$$$) • High density D2D • < 0.5um line/space • > 40um bump pitch • High bandwidth • > 50um D2D spacing • Chip first/last • Power limitation	• Direct D2D ($$$$) • High density D2D • Foundry line/space • > 40um bump pitch • High bandwidth • Shortest interconnect • FC or hybrid bond • Custom die designs

Increasing Bandwidth & Cost

Source: ASE

ASE – INVESTMENT

- Investment Plans
  - Its K11 plant in Kaohsiung plans to recruit an additional 3,000 employees in 2021
  - Evaluating a facility in the US in response to TSMC's fab in Arizona

- Business Highlights
  - Expects tight capacities across its IC packaging and test operations over the next few quarters
  - ASPs for its products are increasing throughout 2021
  - Wire bond and flip chip packaging operations are currently fully utilized, along with other non-backend operations
  - Growth drivers include 5G/WiFi6, automotive, and computer/storage/consumer products

- ASE FoCoS has been in full production for many years for one customer with a few designs
  - Not everyone can make this solution work for them. Chips-last may be necessary
  - Prototype line using 300 x 300mm panels for high-density chips-last development
  - 600 x 600mm panels for lower-density chips-first (M-Series) would only be developed as customer demand grows

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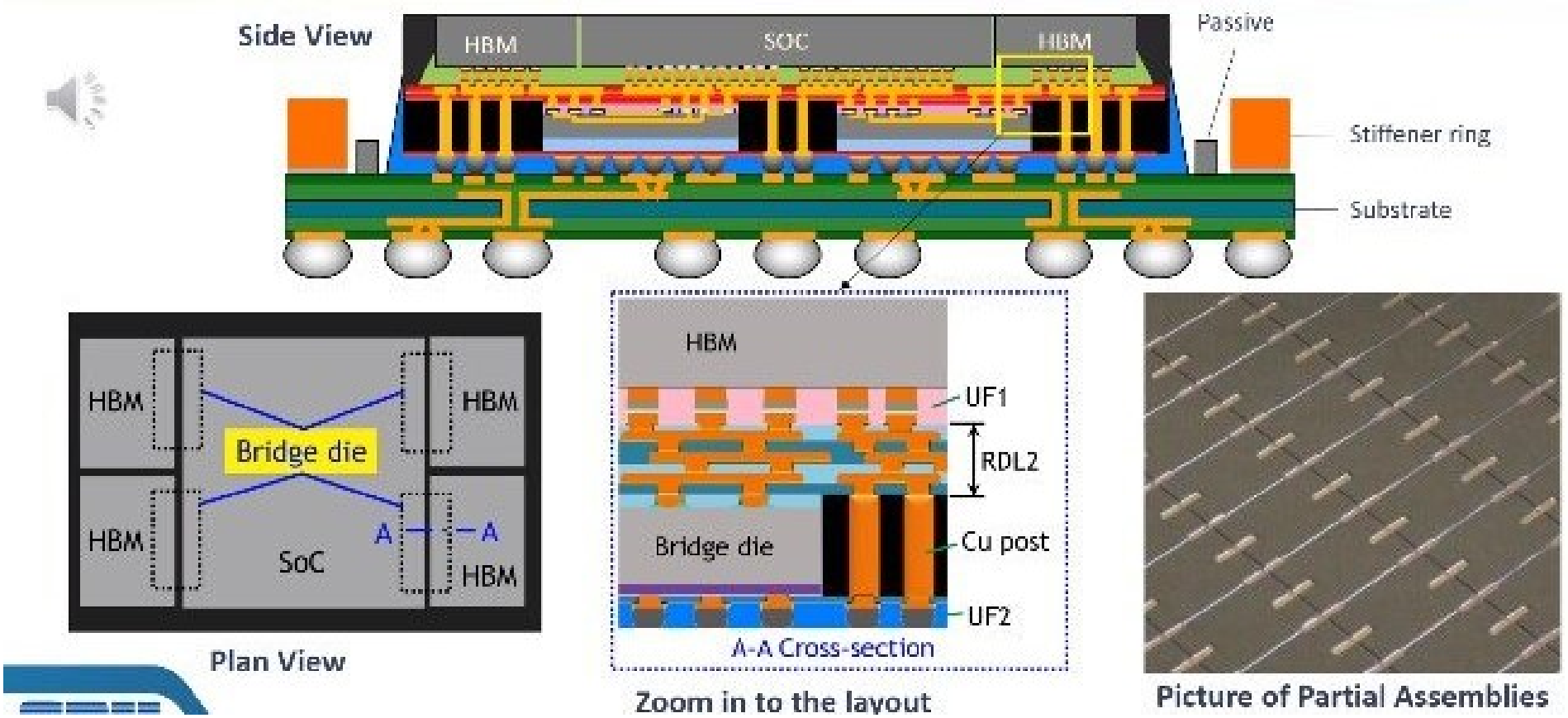
SPIL – ADVANCED PACKAGING

- SPIL working with China and Taiwan customers on alternatives to 2.5D and FoCoS / INFO_OS
- Below is development of a Fan-Out Embedded Bridge (FO-EB) to improve warpage vs. alternatives
  - Potential partners with AMD, Xilinx, and HiSilicon
  - Qualifications in 2021, production 2022
  - Bridge silicon coming from Global Foundries or UMC



Source: SPIL, ECTC 2020

SPIL TECHNOLOGY DEVELOPMENT

- Focus on Fan-out WLP and advanced SiP packages
  - Extremely thin WLCSP
  - FO-WLP capacity of 10-20K wafer per month
  - FO-panel remains an idea, but not being pursued at this time
  - SiP: 5G AiP, power management and RF modules, double-sided SiP with high-thermal solution
- FCCSP
  - PoP offering thin and high bandwidth, large-die
  - 3D IC in FCCSP
  - Thermally enhanced FCCSP
- FCBGA
  - 2.5D for AMD and others at <50K/month
  - FO-MCM ~100K/month for HiSilicon and others
  - SPIL claims to be lower cost than competitors for advanced packages
  - FO-EB: Fan Out Embedded Bridge – license of idea from AMD and looking to qualify in 2021
- Leadframe
  - Triple row QFN, pre-mold spacer-stacked QFN, QFN with passives
  - Triple row QFN can help relieve lack of substrate capacity

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COMMENTS ABOUT CHINESE OSAT COMPANIES

- Chinese OSAT companies are more focused on fan-out technology developments instead of 3D or 2.5D (Si Interposer) packaging technologies
- Very limited exposure of advanced packaging developments to overseas customers
- JCET
  - JCET Shaoxing, will start operation in 1H 2022
  - Focus on fan-out packaging
    - 20,000 wafers/month capacity for eWLB packaging
    - 20,000 wafers/month capacity for multiple die fan-out
  - JCAP bought 10 die bonder for fan-out products, possibly FO ECP
  - Seems very busy in 2021
    - Overseas customers, TI, Infineon, etc.
    - HiSilicon
    - Also doing chip assembly for MTK
    - Many local design house customers
- TFME
  - Customers: AMD, MediaTek, HiSilicon, local customers
  - Appears to be very busy with local customers in 1H 2021
  - Fan-out, 3,000 to 5,000 wafers/month capacity. Not sure for which customers or applications
  - Seems not to be making any progress in fan-out packaging
  - MTK feels TFME's support is getting worse. Busy with local customers

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JCET – NEW INVESTMENTS

- Investment Plans – JSX
  - Completed construction of a new advanced 300mm packaging facility in the eastern city of Shaoxing in June 2020
  - With a planned total investment of $1.15Bn (RMB8Bn), the new Shaoxing facility will focus on providing advanced packaging services, such as WLP, with an annual capacity of 40,000 (12-inch) wafers/month in Phase I production
  - Production of eWLB, ECP, and XDFOI™ to start in HVM by 2022
  - Will begin production at its Suqian Phase II facility in the near future

- Business Highlights
  - Both its Jiangyin, China, and Korean plants have received in-vehicle product qualifications from large customers located in the US, Europe, and Korea, particularly ADAS products
  - In the semiconductor storage sector, it offers DRAM, Flash, USB, and SSD solutions
  - It has volume production capability for 16-layer stacked chips in Jiangyin
  - Going forward, the company will continue to develop high-end products for use in new advanced applications, such as 5G

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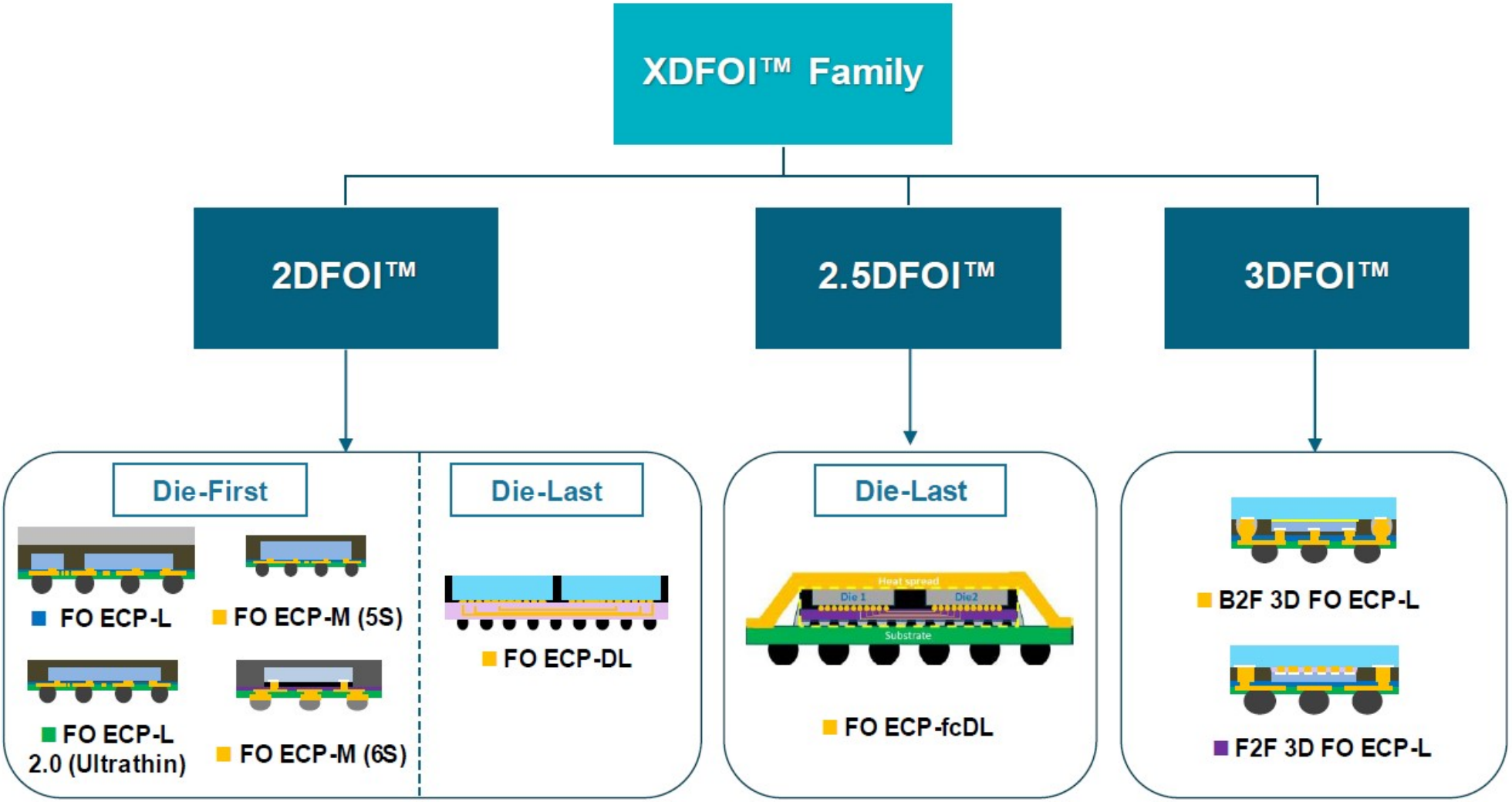
JCET/JSX XDFOI™ PORTFOLIO



Source: JCET

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COMMENTS ABOUT CHINESE OSAT COMPANIES

- Huatian
  - It seems most of the growth comes from local customers
  - Has recently bought 10 die bonder for fan-out assembly in 2021
  - There are many design houses in China. They are producing PA, filter RF ICs, BAW filters, baseband, AI chips, etc.
  - They used to use Taiwanese OSAT companies, but changed to local OSAT companies, like Huatien and Tongfu for a lower cost
  - Huatian seems aggressive in new technology developments, such as bumping, flip chip assembly, fan-out, and others
  - Can produce WLCSP products

- China has a lot of semiconductor design houses. That is likely to change some company's attitude toward using local OSAT companies.

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NEXT-GENERATION PACKAGE MARKET SUMMARY

Package Type	Examples	Applications	Leading Design Houses 2020	M Packages 2019	2020	2025	Comments
FO-Small Die	eWLB, M-series, PLP	PMIC, TrX, Codec	Qualcomm, MediaTek, Samsung, NXP, Infineon, others	650	660	1,500	Low end RDL needs
FO-POP	**InFO_PoP**	**Mobile AP**	**Apple**	**246**	**250**	**400**	**Dominated by Apple/TSMC**
Bridge Chip	**EMIB, FO-EB, InFO_LSI**	**CPU, GPU, FPGA, Networking Processor/ASIC**	**Intel, others?**	**2**	**2.5**	**200+**	**Intel EMIB gaining traction**
FO-MCM	**FOCoS, InFO_oS**	**Networking Processor/ASIC**	**HiSilicon, MTK/Nephos**	**4**	**3.5**	**15**	**Notable interest, yield issue**
2.5D	**CoWoS**	**GPU, Networking, ASIC, AI, CPU**	**Nvidia, Google, XilinX, Broadcom, AMD, Intel, HiSilicon, Fujitsu, NEC**	**4**	**5**	**12**	**Best solution, high cost**
3D Logic	Foveros, SoIC	CPU chiplet + I/O die	Intel, Samsung, and others (AMD) with TSMC	0	5	100++	Early stages

Most current investment and interest is related to above "next-generation" packages

This leaves reduced interest in embedded die, panel level packaging and glass interposers each of which has had limited commercial success

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SUMMARY OF INVESTMENTS IN ADVANCED PACKAGING

- Leading FCBGA substrate suppliers continue to upgrade and expand capacity
  - Nearly $15Bn total investment planned for FCBGA substrates during 2019-2024
- TSMC continues to expand its advanced packaging capability
  - $1Bn invested for InFO in 2016/2017, with investment levels resuming in 2019/2020
  - Capex for back end estimated at $1.5Bn for 2021 alone, driven by new site and SoIC
  - By Q2, expect 15-20% capacity addition of RDL processing to be ready for HVM
- While OSATs have increased overall spending dramatically to align with current and near-term demand, most OSATs remain a bit conservative when it comes to fan-out investments
  - ASE, Amkor, JCET have recognized limited returns in low-end fan-out packages
  - All have had long-term development of high-density fan-out, but volumes remain low
  - Recent plans by JCET/JSX, SPIL, ASE, and others appear to have justified backing
  - Reality remains that TSMC, Intel, and Samsung are better positioned for many advanced technology solutions: 2.5D, HD-FO, 3D / hybrid bonding
  - 5 → 3 “nm” chip designs requiring <50µm bump pitch will encourage all above to accelerate advanced package platforms that may have been idled for some time
- **The current high level investment environment for both conventional and advanced packaging is likely to last through the end of 2022**
  - **For 2023 and beyond, Prismark expects a typical correction period as sufficient capacity additions catch up with the slower underlying growth in demand for semiconductors**

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THANK YOU!

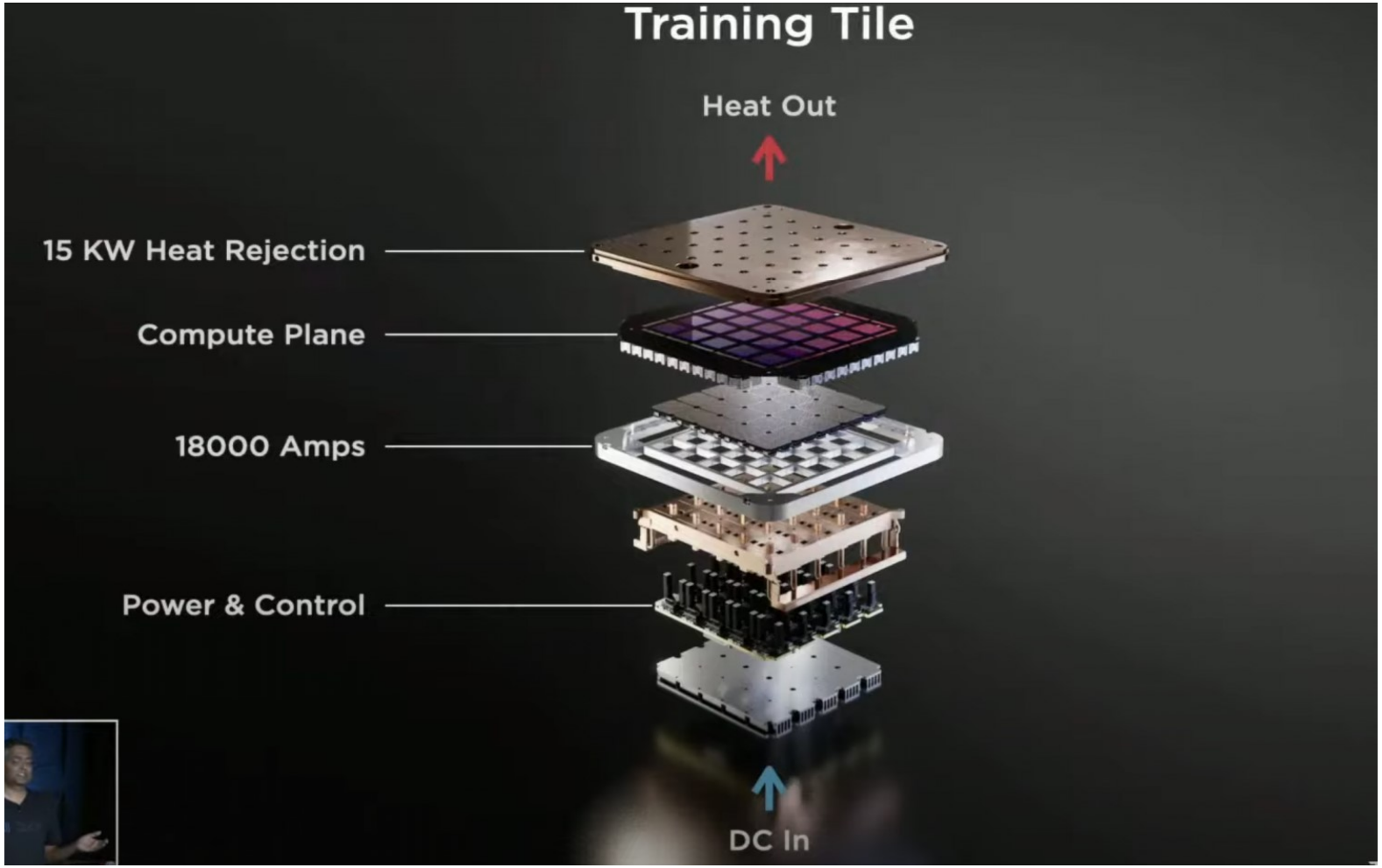
Further questions, please contact bprior@prismark.com

Brandon Prior
Senior Consultant

FURTHER SLIDES ON MOBILE PACKAGING / PLP

TESLA: PROJECT DOJO

- TESLA announced its Dojo AI training solution in August 2021, with limited details
- Presumed to be working with TSMC using InFO type packaging
- Currently TESLA is using Samsung foundry for self driving CPU in vehicles



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TESLA: PROJECT DOJO

- Likely using RDL to connect high density memory to CPU tile
- TSMC InFO-SoW package would allow Tesla to mount VRM modules directly on top of the CPU die

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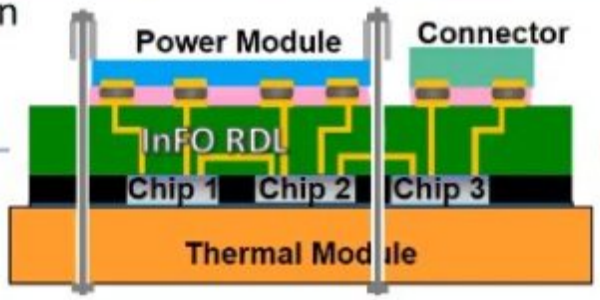
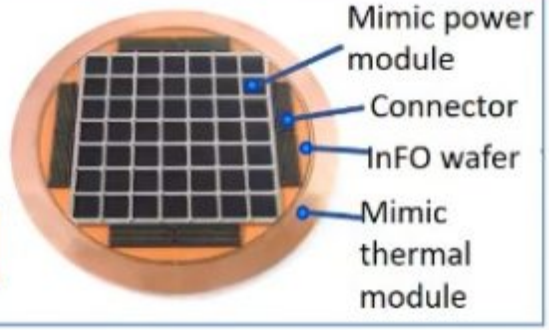
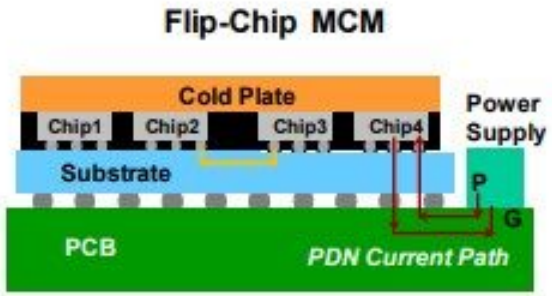
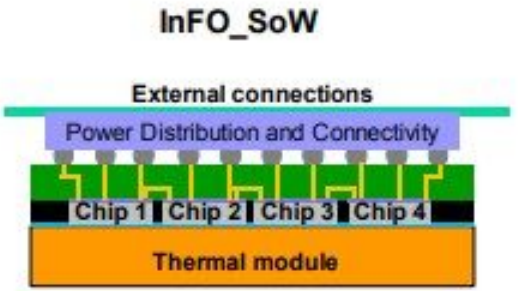
TSMC InFO-SoW (SYSTEM-ON-WAFER)

Index	Key Advantages of InFO_SoW- Higher compute density & faster training time
Electrical Performance	✓ Low latency C2C communication ✓ High bandwidth density ✓ Low PDN impedance
Cost & Yield	✓ Mature InFO process ✓ Known-good chip ✓ Heterogeneous integration









Line width / space (µm)	10 / 10	5 / 5
Line density	1x	2x
Bandwidth density	1x	2x
PDN impedance	1x	0.03x

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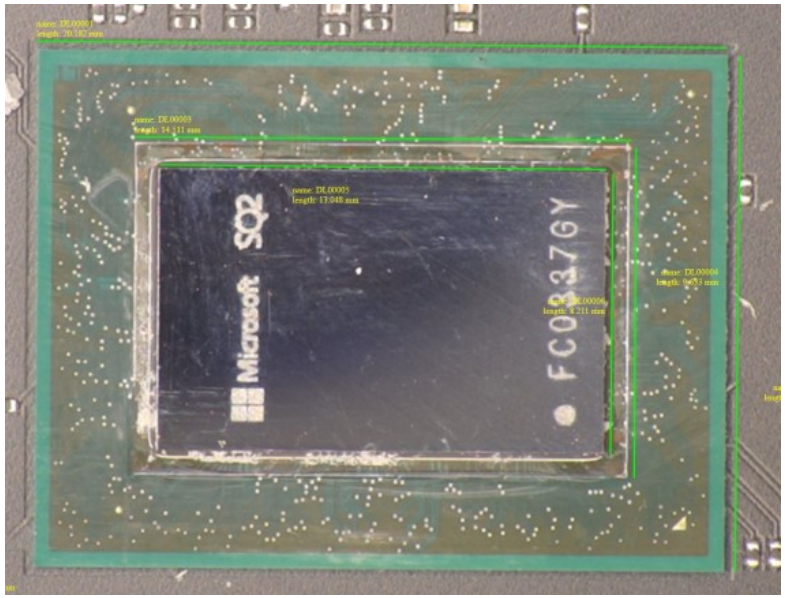
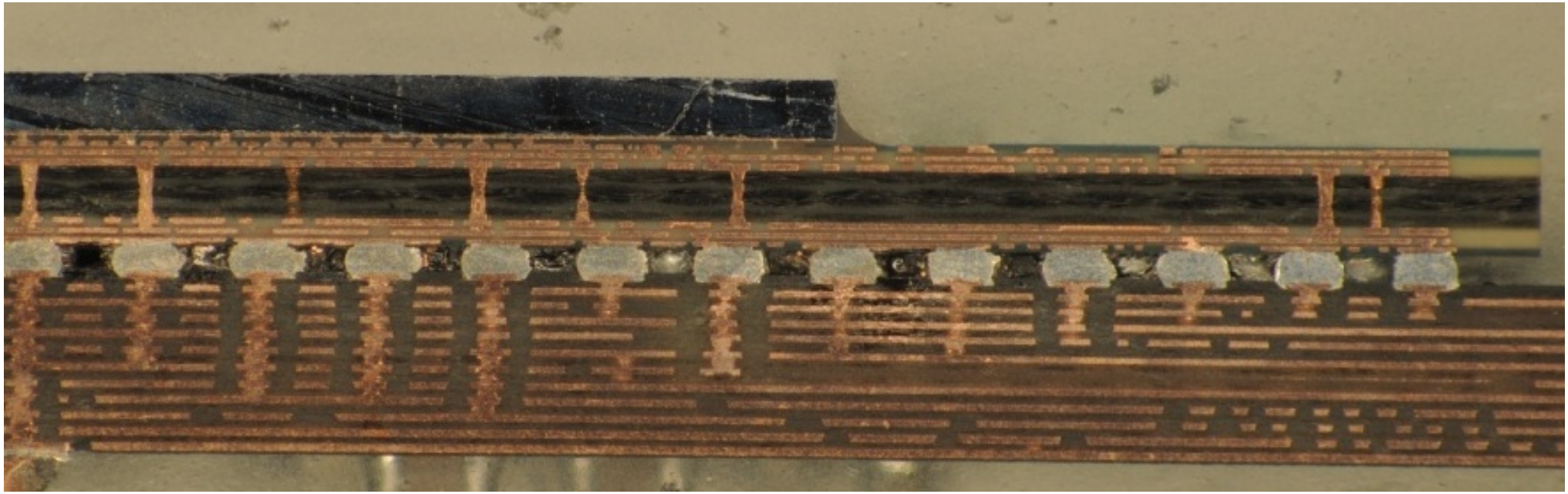
MICROSOFT/QUALCOMM SQ2 NOTEBOOK CPU

- 15 x 20mm FCBGA (FCCSP by Prismark definition)
  - 2-2-2 Layer count using SAP/ABF
  - 0.98mm mounted height
- 8.2 x 13.1mm die
  - 300µm thick
  - Capillary underfill
  - 12.5 x 14mm





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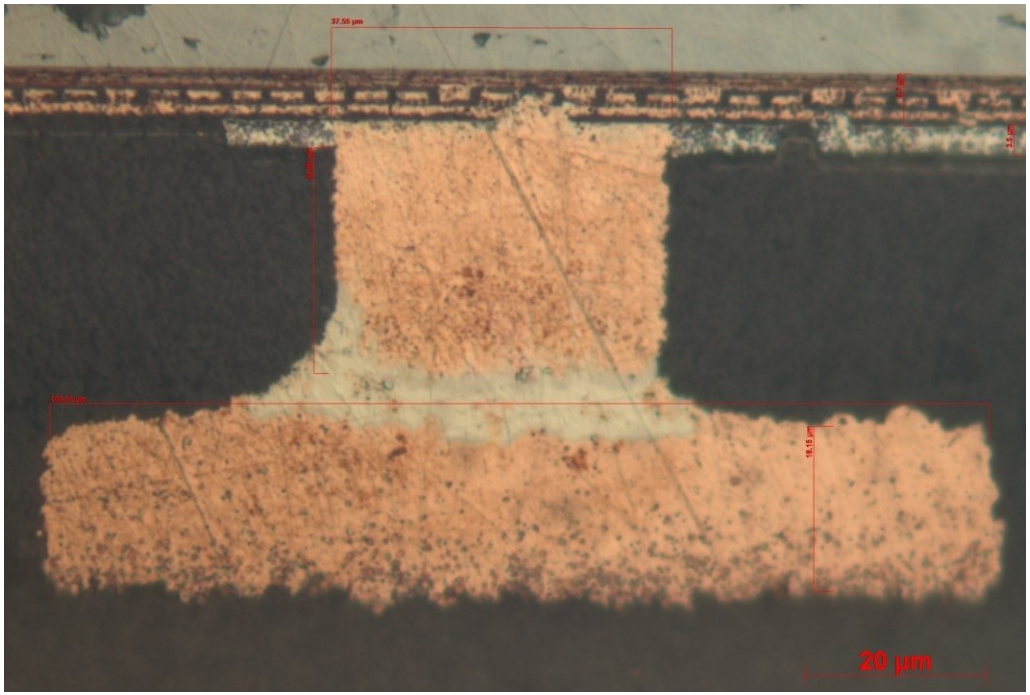
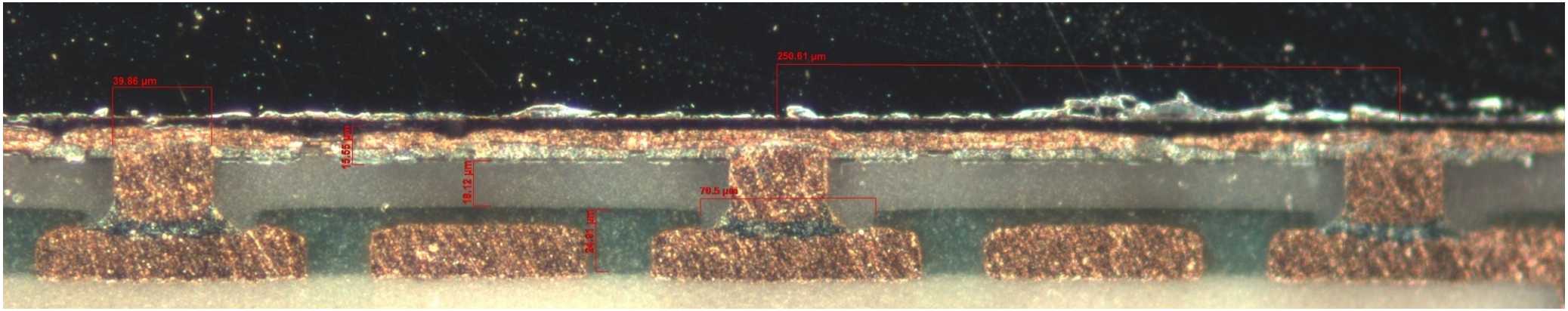
Photos source: Prismark/Binghamton University

MICROSOFT SQ2 – FLIP CHIP BUMPS

- Copper Pillar bump with SnAg cap
  - 35µm standoff height
  - Measured 37µm diameter
- Effective bump pitch of 175µm at this location





Photos source: Prismark/Binghamton University

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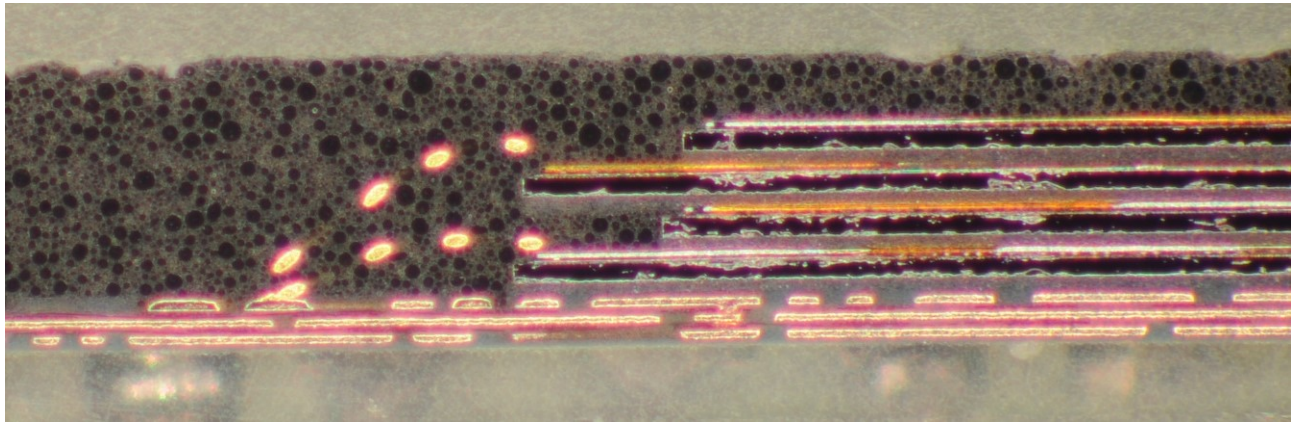
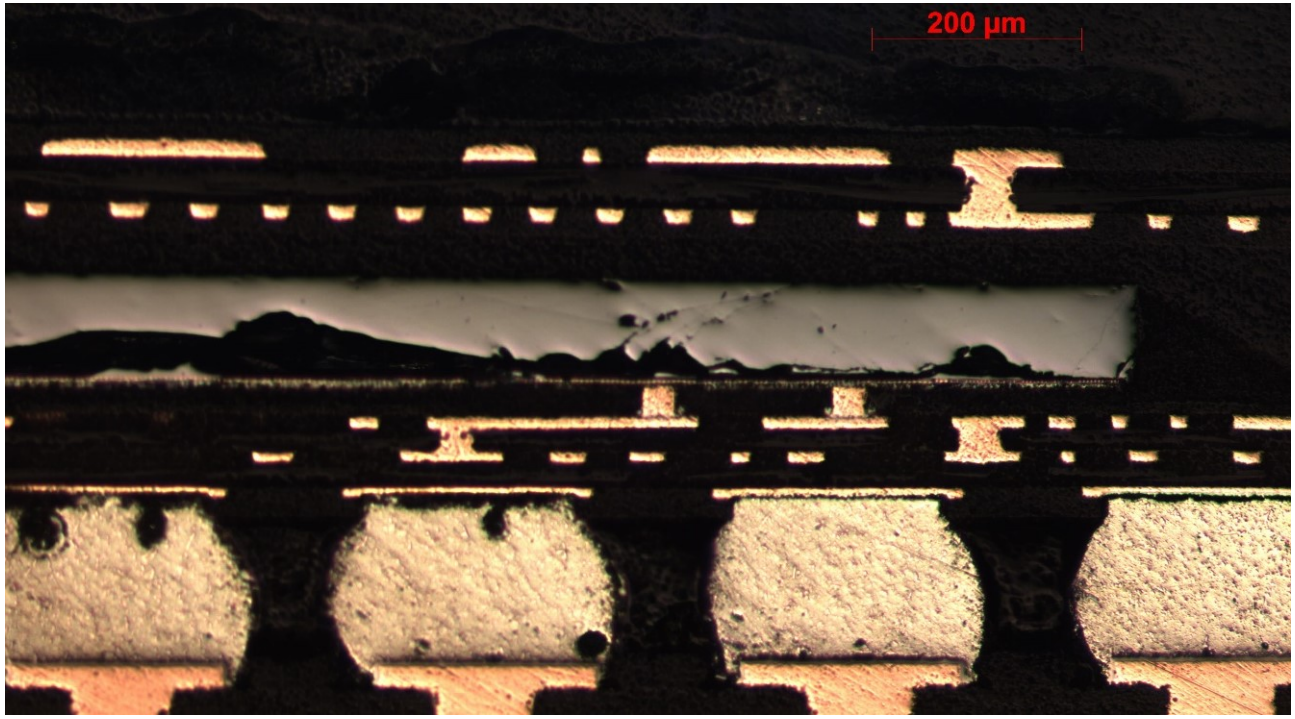
QUALCOMM SNAPDRAGON 888 POP

- Top Package: Memory
  - 8 die in two 4-up staggered stacks
  - All die wire bonded
  - 3L substrate, 45µm L/S, 80µm thick
  - 14.0x15.8mm package
  - 0.4mm pitch balls



- Bottom Package: Processor
  - Flip chip die, ~100µm pitch bumps
  - Top substrate to top package
    - 2L, 20-25µm L/S, 75µm thick
  - Bottom substrate to main PCB
    - 3L, 15µm L/S, 75µm thick
  - 15.8x15.8mm package
  - 0.35mm pitch balls

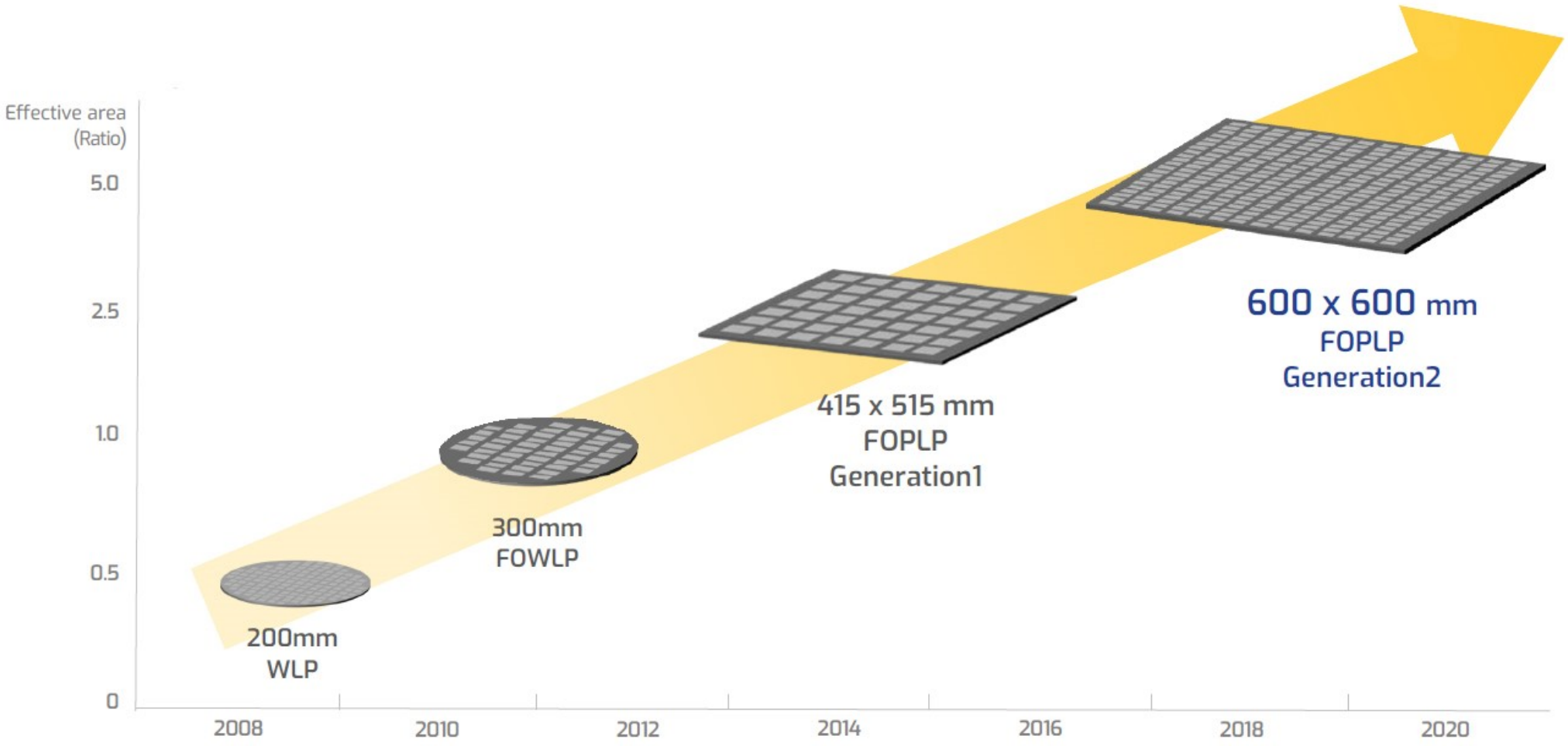


Source: Prismark/Binghamton University

1221.193mvc

NEPES FO-PLP PROGRESSION

- 300mm FOWLP done in Philippines using DECA M-Series™
- 600mm PLP line in Korea ready for HVM as of Q4 2021 using DECA M-Series™



Source: NEPES

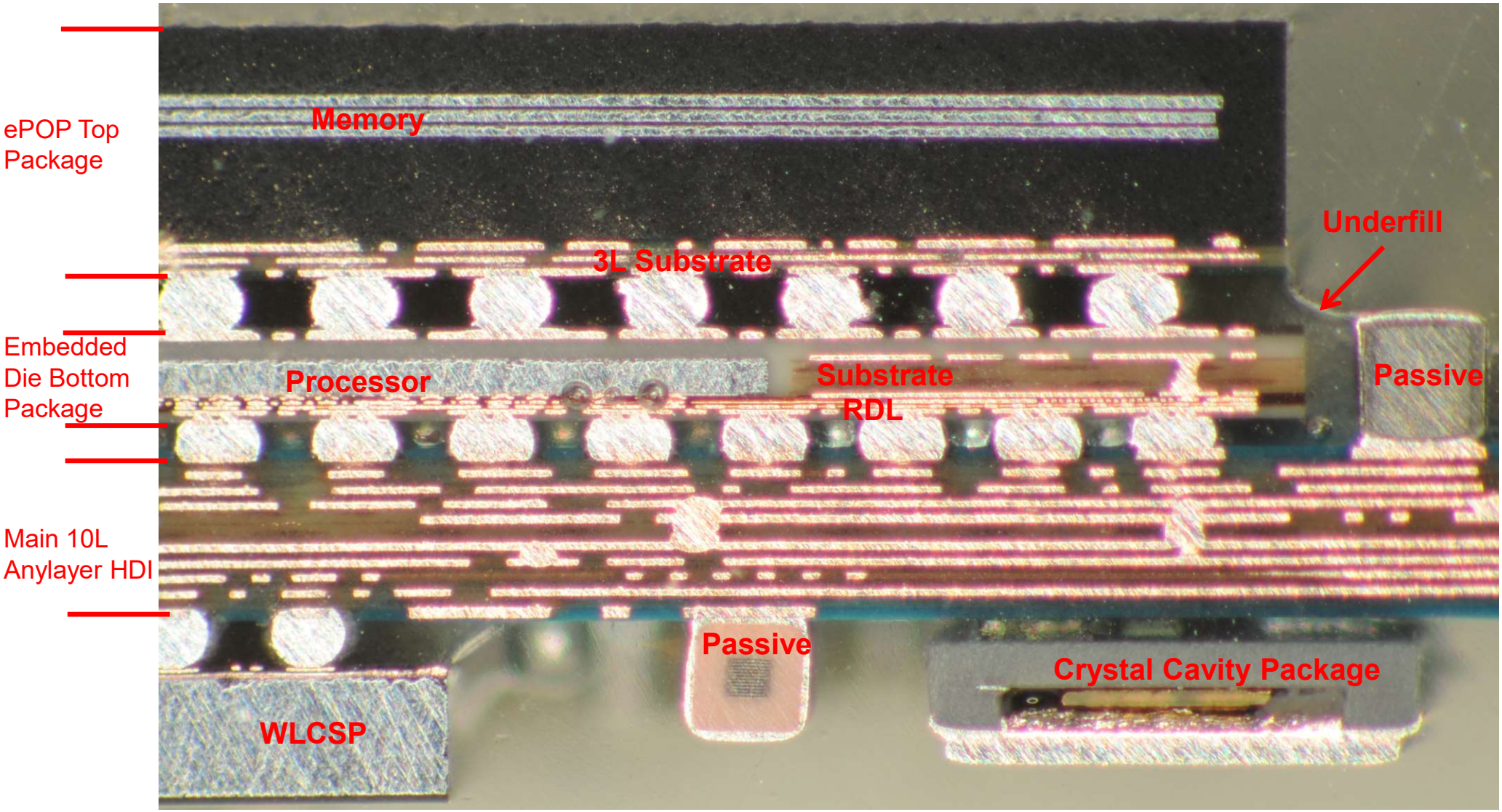
1221.085.bp

PANEL LEVEL PACKAGING (PLP) DEVELOPMENTS

- SEMCO/Samsung invested over $400M in panel packaging back in 2017/2018
  - 410 x 515mm panels for “standard” resolutions in production since 2018 for watch (and still used in 2021); with some small volumes for PMIC used in SSD
  - 510 x 515mm panels for 2µm L/S for future mobile processors; relatively inactive
- NEPES plan for production on 600 x 600mm panels
  - Limited customer base and design wins prior to 2020
  - Licensee of DECA and has taken control of Philippines operation
  - Expanding PLP capacity for M-Series and large customer ramp in 2022
- PTI had low production on 510 x 515mm panels in 2019/2020
  - Single design win for MediaTek PMIC in FO-WLP
  - Multiple versions, but focus on fine L/S
  - Recently pushed out ambitious investment plans, but continues to voice plans to move ahead
- ASE using 300 x 300mm panels for high-density chips-last development
  - 600 x 600mm panels for lower-density chips-first (M-Series) pushed out, again
- Numerous ongoing panel die assembly “developments” in China:
  - ACCESS, Sky-Chip / SCC, BOE/ESWIN, Foxconn
- SKC $470M investment for glass carriers in Georgia

1121.081.bp

SAMSUNG GALAXY WATCH 4 POP - PLP

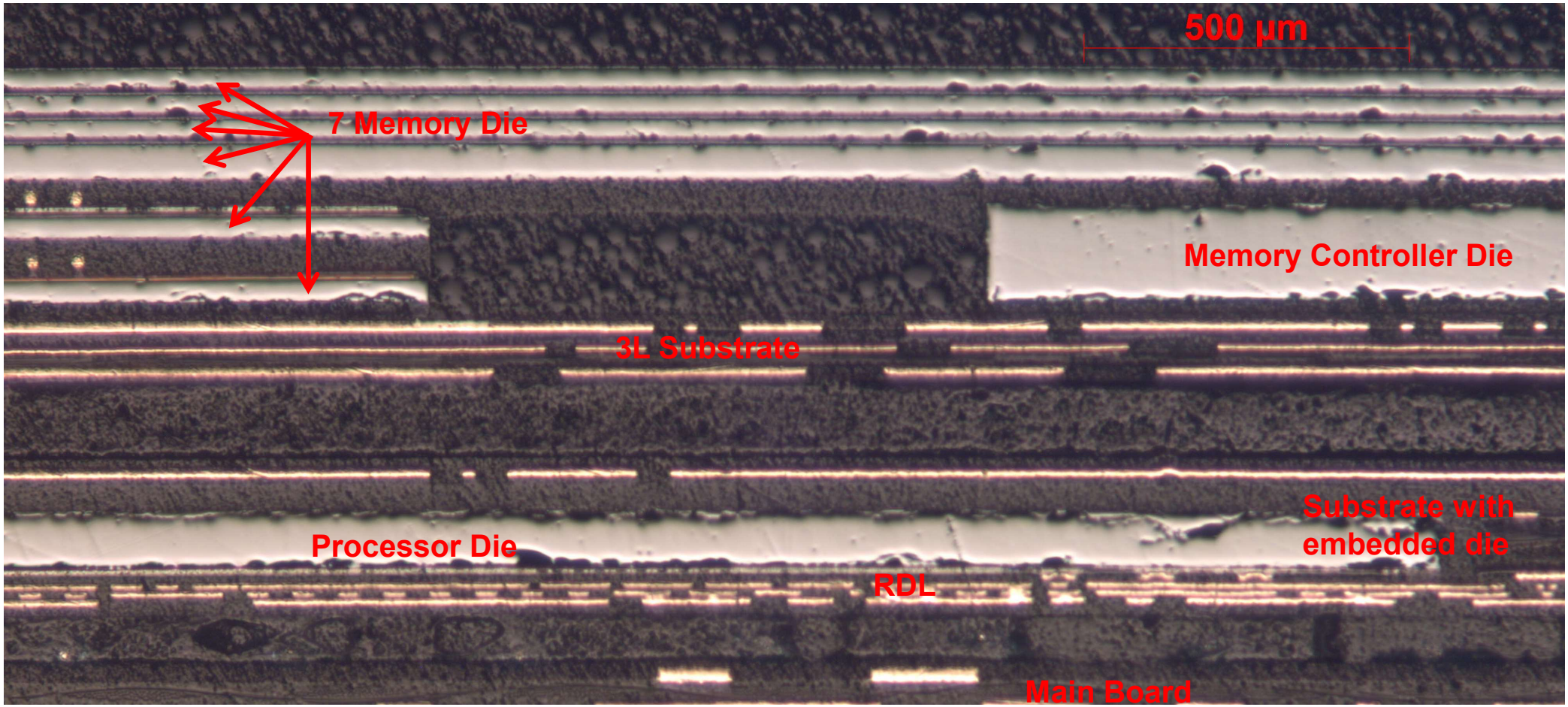


Photos source: Prismark/Binghamton University

- 10 x 9mm PoP, 1.1mm total collapsed height
  - 7 wire bonded die in top package, side-by-side with 5 max in continuous stack
    - 3L substrate, 30µm L, 80µm thick
  - 1 die (or 2 die side-by-side) in bottom package
    - "Embedded die" plus RDL, 250µm thick

1021.408mvc

SAMSUNG GALAXY WATCH 4 POP

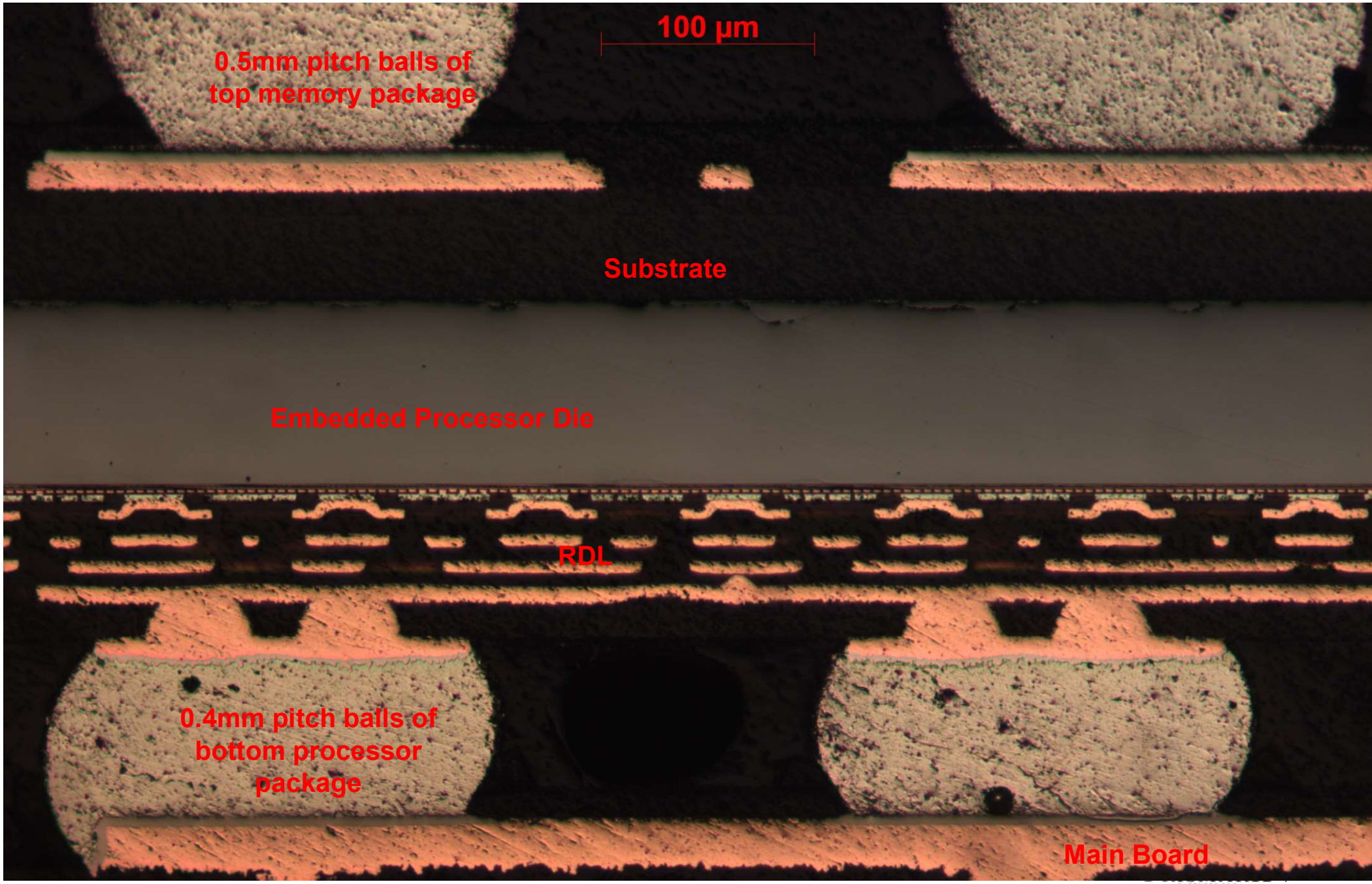


Photos source: Prismark/Binghamton University

- 10 x 9mm PoP, 1.1mm total collapsed height
  - 7 wire bonded die in top package, side-by-side with 5 max in continuous stack
    - Substrate, 30µm L/S, 80µm thick
  - 1 die (or 2 die side-by-side) in bottom package
    - "Embedded die" plus RDL, 250µm thick

1021.408mvc

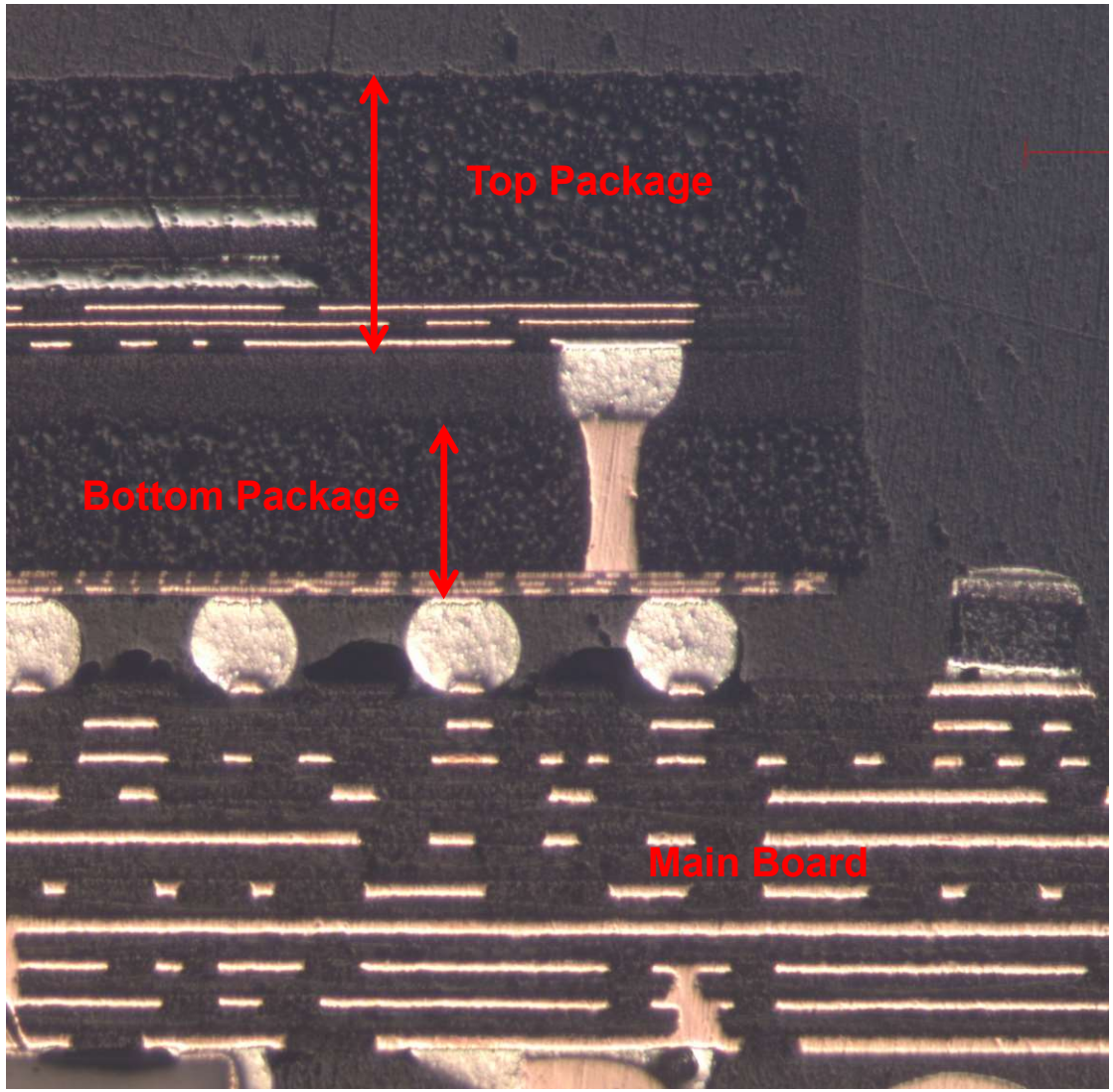
SAMSUNG GALAXY WATCH 4 POP



Photos source: Prismark/Binghamton University

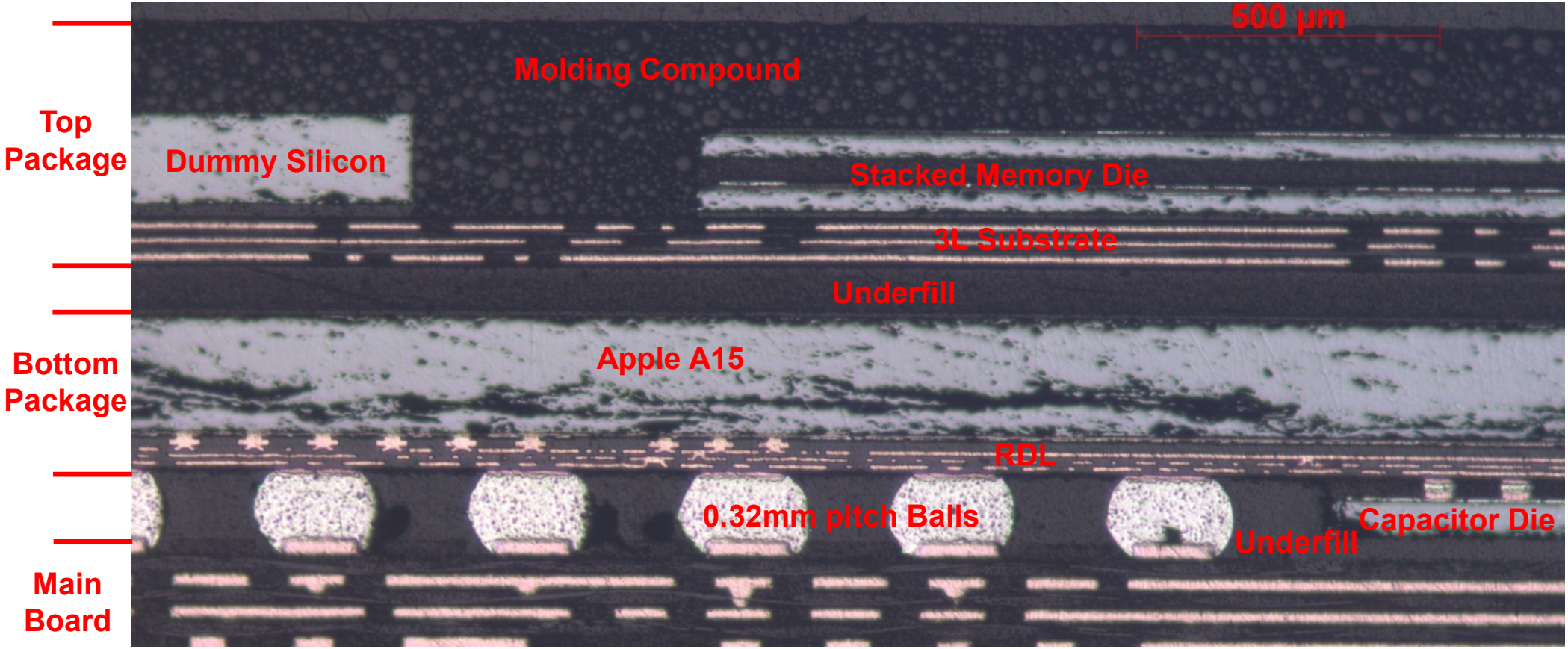
APPLE A15 FO-WLP POP

- Apple A15 in FO-WLP as bottom package
  - 200µm thick die, 370µm package
  - 5 metal RDL, 8µm L/S, 60µm thick
  - 0.3mm pitch TMV to top package
  - 0.32mm pitch balls to main board
  - Capacitor die on bottom of package
  - Measured as 13.0 x 17.4mm
- Memory in top package (500µm thick)
  - 4 memory die in 2 stacks
    - 35µm thick die, wirebonded
  - 1 dummy silicon in center
    - 150µm thick
  - 3L substrate, 20/35µm L/S, 70µm thick
  - 0.3mm pitch peripheral balls
- Total stack 870µm thick as assembled
  - Underfill between packages and under bottom package



1021.431mvc

APPLE A15 FO-WLP POP



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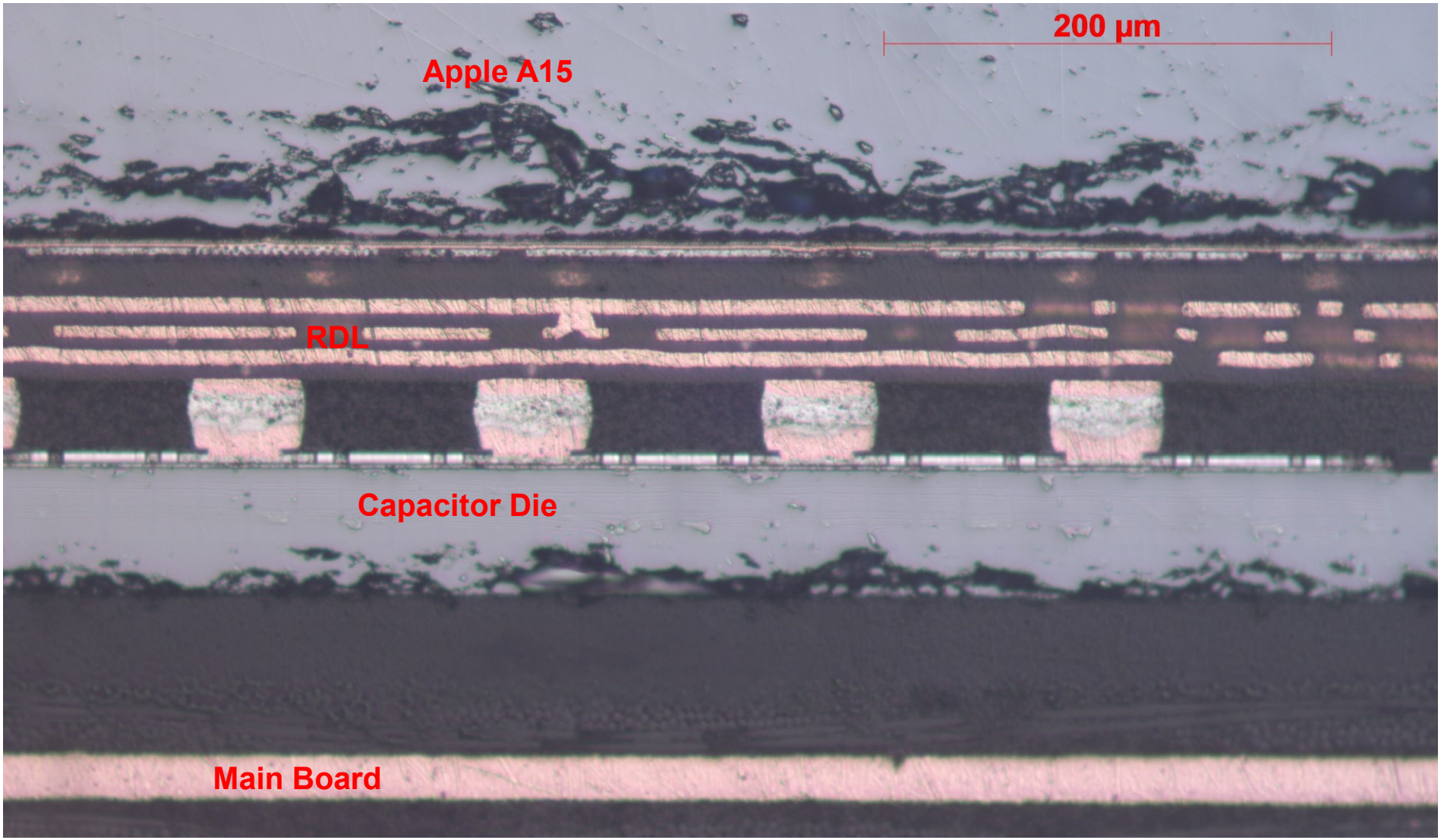
APPLE A15 FO-WLP POP



- Apple A15 (200µm thick die) in FO-WLP as bottom package
  - RDL, 8µm L/S, 60µm thick
  - Capacitor die on bottom of package
    - 70µm thick, 125µm bump pitch

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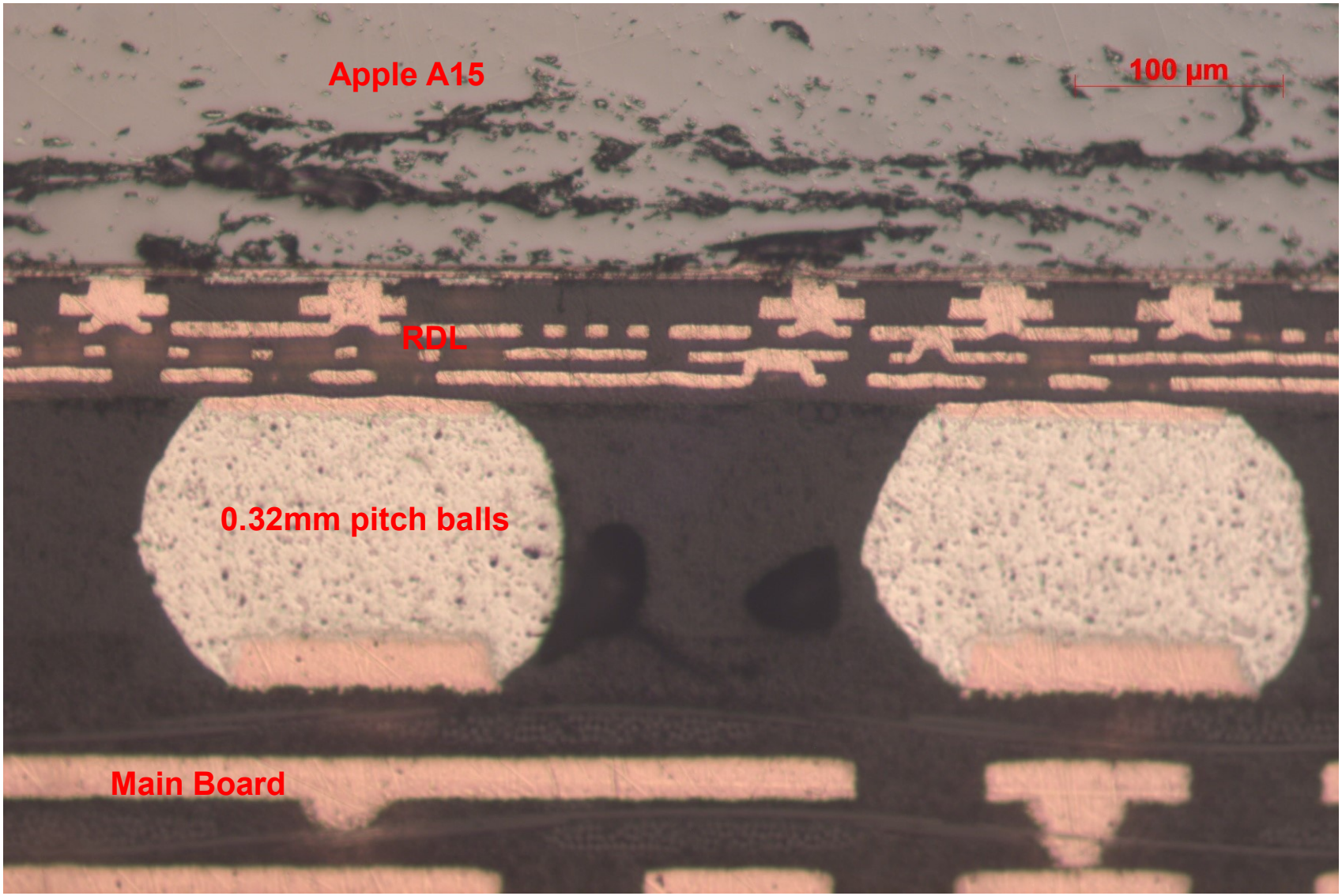
APPLE A15 FO-WLP POP



- Apple A15 (200µm thick die) in FO-WLP as bottom package
  - RDL, 8µm L/S, 60µm thick
  - 0.32mm pitch balls to main board

1021.431mvc

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