Ask the pioneers:

# What's next for materials science?

At the beginning, we introduced various materials produced in Japan that have changed the world. How was Japan able to achieve such groundbreaking accomplishments? And what is necessary for Japan to continue churning out such results? In the face of mounting global challenges, the various roles to be filled by new materials will continue to increase. I asked the founders of Japan's materials science to tell us based on their experience what Japan must do to retain its strength in materials science considering the limits on element resources.

Interviewer: Atsuko Tsuji

## Completely new materials will be discovered by humans, not AI

### Dr. Masato Sagawa, developer of the neodymium magnet

**▶How were neodymium magnets created?**

The strongest magnets at that time were samarium-cobalt magnets, but I felt that a strong inexpensive magnet could be produced by replacing cobalt with iron. This thought stayed with me until one day at a lecture I had the idea of incorporating boron. The experiments with boron proved promising, and I also found that neodymium worked well. We completed the actual neodymium magnet two months after I joined a magnet manufacturer called Sumitomo Special Metals. Two weeks after we applied for a patent, a similar application was filed in the U.S.

**▶That was very close timing.**

I think the manufacturing company played a major role by making the snap decision to invest in me as a venture and facilitate my research.

**▶Thanks to your early action, magnet research was expanded as a major area in the Element Strategy Initiative.**

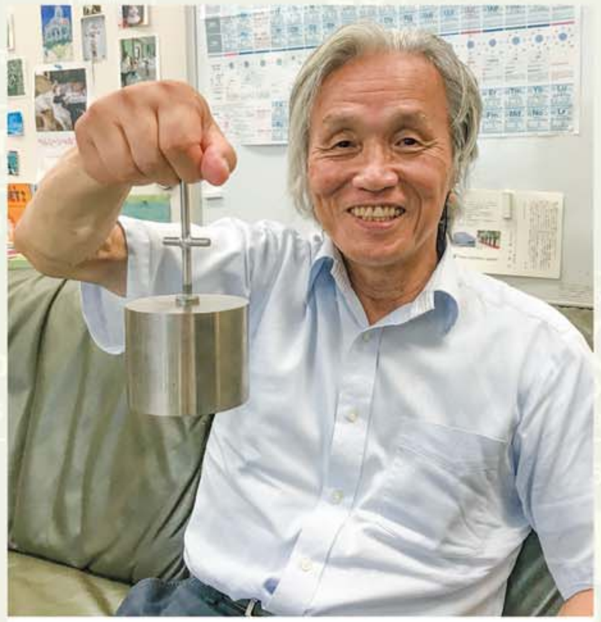
We applied a deductive approach to advance from basic research to applications, expanding research into both industrial and academic areas, and I believe we produced some world-leading results. Surprisingly some of these results contradicted conventional theories on the role of boron in neodymium magnets, which has heightened the mystery.

**▶It gives one a sense of profundity, does it not?**

Magnets using iron cannot exist without boron, yet we still don't know the role of boron. Perhaps my initial idea was correct, but I don't know. One cannot produce something entirely new through deductive thinking alone. Trial and error is also indispensable. Even with our element strategy, we have great hopes of discovering through trial and error new magnets with the potential to be the strongest ever. I hope we continue to value such an approach.

**▶Does it appear that AI will be of use?**

AI is certainly powerful, but it is powerless to discover entirely new things. Only humans can do that. They may even discover a new magnet that does not use iron.



A 1-g neodymium magnet can lift 3 kg of iron

**Masato Sagawa**

An advisor for Daido Steel Co., Ltd. who developed new materials for permanent magnets from a unique perspective, discovering a Ne-Fe-B (neodymium, iron, and boron)-based composition in 1982. Over the course of developing processing techniques, he perfected a composition for industrial use. Neodymium magnets are far superior to other types and have maintained their place as the strongest in the world.

**▶What does Japan need in order to grow its materials research?**

A research system and training capable of challenging research on the creation of a new "core" is essential above all else.

## Synergy among different fields will awaken Japan's potential

### Dr. Akira Yoshino, developer of the lithium-ion battery

**▶What were the main factors that led to the successful development of the lithium-ion battery?**

Firstly, Japan's strength in materials science has supported its success in compact batteries. In other words, cathodes, anodes, electrolytes, and separators—the four main components of such batteries—were the culmination of new materials, which is Japan's specialty. My research was triggered by the conductive polymer polyacetylene, which had recently been developed by Mr. Hideki Shirakawa. While exploring applications for this polymer, I discovered it could be useful as an anode material, which had been an impediment to the development of new 2D batteries. This revelation led to my development of a carbon anode.

Discovering springboard materials and ascertaining their natures may ultimately lead to usable materials, even if the original materials do not prove useful. I think this process is important in materials research.

**▶Advances were also made on battery research in the Element Strategy Initiative.**

The introduction of computational science, which provided the second wheel of the cart to go along with empirical science, I think was a brilliant move for advancing battery research. Moreover, I believe that material informatics has been a great force recently in materials science. The next important step will be the synergy among dissimilar fields. For example, by combining computations with experiments and multiplying their results, you may come up with something even more extraordinary.

Lithium-ion batteries comprise four main elements.
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**Akira Yoshino**

Honorary Fellow, Asahi Kasei Corp. Professor, Meijo University. In 2019, was awarded the Nobel Prize in Chemistry for developing the lithium-ion battery. Owing to their light weight, high-output, and ability to be recharged repeatedly, Li-ion batteries sparked the mobile age with their use in smartphones and other devices. More recently, they have been used in electric vehicles and have contributed to the realization of a society not reliant on fossil fuels.

**▶The participation of companies is also important, is it not?**

Absolutely. We used special carbon fibers developed by Asahi Kasei Corporation for our anodes as they have exceptional properties. One could not obtain these at a university. By cultivating an honest relationship between companies, their multiplication could awaken Japan's potential.

**▶How should we handle the issue of rare elements like lithium?**

There are three important approaches: production without use of rare metals, recycling, and sharing, such as repurposing solar cells at night.

**▶Do you think AI will be helpful?**

Japan is dominant in materials science and has amassed a lot of data, but the key will be how much failure data is incorporated into big data in the AI age. Without such data, AI will never become intelligent in the true sense but will provide incorrect answers. So perhaps we should collect failure data.

## It is essential to create an environment for tackling difficult challenges

Dr. Hiroshi Amano,
developer of the blue LED

**▶What were the main factors that led to the successful development of the blue LED?**

The most important factor was the presence of Professor Isamu Akasaki, who led the way. We elected to use gallium nitride for the solidity of its crystal as Professor Akasaki, who had a strong spirit of commercial practicality, felt there was no point in research into something people cannot use, and was persistent in this tough stance. Materials that are easy to make have a short lifetime. When I was assigned to the Akasaki Laboratory, Prof. Akasaki showed me a crystal he had created during his research stint at Matsushita Electric Industrial, and I thought "this is it!" I became obsessed with it, not knowing how difficult it would be.

**▶And now you are working on the development of high-frequency, high-voltage devices using the same gallium nitride?**

The blue LED was born from a preference for gallium nitride.
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Hiroshi Amano
Professor, Nagoya University. Director of the Center for Integrated Research of Future Electronics at the Institute of Materials and Systems for Sustainability. Awarded the 2014 Nobel Prize for Physics together with Isamu Akasaki and Shuji Nakamura for the development of a blue LED from high-quality gallium nitride. Currently working on developing next-generation power devices using gallium nitride.

Such power devices also require the use of tough materials. I believe that research must be thought through all the way to an innovative achievement. To earn the trust of a company, it's important to take the first steps at a university and demonstrate actual viability.

**▶In the Element Strategy Initiative, you have also been applying a coherent approach from theory to materials discovery.**

Elucidating the mechanisms of functional expression and achieving that expression with a different element is a magnificent scientific and design technique. On the other hand, substitution techniques have the potential for increasing costs. So I think it is crucial to set comprehensive R&D objectives in coordination with the research system.

As for eventual applications, there are limitations for what a single material can do. I would rather use materials in combination to expand the number of applications. For example, developing a system using deep UV LEDs to inactivate coronavirus would require various new materials that do not degrade under UV light. I would like to see more efforts toward encouraging new collaborations through information sharing.

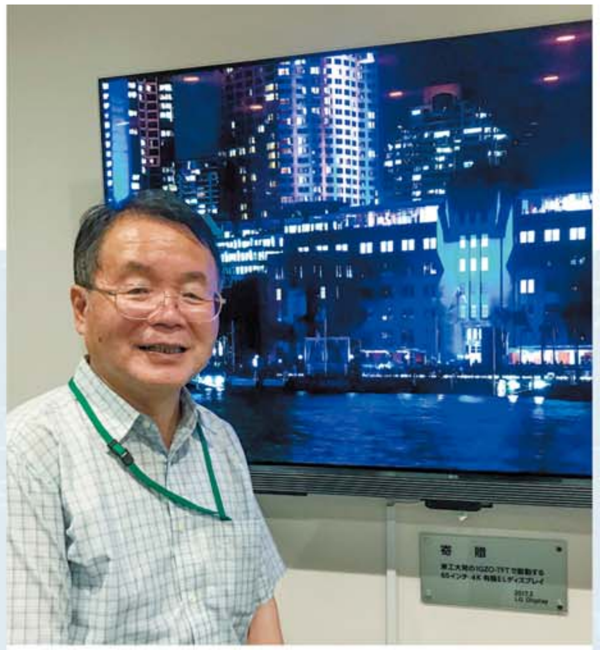
**▶Gallium is also a rare element.**

The gallium reserves are mostly confined to China, but aluminum, which belongs to the same group, can be refined from bauxite. Thus, bauxite-producing countries such as Guinea and Australia have the potential to become gallium-producing countries. There are likely other elements that have been needlessly discarded due to the nation not understanding their commercial value or not having the necessary refining technology. Thus, cooperation with resource-rich countries from a technological and business standpoint, as well as building good relationships with those countries on an administrative level, will likely be essential.

**▶What will be needed for future research growth?**

Above all else, it will be important to create an environment for taking on difficult challenges and particularly a system in which young researchers can feel secure in tackling such challenges. I'm convinced that there are no challenges that cannot be overcome by combining the best fields and personnel for the various projects and I expect we will develop a strategy and organization that will enable us to compete with the rest of the world.





A 65-inch OLED display using IGZO, gifted by LG.

Hideo Hosono
Institute Professor and Honorary Professor at the Tokyo Institute of Technology. Director of the Materials Research Center for Element Strategy. Produced such outstanding research achievements as the creation of iGZO semiconductors used in LCD and OLED TVs, the development of a method to synthesize ammonia at low temperature and pressure using electrides expected to have a ripple effect throughout the energy industry, and the discovery of an iron-based superconductor that defies conventional wisdom.

## Creating a system that allows free rein to impertinent youth

Dr. Hideo Hosono,
developer of the IGZO semiconductor

**▶What's your secret to continually producing such diverse achievements like IGZO, iron-based superconductors, and synthetic ammonia catalysts?**

The properties of a material are not determined by their elements alone. Structure is also important because structure affects states of electrons and states of electrons determine the function of the material. The key is connecting structure to function. I felt that there was no reason iron could not be used to make a superconductor, so I actually made one. I was told that glass would not make a good semiconductor, so I designed and created IGZO. Throughout, I have worked only with electrons.

**▶Your work seems closer to physics than chemistry.**

More like physics + chemistry. The key is "tunneling," whereby electrons pass smoothly through a barrier. To me, that is what's interesting in materials science. However, unlike those who study condensed matter, I am always considering the "use" of matter as a material. Above all else, I am searching for chemical stability, not simply good performance at instantaneous wind speed. If it can be used, it is a material.

**▶I suppose companies play a major role in what is used.**

Manufacturing materials on actual machinery at a production site produces better performance. A company also helped resolved issues I had with IGZO. The role of the researcher is to develop materials that make the company want to use them even if it takes time and effort.

**▶Which is the aim of the Element Strategy Initiative, isn't it?**

Yes. It is important to develop new scientific concepts. In the Element Strategy, foundations were consistently established on new science, and we were free to conduct research to produce desired outcomes. This pursuit is expected to realize materials that can be produced worldwide without reliance on rare elements, which is the objective of the Element Strategy Initiative.

**▶What is essential to continue producing new concepts?**

You can't conduct materials research among only materials researchers. It is necessary to cross boundaries and break molds, and we need a system and funding to do that. I am particularly hopeful for such impertinent youths who make declarations like, "It's not as simple a problem as the professor thinks." I want to create a system with no social order in which these people can work freely. Naturally, it's also important to challenge the senior researchers to compete. I'd like to create an environment in which young people can thrive without being coddled.

### Final Thoughts

These interviews made me realize once again the important role that companies play. Drs. Sagawa and Yoshino talked about the indispensable assistance they received from companies, and Dr. Akasaki's corporate experience also proved to be key. Thus, the importance of industry-academia collaboration in the true sense of company involvement is an opinion shared by all. They also talked about the need for university researchers to take a step forward and the company-side to have an eye toward technology. I look forward to the Element Strategy Project creating more opportunities for collaboration in order to produce more world-changing achievements.

Atsuko Tsuji
Professor, University Research Administrator Organization, Chubu University. Was engaged in science-based reporting at Asahi Shimbun and, from 2004 through 2013, was an editorial writer in charge of editorial articles on science and technology and medicine. Became a designated professor for Nagoya University International Organization in October 2016. For three and a half years, published *Nagoya University Watch* on the university's website showing the university from a journalist's perspective. Nagoya University also published a paperback edition with the same themes. Was appointed to her present position in June 2020.