The Importance of Onshore Semiconductor Innovation

And the Indispensable Nature of Intel's Contributions

Summary

Semiconductors are the brains of the technology market — the critical infrastructure behind modern innovation. While businesses and consumers alike have become enamored with AI and other technology trends, it is the underlying hardware, anchored by semiconductors, that brings those ideas to life.

Most people associate semiconductors with CPUs, GPUs, and other specialized chips that power our devices, cars, computers, and even the cloud. However, a well-designed chip is meaningless without the underlying technology to drive performance and efficiency. Advanced transistor designs, combined with world-class manufacturing, that enables chip design houses to pack more computational capacity into a smaller spaces and consume less power.

There is no shortage of innovation in chip design — some say ideas are the easy part. The challenge lies in designing the underlying technology, which is very impressive yet often overlooked.

The United States has historically been the leader in chip technology. However, over the last three decades, its position has eroded as production shifted to overseas foundries, particularly in Taiwan and South Korea. This shift has created a delicate supply chain that is efficient enough under normal geopolitical circumstances but at risk in times of disruption. If global innovation relies on chips, then national security, economic growth, and technological sovereignty rest on who builds them.

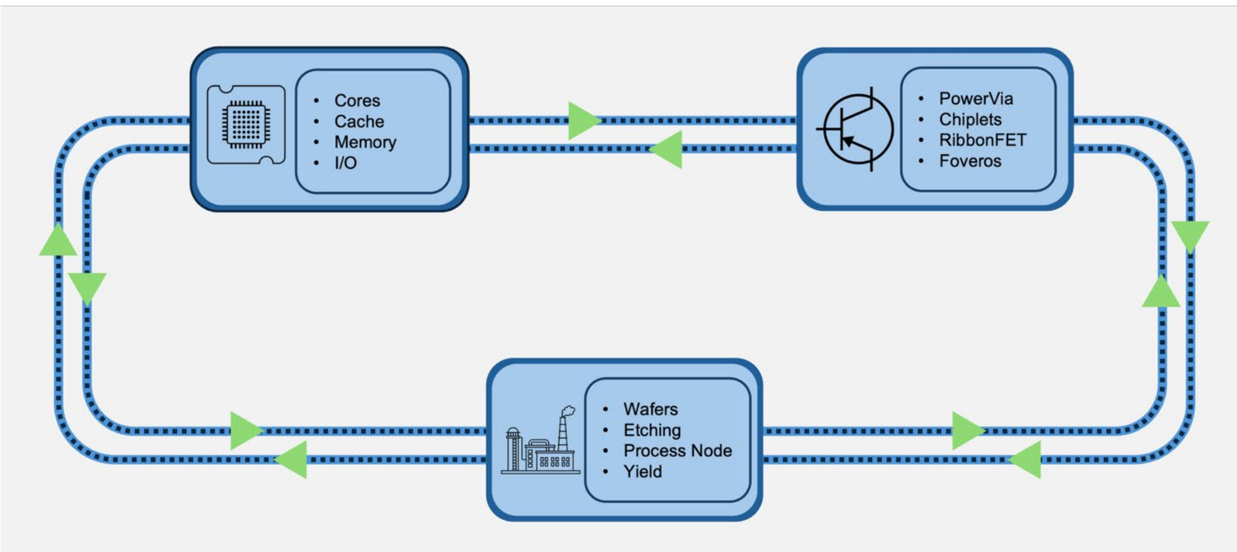
This research brief examines the semiconductor market trends that drew innovation away from the United States. It also looks at how one company, Intel, has helped maintain the country's competitive position, and why the success of Intel's chip technology and manufacturing business is crucial to both the industry and national security.

From Sand to Compute: Understanding the Semiconductor Lifecycle

The semiconductor market is significantly larger and more complex than the chips that power our servers and computers. It operates in three distinct areas — chip design, chip technology, and chip manufacturing.

In its simplest form, silicon is just refined sand (silicon dioxide) purified into large single-crystal ingots. These are sliced into wafers, polished, and etched with patterns that form billions of transistors.

Figure 1: The Semiconductor Lifecycle



Chip design, technology, and manufacturing are tightly coupled.
Source: Moor Insights & Strategy

Each stage of the semiconductor lifecycle depends on the others. A chip designed for ultimate performance can't deliver if it uses decade-old transistor technology or if the process can't scale to mass production.

Chip Design

Many companies design chips — and design them well. This encompasses the architecture, the cores, and the logic of how the cores communicate, as well as how caches are structured and how other forms of acceleration are built into the chip. Chip design is where creativity meets logic — expressed in circuits.

The design level delivers differentiation through microarchitectures, instruction sets, and workload-specific optimizations. In recent years, Moor Insights & Strategy (MI&S) has seen the market shift in three key areas to enable greater levels of performance and power efficiency.

- **Chiplets:** Traditional monolithic dies are being replaced by modular chiplets stitched together via high-bandwidth interconnects, enabling performance gains despite the slowing scale of transistor layouts.
- **Heterogeneous computing**: Designers now use general-purpose computing with accelerators, such as GPUs for parallel computing or NPUs for AI inference, to deliver better overall performance. This is especially prevalent in client computing, where it's critical to deliver better graphics or faster copilot capabilities without sacrificing significant power.
- **Instruction set architecture** (ISA): Intel's x86 architecture, introduced in 1978, has dominated the client and enterprise datacenter market for decades. However, the market has seen both Arm and RISC emerge as credible architectural alternatives for some functions and workloads.

The United States leads globally in chip design. Chip design houses, such as NVIDIA, Intel, AMD, Qualcomm, Arm, and Apple, are joined by custom silicon designers like Broadcom and Marvell to design what is deployed around the world.

However, brilliant designs mean nothing without enabling technology.

Chip Technology

Chip technology is where design meets physics. The transistor is the heartbeat of semiconductor progress, each generation extending Moore's Law through smaller features and greater efficiency. Intel is the clear leader in transistor technology. Its major contributions include:

- **Silicon Gate MOS Transistor** (1970s): Pioneered the commercial MOSFET (metal-oxide-semiconductor field-effect-transistor), improving speed and manufacturability
- **Polycide and Silicide Techniques** (late 1970s): Uncovered a method to enhance how transistors delivered performance at scale as transistor density increased significantly

- **Strained Silicon** (early 2000s): Introduced a method of slightly stretching the atomic lattice of silicon, allowing electrons to pass more easily and increasing performance by 20% without added power
- **Tri-Gate (FinFET) Transistor** (2011): Introduced 3-D FinFETs, with vertical fins to reduce leakage considerably, into mass production

Examining the current 2nm process technology, we've seen more Intel innovation continue, helping further enable this process shrink. They include:

- **RibbonFET Gate-All-Around**: This next-gen transistor technology surrounds a nanosheet channel on all sides with the gate, further enhancing electrostatics. This reduces leakage current and allows for lower operating voltages, resulting in improved performance per watt. Crucially, it also enables smaller and faster process node transitions, further enabling the advancement of Moore's Law.
- **PowerVia**: This technology reroutes power to the chip through the back of the wafer, lowering resistance, improving the IR (current-resistance) drop, and freeing the front side for faster signal routing. PowerVia results in improved transistor density, cleaner power, and higher frequency ceilings, enabling chips to consume less power while running at faster speeds. Although a semiconductor industry standard, MI&S finds Intel to be the only company that has incorporated PowerVia as part of its 2nm process node (Intel 18A). This should give the company a distinct advantage, especially in datacenter workloads such as high-performance computing.
- **3D Stacking (Foveros)**: Introduced around 2018, this process enables the vertical stacking of chiplets. It allows the mixing of logic blocks built on different nodes (e.g., a CPU on Intel 18A and I/O built on Intel 3) into a single package, delivering better bandwidth and modularity.

These technological breakthroughs translate directly into real-world chip performance. For example, Intel's upcoming Clearwater Forest Xeon 6E+ moves from Intel 3 to 18A, leveraging RibbonFET and PowerVia for a 15% IPC uplift and double-digit power savings.

Chip Manufacturing

Chip manufacturing transforms design and transistor technology into physical silicon. The fabs (factories) that produce these chips are a science fiction novel come to life as wafers sliced from ingots are etched using deep-ultraviolet (DUV) or, at precisions greater than 2nm, extreme-ultraviolet (EUV) light.

Semiconductor manufacturing is divided into two major sections: front-end-of-line (FEOL) and back-end-of-line (BEOL). In high-level terms, think of FEOL as building the transistors and BEOL as connecting these tens of billions of transistors with metal interconnects. Each 300 mm wafer is sliced into between 50 and 100 server-class dies (chips), such as Intel Xeon processors.

Yield is essential in semiconductor manufacturing. In simple terms, yield represents the average number of good chips that are cut out of each wafer. Given that a chip can contain tens of billions of transistors, it’s easy to understand the challenges of mass producing these server chips.

Because the manufacturing process is so complex and costly (requiring tens of billions of dollars in investment), many chip companies focus on design and outsource fabrication. This has led to a reduction in the number of chip manufacturers in the United States, with MI&S identifying only three major players: Samsung, TSMC, and Intel. Of the three, Intel is the only U.S.-based company that designs and builds its own chips. Furthermore, it is the only U.S.-based fab at the leading edge.

The Risk of Offshore Manufacturing

In 1990, the United States produced 37% of the world’s semiconductors. Today, this number is closer to 12%, with TSMC (Taiwan) and Samsung (South Korea) capturing a significant share of the offshore opportunity. This has enabled those offshore leaders to further invest in process node innovations, a cycle that has continued until Intel once again captured the innovation crown.

The risk associated with this offshore manufacturing is well known, given that one geopolitical incident or natural disaster could halt chip manufacturing. More accurately, we are one event away from U.S. and Western consumers and businesses being locked out of chip supplies.

In this environment, Intel remains the counterbalance with its advanced features such as PowerVia and fabs in Oregon and Arizona that rival or surpass overseas facilities. For example, Intel’s Fab 52 in Chandler, Arizona, which is the result of R&D from its Ronler Acres site in Oregon, is home to the world’s most advanced semiconductor manufacturing.

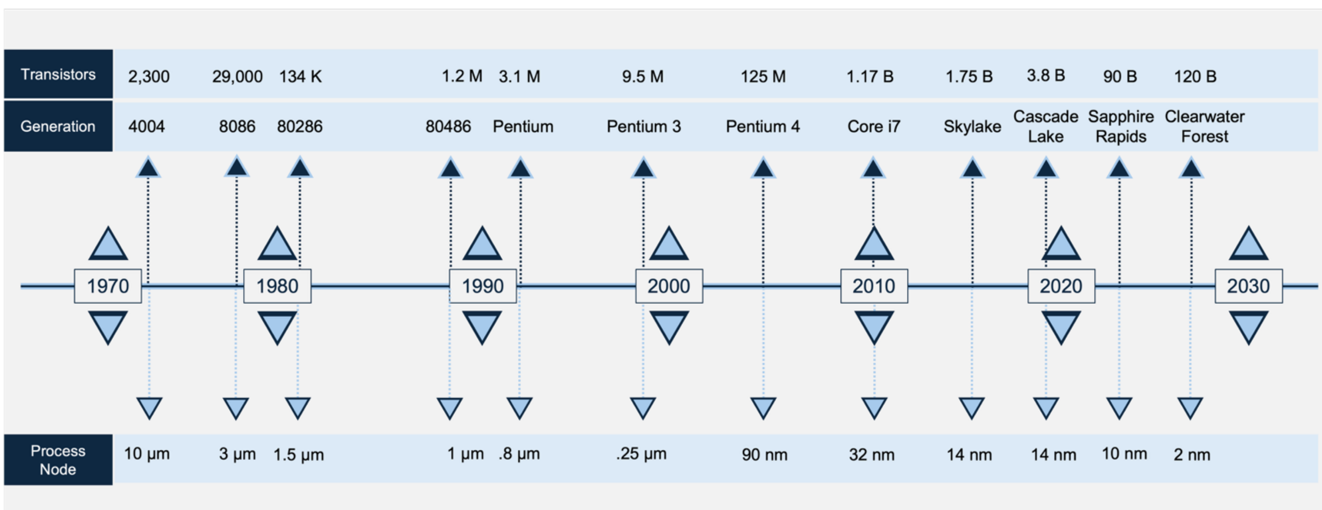
The importance of onshore chip manufacturing in helping the United States maintain its global lead in technology innovation can’t be overstated. Onshore manufacturing is the guarantee that the technology needed to deliver breakthroughs in biotech, national defense, and critical infrastructure is available.

Other manufacturers, such as TSMC, claim to manufacture chips in the U.S. — and this is partially true. However, wafers produced in the U.S. must be sent back to Taiwan for final assembly, so a geopolitical event can still disrupt the availability of chips.

Intel — Innovation Reintroduced

Undoubtedly, Intel has long been the gravitational center of the semiconductor industry. It began with the introduction of the world's first commercial microprocessor in 1971, and has evolved to today's CPUs, which are designed to accelerate AI performance. Intel's contributions to the semiconductor industry have been significant across all three pillars: chip design, chip technology, and chip manufacturing.

Figure 2: Intel Processor Innovation Timeline



Intel has driven a considerable process node shrink while increasing transistor counts exponentially.
Source: Moor Insights & Strategy

Chip design is the most visible aspect of Intel's innovation — the part customers notice when choosing a CPU for their laptop, workstation, or server. In this space, Intel has been a pioneer. The original Intel 4004 defined the microprocessor itself and set in motion Moore's Law. Furthermore, the company pioneered and introduced microarchitectures, such as x86, and integrated floating-point units.

Almost 50 years later, the x86 architecture remains the industry standard. And Intel continues to innovate for the AI era. On the client side, this includes designing a neural processing unit (NPU) to offload AI functions from the CPU, thereby improving overall AI performance and tasks such as image enhancement, facial recognition, real-time translation, and the like.

With its datacenter CPU, Intel Xeon, the company has been at the forefront of the market with the release of dedicated accelerators that boost performance for targeted workloads. Accelerators such as Advanced Matrix Extensions (AMX) enable CPUs to perform functions like inferencing without the need for a dedicated GPU.

In chip technology, Intel has challenged norms and set new standards. As detailed earlier, the company has a long history of delivering new transistor technologies that have fundamentally changed the performance-power curve.

In chip manufacturing, Intel has long enjoyed an advantage due to its ability to fabricate at scale and with precision. Its advanced fabs in the United States have enabled the most advanced and sophisticated production facilities anywhere — massive fab campuses where billions of transistors are patterned, etched, and interconnected at atomic precision. This is where chip design and technology are brought to life.

With Intel's Foundry business, the company has expanded its world-class manufacturing capabilities to third parties, offering its Fab 52 (Intel 18A) and other production capabilities to support chip designers — even those considered competitors.

It is not an exaggeration to say that Intel's contributions across these three disciplines have benefited the market as a whole — customers and industry peers alike.

Call to Action

Technology drives the world — and semiconductors drive technology. As AI takes center stage, the chips that power it (CPUs, GPUs, and other acceleration chips) become ever more critical. This extends not only to improving operational efficiency, but to operations as a whole.

For decades, the United States dominated every segment of the global semiconductor market, from design to technology to manufacturing. However, over the past decade, it has seen its leadership in manufacturing overtaken by foundries such as TSMC in Taiwan and Samsung in South Korea. This offshore dependency has made U.S. businesses and citizens vulnerable to geopolitical tensions that could disrupt the supply of critical infrastructure.

Intel stands alone as a U.S. company with leadership across all three semiconductor disciplines. It is the developer of the x86 architecture, numerous semiconductor technology "firsts," and a cutting-edge manufacturing process.

We believe it is critical for the United States to maintain its prowess in chip design and technology and re-establish the country as a global manufacturing leader. This is not simply a matter of national pride; it's a matter of national security. In this context, MI&S views Intel and its foundry business as being poised for significant growth and sustained leadership as more chip designers recognize the technical and geopolitical advantages of working with a U.S.-based chip manufacturing power.

For more information, please visit:
https://www.intel.com/content/www/us/en/foundry/overview.html

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