



Empowering Semiconductor Industry with Edge AI Innovation

Boosting Productivity and Quality in Semiconductor Processes

Presented by
Marketing Intelligence

Part I

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Semiconductor

Part I

1. Trends and Overview of the Semiconductor Industry

Trends of the Semiconductor Industry

The semiconductor manufacturing sector is undergoing rapid growth and transformation, primarily fueled by demands from digital transformation, the Internet of Things (IoT), Artificial Intelligence (AI), 5G, Electric Vehicles (EVs), and High-Performance Computing (HPC). These applications require higher performance, efficiency, and functionality from chips, giving rise to several key trends in semiconductor manufacturing technologies:



- Continuous Breakthroughs in Advanced Process Technologies

The demand for high-performance, low-power chips continues to drive advancements in semiconductor nodes, such as the development and mass production of 3nm and 2nm technologies. These processes achieve higher transistor density and performance but also introduce significantly increased manufacturing costs and technical complexity. To overcome these challenges, semiconductor manufacturers are actively adopting cutting-edge technologies such as Extreme Ultraviolet (EUV) lithography to enhance production capacity and meet market demands.

- Heterogeneous Integration Becoming Mainstream

As the pace of Moore's Law decelerates, the industry is increasingly adopting heterogeneous integration, leveraging 2.5D and 3D packaging to combine multiple functional chips within a single package. This enhances performance and conserves space. In fields like AI and HPC, such integration technologies have become critical to boosting system performance. Consequently, the demand for advanced packaging technologies and high-performance materials continues to rise.

• EVs and Smart Manufacturing Driving Growth

The growing adoption of EVs and smart manufacturing has led to a surge in demand for power semiconductors, such as silicon carbide (SiC) and gallium nitride (GaN) devices. These materials offer high performance and heat resistance, making them crucial for fast EV charging and energy efficiency. Additionally, demand for sensors, controllers, and AI processors in smart manufacturing continues to push the boundaries of semiconductor technology.

• Sustainability Requirements

With increasing global emphasis on carbon neutrality and environmental protection, semiconductor manufacturers are focusing on improving energy efficiency and reducing carbon emissions during production. Green manufacturing and the use of renewable energy have become key indicators of corporate competitiveness.

Overall, the semiconductor manufacturing sector is increasingly driven by both advanced technology and diversified applications. Under the combined influence of technological breakthroughs, industrial policies, application demand, and sustainability initiatives, the semiconductor market is poised for continued expansion—bringing both innovation opportunities and challenges. Businesses must stay aligned with market trends, proactively invest in R&D, and optimize their supply chains to remain competitive on the global stage.

Global Market Size Forecast

According to market projections, global semiconductor demand will continue to grow steadily in the coming years, with the total market size expected to reach approximately USD 1.2 trillion by 2035. In terms of demand distribution, data centers and high-performance computing (HPC) are anticipated to account for the largest market share. Additionally, the electric vehicle (EV) sector and related power components are expected to see a significant surge in demand, positioning them among the fastest-growing application segments. While the growth rate of smart terminal devices—such as smartphones and wearables—may slow down, stable demand will continue to support a substantial shipment volume. At the same time, industrial automation and smart manufacturing will drive increased demand for embedded chips and sensors. This diversified demand landscape highlights the growing breadth of semiconductor manufacturing and underscores the importance for companies to optimize technologies for different application scenarios—in order to meet market challenges and capitalize on growth opportunities.

Dynamic Applications of Semiconductor

Semiconductors are the cornerstone of modern technological advancement, with applications spanning a wide range of sectors including consumer electronics, industrial automation, automotive electronics, communications and networking, artificial intelligence (AI) and high-performance computing (HPC), medical technology, and aerospace and defense. From everyday devices such as smartphones and laptops, to industrial use cases like smart manufacturing and machine vision inspection, and even military and defense systems including high-precision radars and satellite navigation, semiconductor technology is omnipresent—continuously driving global industrial innovation and advancement.



In the consumer electronics sector, semiconductors significantly enhance processing power and energy efficiency, enabling smartphones, tablets, and smart home appliances to achieve faster computing speeds, longer battery life, and superior display performance.



In industrial applications, smart manufacturing is increasingly adopting AIoT (Artificial Intelligence of Things) and machine vision systems to boost production efficiency. Through precision sensors and real-time data analytics, enterprises can achieve high-precision quality inspection and process optimization, reducing manufacturing costs and increasing yield. Advances in energy management technologies—such as smart grids, solar power generation, and power management systems—also benefit from semiconductor innovation, resulting in more efficient operations.



In automotive electronics, the rise of EVs and autonomous driving has driven demand for high-performance processors, AI chips, and sensor modules—facilitating the transformation from traditional internal combustion engines to intelligent and electrified vehicles. The evolution of advanced driver-assistance systems (ADAS) and in-vehicle infotainment platforms has made driving experiences safer, more convenient, and smarter.



In communications and networking, advancements in 5G base stations, Wi-Fi 6/7, optical communication, and satellite communication have drastically improved global data transmission capabilities. These technologies provide faster and more stable network connections, supporting applications such as edge computing, smart cities, and interconnected infrastructure.



The AI and HPC domains have become increasingly dependent on semiconductor innovation. Technologies like AI accelerators, GPUs, NPUs (Neural Processing Units), cloud computing, and edge AI are continuously fueling the growth of data centers and intelligent applications.



The medical technology field is also benefiting from semiconductor advancements. Applications such as medical imaging processing, wearable health devices, and telemedicine solutions are transforming traditional healthcare models, improving diagnostic accuracy and enabling more comprehensive health monitoring.



Last but not least, in aerospace and defense, the evolution of semiconductor technology has propelled the development of satellite navigation, military-grade radar, and unmanned aerial systems (UAS) enhancing national security and precision communication. Whether in precision strike systems, global positioning, or battlefield communications, the high-performance computing power of semiconductors plays a mission-critical role.

2. Semiconductor Manufacturing Process

- Upstream: IC Design, Materials, and Equipment

The upstream sector includes IC design, semiconductor materials, and equipment. Key materials such as silicon wafers, photomasks, photoresists, etching agents, and packaging substrates have a direct impact on chip yield and performance. Critical manufacturing equipment includes photolithography systems, etching tools, thin-film deposition systems, and ion implanters. IC design is a core process in which companies define the chip architecture, logic, and circuits before sending the designs for fabrication.

- Midstream: Wafer Manufacturing

Wafer fabrication is the heart of semiconductor manufacturing and consists of complex processes like photolithography, etching, thin-film deposition, ion implantation, CMP (Chemical Mechanical Planarization), and metal interconnect formation. The overall process can be divided into two phases:



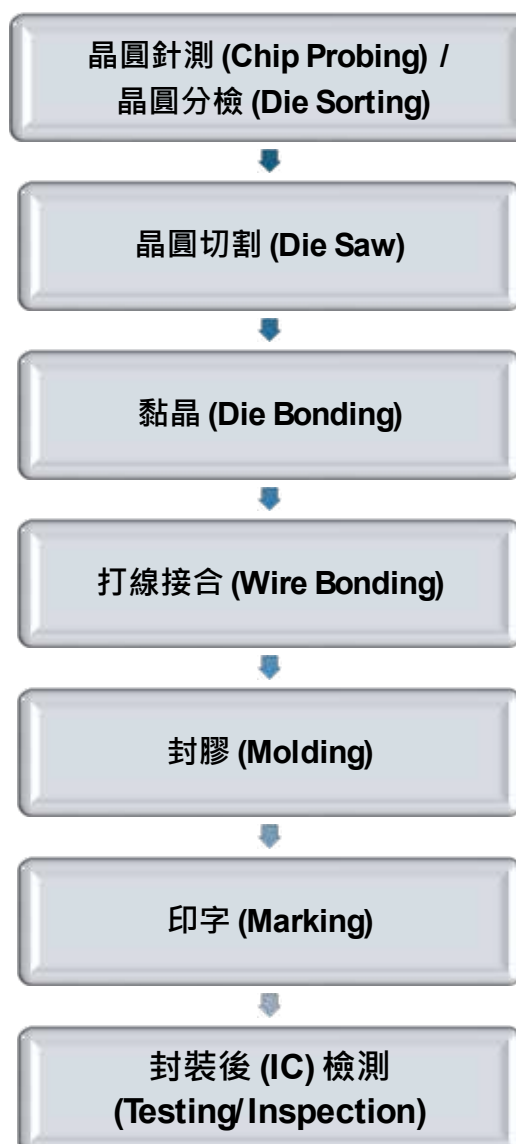
Midstream: Phase 1 – Wafer Production

- **Purification:** Semiconductor-grade silicon is extracted from quartz sand (SiO_2) and purified to obtain ultra-pure polycrystalline silicon.
- **Crystal Growth:** Monocrystalline silicon is grown using the Czochralski (CZ) method or zone refining techniques.
- **Ingot Pulling:** Silicon ingots are formed using CZ or Float Zone (FZ) techniques.
- **Wafer Slicing:** Diamond wire saws slice ingots into thin wafers.
- **Grinding & Polishing:** The wafer surface must be extremely smooth. CMP is used to remove residual impurities and reduce surface roughness, ensuring the wafer is ready for photolithography.

Midstream: Phase 2 – Wafer Processing

- **Deposition:** Different films are deposited to form insulating, conductive, or functional layers.
 - **Photoresist Coating:** A light-sensitive polymer is applied uniformly using spin coating.
 - **Exposure:** A photolithography system transfers circuit patterns onto the photoresist. EUV (Extreme Ultraviolet) is used for advanced nodes below 2nm, while DUV (Deep Ultraviolet) is used for older processes.
 - **Developing:** Developer selectively dissolves exposed or unexposed regions depending on the resist type, revealing circuit patterns for etching.
 - **Etching:** Dry or wet etching removes unprotected material to form circuit structures.
 - **Photoresist Stripping:** Residual photoresist is removed after etching.
- Downstream: IC Packaging and Testing

IC Packaging & Testing



After wafer fabrication, chips move to packaging and testing. Packaging protects the chip and ensures electrical connectivity, typically bonding the bare die onto a substrate using wires or Through-Silicon Vias (TSV). Traditional packages include DIP (Dual In-Line Package) and QFP (Quad Flat Package), while advanced methods like Flip-Chip, Fan-Out, and 3D IC enhance performance and integration. Testing includes functional and reliability tests to ensure the chip's performance across various conditions.

3. How Edge AI Enables Smarter, More Efficient Wafer Manufacturing

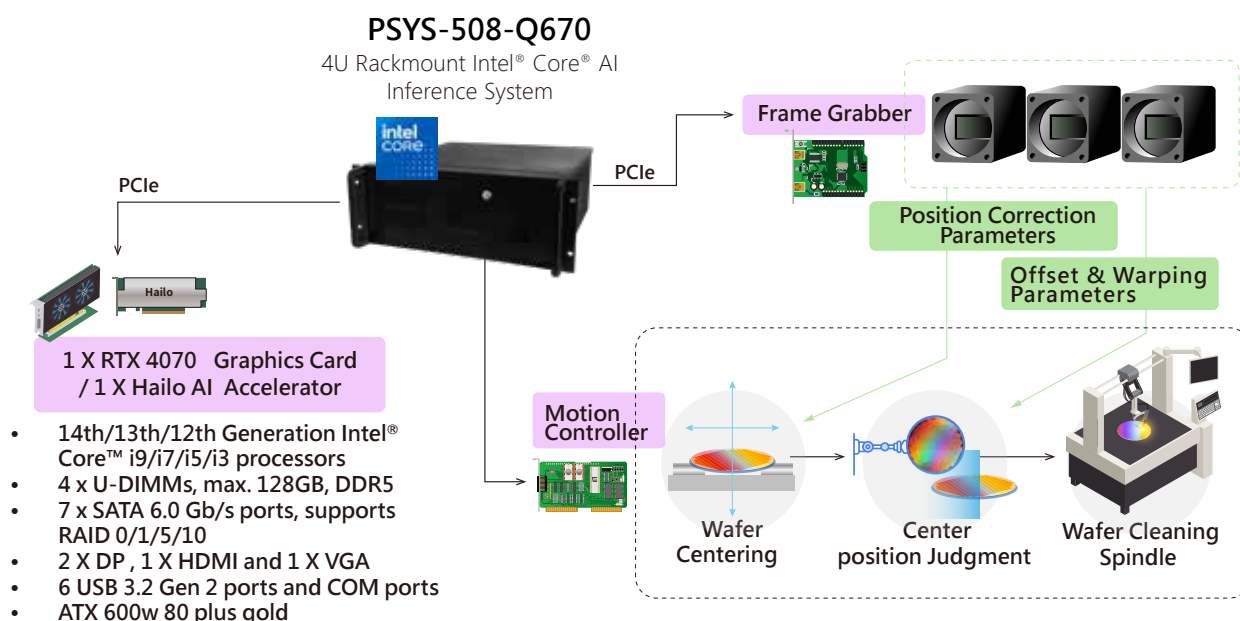
With semiconductor demand surging, the importance of manufacturing precision and efficiency has grown. Integrating edge AI into production scenarios is driving innovation in wafer manufacturing and downstream packaging and testing. Edge AI enhances real-time data processing and decision-making directly at the production site, leading to significant improvements in various manufacturing processes. Below is an edge AI use case in wafer cleaning:

Wafer Cleaning: Vision-Based Positioning System

Wafer cleaning is a critical process that directly impacts yield and process stability. By using chemicals and ultrapure water to remove photoresist, organic compounds, metal residues, and particles, the wafer surface is polished and prepared for subsequent steps. Cleaning accounts for roughly one-third of the manufacturing cycle and is crucial for defect reduction and contamination control. After wafers are removed from the FOUP (wafer pod), mechanical arms and algorithms handle precise alignment. However, repositioning can cause delays. To overcome this, manufacturers integrate machine vision with motion control systems. Vision systems detect wafer offset and warpage in real time and provide precise data to guide positioning and cleaning actions. Vision systems also optimize cleaning parameters, avoiding over-processing or wafer damage. This improves precision and efficiency, especially for removing microscopic particles while preserving surface integrity.

Advantages of Using Portwell PSYS-508 Advanced Edge AI System in Wafer Cleaning

AI-Driven Semiconductor Wafer Cleaning Solution



- **Optimized Performance:** Supports the latest Intel® Core™ processors, PCIe Gen5 and M.2 slots for integrating high-performance components like frame grabbers and GPU (e.g., NVIDIA® GeForce RTX™ 4070) or AI accelerators (e.g., Hailo).
- **Integrated Vision and Motion System:** Real-time detection of wafer offset and warpage enables precise positioning and cleaning coordination.
- **High-Bandwidth Memory:** DDR5 memory up to 128GB, supports multi-stream image processing and real-time inference.
- **Efficient Data Management:** RAID-capable SATA Ports allow for bulk image data storage and faster access.
- **Comprehensive Connectivity:** Features 2.5GbE, USB 3.2 Gen 2, and multiple serial ports for seamless subsystem integration.
- **Real-Time Monitoring:** Multi-display output options (HDMI, DP, VGA) facilitate real-time monitoring and visualized adjustments.
- **Industrial-Grade Reliability:** Robust 4U chassis and 80 Plus Gold PSU ensure long-term, high-load operation

Next Publication

4. Part 2: How Edge AI is Revolutionizing IC Packaging and Testing Quality and Efficiency

Driven by growing market demand, the semiconductor industry is experiencing sustained expansion. As advanced processes and packaging technologies continue to evolve, these advancements not only enhance chip performance but also enable practical AI implementation. The industry is now at a critical juncture where technological innovation and market needs are simultaneously pushing boundaries. Edge AI offers a transformative opportunity to enhance efficiency and quality in the following downstream semiconductor manufacturing processes:

(A) Die Sorting: Accelerating Die Inspection Cycles

Die probing and sorting are vital for quality control and manufacturing efficiency. These processes identify defective chips, grade quality levels, and allow manufacturers to perform defect repairs. By doing so, they lower costs, improve yield, and maintain competitive advantages. Advanced die sorters integrate machine vision, AI, and edge computing with multi-axis motion control systems. The vision system evaluates chip surface quality, position, and dimensions, transmitting real-time data to the motion system for precise control during pickup, rotation, classification, and placement. The motion system ensures chip stability during high-speed movements, reducing misalignment and vibration-induced issues. These integrations shorten inspection cycles, minimize human error, and enhance production reliability.

(B) Wafer Saw: High-Precision Visual Positioning for Dicing

Edge AI systems provide precise and efficient inspection during wafer dicing. With Edge AI, automated correction boosts accuracy and reduces reliance on manual labor. In a typical setup, an industrial camera captures the wafer's dicing location under auxiliary lighting. The images are sent to an edge AI system via network switch. The AI analyzes alignment accuracy; if misalignment is detected, the system triggers auto-calibration commands to adjust the dicing blade.

(C) Die Bonding: High-Precision Die Attach with Vision + Motion Synchronization

Die bonding is a critical step in IC packaging that directly impacts chip performance and reliability. A die bonder must precisely pick and place dies from a wafer onto the substrate using epoxy adhesives. High-speed, micron-level accuracy is essential to ensure electrical and thermal integrity.

Traditional optical alignment systems struggle to meet modern precision demands.

High-performance die bonders now integrate motion and machine vision systems for real-time detection and dynamic compensation.

The vision system determines chip position and angle, calculating relative placement to the substrate. Compensation data is fed to the motion system, which dynamically adjusts its actions to prevent cumulative deviation, maintaining sub-micron placement accuracy.

Part II to be continued....





Portwell, Inc. Headquarters

No. 242, Bo'ai St., Shu-Lin Dist,
New Taipei City 238, Taiwan
Tel: +886-2-7731-8888
Fax: +886-2-7731-9888
E-mail: info@portwell.com.tw
www.portwell.com.tw

Americas

American Portwell (Fremont, CA)

44200 Christy St., Fremont, CA 94538, USA
Tel: +1-510-403-3399
Fax: +1-510-403-3184
E-mail: info@portwell.com
www.portwell.com

Japan

Portwell Japan, Inc. (Tokyo)

〒112-0011 4-27-10, Sengoku, Bunkyo-ku,
Tokyo, Japan
Tel: +81-3-6902-9225
Fax: +81-3-6902-9226
E-mail: info@portwell.co.jp
www.portwell.co.jp

Portwell Japan, Inc. (Osaka)

〒532-0004 Ste.501 Nippo Shin-osaka Dai-2
Bldg, 1-8-33 Nishi-Miyahara, Yodogawa-ku
Osaka Japan
Tel: +81-6-4807-7721
Fax: +81-6-4807-7720
E-mail: info@portwell.co.jp
www.portwell.co.jp

Europe

European Portwell

Schillingweg 3, 2153 PL
Nieuw Vennep, The Netherlands
Tel: +31-252-620790
E-mail: info@portwell.eu
www.portwell.eu

KIOSK Embedded Systems GmbH

Am Technologiepark 8-10,
D-82229 Seefeld
Tel: +49-8152-3962-500
E-mail: info@portwell.eu
www.portwell.de

Portwell UK Ltd.

Office TH2
Trident House, Trident Park Basil
Hill Road, Didcot, OX11 7HJ, UK
Tel: +44(0)1235-750-760
Fax: +44(0)1235-750-761
E-mail: info@portwell.eu
www.portwell.eu

China

Shanghai Portwell

(201612), Room 1303-1, Building 33, No.258,
Xinhuan Highway, Songjiang District,
Shanghai
Tel: +86-21-5771-2505
Fax: +86-21-5772-2965
E-mail: info@portwell.com.cn
www.portwell.com.cn

Korea

Portwell Korea, Inc.

O-BIZ Tower 1901, No.126,
Beolmal-ro, Dongan-gu, Anyang-si,
Gyeonggi-do, Korea, 431-060
Tel: +82-31-450-3043
Fax: +82-31-450-3044
E-mail: info@portwell.co.kr
www.portwell.co.kr

India

Portwell India Technology Private Limited.

3rd Floor, Jeet Dynasty, Old Madras Rd,
next to Gopalan Signature Mall,
Nagavarapalya, Benniganahalli,
Bengaluru, Karnataka 560093, India
Tel: +91-80-4168-4255
E-mail: enquiry@portwell.in
www.portwell.in



www.portwell.com.tw