Executive Summary

Advanced materials and device technologies support our lives in various fields. They play a central role in information and communication device technology in functions of smartphones, automobiles, robots, and communication. They contribute to carbon neutrality through various devices and materials such as solar cells, rechargeable batteries, power semiconductors, magnets/magnetic materials, water and CO_2 electrolysis cells, and separation membranes. In the fields of healthcare and medicine, they are used in artificial microsystems such as mRNA vaccines for the COVID-19 virus, highly sensitive sensor devices for early diagnosis and biological information monitoring, and devices and materials for the prevention, diagnosis, and treatment of cancer and brain diseases.Nanotechnology, which enables observation, control, and processing of the structure of matter on a very small scale, is indispensable for realizing these materials and devices.

Recent world affairs that have a particularly strong connection with this field are the instability in the global supply chain caused by the struggle for technological hegemony between the United States and China, the COVID-19 pandemic, and Russia's invasion to Ukraine. These changes in the world situation are destroying the premise of the global supply chain that “production in the most suitable place is optimal for increasing overall efficiency”. As the most important issue for economic security, each country is promoting policies such as listing rare resources and industrial products with limited supply sources and returning to domestic production of important technologies. The movement toward a global open economy, which has continued since the end of the Cold War, stagnates, and the rise of nationalism and protectionism together with economic decoupling are about to occur. Such social trends are affecting not only the economic field but also advanced scientific research in academia.

Another major international demand to this field is contribution to SDGs. In particular, in order to achieve carbon neutrality by 2050, renewable energy utilization technology and power saving technology to reduce CO_2 emissions, CO_2 capture and utilization technology, recycling and reuse technology need to be newly developed. In addition to the development of these new technologies, it is also necessary to reexamine production technologies that were previously thought to be already established and optimized. In order to make a breakthrough in a field where research and development has been carried out for a long time, it may be necessary to renovate from the principle level of materials and production processes, and, therefore, close international cooperation is highly required for such basic research and development.

In this difficult situation in which competition and cooperation coexist, Japan is also implementing policies that address both sides. Various research and development are vigorously progressing under national strategies such as “Green Growth Strategy Through Achieving Carbon Neutrality in 2050”, “Materials Innovation Strategy”, and “Quantum Technology and Innovation Strategy”. These are being implemented in order to respond to various aspects, such as the challenges faced by Japan, contributions to the common goals of the international community, and establishment of economic security. Also, what has been attracting particular attention recently is an effort to restart Japan's advanced semiconductor process development.

Based on the “Strategy for Semiconductors and the Digital Industry”, active investment for research and development of semiconductors is being made in all directions of front-end and back-end processes of semiconductor manufacturing, manufacturing equipment, and material development. In addition, measures such as support for development expenses for companies with factories in Japan are also being implemented, aiming to revitalize the domestic semiconductor industry.

Remarkable R&D trends in the world can be seen in energy and environment fields such as electric energy storage devices and water electrolysis, in healthcare and medical fields such as mRNA nano-medicine, in electronics fields such as advanced semiconductors and brain chips, and in emerging technology fields such as quantum computing and topological materials. Methodological innovation in materials science through data-driven materials design is also remarkable. Other countries are conspicuously focusing on these fields and developing technologies with the aim of establishing their own presence and competitiveness in science and technology and innovation in the future.

The status and challenges of research and development in Japan are as follows. Japan maintains traditional competitiveness in materials design and manufacturing of energy materials, electronic materials and composite materials, precision machinery, measurement/ analysis / evaluation / processing technologies. However, the advantages of basic research in fundamental science and technology have not been fully utilized in internationally competitive businesses. There should be issues in the transfer of technologies through industry-academia collaboration and/or the construction of medium- to long-term innovation ecosystems. In addition, various initiatives are required, such as enhancing human resource development programs to deal with the shortage of advanced specialists.

It is necessary to further focus on quantum technology, data-driven material development, hydrogen/carbon neutral technology, and medical-engineering collaboration for innovation in biotechnology, all of which are being invested in also by other countries.

In this report, we surveyed and analyzed the social, economic and R&D trends both in Japan and overseas, as well as the issues facing Japan. In conducting the survey, we analyzed this field in 7 categories and 29 research and development areas described in Chapter 2 of this report, and then derived future directions. Consequently, we identified 12 new research and development items that will be important for Japan in the future, as shown below.

12 research and development items

1. Advanced semiconductor materials and device technology, 2. Manipulation, control, and utilization of unique properties of quantum technology, 3. Advanced electricity-material energy conversion technology, 4. Multi-scale thermal control technology, 5. Material technology that achieves both resource recycling and carbon recycling, 6. Expanded understanding and control of biocompatibility, 7. Hybrid materials utilizing biological functions, 8. Nanoscale high-performance materials, 9. Highly reliable materials in extreme environments, 10. Material DX fundamental technology, 11. Operando-multimodal measurement, 12. Strategic governance of new materials

The following three perspectives were taken into consideration to provide direction and content for research and development that will be particularly important for Japan in the future: "New demands for science and technology brought about by changes in society," "Necessity of strategic investment accompanying the emergence of new trends in science and technology," "Japan's industrial competitiveness and national security." Details of the contents are described in 1.3.3.