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Development Strategies for Rare Earth Functional Materials by 2035

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Abstract: Rare-earth functional materials are critical and strategic in supporting high-tech fields such as new-generation information technology, aerospace and modern weaponry, advanced rail transit, energy-saving and new-energy vehicles, and high-performance medical devices. In this article, the development status and trends of the rare-earth functional materials industry in China are introduced and the problems of the industry are analyzed. To promote the competitiveness of rare-earth functional materials in China, some policy suggestions are proposed, including strengthening strategic prediction and policy support, promoting basic research and application, and enhancing the building of advantageous teams and the development of personnel in the rare-earth field.
Keywords: rare-earth functional materials; critical and strategic materials; new materials power strategy 2035

1 Introduction

The rare-earth elements (a total of 17 elements including 15 lanthanides, yttrium, and scandium) have excellent magnetic, optical, electrical, and other physical and chemical properties owing to their unique electronic structure. They are indispensable core materials in new-energy automobiles, electronic information technology, aerospace, energy conservation and environmental protection, high-end equipment manufacturing, national defense, and the military industry [1].

Rare-earth-type materials, represented by rare-earth functional materials, have been in the subject of global competition because many developed countries and regions such as the United States, Japan, and Europe are scrambling to incorporate them as strategic reserves and key materials. For instance, in projects such as the Key Materials Strategy formulated by the US Department of Energy, the Element Strategic Plan developed by the Ministry of Education, Culture, Sports, Science, and Technology of Japan, and the EU Critical Raw Material Plan established by the European Union, have already identified rare-earth functional materials as the key research field for long-term supports. More recently, the United States has declared a restart of their rare-earth industry to guarantee rare-earth magnet applications for military purposes. It can be said that the competition for rare-earth permanent magnet materials has become the focus in the field of rare-earth functional materials.

Therefore, rare-earth functional materials are highlighted as strategic resources of national key resource management and development in China, and they are listed in the mid- and long-term development plans of China, including the Made in China 2025 10-year plan. In addition, the *State Council's Opinions on Promoting the Sustainable and Healthy Development of the Rare-Earth Industry* and other relevant regulations are facilitating scientific and technological innovations involving rare-earth functional materials. Furthermore, they are promoting the continuous improvement of the quality of the Chinese rare-earth functional materials industry and optimizing

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the rare-earth productive structure.

2 Development status of rare-earth functional materials

As the largest resource reserves in the world, China's rare-earth resources become one of the country's most important strategic resources and advantageous fields. According to a survey, the total global rare-earth resource reserves are roughly 1.2×10^8t and China is the largest producer in the world, accounting for 4.4×10^7t or about 37.8% [2,3]. In 2019, the global output of rare-earth mines was about 2.1×10^5t, of which China's output reached 1.32×10^5t, accounting for 63%. More importantly, China is a rare-earth industrialized country with a complete and independent industrial system that covers the entire industrial chain, from upstream beneficiation, midstream smelting and separation, oxide and rare-earth metal production, to downstream rare-earth materials and device applications. According to 2018 data, the production value of China's rare-earth industrial chain was about 90 billion CNY. Of this amount, rare-earth functional materials accounted for 56% (about 50 billion CNY), whereas smelting and separation was 27% (about 25 billion CNY). Rare-earth permanent magnets represented the highest proportion of rare-earth functional materials, accounting for 75% (37.5 billion CNY). In addition, the production of catalytic materials accounted for 20% (about 10 billion CNY). From the perspective of the consumption structure of China's rare-earth functional materials, rare-earth permanent magnet materials, which have benefited from the rapid development of new-energy vehicles and the electronics industry, represent up to 40% of rare-earth consumption. Meanwhile, metallurgy and machinery, petrochemicals, and glass ceramics account for 12%, 9%, and 8%, respectively; hydrogen storage materials and luminescent materials each account for 7%; and catalytic materials, polishing materials, and agricultural light textiles each account for 5% [4].

2.1 Rare-earth smelting and separation

Since China's rare-earth production surpassed the United States in 1988 to become the largest rare-earth producer, it has led the world and controlled the global market for high-purity rare-earth raw materials, and that situation continues today. At present, the leading companies in China's rare-earth smelting and separation industry are six major rare-earth groups: Northern Rare Earth High-Tech Co., Ltd. (Group), China Southern Rare Earth Group Co., Ltd., Guangdong Rare Earth Industry Group Co., Ltd., China Rare Earth Co., Ltd., Minmetals Rare Earth Group Co., Ltd., and Xiamen Tungsten Industry Co., Ltd. The rare-earth smelting and separation companies and projects abroad include the Mountain Pass Project of the American Molybdenum Corporation (acquired by Shenghe Resources Holdings Co., Ltd.), Australia's Lynas smelting separation project in Kuantan, Malaysia, and Belgium's Solvay Group (Solvay) project.

2.2 Rare-earth permanent magnet materials

Rare-earth permanent magnets are not only the area with the fastest growth, the highest rare-earth consumption, and the most complete industrial scale in the rare-earth field, but they are also one class of irreplaceable and indispensable key materials for the national defense industry. Moreover, the industrial scale of China's rare-earth permanent magnet production has continued to expand since 2000. For example, the production of sintered Nd-Fe-B magnet blanks increased from 8×10^4 t at the beginning of the "12th Five-Year Plan" period in China to 1.8×10^5 tons in 2019. This growth has soared more than two fold and accounts for more than 85% of global rare-earth production. In the case of other permanent magnet materials, Sm-Co permanent magnet production is about 2400 t, accounting for more than 80% of global output.

Sintered Nd-Fe-B magnets, which are applied extensively in wind power generation, hybrid and electric vehicles, energy-saving home appliances, industrial robots, high-speed and maglev trains, and other high-tech industries, provide a driving force and considerable growth rate for the development of the rare-earth permanent magnet industry. It is known that the manufacturing techniques of Chinese enterprises are close to the world's most advanced level in the fields of high-performance rare-earth permanent magnets, balanced utilization of high-abundance rare-earth permanent magnets, heavy rare-earth reduction technology, and magnet recycling technology.

It is noteworthy that China is the world's largest producer of rare-earth permanent magnet materials. It also leads the world in some fields represented by high-abundance rare-earth permanent magnet materials. However, the quality of China's high-end permanent magnets in emerging industries such as high-end robots, fifth-generation mobile communication technology (5G), and photolithography machines cannot currently satisfy the rising technical demands. Furthermore, the core intellectual property rights and technologies including sintered

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rare-earth permanent magnets, hot pressing/hot deformation, grain refinement, continuous intelligent equipment, and other state-of-the-art preparation technologies still lag far behind developed countries such as the United States and Japan.

2.3 Rare-earth luminescent materials

With the accelerated penetration of semiconductors in the fields of illumination, display, and information detection, the demand for high-quality light sources is also increasing. In the lighting field, the realization of full-spectrum lighting is currently considered to dominate the new generation of white light-emitting diode (LED) lighting. As for other luminescent materials, near-infrared detectors are becoming an important component of Internet of Things (IoT) devices and are globally involved in the fields of security monitoring, biometrics, food, and medical detection [5].

Taking the lighting and display materials for white LEDs as an example, the production, sales, and assets of Japanese companies, such as Mitsubishi Chemical Co., Ltd., Denki Chemical Co., Ltd., and Nichia Chemical Industry Co., Ltd., have an absolute advantage in the global market. Although the localization rate of white LED phosphors in China has also increased from less than 5% in 2000 to about 85% at present, there is still a considerable technological gap between Chinese enterprises and foreign transnational corporations in terms of the driving force for innovation and self-improvement capabilities. At present, the leading Chinese enterprises in this area include Grinm Advanced Materials Co., Ltd., Jiangsu Bree Optronics Co., Ltd., and Jiangmen Keheng Industrial Co., Ltd.

2.4 Rare-earth crystal material field

Rare-earth crystalline materials are mainly composed of rare-earth laser crystals and rare-earth scintillation crystals, which are widely used in the fields of national defense and military equipment, cutting-edge scientific equipment, medical devices, detection, and security inspection. Advanced medical diagnostic techniques such as positron emission computed tomography (PET-CT) have developed rapidly and generated huge market potential for high-performance rare-earth scintillation crystals, such as yttrium lutetium silicate (LYSO). According to estimates, based on an average of one unit per million people, the Chinese market is desperate to add about 1000 PET-CT scanners, and the cost for the rare-earth scintillation crystals is expected to exceed 3 billion CNY.

2.5 The rare-earth catalytic materials

It is known that rare-earth catalytic materials are widely used in the field of energy and the environment. The extensive applications of high-abundance light rare-earth elements such as lanthanum and cerium can alleviate and eventually solve the imbalance of rare-earth consumption in China, upgrade energy and environmental technology, and improve the human living environment. Petroleum cracking and vehicle exhaust purification are two of the largest applications of rare-earth catalytic materials, which include tail gas purification of mobile sources (e.g., motor vehicles, ships, and agricultural machinery) and stationary sources (e.g., industrial exhaust gas, natural gas combustion, and organic waste gas).

Compared with foreign catalysts, the performance of domestic cracking catalysts has reached an equivalent level. However, the system integration, key technologies and equipment, and other key materials in catalysts for automobile exhaust purification and high-temperature industrial exhaust gas denitrification for thermal power plants, cerium-zirconium rare-earth oxygen storage materials, modified alumina coatings, and the mass production of large-scale, ultra-thin-walled carriers (>600 mesh) lag far behind the advanced level of foreign countries.

2.6 High-purity rare-earth metals and target materials

High-purity rare-earth metals are widely used as the core raw materials in magnetic materials, functional optical materials, catalytic materials, hydrogen storage materials, functional ceramic materials, and sputtering targets in electronic information and other high-tech fields. Since the end of the 20th century, Japanese, European, and American enterprises, such as Nippon mining Metal Co., Ltd., Dongcao Co., Ltd., Honeywell International Co., Ltd., have transferred from the preparation of high-purity metals to providing key materials for industrial development and application, including high-level process integrated circuits below 7 nm, 5G communication devices, high-power devices and intelligent sensors, solid-state memory, and other advanced electronic information products. Many famous enterprises of high-purity rare-earth metal and target manufacturing are ranked in the world's top 500 enterprises, such as Japan Dongcao Co., Ltd., and Honeywell International Co., Ltd. Compared with foreign transnational enterprises, China's high-purity rare-earth metal and target manufacturing enterprises mainly include the Youyan Rare-Earth New Materials Co., Ltd. and the Hunan Rare-Earth Metal Material Research Institute. Admittedly, there are large gaps in technological innovation, advanced equipment, and basic frontier research. Despite that fact that China has gained the preparation technology for ultra-high-purity rare-earth metals, it is a long way from realizing industrialization and ensuring the development of the electronic information industry, in areas such as integrated circuits.

3 Difficulties and challenges in the development of rare earth functional materials

According to the research on the above-mentioned rare-earth functional materials, it can be found that rare-earth resources, as non-renewable global scarce strategic resources, have always attracted the global attention. Rare-earth and rare-earth permanent magnet materials as "keywords" have always been involved in the US–China trade tensions and are frequently mentioned by the domestic and foreign media. The reason is that China's leading position in the global rare-earth and rare-earth permanent magnets industrial chain is distorted as being a threat to the national security of the United States.

Although China's rare-earth resources and rare-earth mining, beneficiation, metallurgy, and other technologies are at the leading position in the world, both opportunities and challenges exist in the development of rare-earth functional materials. The external challenges of rare-earth functional materials come mainly from the United States, which is trying to disrupt China's rare-earth permanent magnet supply chains, through the project of "Nationwide System and Global Camp". In addition, some US politicians are constantly lobbying other countries to stop purchasing China's rare-earth permanent magnets, for the purpose of blocking and impeding the rapid development of China's rare-earth industry. On the other hand, in the midstream and downstream applications of rare-earth functional materials, most of China's previous R&D is lagging advanced foreign technologies. Although the number of Chinese patent applications in the field of rare-earth materials has increased rapidly in recent years, most of them belong to improved or marginal patents. There are few achievements with core independent intellectual property rights, and there is a particular lack of the original essential patents. Furthermore, many key technologies are restricted by foreign patent technology barriers, which seriously affect the high-quality development and internationalization of the Chinese rare-earth industry.

The internal challenges related to rare-earth functional materials come mainly from the less powerful foundations of the rare-earth industry. Enterprises and institutions are more inclined to fund some quick-win projects or introduce those matured technologies, and are on the fence to support so-called high-risk original technologies with high difficulty, high cost, and a long research period; it is necessary to strengthen multidisciplinary and cross-cutting collaboration in rare-earth functional materials. Overall, China's original innovations are insufficient, and it is not powerful enough to hold the core technology in the field of rare-earth functional materials.

Therefore, focusing on the development of rare-earth functional materials in 2035 and global perspectives, we should pay more attention to constructing innovative capabilities in rare-earth functional materials, including the control of core technology, studies and absorption of advanced international technology, as well as the persistence and steady improvement of the rare-earth functional materials industry.

4 Future development ideas, directions, and goals for rare-earth functional materials

4.1 Development ideas

According to the 14th Five-Year Plan (2021–2025) of China for national economic and social development, and the long-range objectives through the year 2035, which aim at future intelligent robots, smart cities, marine and interstellar development, a big-data society, and human–machine interfaces, we suggest that rare-earth functional materials should break through the key technologies for engineering and industrialization. We also suggest a breakthrough in the core technologies of advanced rare-earth functional materials, including the preparation technology, intelligent production equipment, special testing instruments, and application technologies in the field of rare-earth permanent magnet materials, rare-earth luminescent materials, rare-earth catalytic materials, rare-earth crystal materials, and high-purity rare-earth metals and targets. Through simultaneous innovations in the entire industry chain, advanced technologies and achievements can be implemented, ensuring an effective supply of key materials for strategic emerging industries, national defense and military industries, and intelligent

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manufacturing. The independent supply of rare-earth functional materials for high-end applications can be realized. Furthermore, it is vital to carry out fundamental research by increasing the investment and data accumulation related to cutting-edge scientific issues, so that we can look forward to proposing more original theories and gaining a large number of original discoveries for novel rare-earth materials and new applications. Finally, we hope that these policies and measures will be beneficial to China's strategic transformation from a big rare-earth country to a strong rare-earth country, which can lead the future development of rare-earth technology and industry, and provide material safeguards for the realization of China's strategic goal of "being among the top innovative countries by 2035."

4.2 Prior development directions

4.2.1 Preferential strategies for preparation of ultra-high-performance rare-earth permanent magnet materials and their efficient balanced utilization

According to the technological demand and current technological level of high-performance rare-earth permanent magnet materials, there are many crucial issues that should be mentioned.

(1) With respect to Nd-Fe-B permanent magnet materials, the following domains should be focused on, for example: the preparation technology for sintered Nd-Fe-B with high comprehensive performance; the mechanism of grain boundary diffusion for heavy rare-earths in sintered Nd-Fe-B magnets; the recovery technology and application of sintered Nd-Fe-B; and the service performance prediction technology and theoretical explorations of sintered Nd-Fe-B magnets.

(2) With respect to Sm-Co permanent magnet materials, the following directions should be paid more attention: the element diffusive mechanism of high-remanence samarium-cobalt magnets; nanostructure and microdomain composition regulation in high-performance Sm-Co permanent magnets; oxidation-resisting technology; surface protection technology for high-temperature Sm-Co permanent magnets, etc.

(3) With respect to hot-pressed permanent magnet materials, the formation mechanism of thin-wall, hot-pressed magnetic ring anisotropy; high-performance magnetic powder preparation technology for hot-pressed magnetic rings; preparation technology and application of high-performance hot-pressed permanent magnetic rings; and preparation equipment and technology for high-performance hot-pressed magnetic rings, etc.

(4) With respect to high-abundance permanent magnet materials, the core issues are the balanced utilization of high-abundance (e.g., La, Ce) rare-earths in permanent magnets and the structure and coercivity enhancement technology for dual-phase cerium magnets.

(5) Combining artificial intelligence (AI) and materials genetic engineering methods, it is necessary to develop methods of structural design and performance prediction that are suitable for magnetic functional materials. It is beneficial to explore new-type permanent magnet materials, aiming at the new generation of rare-earth permanent magnet materials that satisfy the key performance indicators of high-energy product and high coercivity.

(6) According to the characteristics of rare-earth magnetic functional materials, it is important to build new principles and new equipment, and gradually lessen the dependence on foreign countries for analysis and testing equipment.

4.2.2 Novel rare-earth permanent magnet materials and key technologies for customized applications

With human society aiming toward a low-carbon economy and environmental protection, certain fields and applications are gaining more importance: intelligent rail transit and intelligent industrial manufacturing; energy-saving and energy-efficient permanent magnet materials and magnetic power systems represented by permanent magnet bearing technology, permanent magnet eddy-current transmission and braking technologies; highly corrosion-resistant rare-earth permanent magnets serving in wind power systems and direct drive generators; and permanent magnet materials with high-energy product and high coercivity, which apply to the fields of robotics and smart cities with the advantages of miniaturization and high processing precision.

4.2.3 Advanced rare-earth luminescent materials and their key preparation technologies and equipment

With the increasing demand for high-quality light sources in the semiconductor lighting market, it is necessary to focus on the development of high-end rare-earth luminescent materials and their key preparation technologies and equipment. This will ensure that application requirements in the fields of lighting, display, and information detection can be met. The following subjects should be of great concern: new rare-earth luminescent materials and their preparation technologies with high-efficiency emission, non-visible, and up-conversion luminescence, as well as the theoretical mechanism to enhance their infrared emission efficiency under purple and blue light excited conditions; the green and red emitting materials and their preparation technologies with high-efficiency, narrow-band emission and high color purity under blue light excitation; the novel materials must be developed with independent intellectual property rights and designed based on the principle of structural similarity, compatibility, and isomorphic substitution, and new rare-earth optical materials must be obtained by high-throughput material design.

4.2.4 Key preparation technology for rare-earth catalytic materials

Rare-earth catalytic materials are some of the high-tech materials that promote the applications of high-abundance light rare-earth elements, such as lanthanum and cerium. These materials can effectively solve the rare-earth consumption imbalance problem in China. They can also improve energy and environmental technology, the human living environment, and people's livelihoods. The suggested key development directions include the key industrialization technologies of rare-earth catalysts for efficient, energy-saving, and long-life petrochemical applications; technologies of rare-earth catalysts for clean energy synthesis, vehicle exhaust pollution control, and industrial waste gas pollution control; and cerium-zirconium materials and their key preparation technologies with nano-caged molecular assembly structures and high specific surface areas. These directions also satisfy the applications of ultra-high-performance rare-earth catalytic materials, which may require the large-scale application of high-efficiency rare-earth catalytic purification for the components of fixed- and mobile-source exhaust systems.

4.2.5 Advanced rare-earth crystal materials and their industrial preparation technologies

Rare-earth crystal materials are widely used in the national defense and military fields, advanced scientific devices, medical treatment, detection, and safety inspection. The development of rare-earth crystal materials and their industrial preparation technology will be one of the important development trends of the future.

The key development directions for rare-earth laser crystals include the technology and equipment for large-scale, high-quality rare-earth laser crystal growth and process; high-quality rare-earth laser crystals and high-efficiency preparation technology for laser fibers; and new laser application technologies based on rare-earth laser crystals.

More attention should be paid to the development of high-performance rare-earth scintillation crystals and their high-efficiency preparation technologies, high-energy resolution rare-earth scintillation crystals and their large-scale single-crystal growth technologies, as well as their high-throughput preparation and characterization technologies.

4.2.6 Preparation technology for high-purity rare-earth metals and targets

The new generation of electronic information and energy materials is one of the important applications for high-purity rare-earth metals and target products. In the future, the significant R&D directions of high-purity rare-earth metal materials will include further improvement of the purity of rare-earth metals to reach a level above 4N5 (99.995%), the development of low-cost, large-scale preparation technology for ultra-high-purity rare-earth metals, and the supply of key raw materials for high-purity rare-earth targets. It will also include the development of fine purification control technology and large-scale high-vacuum purification equipment, such as large-scale zone furnaces, single-crystal purification furnaces and other high-end equipment, and the development of analysis and detection technology for trace impurity elements in ultra-high-purity rare-earth metals and target materials.

4.3 The goals of development of rare-earth materials

4.3.1 Goals for 2025: To complete the transition of the rare-earth industry from following to equaling

By 2025, China is expected to be a powerful country in the field of rare-earth functional materials. Part of the core technologies of rare-earth magnetic materials and manufacturing equipment should be held through independent intellectual property rights by meeting the major demands of new-generation information technology, modern transportation, new-generation lighting and display, energy conservation and environmental protection, integrated circuits, biological medicine, national defense and the military industry, etc. In the applications of high-end magnetic materials such as new-energy automobiles, aerospace, industrial servomotors, the replacement rate of rare-earth permanent magnetic devices will reach 70%. The localization rate will have been increased to more than 80% by mastering the stable preparation technology for rare-earth luminescent materials; the key preparation technology for new rare-earth functional materials such as high-performance rare-earth crystal materials, high-purity rare-earth metals and target materials, which will be needed to break through and partially

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replace imports to meet the requirements for high-end medical equipment, intelligent detection, integrated circuits, etc.; and new rare-earth functional materials and their preparation technologies, which should be developed and expanded for new applications. By 2025, a series of key core technologies for novel rare-earth materials should be developed; multinational companies and industrial clusters with strong international competitiveness can be formed, and their position in the global industrial value chain are expected to improve and achieve the transition of rare-earth industry from following to equaling.

4.3.2 Goals for 2030: To preliminarily construct a powerful rare-earth country

By 2030, in the field of rare-earth functional materials, the innovative capability will have been greatly improved to lead the global research and industrial development of rare-earth permanent magnets and preliminarily achieve the goal of being a powerful rare-earth country. Ultra-high-performance permanent magnets will have been fully applied in equipment and projects such as robotics, medical equipment, aerospace, IoT, ships, and petrochemicals. The key core technologies of rare-earth magnetic materials and their manufacturing equipment can be owned through independent intellectual property rights. The replacement rate of rare-earth permanent magnets will have reached 80% in high-end magnetic applications such as new-energy vehicles, aerospace, and industrial servomotors.

4.3.3 Goal for 2035: To build a powerful country of world’s rare-earth

By 2035, major breakthroughs are expected to be made in the field of rare-earth functional materials, and innovative capabilities can be greatly improved. China’s innovation in new rare-earth materials can join the ranks of high-level countries. Overall competitiveness can be significantly strengthened, and in some advantageous domains, China can form the leading capabilities of global innovation. Finally, China can be a powerhouse in rare-earth functional materials.

By 2035, China’s rare-earth permanent magnet materials, catalytic materials, luminescent materials can reach the advanced international level and achieve self-sufficiency. The self-sufficiency rate in optical functional crystals and ultra-pure rare-earths for defense applications can be greater than 95%. The key core technologies and intellectual property rights of rare-earth magnetic materials and their manufacturing equipment can achieve independent control. The replacement rate of rare-earth permanent magnets can reach 85% in the field of high-end magnetic devices for new-energy vehicles, national defense and the military industry, aerospace, intelligent manufacturing, medicine and health, and marine engineering, etc. The standards for rare-earth functional materials established by China can account for more than 30% of international standards, and China can have a say in the global standards set for high-end materials; and innovative talent and rare-earth functional materials groups will be cultivated, and a new development model will be used to drive new applications for rare-earth functional materials. Finally, a world-leading and technologically innovative industrial system can be established to provide a platform for the incubation of original technology.

5 Policy suggestions

To confront the 2035 development strategy for rare-earth functional materials and to construct a new development pattern of scientific and technological innovation for those materials, it is necessary to accelerate the optimization of scientific, technological, and human resources in rare-earth-advantageous regions, and to consolidate the advantages of rare-earth functional materials. Efforts should be made to improve original innovation capabilities, large-scale engineering, and achievement transformation. The green manufacturing of rare-earth functional materials must also be promoted. High-performance rare-earth magnetic, optical, electrical, and other new functional materials and application technologies with independent intellectual property rights need to be vigorously developed to meet high-end applications. The establishment of innovative platforms for the “production, education, scientific research, and practical application” of advanced rare-earth materials is indispensable. A low-carbon economic industrial chain for rare-earth materials and a complete industrial base for high-performance rare-earth materials with independent intellectual property rights are vital to transforming China’s rare-earth industry from a major rare-earth producer to a rare-earth power. To summarize, the following specific policy measures are suggested.

5.1 Strengthening the strategic research and policy safeguards of rare-earth functional materials at the national level

First, a system composed of all kinds of value elements, including intellectual property, technology, talent, and platforms in the field of rare-earth functional materials needs to be coordinated and expedited at the national level.

It is also important to form long-term stable financing and avoid intermittent year-by-year support, especially the continuity of national medium- and long-term R&D projects in the field of rare-earth functional materials.

In addition, awareness of intellectual property protection in the field of rare-earth functional materials needs to be strengthened and the corresponding legal system and implementation mechanisms need to be improved. Incentive measures for the creative activities of inventors need to be completely implemented to stimulate the endogenous power of technologists and promote the emergence of innovative technologies.

5.2 Strengthening basic research and basic research for application in the field of rare-earths to promote the emergence of first innovative achievements

First, it is worthwhile to launch major special projects or key projects related to novel rare-earth materials and to make a prospective layout to intensify the research and development of the new generation of rare-earth functional materials. It is also worthwhile to strengthen the research and development of new technologies and equipment for the preparation of rare-earth functional materials, so that those materials applied in new national infrastructure and on major projects can continue without interruption to meet the application demands of the national 2035 development strategy.

Then, we strongly recommend that a national rare-earth new material technology innovation center be established in Beijing as soon as possible by taking the advantages of the mineral resources in Ganzhou and Baotou, and the technological advantages of material development and high-tech industrial clusters in Ningbo, Shandong, Beijing–Tianjin–Hebei, and other regions. The reason is that Beijing has the greatest Chinese scientific and technological resources and talent advantages, which are conducive to forming the integrated rare-earth industrial chain cluster and big-data center for smelting, separation, and material processing to downstream applications and technological innovation. In addition, we suggest that overseas scientific and technological institutes be assembled to attain more extensive global cooperation, rather than standing still or refusing to make progress.

Finally, it is important to strengthen the personalized and customized research and development of rare-earth functional materials to ensure the “availability of materials” for various major projects. We hope to continue to support the development of special permanent magnet materials for defense equipment and consolidate the iterative applications of rare-earth permanent magnets in industrial motors and other devices.

5.3 To enhance the talents construction and the sustainable innovative capabilities of rare-earth functional materials

First, it is suggested that a series of national scientific and technological innovation platforms for rare-earth functional materials be established as soon as possible, and that stable long-term support be provided to the excellent R&D groups at various levels and in various domains.

Also, we recommend exploiting the knowledge of older-generation, middle-aged, and young experts to avoid talent gaps and the waste of talent resources.

In addition, it is crucial to cultivate young talent and full-time technicians in the field of rare-earth functional materials. To encourage outstanding technical experts, policy restrictions could be appropriately relaxed. If they make a noticeable contribution, they will have the chance to realize their personal potential, which may promote the spontaneous emergence of leading talent in scientific research and innovation activities.

5.4 To reinforce international cooperation and enhance China’s global competitiveness in the field of rare-earth functional materials

First, in the current international environment, various opportunities should be seized as much as possible to enhance international cooperation and scientific and technological information communication; the managers of departments should provide convenient conditions for international exchanges. They must also ease the time restrictions on scientific researchers participating in academic conferences and technical exchanges to prevent them from falling into a self-blocked situation.

Additionally, in accordance with the current domestic and international situations, when we focus on reinforcing domestic circulation in the field of rare-earth functional materials, we are also expanding new international markets and international (external) circulation at the same time. On one hand, it is necessary to strengthen the level of openness to the outside world, create more conditions to introduce high-end application enterprises to

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rare-earth materials, and actively build a global rare-earth industry and technology community with a common destiny. On the other hand, it is suggested that the importing of rare-earth raw materials be moderately loosened to reduce the pressures of domestic environmental protection and rare-earth resource consumption. At the same time, we encourage Chinese rare-earth enterprises to go out, invest, and acquire firms in high-tech applications, such as robot servomotors, electric vehicle drive motors, and similar products. This will improve the commercial and technological development environment domestically and abroad, as well as enhance the competitiveness of China’s rare-earth functional materials in the global industrial chain and supply chain.

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