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Associates*

ChangXin
Memory
Technologies:
China's Rising
DRAM
Manufacturer

ChangXin Memory Technologies: China's Rising DRAM Manufacturer

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Introduction

The semiconductor industry is a global industry. Design of semiconductor chips is done throughout the world. The actual manufacturing of semiconductor devices (chips) is dominated today by companies in the Asia-Pacific.

These include companies in China, Japan, Singapore, South Korea and Taiwan. Some companies that build sophisticated chips (such as CPUs, GPUs, MCUs and other embedded devices) design and manufacture many of their own chips (e.g. Intel) but many others design their chips and then have them manufactured in semiconductor foundries. Firms that design but don't manufacture chips are called fabless semiconductor companies.

Memory (e.g. DRAM) and solid-state storage (e.g. NAND flash) chips are special purpose devices that are, in general, built by the companies that design them, rather than built in a foundry. Like semiconductors in general, most of the manufacturing and much of the design of modern memory and solid-state storage products is done in the Asia Pacific region.

Memory and solid-state storage are mostly incorporated into finished products for enterprise, industrial, agricultural and consumer applications, as additional chips on circuit boards (or by bonding die together as is done in many smart phones). The number of these chips needed depends upon the amount of memory or solid-state storage used in the particular product.

Memory and solid-state storage chips are not inexpensive and for many products, such as smartphones, memory and solid-state storage is a significant portion of the build of materials cost of the product. These consumer products rely upon standardized interfaces, which enable interoperable products, such as DDR and LPDDR. Many of the products that we depend upon every day, use memory or solid-state storage chips. The figure below shows some of the common uses for DRAM both in the datacenter as well as consumer-oriented devices.



The major international manufacturers of DRAM

There are three major industry players, who together dominate DRAM memory production. These companies are making significant investments in continued scaling at their DRAM fabs.

In January 2021 Micron announced their 1 α process technology that they said would increase DRAM density by up to 40%, compared to the company's current 1z process. Samsung has said that it plans big innovations in its DRAM and NAND memory in 2021. Samsung is delivering 1z DRAM without Extreme UV (EUV) and is starting to introduce its 1z DRAM made with EUV lithography in the second half of 2021. Samsung invested billions of US dollars in memory capacity expansion in 2020.

SK hynix said that it has completed a new fabrication site for DRAM production in Korea for over three billion US dollars that includes EUV as well as ramping up DRAM output in its factories in China.

Micron plans to introduce these advanced DRAM lithographic nodes without using the more expensive EUV lithographic processes and instead plans to use various kinds of multi-patterning technology. The company is doing R&D using EUV, which the company may need in four DRAM generations from now (its 1 δ process).

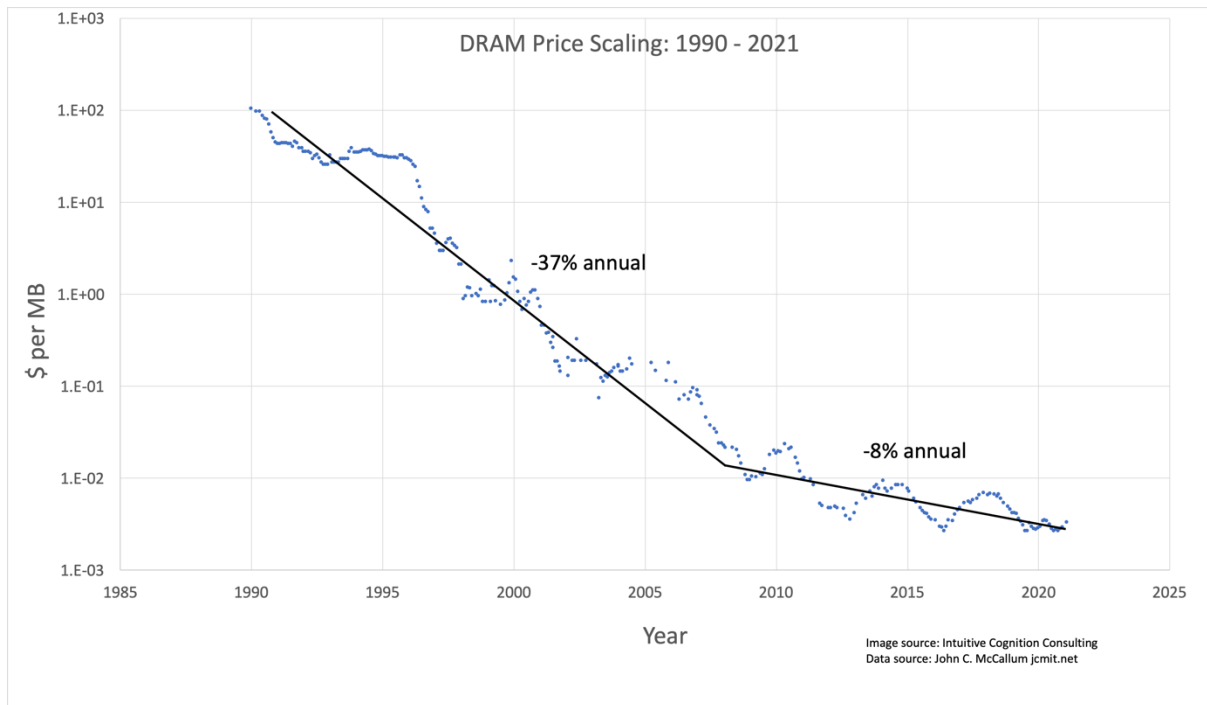
It is estimated that Samsung, SK hynix and Micron together produce about 86% of all DRAM wafer starts (semiconductor devices are made by slicing up these wafers). Samsung has about a 36% wafer start market share, SK hynix and Micron each have about a 25% wafer start market share.

Samsung is estimated to have a DRAM revenue market share of about 42%, SK hynix has about 28% and Micron has about 25%, for total DRAM revenue share between these three companies of about 95%. The remaining 5% of revenue and 15% of wafer starts are split between smaller companies, including Nanya located in Taiwan and ChangXin Memory Technologies (CXMT) located in China

Challenges in future DRAM advances

DRAM is working memory used in almost all electronic devices, from consumer to industry and to enterprise applications. Like many semiconductor technologies, it has become more difficult to continue the pace of lithographic shrinks and increasing transistor density than it was in past decades. The figure below shows the slowing of DRAM scaling since 2007¹. Although there are variations in supply and demand that also impact the cost and price of DRAM, DRAM price scaling (\$/GB) declined by about 37% annually for 37 years until slowed to about 8% annually starting in 2008.

¹ Intuitive Cognition Consulting with data from John McCallum, jcmit.net



The difficulties in scaling translates into more intensive R&D and manufacturing investments required to remain competitive in product densities. Modern DRAM manufacturing facilities cost several billion US dollars to build. High R&D and fab costs are significant barriers to entry into the DRAM industry. To get into the business, a significant amount of funding is needed.

Issues that impact DRAM operation, and thus the scaling, include row hammer, which allows influencing the data in adjacent cells through leaked charges from changing the content of nearby DRAM memory rows. This is a potential security as well as a reliability issue as accessing data repeatedly on one cell can create errors in adjacent cells. Improving isolation from the leakage current can help, but requires more layers and new materials and may limit the cell size reductions.

As the feature sizes decreases in DRAM cells the signal from the cell gets smaller, reducing the sense margin. Solving this issue generally requires added circuitry which leads to additional power consumption, circuit complexity and increased size and thus scaling costs. These issues are also creating a push to improve the logic transistors in DRAMs, leading to tighter control of these transistor tolerances. This could increase the complexity and/or cost of these logic transistors. These DRAM scaling issues are shown in the figure below from a Micron keynote talk at the 2020 IEEE IEDM Conference².

² Image taken by Tom Coughlin from Dr. Naga Chandrasekaran, Micron Technology Keynote, 2020 IEEE IEDM Conference

DRAM

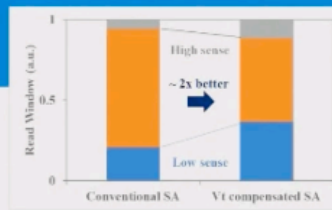
System-level collaboration needed to enable scaling, meet performance/reliability requirements

Row Hammer



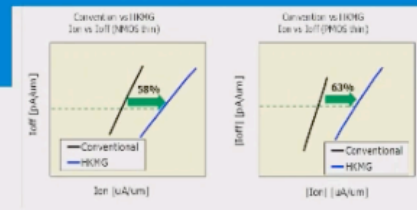
Cell-charge gain, increased error rates cause failures in "ones" and "zeroes"

Sense Margin



Added circuitry leads to areas of power penalty, complexity for cost scaling

High Performance CMOS

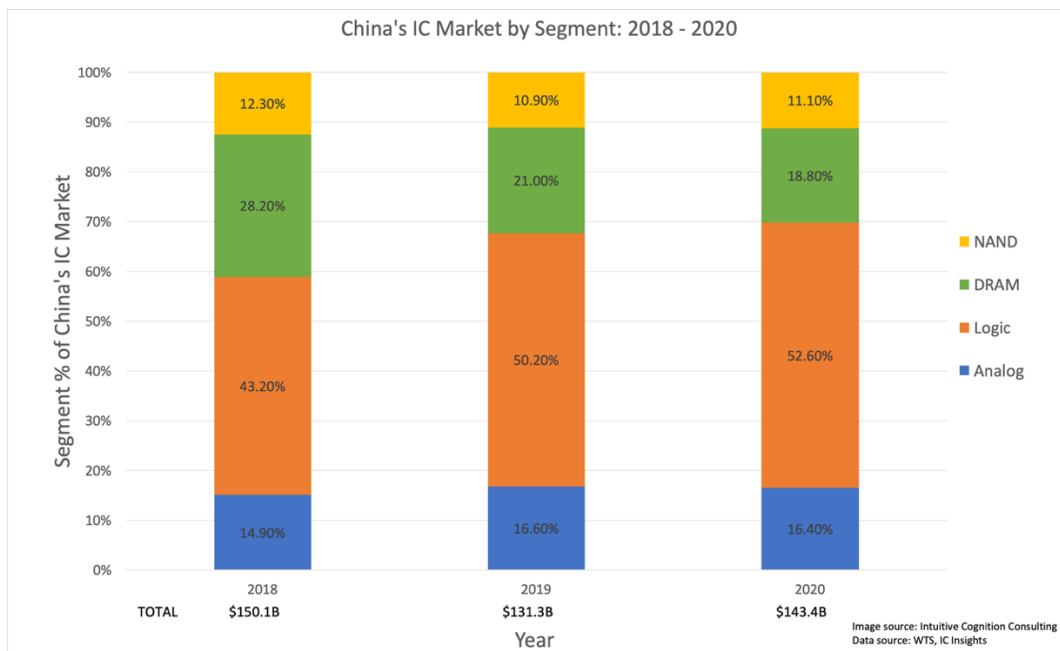


Reduction in Vt variation and mismatch; expect to close the gap to Logic CMOS technology.



Semiconductor memory in China

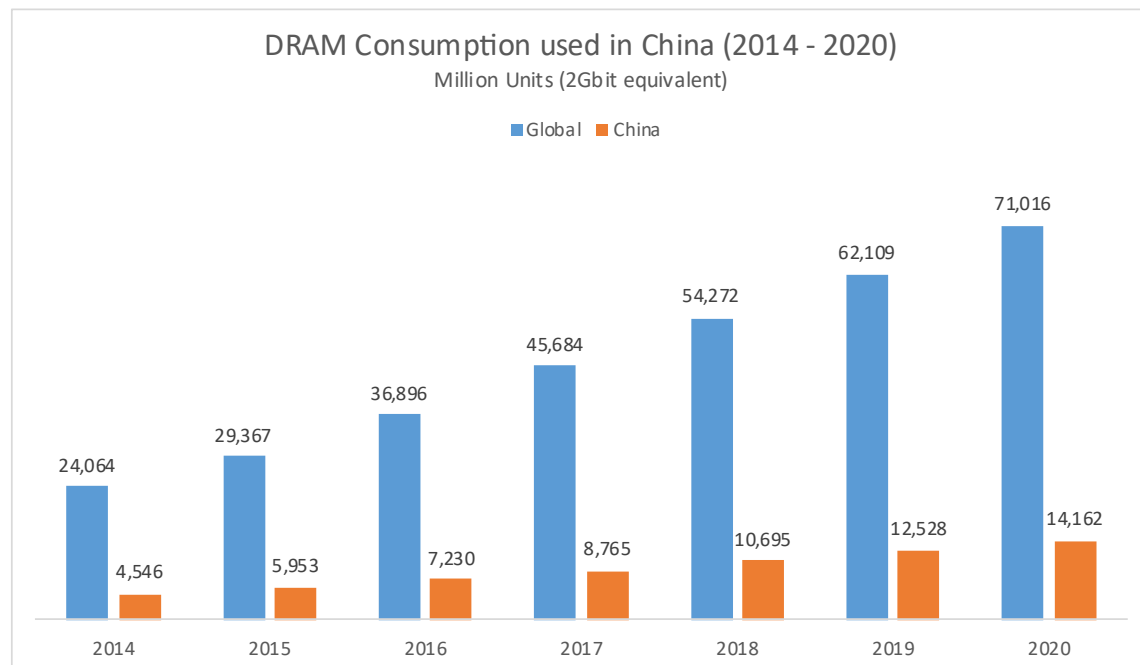
IC Insights³ has stated that companies headquartered in China produced a total of 3B chips in 2020, which is 5.9% of the country's total chip market of 43B chips (9% more than in 2019). About 60% of the ICs in China are used in exported products with about 40% of these ICs used in domestically consumed products. The figure below shows the percentage of various types of ICs, including DRAM, consumed by the Chinese market in 2018, 2019 and 2020.



³ China provides only 6% of its own needs for semiconductor products, 4U Daily, February 2021, <https://4youdaily.com/development-and-manufacture-of-electronics/china-provides-only-6-of-its-own-needs-for-semiconductor-products/>

As shown in the figure, DRAM memory chips accounted for 19% of the Chinese IC market in 2020. DRAM is an important component in modern electronic products, many of which are made in China, and many consumed in China. China currently manufactures only a very small percentage of the world's total DRAM and a very small percentage of the DRAM used in Chinese domestic electronic products.

Total DRAM revenues in 2020 exceeded US\$65B, according to IC Insights⁴. China consumes about 20% of the global DRAM from 2014-2020, as shown in the figure below⁵.



Because of the amount of semiconductor chips, including DRAM, that are imported into China, in 2015, the country embarked on an ambitious plan to produce many of the semiconductor devices used in the country.

However, the overall success of these domestic investment efforts are subject to debate. In January of 2021 IC Insights forecast that semiconductors made in China will account for at most about 20% of all integrated circuits (ICs) sold in China by 2025, which is far below the Chinese ambition⁶.

Of the Chinese semiconductor production in 2020, only about 37% of the country's IC output was done by Chinese owned companies⁷. The vast majority of the Chinese IC production was in local

⁴ <https://www.sourcengine.com/blog/2020-dram-and-nand-revenue-tops-integrated-circuit-sales-charts>

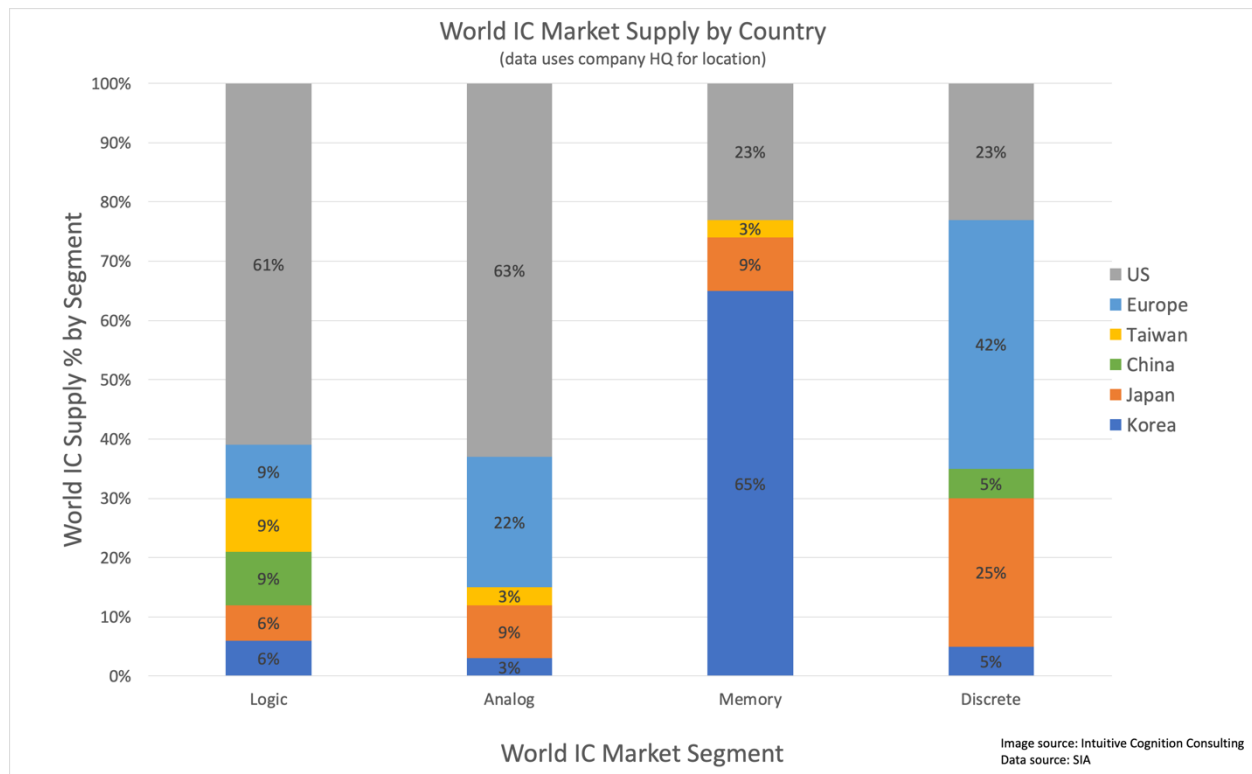
⁵ DRAM analysts and CXMT internal research

⁶ China Forecast to Fall Far Short of its "Made in China 2025" Goals for ICs, IC Insights, EE Times Asia, 1/13/21, <https://www.eetasia.com/china-forecast-to-fall-far-short-of-its-made-in-china-2025-goals-for-ics/>

⁷ Get real about the Chinese semiconductor industry, Scott Foster, Asia Times, 1/18/21, <https://asiatimes.com/2021/01/get-real-about-the-chinese-semiconductor-industry/>

wafer fabs owned by TSMC, Samsung, SK hynix, Intel and other foreign companies. Chinese owned IC production was about 6% of the total China IC market and only 2% of the global market¹⁸.

The figure below shows various types of semiconductor market share, by segment, for various nationally headquartered companies in 2019⁹. Note that Chinese headquartered companies producing memory (i.e. DRAM and NAND flash) market share was too small to show up on this chart.



Samsung and SK hynix from Korea, and TSMC from Taiwan have existing semiconductor manufacturing in China and plan major investments in additional IC production in China. In early January 2021 the Nikkei newspaper from Japan reported that Samsung Electronics may invest more than \$30B in its Chinese memory and logic semiconductor factories in 2021¹⁰. TSMC is said to be planning on spending between \$25B-\$28B this year on semiconductor expansion in China⁸. SK hynix has a DRAM manufacturing plant in Wuxi, China that began operations in December 2020¹¹. The only current Chinese owned and operated DRAM manufacturer is CXMT.

⁸ Scott Foster, Get real about the Chinese semiconductor industry, Jan. 18, 2021, <https://asiatimes.com/2021/01/get-real-about-the-chinese-semiconductor-industry/>

⁹ SIA Document, 2020 State of the US Semiconductor Industry, <https://www.semiconductors.org/2020-state-of-the-u-s-semiconductor-industry/>

¹⁰ <https://oltnews.com/samsung-to-invest-30-billion-in-booming-chip-business-nikkei-asia>

¹¹ SK hynix 200mm fab in Wuxi, China is officially put into operation, SemiMedia, <http://www.semimedia.cc/?p=8860>

ChangXin Memory Technology (CXMT)

CXMT, a manufacturer of commodity LPDDR4 DRAM used in low end mobile phones and DDR4 used in PC memory modules, was funded in 2016 by Hefei Industrial Investment Fund with a minority strategic investment by GigaDevice. The Hefei Industrial Investment Fund is a local government fund that aggregates private investments in the city where the company operates. The initial investment involved no in-direct Chinese national government investment. CXMT has no association with the Tsinghua Unigroup, which has considerable investment from the Chinese national government and has funded Chinese companies such as NAND flash manufacturer, YMTC. Below is a photo of the city of Hefei, China.



CXMT's second round of funding in December 2020 of about US\$2.39B resulted in the following breakdown of percentage ownership¹²:

1.	Hefei Stony Creeks Integrated Circuit LLP	38.59%
2.	ChangXin Integrated Circuit LLC	19.72%
3.	China IC Investment Fund Co. Limited	14.08%
4.	Anhui Industry and Innovation Investment Fund	14.08%
5.	Other investors (follow up from initial holdings)	11.27%
6.	Hefei JiXin LLP	1.41%
7.	GigaDevice Inc	0.85%

A significant percentage of the investment is controlled by Yiming Zhu (shown below), who serves as chairman of both CXMT and GigaDevice¹³. This investment is being used to expand the company's production capacity.

Yiming Zhu is the CEO of CXMT. The Tsinghua University graduate earned a master's in electrical engineering at SUNY-Stony Brook in 2000, then spent eight years working in the US, including a

¹² <http://data.eastmoney.com/notices/detail/603986/AN202011111428221596.html>

¹³ China's First DRAM Chipmaker ChangXin Memory Raises \$2.39B, Caixin, Dec. 16, 2020

stint at California-based memory designer MoSys. He founded GigaDevice in Silicon Valley but moved the company to China in 2005 since there was little indigenous memory chip manufacturing in the US. His leadership of CXMT is guided by his start-up experience in Silicon Valley.



GigaDevice originally licensed IP to other chip companies but then focused on designing its own chip products, including flash memory and general purpose MCUs. GigaDevice is the number three manufacturer in discrete NOR flash devices. In July 2018, Zhu resigned as GigaDevice CEO to take up the post of chairman and CEO of Innotron Memory, since renamed ChangXin Memory Technologies (CXMT) in Hefei, China.

CXMT has over 4,000 employees and a 65,000 square meters cleanroom space in its DRAM factory (see figure below).



CXMT's annual capital investment is about \$2B¹⁴, which is a reasonable amount based upon its current manufacturing capacity and future growth plans.

This cleanroom space has the capability to expand to 120,000 12-inch wafer starts per month, although actual production volume by the end of 2020 was 40,000 wafers per month, up from 20,000 wafers per month in early 2020. The company does not expect its production capacity to exceed 40,000 per month until sometime in 2022.

CXMT has the land available to build another DRAM production fab that could double again its production capacity, but this would take about two years to come on line, once a decision was made to proceed. Considering the production capacity expansion plans of Samsung, SK hynix and Micron, even if CXMT decided to start construction on new fab facilities in 2022, it is likely to continue to provide less than 2% of total DRAM capacity production through 2024 (as discussed below).

CXMT has developed their own semiconductor IP, based upon some older IP originally licensed and acquired from Qimonda and other sources. CXMT continues to file for its own patents in China and the US as well as licensing and purchasing important DRAM patent portfolios.

CXMT's DRAM Production

CXMT in 2020 delivered about 2.9% of the total worldwide DRAM wafer starts per month. However, their lithographic feature size has been reported as 19nm, according to DigiTimes¹⁵ with the company's current generation product. TechInsights recently issued a teardown report on CXMT DRAM¹⁶. This can be compared to sub-15nm DRAM products currently in production by

¹⁴ Semi-Engineering, <https://semiengineering.com/semiconductor-capex-to-grow-13-0-in-2021/>

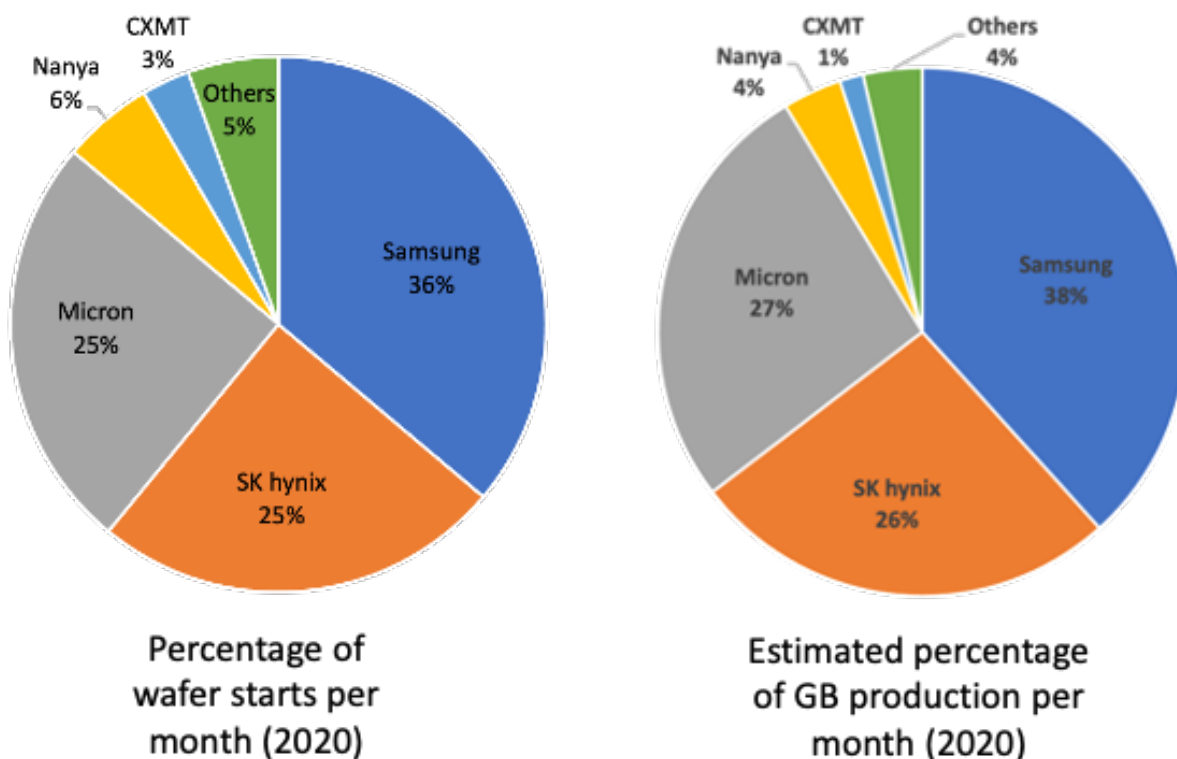
¹⁵ CXMT scaling up 19nm DRAM output with better yield rates, Digitimes Asia, August 25, 2020.

¹⁶ <https://www.techinsights.com/products/pff-2006-801>

Samsung, SK hynix and Micron (who together have about 86% of the total DRAM wafer starts per month).

As a consequence, total DRAM memory production per wafer at CXMT is considerably less than these major producers (probably about 46% of the memory capacity for CXMT wafers versus these major vendors). Therefore, CXMT's memory GB production is likely about 1.4% of the total worldwide production based upon their current 19nm process and 40,000 wafers per month production (assuming comparable wafer yield for CXMT and Samsung, SK hynix, Micron and Nanya). If CXMT invests in advancing their process and production capacity, they could take a larger percentage of the total market.

The figure below shows the percentage of raw wafer starts per month for the DRAM manufacturers¹⁷ (left) and an estimated GBs of memory production by considering the difference in the lithographic feature size (right).



Thus, China is currently producing only a very small amount of the total DRAM consumed in the country, even for the electronic products using DRAM that are sold in China. On the other hand, Korean companies produce more than 64% of the worldwide supply of DRAM, yet consumes less than 10% of the world's DRAM in Korean made products¹⁸.

¹⁷ DRAmExchange Memory Technology Summit, December 2019

¹⁸ Intuitive Cognition Consulting analysis

Samsung, SK hynix and Micron took in about 96% of total DRAM revenue in 2020. Nanya had perhaps 3% of 2020 DRAM revenue. So, it makes sense that CXMT, while ramping production through 2020 captured around 1.0% of total DRAM revenue in 2020. This is in line with our estimated DRAM production capacity discussed above (less actual shipped capacity from produced wafers, combined with the fact that lower end DRAM products result in less revenue).

Therefore, we estimate that CXMT currently produces about 1.4% of the world's total DRAM production and all this commodity DRAM is used within China for Chinese consumer products. Since China consumes over 20% of the world's DRAM, then CXMT is supplying approximately 7% of the DRAM used in China. It will take several more years before CXMT achieves a substantial share of the Chinese DRAM market.

The next generation CXMT product, which is expected in 2022, could move to 17-18nm feature size, but this is likely to still remain a few generations behind the major DRAM competitors, who will have advanced to sub-15nm lithographic nodes by that time.

It is reported that CXMT plans to double its monthly wafer starts per month by mid to late 2022 (80,000 wafer starts per month), which could bring it within range of the wafer starts per month of Nanya, the next largest DRAM manufacturer (based in Taiwan). However, Micron, Samsung and SK hynix are increasing their production capacity as well in 2021 (as noted above), so this CXMT production expansion will not significantly impact these larger company's market shares.

It is expected that CXMT could roughly equal Nanya's current wafer production output in 2023. Note that Nanya recently announced that it was investing about \$10.7B to build a new DRAM fab with 10nm class technology. The chipmaker expects the fab to start commercial shipments in 2024, with a monthly capacity of 15,000 wafers in the first phase¹⁹.

CXMT is several lithographic generations behind Micron's current DRAM product. Thus, it is unlikely that the company will require EUV technology any time soon, particularly if they follow Micron's lead in using multi-patterning for several more lithographic product generations.

CXMT Patent Portfolio

CXMT is very focused on developing its own IP and licensing IP that it needs for its DRAM products. The company has over 3,000 patents in China, and has licensed portfolios containing more than 30,000 patents from several international companies. Globally they have a few hundred patents and recently they have been very active in US patent filings. They have also bought international patents from big patent portfolios (most notably was their purchase of Qimonda DRAM patents in 2019). The company continues to license technologies and patents

¹⁹ The chipmaker expects the fab to start commercial shipments in 2024, with a monthly capacity of 15,000 wafers in the first phase.

from multiple sources and maintains an annual budget for licensing IP. In 2019, CXMT and Rambus publicly announced that CXMT had licensed Rambus' DRAM patent portfolio.

It should be noted that CXMT's Chinese patent portfolio is much greater than the Chinese patents from non-Chinese DRAM companies, who only have a few Chinese patents.

CXMT DRAM Use

CXMT DRAM is being used exclusively in the Chinese consumer product market and the company plans to solely support the Chinese market for several more years. These uses include DDR4 memory for PCs and LPDDR4 memory modules for low end Chinese mobile phones.

Despite inaccurate statements that CXMT has ties to and is supplying memory products to the Chinese military, the end use for CXMT memory products is entirely for civilian applications. During an interview with Mark Cao, CXMT EVP of Strategy, he said, "CXMT has no relationship to the Chinese military and the company has internal rules not to do any business with the Chinese military."

CXMT is a member of JEDEC and is involved in the DDR and LPDDR standard setting for memory modules. DDR and LPDDR DRAM memory modules are made to the JEDEC specification to ensure interchangeable consumer products between vendors.

At this time CXMT DRAM is being sold exclusively in China, incorporated in DDR4 and LPDDR4 modules, with the modules manufactured by several companies. A following report will provide more detail on CXMT's publicly acknowledged customers.

Summary

Considering the volume of consumer electronic products using commodity DRAM that are made in China, it makes sense that a local manufacturer like CXMT would emerge to satisfy some of the needs of the lower end domestic Chinese market. The Chinese market for such consumer products is price sensitive and commodity DRAM, like that CXMT manufactures, enables this market. For CXMT, the domestic Chinese consumer electronics market will provide significant growth for several more years.

It is unlikely that CXMT products will be used outside of China before 2025, at the earliest and it appears likely that CXMT's DRAM technology will continue to lag behind the products from the three major DRAM producers. In addition, CXMT DRAM has yet to be commercialized in datacenters and the high quality and reliability requirements of this market may prove to be difficult for them to address in the foreseeable future.

CXMT doesn't appear to be a threat any time soon to the larger DRAM manufacturers. CXMT is focused on developing its own technology and IP, while also licensing the relevant IP created by others.

CXMT funding appears to have come mostly from regional sources since its founding until late 2020, when, after the failure of several other Chinese national government supported fledgling DRAM companies, the Chinese national government semiconductor fund participated as a minority investor in the most recent CXMT funding round. CXMT is a domestic Chinese company focused on meeting the needs of the domestic Chinese consumer electronics memory market with commodity DRAM for the foreseeable future.

About the Author



Tom Coughlin, President, Coughlin Associates is a digital storage analyst as well as a business and technology consultant. He has over 40 years in the data storage industry with engineering and management positions at several companies.

Dr. Coughlin has many publications and six patents to his credit. Tom is also the author of Digital Storage in Consumer Electronics: The Essential Guide, which is now in its second edition with Springer. Coughlin Associates provides market and technology analysis as well as Data Storage Technical and Business Consulting services. Tom publishes the *Digital Storage Technology Newsletter*, the *Media and Entertainment Storage Report*, the *Emerging Non-Volatile Memory Report* and other industry reports. Tom is also a regular contributor on digital storage for Forbes.com and other blogs.

Tom is active with SMPTE (Journal article writer and Conference Program Committee), SNIA (including a founder of the SNIA SSSI, now CMSI), the IEEE, (he is Past Director for IEEE Region 6, Past President of IEEE USA, Past Chair of the IEEE New Initiatives and Public Visibility Committees and active in the Consumer Electronics Society) and other professional organizations. Tom is the founder and organizer of the Storage Visions Conference (www.storagevisions.com) as well as the Creative Storage Conference (www.creativestorage.org). He was the general chairman of the annual Flash Memory Summit for 10 years. He is a Fellow of the IEEE and a board member of the Consultants Network of Silicon Valley (CNSV). For more information on Tom Coughlin and his publications and activities go to www.tomcoughlin.com.