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Views & Comments

Research on the Innovative Development of New Materials Science and Technology in China

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1. Background

New materials, which are also known internationally as "advanced materials," refer to newly emerging materials with excellent performance and special functions or traditional materials with significantly improved performance or new functions after improvement and modification. At present, the multidisciplinary cooperation of information technology, biotechnology, new energy technology, and new materials technology is triggering a new round of scientific and technological revolution and industrial transformation [1]. Due to their intrinsic attributes, new materials are located upstream in the manufacturing chain of each industry they are applied to, such as aerospace equipment, marine engineering equipment, advanced rail transit, new energy vehicles, and other manufacturing industries. They penetrate every sector of production, logistics distribution, and consumption, acting as a strong driving force for and greatly influencing downstream industries. With the rapid development of high-tech industries and the continuous upgrading of the manufacturing industry, global demand for new materials continues to be high, and the scale of the new materials industry continues to grow. According to the statistics and forecast of the China Center for Information Industry Development, despite a sluggish global economic growth rate, the global output of new materials has maintained a compound annual growth rate of more than 10% since 2015 and has even exceeded 20% in China. At present, the scale of the new materials industry in China accounts for about 30% of the global industry; moreover, some areas of the Chinese new materials industry lead the world in terms of industrial scale.

The level of research and development (R&D) and the industrial scale of new materials are significant indicators of national economic and social development, scientific and technological advancement, and the strength of national defense; therefore, new materials are regarded as a foundational technology for national competitiveness. In general, developed countries and regions are still leading in the field of new materials worldwide, with the United States, Japan, and the European Union in the first tier; China, the Republic of Korea, and Russia in the second tier; and Brazil and India in the third tier. China's ability of original innovation is not strong enough, its industrial foundation is weak [2], and its ability of technology transformation requires improvement, resulting in a large gap in the technological competitiveness of new materials between China and the United States, Japan, and Europe.

2. Opportunities and challenges

2.1. Opportunities

Nowadays, China's new materials development has entered a critical period and is presenting grand opportunities. With industrial upgrading, China's new-generation industries such as information technology, new energy, equipment manufacturing, aerospace, rail transit, marine engineering, and healthcare have developed rapidly, providing a prosperous scenario for new materials and their wide application, driving the continuous iterative upgrading of new materials technology, and creating and releasing huge market increments. For example, in order to realize China's national commitment to achieve carbon peak and carbon neutrality, it is urgent to develop and apply new energy devices such as offshore wind power on a large scale. This will generate a huge demand for new materials, including third-generation semiconductor materials and devices, weather-resistant rare-earth permanent magnet materials, high-temperature superconductive materials, and low-cost large-bundle carbon fibers. As another example, the global annual plastic production is close to 300 million tonnes, of which the production in China accounts for about one third [3]. The Organisation for Economic Co-operation and Development (OECD) has predicted that 25% of petrochemical plastics will be replaced by bio-based plastics produced from natural substances such as starch by 2030 [4]. Thus, it is essential to carry out R&D on and an industrial layout of bio-based materials in China in order to reduce the excessive dependence on petrochemical resources.

2.2. Challenges

On the international stage, developed countries rely on their inherent strategic advantages to use means such as technology, standards, and patents to lay out the world's industrial ecology and even create technical and market barriers. For example, in

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the Japan–Republic of Korea dispute in 2019, Japan conducted a precise attack on the Korean electronic information industry by controlling three kinds of electronic materials. In general, there is still a huge gap between China's capability for the R&D of new materials and the international advanced level.

2.2.1. Lacking the ability to lead development in invention and discovery

Although Chinese scientists have made many achievements in the field of materials science, they have yet to make any epoch-making contributions in terms of breakthroughs in important materials. Existing epoch-making materials, such as Invar alloy and Elinvar alloy, semiconductor materials, fullerene and graphene, optical fibers, blue light-emitting diode (LED), topological phase-change materials, and topological materials, were not discovered by Chinese scientists [5].

2.2.2. Lacking systematic and sustainable investment in R&D

The construction of China's industrial system started relatively late. Therefore, in the process of catching up with developed countries' industrialization, China lacks systematic and sustainable investment in materials R&D. A comparison of the investment intensity in materials R&D in relevant countries reveals that, despite the impact of the economic crisis and the coronavirus disease 2019 (COVID-19) epidemic, the investment intensity in new materials R&D in countries all around the world is generally increasing year by year. This reflects the great attention all countries pay to competition in new materials science and technology. Although the investment intensity of new materials R&D in China is also continually increasing, there is still a large gap in comparison with world-leading countries in new materials, as shown in Table 1. In 2021, the investment intensity of new materials R&D in China was only 2.92%, which was not only lower than that of the United States, Japan, the United Kingdom, France, and Germany in the first tier but also lower than that of Russia and the Republic of Korea in the second tier [6–9].

2.2.3. Insufficient novelty of patents

The number of patents applied for in the field of materials in China ranks first in the world, but their level of novelty is insufficient. According to a patent analysis in the fields of advanced steel materials, nonferrous materials, petrochemical and chemical materials, inorganic non-metallic materials, fiber and composite materials, and cutting-edge new materials by the China National Intellectual Property Administration, the average licensing rate of domestic invention patents is 28.7%—much lower than the average licensing rate of foreign invention patents in China, which is 37.2% [10–12]. From a technical perspective, China's patented technology mainly focuses on improving devices, optimizing processes, reducing costs, improving production efficiency, expanding material sustainability, and improving environmental friendliness, rather than focusing on the R&D of material composition and structure itself; thus, most of China's patents are peripheral improved inventions with little basic R&D. As a result, there is a large gap between China and the United States, Japan, and Europe in terms of originality. On an international scale, the average global share value of the Patent Cooperation Treaty (PCT) held by Chinese applicants is only 4.37%, while that held by applicants in the United States, Japan, and Europe is 31.6%, 28.8%, and 23.6%, respectively—about 5–7 times that of China [10–12].

2.2.4. Insufficient investment in promotion and application services

The number of papers published in the field of materials in China also ranks the first in the world, but the current situation of "emphasizing papers and neglecting transformation" (i.e., focusing on publication rather than industrialization) has not been fundamentally reversed. China's evaluation system for science and technology is imperfect, and its investment in promotion and application services for science and technology is insufficient. Although the input intensity in China has exceeded that in Germany, Russia, and the Republic of Korea since 2020, there is still a large gap between China and the United States, Japan, and the United Kingdom, as shown in Table 2 [6–9].

3. Development strategies

The development of new materials in China had a late start and thus has a weak foundation and insufficient accumulation. In the present stage of rapid economic development, innovation resources are mainly being invested in application-end innovation; moreover, society is paying insufficient attention to materials development and insufficiently investing in materials development in the upstream of the industrial chain. The reform of a new materials R&D model and achievement-evaluation mechanism is slow, and the current separation between scientific research and industry has not been fundamentally improved. These are the main obstacles to the development of new materials science and technology innovation in China. Effective measures should be taken to concentrate on advantageous resources and to promote the rapid improvement of China's capacity for the technological innovation of new materials.

3.1. Building and improving new materials technology innovation platforms

At present, with the rapid global development of emerging industries, higher requirements for materials have been put forward, such as ultra-high purity, ultra-high performance, ultra-low defects, and high-speed iteration, introducing unprecedented challenges to the R&D of new materials [13]. Breakthroughs in basic disciplines and interdisciplinary and multi-technology integration are accelerating the rapid development of new materials. China should carry out top-level design based on the development characteristics and needs of materials science and technology, establish and improve a new materials innovation system [14], and promote the supply capacity of new materials technologies.

3.1.1. Accelerating the construction of a national laboratory for materials

Learning from the successful experience of Oak Ridge National Laboratory in the United States [15], research on materials science, materials technology, and materials engineering should be laid out

Table 1
Investment intensity of new materials R&D in first- and second-tier countries (%).

Year	Investment intensity (%)							
	China	United States	Japan	United Kingdom	France	Germany	Russia	Republic of Korea
2021	2.92	3.53	3.85	3.46	3.19	3.67	3.07	3.33
2020	2.83	3.41	3.67	3.25	2.96	3.44	2.74	2.77
2019	2.78	3.36	3.63	3.22	3.03	3.31	2.62	2.62

Table 2
Investment intensity of new materials science and technology promotion and application services in first- and second-tier countries (%).

Year	Investment intensity (%)							
	China	United States	Japan	United Kingdom	France	Germany	Russia	Republic of Korea
2021	2.77	3.22	3.43	3.01	2.79	2.54	2.24	2.55
2020	2.58	3.06	3.25	2.90	2.68	2.26	1.88	2.23
2019	2.31	2.73	2.89	2.59	2.43	1.60	1.34	1.42

in such a way as to enable the systematic solving of major problems. Given the major scientific tasks that must be addressed in the future, a stable, high-level, efficient, and innovative new materials R&D base should be established.

3.1.2. Reorganizing and optimizing national key laboratories in the field of materials

After 40 years of construction, China's national key laboratories have formed a huge system; however, problems exist such as the dispersion and homogeneity of scientific research resources. The orientation and research direction of the original national key laboratories should be adjusted, and overall planning, systematic layout, and classified management should be carried out to meet the needs of new materials in key fields such as the new generation of information technology, new energy, national defense and the military industry, high-end equipment manufacturing, and quality of life and public health, to bring new vitality into the new era [13].

3.1.3. Building comprehensive scientific and technological facilities for life-cycle characterization and evaluation

Based on the requirements of a theoretical basis, preparation technology, and full life-cycle assessment technology for materials science, materials manufacturing, and materials application, huge experimental devices and comprehensive research and assessment facilities for the full life cycle of materials must be arranged and constructed. Demonstration and application research on genetic engineering materials technology in frontier materials discovery, new materials performance improvement, and production process optimization should be carried out. By building a new materials data center and activating new energy for data production factors, a big data ecosystem of materials with rich resources, prosperous applications, and orderly governance could be created.

3.2. Consolidating the technical foundation of new materials

The role of new materials in promoting the development of basic science has become increasingly powerful, making new materials an important means of verifying the major theoretical research achievements of different disciplines (e.g., physics, chemistry, and biology) and of making major scientific discoveries. At the same time, they provide an important basis to promote the transformation of basic science in areas such as quantum mechanics, materials science, and life science into cutting-edge technologies. In addition, the original discovery of new materials has continuously spawned new research fields such as quantum biology, twistronics, and mesoscopic neurodynamics, and provided advanced research and detection tools for these new fields, enabling people to deepen their understanding of the essence of matter and life. It is an urgent task for China to make up for its lack of understanding and research in these common fields.

At present, China should learn from the successful experience of developed countries in fundamental research. First, to provide a foundation for new materials research, it is necessary for universities and research institutions to act as the main research body in order to strengthen the continuous and stable investment of government funds and resources, enhance the accumulation of knowledge, improve researchers' ability for original innovation, and strive to achieve major original achievements. This step should cover common fields, multidisciplinary and forward-looking fields (e.g., the theory of matter-to-material evolution, materials genetic engineering, evaluation methods for materials life-cycle serviceability and characterization, and green intelligent technology in process manufacturing), and cutting-edge new materials fields (e.g., topological materials, quantum materials, superconducting materials, and meta-materials). Second, in the five basic industrial fields of key basic raw materials, basic processes and equipment, basic parts and components, basic inspection and testing instruments, and basic industrial software, China should take leading enterprises as the main industrial body and closely combine industry, academia, and institutes, comprehensively improve its basic industrial capacity, and then provide a continuous impetus for the development of the new materials industry.

3.3. Promoting innovation in system mechanisms and R&D mode

3.3.1. Further strengthening the dominant roles of enterprises in scientific and technological innovation

In order to integrate resources, enterprises can take on dominant roles in scientific and technological innovation: First, led by large science and technology enterprises, such as the China Iron and Steel Research Institute Group Co., Ltd., and jointly organized by more than ten leading enterprises in various major fields, a high-end metal materials innovation consortium could be built. The consortium would focus on the application requirements of high-strength and high-toughness structural steel, advanced heat-resistant steel and alloys, high-performance stainless steel and corrosion-resistant alloys, superalloys, refractory alloys, and so forth. It would establish a collaborative innovation organization system integrating materials R&D, production, testing, verification, and application. Second, led by local (i.e., provincial and municipal) laboratories, such as Ji Hua Laboratory, and acting in cooperation with China's leading research units in the field of equipment and with enterprises located upstream and downstream of the industrial chain, an action plan for innovation in equipment manufacturing could be jointly initiated, and a consortium on local innovation in manufacturing equipment could be established, with the aim of solving the "lack of chips and screen" problem of the next-generation of technology and equipment in China. Third, private leading enterprises, such as Huawei, with their R&D experience in 5G and storage, can lead an acceleration of the integration of enterprises with the Chinese scientific and technological innovation system, accelerate the establishment of a roadmap for R&D in next-generation broadband and storage technology materials, and improve the industrial chain and supply chain.

3.3.2. Reforming the scientific research evaluation mechanism

Approval reviews of science and technology projects should strengthen the goal orientation and pay increased attention to professionalism and the implementation of a project rather than a focus on the openness and fairness of the program design. The evaluation of scientific and technological achievements should continue to break the "paper-centric theory" [16], meaning that the focus of the evaluation system should be transferred from paper to a comprehensive evaluation of the innovation, practicality, and social benefits. Moreover, young scientists in the field of new materials should be encouraged to carry out R&D activities for major applications.

3.3.3. Promoting the transformation and application of scientific and technological achievements

A long-term investment and risk-compensation mechanism could be established to adapt to the characteristics of major investment and a long cycle for new materials R&D. Additional verification platforms and application scenarios for new materials in high-end equipment manufacturing fields such as aerospace equipment, rail transit, high-tech ships, and new energy vehicles could be provided, accelerating the upgrading and iteration of new materials.

3.3.4. Reforming the operation mode of R&D project management

Taking foreign experience as a reference, different project leaders or institutions should be selected according to the nature and actual situation of each project. In the research direction of common technology, well-known scientists can take on leading roles, and universities, scientific research institutions, and enterprises can be organized to participate together. In the direction of competitive technological research, competent leading enterprises can take leading roles in organizing joint research with enterprises upstream and downstream in the industrial chain. In terms of capital investment, guided by government investment, social capital should be activated to participate in investment, building a multi-factor and sustainable science and technology financial chain network, and forming a long-term capital chain based on national credit to support the R&D chains of new materials. The decisive role of the market in allocating resources could be stressed, and the application end could be guided to feed diversified social capital back to the R&D end. Combined with leading enterprises in the field of new materials, industrial alliances or jointly established market-oriented investment platforms could be formed, giving concentrated investment to major tasks.

3.4. Strengthening talent training and international exchange and cooperation

It is necessary to cultivate interdisciplinary high-end talents and guide young scientists to work intensively in the field of new materials. Policy support should be increased to attract high-end talents from overseas. The current trend of anti-globalization is surging, making it difficult to change the general development of international division and cooperation; however, China should continue to strengthen international exchanges and cooperation in the field of new materials and contribute to the global development of the new materials industry.

4. Conclusion

With new-generation materials and new-generation technology, the strategic significance of the new materials industry is becoming increasingly prominent. At present, new materials science and technology and industrial development in China are in a critical period of historical transition. Materials development has moved from an expansion stage focused on solving the problem of short supply to a high-quality development stage focused on meeting the country's major strategic needs and promoting international competitiveness. The rapid and sustainable development of new materials science and technology in China must be achieved by increasing R&D investment, building and improving new materials technology innovation platforms, consolidating the technical foundation of new materials, promoting innovation in system mechanisms and R&D, and strengthening talent training and international exchange and cooperation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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