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Nanotechnology for Sustainable Society

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1. Introduction

The new horizon of technology based on science in nano space is rapidly developing and finding innovative applications in modern society. The primary role of nanotechnology is to provide disruptive technologies for society and retain the industrial sustainability of a given region. It covers a wide range of technologies such as materials, devices, fabrication processes, characterization, and simulation. The theme of this presentation is to discuss the future direction of nanotechnology R&D in global society.

2. Social Innovation for Sustainable Society

In Japan, the development of homegrown technology was recognized as vital in late 1960s after the period of technology transfer from the USA and European countries. This was a golden era of electronics in which semiconductors, optical devices, magnetic devices, imaging systems, and consumer products bloomed. Japanese industry as well as academia made significant contributions through the invention and commercialization of new devices and products.

The rapid technological progress soon focused on higher performance and better functionality. However, the approach of this technology-push has recently come under re-examination since the critical situation of world sustainability has been recognized. Modern industrialization and resultant advanced lifestyles depend heavily on massive consumption of natural resources. In addition, side effects like the increase of CO_2 in the air are a serious concern in conjunction with climate changes.

Society requires us to solve these issues through technology-based innovation. Social innovation for sustainable society (green innovation) is an example of a solution. Green innovation covers renewable energy, high efficiency power generation, efficient and smart use of power, resource recycling, and eco-system conservation.

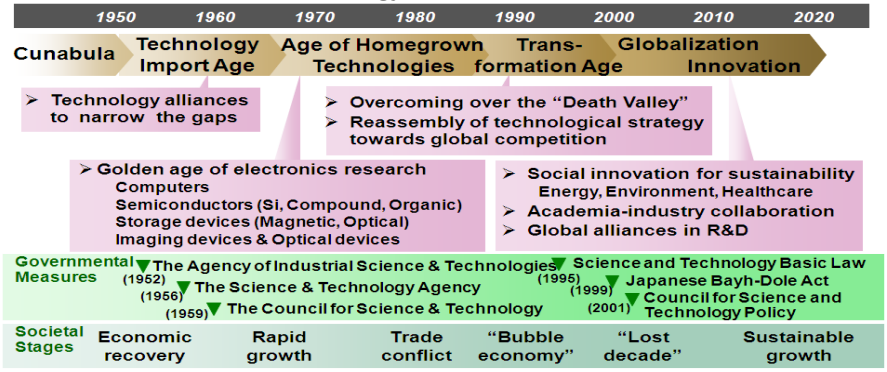
Our goal is a sustainable society where the welfare and well-being of society is achieved along with the sustainability of the globe. The role of nanotechnology is to provide disruptive technologies for such innovations.

From the industrial point of view, the new approach is also a way to retain the competitiveness of the manufacturing industry. Since 1990s, digital technology and the modular manufacturing model have accelerated changes in global economy as developing countries have taken advantage of them for their industrialization. Their economies have grown through assembling manufacturing based on the modular manufacturing model.

Problem-solving innovation is achieved by a spiral creation of social values. It is composed of contiguous activities related to problem definition, technology development, prototyping, market creation, and outcome evaluation. The profit is then funneled into the next R&D and human resource development. New experience and knowledge obtained in the cycle are used in the future, and it also inspires new research. Nanotechnology R&D should needs to be embedded in the spiral value creation.

3. Nanotechnology R&D

It is worth noting that during the golden era of electronics in the previous century, pioneering research on nano science was conducted in Japan. In the early 1960s, R. Kubo presented a famous paper on the Kubo effect of fine particles, followed by a number of outstanding works on photo-catalyst, quantum effect devices, ultrafine particles, and perpendicular recording. These achievements allowed us to usher in the nanotechnology era in the 21st century. Japanese academia played pioneering roles in nano science. The following are the major areas of nanotechnology-related R&D at present:



- *nanotechnology for green innovation*
- *nanotechnology for life innovation*
- *nanotechnology for ICT*
- *manufacturing and characterization tools*
- *nano simulation*

The first two areas are R&D for problem-solving innovations as described above. The ICT has dual features: it is an enabling technology for both green innovation and life innovation. It also requires power consumption be reduced by nanotechnology. The remaining items are the fundamental (common) technologies.

For green innovation, high efficiency and low cost solar cell technology has been studied both for Si and non-Si (including organic materials) for future solar energy systems. Li-ion battery technology is focused on higher reliability, lower cost, and higher power density. Long term R&D is focused on creating heat-resistive materials for super-critical power generation.

For life innovation, the role of nanotechnology is also diverse. A drug delivery system (DDS) that uses liposome as a carrier has opened a new era of medical treatment. MEMS technology is finding new applications in biochips for diagnosis and the support of drug discovery.

The importance of ICT systems with low power operation has long been recognized, and nanoelectronics technologies have been pursued for that purpose. Among recent efforts in the area of nanoelectronics is the development of advanced CMOS technology. A metal gate transistor with high dielectric constant oxide films has been successfully developed for a few tens nm era. Carbon nanotube via-interconnection with high conductivity has also been demonstrated.

The new emphasis on nanoelectronics is evidenced in *Beyond CMOS* approaches: approaches that aiming for extreme low voltage operation using a new material represented by graphene. Si photonics and Spintronics are expected to pave the way for new Si electronics by introducing the concept of light and spin.

Manufacturing and measurement equipment have contributed significantly to the development of nanoelectronics so far. For EUV lithography, atomic level flatness is required for a mask, encouraging the progress on film deposition and surface measurement methods to a great extent. Simulation has also made great progress owing to the improvement of nano scale simulation models and computing power.

4. Collaborative R&D

Japan has had a series of successful joint laboratories in the past. This year, a new grand initiative called Tsukuba Innovation Arena-nano (TIA-nano) has been launched by the joint efforts of the Japanese government, AIST, NIMS, Tsukuba University, and Nippon Keidanren (the Japan Business Federation). This initiative features R&D projects well aligned with national priorities on innovations, including green nanoelectronics, SiC power transistors, low voltage CMOS, Si photonics, MEMS, and spin devices. Also, collaborative work among materials, tools, and devices will be encouraged. Dedicated R&D infrastructures are prepared in the arena. TIA extends collaboration to major universities in Japan, and it also has a strong tie with the National Nanotechnology Network Programs. The TIA-nano also plans to become a globally open R&D hub in Asia.

5. Toward Social Innovation: Hitachi' Case

Hitachi has recently changed its business structure as part of its strategy to establish a new business portfolio and thus ensure the company's future. It is transforming from a diversified electric company into a company with a greater focus on social innovation business. Social innovation business includes social infrastructure businesses empowered by ICT and core technology businesses.

The rationale for Hitachi's new initiatives is based on the company's foundation principle: to contribute to society through superior technology.

Hitachi was founded 100 years ago as a machine repair venture for a mining company. Soon, it widened its interests to include social infrastructures like power generation, trains, and urban systems. It then expanded to consumer products, semiconductors, and ICT. The strength of Hitachi–its accumulated knowledge and skills, in particular of ICT and social infrastructures–is key to social innovation business.

Hitachi's "Environmental Vision 2025," which was established in December 2007 to provide a common goal for all Hitachi Group companies: to achieve in their efforts to protect the global environment. Hitachi aims at making all products environmentally–friendly by applying advanced technologies to their development.

The smart grid is an environment-conscious energy solution. It is an essential infrastructure in ensuring the proliferation of renewable energy. Efficiently managing the smart grid will allow the stable supply of power from multiple power sources.

High capacity, high safety Li-ion batteries adopting advanced material technology are currently being developed for industrial applications and automotive vehicles.

Hard disk technologies with advanced perpendicular recording schemes have been developed, thus contributing to the reduction of power consumption in storage systems. In the research phase, a recording density of $2Tb/in^2$ has been demonstrated by developing futuristic thermal-assist recording technology in a NEDO project.

6. Summary

It is exciting to imagine how we can resolve social challenges and reinforce industrial competitiveness with advanced nanotechnology R&D. We have shown that nanotechnology is playing key roles in the spiral cycles of green innovation and life innovation. However, nanotechnology can have even greater value if bridging technologies such as design tools, IPs, firmwares, and architectures for nano systems are well established. For this reason, a comprehensive system approach is crucial in terms of achieving nanotechnology–based innovations.

TIA-nano is a new initiative for open innovation, and it will likely accelerate the change of Japanese culture in many ways. Collaborative efforts between academia, independent R&D institutes, and industry *under one roof* will overcome organizational constraints and work better for education, technology development, and resolving social challenges. Inviting overseas researchers and partners will also pave the way for a new R&D culture. TIA-nano is a venue of inspiration and challenge. Needless to say, the strength of traditional culture and long–term commitment to society should not change. Although our lifetime may not span a hundred years, we have the concerns of one thousand years.