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Tomorrow's Chip Industry: Challenge of The Unknowns

M S S EL Namaki[a]

[a]VU School of Management, Switzerland

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Abstract

Purpose –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 billion transistors on the same silicon wafer profile.
Design/Methodology/Approach – 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 challenge.
Findings – The article is an attempt at dealing with some of those variables and suggests a few hypotheses. 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.
Research Implications – The question, however, is where will the industry be tomorrow given all those disruptive variables? More specifically what is the level of concentration of the industry that will emerge from those ever-changing drivers? This article provides an attempt at answering this question. The answer will be a set of hypotheses built around an analytical matrix.The article relies on the myriad of material produced on the chip industry today. Analysis is qualitative. ange. And it complements the concept with an operational model leading to specific modes of this strategic behaviour.

Keywords: chip industry,technology, concentration, strategic positioning
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[a] M S S EL Namaki, Dean, VU School of Management, Switzerland, Dean (retired) Maastricht School of Management (MSM), Netherlands
First Author, E-mail: dr.el.namaki@gmail.com

I. 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 manufacturing industries in the 1980s. The industry became a complex chain with design, production, manufacturing, sales and service facilities. Design covered functionality and performance requirements, architecture and circuit diagrams, and simulating and verifying them. Production implied producing the chip through wafer dicing, crystallization, and photo lithography. Manufacturing included placing components on the chip and testing them.

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. Much has changed in the intervening years but this same basic principle is applied in the building of today’s billions of transistor chips. (A Brief History of Semiconductors - Semi Wiki).

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, each belonging to separate companies or subsidiaries. Some companies, known as integrated device manufacturers, both design and manufacture semiconductors (see figure).

The dynamic state and outlook of the industry is perfectly described by the leader of the industry TSMC’ or Taiwan region Semi conduct Manufacturing Company).It states: “The power-performance-area (and cost) advances of the last five decades have mostly been achieved through dimensional scaling of the transistor. What will the semiconductor industry do after transistor scaling crosses the nanometer threshold from the once applied threshold of 16/12 nm to today’s much touted 2 nm and 1.4 nm and the current search for sub nanometer size?New applications will undoubtedly demand new chip capacities and technologies, one of the most pressing questions facing the semiconductor industry today.

“The path for IC technology development going forward is no longer a straight line. The need for out-of-the-box solutions is ushering in a golden age of innovation. Future electronic systems will require co-innovation of the computing architecture together with device and packaging technology.” (https://research.tsmc.com/english/research-areas.html)

1. Technology: The race of the manometers.

A key dimension of semi-conductors 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 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 region, 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 claims that the maximum number of transistors on a silicon chip will double every two years, a claim that is losing credence.

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 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. Gate-all-around or GAA transistors are in fact 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. (ASML).

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.

In brief, Moore's law innovation continues, driven by multiple engines of performance scaling. Meanwhile, process technology innovation continues attracting new applications.

2.Concentration: Industry structure

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 region, South Korea, Japan and the Netherlands. The United States leads, followed by South Korea (19%), Japan (10%), Europe (10%), Taiwan region (6%), and China (5%) in terms of global market share (see figure below).

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

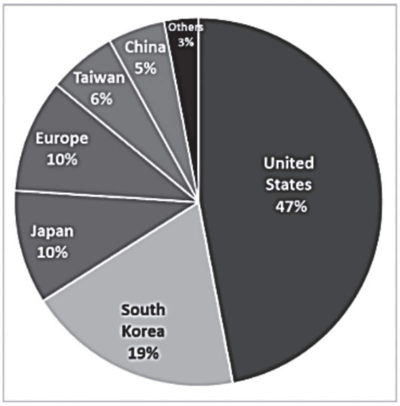

Figure 1. Global semiconductor industry market share, by sales, 2o17
Source:SIA 2020 State of the US Semiconductor Industry p7.

3.Rivalry: Geopolitical stride.

Chip making relies on complex equipment. This equipment is made and sold by not so recognized names in the West.

Those include ASML (Netherlands), Applied Materials, Tokyo Electron, KLA and Lam Research whose equipment are irreplaceable in the manufacture of the microscopic integrated circuits that power the digital economy. This equipment handles the complex processes of scratching billions of electric circuits into the silicon wafer. And this generates considerable revenue. In 2014 those five main toolmakers sales amounted to $3.3bn and 10% of that went to China. Today China makes up a quarter of global revenues (see chart). This new reliance has created political problems especially for Applied Materials.China's appetite for chipmaking tools is also causing commercial difficulties for non-Chinese chipmakers, depriving them of equipment and hence 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 similar to those imposed by the USA.

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 "America has a plan to throttle Chinese chip makers", Apr 30th 2022)

This leaves the United States with a critical problem.

Most advanced fab production in China is performed by non-Chinese firms. Intel, Samsung, and TSMC are among the major global semiconductor firms that operate fabrication facilities in China. Chinese firms, such as Semiconductor Manufacturing International Corporation (SMIC), appear to be advancing their capabilities due to collaboration with foreign companies. China continues to attract global industry collaboration with the pull of government financing, leading to the expansion of China's fabrication capacity.

4.Capital: R and 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 it is now postponed to 2025/2026, and the price is expected to exceed 300 million US (Designing a 2nm Chip Costs at Least $725 Million, 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 USA, the EU, China and Taiwan region head the list.

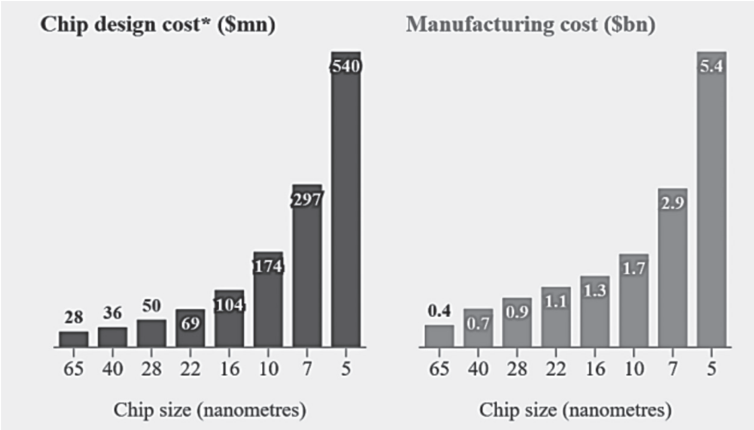

Figure 2. Chip design and manufacturing costs
Source: IBS, McKinsey, FT June 1st, 2023.

Figure 3. Chip investment over time.
Source: Future Horizons, Jan-Nov. The Economist

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.

Ⅱ. Tomorrow 's scenario: a hypothesis

It is the authors contention, hypothesis, that tomorrow 's chip industry will be driven by known and unknown drivers. Technology will be the dominant variable and much of the future will depend on the state of today's technology as opposed to the state of tomorrows.Concentration will provide a second inclusive driving force i.e. Reflects the impact of the other two variables; rivalry and capital.

The following matrix provides an approximation of the strategic positioning of some of today's players and their tomorrow outlook within this strategic space.The matrix tries to relate technology to concentration. It scales technology along a knowledge scale i.e. known and unknown and concentration along intensity level i.e. low versus high concentration. The matrix reveals four possible positions.An A or "superior" position is a position where unknown technology is combined with high concentration.A "D" position relates known technology to low concentration.

A "B" position relates high concentration to known technology. And a "C" position relates unknown technology to low concentration. Conversion of unknown technologies to known technologies would introduce a dynamic element in the matrix and underline the strategic choices facing today's operators.

Today's key operators i.e. ASML and TSMC could be placed in a today "B" position. This judgmental positioning is subjective and further research will have to substantiate several of the assumptions and the outcomes. "Their strategies should aim at the "A" position assuming that their search for new currently unknown technologies will lead to known technologies, enhance their posture and increase their market hold. And demonstrate the dynamics of the matrix "

Further research should explore these hypotheses and reveal a potential long term positioning profile.

Technology

Unknown	C	A
Known	D	B

Industry concentration

Low **High**

Figure 4. Concentration versus technology over time

Ⅲ .Summery and conclusions

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 billion 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 challenge.

A brief history of the chip industry is followed by an analysis of prospective industry challenges from never heard of technologies and heavy R and D investment to high industry concentration. This level of concentration is the focus of analytical matrix where concentration is related to the measure of technology development.The ultimate hypothesis is that unknown technologies will lead to a high measure of concentration. Who will feature in this concentration is an issue for further analysis.

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