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Shakhboz Juraev

THE POTENTIAL OF THE SEMICONDUCTOR INDUSTRY IN RUSSIA IN THE CONTEXT OF GREAT POWER COMPETITION

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The geopolitical realities are influenced and changed by technological and technical advancement. As we stand on the brink of the Fourth Industrial Revolution, the emergence of new opportunities and challenges is inevitable. However, nearly all modern innovations are based on semiconductors. This research analyses the potential of the Russian semiconductor industry to assess the technological and technical capacity of an actor in international relations. Methods of SWOT analysis and questionnaires among experts are used to get clearer estimations about the industrial environment of semiconductors in Russia.

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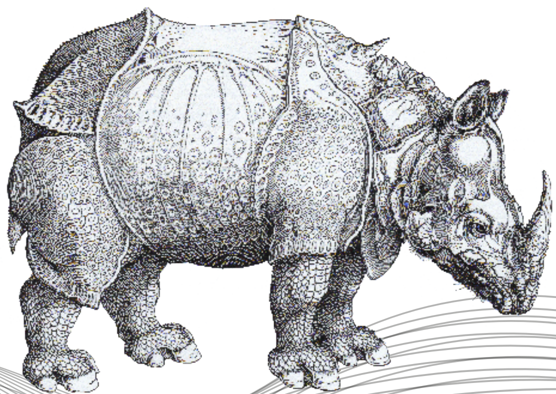

Contents

Highlights

- The role of the semiconductor industry in the new stage of great power competition has critically increased due to the race in outer space, cyberspace, and artificial intelligence. The sector plays a decisive role in developing precision weaponry, Big Data analysis, and the connectivity of units. Moreover, a cyber-operation targeting an opponent's critical infrastructure depends on the power of computers that subsequently link with the processors and chips.

- The American-Chinese tension over Taiwan, the island of critical and modern chips, demonstrates the significance of the industry. However, it is essential to pay attention to the fact that Russia, the opponent of the US during *the nuclear bomb era*, is replaced by China in this contest. For example, the DUV/EUV lithography sector in Russia remains underdeveloped and grows into one of the weakest points of the semiconductor production line.

- Research on Russian semiconductor potential reveals that the country possesses capacity in terms of raw materials and R&D fundamentals. Furthermore, trade relations with China are likely to alleviate the situation. The conglomeration of Tomsk, Novosibirsk (intellectual bases), and Krasnoyarsk, Shelekhov, and Chita (mineral bases) near the border with China enables Russia to re-innovate the industry in its southern part.

- On the other hand, overemphasizing China may cause *the second flow of sanctions* indirectly to the Russian semiconductor sector when the US and *the Global West* impose restrictions on the Chinese semiconductor industry.

THE POTENTIAL OF THE SEMICONDUCTOR INDUSTRY IN RUSSIA IN THE CONTEXT OF GREAT POWER COMPETITION

Shakhboz Juraev

INTRODUCTION

For over half a century, the clash between the United States and the USSR (then its successor, the Russian Federation) is seen as the next potential World War. In the 1960s, after the Cuban crisis, tensions reached their zenith. However grandiose these expectations look, the United States and the Russian Federation do not have a direct fault line from the point of geopolitics. It is unbelievable that Russia, a land power, would send its army across the oceans to be destroyed by the US naval, and the United States, a sea power, put its cavalry and artillery at nearly the same fate as Napoleon and Hitler's troops in Russian forests and vast plains.

Geopolitically, there are four fault lines with one exception where the great powers of similar types of force may collide with one another in the current world:

- the Atlantic Ocean between the US (sea power) and the UK (sea power);
- Eastern Europe between Russia (land power) and some European countries under the lead of Germany (land power);
- Central Asia, Mongolia, and the China-Russian border between Russia (land power) and China (land power);
- the Pacific Ocean between Japan (sea power) and the US (sea power);
- the only exception is the Korean peninsula and the seas between China (land power) and Japan (sea power), as the space separating two different types of countries is crossable without huge losses.

It is difficult to imagine other cases, for example, that China (land power) and India (land power) go to a full-scale war across the Tibet mountains, in which supply chains are primarily likely to be disrupted geographically. Somehow, this case also applies to direct US-Russian warfare. Nevertheless, the emerging areas of contradiction that enable shortening of the geographical lengths contribute to the great powers' rivalry as a form of an arms race. They include:

- air space where airplanes are used to paralyze the opponent's army, navy, ports, infrastructure, and resource sites, and send paratroops to support one's soldiers. The air space also contains

missiles with the same purpose and nuclear warheads for complete destruction;
- cyberspace, a field where attacks against technologies, technics, plants, and infrastructures are carried out;
- space, where satellite telecommunications are operated.

Yet, not fully developed, these areas may overpass natural borders and change the means of warfare. Consequently, global and regional actors in international relations are keen on building their air, cyber, and space potentials while strengthening land and sea capabilities. Unlike traditional weapons that are mainly composed of *steel and gunpowder*, modern equipment of armies of all five contradiction areas requires semiconductors to improve maneuvers and precision.

ChatGPT, introduced by OpenAI, has revolutionized the perceptions of people about the ability of artificial intelligence (AI), the driver of the Forth Industrial Revolution. The logic behind AI is the self-learning characteristics of the machine, whose main components are computing power, data, and algorithms. As occurred in nearly all industrial revolutions, the ideas on the economic, political, and military uncertainty of consequences have arisen. It is undeniable that a few tendencies that may influence the present world order have emerged on the brink of the AI era.

First, the rise of China as an economic superpower to a degree that could challenge US dominance demonstrates that artificial intelligence is not developed according to unipolar rules. Chinese Huawei and its 5G technological capacity have embarrassed most Western politicians. Secondly, mutual sanctions, boycotts, embargos, tariffs, and limits by the West and Russia after the Ukrainian crisis undermine the ongoing architecture of global cooperation. All of them, along with withdrawals from international conventions, treaties, and pacts, rejuvenate races for the arms sphere, space, and moon-landing.

Both of these tendencies mean that artificial intelligence is subject to the uncertainty of *which actor uses it for what purpose*. This shows that countries may find it difficult to reach common ground on AI, a technology that will play an integral role in economic progress and state defense. As a result, competition for integrated circuits and demand for the national chip industry is expected to increase when it comes to data (memory chips) and computing power (logic chips) of artificial intelligence.

The US Congress's success in passing the CHIPS and Science Act (informally the CHIPS Act) shows that legislators are united: the United States needs to manufacture more semiconductors at home. The CHIPS Act's $52.7 billion investment in domestic semiconductor manufacturing aims to fulfill three main objectives: 1) reduce the likelihood that shocks abroad might disrupt the supply of chips, 2) boost American international economic competitiveness and create domestic jobs, and 3) protect semiconductors from being sabotaged

Unlike traditional weapons that are mainly composed of *steel and gunpowder*, modern equipment of armies of all five contradiction areas requires semiconductors to improve maneuvers and precision

in the manufacturing process[1]. The CHIPS Act prohibits funding recipients from expanding semiconductor manufacturing in China and countries defined by US law as posing a national security threat to the United States. These restrictions would apply to any new facility unless the facility produces legacy semiconductors predominately for that country's market[2].

Furthermore, the proposed European Chips Act aims to strengthen Europe's research and technology leadership towards smaller and faster chips; put in place a framework to increase production capacity to 20% of the global market by 2030; build and reinforce capacity to innovate in the design, manufacturing, and packaging of advanced chips; develop an in-depth understanding of the worldwide semiconductor supply chains; address the skills shortage, attract new talent and support the emergence of a skilled workforce[3].

Both acts hint at a radical shift in chip policy of the West that intends reshoring the related facilities to their territories. These steps by the United States and European Union make it important to study the chip production capacities of more countries and regions to draw a broader image of the industry and technological and technical security. The relevance of the research that focuses on Russia's chip industry potential lies in the above-mentioned view.

The methodology includes data collection, an expert assessment questionnaire, and a SWOT analysis. First, information about Russian raw material mines, R&D laboratories, education and training capacities, chip designing facilities, DUV and EUV machines, fabrication units, and companies is collected. Secondly, initial values are given according to the findings, and further questions for experts' assessment are formulated. Finally, a SWOT analysis is conducted based on both estimations of research findings and experts' assessments.

[1] Kannan V., Feldgoise J. After the CHIPS Act: The Limits of Reshoring and Next Steps for U.S. Semiconductor Policy // Carnegie Endowment for International Peace. November 22, 2022. URL: https://carnegieendowment.org/2022/11/22/after-chips-act-limits-of-reshoring-and-next-steps-for-u.s.-semiconductor-policy-pub-88439 (accessed: 06.04.2023).
[2] The CHIPS Act: What it means for the semiconductor ecosystem // PwC. URL: https://www.pwc.com/us/en/library/chips-act.html (accessed: 06.04.2023).
[3] European Chips Act // European Commission. URL: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en (accessed: 06.04.2023).

CHAPTER I. THE POTENTIAL OF THE SEMICONDUCTOR INDUSTRY IN RUSSIA

1.1. Raw Materials

The most used semiconductor materials are silicon, germanium, and gallium arsenide. Of the three, germanium was one of the earliest used. Silicon has been extensively used as a semiconductor since the 1950s. Gallium arsenide is the second most common semiconductor in use today[4].

Russia is the world's second-largest silicon producer, with its production estimated at 640 thousand metric tons in 2022[5]. Deposits of quartz raw materials suitable for smelting crystalline silicon in the country are Mount Karaulnaya (Antonovskoye) in the Sverdlovsk region for the needs of OAO Kremniy-Ural and Cheremshanskoye in Transbaikalia ore base for ZAO Kremniy. Silicon is produced at the JSC Silicon facility in Shelekhov. It produces two types of products – smelter-grade silicon for producing AlSi alloys and refined silicon for the chemical and electrical industries[6].

About 90% of the world's production of gallium is provided by aluminum production. An analysis of technological schemes for the production of alumina shows that the main amount of gallium passes into alkaline aluminate solutions, regardless of whether the feedstock is bauxite or nepheline[7]. Semiconductor compounds of gallium are also used for the manufacture of various rectifiers, nuclear radiation detectors, devices using the Hall effect, and lasers for both the visible and infrared regions of the spectrum. In addition, the demand for gallium leads to its use in the production of solid-state emitters, thin film transistors, batteries, lithium batteries, and photovoltaic gallium alloys[8]. Gallium arsenide (GaAs) is a promising material for semiconductor electronics. Gallium nitride has excellent chemical and mechanical properties that are typical of all nitride compounds and is used in semiconductor lasers and LEDs[9]. In 2019, Russia was ranked second in the production of gallium with 2.3% and germa-

[4] Semiconductor Materials // IEEE. URL: https://irds.ieee.org/topics/semiconductor-materials#:~:text=The%20most%20used%20semiconductor%20materials%20are%20silicon%2C%20germanium%2C%20and%20gallium,outer%20shell%20of%20the%20atom (accessed: 07.04.2023).
[5] Production volume of silicon in Russia from 2010 to 2022 // Statista. January 2023. URL: https://www.statista.com/statistics/1260898/russia-silicon-production/ (accessed: 07.04.2023).
[6] Kremnij [Silicon] // RUSAL. URL: https://bit.ly/3nM1gv8 (accessed: 08.04.2023).
[7] Bukin V.I., Reznik A.M., Semenov S.A., Lysakova E.I., Smirnova A.G. Ispolzovanie ekstragentov fenolnogo tipa v tehnologii galliya i skandiya [The use of phenolic extractants in gallium and scandium technology] // Vestnik MITHT. 2006. № 6. P. 16.
[8] Ershova Ya.Yu. Fiziko-himicheskie osnovy ekstrakcii galliya i alyuminiya iz shelochno-karbonatnyh rastvorov azotsoderzhashimi ekstragentami fenolnogo tipa [Physico-chemical bases of extraction of gallium and aluminum from alkaline carbonate solutions with nitrogen-containing phenolic extractants]: Thesis on competition of a PhD in Chemistry: 05.17.02. — Lomonosov Moscow State University of Fine Chemical Technologies, Moscow, 2015. P. 9.
[9] Larichkin F.D., Cherepovitsyn A.E., Novosel'tseva V.D., Goncharova L.I. Sostoyanie i perspektivy rossijskogo i mirovogo rynka galliya [State and prospects of Russian and world gallium market] // News of the Ural State Mining University. 2017. №4. P. 110.

nium with 3.8% of world output. Two gallium plants of RUSAL are located in Achinsk of East Siberia and Pikalevo, and there is an OOO *Galiy* plant in Moscow.

The only company in Russia with a complete cycle of germanium processing and the production of compounds is *Germanium* JSC (part of the Rostec Group of Companies). The primary raw materials for obtaining germanium in Russia are caustobiolites (coals), the sources of which are located in the Perm Territory, Sakhalin, and Chita regions. One of the most promising is the deposit of germanium lignite located in the Yenisei region of the Krasnoyarsk Territory[10]. The company divides the consumption of germanium into five main groups: infrared optics – 30%; fiber optics – 20%; PET – 20%; electronics and solar power – 20%; other fields – 10%[11].

Russia is the world's second-largest silicon producer, with its production estimated at 640 thousand metric tons in 2022

The statistics show the abundance of essential raw materials of semiconductors and chips in Russia, a country that was ranked second in all three resources. In addition, the market leader in silicon, germanium, and gallium is China, a neighboring Russian country. In conclusion, Russia is in an advantageous position in terms of mineral resources.

1.2. Silicon Wafers

In the process, the silicon will be purified, which is one of the most essential stages of semiconductor production. Its significance lies in purification at an adequate level. In July 2022, on its webpage, Rostec reported – "Ruselectronics holding of the Rostec State Corporation presented at the Innoprom-2022 exhibition a sample of single-crystal silicon produced entirely from Russian materials. The technology was developed at NPP Salyut of the Ruselectronics holding together with the Institute of Physics of Microstructures of the Russian Academy of Sciences and the Institute of Chemistry of High-Purity Substances of the Russian Academy of Sciences by order of the Russian Ministry of Industry and Trade"[12].

According to its claims, Epiel in Zelenograd is the only company in Russia specializing in the production of epitaxial structures based on silicon and sapphire for a wide range of semiconductor devices, including integrated circuits, discrete power devices, and many other electronic components. Epiel produces silicon epitaxial structures with diameters of 100, 150, and 200 mm, which are supplied to the largest microelectronics plants in Russia – Micron and Angstrom[13].

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[10] Sirotin D.V. Obespechenie rossijskoj poluprovodnikovoj elektroniki mineralno-syrevymi resursami [Provision of Russian semiconductor electronics with mineral resources] // Aktualnye problemy ekonomiki i upravleniya [Actual problems of economy and management]: collection of articles of the VIII All-Russian Scientific-Practical Conference with international participation / Yekaterinburg: Ural State Mining University, 2020. P. 143.

[11] History // JSC Germanium. 2016. URL: http://eng.krasgermanium.com/about-company/history (accessed: 08.04.2023).

[12] Rosteh sozdal kremnij iz rossijskih materialov dlya vypuska elektropriborov [Rostec created silicon from Russian materials for the production of electrical appliances] // Rostec. July 05, 2022. URL: https://rostec.ru/news/rostekh-sozdal-kremniy-iz-rossiyskikh-materialov-dlya-vypuska-elektropriborov/ (accessed: 09.04.2023).

[13] Epiel // Made in Russia. URL: https://madeinrussia.ru/en/catalog/3287 (accessed:

However, it must be noticed that more than 90% of all single-crystal silicon produced in the Russian Federation is of solar panel quality and is intended for export to the EU, Japan, and China in the form of wafers, less often ingots. On the territory of the Russian Federation, there are many small industries that have the necessary capacities for cutting single-crystal silicon ingots into wafers (Zelenograd, Ryazan, Vladivostok, Khabarovsk, etc.)[14].

1.3. Research and Development (R&D)

The innovative potential in the semiconductor industry plays a pivotal role in developing competitiveness and providing strategic technological and technical security. It is no coincidence that Japan and South Korea, countries with fewer mineral resources and more advanced human capital, concentrate enormous and various facilities related to chip production. The main research objectives are the purification of raw materials and minimization of size in nanometer scales. Industrial leaders mostly solve the first topic; however, it remains significant for runners-up. The second one is the *constant problem of semiconductor science*, on which research is regularly conducted to possess advanced technology and technics. On the page *Semiconductors information* by D.W. Palmer, the names of 17 semiconductor research laboratories in Russia (Table 1) are counted[15].

Table 1. Semiconductor research units in Russia

№	Research units	Locations
1	Osipyan Institute of Solid State Physics RAS	Chernogolovka
2	Institute of Microelectronics Technology and High Purity Materials RAS	Zelenograd
3	Joint Institute of Nuclear Research	Dubna
4	Lebedev Physical Institute of the RAS	Moscow
5	National Research University of Electronic Technology	Zelenograd
6	Physics faculty of M.V. Lomonosov Moscow State University	Moscow
7	Institute for Physics of Microstructures RAS	Nizhny Novgorod
8	Faculty of Applied Physics and Microelectronics of Nizhny Novgorod State University	Nizhny Novgorod
9	Physics Department of Novosibirsk State University	Novosibirsk
10	Physics Department of Saratov State University	Saratov

09.04.2023).

[14] Grigorjev A.V., Beller R.V. Perspektivy razvitiya proizvodstva vysokochistogo kremniya v Rossijskoj Federacii [Prospective trends of Russian silicon industry] // Vestnik of Siberian State Aerospace University named after academician M.F. Reshetnev. 2009. P. 153.

[15] Palmer D.W. European Semiconductor Research Laboratories Outside the European Union. 1999-2013. URL: https://www.semiconductors.co.uk/research_laboratories/europe-noneu.htm (accessed: 09.04.2023).

11	St. Petersburg Electrotechnical University	St. Petersburg
12	Ioffe Physico-Technic Institute	St. Petersburg
13	Saint Petersburg State University	St. Petersburg
14	Taganrog State Radio Technical University	Rostov-on-Don
15	Voronezh State University	Voronezh
16	P.G. Demidov Yaroslavl State University	Yaroslavl
17	Institute of Metal Physics of the RAS	Yekaterinburg

For example, the Institute of Metal Physics of the RAS is modern and fully equipped to investigate condensed matters (metals, semiconductors, metal-ceramics, and others) under high and low temperatures, high and low pressure, constant and pulsed magnetic fields[16]. Research and Training Laboratory of IC Design at Voronezh State University, another example, develops schematic-based designs in IC design, testing, and application[17]. However, a review of the information pages of the units (as a form of laboratories, institutes, departments, faculties, universities, or centers) shows that the research processes depend mainly on state sponsorship and grants and are less commercialized, which results negatively in bringing ambitious talents and continuous improvement of material, technological and technic bases.

1.4. Lithography

There are now three giant lithography machine companies worldwide: ASML in the Netherlands, Nikon in Japan, and Canon in Japan. In 2021, ASML had grown to be the absolute leader in lithography machines, with a global market share of nearly 70% and a 100% monopoly of the market for high-end EUV lithography machines[18].

Recent information demonstrates that the lithography sector is the most severe break in the Russian semiconductor system. At a scientific seminar at the National Center for Physics and Mathematics (NCFM) dedicated to EUV lithography and prospects of a Russian EUV lithograph for microelectronics, Nikolay Chkhalo, head of the Department of multilayer X-ray optics at the Institute for Physics of Microstructures (IPM) RAS said a domestic lithograph with a wavelength of 11.2 nm for the production of next-generation microcircuits is being developed by scientists from the Institute of Physics of Microstructures (IPM) RAS by 2030[19].

China, a close ally of Russia in international relations, also lacks sustainable experience and potential in the field. The top Chinese

[16] M.N. Mikheev Institute of Metal Physics of Ural Branch of Russian Academy of Science. URL: https://www.imp.uran.ru/?q=en/content/eksperimentalnaya-baza (accessed: 16.04.2023).
[17] Voronezh State University. URL: https://www.vsu.ru/english/research/labs-phys.html#8 (accessed: 16.04.2023).
[18] Fang Y., He Y. Resolution technology of lithography machine // Journal of Physics: Conference Series. 2022. P. 4.
[19] Proekt innovacionnogo litografa dlya proizvodstva mikroshem razrabatyvayut uchenye

photolithography firm, Shanghai Micro Electronics Equipment (SMEE), has existed for 18 years, but its most sophisticated tool operates at the 90 nm node, about eight generations (16 years) behind the currently leading 5 nm node. even SMEE's 90 nm tool is only a prototype, generating no sales[20].

Furthermore, the lithography machine is a complex structural equipment, and its main components include several major parts, which consist of the laser light source, the objective lens system, the table system, the mask table system, the mask transfer system, the silicon transfer system, and the exposure system. The exposure system consists of a projection objective lens and illumination system, which is the core of the lithography machine[21]. This means that parallel research, development, and investment are needed to build lots of different parts of a single EUV machine for businesses or government organizations.

The innovative potential in the semiconductor industry plays a pivotal role in developing competitiveness and providing strategic technological and technical security

1.5. Chip Design

Chip design is the process of designing a chip and is an essential part of electronics engineering. This chip design process involves the knowledge of circuit design and its logic formation. All chips are made using basic elements known as transistors. Two of the major players in the chip design tool market are Siemens and Cadence[22], alternatives to which cannot be found in Russia.

However dependent on foreign counties for tools its chip designers are, the Russian government tends to support the fabless model, giving design companies an extensive preferential tax policy. The corporate income tax rate has dropped from 20% to 3%[23]. In the Catalogue of Russian Organizations for International Cooperation in Semiconductor Design prepared under the EU-funded FP7 SEMIDEC project in 2010[24] (despite the date being old, the information provided in the document is rare in the sources, and essential to see a façade of the industry), 29 units were listed in the chip design area (Table 2). Further analysis of the data shows several critical points. Firstly, semiconductor materials are diverse including silicon, germanium, gallium arsenide, and sapphire. Secondly, there are operating private and state organizations unlike the R&D laboratories system. Thirdly, the industrial actors are agglomerated mainly in Moscow, Zelenograd,

[The project of innovative lithograph for the production of chips is developed by scientists] // ANO "National Priorities". March 17, 2023. URL: https://xn--80aa3ak5a.xn--p1ai/news/proekt-innovatsionnogo-litografa-dlya-proizvodstva-mikroskhem-razrabatyvayut-uchenye/ (accessed: 16.04.2023).

[20] Hunt W., Khan S.M., Peterson D. China's Progress in Semiconductor Manufacturing Equipment. Accelerants and Policy Implications // CSET Policy Brief. March 2021. P. 14.

[21] Zhang X. An Introduction to Lithography Machine // Advances in Social Science, Education and Humanities Research. 2021. Vol. 582. P. 50.

[22] Chip Design // AnySilicon. URL: https://anysilicon.com/chip-design/ (accessed: 16.04.2023).

[23] Artashyan A. How Russian technologies will survive without chips? // GizChina. March 06, 2022. URL: https://www.gizchina.com/2022/03/06/how-russian-technologies-will-survive-without-chips (accessed: 16.04.2023).

[24] Catalogue of Russian Organizations for International Cooperation in Semiconductor Design. FP7 SEMIDEC project consortium. 2010. P. 4-61.

and St. Petersburg. The facts, such as the existence of the private sector companies and the usage of four types of semiconductor materials, give a positive signal in conclusion.

Given that the US chip industry is also clustered mainly in California, the third factor has less impact on development. In the end, reducing dependency on foreign chip design tools remains a problem to be solved.

1.6. Fabrication

Although Russia has several domestic chip manufacturers (Mikron, JSC MCST, and Baikal Electronics), they are highly dependent on foreign vendors for the supply of finished semiconductor products, such as SMIC (China), Intel (USA), and Infineon (Germany). JSC MCST and *Baikal Electronics* mainly use factories in Taiwan and Europe for contract manufacturing.

At the end of May 2022, it became known that the MCST company, which is the developer of the Russian Elbrus processors, is negotiating the possibility of transferring their production to the Russian Mikron factory[25].

The leading domestic manufacturer of microprocessors, the Zelenograd-based Mikron, now mainly produces chips for bank and transport cards and RFID tags. The company also fell under sanctions, and the thinnest process technology it has mastered is 65 nanometers[26]. Mikron accounts for 54% of Russian microelectronics exports[27].

Other than Mikron, the production of the two companies is less than 100nm. Crocus Nano Electronics reports that it is the only company in Russia capable of mass-producing new-generation non-volatile resistive memory based on the 55 nm ULP (Ultra Low Power) process[28]. the third company, Syntez Microelectronics, which fabricates dies at a 65 nm scale, has outsourced the process to Freescale, XFAB, and other foreign and Russian partners[29]. Reliance on foreign fabs generates uncertainty and instability in the supply of modern chips by Syntez Microelectronics.

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[25] Poluprovodniki (rynok Rossii) [Semiconductors (Russian market)] // TAdviser. March 16, 2023. URL: https://bit.ly/3oR9umm (accessed: 30.04.2023).
[26] Artificial Intelligence and Autonomy in Russia // Center for naval Analyses. 2022. №44. P. 16.
[27] Official website of JSC "Mikron". URL: https://en.mikron.ru/ (accessed: 23.04.2023).
[28] Crocus Nano Electronics has released new generation non-volatile memory // Crocus Nano Electronics. August 12, 2020. URL: http://crocusnano.com/en/crocus-nano-electronics-has-released-new-generation-non-volatile-memory (accessed: 23.04.2023).
[29] Official website of Syntez Microelectronics. URL: http://www.syntezmicro.ru/en/o-kompanii (accessed: 23.04.2023).

Table 2. Catalogue of Russian Organizations for International Cooperation in Semiconductor Design[30]

Units name	R&D activities and competencies in semiconductor design			Technology	Location
	Design areas	Types	Semiconductor Materials		
Scientific Manufacturing Complex *Technological Centre* of Moscow State Institute of Electronic Technology	IC-Design, Process Modelling	Analogue IC, Digital IC, Mixed IC	Silicon	CMOS/ BiCMOS, SOI	Zelenograd
Microelectronics Training and Competence Centre at Vladimir State University	IC-Design, System design	Analogue IC, Digital IC, Mixed IC, SoC, FPGA	Silicon	CMOS/ BiCMOS	Vladimir
Voronezh Innovation & Technology Centre	IC-Design, Process Modelling	Analogue IC, Mixed IC, SoC, RF IC		CMOS/ BiCMOS, Bipolar	Voronezh
Skobeltsyn Institute of Nuclear Physics Lomonosov Moscow State University	IC-Design, Process Modelling, System Design	Analogue IC, Digital IC, Mixed IC, SoC, RF IC, FPGA	Silicon, Germanium	CMOS/ BiCMOS, Bipolar, Flexible and Hybrid boards	Moscow
Research Institute of Material Science and Technology			Silicon, Other	SOI, Other	Zelenograd
Research Centre *Module*	IC-Design, System design	SoC, Digital IC, Mixed IC		CMOS/ BiCMOS, SOI	Moscow
Mikron	System design, IC-Design, Process Modelling, Nanotechnology devices	Analogue IC, Digital IC, Mixed IC, SoC, FPGA, RF IC	Silicon, Germanium	CMOS/ BiCMOS, Bipolar, SOI, Other	Zelenograd
Department of Micro and Nanoelectronics at National Research Nuclear University MEPhI	System design, IC-Design, Process Modelling, Nanotechnology devices	Analogue IC, Digital IC, Mixed IC, SoC, FPGA	Silicon, Gallium Arsenide, Other	CMOS/ BiCMOS, Bipolar, Other	Moscow
Department of Electronics at National Research Nuclear University MEPhI	IC-Design	Analogue IC, Mixed IC, RF IC	Silicon, Germanium	CMOS/ BiCMOS, Bipolar	Moscow
Research and Production Company *Sensor IS*	IC-Design, Process Modelling, System Design	SoC, Digital IC, Mixed IC, Analogue IC	Silicon, Germanium, Gallium Arsenide	CMOS/ BiCMOS, Bipolar, SOI	
PKK Milandr	IC-Design	Analogue IC, Digital IC, Mixed IC, SoC, RF IC	Silicon	CMOS/ BiCMOS, Bipolar, SOI	Zelenograd

[30] Catalogue of Russian Organizations for International Cooperation in Semiconductor Design. FP7 SEMIDEC project consortium. 2010. P. 4-61.

Epiel			Silicon, Germanium, Sapphire	CMOS/ BiCMOS, Bipolar, Silicon on Sapphire, Other	Zelenograd
IDM	IC-Design	Analogue IC, Digital IC, Mixed IC, SoC, RF IC	Silicon, Germanium	CMOS/ BiCMOS, Bipolar, SOI	Zelenograd
IDMPLUS	IC-Design, System design	Analogue IC, Digital IC, Mixed IC, SoC, RF IC	Silicon, Germanium	CMOS/ BiCMOS, Bipolar, SOI, Flexible, and Hybrid boards	Zelenograd
Federal State Unitary Enterprise *Microelectronic Research Institute* PROGRESS	IC-Design, System design	Analogue IC, Digital IC, Mixed IC, SoC, RF IC	Silicon, Germanium	CMOS/ BiCMOS, Bipolar, SOI	Moscow
Digital Solutions	IC-Design, Process Modelling, System Design	Digital IC, Mixed IC, SoC, FPGA		CMOS/ BiCMOS, Bipolar, SOI, Flexible and Hybrid boards, and Other	Moscow
Department of Electrical Engineering and Telecommunications at Saint Petersburg State Polytechnical University	IC-Design	Analogue IC, Digital IC, Mixed IC, SoC, FPGA, RF IC		CMOS/ BiCMOS, SOI	St. Petersburg
Department of Telematics at Saint Petersburg State Polytechnical University		FPGA		Other	St. Petersburg
JointStock Company Research Institute of Semiconductor Devices	IC-Design, Process Modelling, System Design	Analogue IC, RF IC	Gallium Arsenide	Other	Tomsk
Intel Labs St. Petersburg	System design	SoC	Silicon	CMOS/ BiCMOS	St. Petersburg
IC Design Centre *Alfa Cristal*	IC-Design	Analogue IC, SoC, Mixed IC		CMOS/ BiCMOS, SOI	St. Petersburg
Laboratory of Innovation Technology Ltd.	System design, Process Modelling, Nanotechnology devices	SoC, Mixed IC	Silicon, Germanium	Bipolar, Flexible, and Hybrid boards, SOI	Zelenograd
ELNAS	IC-Design	FPGA, RF IC	Silicon	CMOS/ BiCMOS and RF CMOS	Voronezh
Moscow State Institute of Electronics and Mathematics	Process Modelling	Analogue IC, Digital IC, Mixed IC	Silicon, Other	SOI	Moscow
Electronic VLSI Engineering and Embedded Systems Research and Development Center of Microelectronics	System design, VLSI Design, Process simulation, Nanotechnology devices	Analogue IC, Digital IC, Mixed IC, SoC, Microvawe IC	Silicon	CMOS/ BiCMOS, 65-250nm	Zelenograd

Ioffe Physical Technical Institute of Russian Academy of Science	Process Modelling, Nanotechnology devices		Silicon, Germanium, Gallium Arsenide		St. Petersburg
Saint Petersburg State Electrotechnical University LETI	System design, Nanotechnology devices	FPGA, RF IC	Silicon	Bipolar, Flexible, and Hybrid boards	St. Petersburg
Centre *Nanotechnologies* at Taganrog Institute of Technology (Southern Federal University)	System design, IC-Design, Process Modelling, Nanotechnology devices	Analogue IC, FPGA	Silicon	Bipolar	Rostov
Nevatron	IC-Design, System design	Analogue IC, Digital IC, Mixed IC, SoC, RF IC	Silicon	CMOS/ BiCMOS	St. Petersburg

Table 3. Semiconductor plants in Russia[31]

№	Company	Plant Location	Started production	Process technology
1	VSP Mikron	Voronezh	1959	900+
2	NM-Tech	Zelenograd	2016	250-110
3	Angstrem	Zelenograd	1963	1200
4	Angstrem	Zelenograd	1963	600
5	Mikron Group	Zelenograd	2012	95-60
6	Mikron Group	Zelenograd	2009	180
7	Crocus Nano Electronics	Moscow	2016	90-55
8	NIIIS	Nizhny Novgorod	2010	350-150
9	NPP Istok	Fryazino		
10	Micran	Tomsk	2015	
11	Kremny El	Bryansk	2019	500
12	Syntez Microelectronics	Voronezh	1992	350-65
13	NZPP Vostok	Novosibirsk	1956	250-180
14	Russian Space Systems	Moscow		1000
15	Ruselectronics	St. Petersburg		1000, 800, 500, 200
16	OKB-Planeta	Veliky Novgorod		150

[31] List of semiconductor fabrication plants // Wikipedia. URL: https://en.wikipedia.org/wiki/List_of_semiconductor_fabrication_plants (accessed 23.04.2023).

1.7. Education and Training Capacities

A degree in materials science and engineering or a related field, such as applied physics with materials science or electrical engineering, is usually considered a good background for those interested in a career as a semiconductor engineer[32]. According to the QS World University Rankings, 15 universities teaching Electrical and Electronic Engineering (Table 4) and 13 teaching Material Science (Table 5) are included in Top-1000 in 2023. It is noticeable that ITMO University and the Moscow Institute of Physics and Technology are ranked higher in both subjects. The facts show that Russia possesses adequate training potential at its universities and institutes to provide the industry with specialists.

Table 4. Top universities (or institutes) on Electrical and Electronic Engineering[33]

№	University (or institute)	Location
1	ITMO University	St. Petersburg
2	Bauman Moscow State Technical University	Moscow
3	Moscow Institute of Physics and Technology	Moscow
4	National Research Tomsk Polytechnic University	Tomsk
5	Novosibirsk State University	Novosibirsk
6	Peter the Great St. Petersburg Polytechnic University	St. Petersburg
7	National Research Nuclear University MEPhI	Moscow
8	Ural Federal University	Yekaterinburg
9	National Research University Moscow Power Engineering Institute	Moscow
10	National University of Science and Technology	Moscow
11	HSE University	Moscow
12	RUDN University	Moscow
13	Saint Petersburg Electrotechnical University	St. Petersburg
14	Tomsk State University	Tomsk
15	Novosibirsk State Technical University	Novosibirsk

[32] Official website of Purdue University. URL: https://www.purdue.edu/science/careers/what_can_i_do_with_a_major/Career%20Pages/semiconductor_engineer.html#:~:text=Educational%20Requirements,career%20as%20a%20semiconductor%20engineer (accessed 24.04.2023).
[33] QS World University Rankings by Subject 2023: Electrical and Electronic Engineering. URL: https://www.topuniversities.com/university-rankings/university-subject-rankings/2023/electrical-electronic-engineering?&countries=ru (accessed 24.04.2023).

Table 5. Top universities (or institutes) on Material Science[34]

№	University (or institute)	Location
1	National University of Science and Technology	Moscow
2	Lomonosov Moscow State University	Moscow
3	ITMO University	St. Petersburg
4	Moscow Institute of Physics and Technology	Moscow
5	Ural Federal University	Yekaterinburg
6	National Research Nuclear University MEPhI	Moscow
7	National Research Tomsk Polytechnic University	Tomsk
8	Saint Petersburg State University	St. Petersburg
9	Tomsk State University	Tomsk
10	Novosibirsk State University	Novosibirsk
11	Peter the Great St. Petersburg Polytechnic University	St. Petersburg
12	South Ural State University	Chelyabinsk
13	Bauman Moscow State Technical University	Moscow

Furthermore, education, along with R&D, is a more mobile and borderless stage of the supply chain in contrast to the mining of raw materials and fabrication process. Researchers are flexible about being engaged in laboratories and centers from universities in different countries. In the meantime, students may travel and study at more universities around the world. Online education and remote training opportunities have also accelerated the mobilization of human capital. These factors allow an accessible climate for industries, including Russia's semiconductor production sector, to acquire know-how and knowledge and enrich the organizations and companies in the field with high-portfolio cadres.

1.8. International Trade

Since the crisis in Ukraine, several sanctions, restrictions, and boycotts have been exchanged between Russia and the *collective West*, which resulted in the disruption of the trade of several goods, including semiconductors imported to Russia. For example, the European Union (EU) banned the export of cutting-edge technologies to Russia, listing advanced semiconductors and electronic components among them[35]. The export-banned products list has covered laptop computers and computing components

[34] QS World University Rankings by Subject 2023: Materials Sciences. URL: https://www.topuniversities.com/university-rankings/university-subject-rankings/2023/materials-sciences?&countries=ru (accessed: 24.04.2023).
[35] EU sanctions against Russia explained // Council of the European Union. URL: https://www.consilium.europa.eu/en/policies/sanctions/restrictive-measures-against-russia-over-ukraine/sanctions-against-russia-explained/ (accessed: 25.04.2023).

in the 9th package[36] and electronics goods in the 10th package of the EU sanctions. Furthermore, Australia, New Zealand, Norway, and Canada have been added as partner countries to the EU[37].

In a White House report on February 24, 2022, the United States imposed restrictions on semiconductors, telecommunication, encryption security, lasers, sensors, navigation, avionics, and maritime technologies[38]. The global computer chip industry, including the giant Taiwan Semiconductor Manufacturing Company, began halting sales to Russia in the wake of U.S. sanctions[39]. In February of 2023, Japan announced a prohibition on delivering items, and semiconductor equipment too, to 49 organizations in Russia[40]. In April 2023, South Korea decided to expand the scope of its export controls over items, including semiconductors, in its trade with Russia and Belarus[41].

On the other hand, the data also showed that China exported a total of US $312.93 million worth of semiconductors and integrated circuits to Russia in 2022, up from US $231.97 million in 2021, or a year-on-year increase of 34.9 percent[42]. Moreover, in an interview with RIA Novosti, Malaysian Ambassador to Moscow Bala Chandran said that the authorities of his country would consider any request from Russia regarding the supply of semiconductors and electronics. The Malaysian Ambassador to Moscow added that he did not yet know anything about possible negotiations at the government level, but at the same time expressed hope for a dialogue between businessmen[43]. It is noticeable that most of the South-Eastern Asian countries, as well as India, have been continuing their trade with Russia. Singapore is the only state that supported the sanctions on Russia[44].

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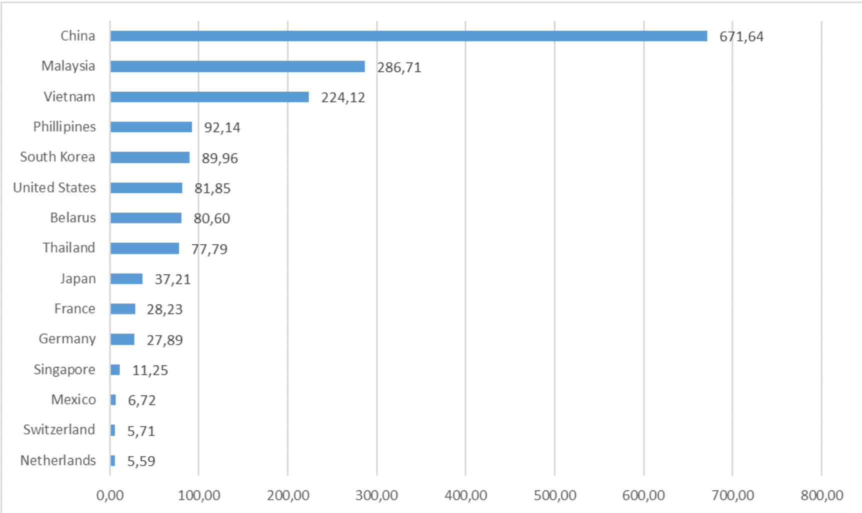
[36] Ukraine: EU agrees ninth package of sanctions against Russia // European Commission. December 16, 2022. URL: https://ec.europa.eu/commission/presscorner/detail/en/IP_22_7652 (accessed: 25.04.2023).
[37] EU agrees 10th package of sanctions against Russia // European Commission. February 25, 2023. URL: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1185 (accessed: 25.04.2023).
[38] Fact Sheet: Joined by Allies and Partners, the United States Imposes Devastating Costs on Russia // The White House. February 24, 2022. URL: https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/24/fact-sheet-joined-by-allies-and-partners-the-united-states-imposes-devastating-costs-on-russia/ (accessed: 25.04.2023).
[39] Whalen J. Computer chip industry begins halting deliveries to Russia in response to U.S. sanctions // The Washington Post. February 25, 2022. URL: https://www.washingtonpost.com/technology/2022/02/25/ukraine-russia-chips-sanctions-tsmc/ (accessed: 25.04.2023).
[40] Japan tightens Russia sanctions, expands export ban list // Al Jazeera. January 27, 2023. URL: https://www.aljazeera.com/economy/2023/1/27/japan-bans-exports-of-robots-semiconductor-parts-to-russia (accessed: 25.04.2023).
[41] South Korea to expand export restrictions on Russia, Belarus // TASS. April 24, 2022. URL: https://tass.com/economy/1608479 (accessed: 25.04.2023).
[42] Lee A. Stymied by the West, Russia is getting critical semiconductors from mainland China, Hong Kong // South China Morning Post. February 03, 2023. URL: https://www.scmp.com/economy/china-economy/article/3209034/stymied-west-russia-getting-critical-semiconductors-mainland-china-hong-kong#:~:text=The%20data%20also%20showed%20that,increase%20of%2034.9%20per%20cent (accessed: 29.04.2023).
[43] Malajziya gotova pomoch Rossii s poluprovodnikovoj produkciej [Malaysia is ready to help Russia with semiconductor products] // IXBT. April 25, 2022. URL: https://www.ixbt.com/news/2022/04/25/my--torgovoe-gosudarstvo-malajzija-mozhet-pomoch-s-rossii-s-poluprovodnikovoj-produkciej.html (accessed: 29.04.2023).
[44] Sanctions and Restrictions Against Russia in Response to its Invasion of Ukraine // Ministry of Foreign Affairs of Singapore. March 05, 2022. URL: https://www.mfa.gov.sg/Newsroom/Press-Statements-Transcripts-and-Photos/2022/03/20220305-sanctions (accessed: 29.04.2023).



Graph 1. Value of semiconductor imports in Russia in 2021, by country of origin (in million U.S. dollars)
Source: www.statista.com

In the end, the Russian opportunities for semiconductor trade are divided into two groups: 1) the countries that have restricted semiconductor exports and 2) the countries that have been continuing their trade. The former group has been playing a lower role in transfers until 2021 (Graph 1), while companies and organizations of those countries provide advanced chips and production technologies. The latter, such as China, Malaysia, and Vietnam, are Russia's top three semiconductor providers and remain in their sound relations with Moscow. However, the second group also depends on the technologies developed by the United States, Germany, Japan, South Korea, and the Netherlands and is at risk of secondary sanctions. As a result, the dilemma of Eastern markets or further sanctions has appeared in discussions of the *Collective West*, and the polarization of the tech world is increasing.

1.9. Overview

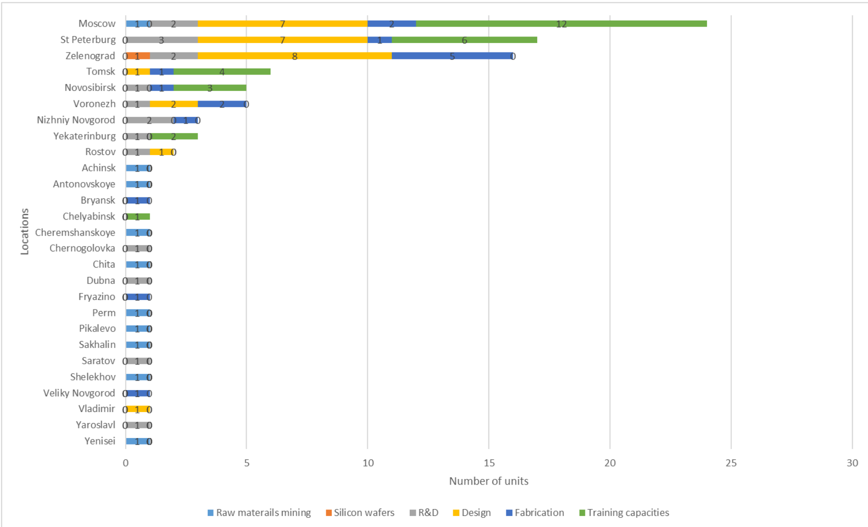
In Russia, overall, 99 units are found to be in the semiconductor industry or training cadres for the sector directly or indirectly. The highest share (28 units) belongs to the top 1000 universities/institutes that teach materials science or electrical engineering. This gives Russia a clear advantage in developing the industrial knowledge relying on the national education system. R&D potential (17 units) is also noticeable to enable to innovate at a substantial level. Together, these two stages account for nearly half of all units in the Russian semiconductor industry. The production of standard-purified silicon wafers and the construction of DUV/EUV machines (0 units) have been exposed as the main problems Russia faces.

The information collected about the actors in the Russian semiconductor industry (Graph 2) displays two lines of agglomeration: the Western line and the Southern line. The Western agglomeration (Graph 3) starts from Saint Petersburg, crosses Zelenograd and Moscow, Voronezh, and ends in Voronezh. It includes 64 objects or about 2/3 of the industrial potential. The locations are connected via M-11, MKAD, and M-4 routes, and both sites of the line are open to the sea trade[45]. The disadvantage of this agglomeration is its distance from the growing markets in China, India, and East Asia and ally or neutral countries to Russia.

The Southern line of agglomeration, around a 6000 km automobile route, stretches from Chita, a site of caustobiolites mine for germanium, to the Shelekhov (silicon) and Achinsk (gallium) mines of RUSAL. Westward, Novosibirsk, and Tomsk are destinations of R&D, training, fabrication, and design capacities. Despite its relatively modest magnitude compared to western agglomeration, the area possesses an opportunity to be developed as a tech hub between China and Russia.

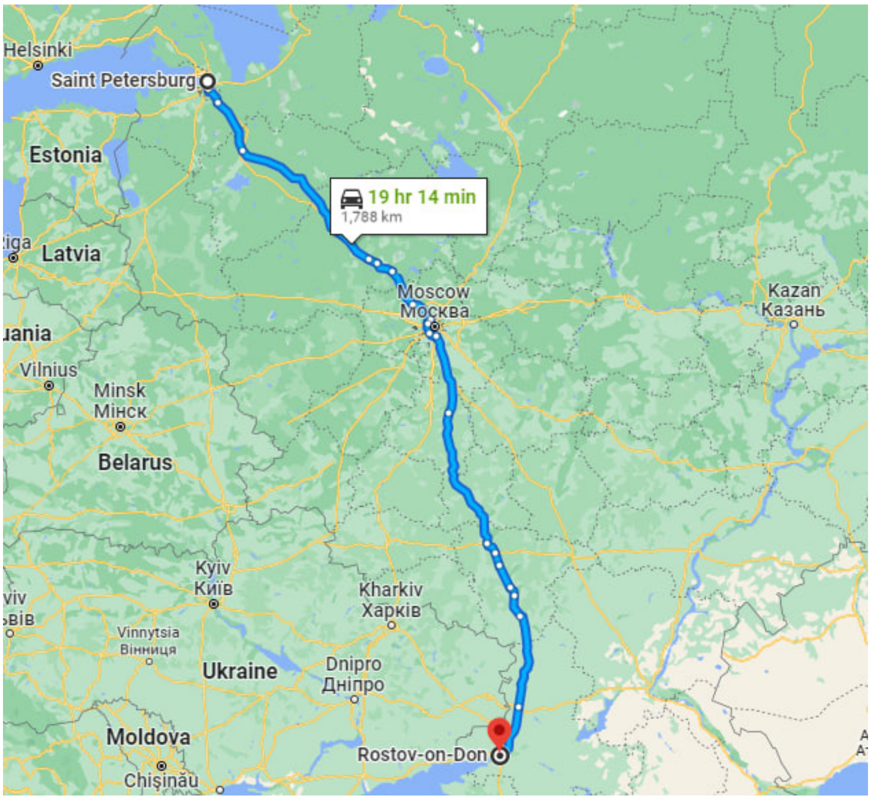
Graph 2. Number of units (mines, plants, companies, universities, fabrics, etc.) with their locations

Source: compiled by author in accordance with the collected information



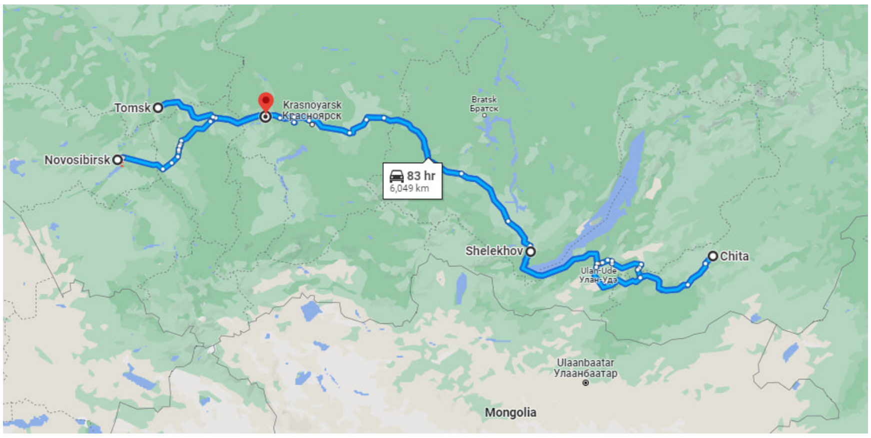
Note: only the training capacities included in QS top-1000 ranking are included.

[45] Google Maps. URL: https://www.google.com/maps/dir/Saint+Petersburg,+Russia/Rostov-on-Don,+Rostov+Oblast,+Russia/@55.5852974,36.6171012,8.54z/data=!4m14!4m13!1m5!1m1!1s0x4696378cc74a65ed:0x6dc7673fab848eff!2m2!1d30.3609096!2d59.9310584!1m5!1m1!1s0x40e3c777c3b4b6ef:0x8248b451e48b4d04!2m2!1d39.701505!2d47.2357137!3e0 (accessed: 30.04.2023).



Graph 3. The Western agglomeration line of Russian semiconductor capacities

Source: www.maps.google.com



Graph 4. The Southern agglomeration line of Russian semiconductor capacities

Source: www.maps.google.com

CHAPTER II. ANALYSIS OF THE SEMICONDUCTOR INDUSTRY POTENTIAL OF RUSSIA

2.1. Analysis with Methods

The findings in the first chapter release the strengths and weaknesses of the semiconductor industry of Russia along with opportunities and threats to the sector for further analysis. Based on the results, the initial SWOT analysis form is shaped, and the values of P_i, K_i, and A_i are given. The values of how the strengths and weaknesses affect the opportunities and threats are determined according to the expert assessment (a_{ij}) in a range of scores from 0 to 5 (Table 6). Final estimations are calculated with the following formula:

$$A_{ij} = A_i K_j P_j a_j$$

Table 6. Questionnaire of expert assessment

№	Question	Average assessment
1	How do you assess that the abundant resources of Russia help to develop the semiconductor industry in cooperation with China?	3.5
2	How do you assess that the abundant resources of Russia help to develop the semiconductor industry in cooperation with India?	2.75
3	How do you assess that the abundant resources of Russia help to develop the semiconductor industry in cooperation with Southeast Asian countries?	2.5
4	How do you assess that the universities/institutes of Russia help to develop the semiconductor industry of in cooperation with China?	3
5	How do you assess that the universities/institutes of Russia help to develop the semiconductor industry in cooperation with India?	2.75
6	How do you assess that the universities/institutes of Russia help to develop the semiconductor industry in cooperation with Southeast Asian countries?	1.33
7	How do you assess that the R&D capacities of Russia help to develop the semiconductor industry in cooperation with China?	3.25
8	How do you assess that the R&D capacities of Russia help to develop the semiconductor industry in cooperation with India?	3.25

9	How do you assess that the R&D capacities of Russia help to develop the semiconductor industry in cooperation with Southeast Asian countries?	1.75
10	How do you assess that the abundant resources of Russia help to mitigate the US sanctions on the semiconductor industry?	3
11	How do you assess that the abundant resources of Russia help to mitigate the EU sanctions on the semiconductor industry?	3.5
12	How do you assess that the abundant resources of Russia help to mitigate the sanctions of East and Southeast Asian countries on the semiconductor industry?	3.5
13	How do you assess that cadres from universities/institutes of Russia help to mitigate the US sanctions on the semiconductor industry?	2.25
14	How do you assess that cadres from the universities/institutes of Russia help to mitigate the EU sanctions on the semiconductor industry?	2.25
15	How do you assess that cadres from universities/institutes of Russia help to mitigate the sanctions of East and Southeast Asian countries on the semiconductor industry?	2.75
16	How do you assess that the R&D capacities of Russia help to mitigate the US sanctions on the semiconductor industry?	3.25
17	How do you assess that the R&D capacities of Russia help to mitigate the EU sanctions on the semiconductor industry?	3
18	How do you assess that the R&D capacities of Russia help to mitigate the sanctions of East and Southeast Asian countries on the semiconductor industry?	3.75
19	How does the absence of DUV/EUV lithography production impact the development of the semiconductor industry of Russia in cooperation with China?	3
20	How does the absence of DUV/EUV lithography production impact the development of the semiconductor industry of Russia in cooperation with India?	3
21	How does the absence of DUV/EUV lithography production impact the development of the semiconductor industry of Russia in cooperation with Southeast Asian countries?	3.25
22	How much does the absence of a Russian lithography industry increase the impact of the US sanctions on the semiconductor sector of Russia?	2.5
23	How much does the absence of a Russian lithography industry increase the impact of the EU sanctions on the semiconductor sector of Russia?	3
24	How much does the absence of a Russian lithography industry increase the impact of the sanctions of East and Southeast Asian countries on the semiconductor sector of Russia?	3
25	How does the insufficient development of cutting-edge semiconductors production impact on the development of the semiconductor industry of Russia in cooperation with China?	4

26	How does the insufficient development of cutting-edge semiconductors production impact on the development of the semiconductor industry of Russia in cooperation with India?	4
27	How does the insufficient development of cutting-edge semiconductors production impact on the development of the semiconductor industry of Russia in cooperation with Southeast Asian countries?	3.75
28	How much does the insufficient development of cutting-edge semiconductors production increase the impact of the US sanctions on the semiconductor sector of Russia?	3.75
29	How much does the insufficient development of cutting-edge semiconductors production increase the impact of the EU sanctions on the semiconductor sector of Russia?	3.75
30	How much does the insufficient development of cutting-edge semiconductors production increase the impact on the sanctions of East and Southeast Asian countries on the semiconductor sector of Russia?	2.25

2.2. Explanation of the Results

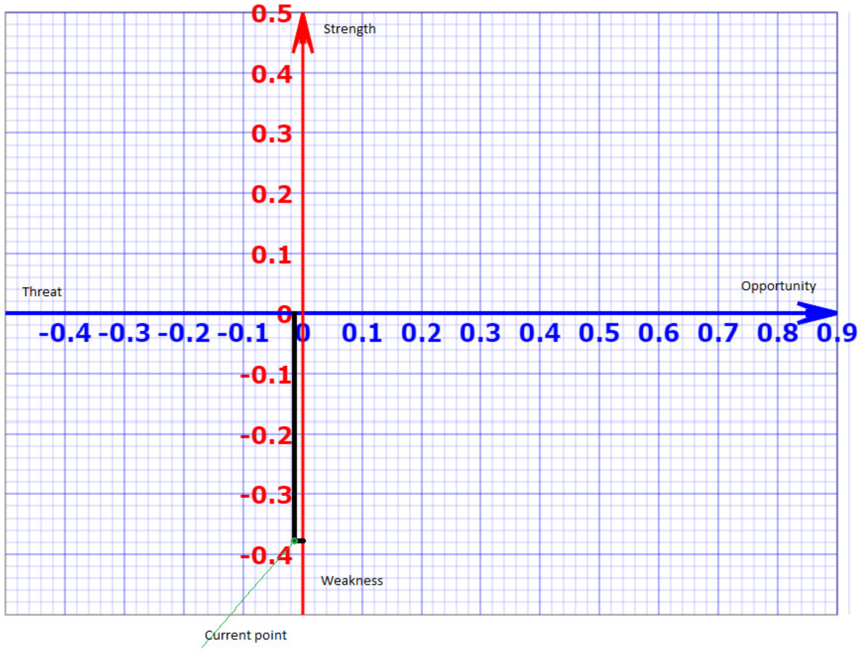
The SWOT analysis (Table 7) reveals that the current point of the semiconductor industrial potential of Russia is in a situation that necessitates some strategic changes, such as diversification, regrouping, or liquidation. For example, moving from the Western line (Graph 3) to the Southern line (Graph 4) can enable actors to regroup near resource-rich Eastern Russia and the border of the leading international partner, China. In addition, China is one of the largest markets to diversify clients on account of the US suppliers that are forced to leave the country due to mutual trade tensions. As the intersection of abundant resources (strength) and cooperation with China (opportunity) in the analysis is marked with a high positive point (0.33915), the importance of the location of the Southern agglomeration increases.

Table 7. SWOT analysis of Russian semiconductor industrial potential

		Opportunities (O)			**Threats (T)**		
		Tradae with China	**Trade with India**	**Trade with South-East Asian countries**	**Sanctions by the USA**	**Sanctions by the EU**	**Sanctions by the East Asian and South-East Asian countries**
P_i probability of occurrence		0,19	0,14	0,12	0,19	0,19	0,17
K_i influence coefficient		0,17	0,11	0,15	0,18	0,20	0,19
Strength (S)	A_i						
Abundance of resources	3	$+3.5^{0.33915}$	$+2.75^{0.12705}$	$2.5^{0.135}$	$+3^{0.3078}$	$3.5^{0.399}$	$3.5^{0.33915}$
Universities/ institutes	3	$+3^{0.2907}$	$+2.75^{0.12705}$	$+1.33^{0.07182}$	$+2.25^{0.23085}$	$2.25^{0.2565}$	$2.75^{0.266475}$
R&D fundamental bases	3	$+3.25^{0.314925}$	$+3.25^{0.15015}$	$+1.75^{0.0945}$	$+3.25^{0.33345}$	$3^{0.342}$	$3.75^{0.363375}$
Weakness (W)							
Absence of DUV/EUV lithography construction	-5	$-3^{0.4845}$	$-3^{0.231}$	$-3.25^{0.2925}$	$-2.5^{0.4275}$	$-3^{0.57}$	$-3^{0.4845}$
Insufficient development of cutting-edge semiconductors production	-4	$-4^{0.5168}$	$-4^{0.2464}$	$-3.75^{0.27}$	$-3.75^{0.513}$	$-3.75^{0.57}$	$-2.25^{0.2907}$

$\sum_{Strength}=1.650345$ $\sum_{Weakness}=2.0412$ $\sum_{Strength} - \sum_{Weakness}= -0.390855$

$\sum_{Opportunity}=2,8386$ $\sum_{Threat}=2,8557$ $\sum_{Opportunity} - \sum_{Threat}= -0,0171$



Graph 5. Results of the SWOT Analysis

Source: compiled by author

In the process of the strategic shifts, there are several aspects to take into account:

1. Overdependence on resources. The section of abundant resources is assessed as a significant factor to support the development of the industry in cooperation with China (0.33915 points) and reduce the impact of the sanctions by the US (0.3078 points), the EU (0.399 points) and East and South Asian companies (0.33915 points). However, overreliance on raw materials does guarantee security and stability for the semiconductor industry, even in cooperation with China, because the Asian giant itself is the leader in silicon, germanium, and gallium minerals production.
2. Industrialization of scientific inventions. It is a paradox that the high positive points belong to the R&D capacities to mitigate the threats of sanctions while the highest negative points are the absence of lithography (0.57 points) and cutting-edge semiconductors production (0.57 points) triggered by the EU sanctions. This fact means there is a break (or breaks) in the process from scientific research to practical implementation in the semiconductor industry of Russia.
3. Overemphasizing China. The numbers demonstrate that estimations in all three *strength points* in cooperation with China are at least twice as big as other potential partner countries (India and South-East Asian countries). It may cause a second flow of problems related to sanctions for the Russian semiconductor sector in a rise of tensions between the US and China.

Overall, the SWOT analysis shows that the semiconductor industry in Russia needs more radical changes alongside balancing international cooperation, reviewing educational and research programs, and decreasing dependence on resources.

CONCLUSION

In the context of the technological and technical advances in the Fourth Industrial Revolution, the realities of geopolitics (cyber world, competition for space) are emerging, which makes a hybrid structure of powers a necessity. The weaponry of the existing fields (sea, land, air) is being re-innovated with intelligent systems, unmanned aerial vehicles, drones, etc. However, nearly all of these innovations are based on the computation and memory that are provided by chips.

The Analysis of the semiconductor industry in Russia reveals several aspects of this significant sector of the new geopolitical era. First of all, the agglomeration of the actors along the Western and Southern lines. Secondly, the main strengths and opportunities of the industry in Russia include abundant resources, R&D capacities, and cooperation with China. Thirdly, the negative impact of the insufficient development of modern semiconductors production and the absence of lithography construction are increased with sanctions, mainly by the European Union. Finally, the semiconductor industry of Russia needs more radical changes such as liquidation, diversification, and regrouping of actors to raise its competitiveness. ■

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Shakhboz Juraev

The Potential of the Semiconductor Industry in Russia in the Context of Great Power Competition

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The project is aimed at studying the potential for cooperation in the use and regulation of new technologies, as well as transforming the challenges to Russia's military and non-military security. The Project participants are looking for solutions that will minimize potential threats through broad discussion and adoption of international regulation by means of multilateral dialogue and mutually beneficial cooperation.

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This occasional paper was produced within *the Evstafiev Series*. This is a collection of research and practice-oriented publications by young, novice authors from Russia and abroad in the field of global security. For many, this is their first or one of the first peer-reviewed publications. All drafts are subjects to external evaluation by a panel at expert-level or educational seminars by PIR Center or in similar formats. Only drafts accepted by the expert panel are submitted for peer review and, if positive, for publication in the Series.

Gennady M. Evstafiev (1938-2013) is an outstanding Soviet and Russian intelligence officer and diplomat, Lieutenant General of the Russian Foreign Intelligence Service, one of the patriarchs of nuclear nonproliferation. He devoted the last ten years of his life to PIR Center, where he worked as a Senior Advisor and Senior Vice President. Gennady M. Evstafiev paid special attention to the progress in creativity and analytical skills of young generation, considering this to be PIR Center's – and his own – most important mission. To visit Gennady M. Evstafiev's memory gallery, please, go to: www.pircenter.org/en/nonproliferation-world/so-it-was-his/gennady-evstafiev-memory-gallery/

In 2021, in memory of Gennady M. Evstafiev PIR Center established a Contest for the Gennady M. Evstafiev Award, or *the Evstafiev Award*, for the best research work in the field of global security. The competition is held annually among young Russian and foreign researchers and looks for research papers dedicated to relevant issues of international security, predominantly the issues of WMD nonproliferation, arms control, strategic stability, cybersecurity, countering international terrorism, and regional security challenges and threats. All submitted works are examined by the Commission on the Legacy of Lieutenant General Gennady M. Evstafiev. More information about *the Evstafiev Award* can be found here: www.pircenter.org/en/evstafiev-award/.

List of winners of *the Evstafiev Award*:

– Mr. Sergey Semenov, Strategic Offensive Arms Control in Russia-U.S. Relations: Lessons Learned (2021);

– Mr. Leonid Tsukanov, The Ups and Downs of the Cyber Caliphate: Al-Qaeda* and ISIS* in the Digital Space (2022).

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* Terrorist organizations banned in Russia.