

High Volume – Mainstream Memory

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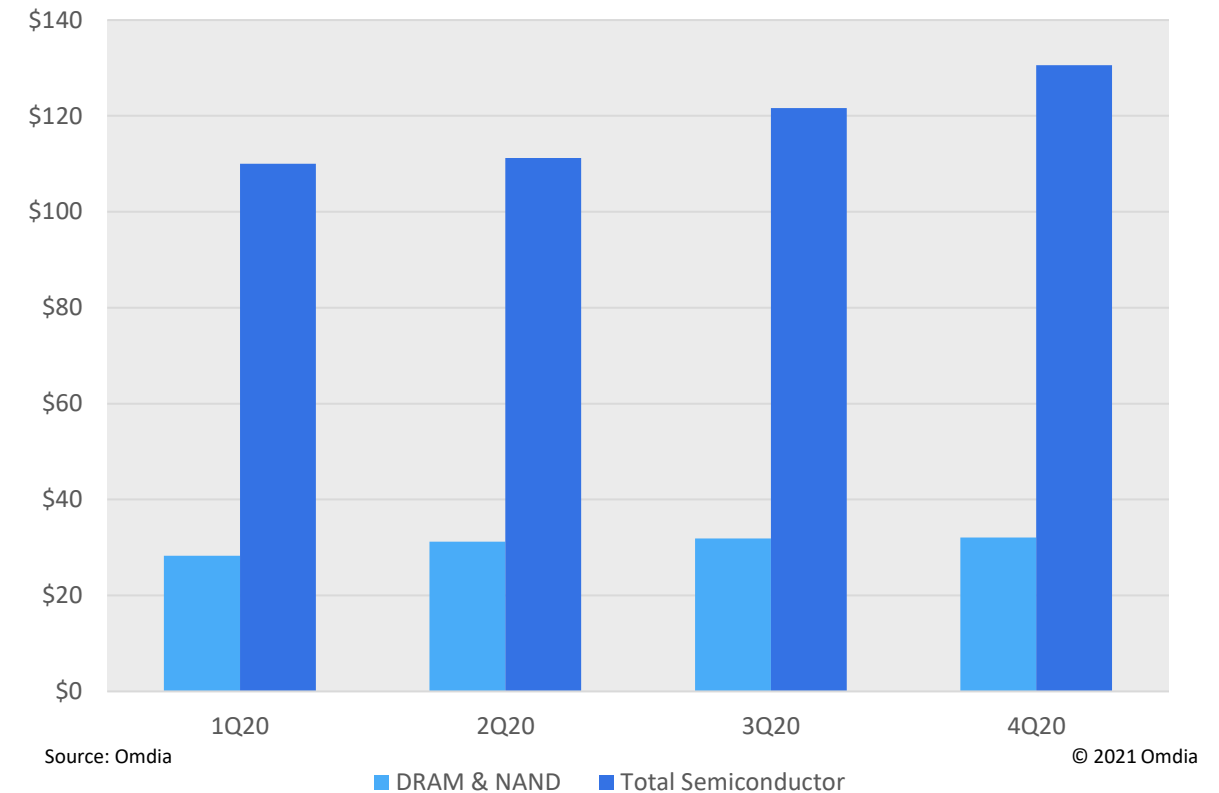
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Mainstream memory- what is DRAM & NAND?

- DRAM and NAND are the high-volume, commodity memory semi-components, working together in a system (such as PC, server, smartphone), but for different reasons.
 - DRAM manages your data, requires power (volatile)
 - NAND stores your data, does not require power (non-volatile)
- Memory is in just about all electronics
 - Enterprise (server & data center), PC, and Mobile make up 80+% of DRAM and NAND demand.
 - TV's, game console, removeable storage cards, automotive, smart speakers, other CE, Industrial & medical applications, military, etc.
- In 2020, DRAM & NAND combined revenue reached ~\$120 billion.
- In 2020, the total semiconductor market reached revenue of ~\$470 billion.
 - DRAM & NAND made up ~25% of worldwide total semi revenue.
- DRAM & NAND are a significant influence on the overall semiconductor market.

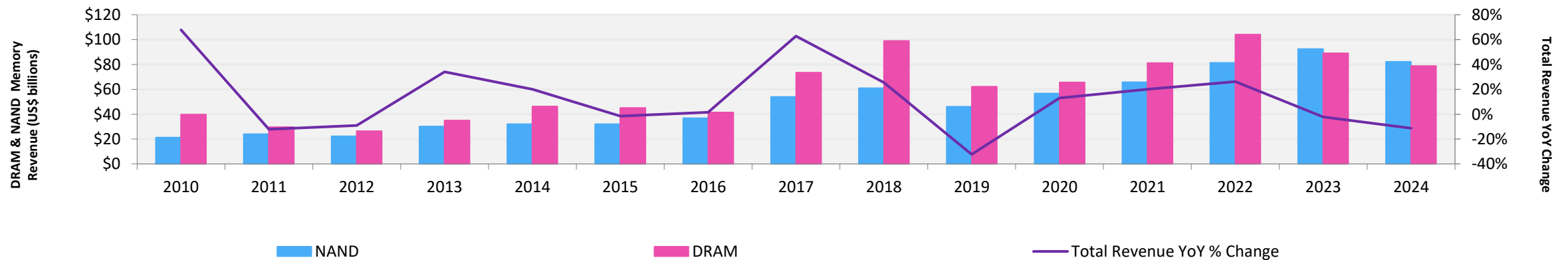
Figure 1: Memory Revenue vs. Total Semi Revenue (\$Billions USD)



Memory cycles of DRAM & NAND

- The memory industry is well understood to be cyclical, driven by supply and demand.
- Most recently, following record revenues in both 2017 and 2018, 2019 was a historical down cycle for both DRAM and NAND as demand grew stagnant, memory bit growth persisted, and inventory levels increased resulting in aggressive average selling price (ASP) declines.
 - In the memory industry, what goes up, typically comes down, then back up.....
- In 2020, the memory industry bounced back, even during a worldwide pandemic.
 - It takes a lot of infrastructure to support work-from-home, educate-from-home, and entertain-from-home environments.
- Looking ahead, we expect cycles to continue as strong revenue years is re-invested into capacity expansion.

Figure 2: Memory Revenue



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Looking back at 2020

2020 Review

- The year 2020 had been projected to be a rebound year from a disastrous 2019.
 - Then COVID-19 hit.....
- Scars of memory production shut-downs, logistical issues, and demand going stagnant put the market on high caution.
- Smartphones took the early big hit in demand.
 - ~200 million smartphones were taken out of the total 2020 forecast in early 1Q20 due to COVID-19.
- However, memory demand from datacenters erupted due to “at-home” environments.
- PC markets flourished as corporate, consumers, and educational markets were upgrading PCs for at-home use.
- At-home entertainment spiked (TV, gaming).
- Memory pricing increased in 1H20.
- By 2H20, the mobile markets had bounced back, PC demand continued to outperform, but the enterprise markets went into an inventory management phase and demand slowed.
- Memory pricing began to decline in 2H20.

Memory Long-Term Assumption (Demand)

	Short-term (2021)	Mid-term (2022-2024)	Long-term (beyond 2024)
Consumer	<ul style="list-style-type: none"> Strong home entertainment demand (TV, Set-top-box, smart speaker) 	<ul style="list-style-type: none"> Mild correction in consumer device (TV, Set-top-box) Continued IoT demand 	<ul style="list-style-type: none"> Continued demand of consumer electronic devices
Graphics	<ul style="list-style-type: none"> Strong game console demand (new SSD demand) GPU demand boosted by Cryptocurrency mining 	<ul style="list-style-type: none"> Mild correction in game consoles and GPUs 	<ul style="list-style-type: none"> Multi-year cycle of new game consoles and GPUs
Mobile	<ul style="list-style-type: none"> Recovery of smartphone Continued low/mid-tier priced 5G smartphone launches 	<ul style="list-style-type: none"> Saturated 5G smartphone Set growth in low-end segment from emerging countries 	<ul style="list-style-type: none"> Replacement demand of smartphone
Server	<ul style="list-style-type: none"> Recovery of enterprise server, Intel Ice Lake launch Cloud server demand is slower than last year 	<ul style="list-style-type: none"> DDR5 Replacement Demand, SSD buildout continues Edge Server, AI momentum 	<ul style="list-style-type: none"> Edge computing, A.I momentum continues HDD cold storage replacement with SSD
PC	<ul style="list-style-type: none"> Strong Demand: Educational & Gaming Notebook Caution for a possible softening in 2H21 	<ul style="list-style-type: none"> Stability from Notebooks 	<ul style="list-style-type: none"> Replacement demand of Enterprise segment Continued positive momentum of low-end segment

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DRAM Memory Technology & Manufacturing

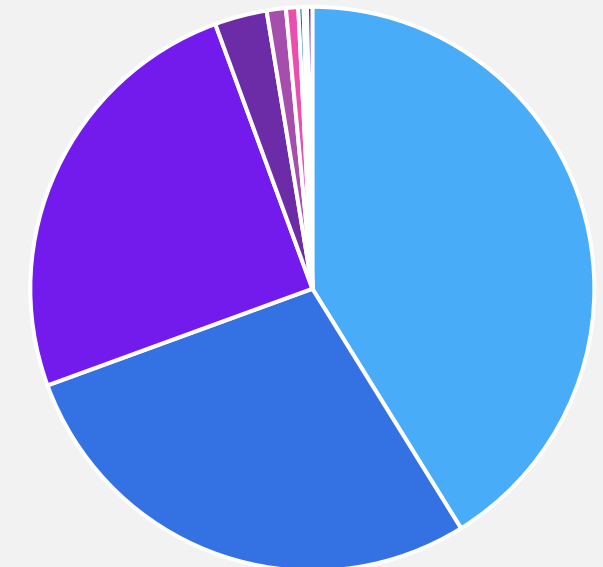
DRAM Technology

- DRAM has historically gone through “die shrinks”.
 - The printed x/y memory cell pattern on the silicon wafer gets smaller and smaller with next generation lithography nodes and architectural changes.
 - Next generation die brings higher capacity, faster speeds, lower power.
 - More die per wafer, more bits per wafer = better cost per wafer.
- However, as DRAM moves down the roadmap, next generations are becoming more challenging (longer time between generations), more expensive, and not as big of a cost savings.

DRAM Manufacturing

- Three manufactures make up roughly 95% of all DRAM revenue.
 - Samsung, SK hynix, and Micron
 - By comparison, in 2008 the same three made up only ~60% revenue share.
 - Very volatile markets lead to strong supply growth, fierce competition, and ultimately M&A.
- With only 3 major player, and with DRAM technology getting challenging and longer to get to next generations, DRAM output is much more stable.
- CXMT – New DRAM manufacture starting up in China

Figure 3: 3Q20 DRAM revenue share



Source: Omdia

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NAND Memory Technology & Manufacturing

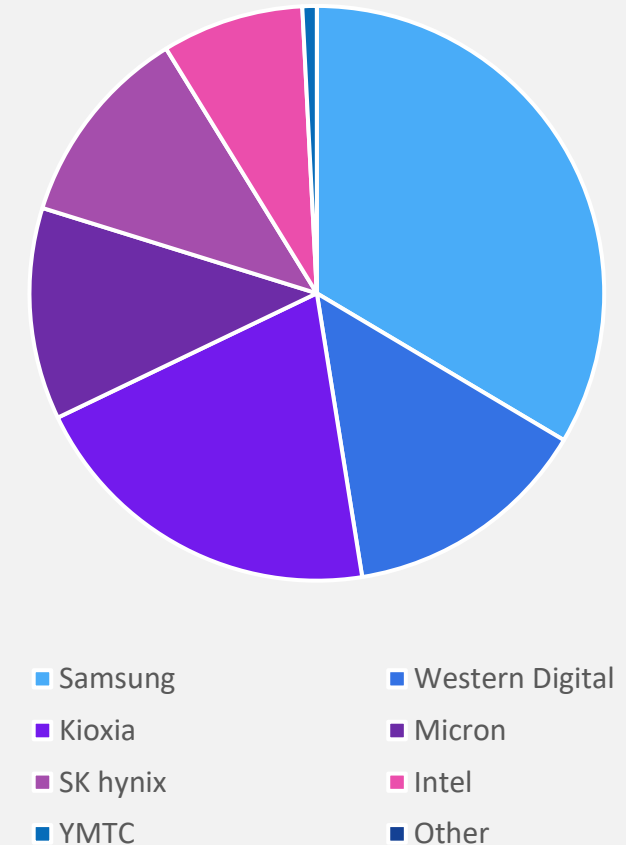
NAND Technology

- Beginning in 2017, the NAND industry went through a 2D → 3D NAND architecture change.
 - NAND performed die shrinks as far as it could go, so went vertical.
 - Think of it as a single-story home to a high-rise apartment. Same footprint but more capacity.
- These vertical layers create more bits per wafer, better cost, higher capacity (with more layers).
- Today, the NAND industry is on 96-layer 3D NAND, with 128-layer in early production.
- There is no declaration of how high the industry can stack, but it will become more challenging to achieve ideal yields.

NAND Manufacturing

- Samsung, SK hynix, and Micron also manufacture NAND, and the three comprise of roughly 67% of worldwide NAND revenue.
- Kioxia (formerly Toshiba Memory) and Western Digital have a partnership, near splitting wafer output.
- Intel is being acquired by SK hynix beginning late 2021.
- YMTC is the new company out of Wuhan, China but still very small output.

Figure 4: 3Q20 NAND revenue share



Source: Omdia

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Summary

- DRAM and NAND combined is a \$100+ billion industry, but very cyclical and driven by supply and demand.
- DRAM and NAND make up ~25% of the total semiconductor industry.
- PC's, mobile, and enterprise (data center/server) make up roughly 80% of all DRAM & NAND demand.
- Overall, the memory industry is expected to continue to grow to meet demand from consumer electronics, hyperscale data centers, AI, IoT, autonomous vehicles. However, technology challenges will only persist in the years ahead.
 - DRAM die shrinks are becoming more challenging, but with three manufactures making up most of the DRAM output, supply can be more stable and predictable.
 - NAND has gone vertical, now at 96-layers and moving to 128-layers.
- DRAM and NAND are a significant influence on the total semiconductor market, either up or down.

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Omdia's memory and storage team brings years of industry experience, from memory manufacturing, to SSD engineering, and corporate memory business/market intelligence. The team has in-depth knowledge of how the memory markets evolve, the psychologies of what drives the industry, as well as future trends that may impact the markets.

Additionally, the memory and storage team has access to the vast internal resources Omdia has to offer, such as application research and demand, as well as a full suite of semiconductor manufacturing reports and analysis to get a full view on the markets.

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