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The Geostrategy of Computer Chips (Semiconductors)

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Summary
After a long-term dominance of the perspective of the cyberspace as a virtual world, security experts are gaining a more and more physical understanding: who controls the devices and the cables, also controls the data in them. Meanwhile, it was realized that the production of computers and digital devices has critical bottlenecks and that the control of critical elements like rare metals and semiconductors (computer chips, computing chips, microprocessors) as core element of each digital device could be used for geostrategic purposes. Without advanced chips, further progress of digital technology is slowed down or even impossible. For this reason, an intense competition between US and China has taken place. The market analysis shows that US and its Asian allies (Japan, South Korea and Taiwan) dominate most of the chip production steps while China controls the materials needed for the production of the surrounding computers and digital devices, the rare metals.
Since 2018, the United States stepwise restricted the export of semiconductors and related manufacturing equipment to China. Amongst other activities, the United States were able to block the selling of the so-called EUV technology to China which makes it in future for China quite difficult or even impossible to produce advanced chips (and thus advanced computers). On 07 Oct 2022, these restrictions were significantly expanded to restrict Chinas ability to obtain advanced computing chips, develop and maintain supercomputers, and manufacture advanced semiconductors. This step could significantly slow down Chinas technological development for years and China is now facing hard strategic choices and decisions.

Content

1 Introduction

After a long-term dominance of the perspective of the cyberspace as a virtual world, security experts are gaining a more and more physical understanding: who controls the devices and the cables, also controls the data in them. The physical data control could be (re)gained by several approaches, namely by physical system access, creation of cyber-islands and squeezing foreign companies out of their own security architecture. Meanwhile, it was realized that the production of computers and digital devices has critical bottlenecks and that the control of critical elements like rare metals and semiconductors (computer chips, computing chips, microprocessors) as core element of each digital device could be used for geostrategic purposes.

2 Computer Chips (Semiconductors)

2.1 Introduction

Chips are for example essential for personal computers and servers in data centers (including memory chips), video and graphic processing and display, servers, tablets, cellphones, automobiles, digital televisions, set-top boxes, game consoles, medical devices, wearable systems, wireless networks, military systems, and other industrial applications[1].

The value of the global chips market in 2021 was roughly 550 billion US-Dollars with the leading sectors computing, including personal computers (PCs) and data center infrastructure (32%), communications, including mobile handsets and network infrastructure (31%), and consumer electronics (12%)[2].

The COVID-19 crisis with shifting industrial and consumer demands, production declines and transportation/logistics disruptions led to a semiconductors shortage that showed that all major industries and powers are highly vulnerable through restricted access to modern semiconductors[3].

2.2 Technical Background

Semiconducting materials like silicon and germanium allow to direct the flow of electric energy in certain directions. As bits and bytes are electromagnetic conditions, these materials allow to store, to move and to process data which is the basis of all computing.

Semiconductors are also known as computer chips or chips or microprocessors. In 1958, the integrated circuit (IC) was invented where lots of small elements like transistors could be "printed" (engraved) and connected on a single piece of semiconductor material as a single integrated device. The first step is to produce round plates, the **wafers,** which typically have a diameter of 300 millimeter (which requires high purity and a dust-free environment). On these wafers, the chip designs are then placed in a sequence of more than 250 photographic and chemical processing steps[4].

The smaller the elements on the chips, the faster and more efficient the chip and the surrounding computer can work. The most advanced chips typically have elements with 7 or 10 nanometers size. The *Taiwan Semiconductor Manufacturing Company TSMC* can produce them with a 5-nanometer technology, in the near future 3-nanometer chips are expected; for the most advanced chips the market share of Taiwan is 92% in 2022[5]. In simple terms, **each advance in nanometer size represents a new chip generation** and by this a new generation of computers and digital devices.

[1] Platzer/Sargent Jr. 2020
[2] EU 2022
[3] EU 2022, Sargent Jr./Sutter 2022
[4] Platzer/Sargent Jr. 2016 and 2020
[5] Bost 2022

The “printing” or engravement of the smallest elements requires special machines and for the most advanced chips a unique technology called **extreme ultraviolet (EUV) lithography** is required which is only provided by one(!) company, the Dutch *ASML Holdings*. EUV lithography is complex and cannot be simply copied: droplets of tin are dropped into a vacuum, bombarded with powerful lasers, and vaporized into plasma, which then emits EUV light at the target wavelength[6].

Both major cyber powers USA and China have realized that **the ability to produce advanced chips is a key strategic factor**. Without advanced chips, further progress of digital technology is slowed down or even impossible. For this reason, an intense competition between US and China has taken place.

2.3 Chip Production

The chip production is controlled by specialized companies and some production steps only by a very few companies which creates further strategic dependencies and vulnerabilities.

Production steps are[7]:

- Design: here, research and development (R&D) and the control of patents (Intellectual Property IP) is essential, this may also come from specialized design firms. Due to the extreme complexity, the design cannot be done anymore by humans alone, it requires design software (called **electronic design automation, or EDA**, software).
- Front-end fabrication (“chip making”), this is the creation of microscopic electric circuits on silicon wafers. This producing units are called “fabs” (short from “fabrication”). This step requires supply of materials (including the “wafers”) and **semiconductor manufacturing equipment (SME)** like the above-mentioned EUV machines.
- Back-end fabrication: the wafers are sliced into single chips, these are then assembled as needed and encased in plastic. Before putting them into computers, quality tests for defects are done. A standard term for these activities is back-end assembly, testing, and packaging (ATP). ATP is labor-intensive and done by outsourced semiconductor assembly and test (OSAT) firms.

Meanwhile, there are two production models. A few companies still do all production steps as **integrated device manufacturers (IDMs)** with their own fabrication facilities (“fabs”). Other chip firms are “fabless,” meaning that they design and market semiconductors but contract production to “foundries” that manufacture semiconductors for them. The Taiwanese *TSMC* is the globally leading foundry. From a strategic perspective, the integrated IDM model allows much more control and autonomy, but the fabless/foundry model appeared to be more profitable and is meanwhile dominant. As a result, the global US share of semiconductor fabrication capacity fell from 40% in 1990 to 12% in 2020[8].

2.4 The Chip Market

The market analysis shows **that US and its Asian allies (Japan, South Korea and Taiwan) dominate most of the production steps** which makes China vulnerable for US countermeasures against Chinas rise in the digital world. But also Europe has with a few exceptions only small market shares, typically less than 10%[9]. Chinas vulnerabilities include equipment (SME), design software (EDA), critical patents (core IP), and certain materials used in manufacturing[10]:

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[6] Eurasia Group 2020
[7] Kahn et al. 2021, Platzer/Sargent Jr. 2016 and 2020
[8] Sargent Jr./Sutter 2022
[9] EU 2021 and 2022
[10] Khan 2021

- **Design:** The most advanced chips are designed by US companies like *Apple, Google, Intel, AMD, Nvidia* and *Qualcomm*[11]. Seven of the top 10 fabless semiconductor design firms such as *Broadcom, Qualcomm,* and *Nvidia* are in the US while the other three are headquartered in Taiwan.
- **Wafer:** 90% of the world's silicon wafer production is controlled by five firms only, thereof 60% by the Japanese firms *Shin-Etsu* and *Sumco*.
- The integrated manufacturing **IDM** is dominated by US firms with 51% of total global IDM revenues, followed by South Korea (28%) and Japan (11%).
- The **semiconductor manufacturing equipment (SME)** is dominated by five firms only with around 75% global market share, these are the US firms *Applied Materials, Lam Research Corporation,* and *KLA Corporation*, the Dutch company *ASML* (which has a monopoly for EUV machines[12]) and the Japanese firm *Tokyo Electronics*.
- **Chip production:** only the Taiwanese *TSMC*, the US firm *Intel* and the South Korean *Samsung* can currently produce the most advanced semiconductor chips with elements (transistors) of 10 nanometer or smaller. In 2020, only *TSMC* and *Samsung* manufactured chips at 5 nanometer while *Intel* was still at the 7-nanometer level. In 2022, China is currently advancing to the 7-nanometer level[13]. Europe has no foundries that offer manufacturing of components below 22 nanometer[14].
- **Foundries:** For computer chips, the market is dominated by Taiwan and South Korea. Taiwan has a global market share of 64%, the *Taiwan Semiconductor Manufacturing Company TSMC* alone already of 50%, for the most advanced chips the market share of Taiwan is even 92%. *TSMC* has a production facility in China, but produces there only less advanced chips of 16 and nanometer[15]. South Korea is the second largest provider, while China has less than 10% market share[16].
- **ATP:** Taiwan firms make 54% of the global outsourced ATP revenues, followed by firms based in the United States (17%) and China (12%).

In summary, **the key bottlenecks** in semiconductor (chip) production **are the firms TSMC and ASML[17]**.

On the other hand, **China controls the materials needed for the production of the surrounding computers and digital devices, the rare metals**:

China is the main producer of physical electronics of computers and smartphones, even US firms outsource their production often to China. This is logic as China is the main owner of computer-relevant metals. Also, China produces 75% of the mobile phones and 90% of all PCs, as even US companies outsource this production step to China.

China had in 2010 a 97% market share[18] for rare industry metals such as niobium, germanium, indium, palladium, cobalt, and tantalum which cannot yet be recycled in an efficient manner and are irreplaceable in IT industry. The extremely high market share resulted from low prices of Chinese metals which led to resignation of most competitors; however, the search for and exploitation of such metals was restarted resulting in decreased prices.

[11] Cronin 2022
[12] DoD 2022. Note that even ASML has its own dependencies. The laser technology for the machines is provided the German Company *Trumpf*, the mirrors by the German company *Zeiss*; Smolka/Theile 2022
[13] Ankenbrand/Finsterbusch 2022, Welter 2022
[14] EU 2021
[15] Ankenbrand et al. 2022
[16] Bost 2022
[17] DoD 2022
[18] Büschemann/Uhlmann 2010, p.19

The US has identified 35 raw materials as critical, for 14 of these raw materials have no own production. For rare metals, China has 71% market share and 37% of reserves in 2019, while Vietnam and Brazil, each with 18% reserves, could be future alternative support states.[19] To help build resilience in raw materials, the European Commission established the *European Raw Materials Alliance (ERMA)* [20].

On the other hand, US dominate the infrastructure level of central servers and of deep-sea cables. In the physical world, the internet is finally bound to a physical network with a significant level of centralization. The US-based company *Equinix* controls according to their website with their own central computer nodes (IXPs) and co-location of client computers in their data centers roughly 90% (!) of the data volume transfer of the internet.

US Technology companies currently control more than 50% of the deep-sea cables which currently transfer 95% of all internet data. Currently, there are 400 cables with 1.3 million km length and until 2025, 45 further cables are planned.

Now, new global players appear, e.g., China with the *Pakistan and East Africa connecting Europe (Peace) Cable* from China via land to Pakistan, then in the sea to France[21]. From 2016-2019, Chinese companies were involved in around 20% of all deep-sea cable projects[22]. China is also engaging in this area as part of China's *Digital Silk Road*. There is a growing importance of Chinese companies like the *Hengtong* Group and its subsidiaries *Hengtong Marine* and *Huawei Marine* in investment, construction, ownership and operation of undersea cables[23]. Western states try to avoid involvement of Chinese companies while China tries to stop *Google*-owned cables where possible.

3 The Competition between USA and China

The rivalry in technology is considered the Director of the *Central Intelligence Agency (CIA)*, Bill Burns, as the "main arena for competition and rivalry with China."[24] With respect to digital technology, China competes with US in the areas artificial intelligence (AI), 5G, quantum information science (QIS), semiconductors, biotechnology, and green energy[25] and China is already leading in quantum communication.

According to the 2017 *New Generation AI Development Plan*, China is aiming to become the global AI leader and develop a domestic AI market worth USD 150 billion by 2030[26]. The Chinese government views AI as an opportunity to "leapfrog" the United States by focusing on AI for enhanced battlefield decision-making, cyber capabilities, cruise missiles, and autonomous vehicles in all military domains[27]. The *US Department of Defense (DoD)-National Security Commission on Artificial Intelligence (NSCAI)* believed in 2020 that US has still no credible alternative to the Chinese provider *Huawei* use in 5G[28] which is a major security problem because 5G networks will be a kind of "connective tissue" between AI applications.[29]

Already in 2004, the US *Department of Defense (DoD)* implemented a trusted supplier program, whereby the government pays a fee to U.S. companies to guarantee the access and

[19] FAZ 2019, p.17
[20] EU 2022
[21] Rolfs 2021, Gollmer 2022
[22] Perragin/Renouard 2022
[23] Velliet 2022
[24] Cited in Allison et al. 2021
[25] Allison et al. 2021
[26] Hoadley/Sayler 2019, p.1, NATO 2019, p.10
[27] NATO 2019, p.10
[28] NSCAI 2020, p.54
[29] NSCAI 2020, p.55

reliability of components that are important to national defense[30]. However, this covers only small portion of the military needs and the DoD is heavily dependent on the commercial supply chain many non-US suppliers[31]. In 2022, the DoD noted with that "the slow pace of technology implementation occurring in US facilities, coupled with the aforementioned risk-averse position adopted by domestic manufacturers, has led to increased consolidation of State-of-the-Art (SOTA) manufacturing technology in foreign nations".[32]

In June 2014, China released its *Guidelines to Promote National Integrated Circuit Industry Development*, with the goal of establishing a world-leading semiconductor industry in all areas of the integrated circuit supply chain by 2030[33]. In August 2020, the Chinese government updated its semiconductor policy to emphasize foreign academic and industry collaboration to bring more knowledge, capacities and investments to China. The *China Integrated Circuit Investment Industry Fund (CICIIF)* was created to support the domestic industry, state-directed overseas acquisitions, and the purchase of foreign semiconductor equipment[34]. The semiconductor policy is also part of the *Made in China 2025* initiative and a key element of President Xi Jinpings *Chinese Dream of a Great Rejuvenation of the Chinese nation*[35].

Chinas strategy to promote its semiconductor capabilities includes the acquisition of specialized technology firms, intensified collaboration, and transfer by joint ventures, licensing agreements, use open-source technology platforms, hiring of foreign talent and the purchase of US equipment and software tools[36]. However, US complained that this was accompanied by forced technology transfer requirements, cyber-enabled theft of US intellectual property and trade secrets, discriminatory and nonmarket licensing practices, and state-funded strategic acquisition of US assets[37].

Since 2018, the United States set up a variety of initiatives to stop or at least to slow down China's rise in this area.

In 2018, the US reacted with implementation of tariffs on Chinese chips[38] while the Department of Justice started charges due to theft of intellectual property and trade secrets. In the same year, the *Committee on Foreign Investment in the United States (CFIUS)'* foreign investment review authorities were strengthened by the *Foreign Investment Risk Review and Modernization Act (FIRRMA)* for strategic investments, after *CFIUS* enhanced its activities on Chinese semiconductor business already since 2015[39]. Between 2015 and 2018, several acquisitions by of specialized US firms by Chinese firms were abandoned or blocked[40]. At the same time in 2018, the *Export Control Reform Act (ECRA)* was released which restricts dual-use technology exports to China in response to China's military-civil fusion program. To specify this, the *Department of Commerce's Bureau of Industry and Security (BIS)* released an initial list of 14 emerging technologies to be restricted, including robotics, additive manufacturing (e.g., 3D printing), and advanced surveillance technologies[41]. The ECRA is implemented by the *Export Administration Regulations (EAR)*. Under the *De minimis* rule, the EAR is e.g., applicable for exports to China for any product manufactured abroad by a foreign company if the value of US components exceeds 25%. The *Foreign Direct Product Rule (FDPR)* states that if certain

[30] Platzer/Sargent Jr. 2020
[31] Platzer/Sargent Jr. 2020
[32] DoD 2022
[33] Platzer/Sargent Jr. 2020
[34] Sutter 2021
[35] Cronin 2022
[36] Platzer/Sargent Jr. 2020
[37] Platzer/Sargent Jr. 2020
[38] Platzer/Sargent Jr. 2020
[39] Platzer/Sargent Jr. 2020
[40] Platzer/Sargent Jr. 2020
[41] Lazarou/Lokker 2019

controlled US software or technologies are used to produce a good (abroad by foreign companies), it will require a US license to be exported to China. This is applicable irrespective of the value of the US component. This affects US semiconductors as well as almost all US semiconductor manufacturing equipment[42].

Also in 2018, China's *Semiconductor Manufacturing International Corporation (SMIC),* wanted to purchase an *extreme ultraviolet lithography (EUV)* machine from the Dutch *ASML* which is essential for the manufacture of the most finely engraved chips (7 nanometers and below)[43].

The United States massively engaged on the highest diplomatic level (including visiting the Dutch prime minister Rutte) to block the delivery of advanced EUV lithography equipment to the Chinese *SMIC* by *ASML*. The US pointed out that "good allies" do not sell this type of equipment to China and also that *ASML*'s machines could not function without certain US components[44]. At the end, the machine was not sold to China's *SMIC*.

Without access to this equipment and specialized staff, *SMIC* and thus China cannot reach process nodes below 7 to 10 nanometer in the foreseeable future.[45] **This will significantly slow down or even partially stop Chinas future progress for digital devices**.

The next Internet communication generation **5G** is coming which will allow the first time a broad implementation of the **Internet of Things** and of smart home and smart city solutions, in particular by much higher data flows, real-time transfer massively reduced latency times (transmission delays) under 1 millisecond and also reduced energy need for transfer per bit. From the geostrategic perspective it is apparent that who controls 5G, controls the civilization of the respective country. The Chinese company *Huawei* is one of the largest global smartphone producers and also one of the largest infrastructure providers, in particular radio antennas for smartphones and other data traffic. The US sanctions against *Huawei* 2019 should stop *Huawei*'s rise, e.g., the US advises other countries not to use *Huawei* products in sensitive areas. *Huawei* was in 2019 the world's leading mobile infrastructure provider with more than 30% market share, i.e., higher than *Apple* for smartphones. *Huawei* has 92 suppliers, including 33 from the US, such as Google's *Android* system, *Qualcomm* chips and *Microsoft* applications.[46] In May 2019, the Department of Commerce denied the export of Qualcomms *Snapdragon* Chips which were essential for *Huawei*'s 5G capabilities. As a result, *Huawei's* smartphone revenue dropped in 2021 by 28.9%, after their stockpile of chips was fully utilized[47]. Further restrictions for trade between US and *Huawei* were implemented in 2020 which targeted Huawei's production ability[48]. Since May 2020, the BIS has amended rules to restrict Chinas leading firm *Huawei* Technologies Co. and its affiliates' ability to acquire chips from any source using US design software or enabling equipment[49].

In August 2022, the *Semiconductors, Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act* was released with support of both Democratic and Republican parties[50]. This provides various support measures for the US domestic industry, but all recipients of federal funding have to join an agreement prohibiting certain material expansions

[42] Velliet 2022
[43] Velliet 2022
[44] Velliet 2022
[45] Eurasia Group 2020
[46] Müller 2019, p.9
[47] De Chant 2022
[48] Ankenbrand/von Petersdorf 2020, p.16
[49] Platzer/Sargent Jr. 2020
[50] PCAST 2022

of semiconductor manufacturing in the People's Republic of China or in other countries of concern[51].
Furthermore, the United States also wanted to stop *ASML* to sell argon fluoride (ArF) immersion lithography technologies, used in DUV (deep ultraviolet), i.e., the less advanced precursor technology of EUV.

On 07 October 2022, the *Department of Commerce's Bureau of Industry and Security (BIS)* released *New Export controls on Advanced Computing and Semiconductor Manufacturing Items to the People's Republic of China (PRC)*[52] with two sets of regulations restricting Chinas ability to obtain advanced computing chips, develop and maintain supercomputers, and manufacture advanced semiconductors. Legally, this expands the *Export Control Reform Act* of 2018 and its implementing regulations, the *EAR*.

The first regulation imposes restrictive export controls on certain advanced computing semiconductor chips, transactions for supercomputer end-uses, and transactions involving certain listed organizations. The second regulation imposes new controls on certain semiconductor manufacturing items and on transactions for certain integrated circuits (ICs) end uses. This includes new license requirements for items destined to a semiconductor fabrication "facility" in the China that fabricates certain ICs. Facilities owned by China will face a "presumption of denial"[53].

Also, US personnel should not support or develop such production in Chinese facilities. As a result, US suppliers already started to withdraw staff from China[54]. The Dutch *ASML* instructed its US management to stop direct or indirect support to Chinese customers[55]. Experts estimate that these measures will cost China years of development time for advanced and supercomputers[56].

These activities are accompanied by **attempts to separate the US and China's internet**: While US is dominated by the 'big five' (*Google, Apple, Microsoft, Amazon* and *Facebook*), China has the messenger platform *WeChat* (owned by *Tencent*), the search engine *Baidu*, the Twitter-equivalent *Sina Weibo* and the video applications *Tiktok, Duoyin* (both owned by *Bytedance*) and *Kuaishou*[57]. Now, both states work on the complete separation of their internet infrastructure which bears the risk of a separation of the internet into two different technology worlds.

In the *3-5-2 project* from late 2019, Beijing has ordered all government offices and public institutions to remove foreign computer equipment and software within three years, with 30% in first, 50% in second and 20% in third year, which explains the name 3-5-2[58]. On the other hand, the United States set up the *Clean Network Program* in 2020 which intends to remove Chinese IT components from IT infrastructure with the five areas *Clean Carrier, Clean Apps, Clean Store, Clean Cable* and *Clean 5G Path*[59].

4 Discussion and Conclusions

Meanwhile, it was realized that the production of computers and digital devices has critical bottlenecks and that the control of critical elements like rare metals and semiconductors

[51] Sargent Jr./Sutter 2022, GPO 2022
[52] BIS 2022
[53] BIS 2022
[54] Ankenbrand et al., 2022
[55] Smolka/Theile 2022
[56] Mayer 2022
[57] Gollmer 2019, p.7
[58] Financial Times 08 Dec 2019
[59] State Department 2020

(computer chips, computing chips, microprocessors) as core element of each digital device could be used for geostrategic purposes. Since 2018, the United States stepwise restricted the export of semiconductors and related manufacturing equipment to China. Amongst other activities, the United States were able to block the selling of the so-called EUV technology to China which makes it for China very difficult or even impossible to produce advanced chips (and thus advanced computers). On 07 Oct 2022, these restrictions were significantly expanded to restrict Chinas ability to obtain advanced computing chips, develop and maintain supercomputers, and manufacture advanced semiconductors. This step could significantly slow down Chinas technological development for years and China is now facing hard strategic choices and decisions.

The geostrategic problem for China is **that they cannot wait anymore**, if they want to achieve global leadership. The main reasons are the demography with an aging workforce and the fact that China despite its massive efforts has still a lower nominal per-capita income than the Seychelles[60]. Either they accept that the United States will maintain the global leadership for a certain time or they decide to fight for leadership as indicated by China's president Xi Jinping who told his people on 16 Oct 2022 to prepare for the "worst cases".

A potential attack on Taiwan to bring it under Chinese control (to a re-unification from a Chinese perspective) could damage the Taiwanese chip industry and by this heavily affect to global digital industry. Taiwan still hopes that the expected damage deters China from an attack, this concept is called "silicon shield"[61]. However, United States would be massively damaged as well then. But an attack on Taiwan could serve further strategic goals as well. It would urge United States to declare war. If they do not, United States have lost their military credibility which would result in the collapse of the US security architecture and its influence in Asia. But if they do, the US Pacific Fleet would be urged to operate close to the Chinese coast where China likely has a local conventional superiority and could also use their advanced *Dongfeng* anti-ship missiles with massive damage for the US Navy. Things could be different if e.g., Japan would back-up US forces with their very large and modern Navy. This is the reason why Taiwan is currently discussed as a major strategic issue by Japan[62].

But this remains speculative. Fact is that strategic moves on small things like chips are able to challenge major powers significantly.

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