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Tomorrow's Chip Industry: Threats, Opportunities and Strategy Framework

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Abstract

Few industries are as volatile as the chip industry. The rather short history of the industry has witnessed all types of dramatic cyclical swings and disruptions from the technological to the geopolitical. Technology drove the industry from the simple "few transistors on a silicon wafer" state to the multi-million transistors on the same silicon wafer profile. And from simple transistor placement to Lith photography. Geo politics saw political leaders flying all the way around the world in order to ascertain access to supplies and declare readiness to pursue hostilities in order to defend these supplies. Yet all of that will most likely pale against potential events of the coming decade. The future state of technologies, the evolving forces of data sciences, and the unraveling currents of geopolitics will all induce grass root change. A blend of these disruptive forces will expose the chip industry to genuine threats and, very likely, a few opportunities. And this will be the focus of the following article. A brief history of the chip industry will provide an introduction. An analysis of the prospective threat from never heard of technologies and heavy R & D investment to high industry concentration and distinctive pattern of rivalry follows. Opportunities will also be there, some in industry product competencies and others in economic value added. A conclusion will project a possible future scenario, or hypothesis, of the chip industry.

A Brief History of the Chip Industry

The development of the chip industry began in the 1950s but progressed rapidly in the 1960s and 1970s, and became one of the world's leading manufacture ring industries in the 1980s. The industry became a complex chain with design, production, manufacturing, sales and service facilities. Design covered functionality and performance requirements as well as architecture. Production implied producing the chip through wafer dicing, crystallization, and photo lithography.

The transistor is one of the most important inventions of the 20th century. It was invented at Bell Labs in New Jersey in 1947. It stands at the heart of almost all electronic devices. The invention of the integrated circuit, took place simultaneously at Fairchild and Texas Instruments from 1957 to 1959. Jean Hoerni at Fairchild developed the planar transistor then Jack Kilby at Texas Instruments and Robert Noyce at Fairchild developed the integrated circuit. By 1962 Fairchild was producing integrated circuits with about a dozen transistors. This same basic principle is applied today. (A Brief History of Semiconductors - Semi Wiki).

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The chip industry is having its share of problems. There is process technology, player's competition, government regulation and demand uncertainties. (Imedia, A brief introduction to the development history of the chip industry, 17.05.2023).

The industry is based on the foundry model, which consists of semiconductor fabrication plants (foundries) and integrated circuit design operations independently. Some companies, known as integrated device manufacturers, both design and manufacture semiconductors. The foundry model has resulted in consolidation among foundries. (see figure)

Today's Threats

A dynamic industry as chip making cannot go without threats.

1. The Race of the Manometers

A key dimension of semiconductors is the size of the transistor gate length as measured in billionths of a meter, or nanometer (nm). The extraordinary advances in chip processing power have resulted primarily from continued reductions in the size of nanometers. The smaller the "nanometer", the more powerful the chip given the larger number transistors that can be placed.

An ongoing race towards narrower nanometer is led by key chip industry operators in the United States, Taiwan, China and Korea. Others as Germany and India, who do not want to be left behind, are joining the fray. This nanometer race revolves around achieving smaller but potent internal components of chips. Reason is Moore's Law claim that the maximum number of transistors on a silicon chip will double every two years, a claim that is losing credence today.

The standard length of transistors was, for some time, 10 nanometers. Twenty and sixteen nm chips had, however, problems with copper- transistor interconnection and the challenge of moving currents through small wires and smaller nanometers. The "Gate All Around "or GAA architecture, a next-generation foundry micro fabrication process, seemed to provide a next technology solution. It emerged as a response to the race among the microchip industry for the fastest, finest and most energy-efficient circuitry. GAA transistors are an upgraded transistor structure where the gate can come into contact with the channel on all sides. These separate horizontal sheets are vertically stacked so that the gate surrounds the channel on all four sides. The outcome is an improved performance induced by superior electrical signal passing through and between the transistors.

GAA transistors are poised to become part of the most advanced chip designs in the near future. These transistors can be manufactured at an "accommodating" cost, striking a balance between cost of mass production of advanced chips and enhanced performance. GAA's reduced leakage and lower energy consumption makes them, moreover, superior to older designs.

Semiconductor manufacturers are chasing this GAA technology in search of improved electrostatic properties, increased performance, optimized chip design, and reduced power usage. (Avi Gopani, the race to reduce nanometers in chips, AIM, January 5, 2022).

This constitutes a challenge and a threat.

2. Industry Concentration

The chip industry is highly concentrated whether from manufacturing or supplying points of view.

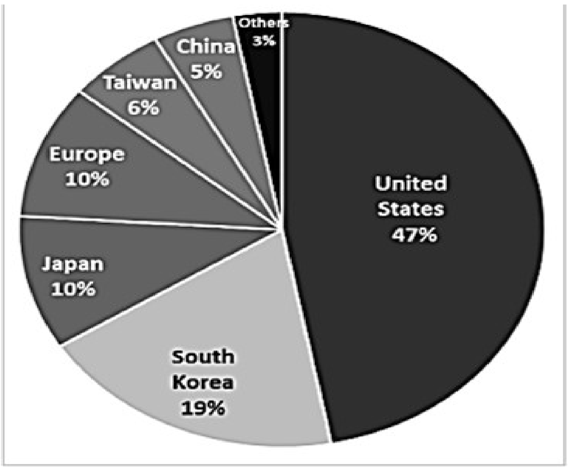
The global semiconductor industry is dominated in terms of manufacturing and supplying by companies from the United States (47%) , Taiwan, South Korea, Japan and the Netherlands. The United States leads, followed by South Korea (19%), Japan (10%), Europe (10%), Taiwan (6%), and China (5%) in terms of global market share (see figure below/ 2017 data).

The world's top five semiconductor suppliers accounted for an estimated 43 percent of 2017 total chip sales. The trend is for more market share being concentrated in fewer hands. (The Concentration of Semiconductor Market Share, By Dylan McGrath, EE Times, 04.12.2018).

Concentration in equipment making is remarkably high. ASML is, according to industry data, the only company in the world that owns the technology and makes the machinery to make physical chips out of silicon wafers. Chip makers like TSMC, NVIDIA and Intel would not be able to make the chips they do without ASML's EUV technology.

Concentration in advanced semiconductor making is also high. TSMC of Taiwan, Samsung of South Korea, and Intel of the United States are, as of 2021 the only three firms able to manufacture the most advanced semiconductors:

Figure 1: Global semiconductor industry market share, by sales, 2017



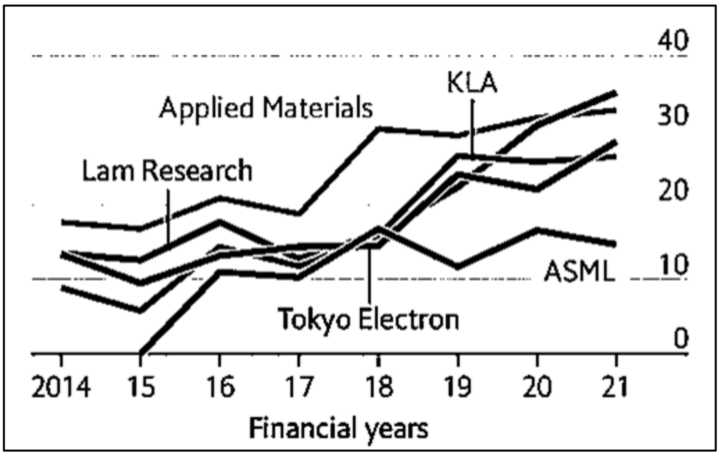
Source: SIA 2020 State of the US Semiconductor Industry p7

3. Techno Stride

Chip making relies on complex parts and equipment. These parts and equipment are made and sold by a variety of "makers" as Applied Materials, Tokyo Electron, ASML, KLA and Lam Research whose products are irreplaceable in the manufacture of the microscopic integrated circuits. This equipment handles the complex processes of embedding billions of transistors into the silicon wafer. China's appetite for chipmaking tools constitutes a problem. Apart from the size of this demand, it deprives nonchains makers of the capacity to manufacture chips. America's allies—in particular Japan and the Netherlands, home to Tokyo Electron and ASML — were asked to impose export controls on their toolmakers.

Chinese government has invested heavily in domestic chip making but relied on equipment provided by US sources. More than 90% of the semiconductors China uses are either imported or made domestically by foreign chip makers. In 2019, 24 of the 126 300mm wafer fabrication plants in operation worldwide were located in China, according to SEMI (Economist, Apr 30th 2022)

Figure 2: Selected semiconductor equipment manufacturers revenues from China, as a percentage of total



Source: Bloomberg

This leaves the United States with a critical problem. China-based integrated circuit products are generally less technologically advanced than "foreign" ones, whereas the most advanced fab production in China is performed by non-Chinese firms as Intel, Samsung, and TSMC. Chinese firms, such as Semiconductor Manufacturing International Corporation (SMIC), appear to be advancing their capabilities through, partly, foreign companies. It is estimated that at least half of semiconductor production in China in 2023 came from foreign-controlled fabs, with the balance coming from Chinese fabs.

The USA is, however, taking action. A National Semiconductor Technology Center (NSTC) and a National Defense Authorization Act (NDAA) were created in 2021 as a public-private consortium with the goal of conducting advanced semiconductor manufacturing, design, packaging research and prototyping.

4. Heavy R & D Investment

Chip design and manufacturing are associated with heavy capital outlays (see figure below). These outlays are needed in order to cover main industry investments from chip design and manufacturing to chip packaging and testing. And investment is also needed in order to provide supporting industry investments as intellectual property and electronic design automation. The fabrication of each new generation of semiconductors requires more costly equipment and capital-intensive processes. Leading-edge semiconductor manufacturers have, moreover, to make parallel R&D investments in support of multiple generations of technology.

EUV lithography machine costs more than 100 million US dollars, for example. In 2018, SMIC and ASML signed an agreement to acquire an EUV lithography machine against US$120 million.

A higher price and higher quality ASML second-generation EUV lithography machine will be the NXE:5000 series. It was originally planned to be released in 2023, but a price may exceed $ 300 million when released in 2026. (Mila Liu, December 12, 2022 LinkedIn).

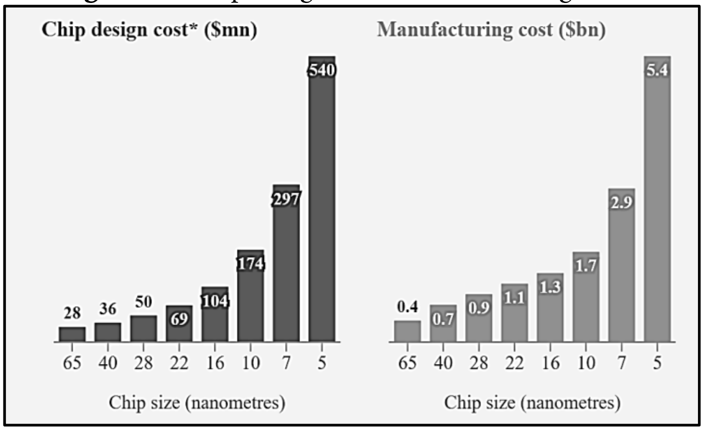
Strategic considerations made almost each and every lead player, whether a company or a country, contemplate a substantial investment in both elements of the process.

The governments of India, Malaysia, the Philippines, Singapore, Vietnam, and Thailand, for example, have introduced incentive packages to attract foreign semiconductor company investment. The European Commission passed the "EU Chips Act," a plan to double the continent's share in global chip production

by 2030 through mobilizing $47 billion in public and private investment.

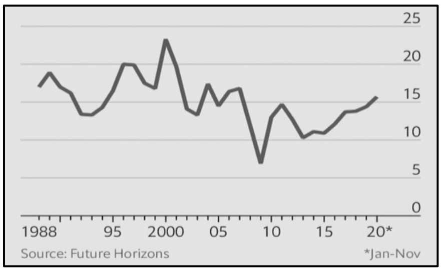
The future will therefore, be more complicated from both product and process point of view. It will not only be a question of physics but of novel constraints not thought of before. And investment implications could, in addition, be dire. Chip breakthroughs tend, as a result, to be more zealously guarded.

Figure 3: Chip design and manufacturing costs.



Source: IBS, McKinsey, FT June 1st, 2023.

Figure 4: Chip investment over time: semiconductor firms capital expenditure as percentage of sales, annual average.



Source: Future Horizons, Jan-Nov. The Economist

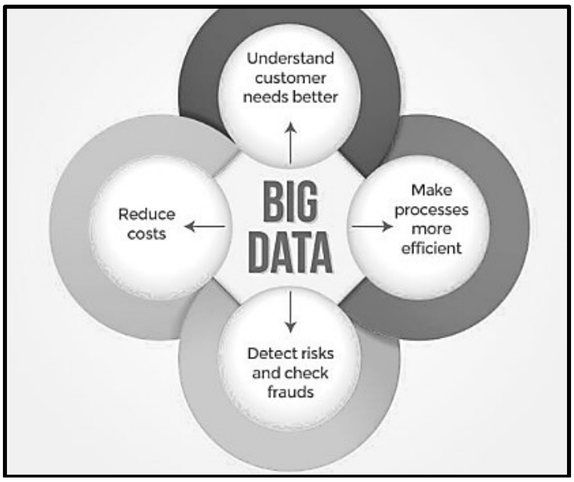
The Opportunities

1. The Ever-increasing Impact of Data Sciences

Data constitute a prime input into the AI system and provide a strong driver of the process. Increasing data use in AI processes is leading to enhanced opportunities from new markets and high customer services to effective social media interaction and enhanced predictions.

"Real" data is gradually being supplemented by "synthetic" data generated by algorithms simulating the statistical properties of real data. These synthetic data will play a major role in enhancing effective data use as it avoids bias inherent in smaller "real" datasets by emulating the distribution and characteristics of the original data despite the possibility that it might not represent the quality and the amount of variability that is present within real-world data.

Figure 5: Big data impact on productivity



Source: https://www.promptcloud.com/blog/best-way-to-increase-business-productivity-with-big-data/

As AI technology advances it could develop an autonomous ability to seek, classify and validate data. Data will provide a potent instrument for diagnosis and prediction and will influence business strategic thinking and innovation. Innovation in the field of big data and advanced data analytic tools have a large impact on productivity (Hallman et al., 2014).

2. Technologies that Never Existed Before

Innovation in technology is assuming remarkable speed and we seem to be entering the era of the unknowns or the products and processes that never existed before. New physical devices that may, for example, supersede the smartphone as the dominant mean of connecting people to information and services. Whoever makes such devices will therefore control new opportunities and access to ultimate users.

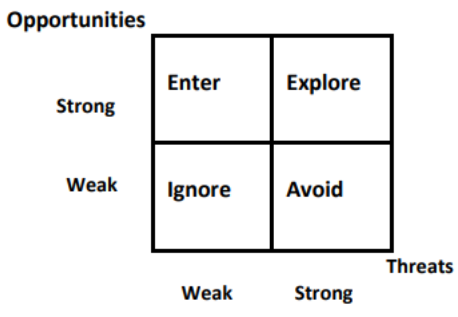
Take for example, the optical switch developed by the National Institute of Standards and Technology (NIST, USA). It can redirect light between computer chips using nanometer-scale gold and silicon components. The light can pass between chips in 20 billionths of a second, the fastest light has been rerouted between chips. This could revolutionize the way data is transported within certain systems. (Photons travel much faster than electrons, Benson T, "We're getting close to computer chips that use light instead of electricity", Inverse, Nov 14, 2019). Information on computer chips could be processed by using light instead of electricity. Using photons to transfer data would also mean the computer wouldn't heat up from the electricity, and using light instead of electricity would reduce a system's energy use.

Optical computers hold a lot of promise. In theory, a fully optical computer would run faster and operate at lower temperatures than electronic systems. By using nonlinear optics it's possible, in theory, to build logic gates similar to those used in conventional processors. There are, however, many practical and technological hurdles to overcome before photonic computers play a significant role. (Butler S, "How "Photonic Computers" Could Use Light Instead of Electricity", How-To Geek, MAY 11, 2022) (Benson T, "We're getting close to computer chips that use light instead of electricity", Inverse, Nov 14, 2019)

Tomorrow: A Conceptual and Operational Framework for Operator Positioning and Strategic Choices

Both outlook and perspectives of the chip industry are complex whether one considers the serious threats or the promising opportunities. The following figure is an attempt at putting the issue within an analytical framework that projects both variables in terms of severity and possibly impact on the strategic positioning of the operators. The Y axis represents opportunities viewed as either strong or weak. The X axis represents threats also segmented according to impact, as strong or weak. Strong opportunities imply venturing into new technologies that the industry did not know before. Weak opportunities connote a successful continuation of the current process of improving and enhancing the nm technology. Strong threats imply an escalation of one or more of those threats identified in earlier analysis. One of those could be a slowing down or even temporary suspense of technology enhancement measures. Another one could be the decline in innovation capital access. Yet another one could be an increase in geopolitical stride.

Figure 6: Strategic positioning of industry operators



An industry operator position within this matrix depends on the subjective combination of opportunities and threats that he musters. And his strategic response would depend on this position going all the way from entry to avoidance. This could provide the following phase of this research.

Conclusion

Few industries are as volatile as the chip industry. The rather short history of the industry has witnessed all types of dramatic cyclical swings and disruptions from the technological to the geopolitical. Technology drove the industry from the simple "few transistors on a silicon wafer" state to the multi-million transistors on the same silicon wafer profile. All of that will most likely pale against potential events of the coming decade. The future state of technologies, the evolving forces of data sciences, and the unraveling currents of geopolitics will all induce grass root change. A blend of these disruptive forces will expose the chip industry to genuine threats and, very likely, a few opportunities.

The article is an attempt at dealing with those variables. It starts with a brief history of the chip industry followed by an analysis of the prospective threat from never heard of technologies and heavy R and D investment to high industry concentration and distinctive pattern of rivalry follows. Opportunities will also be there, some in industry product competencies and others in economic value added. Industry operators could be positioned according to their respective subjective "score" along any of the two parameters: opportunities and threats.

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