NAND revenue is expected to expand over time as cost reductions enable further penetration of NAND-based storage. Revenue is expected to increase from $56 billion in 2020 to $70 billion in 2021, a huge increase of 25%. By 2026, NAND market revenue is expected to exceed $90 billion.

NAND is the most common and widely used type of non-volatile memory technology because it offers a combination of high storage capacity and low cost per bit. Demand for this memory technology continues to grow (2020-2026 NAND bit growth CAGR of 29%), led by important megatrends such as mobility, cloud computing, AI, and the Internet of Things (IoT).

This report focuses on technologies from Samsung, SK Hynix, and Intel, who respectively held market shares of 34%, 11%, and 9% in 2020.

3D NAND technology continues to rapidly develop. NAND memory improves device capacity by stacking memory cells into vertical layers. In 2015, commercialized 3D NAND memory used 32-layers, while in 2021 most manufacturers are mass producing 128-layer 3D NAND memory. The progressive addition of wordline layers results in significant changes in the manufacturing processes of memory devices. Storing multiple bits per memory cell equates to improved capacity without any additional manufacturing process steps.

In this report, three memories taken from solid-state drives are analyzed: Samsung’s 128-layer, SK Hynix’s 128-layer, and Intel’s 144-layer. This report presents a detailed study of Samsung’s latest 128-layer V-NAND using charge trap flash and triple-level cell NAND memory cells; SK Hynix’s 128-layer (also referred to as the ‘4D NAND’ by SK Hynix) using periphery under cell technology (PuC); and Intel’s unique technology, which combines floating gate architecture with CMOS under array (CuA). Also included in this report is a full analysis and comparison of the NAND memories. Details on package teardown are provided as well, accompanied by optical and high-resolution SEM images of the memory dies that show the dies’ features and process. The die cross-section reveals Samsung’s single deck, SK Hynix’s double deck, and Intel’s wordlines in three decks. The cross-section images disclose the memory floating gate or charge trap technology used by each memory. Also furnished is the manufacturing process of the 3D NAND memory and the cost analysis and comparison. Finally, this comparison report includes the manufacturing process comparison and the cost comparison detailing the NAND array wafer cost, CMOS cost, die cost, and cost per gigabit of the three memories.

COMPLETE TEARDOWN WITH:
- Detailed photos
- Precise measurements
- Materials analysis
- Manufacturing process flow
- Supply chain evaluation
- Manufacturing cost analysis
- Physical analysis, manufacturing process, and cost analysis comparison
TABLE OF CONTENTS

Overview/Introduction
- Executive Summary
- Reverse Costing Methodology

Company Profile
- Samsung/SK Hynix/Intel – Financial Results
- 3D NAND Memories

Physical Analysis
- Samsung Memory
- SK Hynix Memory
- Intel Memory
  - SSD overview
  - Memory package view & dimensions
  - Memory package cross-section
  - Memory package opening
  - Memory die view & dimensions
  - Memory die cross-section
  - Memory die process

Physical Analysis Comparison
- Memory Package
- Memory Die Area and Density
- Memory Die Cross-Section

Cost Analysis
- Summary
- Yields & Hypothesis
- Memory Die Front-End Cost
- Memory Die Cost
- Memory Packaging Cost
- Memory Component Cost
- Memory Cost per Gb

Cost Analysis Comparison
- Wafer Cost Comparison
- Die Cost Comparison
- Packaging Cost Comparison
- Component Cost Comparison
- Cost per Gb Comparison

Selling Price

AUTHORS

Belinda Dube is working for System Plus Consulting as an Engineer & Analyst, Semiconductor Memories, especially DRAM and 3D NAND flash memory. At the same time, she also investigates IC technologies as well as advanced packaging. Belinda is also engaged in the development of reverse engineering & costing analyses with the power electronics and compound semiconductors team.

Véronique Le Troadec has joined System Plus Consulting as a laboratory engineer. Coming from Atmel Nantes, she has extensive knowledge in failure analysis of components and in deprocessing of integrated circuits.

RELATED ANALYSES

3D NAND Memory Comparison 2019
Complete technology and cost analysis of 3D NAND memories from Toshiba/SanDisk, Samsung, SK Hynix and Micron.

YMTC’s 3D-NAND Flash Memory
Technology and cost analysis of YMTC’s 64-layer 3D NAND with hybrid bonding.

NAND Quarterly Market Monitor
After a difficult finish to 2020, the NAND market outlook improves in early 2021.
WHAT IS A REVERSE COSTING®?

Reverse Costing® is the process of disassembling a device (or a system) in order to identify its technology and calculate its manufacturing cost, using in-house models and tools.

CONTACTS

System Plus Consulting is specialized in the cost analysis of electronics from semiconductor devices to electronic systems. A complete range of services and costing tools to provide in-depth production cost studies and to estimate the objective selling price of a product is available.

Our services:
- STRUCTURE & PROCESS ANALYSES
- TEARDOWNS
- CUSTOM ANALYSES
- COSTING SERVICES
- COSTING TOOLS
- TRAININGS

www.systemplus.fr
sales@systemplus.fr

COSTING TOOLS

Our analysis is performed with our costing tool IC Price+. System Plus Consulting offers powerful costing tools to evaluate the production cost and selling price from single chip to complex structures.

IC Price+
The tool performs the necessary cost simulation of any Integrated Circuit: ASICs, microcontrollers, DSP, memories, smartpower...

WHAT IS A REVERSE COSTING®?

Reverse Costing® is the process of disassembling a device (or a system) in order to identify its technology and calculate its manufacturing cost, using in-house models and tools.
TERMS AND CONDITIONS OF SALES

Definitions: “Acceptance”: Action by which the Buyer accepts the terms and conditions of sale in its entirety. It is done by signing the purchase order which mentions that “I hereby accept Yole Development’s Terms and Conditions of Sale”.

“Buyer” means the person or entity who has acquired (or intends to acquire) one or more of the Seller’s products for its own use (for its business needs) entering into the following general conditions to the exclusion of any particular interests.

“Contracting Parties” or “Parties”: The Seller on one hand and the Buyer on the other hand. “Intellectual Property Rights” (“IPR”) means any rights held by the Seller in its Products, including, without limitation, patents, trademarks, know-how, and any other intangible possessory rights and similar in any part of the world, notwithstanding the fact that they may not be registered or not having been registered as stated in the above-mentioned rights.

“Product(s)” Dependent of the purchase order, reports or monitors on MEMS, Imaging, SSL, Advanced Packaging, MedTech, Power Electronics and more, can be bought either on a unit basis or as a bundled offer (i.e. subscription for a period of 12 calendar months). “Report” Reports are established in PowerPoint and delivered in a PDF format with an additional Excel file. Excel file is also included if the study/advisory request is conducted. “License” The report can be shared by the identified user of the Company purchasing the report with the number of people provided, number of print-outs and so on. However, these rights are limited to the country of the identified user. Subscribers and joint-ventures are excluded. “Order” Order: The report is intended for only one identified user at the Company purchasing the report - Sharing is strictly forbidden

3.4 AIBAN: FR76 3005 6001 7001 7020 015 6 587

“Seller”: Based in Villeurbanne (France, headquarters) YoleDéveloppement provides Reverse Engineering/Costing services as well as IP and patent analysis. With more than 70 employees who shall place an order with Yole Group of Companies for such purpose. Nothing is intended to prevent the Yole Group of Companies from offering to sell a report to an employee who shall place an order with Yole Group of Companies for such purpose.

3.4 AIBAN: FR76 3005 6001 7001 7020 015 6 587

1.2 BINDING IN ANY WAY ON THE SELLER.

4.5 “Subsidiaries” are included, while joint-ventures are excluded. Nothing herein is binding.

4.7 No return of Products shall be accepted without prior information to the Seller, even in the case of a particular written agreement. If the Buyer fails to pay within this time and fails to contact the Seller, the latter shall be entitled to invoice interest in arrears based on the annual rate Refl of the «BCE» + 7 points, in accordance with article L 441-6 of the French Commercial Code.

9. GOVERNING LAW AND JURISDICTION

3.5 In the event of termination of the contract, or of misconduct, during the contract, the Seller will have the right to invoice at the stage in progress, and to take legal action for damages.

4.1 The Buyer or any other individual or legal person acting on its behalf, being a business user buying the Products for its business activities, shall be solely responsible for choosing the Printer and for the use and use of the Printer in accordance with the results he obtains, and of the advice and acts it deduces thereafter.

4.1 No claim attributable to errors, omissions or other inaccuracies in the Product or information provided therein.

1.6 A Corporate license: The report can be shared by the identified user of the Company purchasing the report with the number of people provided, number of print-outs and so on. However, these rights are limited to the country of the identified user. Subscribers and joint-ventures are excluded. “Order” Order: The report is intended for only one identified user at the Company purchasing the report - Sharing is strictly forbidden

9.8 The Buyer may, from time to time, update these Terms and Conditions and the Buyer, is deemed to have accepted these new Terms and Conditions against the Buyer.

4.3 In no event shall the Seller be liable for any indirect, incidental, consequential, punitive or special damages (including, but not limited to, damages for loss of profits, business interruption and loss of information or data) arising out of the use of or inability to use the Seller’s website or the Products, or any information provided on the website, or in the Products; b) Any additional, different or conflicting terms and conditions in any other agreement by the Buyer and the Seller.

4.3 The Seller does not make any warranties, express or implied, including, without limitation, those of sale ability and fitness for a particular purpose, with respect to the Products. Although the Seller endeavors to keep the Products free from viruses, worms, Trojan horses or other codes containing contaminating or destructive code, before making these Products available, the Seller cannot guarantee that any Product will be free from infection.

5. FORCE MAJEURE

4.1 If the Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product in a way that it is protected by it (i.e. not the Product’s coverage, the country of the primary user). The Buyer shall have the right to use the Products solely for its own internal information purposes. In particular, the Buyer shall therefore not use the Products for purposes such as:

- Information storage and retrieval systems;
- Recordings and re-transmissions over any network (including any local area network);
- Use in any timesharing, service bureau, bulletin board or similar arrangement or public display;
- Posting any Product to any other online service (including bulletin boards or the Internet);
- Licensing, leasing, selling, offering for sale or assigning the Product.

6.5 The Buyer shall define within its company a contact point for the needs of the contract. This person will be the recipient of each new report. This person shall also be responsible for ensuring that the rights and obligations resulting from the use of the Product(s) are respected in the company. In the context of Bundle and Annual Subscriptions, the contact person shall decide who within the Buyer, shall be entitled to receive the protected link that will allow the Buyer to access the Product(s).

6.6 Please note that whether in Bundles or Annual Subscription, all unselected reports will be canceled and lost after the due date.

6.7 As a matter of fact the investor of a company, external consultants, the joint venture done with a third party, and so on cannot access the report and should pay a full license price.

7. TERMINATION

6.2 The Buyer agrees to receive a notification from the Seller by recorded delivery letter upon which, after thirty (30) days, the Seller shall be entitled to terminate all the pending orders, without being liable for any compensation.

7.2 In the event of breach by one Party under these conditions or the order, the non-breaching Party may send a notification to the other by recorded delivery letter upon which, after thirty (30) days, the Seller shall be entitled to terminate all the pending orders, without being liable for any compensation.

8.4 The Seller shall only be liable for (i) defect and (ii) loss caused to the Buyer's website or the Products, or any information provided on the website, or in the Products; b) Any additional, different or conflicting terms and conditions in any other agreement by the Buyer and the Seller.

8.6 The Buyer hereby agrees that the Products contain defects, the Seller undertakes to replace the defective products as far as the supplies allow and without indemnities or compensation of any kind for labour costs, delays, lost cause or other reason. The replacement is guaranteed for a maximum of two months starting from the delivery date. Any replacement is excluded for any event as set out in article 5 below.

9.1 Any dispute arising out of or linked to these Terms and Conditions or to any transaction entered into between the Buyer and the Seller shall be settled by the French Commercial Courts of Lyon, which shall have exclusive jurisdiction upon such issues.

9.2 French law shall govern the relation between the Buyer and the Seller, in accordance with these Terms and Conditions.