Our research aims to discover the simple, beautiful truth

Evaluating semiconductor quality using light to advance solar batteries and LSI technologies

Dr. Michio Tajima, Doctor of Engineering

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Dr. Tajima received his Doctor of Engineering degree from the University of Tokyo's Faculty of Engineering in 1975. He then joined the Electrotechnical Laboratory at the Agency of Industrial Science & Technology within the Ministry of International Trade & Industry. Later, he was appointed as a professor at ISAS and at the Graduate school of the University of Tokyo. Among his many awards are the Watanabe Memorial Research Incentive Award from the Semiconductor Research Institute and the Conference on Solid State Devices and the Materials Award from the Japan Society of Applied Physics.

In the mid-1970s, a thought struck the young Michio Tajima—Could the luminescence phenomena of semiconductors be used to detect impurities? This idea ultimately supported the later prosperity of the semiconductor industry and also played an important role in solar battery development. Dr. Tajima is a researcher who pursues originality and simultaneously advocates contributing back to society through the popularization of technologies. We interviewed Dr. Michio Tajima, Professor Emeritus at ISAS/JAXA, about his career and his enthusiasm for research.

Developing an evaluation method "outside the box"

—Semiconductors, which are widely used in home electronics, PCs and a broad range of other products, are a vital component of our daily lives. You developed a very popular method of evaluating semiconductor quality.

Put simply, a semiconductor is a material with electrical conductivity that is intermediate in magnitude between that of a conductor, such as metal, and an insulator. Silicon is an example of a semiconductor. The amount of impurity contained within a semiconductor changes its level of conductivity.

Some impurities degrade the functions of materials while others help improve them. This means that when you want to make use of impurities to enhance the quality of silicon wafers for LSI (large-scale integration) circuits, you first need to identify the appropriate impurity elements and quantify them. This is because it is impossible to provide stable quality if you are unsure about the kinds and amounts of impurities contained within your materials. I developed an original method to conduct such measurements using photoluminescence.

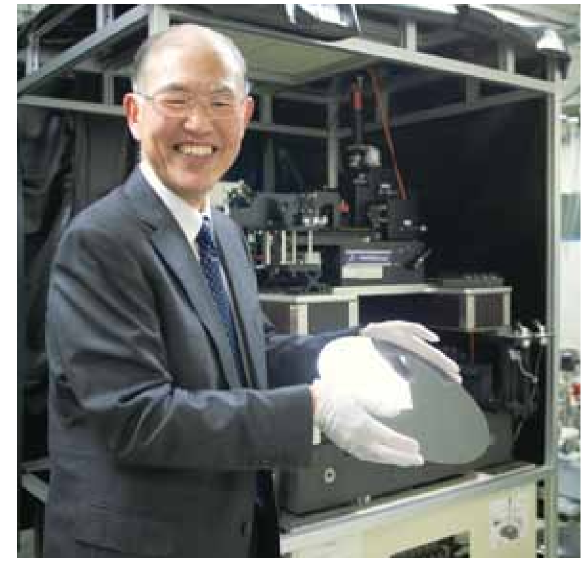
—Can you introduce us to that method, the Photoluminescence Method, which you developed?

This may get a bit technical, but generally speaking, when you apply energy to substances, they absorb that energy. The absorbed energy is then later released in different forms. When energy is released in the form of light-emission it is called luminescence. The term "photoluminescence" refers to the process in which a substance absorbs energy provided as photons and then emits photons.

Silicon crystals, which are commonly used in the semiconductor electronics industry, emit light when exposed to laser-beam radiation because defects and impurities within them react to the beam. I applied this to evaluate crystals by measuring and analyzing the light emitted in order to identify the kinds and amounts of the impurities contained within semiconductors. I think that the experience of measuring weak light in my research on light-emitting diodes as a graduate student at the University of Tokyo helped me a lot.

▲Laser beams play a significant role in semiconductor evaluation

—You successfully developed the crystal evaluation method during your second year at the Electrotechnical Laboratory, which you joined upon completing your graduate studies. Things went very smoothly for you, didn't they?



▲Dr. Tajima stands in front of a measurement instrument holding an actual wafer

Actually, not really. In retrospect, I can say that knowing no fear whatsoever at that time was the reason I gave it a try. After all, measuring ultra-trace amounts of impurities contained within silicon wafers on the order of parts per billion was anything but easy. Moreover, it was almost unprecedented to perform such measurements using photoluminescence. If I were to go back to when I was in my 20s, would I want to do the same thing again? No, I don't think so (laugh). From an objective point of view, it was quite the fool's errand.

Nevertheless, in those days I worked very hard—almost too hard, perhaps—with what you might call the "bravado of youth." Then, one day, after numerous trials and errors, I finally detected light emitted from the crystals. I proceeded to gather many pieces of data that suggested a very simple, very beautiful rule that governed the phenomenon. I immediately designed appropriate measurement conditions and conducted tests again in order to validate the rule. The second set of results established the reproducibility of the rule. The memory of that moment is still vivid and fresh in my mind.

—The Photoluminescence Method has been adopted in ASTM (American Society for Testing and Materials) standards as well as JIS (Japanese Industrial Standard) and is now in widespread use around the world.

It is rare for JIS to approve this kind of evaluation method. It also was the first Japanese technology registered with ASTM, which is considered a global authority in this area, so I felt extremely honored and flattered.

I had always wanted to develop helpful technologies to aid the growing semiconductor industry; this was the original inspiration behind my research efforts. I had also been working hard to standardize the evaluation method, which I had developed working in cooperation with manufacturers, in order to bring it into wider use across the entire industry. Therefore, it meant a lot to me when the method was approved as a standard.
The efforts one must make to standardize technologies differ from those necessary for research. One must get far more people and organizations involved—for example, preparing 50 sets of standard samples and distributing them to the leading global semiconductor companies. In fact, it took us more than 10 years to standardize the method.

Researchers must understand the principles behind measurement instruments

—The Photoluminescence Method is also applied in the area of solar batteries, which contain semiconductors.

As you know, demand for solar batteries is now growing rapidly. Improving their quality is also an urgent task because higher quality solar batteries with enhanced power generation efficiency will take up less space when installed, use fewer materials and have lower costs.
As part of our efforts to realize higher quality, our laboratory has developed the hydrofluoric acid liquid-immersion photoluminescence imaging method. This is a method for evaluating the quality of silicon, the main ingredient in solar batteries. By using this method, one can ascertain quality in under a second. The conventional method requires about 20 minutes to do the same thing. Moreover, this new method offers 20 times higher resolution—in other words, measurement performance.
Solar batteries are closely related to the space industry and artificial satellites. In fact, I have been involved in a number of scientific satellite projects as the leader of the power supply system group. Since solar batteries intended for use in space must have special durability characteristics and other high performance features, the semiconductors used in them are often made using a multilayer structure. That is why we modified the original Photoluminescence Method in this field in order to provide a new method for selectively evaluating the respective layers of semiconductors. With no need for pretreatment, this non-destructive, non-contact method is now playing a major role in defect analysis for solar batteries intended for use in satellites.

—Thank you very much for using HORIBA's measurement instruments. We understand that measurements are an essential part of your research.

Yes, indeed. You could even said that measurement is the very theme of my research. To evaluate the quality of semiconductors is none other than to measure their impurities and defects.
Whenever I work to develop a new evaluation method, I must improve measurement instruments with the support of manufacturers. This is why I don't want to let others look at the instruments I am using when I am working on cutting-edge development, as I put a lot of my know-how into them (laugh). Germany is excellent at manufacturing. For example, the research activities of the Max Planck Institute for Solid State Physics, where I used to work as a researcher, were supported by highly skilled engineers known as Meister. However, Japan also has quality engineers worthy of the Meister name. In fact, during the process of establishing the Photoluminescence Method, many brilliant Japanese engineers, including those from HORIBA who to this day have continued to take care of my instruments, worked night and day with us to develop the method.


▲Dr.Tajima's style is to always write down measurement results in his notebook

—Do you have any requests for measurement instrument manufacturers?

Above all, I want manufacturers to create instruments that produce accurate, repeatable results and to guarantee a certain level of precision regardless of the skill of the user. In addition, given the increasingly "black box" nature of today's instruments that is a consequence of their ever increasing sophistication, I would find even more user support very helpful. For example, at times manufacturers handle product failures simply by replacing parts, leaving me in the dark about what actually occurred.
At the same time, researchers also need to keep in mind that users must learn and understand the principles behind the measurement instruments which they use. We should not merely press buttons and wait for the results. Otherwise, we may fail to understand what our data really mean and overlook something very important.

Earnest "dialogues" may cause chemical reactions

—Are there any policies that you have advocated for as a researcher throughout your career?

I place great emphasis on having dialogues during research. In fact, I faced a large number of different criticisms and debates, both inside and outside Japan, immediately after I published the results of my research on photoluminescence. Since the method offered a much higher sensitivity than the then conventional evaluation methods, many people had doubts about its effectiveness, wondering whether it was really possible and reliable.
I also received many questions at international academic conferences. When I was unable to answer them on the spot, I worked through the night to prepare answers in order to respond the following day. As I handled these pieces of feedback one by one in this way, I developed a deeper understanding of the subject and noticed many new things. Interacting with other people in earnest sometimes enables one to discover things which one otherwise could not. In fact, some of my major breakthroughs are a result of such dialogues. Having those heated debates is now among my most precious memories and also gave me invaluable personal contacts, both in Japan and overseas.

—That is very interesting. Do you place importance on anything else in your research?

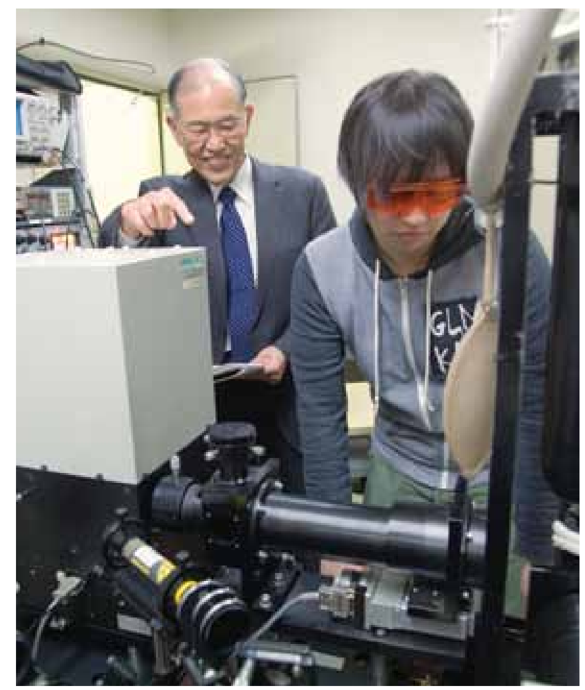
As for the mental aspect, I would say concentration and relaxation. To demonstrate your creativity and originality, you must have good concentration, which in turn requires that your mind be relaxed. It may just be me, but I feel that my mind was always in some kind of relaxed mode when I made valuable discoveries. Of course, some element of luck is also a vital component of such discoveries. Nevertheless, it's true that you are more likely to make the most of your luck when relaxed.

—You have not only produced great results as a researcher but also provided a driving force for industry growth. What satisfaction do you get from your research and what is the source of your energy?

I am proud to say that the precise evaluation method for different types of wafers that was developed at JAXA, which I mentioned earlier, contributes to the practical use of space devices. I also feel that I have contributed to improving the quality of semiconductor materials. What is the point of engineering if it doesn't do people or society any good? As such, seeing our technologies being used in industry boosts my motivation.
However, rather than carrying out research with a special sense of mission, personally I feel that I am just focusing on what I can do at the moment to resolve the challenges at hand. Semiconductors have been experiencing dramatic evolution—from silicon to gallium arsenide to SOI (silicon on insulator) to SiC (Silicon carbide). I have also been striving to develop new evaluation methods to effectively evaluate each of these in turn. I believe that my achievements so far are the results of my efforts to resolve these problems one-by-one by making the most of the technologies and know-how that I have accumulated.
As for the satisfaction that I get from my research, the best thing about doing research is discovering the truth. Although words can hardly describe this, genuine truth is extremely simple and tremendously beautiful. I feel that finding such truth is the most rewarding and joyful thing about being a scientist.

—Lastly, what would you say to the young researchers and students who are the future of this field?

More than anything else, researchers must be creative. "Do yourself what no one has ever done before." "Discover new things, even if they seem trivial." I frequently say such things to the students whom I teach and supervise.
In a way, discovering new things and establishing new methods is a lonely and painstaking exercise. Also, although you may need to inherit work from your predecessors, that alone is not very interesting. When you encounter something that captures your imagination during difficult research—that is when you feel the real pleasure of research. Moreover, those who experience this always grow exponentially afterwards without requiring any additional impetus. In my opinion, the key to growth is to focus on pursuing the truth.


▲Guiding students through new discoveries is now one of Dr. Tajima's important jobs