Technotalk

Use of Interdisciplinary Knowledge to Improve Measurement and Analysis Technology

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Part of the foundations of science and industry, measurement and analysis technologies are used in a wide variety of fields, including the development of new materials, biology, electronics, the environment, and renewable energy. Hitachi has contributed to the development of industry and society through measurement and analysis technology and its applications, having had a long involvement in instrumentation, electron microscopes, spectrophotometers, and other such devices. Along with strengthening its core technologies and expanding its product range, Hitachi is also pursuing collaborative creation and open innovation with customers in specialist fields, utilizing measurement and analysis technology to provide extensive support everywhere from the latest academic research to industry.

Enabling Dynamic Observation and Establishing Platforms

Shinada: The abilities to observe, measure, and analyze are fundamental to science and industry, and society is underpinned by the widespread use of measurement and analysis technology everywhere from advanced research and development to the factory floor. Today we have invited a number of experts in the fields of materials development, medicine, and biology. I would like to start by asking each of you to summarize the contribution of measurement and analysis technology and the latest trends in your own field.

Kitagawa: In my own specialty of materials science, capabilities like in situ observation and "operand measurement*" are becoming increasingly important. Overseas, in particular, progress is being made on the development of methods such as performing surface observations under an electron microscope when hydrogen or other gases are injected and react with a catalyst, or observing the condition of materials inside a battery during use. While such techniques are also increasingly being adopted in Japan, this is a field where greater effort is still needed.

Work is also proceeding on materials informatics whereby data analysis techniques are applied to materials design, with a database of materials information being created, primarily through the National Institute for Materials Science (NIMS). While progress has already been made on the fusion of materials science and design techniques, this use of data analysis and information processing is likely to become essential in the future. Advanced measurement and data analysis techniques are seen as holding the key to future leading-edge research.

Another area where Japan needs to make a greater effort is in the establishment of platforms. Japan has a large number of joint research facilities, including supercomputers, synchrotrons, neutron beam generators, large electron microscopes, and research facilities for strong magnetic fields and nuclear magnetic resonance (NMR). While these serve as sites for undertaking basic research and other advanced studies, there is a need to proceed with the development of research platforms by establishing hubs and networking them to improve the international competitiveness of science and industry.

Ushiki: In medicine and biology, electron microscopes have made a major contribution to the progress of cell biology. It is only thanks to the resolution of electron microscopes that we have been able to observe the

* Measurement and analysis of catalysts and devices under actual operating conditions.

structures of viruses and of the Golgi apparatus, mitochondria, and other cell components, and without this ability there would be no modern biology. Meanwhile, while it builds on knowledge of cell biology acquired by electron microscopes, the focus in recent times has been on fields such as molecular biology working with molecules and genes that can be labeled by optical microscopy.

Nevertheless, this does not mean that electron microscopes will not be used in the future as there remains a need for reliable shape observations. The problem with electron microscopes is that, for all the high resolution they have, their ability to view shapes is not accompanied by being able to view color or function. Instruments such as confocal microscopes and two-photon microscopes that use laser light have become more widely used recently, and optical microscopes have the advantage that they can be used for dynamic observation of living cells. If the challenge of being able to view moving specimens can be overcome, then we can expect to see greater uses for electron microscopes in medicine and biology.

Shinada: The establishment of platforms spoken about by Professor Kitagawa is also important for open innovation. Hitachi, too, is actively seeking to collaborate and cooperate with universities, research institutions, and other companies. In this context, I would like to ask Professor Sugiyama, a leader in collaboration between industry and academia, for his thoughts on open innovation.

Sugiyama: Having worked in steel industry laboratories researching ferrous materials up until March 2015, I have taken up a joint research chair post at Osaka University. It is important to work out how alloying elements distribute themselves through the steel we produce to achieve the desired mechanical properties, something that would be impossible without the use of electron microscopes and other analytical equipment.

Recent years have seen an intensification of development competition in materials with high strength, with emerging economies becoming more prominent. This has forced companies and universities to engage in joint research, even more so than in the past, with extensive knowledge of materials science being needed to ensure that the end products have specific mechanical and other physical properties in actual use. This has been accompanied, however, by a shift away from the contract research used in the past, toward more integrated research efforts in order to obtain timely and effective solutions to problems. Naturally, this is an important part of open innovation, and we can also see this as a trend toward companies and universities acting together to develop human and technical resources in the short and medium terms. Our plans for joint work go beyond basic materials science to include research on new characterization techniques for overcoming the deficiencies of existing

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Graduated from the School of Medicine, Niigata University and obtained a doctorate from the Graduate School of Medicine. Following appointments that included associate professor at Hokkaido University, he was appointed professor at the School of Medicine, Niigata University in 1995, and to his current position in 2014. Doctor of Medicine. His specialty is microscopic anatomy. His publications include an "Introduction to Histology" (published by Nankodo, in Japanese).

analytical equipment.

Shinada: Collaboration between industry and academia is important for equipment development, just as much as in basic science. Professor Ushiki, you have worked with Professor Futoshi Iwata on the Faculty of Engineering at Shizuoka University, Hitachi High-Technologies Corporation, and others on the development of a scanning electron microscope (SEM) that can be used for realtime three-dimensional (3D) imaging and a high-resolution 3D monitor that can be viewed with the naked eye, the work being undertaken as part of a Japan Science and Technology Agency (JST) program for the development of advanced measurement and analytical techniques and equipment. What do you see as the key factors in the success of collaborations like this?

Ushiki: Because our interests in our own specialties do not always overlap with corporate development objectives, it is important that both sides make allowances. The development of analytical equipment for solving highly specialized problems needs to be approached with patience as a number of steps are worked through. Achieving this requires that you find partners with whom you can develop mutual respect and share goals. Success comes from having people who appreciate other fields and who can act as go-betweens.

Kitagawa: As you say, building the right environment is important. The need for data analysis and information processing was mentioned earlier, but there is a significant gap between specialists in that field and materials science researchers. It may be that what is needed is a way to bring together people with an interest in each other's work so as to develop fields that tie together different disciplines in this way along with people who understand both sides.

Moving from Equipment to Solutions

Shinada: Now that you have told us about the latest developments regarding analytical equipment, what are your comments on the work of Hitachi High-Technologies?

Ito: With regard to the "operand analysis" practices spoken of by Professor Kitagawa, development is underway aimed at using transmission electron microscopes (TEMs) for this purpose. Looking at measurement and analysis systems in overview, Hitachi has for some years been working to strengthen its lineup of TEMs, SEMs, and focused ion beam (FIB) instruments. In the field of materials development referred to by Professor Sugiyama, for example, we have supplied the materials industry with a field emission scanning electron microscope (FE-SEM) fitted with a Schottky emitter electron gun that was released in 2014. We have also contributed to society, with the realtime 3D-SEM we developed in partnership with Professor Ushiki, which subsequently launched

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Graduated from the Division of Materials Physics, School of Engineering Science, Osaka University, and obtained a doctorate from its Graduate School of Engineering Science. After joining Nippon Steel Corporation (now Nippon Steel & Sumitomo Metal Corporation), he was engaged in research into first ceramics, and then steel. He was involved in technology planning and the study of material microstructure control, primarily electron microscope technology. He was appointed to his current position in 2015. Doctor of Engineering. He is a member of the Japanese Society of Microscopy (JSM), The Japan Institute of Metals and Materials, and the Iron and Steel Institute of Japan.

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Joined Hitachi Naka Seiki, Ltd. in 1984 where he worked on the design and development of scanning electron microscopes. He is currently engaged in managing the design and development of electron microscopes and focused ion beam milling machines. He is a member of the JSM.

on the market (with more than 180 instruments shipped). Along with high-end products, we are also seeking to expand our user base by developing SEMs, TEMs, and FIB instruments that anyone can use.

In the future, it will be necessary to supply not only instruments but also solutions and systems. We are also launching initiatives aimed at identifying requirements in consultation with users and academics at universities and research institutions. For example, we have been looking into live correlative light and electron microscopy (CLEM), a bioimaging technique that is capable of structural analysis at the molecular level using both a fluorescence and an electron microscope, and we are working on joint development with National Research and Development Institute, RIKEN, to build systems that are easier to use.

Tamochi: What is important when it comes to solutions is to provide total support that extends from sample preparation to measurement and subsequent tasks. Accordingly, we established our Tokyo Solution Laboratory in February 2011. By providing a venue that is closer to customers for holding demonstrations and hands-on training on key products, we are seeking to improve user convenience and strengthen collaborations with universities and research institutions in Japan and elsewhere.

In 2012, Hitachi High-Technologies acquired SII NanoTechnology Inc., an analytical equipment business, and re-established it as Hitachi High-Tech Science Corporation. This enabled us to add surface analyzers, scanning probe microscopes (SPMs), and coherence scanning interferometers to our product lineup. We are drawing on the resulting synergies to devise systems that can use an SPM and SEM in tandem to combine surface images with localized physical properties analysis, for example.

Hitachi High-Tech Science has X-ray analyzers and is working on deploying this general-purpose technology in specific purpose instruments such as those for detecting contaminants in food or those used in quality control of lithium-ion batteries. Our aim is to promote innovation through analytical equipment by utilizing core technologies for electron beams, ion beams, spectrometry, and X-ray analysis to supply solutions to a wider range of customers.

Kitagawa: Nowadays, paying attention to feedback from users is as important as the technology itself when it comes to overcoming competition from overseas suppliers of analytical equipment.

Shinada: In this respect, it is important to take note of open innovation. For Hitachi as a whole, open innovation and collaborative creation are key concepts as we go about our Social Innovation Business, research into advanced technologies, and product and service development. Accordingly, we have reorganized our research laboratories to strengthen collaborative-creation with customers and customer-

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Joined Hitachi, Ltd. in 1985 where he worked initially at the Central Research Laboratory and then in the research and development of semiconductor production and inspection machines based on electron microscopy and on electron sources and electron guns. He is currently engaged in development and applied research into holography electron microscopes. Doctor of Engineering. He is a member of the JSM, The Japan Society of Applied Physics, and the Society of Instrument and Control Engineers.

inspired research and development.

Sugiyama: While it is vitally important to take account of user feedback in product development, as technology advances, it is also essential that a variety of researchers share their core knowledge in order to make the breakthroughs for the next generation of technologies. I believe this is why a growing importance is being placed on open innovation across different companies. Rather than companies in the same industry, I believe that the key lies in the fusion and integration of knowledge from different disciplines and industries, and that universities can serve as go-betweens to make this happen.

Overcoming New Challenges by Incorporating Interdisciplinary Knowledge

Shinada: I see collaborative creation between industry, government, and academia growing in importance as a way to create innovative measurement and analysis technology.

Tamochi: One of the most important aspects of measurement and analysis technology is the analysis of data obtained through observation. The higher the level of the object under observation, the higher the level of data interpretation will become, and therefore it is necessary to incorporate domain-specific knowledge.

Sugiyama: In the microstructure of an observed object can appear completely different when viewed from a slightly different angle in TEM. To obtain a quick solution, it is important that there is a sense of solidarity between experts in measurement and analysis technology and those in materials development who need to use this technology. Furthermore, it may be possible to discover facts that were previously hidden by combining techniques from big data analytics to view large data sets from different perspectives. In this case, it will also be necessary to educate researchers to be able to find something new in overlooked data or noise, making it important to find ways to bring people together by establishing hubs and platforms.

Ushiki: In biology, whereas imaging has been important for qualitative assessment, I believe we are well behind when it comes to ways of using image data from electron microscopes to perform the statistical and quantitative analyses that have become necessary in recent times. In this respect, while we may talk about analytical equipment, there are numerous aspects in which *measurement* is not the right word.

Shinada: Hitachi High-Technologies supports the precision measurements required in semiconductor manufacturing by developing the measurement SEM inspection systems used for dimensional measurement. The know-how built up in this field has the potential to be useful in the development of quantitative techniques for image analysis. It could also lead to breakthroughs in the application of big data analytics and artificial intelligence (AI) to microscope images.

Kitagawa: My greatest concern at the moment is that, while scanning transmission electron microscopes (STEMs) are very useful instruments, they are only able to focus on a narrow range. In the case of metals, for example, I was interested in high-entropy alloys with a large number of alloying elements and wanted to use STEM energy dispersive X-ray analysis (STEM-EDX) to gain a 3D view of the distribution of elements in a nano-sized grain, but the analysis was complicated by problems with focusing the STEM and with overlapping EDX characteristic X-rays. I believe there must be a way of doing it, whether it be a physical solution or using a data analysis technique such as multivariate analysis, and I hope you can show me what it is.

Ushiki: Perhaps you can deal with your focusing problem by taking lots of images with different focuses and merging only those parts that are in focus.

Tamochi: That's right. In-lens SEM incorporates a technique whereby a series of images are taken automatically with different focuses and only the sharp parts of each image are overlaid, so that is an approach you could try.

Ito: To deal with EDX sensitivity problems, we are working with Dr. Toru Hara of NIMS and others on the development of a micro-calorimeter with a transition edge sensor (TES) using a technique from Hitachi High-Tech Science. If this instrument can be successfully developed, it should prove useful for precise nano-scale composition analysis by providing much higher energy resolution than conventional EDX systems.

Kitagawa: I will look forward to that. In materials science, it is known that, in between the microscopic world at the molecular level and the macro world of visible crystals, structures in the mesoscale range have an influence on material properties. However, there are numerous difficulties with the techniques for viewing at this scale, and so I see much potential for the use of electron microscopes.

Shinada: Even as science progresses, there remain numerous areas that are yet to be understood, so to help address these challenges is essential that the field of measurement and analysis adopt a wide range of technologies, knowledge, and people.

Hitachi has been working on holography electron microscopes for a long time, particularly the late Akira Tonomura, who was recognized with the title "Fellow of Hitachi, Ltd." A holography electron microscope with an accelerating voltage of 1.2 MV developed by a project entitled "Development and Application of an Atomic-resolution Holography Electron Microscope," which was supported by the Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program), achieved world-leading resolution of 43 pm in December 2014. It is hoped that the microscope will make a major contribution to progress in basic science in addition to its use, not just at Hitachi, but also in Japan's leading-edge development of functional materials. I invite you all to submit any research projects you might have.

Sugiyama: It is important to make the best equipment in the world. The success in technology attracts people and breeds confidence in the field. New technical innovations are invariably needed for world-leading achievements, and the knowledge you gain in the process often proves its worth over and over again in the future.

Ushiki: Any improvement in resolution, even if only a small increment, makes it possible to view things that could not previously be seen. You also need to make an effort to take advantage of this.

Kitagawa: Japan's measurement and analysis technology is in itself at a high level by world standards, and it is important that we continue to move toward the high end. On the other hand, an overemphasis on specifications can also result in technology being difficult to use. What is needed is to combine top-level technology with user-friendly features that enable all users to achieve a certain level of performance.

Ito: That's right. Our aim is to contribute to advances in the measurement and analysis platforms that underpin science and industry by improving ease-of-use as well as by taking on new challenges in pursuit of performance, quality, and reliability.

Shinada: It has become clear to me that ways of establishing horizontal links and developing human resources are just as important as delving into the specialist technologies and fields in which Japanese people have expertise.

Our intention is to contribute to progress in society and science through open innovations in which measurement and analysis play a pivotal role, while also continuing to develop the measurement and analysis technologies of Hitachi. Thank you for your time today.