Entegris

The Internet of Things:

A Sustainable Driver for Integrated Circuit Growth

White paper

INTRODUCTION

> *"We stand on the brink of a technological revolution that will fundamentally alter the way we live, work, and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before."*
>
> — *Klaus Schwab, Founder and Executive Chairman, World Economic Forum*

We are living through the Fourth Industrial Revolution, an era that Klaus Schwab, founder of the World Economic Forum, describes as "characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological." This era is being driven by a confluence of emerging disruptive technologies including artificial intelligence, robotics, autonomous vehicles, and the Internet of Things (IoT). In practical terms, the Fourth Industrial Revolution is more than just a bunch of converging technology trends: it heralds a new way of life.

For the semiconductor industry, the implications of the Fourth Industrial Revolution are characterized by a proliferation of chips of all types, driven in large measure by the demand for IoT devices and related applications. In 2017, global semiconductor industry sales topped $412 billion, an increase of 21.6 percent over 2016 sales, according to Semiconductor Industry Association (SIA) research.[1] Entegris believes this market expansion marks the end of cyclical semiconductor sales dominated by the growth of specific devices (e.g., PCs, smartphones, etc.). It's an unprecedented opportunity for all parties in the semiconductor ecosystem, but one that comes with significant challenges the entire industry must address.

IOT: THE WORLD OF "SMART EVERYTHING"

From smart speakers to smart homes, smart cities, smart transportation, smart pharmaceuticals, and smart grids, it is not hard to imagine a world where there are chips in just about everything. The industry is already riding this wave and most industry experts see the same trajectory for the foreseeable future.

In particular, automotive applications are a rapidly growing segment of the market. In its most recent forecast, Gartner noted: "By 2022, automobiles will require nearly 50% more semiconductors as cars become more automated, cleaner, and more connected."[2] This is driven in large measure by growing demand for assisted and autonomous driving features, safety and environmental mandates, connectivity, and in-vehicle "infotainment." This will include sensors (cameras, radar, LIDAR), communication modules, high-speed connectivity, and powerful data processing capabilities, among others.

While emerging, state-of-the-art devices get a lot of attention, traditional ICs continue to be the workhorse of the digital economy. This is great news for the semiconductor industry as the capital expenditure (CapEx) requirements for increasing existing capacity are significantly less than those needed to build new capacity from the ground up. Regardless, it is abundantly clear that the world of "smart everything" is going to require both CapEx investment and cost reductions across the board.

Smart devices also present a host of unique considerations depending on the application. For example, if your smart refrigerator fails, it may feel inconvenient, but the implications are not all that significant. If your smart self-driving car fails, on the other hand, the consequences could be dire. So, it is not enough to simply build out capacity and manufacture IC components specific to each application. Superior reliability and performance also need to be considered.

IHS Markit forecasts that by 2025, there will be more than 75 billion installed IoT devices worldwide[3] (see figure 1).

IoT Installed Base, Global Market

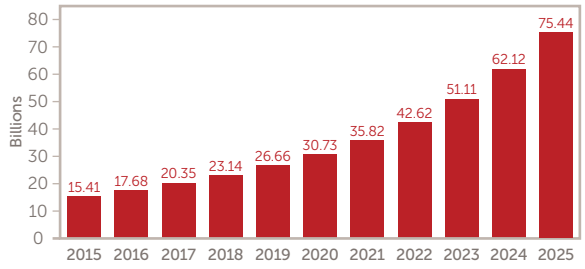
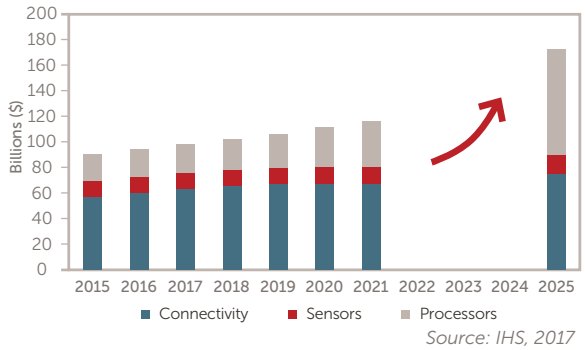


Figure 1. The IoT market will be massive.

Those 75 billion devices will use IC components from both leading-edge and mainstream nodes, while also increasing data processing challenges in the data center (see figure 2).

IoT Semiconductor Market

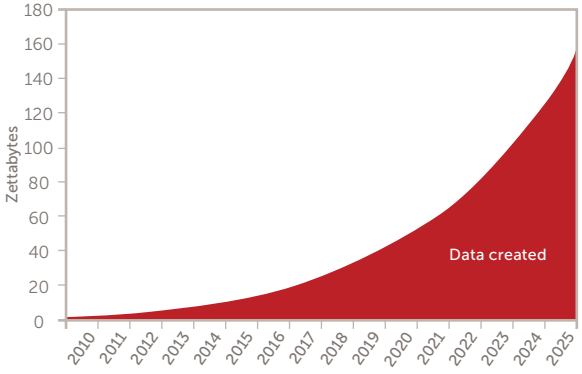


Source: IHS, 2017

Figure 2.

For example, as devices proliferate so too does the need for sensor and control ICs, most of which can be made with mainstream nodes (28 nm and higher). As a result, expect to see renewed growth in the industry's mainstream capacities. In the communications layer, expect that demand for communication ICs including wireless networks (4G/5G), Wi-Fi networks, near field communication (NFC, RFID, Bluetooth), and communication chips will also grow, adding to capacity challenges for both mainstream and leading-edge nodes in IC manufacturing. According to an IDC study for Seagate, the volume of global data is set to increase 10x to 163 zettabytes (one trillion gigabytes) from 2016 to 2025[4] (see figure 3). Therefore, data storage, analysis, and process will play a central role in the IoT infrastructure. This will drive the growth of memory (both DRAM and 3D-NAND), processors (CPU, GPU, FPGA, etc.), and other IC devices, mostly in the leading-edge nodes.

Annual Size of the Global Datasphere



Source: IDC's Data Age 2025 study, sponsored by Seagate, April 2017

Figure 3.

In fact, memory is currently the largest and fastest growing product segment, according to World Semiconductor Trade Statistics' (WSTS) sales data from 2017 (see figure 4). While some of this growth is the result of demand for both DRAM and NAND flash products beyond current industry capacity, memory will remain a healthy segment as the demand and supply rebalance. Likewise, sales have increased across mainstream nodes as demand for logic, analog, and micro ICs remains strong, and the market for sensors continues to grow. With such forecasts of growth, there is ample business opportunity if the industry can address the capacity and technical challenges at each step of the supply chain.

Semiconductor Revenue and Forecast 1991-2021

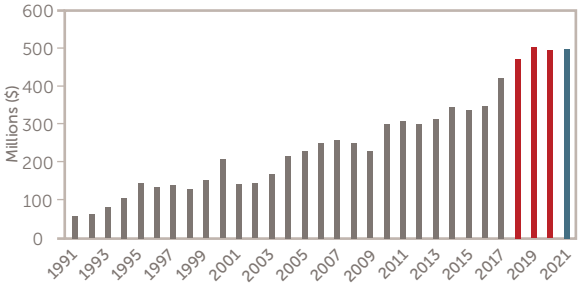


Figure 4.

CHALLENGING MOORE'S LAW, ECONOMICS, AND DEMONS FROM THE PAST

As noted by the Greek philosopher Heraclitus, "The only constant is change," and the semiconductor industry is not exempt. New applications will bring new challenges for which the industry needs to anticipate and prepare. With billions of IoT devices generating zettabytes of data, it is clear there is still lots of hard work ahead for the industry. Between the device, the edge, and the data center — even with advanced analytics, artificial intelligence, and machine learning — significant innovation will be needed to keep pace with the advancing application space. There is evidence of this as computing, sensors, and connectivity are increasingly combined into a single system on chip (SoC).

For years, the semiconductor industry has been packing big processing power into increasingly smaller chips. As the traditional scaling approach to Moore's Law has slowed (it is more and more difficult to miniaturize a device), there has been pressure to find new ways to improve performance and manage costs through innovations in design, equipment, and materials. With challenges like this on the horizon, it is time for our industry to adjust its mindset and proactively address the key challenges that the Fourth Industrial Revolution presents. The industry cannot wait for the orders to come in — they will risk underperforming in these emerging markets.

THE THREE KEY CHALLENGES:

Challenge 1: Capacity and Cost

To handle rapidly increasing volumes of data, more chips will be required — both advanced logic and mainstream nodes. While many fabs can incrementally increase output through improved tool performance and yield, there is also the need to build new capacity in every segment. The market for memory is booming but demand will likely continue to outpace planned capacity for both DRAM and NAND in the next few years. The same holds true for sensors and logic. And the capacity challenge isn't confined to the chip makers. Manufacturing a greater number of more sophisticated chips, requires new and more precise equipment. In 2019, EUV lithography will become mainstream, and advanced dry etch, deposition, and CMP are being introduced. More raw materials will be needed, especially wafers, but also etch gases, precursors, photoresists, and CMP consumables as well.

It goes without saying that managing costs is a top challenge in our industry — adding capacity is costly and so is the innovation needed to improve device performance. For mainstream nodes, new solutions are needed that drive even greater efficiencies in the ongoing effort to reduce costs. On the leading edge, pushing the limits of Moore's Law will require innovation at every step in the supply chain. As manufacturing processes become more complex, no single company will be able to provide solutions at every step. That means there must be a commitment to collaboration and a more concerted effort as an industry to solve these problems together.

Challenge 2: Performance and Complexity

The new materials and more sophisticated integration flows required to achieve higher performance devices add fabrication steps and increase process complexity. Greater complexity, in turn, makes yield ramps more challenging. Process maturity for an advanced node FinFET device is much less than that for a planer device of an earlier node generation. While many industries have to do more with less, the semiconductor industry must do more with more — at least when it comes to complex manufacturing processes. Every new step added to our manufacturing processes creates a potential point of failure (or more) and solving each of these challenges is time consuming and costly.

Challenge 3: Yield and Reliability

To address the challenges of increased process complexity, the industry must continue to adopt new processes and materials to enable scaling, better contamination control, and defect reduction to improve yield. While reliability is also important, historically, cost and yield has been prioritized above all else. With the emerging IoT, there must be a better balance. Plenty of IoT applications will not need to factor in new reliability requirements. Smartphones and many other consumer-facing connected devices are "good enough." But when it comes to medical devices, self-driving cars, and many industrial/infrastructure IoT applications, good enough will not cut it. Design and manufacturing for reliability, in addition to performance and yield, will also require innovations in defect and contamination control. Long-term reliability improvement is not only a social responsibility, it will quickly become a competitive differentiator — especially for mission-critical devices — as the IoT grows.

DRIVING IOT INNOVATION TAKES A VILLAGE

As stated, the proliferation of IoT applications and devices is poised to drive unprecedented levels of demand for memory, processing speed, and bandwidth. The semiconductor industry must evolve to serve this rapidly growing market opportunity. The time to address these changes is now:

- The IoT opportunity is broad, which benefits the entire industry no matter what types of chips are being produced.
- The market remains strong and the industry needs to invest in capacity at all levels before the industry falls farther behind.
- Requirements are changing, so a better job will need to be done balancing performance, yield, reliability, and cost.
- Collaboration is critical, the industry will be most successful if the industry works together.

Rather than addressing challenges step-by-step and vendor-by-vendor, let's closely collaborate to identify potential challenges and solutions in product roadmaps with input from across the supply chain. That means IDMs, foundries, OSATs, equipment, materials, and component companies will need to work together to meet capacity, cost, performance, yield, and reliability challenges. Improvements in product design, manufacturing, and contamination control is also needed. By working together, higher standards can be achieved as well as lower costs, and greater efficiencies.

Our industry as a whole has a vested interest in getting new products to market as quickly as possible. A reduction in — or even elimination of — friction points will be key to addressing the vast opportunities presented by the IoT age.

ABOUT ENTEGRIS

Entegris is a leader in specialty chemicals and advanced materials solutions for the microelectronics industry and other high-tech industries. Entegris is ISO 9001 certified and has manufacturing, customer service, and/or research facilities in the United States, China, France, Germany, Israel, Japan, Malaysia, Singapore, South Korea, and Taiwan. Additional information can be found at www.entegris.com

References

[1] SIA: Annual Semiconductor Sales Increase 21.6 Percent, Top $400 Billion for First Time, (February 5, 2018)

[2] Forecast Analysis: Electronics and Semiconductors, Worldwide, 1Q18 update (April 2018)

[3] IHS: IoT platforms: enabling the Internet of Things

[4] IDC study for Seagate, Data Age 2025: The Evolution of Data to Life-Critical, (April 2017)

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Entegris

Corporate Headquarters
129 Concord Road
Billerica, MA 01821
USA

Customer Service
Tel +1 952 556 4181
Fax +1 952 556 8022
Toll Free 800 394 4083