Energy-saving policy and standard research for solid-state lighting in the United States

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When Dr. Yoshi Ohno, who engages in the research of photometry standards at the National Institute of Standards and Technology (NIST) of the United States, visited AIST in December, 2008, Ono and Tanaka, editors of the *Synthesiology* Editorial Board, took this opportunity to interview him. We were able to hear the ambitious plans of the United States Government to execute its energy-saving policy in the field of illumination, as well as the great enthusiasm among the standards researchers in meeting the requirements. It was also interesting to see several common points between Dr. Ohno's research at NIST and the *Full Research* conducted at AIST.

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Full Research and *Synthesiology*

(Ono)
AIST has been publishing an academic journal entitled *Synthesiology* since 2008. Considering the relationship between scientific research and society, when a scientifically significant discovery or invention is made, it draws the attention of society, and large amounts of research funds may be allotted to its research. Yet in general, it is rare that the discovery or invention makes it into society as a so-called "product." There is a period where steady effort and patience are required, when the researcher must realize his goals one step at a time, even after popular initial interests dies down. This is the "nightmare period" for the researcher, when popular interest fades and the research funding becomes thinner. I believe the mission of a public research institution like AIST is to meet these types of challenges during the nightmare period to ensure the utilization of the research results by society.

Today, the value of basic research and, at the same time, the importance of applied research are increasing. We are becoming aware that the issues of global environment, energy, health, food, and other social issues cannot be solved only by engaging in our narrow fields of basic research. Unless we boost what we call "applied research," science will not become part of our social values.

The conventional way of writing a research thesis is to describe the facts, and to draw conclusions from the facts to confirm the logical consistency. One can say, "that's all", although there is actually more to it than that. Yet, we have been writing papers because we believe that there is value in accumulating new facts in our respective fields and polishing logical completeness, without considering what if any linkage there is with social values. Daily research, however, is much more vivid and is affected strongly by social demands and government policies, but we cannot write about such things.

(Ohno)
That's right. Perhaps we see only a few lines of such backgrounds of research in the introduction part of papers.

(Ono)
Yes, indeed. The introduction of a paper is interesting to read, but it does not determine the quality of the paper. Even if the authors have the passion and desire to meet the demands of society, if they put that down in writing, they will be met with the comment: "That's not an academic thesis." Through *Synthesiology*, we wish to present a combination of the researchers' intelligence and intentions.

(Tanaka)
Dr. Ono described for us the objectives of *Synthesiology* and our intentions. I think it is important to maintain the perspective of applied research even if one is engaging in basic research. Is this way of thinking prevalent in the United States?

(Ohno)
In case of NIST where I work, some basic research is done, but I think the majority is applied research. At various opportunities, we are required to explain, "Why I am doing this research." For example, in our Division, we have a project review once in several years, where each project leader presents what is being done in his/her project, what kind of contacts we have with industry, how it will be useful, and then we discuss the project. Since our funding is always limited, it is difficult to do research for which we cannot provide a decent explanation on its benefits to the industry.

Photometry standard research at NIST

(Tanaka)
In the United States, both the Bush and Obama Administrations clearly stated the policy of disseminating solid-state lighting (SSL) for energy savings. Dr. Ohno has been working on photometry standard research at NIST and has made great contributions. This effort can be called a social technology that links the photometric standards research at NIST and the American SSL policy. It probably falls into the general category of the "standardization, policy, and regulation of a technology and product." Can you tell us how you have been working on the photometry standards research?

(Ohno)
The energy currently used for lighting such as incandescent and fluorescent lamps amounts to an enormous quantity. The U.S. Department of Energy (DOE) has set a goal to reduce the current electricity consumption from lighting to half over the next 20 years by gradually introducing SSL to the market.

In 2005, the U.S. Congress decided to promote SSL as a national policy, and DOE was directed to head the promotion. It is expected that using SSL will bring twice as high energy efficiency in lighting. This has gathered a lot of attention since creating light sources twice as efficient will enable considerable energy savings and will also be helpful in halting global warming.

However, since this is a next-generation light source, problems are expected because it is dissimilar to the conventional light sources in many aspects and requires new challenges. In its policy to promote SSL, the DOE is looking at the big picture from the development of core technology (the basic research for semiconductors), to the development of light-emitting diode (LED) and lighting products, and to their introduction to the market as the final step. As Dr. Ono mentioned, in this realm, basic research is linked all the way to market. In this picture, standards play an extremely important role. If a standard is poor, inferior products will become rampant. When a consumer purchases a bad product with poor performance, he/she may be disappointed with the performance of LEDs and may decide not to buy it any more. The initial stage of market introduction is very important for the success of the new technology, and the DOE is working hard to support such commercialization process.

NIST supports standardization in various ways, and is helping Energy Star issued by the DOE. Energy Star is a government program that endorses energy-efficient products including many of electric appliances. The Energy Star label is allowed to be attached to the products that meet the requirements. DOE selects products not only for their energy efficiency but also the quality of the product. The Energy Star program for SSL products has just started.

(Ono)
You mean that NIST is setting the standards for giving out the Energy Star?

(Ohno)
Yes, applications for Energy Star program for SSL are officially accepted since October 2008. We started developing the standard two years in advance. NIST participated


Dr. Yoshi Ohno


Dr. Akira Ono

actively, and took the leading role in some parts.

No standard, no recommendation

(Ono)
So NIST is cooperating in the creation of not only metrology standards, but also industrial standards?

(Ohno)
Yes. I talked about quality earlier. For example, talking about the chromaticity of a lighting source, people dislike lighting when the overall appearance gives a yellowish or greenish hue and this is a cause for products to be returned. Since this was a very important issue, a task group to create a standard for chromaticity for SSL light sources was set up in the American National Standards Institute (ANSI). I became the leader to develop the standard.

(Ono)
As a matter of perception, I don't want to be in a yellow room, and a green room is unsettling. A red or blue room would be more acceptable.

(Ohno)
Yes. We wanted to define that, and establish it as an industrial standard, and ensure good color quality of products through Energy Star.

For measurement, the Illuminating Engineering Society of North America (IESNA) published a document (LM-79), which is a standard for the testing method used as a reference by the Energy Star. I also led this standardization project. For example, it sets standards for how to measure the luminous flux using the unit lumen, how to arrange the integrating sphere, and what kind of detector should be used. There are two types of integrating spheres: one using a photometer and the other using a spectroradiometer. The accuracy for industrial use is much higher when the spectroradiometer is used. But, in order to use a spectroradiometer, a metrology standard for the spectral radiant flux will be needed. NIST has been working on this standard for several years and has made it available, which is one of the key points in this standard.

Dr. Mitsuru Tanaka

If you want to recommend this method, you must have a metrology standard required in the method. Unless you have that standard available, you cannot just put that method down in a document and say, "Please use this method."

(Ono)
The importance of spectral radiant flux measurement has been also recognized at AIST, and we just started working in that direction.

Do we get high quality product by raising the assessment values?

(Ohno)
There's another point concerning the quality of a LED light source. When assessing the color rendering of a lighting source, there is an index called the CRI (color rendering index). This index has a full scale value of 100. 80 points or higher is recommended for interior lighting. This index was created about 40 years ago for fluorescent lamps. However, using my simulation program, it was found that there were many problems when this index was applied to LED light sources.

When the spectrum of the output light is focused to the center of the visible range, the efficiency of the luminous flux value (lumen/watt) will increase, while, in general, color rendering decreases. Companies are competing with each other over the value of lumen/watt. However, it was found by my simulations that if they seek for a spectrum with the highest lumen/watt, for example, at a CRI of 80, the appearance of the light will have an unacceptable poor red color. A LED light source can become unusable for interior lighting even if it has a CRI number of 80 (Fig. 1).

Also, it is possible to raise the color contrast by manipulating the spectrum to some degree. For example, a neodymium lamp, which absorbs the yellow spectrum, is sold on the

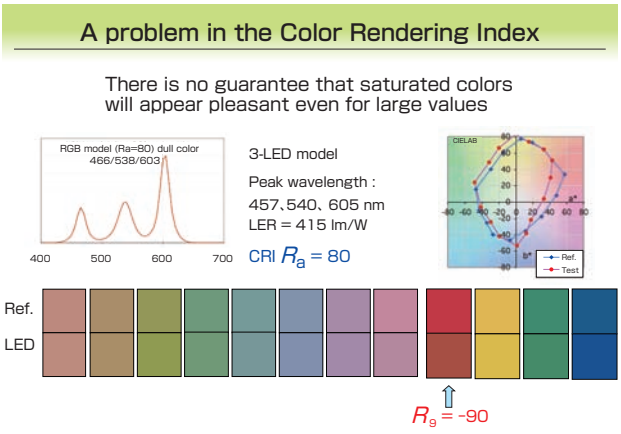

Fig. 1 A problem in the Color Rendering Index.

market. This lamp makes things look brilliant. However, the assessment index of this light bulb is rather low. Yet, I think this is a very good light source to be used in actual practice. In industry, since R&D is conducted to raise the index value of manufacturing products, the development may head in the wrong direction if the index is wrong.

(Ono)
Here, you mean that the industrial standard itself that specifies the quality index is not good?

(Ohno)
Exactly. I thought there will be major problems if such poor LED products with a CRI of 80 are sold on the market.

We've been doing this research for several years, and entered into the "Innovation Measurement Science," which is a competition for a research budget hosted by the Director of NIST. Our proposal was selected for preliminary document screening, and I did a final presentation in front of the Laboratory Directors of NIST, and it passed.

(Ono)
Congratulations.

(Ohno)
First, we were doing simple experiments in a small inspection booth. We found that when objects were placed inside the booth and the RGB (red, green, and blue) spectra were slightly changed, the color rendering changed greatly. At a CRI of 82, which is a good value, the red sample appeared brown. This verified that my simulation was correct (Fig. 2).

(Tanaka)
Yes, I see. Comparing 82 and 71, 71 looks more vivid.

(Ohno)
71 appears very vivid, and your hand looks good when you put it in there. But in Energy Star, it has to be 75. If a CRI of 82 was selected for Energy Star, and not 71, there will be problems. The DOE told us "hurry up and make a new industrial standard."

(Ono)
The values do not reflect the actual performance.

Integrated progression of research and standardization

(Ohno)
This has been published as a paper, but we created a new index that will solve all such problems. We are proposing a new Color Quality Scale (CQS). In this index, the light with CRI=82 in Fig. 2 will have CQS=74, and the vivid light with CRI=71 will have CQS=83, and the numbers are reversed (Fig. 3). A new assessment method is meaningless unless it becomes an industrial standard, and people won't use it unless it becomes an industrial standard. Color rendering is historically an international standard. Therefore, we made a proposal to the International Commission on Illumination (CIE) to set up a committee, where we presented our method, and we are continuing discussions.

This research will come to fruition only after it becomes an international standard and is actually used by the industry.

(Ono)
Yes, indeed. We call this "an integrated progression of research and standardization." Rather than starting to work on standardization after research is complete, we pick up the demand for standardization and this demand is reflected in the research. Then, the result is fed back to standardization. AIST claims that both must run together, and this is a good example.

(Ohno)
I certainly think so. Particularly, DOE's Energy Star is already up and running, and the CRI is currently used because the new standard was not in time. Not just Energy Star, but also the entire SSL industry is advancing rapidly,

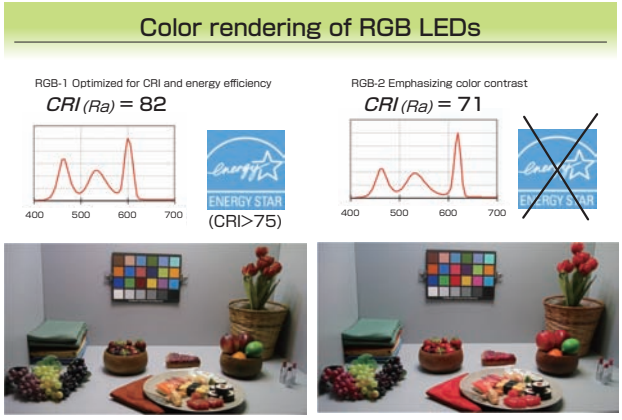

Fig. 2 Color rendering of RGB LEDs.

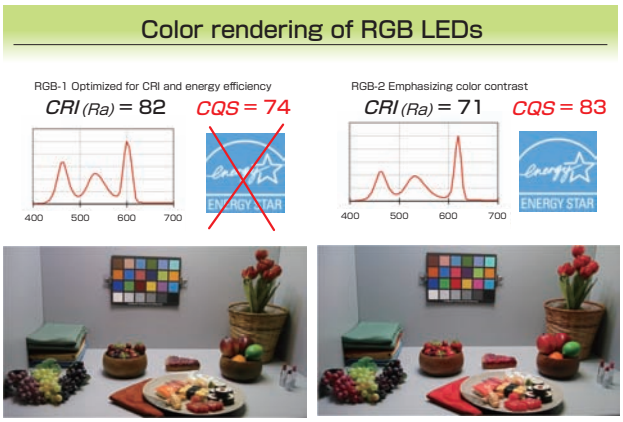

Fig. 3 Color rendering of RGB LEDs.

so if the standard cannot catch up, there is a danger that development may go in the wrong direction producing inefficient products.

Currently, the mainstream for white LED is the method in which blue emission and phosphor are combined. Some people say that RGB method is high cost and has very poor color rendering (CRI). Yet the color rendering to the eye is not that bad. The companies that are working on RGB support us with great enthusiasm.

(Ono)
RGB is composed of three wavelengths with a relatively narrow spectral width. So you will use the CQS rather than the CRI. By the way, what would the Japanese terminology for CQS be?

(Ohno)
I never thought about the Japanese for color quality scale. I'd better think of something.

(Ono)
How about *shikishitsudo*?

(Ohno)
Yes, *shikishitsudo* sounds good. For this research project, we received about half million US dollars as budget for the facilities in addition to cost of labor, so we are creating a new experimental facility where the entire room can be illuminated while freely changing the spectra, the first of its kind in the world (Fig. 4).

(Ono)
I see. You are going from a booth to a room.

(Ohno)
In a room, there is great advantage in that you can actually work in it, talk in it, and see the colors of people's faces. We can't do a final check of the new metric unless we go that far. Currently in this room, we have a temporarily installed system with only three RGB colors. In February 2009, we will have a system that can control peak wavelengths for 25 separate colors. We can study color perception under various lighting conditions, and I believe this will contribute greatly to the research on SSL.

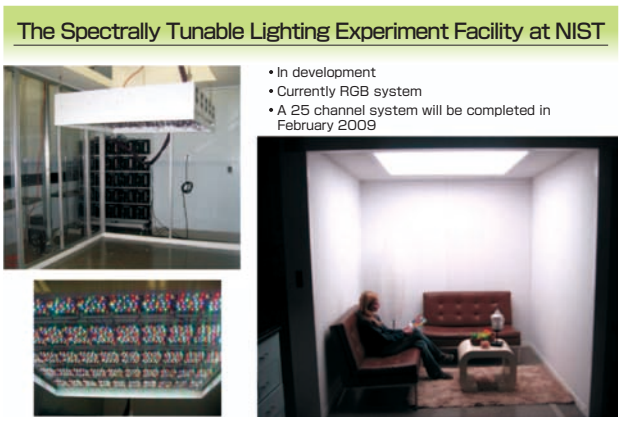

Fig. 4 The Spectrally Tunable Lighting Experiment Facility at NIST

Full Research at NIST

(Tanaka)
You are getting good results of *Full Research* for the DOE policy on SSL.

(Ohno)
Yes. As I mentioned earlier, I think the industrial standard for the chromaticity specification and another standard for the test method called LM-79 are our major outcomes. Chromaticity is the color of light, but even when the color of light is at a good setting, this does not necessarily mean that the color rendering is good. Both are related, but we first need to set the color of light as an industrial standard. Next will be the standard for color rendering.

Although I wasn't in charge, there are additional standards published, for example, the industrial standard of life testing of LEDs. The lifetime of LEDs is very long like 30,000 to 50,000 hours or even longer. Therefore, the current practice in the industry is to test LEDs only for 6,000 hours and extrapolate the degradation curve to 30,000 to 50,000 hours. This method involves very large uncertainties for projected lifetime and it was not agreed upon. Since we had a deadline for the Energy Star, this standard was published without inclusion of the projection method. How far we can go in standardizing such lifetime prediction will be our next challenge.

(Ono)
Newly created technology will progress in a good direction if there is an accumulation of data. In creating such industrial standards, what are the contributions of Japanese companies and researchers?

(Ohno)
Since ANSI and IESNA are American standard organizations, there is basically no participation from Japan. However, Japanese corporations that have companies in the United States can participate. For international standardization such as CIE, there are participants from around the world, but there is not yet very active participation by Japanese companies in LED lighting.

Carrying out research while staying in touch with the demand of industry

(Ono)
Photometry is basic research oriented while at the same

time it is an energy-saving measure that the whole world is interested in. I feel you are doing very important work that links between the two. You are practicing "engaging in research while standardizing." Since Dr. Ohno is a Group Leader at NIST, you must consider the career of young researchers. What kind of advice do you give to people whom you want to become established as researchers and also want to make contributions to society? It will be helpful to hear from you since we face the same problem.

(Ohno)
It is my experience that, when I attend committee meetings or workshops, I hear about many problems in the subject and I find what new researches will be needed. I always learn a lot from various questions asked and requests made at standards committee meetings. I try to take young researchers or let them go to these meetings and conferences as much as possible.

Of course, we let them do research freely in part, but I think it is useful to have them conduct research while staying in touch with the demands of industry.

Important for non-experts to understand

(Ono)
When publishing the results of standardization, I think it is important in which form they are presented. NIST publishes the results in various forms such as monographs and technical notes that are different from research theses. Do you think they are highly valuable?

(Ohno)
Definitely. Scientific papers are important and they must be published, but on the other hand, we also write articles for magazines for lay people. Recently we wrote for *LED Review* and *LEDs Magazine*, which are published on the Internet. I write about color rendering and measurements, and I receive good responses from people in the industry.

In addition to these efforts, NIST publishes press-release articles to the media. They are typically about two pages long. I wrote such articles recently when we completed two standards for SSL and when we developed the measurement method for high power LEDs. These are written for people who are not experts, and perhaps they may be somewhat like AIST's *Synthesiology*. These are highly recognized by management.

(Ono)
As you say, *Synthesiology* covers physics, engineering, agriculture, and pharmacology, and contains everything from life sciences to electronics and metrology standards. We have such editorial policies, and present papers in forms that can be read by people from other fields.

(Ohno)
Yes. I've read it, and felt that I can read the articles of the fields that are outside my expertise.

(Ono)
Thank you. That is one of the issues we were concerned about when we published this journal. I was a reviewer for the paper in the fields of the environment and geology, and I understood the content. I was surprised that I understood them. I was even more surprised that I was writing comments on them.

(Ohno)
You had discussions with the authors. That must have been fun.

Research community works on various issues

(Ono)
There are many important issues such as global environmental problems in which the role of science and technology is huge. However, I felt that the scientists and researchers could not exchange their thoughts, and although they are connected with society through their respective channels, they could not issue a comment as a community. I think it is great that researchers got together for the Intergovernmental Panel on Climate Change (IPCC) to collaborate and publish reports for the process of standardization. The engineers and researchers attending exchanged their thoughts to create something together. I think this is wonderful.

(Ohno)
Standards are taken for granted, and it is a low-profile field. In fact, it's difficult for this field to be visible. Therefore, the issue of SSL standardization was an opportunity for carrying out a major change. SSL is once-in-a-hundred-years event in the history of light sources. I think demand is very high, so if we capture the opportunity well, we can make many contributions as a national institute. There's measurement technology, and in some parts we are moving into the research area of vision science. That is leading to a big dream led by DOE, and I hope to contribute to it.

(Tanaka)
Japan has similar demands and issues, but perhaps we need a clear message in terms of policy.

(Ono)
Thank you very much for talking with us today. I felt there were many common points with *Synthesiology* that came to light.

(Ohno)
It was informative for me, too. Thank you very much.

Profile of Yoshi (Yoshihiro) Ohno

Currently, group leader of the Optical Sensor Group, Optical Technology Division, National Institute of Standards and Technology (NIST) in Maryland, U.S.A. Graduated from the School of Science and Technology, Kyoto Institute of Technology in 1977. Joined the Lighting Research Laboratory, Matsushita Electric Industrial Co. Ltd. (currently Panasonic Corporation) in 1977, and worked on photometry and colorimetry. Studied at NIST (formerly National Bureau of Standards) of the U.S.A. for two years from 1984, and engaged in research of absolute measurement integrating sphere. Received Ph.D. in engineering from Kyoto University in 1993. Immigrated to the United States in 1992, joined NIST, and was appointed Photometry Project Leader. Group leader from 2003. Currently Director of International Commission on Illumination (CIE) Division 2. Also active in American National Standards Institute (ANSI), Illuminating Engineering Society of North America IESNA, and International Committee of Weights and Measures (CIPM) - Consultative Committee of Photometry and Radiometry (CCPR).