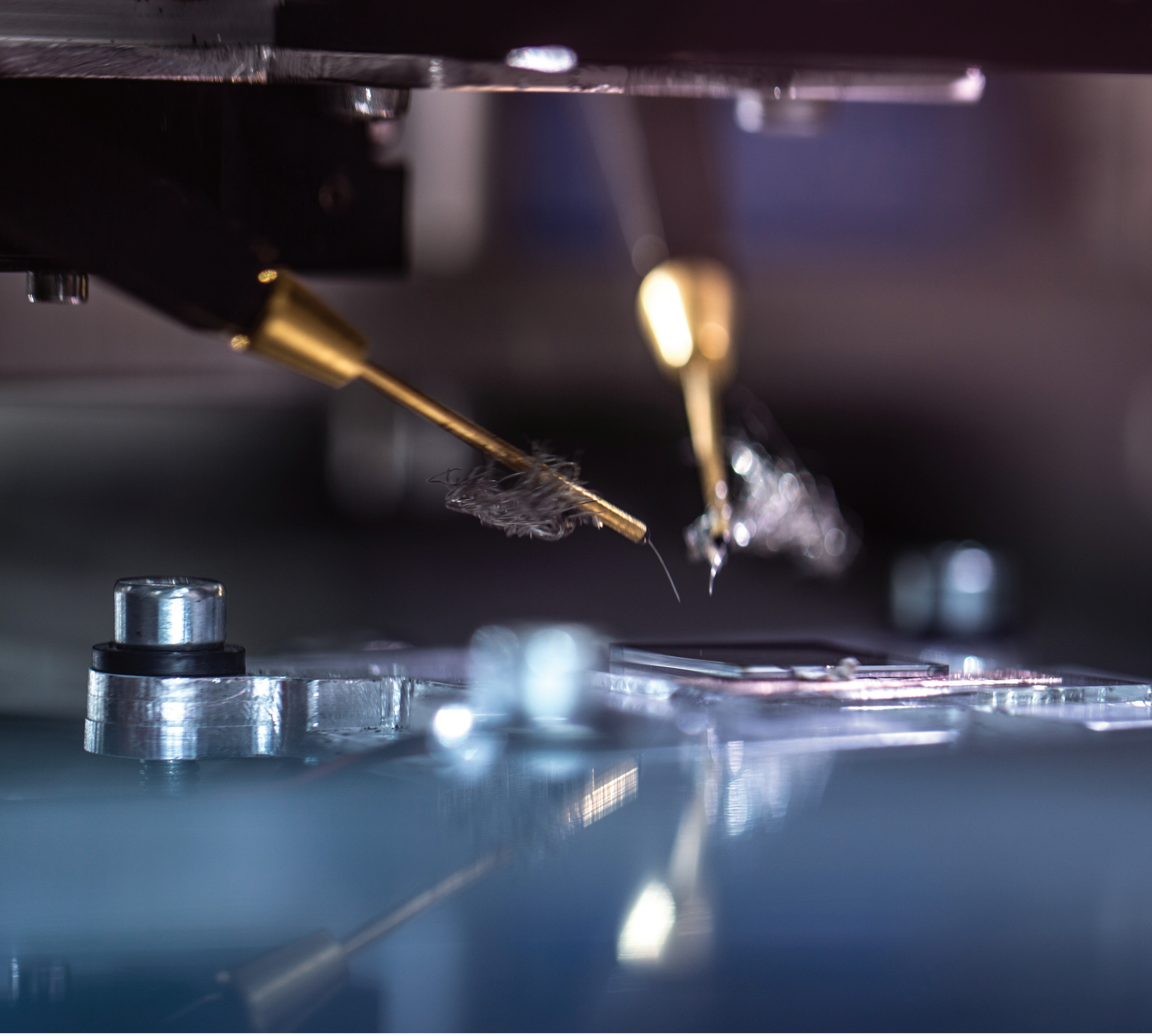

Trends in Semiconductors: A Robust Industry Growth

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Trends in Semiconductors: A Robust Industry Growth

Despite the economic pressures driven by the coronavirus pandemic, global semiconductor revenues increased and are expected to continue to grow into 2022.

In 2020, the sector enjoyed a 6.5% increase to $440 billion. Revenue is expected to jump by 19.7% in 2021 to $527 billion, according to World Semiconductor Trade Statistics (WSTS). Following this recovery, the organization expects slower but substantial growth of 8.8% in 2022.

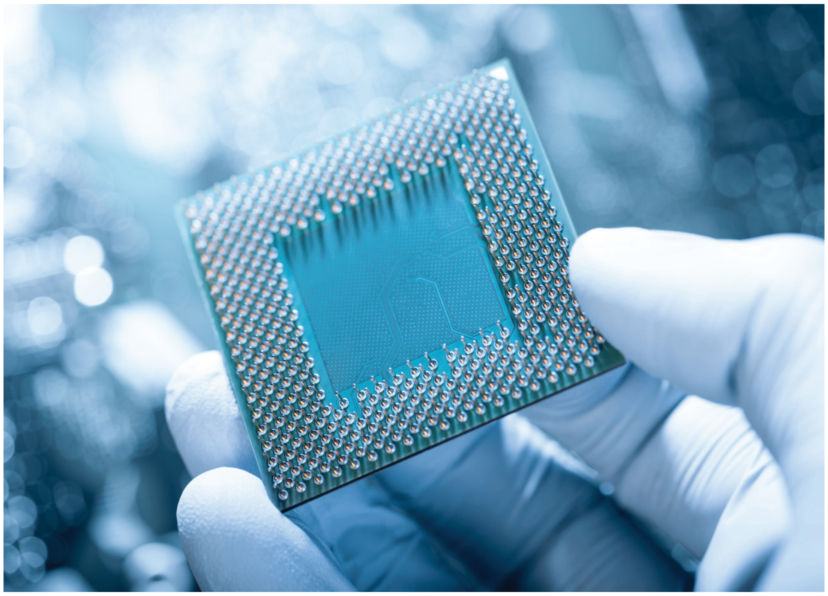
Annual increases in 2021 revenues, by global region, are being led by Asia Pacific at 23.5%, followed by Europe (21.1%), Japan (12.7%), and the Americas (11.1%).

Industries accelerating the demand for semiconductor chips include:

- Communications
- Computing
- Health care
- Online services
- Automotive

Primary applications driving growth are:

- Wireless communications infrastructure, including 5G
- IoT (Internet of Things)
- Automotive electronics
- Cloud computing
- HPC (high-performance computing)
- Data centers
- AI (artificial intelligence)
- Consumer electronics



Within semiconductor industry products, **MEMS (Micro-Electro-Mechanical Systems) sensors** represent the single greatest opportunity for growth in the next few years, according to KPMG International.

MEMS sensors are integrated devices smaller than 100 microns that combine electronics (using IC technology), electrical and mechanical elements to sense a physical quantity, such as temperature or pressure, and convert it into an electrical signal.

A major end user of these devices is the automotive industry, where MEMS sensors are used in nearly all the monitoring systems in modern vehicles. They also are used in a wide variety of other industries, such as chemicals, industrial automation, computing, communications and aerospace.

Global Semiconductor Shortage

The pandemic also drove some large shifts in consumer demand during 2020.

Sales of consumer electronics took off when populations suddenly had to stay at home for work, school, shopping and entertainment. At the same time, **global demand for new cars dropped sharply.**

Both industries are major purchasers of semiconductors. As automotive orders fell off, semiconductor manufacturers faced their own shortages due to COVID-related plant closings and restrictions at ports and international borders. Many of them reallocated their production to meet strong demand from consumer electronics and other industries. Then, when people unexpectedly started buying cars again in the second half of 2020, the auto industry was unable to get the chips it needed. **This resulted in production delays, plant shutdowns and limited inventories.**

United States Committed to Cutting Reliance on Foreign Chips

American industries rely heavily on foreign chip manufacturers. While the United States produced 37% of the world's semiconductors in the mid-1990s, this share is only 12% today. **Two Asian companies now produce more than 70% of the world's semiconductors** - TSMC in Taiwan and Samsung Electronics in South Korea. In 2021, Samsung announced its goal to lead the world in logic chips by 2030.

In addition, nearly three-fourths of the world's wafers, the principal platform for semiconductor devices, were manufactured in Taiwan (22%), South Korea (20%), China (16%) and Japan (16%) in 2020.

The U.S. government is committed to increasing America's self-reliance in semiconductor production and in the industry's supply chain, not only for the growing demand in consumer products, but in critical defense, aerospace and infrastructure applications. The Biden administration seeks less U.S. dependence on manufacturing in East Asia, given China's growing presence in the region.

In early 2021, the administration earmarked $50 billion for U.S. semiconductor manufacturing and research as part of its proposed $2 trillion economic stimulus package. This will significantly impact Intel and a handful of smaller American semiconductor manufacturers, such as Micron and Texas Instruments.

Intel, headquartered in California, is the world's largest semiconductor manufacturer in terms of revenue, with 2020 sales of $74 billion, well ahead of Samsung ($60 billion) and TSMC ($45 billion). Intel's custom chips are more sophisticated and expensive than TSMC's, many of which are commodity ICs. In addition to upgrading its factory in New Mexico, Intel plans to spend $30 billion on building three new chip factories: one in Israel and two in Arizona. The latter two will become operational in 2024. TSMC is building a new chip factory in Arizona as well, a $12 billion plant is under construction.

Global Capacity Additions

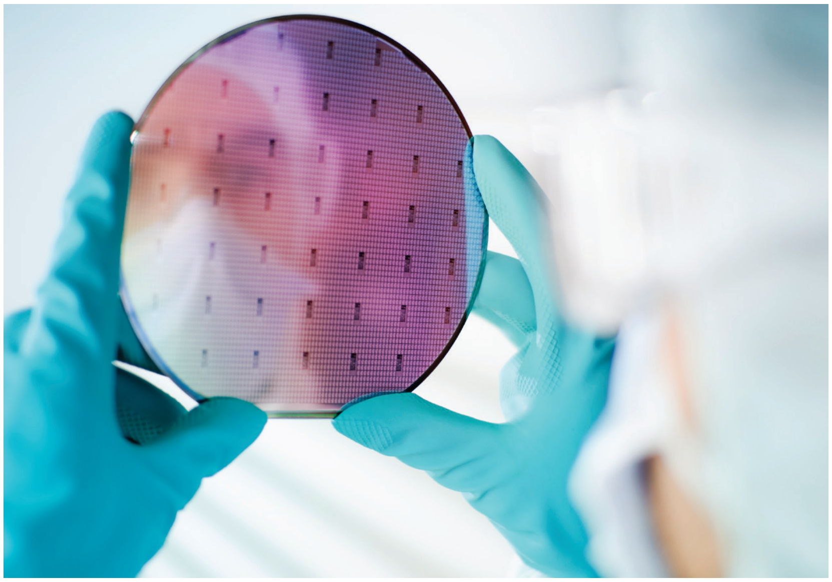
In 2021 and 2022, 29 new high-volume semiconductor factories (fabs) will break ground around the world. Twenty of these are in Asia (eight each in China and Taiwan, two each in Japan and South Korea), six in the Americas, and three in Europe/Middle East. Twenty-two of these fabs will produce 300mm wafers, with the remaining seven making 200 mm, 150mm and 100 mm wafers. The total cost of the manufacturing equipment for these plants is expected to exceed $140 billion, with production for many of them unlikely to start until 2024 or 2025.

Semiconductor Manufacturing Equipment

A key segment of the semiconductor industry is the specialized equipment it uses, which falls into three major categories: **wafer fabrication, assembly and testing.** It takes more than 50 different pieces of equipment to produce wafers and integrated circuits.

Asian semiconductor manufacturers are strongly dependent on equipment and machinery purchased from the U.S., Europe and Japan. China, however, is committed to becoming self-reliant, including manufacturing its own equipment to produce semiconductors. This is unlikely to happen in the next five years or more because China lacks the required cutting-edge technology.

Global wafer fab equipment (WFE) spending is forecast to grow by 7.8% in 2021, after a sizable 13.9% increase in 2020, according to Gartner Research.



Much of the 2021 growth will come from large producers of memory chips adding more capacity. One of these, Taiwan's TSMC, intends to spend $100 billion through 2024 on new factories. SEMI is forecasting 5.8% growth in 2022, with foundry (non-captive fabs) and logic equipment accounting for about half of total WFE sales.

- **Wafer fabrication equipment** primarily grows, deposits or removes materials from a wafer. Processes include ion implantation, physical and chemical vapor deposition, photolithography, and etching, as well as oxidation and diffusion systems and epitaxial reactors.
- **Assembly equipment** converts wafers into finished ICs, which are chips ready for customer applications. This equipment involves various processes applied to wafers and dies, as well as coating, molding, sealing, welding, branding and lead finishing tasks.
- **Automated test equipment (ATE)** is used on assembled semiconductor devices. This computer-controlled equipment tests electronic devices for functionality and performance. Other test equipment includes test handlers, tape & reel, marking and UV erase equipment, burn-in and retention bake ovens, and vacuum sealers.

Technology Advancements

Recent advancements in semiconductor technology include:

- Denser and more complex chips
- Smaller device dimensions, aka "process nodes" (<10nm)

- 3D features: processor functions stacked vertically instead of horizontally, resulting in greater performance in a smaller space
- Larger wafer sizes = more chips per wafer
- Continued demand for 200mm wafers with new fabs and fab upgrades now prompting manufacturers to make 300mm wafers
- Expectations that global equipment spending for 300mm fabs will triple between 2020-2024, from $60 billion to $177 billion, according to SEMI

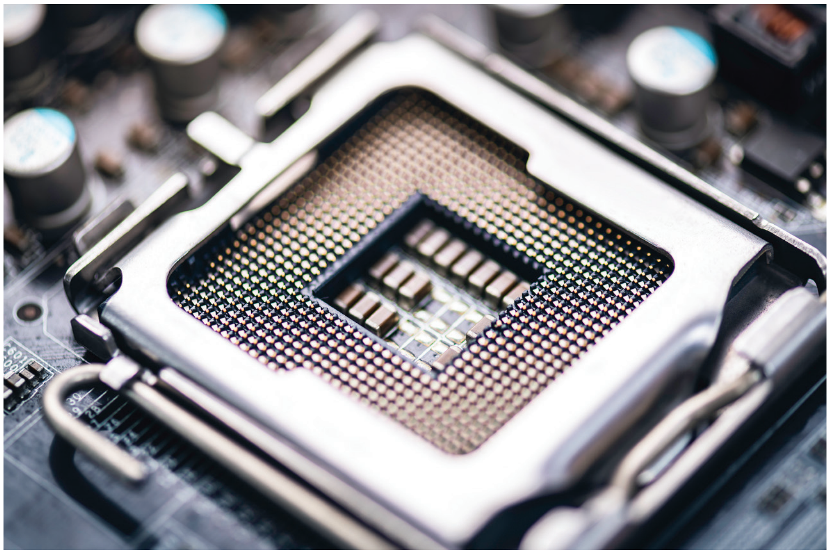
One of the **key measures of next generation semiconductor technology** is how many transistors (electronic switches) can be packed on a chip, which is determined by size. **IBM announced a breakthrough in 2021:** a chip with the world's smallest transistors, each one 2 nanometers wide.

This technology will allow 50 billion transistors to be packed on a single chip, according to IBM. Compared to 7nm transistors used today, this could improve a computer's performance by 45%, lower its energy consumption by 75%, or quadruple a cellphone's battery life.

Most of today's chips that power electronic devices have transistors between 5nm and 10nm wide. (The width of a human hair is 10,000nm.) TSMC and Samsung are now producing 5nm transistor chips, while Intel will not introduce its 7nm chips until 2022. IBM expects to start producing its new 2nm chips in 2024 or 2025.

Smaller Chip Surfaces Require Higher Precision

As chips have gotten smaller, their surfaces have become a larger proportion of the total device. This can greatly affect their electronic properties. **Two key processes in fabricating**



semiconductor surfaces today are atomic layer deposition (ALD) and atomic layer etching (ALE).

ALD is a highly controlled method of depositing ultra-thin films onto a silicon wafer, a few atomic layers at a time, to a specified thickness and uniformity. This includes deposition on complex three-dimensional surfaces, such as 3D NAND. Research is under way to develop patterning methods for ALD, which will allow film deposition in specific locations, as well as perfectly aligning a new pattern over an existing one. Evolving ALD technologies are deemed essential for future 5nm and 3nm chips.

ALD instruments, which can cost between $200,000 and $800,000, are extremely complex, requiring exceptionally high levels of accuracy, repeatability and cleanliness.

ALE is the counterpart of ALD, but is a newer technology, having gone into production in 2016. It is being used increasingly in making state-of-the-art semiconductor devices, although the workhorse technology for etching is still reactive-ion etching (RIE). RIE blasts ions onto the wafer surface to remove materials on a continuous basis, whereas ALE uses sequential steps to remove targeted material at the atomic scale. Of the two types, Plasma and Thermal, Plasma ALE is in production while Thermal ALE remains in development.

The current market for ALE is limited because it is a relatively slow process and is used only for selective applications in the fab. With new-generation chips being made at the atomic level, however, ALE is considered one of the most promising techniques for achieving low variability in etching at this scale. It can, for example, remove material in a structure to form trenches that are 5 atoms wide.

Contamination Challenge

With the introduction of 7nm to 14nm process nodes (smallest device dimensions), semiconductor manufacturers have further tightened their specifications on contaminants coming into the plant.

Contamination control is critical in maximizing device yields, as a single airborne particle left on a tiny chip, for instance, can cause it to fail. For this reason, chip manufacturing is done under strict cleanroom conditions.

Advanced filtration and purification are used to remove increasingly smaller particles, metals and organics, not only from the air but also from every gas and chemical used in production. Some microfiltration systems can remove particles as small as 0.02 microns and from metals at less than 5ppb.

Threat from Climate Change

Semiconductor manufacturing is a highly water-intensive process. One chip factory can consume more than 2 million gallons of ultrapure water a day to constantly rinse impurities from the chips as they are being made.

Warmer global temperatures resulting from climate change are threatening water supplies in many parts of the world, including the American West and Taiwan, both with major semiconductor fabs.

Since 2020, Taiwan has been enduring its worst drought in more than 50 years, with predictions of a 40-60% reduction in annual rainfall by the end of the century if planet warming continues at its current rate. Taiwan's TSMC was trucking in water and boosting its water recycling rates in 2021 in response to government-imposed restrictions on water usage throughout the island.

Arizona, where both Intel and TSMC are building new fabs, is the nation's fourth driest state and is facing a worsening water crisis because of declining groundwater levels. Intel, however, will rely heavily on water recycling and on funding new water restoration projects in the state, resulting in its plants achieving "net-positive water use" in Arizona.

Conclusion

The U.S. semiconductor industry has seen its share of ups and downs in the recent past. But the near future looks strong with the demand for chips only growing from a multitude of industries, in the U.S. and worldwide. Keeping up with growing demand and technology advancements will propel semiconductors forward in Industry 4.0, the new digital age of manufacturing.

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