Consortium style study on the development of highly reliable photovoltaic modules and acceleration test methods

— Management of the "Consortium Study on Fabrication and Characterization of Solar Cell Modules with Long Life and High Reliability" —

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[Translation from *Synthesiology*, Vol.9, No.1, p.39-50 (2016)]

The "Consortium Study on Fabrication and Characterization of Solar Cell Modules with Long Life and High Reliability" was established by the National Institute of Advanced Industrial Science and Technology. The consortium had over 90 participating organizations, which were mostly module-material manufacturers. The purpose of the consortium was to improve reliability and lifetime of photovoltaic modules, and to develop acceleration test methods for accurate assessment of module lifetime. This paper details the establishment procedures and management policies of the consortium, with particular focus on resolving competing interests among the participants, as viewed from the perspective of the secretariat.

Keywords : Photovoltaic module, reliability, consortium, material manufacturer, human resource cultivation

1 Background of the establishment of the consortium

To reduce the cost of photovoltaic power generation, it is essential to increase the generated power during a lifespan through increased reliability and lifetime in addition to high efficiency and reduced manufacturing costs. The reliability and lifetime of the photovoltaic module are determined by the materials of the module including electrodes, interconnector ribbons, back sheets, encapsulants, sealing materials, potting materials, and others. Figure 1 shows the cross-section structure of the photovoltaic module. The interconnector ribbons play the role of soldering, and alternately connect the electrodes on the surface of the photovoltaic cells to the ones on the back. The back sheets protect the module against moisture ingress, and also maintain the electrical insulation and mechanical strength. The encapsulants fix the cells to prevent breakage. The sealing and potting materials protect the module from moisture ingress, just like the back sheets. On the other hand, as indicated in the text inside the box of Fig. 1, when the photovoltaic module is exposed outside for a long time, degradation of such materials occurs and may cause decreased power generation. Therefore, to increase the reliability and lifetime of photovoltaic modules, R&D is necessary in various phases from the materials development to prevent degradation to the assembly of modules, by conglomerating the findings of the photovoltaic cell manufacturers and the chemical and material companies that manufacture the module materials, along with the wide-ranging knowledge of physics, chemistry, electrical and electronic engineering, material science, and others. Therefore, the Research Center for Photovoltaics (this research unit changed its name to Research Center for Photovoltaic Technologies, and then changed its name back to Research Center for Photovoltaics) at the National Institute of Advanced Industrial Science and Technology (hereinafter will be called AIST) established a consortium mainly composed of the chemical and material manufacturers that were involved or were planning to enter into the photovoltaic industry. The plan was to promote R&D through close collaboration with the photovoltaic companies, and preparations were started at the Research Center from the latter half of fiscal year (FY) 2008. In 2008, when the consortium was planned, there was no university or public research institute that could engage in trial production and evaluation of photovoltaic modules in Japan, and verification of effectiveness for the module materials could only be accomplished by sending personnel or materials to the Fraunhofer Institute for Solar Energy Systems (Fh-G ISE) in Germany or the Energy research Centre of the Netherlands (ECN). Therefore, there were demands from the chemical and material manufacturers to set up a trial production and evaluation line in Japan. Of course, tests could be done at the Japanese photovoltaic companies, but in many cases, the conditions were not favorable for the chemical and material manufacturers, because the photovoltaic companies

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Original manuscript received January 16, 2015, Revisions received July 12, 2015, Accepted August 4, 2015

would not readily accept testing of new materials, would not disclose the results even if the testing was done, and partnership would not be possible with any other company if good results were obtained. Another background was that the research of photovoltaics at universities and public research institutes focused solely on cell research and study on modules was hardly done. AIST intended to academically organize as scientific findings the know-how of module reliability that the photovoltaic companies kept to themselves.

The consortium members were widely sought by open invitation, utilizing the example of the Flexible Solar Cell Substrates Consortium[1] conducted previously at the Research Center for Photovoltaics. The briefing session for the open invitation was held in Tokyo on February 2, 2009, and 168 participants were obtained. Another session was held in Fukuoka on February 17, 2009, and 117 participants were gathered. The reason for holding a session in Fukuoka was because a trial production and evaluation line for photovoltaic modules was due to commence operation in October 2010 at AIST Kyushu, and the plan was to use this facility as part of the research. We decided to hold individual interviews later with the participants that showed interest in establishing the consortium at the briefing. The 101 candidate consortium participants with whom we conducted interviews were convened, and a meeting for preparation of establishment was held in Tokyo on May 28, 2009. At the preparation meeting, we explained the principles and management policies of the consortium, exchanged opinions with all the candidates, and a social gathering was organized. On July 9, 2009, the second preparation meeting was held at Tsukuba, and 90 members belonging to the participating organizations that officially decided to participate in the consortium were convened. The consortium was named "Consortium Study on Fabrication and Characterization of Solar Cell Modules with Long Life and High Reliability (hereinafter, will be called the Consortium)," and there were 31 participating organizations (private companies), one collaborating organization (Photovoltaic Power Generation Technology Research Association, hereinafter, will be called PVTEC), and nine cooperating organizations. It was formally established on October 1, 2009 (with additional participation after the start, there were 33 private companies as participating organizations and 10 cooperating organizations in Consortium I in the end).

On October 21, 2009, the opening ceremony was held in Tokyo with Tamotsu Nomakuchi, President (at the time), AIST. Also attending were: Masanori Suzuki, Director-General (at the time), Industrial Science and Technology Policy and Environment Bureau, Ministry of Economy, Trade and Industry; Fumio Ueda, Executive Director, New Energy and Industrial Technology Development Organization; and Yukinori Kuwano, President (at the time), PVTEC.

The membership fee (paid to a joint research fund) of a participating organization was five million yen per fiscal year. The participating organization was required to dispatch one or more joint researchers to AIST, but they were not obliged to be constantly present, and flexibility was given to the dispatching of the researchers where they could visit AIST occasionally to conduct experiments depending on the progress of the research. It was determined that the constant stationing of researchers was difficult for the participating organizations. Moreover, there was a limitation on the AIST staff and research apparatuses, and it was not realistic for all

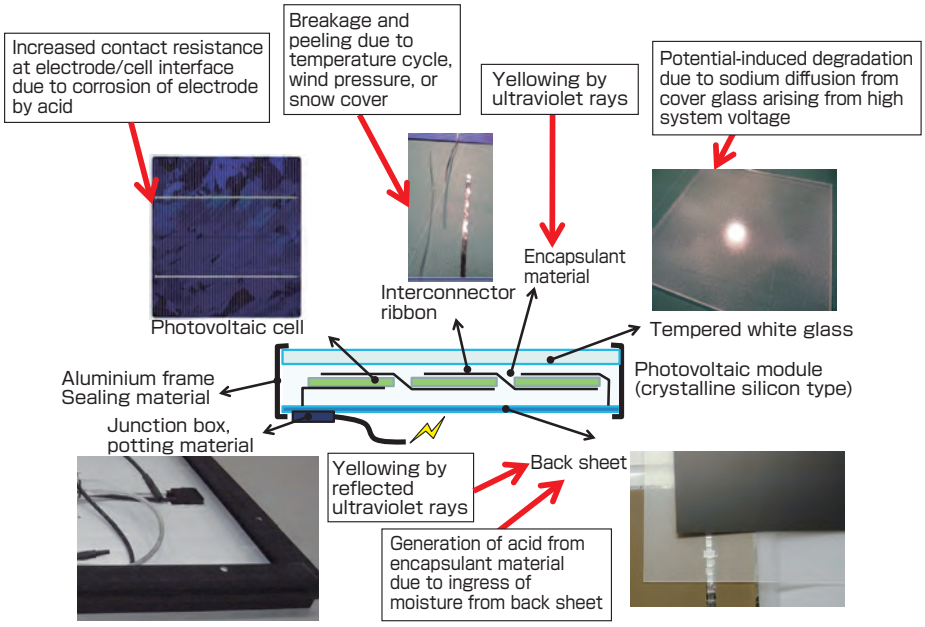

Fig. 1 Cross-sectional structure of photovoltaic modules
Text in the box shows the degradation factors that arise from module materials.

dispatched researchers of the 31 companies to be present at AIST to conduct experiments every day. For the reliability of photovoltaic modules, there was an agreement to engage in R&D under the strong collaboration with PVTEC before the establishment of the Consortium. Therefore, PVTEC was positioned as the collaborating organization, and becoming a member of PVTEC was set as a requirement for the participating organizations of the Consortium. Also, cooperating members were defined as those who would be requested to cooperate in advancing the Consortium research through provision of various findings concerning photovoltaic modules and through provision of materials, apparatuses, and analysis methods, although they would not be engaging directly in research. While the cooperating organizations were not required to pay to the joint research fund, they were asked to dispatch researchers when needed.

The content described in this paper will mainly concern the establishment and the management of the Consortium. The specific research results of the Consortium would be limited to the ones described in Chapter 6, and for full research results, please refer to the Reports[2]-[4] and the published papers listed in them, distributed at the three open report meetings that were held during the Consortium period.

2 Principles and management policies of the Consortium

The most important point of a consortium is to present the principles and conduct management based on the principles without going off course. The basic principle of this Consortium was to conduct R&D using the technological platform provided by AIST, to greatly improve the reliability and lifetime of photovoltaic modules, and to create unique technologies for dramatic cost reduction. Based on this principle, we encouraged open innovation by the participating organizations of the Consortium. The specific management policies were that the research results obtained in the Consortium would be, in principle, disclosed, and publications as papers and presentations at academic conferences were prioritized over patent application. As mentioned earlier, considering the fact that not much academic investigation had been done for the module technology and module reliability, we decided to devote ourselves to fundamental research for the purpose of obtaining academic and systematic research data, for the research of A Members of Consortium II that will be explained in Chapter 4. To realize such policies, we decided to take strict stance against participating organizations bringing in profit interests into the Consortium.

Based on the above principles and management policies, we created a joint research contract and management guidelines. This was done not solely by AIST, but volunteers joined from the Consortium members, and discussions were held about once in two weeks by the people of the following groups: Collaboration Promotion Department, AIST (currently, Collaboration Promotion and International Affairs Division, Research and Innovation Promotion Headquarters), Intellectual Property Department, AIST (currently, Intellectual Property and Standardization Promotion Division, Research and Innovation Promotion Headquarters), as well as the researchers of the Research Center for Photovoltaics, AIST; and participating organizations. It is thought that this involvement of the participating organizations as volunteers in creating the joint research contract and management guidelines played an important role in nurturing trust among the participating organizations and AIST. Majority of the volunteers from the participating organizations that were involved in the creation attended the executive meetings held about once a month as officers of the management committee after the establishment of the Consortium, to solve various obstacles with AIST staff, particularly during the confusion at the start of the Consortium. In the management guideline, various committees that configured the Consortium, including the management committee, the technical advisory committee, and the invention review committee were defined. Particularly, valuable advice was given on the direction of research based on the Consortium principles, from the technical advisory committee composed of about 10 members, and this played an essential role in managing the very start of the Consortium. The members of the technical advisory committee were selected from the members of photovoltaic companies, apparatus companies, material manufacturers, universities, and AIST. By having the technical findings accumulated by the photovoltaic companies reflected in the research of the Consortium participants that were mainly composed of material manufacturers, we ensured that the material manufacturers could engage in research from multi-faceted perspectives. The management guideline is presented in entirety in Reference [4].

3 Management of Consortium I

Consortium I was established under a contract period of one and half years from October 1, 2009 to March 31, 2011. The management of the Consortium immediately after launch was extremely difficult. There were several reasons, but the ones arising from AIST were that AIST hardly had any experience in module research, was not able to take the leading role for the participating organizations, and fumbled along in carrying out the daily research activities. Also, many AIST staff members joined the Consortium immediately before the establishment, and the communication among them was insufficient. On the other hand, the issues of the participating organizations were the different degrees of interest among the organizations. There were members who were already doing business in the photovoltaic industry,

and others who joined with almost no knowledge but hoped to seek opportunities in the emerging photovoltaic industry. The latter members tended to sit and wait for AIST to come up with a solution when the research hit a wall. Joint research must be done by all parties working to arrive at a solution, and our inability to emphasize this policy at the start of the Consortium is a point of reflection.

For the inventions in the Consortium, not once did we have differences of opinion among the Consortium members that required convening the invention review committee, as there were only a few inventions as will be explained later. In the Consortium where all the participating organizations signed the same contract and were on equal terms, it seemed that there was a consciousness that the organization should take the same steps as other participants, and the trouble pertaining to invention was less likely to occur than in a one-to-one contract. On the other hand, there were differences in interest due to cultures and strategies of the participating organizations, such as in the publications of results as papers and presentations at academic conferences, and it could not be denied that some participating organizations were more passive than others.

After about half a year from the launch of Consortium I, some researchers became enthusiastic in becoming involved in the Consortium activities as a whole. This resulted in the search for joint research topics, where topics that might lead to issues solved for the entire industry although it might not lead to short-term profit of the participating organizations were collected, and the volunteers of the Consortium jointly engaged to study the topics. There were three specific topics: 1) survey of the influence of properties of the module encapsulant materials on the module performance, 2) actual state of failures and degradation in the photovoltaic modules, and 3) development of novel testing methods for modules. The AIST researchers took the lead to research the topics. For the research results, after exchanging opinions at the technical advisory committee, Topic 2) for which the research could be started in a relatively short period of time was started immediately, and for Topics 1) and 3), it was decided that research would be started in Consortium II. 11 researchers participated in Topic 2), and research results were presented at a total of 12 meetings to further the discussion. As can be seen from the fact that the results were reported in detail, covering over one-third of the 327 pages of Consortium I Report, this search for joint research topics played a major role in solidifying the Consortium. It should also be noted that this search was proposed by the participating organizations.

4 Establishment of Consortium II

As mentioned in Chapter 3, three joint research topics were found, including the topics that were not addressed in Consortium I, and this allowed the authors to mold the concept for Consortium II, a continuation of I. This meant dividing the Consortium members into A Members who would mainly engage in the above topics that were fundamental research topics where the results could be readily shared by all participating organizations, and B Members who would verify the effectiveness of the module materials that the companies developed on their own.

Although the activities of A Members would not generate short-term profit for the companies, they might generate fundamental results pertaining to the reliability of photovoltaic modules, and might contribute to both the academia and industry. Basically, A Members would engage in the three core research that carried over from the three topics set in the search for joint research topics of Consortium I. Table 1 shows the research of three core topics in which the A Members engaged. Since the A Member's research would contribute to the entire photovoltaic industry, the fee of the A Member was set at 2 million yen/FY that was lower than the fee for B Members. To guarantee the continuous research activity throughout the Consortium, no new members would be accepted during the three-year Consortium II period for the A Members, and no withdrawals would be accepted. Special Member category was set up for A Members which exempted them from membership fees, and removed the requirement that they had to be members of PVTEC. There were the following reasons for doing so. First, by exempting the module manufacturers and related organizations from the membership fee as Special Members, we expected such organizations to participate actively in the Consortium. In Consortium I, it was indicated that the Consortium members who were mainly material manufacturers and photovoltaic manufacturers did not have a strong relationship, and the objective was to solve this issue. Second, in order to incorporate the academic findings into A Members that engage in fundamental research, we hoped to gain active involvement of universities and others by exempting the membership fee. By setting up the special membership system, we opened a way for some photovoltaic manufacturers and universities that were not members of PVTEC to participate as A Members.

On the other hand, the membership fee of B Members was set at a basic 3 million yen/FY to which the amount corresponding to the number of trial production would be added (specific fee). For Consortium I, an equal membership fee of 5 million yen/FY was set for all participating organizations, but the specific fee was set so the fees of the B Members that engaged in average activities would be about equal to the fee of Consortium I. We mentioned that there were differences in interest among the members in Consortium I, and it seemed that the differences were generated from the differences in the purpose of participation and expectation for the Consortium

Table 1. Contents of the three core research topics in which the A Members engaged

Topic No.	Topic title	Outline	R&D points
1	Detailed survey of long-term exposed modules	To analyze the occurrence of module failure/trouble and the degradation of power generation performance, through the destructive analysis of modules that have been exposed for a long period of time or through the survey of installed modules.	・Carefully survey and analyze the degradation and failure factors at a microscopic level through destructive test of long-term exposed modules. ・Collect case studies of failures/troubles of modules installed in megawatt-scale photovoltaic plants.
2	Clarification of degradation factors using the test modules	To clarify the degradation factors of module performance by developing a test module that allows visualization of the area of degradation, a test module that intentionally includes the degradation factor, and sensing technology.	・Develop a test module that allows visualization of the area of degradation, and a test module that intentionally includes the degradation factor. ・Develop sensing technology that enables monitoring the degradation status. ・Clarify the required properties of the module materials and structures through the evaluation of degradation factors.
3	Development of novel reliability test methods	To develop novel reliability test methods, based on the results of Topics 1 and 2.	・Develop novel reliability test methods such as an acceleration test that combines major degradation factors and shortening of the test time by highly accelerated tests. ・Develop novel reliability testing apparatuses. ・Reflect the obtained results in standards.

of individual participating organizations. These differences could not be resolved completely in Consortium I, but roughly separating the research objectives to fundamental research for A Members and short-term R&D for B Members contributed greatly in resolving the differences in interest. Also, it seemed that the membership fee based on a specific fee system helped resolve the differences in interest and the feeling of inequality.

Moreover, we set up the C Membership where the members could learn about the findings in photovoltaic fields through participating in technological exchange sessions held four times a year, in hopes that such findings might help development in their companies and might encourage participation as B Members. In the technological exchange sessions, lectures were given by external experts, and the results of A Members were presented before they became officially public. On average about 100 people participated in these technological exchange sessions, and they functioned as a place of communication for all Consortium members including the A, B, and C Members as well as the cooperating organizations and technical advisory committee members. The membership fee for C Members was set at 500 thousand yen/FY, and one could participate readily due to the lowered hurdle of the membership fee. When the universities and public research institutes participated as C Members, the membership fee was waived in hopes of widening the horizon of this field. While the C Members participated in the Consortium activities, they were less likely to create intellectual properties compared to the research activities of the A and B Members, and various discussions were held on the pros and cons of concluding joint research contracts equivalent to the ones for A and B Members. As a result, both the contract relationship and smooth participation environment were maintained by concluding a joint research contract where the items about intellectual property were greatly reduced, recognizing that there will be no creation of intellectual property. Similarly to Consortium I, a system was established for the cooperating organizations that contribute to the acceleration of Consortium R&D, through provisions of materials, apparatuses, and analysis methods, as well as provision of various findings on photovoltaic modules. The main roles and participating conditions of the A, B, and C Members are shown in Table 2, including comparison with Consortium I.

For the establishment of Consortium II, a planning committee composed of volunteers of Consortium I members and exterior experts was established to bring in wide-ranging expert opinions. Three focused exchanges of opinions were held in a relatively short period of time, on August 31, October 5, and October 28, 2010. The framework and principles of Consortium II was formed based on the above draft by the authors while incorporating the expert opinions, and these were reflected in the application guideline. The briefing session of Consortium II was held in Tokyo on December 16, 2010 and in Tosu, Saga Prefecture on December 17, 2010, and 158 and 76 people attended, respectively. Ultimately, the number of participants surpassed that of Consortium I, and there were 19 participating organizations as A Members, 20 as B Members, 27 as C Members, and 15 cooperating organizations (at the time of establishment). Consortium II was established on April 1, 2011.

Table 2. Comparison of the main role and the participation conditions for A, B, and C Members for the organizations of Consortiums I and II

	Consortium I participating organizations	Consortium II A Members	Consortium II B Members	Consortium II C Members
Main role in the Consortium	・Basically engage individually in research for the topic and goal set by each participating organization, but the research results will be shared at the monthly research meetings.	・Several A Members and AIST form groups and engage jointly in the core topic research. A group is formed for each topic, but information is shared among the groups. ・After the members are set, division of roles is determined based on the consultation with AIST. ・Special Members are defined as the module manufacturing companies, organizations working on standardization, universities, and public research institutes. ・Dispatched researcher will engage in the core topic research at AIST, at engagement ratio (or more) decided after consultation, but the participation in the research topic as B Member will be accepted if additional fee is paid. ・There will be no rules for engagement ratio for the Special Members.	・Conduct trial production and evaluation of module using the materials of the proposing party under individual joint research contract with AIST. ・Joint research is conducted in collaboration with other B Members under mediation by AIST, as needed. ・If requested, AIST mediates the collaboration with module companies.	・Participate in technological exchange sessions (closed participation; results of A and B Members before publication and disclosure information are provided).
Basic participation fee	・5 million yen/FY ・Multiple fiscal year contract from 2009 to 2010	・2 million yen/FY (free for Special Member) ・Multiple fiscal year contract from 2011 to 2013. ・Basic additional participation fee is 1 million yen/FY when engaging in research topic as B Member (Special Member must pay 3 million yen/FY).	・3 million yen/FY ・Single fiscal year contract	・500 thousand yen/FY (free for universities and public research institutes) ・Single fiscal year contract
Fees for trial production and evaluation	・Included in basic participation fee	・Included in basic participation fee when engaging in research topic as A Member. ・Specific fee is set considering the content of trial production and evaluation (size, number, occupancy time, etc.) when engaging in research topic as B Member.	・Specific fee is set in accordance to the content of trial production and evaluation (size, number, occupancy time, etc.).	・Does not apply
Type of contract with AIST	・Conclude joint research contract. Basic participation fee and per capita costs are paid to AIST joint research fund, and the term and method of payment shall be set in the joint research contract.	・Conclude joint research contract. Basic participation fee, additional fee, and per capita costs are paid to AIST joint research fund, and the term and method of payment shall be set in the joint research contract.	・Conclude joint research contract. Basic participation fee, additional fee, and per capita costs are paid to AIST joint research fund, and the term and method of payment shall be set in the joint research contract.	・Conclude joint research contract. Basic participation fee is paid to AIST joint research fund, and the term and method of payment shall be set in the joint research contract.
PVTEC membership	・Must apply for PVTEC membership.	・Must apply for PVTEC membership (Special Member does not need to do so).	・Must apply for PVTEC membership.	・Do not have to apply for PVTEC membership.

Table 3. Members that participated in the Consortium

Membership category	Name of organizations
Consortium I participating organizations	Asahi Glass Co., Ltd.; Asahi Kasei Chemicals Corporation; C. I. Kasei Co., Ltd.; Dai Nippon Printing Co., Ltd.; Daicel Chemical Industries, Ltd. (currently, Daicel Corporation); Daiken Chemical Co., Ltd.; Daikin Industries, Ltd.; Denki Kagaku Kogyo K. K. (currently, Denka Company Limited); DIC Corporation; Du Pont-Mitsui Polychemicals Co., Ltd.; DuPont K. K.; ESPEC Corp.; Fujifilm Corporation; Fujimori Kogyo Co., Ltd.; Hitachi Chemical Co., Ltd.; Kaneka Corporation; Kuraray Co., Ltd.; LINTEC Corporation; Mitsubishi Plastics, Inc.; Mitsubishi Rayon Co., Ltd.; Mitsui Chemicals, Inc.; Nissan Chemical Industries, Ltd.; Nitto Denko Corporation; Okura Industrial Co., Ltd.; Sekisui Chemical Co., Ltd.; Sony Chemical & Information Device Corporation (currently, Dexerials Corporation); ThreeBond Co., Ltd.; Toppan Printing Co., Ltd.; Toray Engineering Co., Ltd.; Toray Industries, Inc.; Toyo Aluminium K. K.; Toyobo Co., Ltd.; ULVAC, Inc.
Consortium I collaborating organization	Photovoltaic Power Generation Technology Research Association
Consortium I cooperating organizations	Dow Corning Toray Co., Ltd.; Hanwha Q CELLS Japan Co., Ltd.; Japan Electrical Safety and Environment Technology Laboratories; Kikusui Electronics Corporation; Kobelco Research Institute, Inc.; Lasertec Corporation; NPC Inc.; SAES Getters S.p.A.; Teijin DuPont Films Japan Limited.; Yocasol Inc. (currently, Japan Solar Factory Co., Ltd.)
Consortium I organizations selected for technical advisory committee	ESPEC Corp.; Gifu University; Kaneka Corporation; Mitsubishi Heavy Industries, Ltd.; National Institute of Advanced Industrial Science and Technology; Sharp Corporation; Toray Industries, Inc.
Consortium II A Members	Choshu Industry Co., Ltd.; Dai Nippon Printing Co., Ltd.; Daikin Industries, Ltd.; DuPont K. K.; ESPEC Corp.; Hitachi Chemical Co., Ltd.; Industrial Research Institute of Ishikawa; Japan Electrical Safety and Environment Technology Laboratories; Kaneka Corporation; Mitsubishi Electric Corporation; Photovoltaic Power Generation Technology Research Association; Ritsumeikan University; Teijin DuPont Films Japan Limited.; The Japan Electrical Manufacturers' Association; Tokyo Electron Limited.; Toppan Printing Co., Ltd.; Toyobo Co., Ltd.; ULVAC, Inc.; Yocasol Inc. (currently, Japan Solar Factory Co., Ltd.)
Consortium II B Members	Asahi Kasei Corp.; Dai Nippon Printing Co., Ltd.; Daikin Industries, Ltd.; Denki Kagaku Kogyo K. K. (currently, Denka Company Limited.); DIC Corporation; Du Pont-Mitsui Polychemicals Co., Ltd.; Fujifilm Corporation; Hitachi Chemical Co., Ltd.; Kuraray Co., Ltd.; Kyodo Printing Co., Ltd.; LINTEC Corporation; Nissan Chemical Industries, Ltd.; Nitto Denko Corporation; Okura Industrial Co., Ltd.; Shin-Etsu Chemical Co., Ltd.; Sony Chemical & Information Device Corporation (currently, Dexerials Corporation); Sumitomo Seika Chemicals Co., Ltd.; TANAKA HOLDINGS Co., Ltd.; Toppan Printing Co., Ltd.; Toray Engineering Co., Ltd.; Toray Industries, Inc.; Toshiba Mitsubishi-Electric Industrial Systems Corporation; Toyo Aluminium K. K.; Toyobo Co., Ltd.
Consortium II C Members	ADC Corporation; Bridgestone Corporation; C. I. Kasei Co., Ltd.; Daiken Chemical Sales & Mfg. Co., Ltd.; Dexerials Corporation; DIC Corporation; Fujikura Ltd.; IHI Corporation; IMV Corporation; Industrial Technology Center of SAGA; ITES Co., Ltd.; Iwasaki Electric Co., Ltd.; Kagoshima Prefectural Institute of Industrial Technology; Kanagawa Academy of Science and Technology; Kanazawa Institute of Technology; KEIWA Inc.; Kitakyushu Foundation for the Advancement of Industry, Science and Technology; Kumamoto Industrial Research Institute (Kumamoto Organic Electronics Collaboration Council); Kuraray Co., Ltd.; Kyushu Electric Power Co., Inc.; Mitsubishi Rayon Co., Ltd.; Mitsui Chemicals, Inc.; Murata Manufacturing Co., Ltd.; NEOMAX Materials, Co., Ltd.; Nisshinbo Holdings Inc.; ORIX Corporation; Saga Ceramics Research Laboratory; Saga University; SAN-EI ELECTRIC Co., Ltd.; SANVIC Inc.; Sekisui Chemical Co., Ltd.; Senju Metal Industry Co., Ltd.; Sumitomo Chemical Co., Ltd.; Togami Electric Mfg. Co., Ltd.; TOKYO OHKA KOGYO CO., LTD.; TOYO Corporation; Ushio Inc.
Consortium II cooperating organizations	Dow Corning Toray Co., Ltd.; Fuji Electric Co., Ltd.; Hanwha Q CELLS Japan Co., Ltd.; ITES Co., Ltd.; JFE Techno-Research Corporation; Kikusui Electronics Corporation; Kobelco Research Institute, Inc.; Lasertec Corporation; NEOMAX Materials Co., Ltd.; NISHIKAWA KEISOKU Co., LTD.; NPC Inc.; ORIX Rentec Corporation; SAES Getters S.p.A.; Shimadzu Corporation; Toray Research Center, Inc.
Consortium II organizations selected for technical advisory committee	ESPEC Corp.; Fuji Electric Co., Ltd.; Honda Soltec Co., Ltd.; Kaneka Corporation; KYOCERA Corporation; Mitsubishi Heavy Industries, Ltd.; National Institute of Advanced Industrial Science and Technology; Osaka University; SANYO Electric Co., Ltd.; Sharp Corporation; Solar Frontier K. K.; Toray Industries, Inc.

Table 3 shows the list of the members for Consortiums I and II.

5 Management of Consortium II

Consortium II was established with a contract period from April 1, 2011 to March 31, 2014. Immediately before the start of Consortium II, the Great East Japan Earthquake occurred on March 11, 2011, and the experimental facilities and infrastructures of AIST Tsukuba were greatly damaged and research could not be conducted for several months. There were companies among the participants of Consortium I with facilities in the disaster area, and recovery became the priority. Due to such circumstances, half-year extension was discussed for Consortium I. The extension was officially decided on April 12, 2011 at Consortium I and II joint emergency management committee meeting held at AIST Kansai to avoid the aftershocks of the earthquake. Therefore, the first half-year of Consortium II was spent trying to restore the laboratories, and there was confusion as research was carried out by both Consortium I and II members. However, since there were also experimental facilities in AIST Kyushu besides AIST Tsukuba, the effect of the disaster on the research was alleviated. This could be evaluated positively as a lesson learned in risk management.

In Consortium II, AIST was uninvolved in the research content of the B Members that individually conducted effectiveness verification of the materials developed on their own. It was thought that the B Members could readily

engage in research if left on their initiative, and the B Members themselves planned and executed research without intervention from AIST, and AIST simply provided materials, apparatuses, analysis methods, and other help based on the research situation. In contrast, AIST took lead in the research done by the A Members, and research meetings were held all afternoon about once a month, where AIST gave detailed advice on data interpretation as well as direction of research. However, over time, the B Members started to voice desire for regular research meetings, and they were held at a frequency of once in several months. This was proof that the Consortium members started to recognize the importance of discussion at such meetings rather than worry about data getting disclosed to competing companies. It seemed we have come a long way from the start of Consortium I. The technical advisory committee was not held in Consortium II, but its importance was recognized, more so than in Consortium I, as the technical advisory members attended the research meetings of the aforementioned A and B Members, and valuable comments were given on the direction of research. The technical advisory members were mostly researchers of the photovoltaic manufacturers, and active discussions were held on some areas that were kept as know-how. We believe the collaboration in the true sense progressed among the chemical, material, and photovoltaic manufacturers, which was one of the objectives of the Consortium.

6 Publication and intellectual property

Based on the Consortium principle that the research results will be disclosed, several presentations were made as papers and given at academic conferences and exhibitions. There were only 42 presentations in Consortium I since it was the start-up period, but there were 152 presentations (at the completion) of Consortium II. There were cases where the comments received at the academic conferences or exhibitions became hints in advancing the research. Moreover, we were able to witness young researchers dispatched from participating organizations grow as researchers through writing papers in English or giving presentations at international conferences. We feel major contributions were made in human resource training.

The representative research results obtained in this Consortium include the following.

Results of Consortium I

- Survey of modules exposed outdoors
  Upon surveying and analyzing 158 modules that were exposed outdoors for a long time, it was found that sodium is deposited at the interface between the encapsulant and the cell surface where peeling occurs,[2][5] and that the interconnector failures occur mainly on the backside of the cell surface.[2][6]
- Development of a high-acceleration test method
  It was found that accelerating the rate of temperature increase/decrease during the thermal-cycle test affects the acceleration of physical and mechanical degradation of the module, and that the *in situ* observation of impedance during the test is effective in capturing the signs of degradation.[7]

Results of Consortium II

- Relationship between long-term outdoor exposure and the acceleration test
  The relationship of long-term outdoor exposure and damp-heat tests that was a matter of concern for a long time was clarified using the amount of acetic acid in the module as an index. It was found that 30 years of outdoor exposure in Japan is equal to 4,000 hours of a damp-heat test at temperature of 85 ºC and relative humidity of 85 %.[4][8] This result was part of the Best Paper Award, 6th World Conference on Photovoltaic Energy Conversion.
- A combined test of salt-mist spray and potential-induced degradation
  Although the photovoltaic properties of the module is not degraded by salt-mist spray only, test results showed that the potential-induced degradation is promoted by prior salt-mist spraying. This supported the phenomenon where the potential-induced degradation seems likely to occur in the coastal area.[4][9]
- Verification of the effectiveness of a new encapsulant material
  By using polyvinyl butyral as an encapsulant material, a thin film silicon photovoltaic module with no degradation after 15,000 hours of a damp-heat test, which is about 15 times the test time set by the international standard, was successfully developed.[4][10]
- Verification of effectiveness of a new surface cover material
  By developing a module that used an acrylic resin material for the cover material, it was possible to reduce the weight of the module to half the conventional one. Moreover, it was confirmed that it passes the fire test as well as various reliability tests. It also proved to have excellent resistance against potential-induced degradation.[4][11]

For patents, there were only two patents throughout Consortiums I and II.[12][13] This was the result of upholding the policy that the technologies valued by the participating organizations such as the manufacturing method of materials or others did not have to be disclosed in the Consortium, and devoted effort was placed on research in the noncompeting fields. On the other hand, we set a rule that the patents created in the Consortium should not prevent the exploitations by other participating organizations of the Consortium. Therefore, if the research result of the Consortium was included in one of the exploitations, the exploitations by other organizations would not be prevented by the patent, and these might include the claims

of a manufacturing method for which the patent holding company would never allow the competing companies to use. For this point, rather than the whole patent permitting the exploitations by other Consortium participating organizations, we attempted resolution by revising the joint research contract and the management guideline to limit the range whereby the exploitations by other organizations would be permitted by the claims based on the research results of the Consortium. On the other hand, the legal and intellectual property divisions of the participating organizations have questioned the interpretation of the contract on whether one-to-one contract between AIST and the participating organization would be enforceable against the exploitations of other organizations. Which style of contract is better for the Consortium remains as a future issue.

7 Consortium secretariat

Since the Consortium is composed of several participating organizations, strict non-disclosure among the participating organizations would be required. The data were under uniform management by the Consortium secretariat, the data obtained from the participating organizations were clearly demarcated and stored, and the access privileges were limited. On the other hand, if the confidentiality of the participating organizations were thoroughly enforced, the unity of the Consortium would be lost. It was extremely difficult to maintain the balance, but through the trust nurtured as the research progressed, there were no major troubles among the participating organizations, and we were able to maintain a unified activity as a consortium. Of course, the activities of A Members were limited to noncompeting fields, and for the activities of B Members, the information that the participating organization wished to keep secret did not have to be brought to the Consortium. This had great effect on the unified management of the Consortium, but ultimately the atmosphere of nurturing trust between AIST and the participating organizations and amongst themselves was important, and such environment could not be obtained simply by setting perfect rules. Of course, the trust in AIST was nurtured as the research results were obtained smoothly. Needless to say, the trust among the participating organizations grew because it was a consortium managed under AIST.

In a consortium in which several organizations participated, difficulties were expected in adjusting the schedule because many of the apparatuses used in research would be shared and the machine time would be limited. The software with a schedule management function that could be accessed by the Consortium members was introduced. However, the presence of a highly talented secretary was crucial in the smooth flow of the Consortium secretariat work, including schedule management of visiting members, scheduling of various meetings on various subjects, making a contract with the participating organizations, budget management including the procurement of items used in research, reservation of venues for the meetings, various notifications to external participants, and management of the actual meetings. In this sense, the Consortium management was successful because we were blessed with an excellent secretary for various administrative affairs.

8 Succeeding consortium

The Consortium Study on Fabrication and Characterization of Solar Cell Modules with Long Life and High Reliability started as Consortium I on October 1, 2009, and after four and half years of activities, it ended successfully on March 31, 2014. During this period, the situation surrounding photovoltaics changed greatly. At the start of the Consortium, as the semiconductor and liquid crystal industries faced hardships, many material manufacturers shifted to photovoltaics as the next pillar of profit. However, the photovoltaic industry in Japan lost the world market share at a faster pace than semiconductors and displays, and currently, the cell and module barely reach 10 % share. Due to such changes in the situation, even the companies that manufacture and sell the photovoltaic module materials currently are struggling to maintain their footing, and there are hardly any new material manufacturers that are willing to enter this field. This situation is clearly reflected in the budget for consortium management and the number of participating organizations. At the latter half of Consortium II, one-third of the B Members decided not to continue, but the number of participating organizations did not drop dramatically due to the binding of contract during the Consortium period. However, as shown in Fig. 2, after the completion of Consortium II, the number of participating organizations decreased dramatically and the amount of budget was also drastically reduced. There were many reasons given for discontinued participation in the Consortium: the facilities for trial production and evaluation of photovoltaic modules were set up in the company; a path for R&D had been cleared in the company; the R&D for photovoltaic module was terminated after review of the business plans; and others. These are not unrelated to the fact that the Japanese photovoltaic industry is losing shares in the market. Therefore, it was impossible to establish a new, large-scale consortium. Instead, we established a small-scale, succeeding consortium with three private companies that participated in Consortium II.

The succeeding consortium continued the research of the A Members of Consortium II, and focused on the fundamental research limited to the clarification of degradation phenomena in the photovoltaic modules and test methods, and aimed at participating in the projects with a government grant. As a result of continuing such activities, the following eight organizations submitted a joint proposal: DuPont K.K.

and Toray Industries, Inc., that were continuing joint research in the succeeding consortium; Industrial Research Institute of Ishikawa, Gifu University, Japan Advanced Institute of Science and Technology, and Tokyo University of Agriculture and Technology that were engaging individually in joint research; Tokyo University of Science (a new member); and AIST. The proposal was selected as contract research entitled "Development of high performance and reliable PV modules to reduce levelized cost of energy / Development of common fundamental technologies (Reliability evaluation technology of PV systems) / Prediction of lifetime and development of test methods for photovoltaic modules" of the New Energy and Industrial Technology Development Organization (NEDO). This enabled the continuation of research for about five years to February 2020, for the fundamental technologies such as the clarification of degradation mechanism and a test method that enables lifetime prediction of photovoltaic modules. An environment is being prepared for an academically systematized study based on scientific findings related to module reliability. This has been the authors' desire since the establishment of the Consortium. Although the general direction is to promote joint research with private companies utilizing the results of the projects run by government grants, collaboration with exterior organizations cannot always be explained by a simple linear model, and peripheral situations must be considered. The story line presented here may become a model case where the project may return to a government-funded phase from joint research with private companies.

On the other hand, for the research carried out by the B Members of Consortium II, one-to-one joint research contracts were concluded rather than the consortium format. In the joint research with Shin-Etsu Chemical Co., Ltd., it was confirmed that the encapsulant material this company developed had remarkable effect on increasing reliability and that it was compatible with the current module fabrication apparatus, and a joint press release on this was published by Shin-Etsu Chemical Co., Ltd. and AIST on June 22, 2015.[14] Considerable time is necessary before the research comes into fruition, and this was a case that showed the importance of steady, continued joint research even after the completion of the consortium.

For the succeeding consortium, to ensure that the researchers could focus on yielding academic results without being tied to the interests of the dispatching companies, the following article was added to the contract: "It is understood that this joint research is a place to conduct scientific and technological discussion and to seek truth through research activities, and it is confirmed that conflict of interest among the parties entering the contract that may impede the execution of this joint research shall not be brought into the research." For the one-to-one joint research, the following article was included to enable trial production of modules for companies other than the organizations currently entered into contract: "AIST may conduct similar joint research (meaning conducting experiments using the same facilities at the same place within AIST's premises) with joint researchers other than the partner organization (entered in this contract), as long as such activities do not violate this contract, without prior or *ex post facto* notification to the partner organization." Based on various experiences we obtained in Consortiums I and II, we believe it is necessary to conclude flexible contracts that allow maximum activation of the research for both AIST and the partner organization according to the

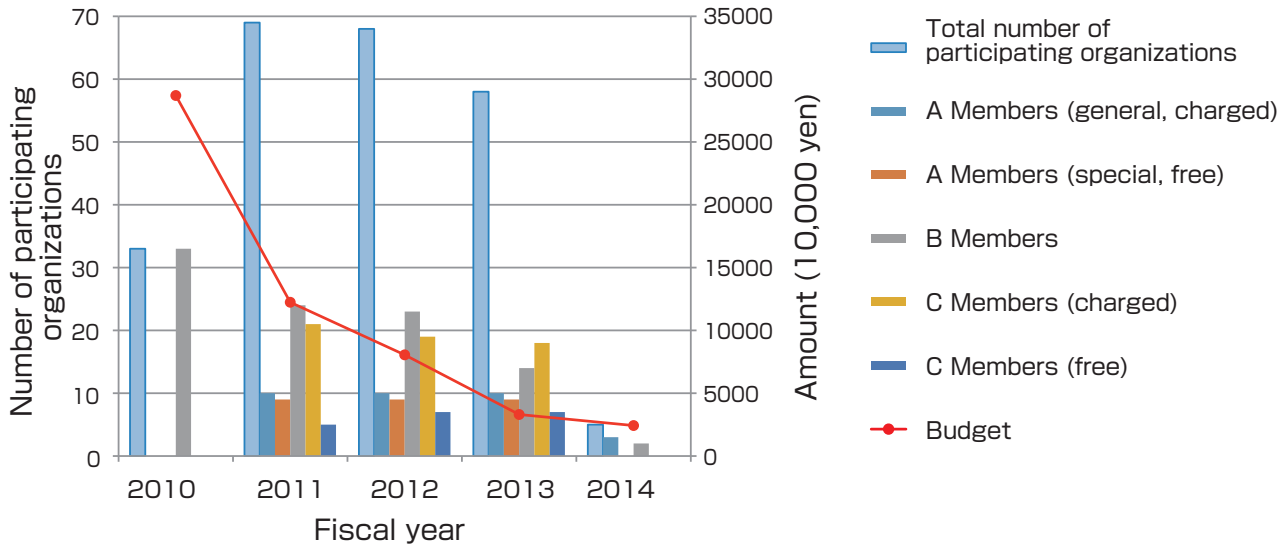

Fig. 2 Number of participating organizations in the Consortium and the transition in budget
For FY 2010, the number of participating organizations in Consortium I from the latter half of FY 2009 and the budget are shown. C Members (charged) were private companies, while C Members (free) were universities and public research institutes. For FY 2014, the participating organizations in the succeeding consortium were defined as A Members, and organizations with individual contracts were B Members.

situation.

The greatest objective of the Consortium was to engage in research of fundamental technology in noncompeting fields and academic deepening and systematization of the research results. In the future, we hope the results of the Consortium will be used in the development of application fields.

Acknowledgements

We express our gratitude to Vice-Presidents Akira Yabe (at the time), Masahiro Seto, and Junji Ito (at the time) of AIST, as we received generous support for the establishment and management of the Consortium Study on Fabrication and Characterization of Solar Cell Modules with Long Life and High Reliability. We are thankful to Shigeru Niki, former Director, and Michio Kondo, former Director of the Research Center for Photovoltaic Technologies. (The Research Center for Photovoltaic Technologies is currently called Research Center for Photovoltaics; Dr. Niki is currently Director, Renewable Energy Research Center; and Dr. Kondo is currently Supervisory Innovation Coordinator, Fukushima Renewable Energy Institute, AIST). We thank Sachiko Hoshino, secretary of Collaborative Module-Reliability Research Team, Research Center for Photovoltaic Technologies, (currently this organization is called Module Reliability Research Team, Research Center for Photovoltaics) for her smooth work and great contribution to the management of the Consortium. In drafting this article, we were inspired by the discussions with Ken-ichi Miyamoto, Manager (at the time), Planning Office, Collaboration Promotion Division, Research and Innovation Promotion Headquarters (this office is currently called Planning Office, Collaboration Promotion and International Affairs Division, Research and Innovation Promotion Headquarters).

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Leader, Strategic Industrialization Team, Research Center for Photovoltaics, AIST in 2005; Leader, Collaborative Research Team for Reliable Photovoltaic Modules in 2010; Leader, Collaborative Module-Reliability Research Team, Research Center for Photovoltaic Technologies in 2011; Leader, Module Reliability Research Team, and Deputy Director, Research Center for Photovoltaics in 2015. Also, Deputy Director, Renewable Energy Research Center in 2015. Collaborative Professor, Saitama University; and Visiting Professor, Japan Advanced Institute of Science and Technology. Received the Best Paper Award, 6th World Conference on Photovoltaic Energy Conversion in November 2014, for the research results obtained in the Consortium described in this article. As described in this paper, contributed to the general management of the Consortium, particularly on its management based on the principle of constructing an academically systematized study through fundamental research to increase reliability of photovoltaic modules and the development of the testing method. In this article, wrote Chapters 1~3, 5, and 7, and parts of Chapters 4, 6, and 8.

Nanako IGAWA

Born in 1982. Completed the master's course at the Graduate School of Public Policy, the University of Tokyo in 2007. Joined AIST in 2007. Worked at the Planning Headquarter; Personnel Office, Human Resource Department (Human Resource Division); Collaborative Research Support Office, Collaboration Promotion Division; Website and Publication Office, Public Relations Department; Public Relations Information Office, Planning Headquarter; to present. While at the Collaboration Promotion Division, worked on joint research contracts and management guidelines for new style consortiums, in which several competing companies joined, and contributed to their adjustment and organization. In this article, wrote parts of Chapters 4, 6, and 8.

Discussions with Reviewers

Overall comment

This is a descriptive article that shows that it is possible for a large number of companies to cooperate in the development of common fundamental technology through the establishment of a consortium. It presents the course by which the topics of the consortium were set based on the decision that both the construction of reliable trial manufacturing line and the establishment of reliability evaluation technology of photovoltaic modules would be valuable, because the reliability evaluation technology of academia and industry were scarce at that time. It also explains the process of obtaining the understanding of the participating companies for the consortium management policy. I believe this is a success story that will have a large ripple effect on other fields in the future.

It should be highly evaluated that for the reliability evaluation technology which is the core, the acceleration test method was established through research supported by scientific evidence to replace know-how and rule of thumb.

From the above points, it is determined that this article is appropriate for publication in *Synthesiology*.

1 Factors that led the Consortium to success

Comment (Akira Kageyama, Research Support Advisor, AIST)

As the factors that led the Consortiums I and II to success, you describe that you clearly defined the basic principles, considered the actual situation the industries were facing in creating the joint research agreement and management guideline to achieve the principles, and you carefully worked on the preliminary preparations to set rules pertaining to the handling of secret information and intellectual properties (Chapter 2). Also, in Chapter 7, you mention that the nurturing of trust amongst AIST and participating companies was extremely important. These are extremely useful to know. However, considering the composition of the article as a whole, I think you should state in Chapter 2 that various guidelines were set because you were conscious of nurturing trust. Of course, as you write in Chapter 7, a big factor is that the secretariat spent effort to respond fairly, swiftly, and appropriately, and there is no problem in emphasizing the nurturing of trust there.

Also, I think that the companies, when they first joined, had different expectations for the Consortium. Can you please offer more specific descriptions on how you managed to point the vectors of interest in the same direction?

Answer (Atsushi Masuda)

Thank you for your very accurate indication. The nurturing of trust between AIST and the participating organizations can be traced back to the fact that the joint research agreement and management guidelines were set through cooperative effort, and this point was added to Chapter 2.

For your second indication, it was not possible to point all vectors completely to one direction in Consortium I. What was useful in bundling the vectors was the categorization of members in Consortium II. I added the description in Chapter 4.

2 Topic setting and its effect

Question (Akira Yabe, NEDO Technology Strategy Center)

While there are several forms of successful open innovation, can you give specific explanation including the background of why you picked the research topics of common, fundamental, and cooperative fields such as lifetime prediction and degradation mechanism, and the test of materials that are characteristic to the companies, in the R&D for photovoltaics? Also, I think it is important to add what topics were taken to which level, and what manner of management was useful for achieving the level for topics addressed in the Consortium.

On the other hand, why didn't you address the issues that may become important in the future, such as the cost reduction by thinner crystalline silicon, or the cost reduction in balance of system other than the photovoltaic cell or module?

Answer (Atsushi Masuda)

Thank you for making precise indications. The research pertaining to reliability such as lifetime prediction and degradation mechanism of photovoltaic modules are fundamental studies, but these were not addressed actively in the academic world, and in reality, many were kept secret as know-how in the industry. In this Consortium, the research on module reliability came to light, and was promoted under the strong will of the authors who wished to contribute to the photovoltaic industry by systematizing the academic knowledge through research supported by scientific evidence. Moreover, at the time, there was demand from the industry to conduct verification tests for module reliability at public research institutes, and the Consortium was born from the matching way of thinking of the two parties.

The most important result of this Consortium was that we found the index that correlates the long-term outdoor exposure and the acceleration test. By obtaining the experimental fact that the 4,000 hours of damp-heat test was equivalent to 30 years of outdoor exposure in Japan, we set a guideline for lifetime

prediction. I believe this is the result of consortium management based on the philosophy of conducting research backed by scientific evidence, for the module reliability that was traditionally dependent on know-how and rule of thumb. I added these points in the paper.

As you indicated, topics such as thinning of crystalline silicon and cost reduction in balance of system are important. However, the former is directly linked to the industry, the phase was different from what the authors had in mind, and the topic stepped into the domain of competition, and I thought it was difficult to establish a consortium for such a topic. For the latter, the recognition of its importance was lower compared to now for the whole industry, and there was lack of human resources at AIST.

3 Categorization of the members and technical advisory committee

Question (Akira Kageyama)

When shifting from Consortium I to II, you separated the A Members whose objectives were to deepen the fundamental technology and B Members whose objectives were to evaluate the company-developed materials by trial manufacturing. Why did you decide to make such foundational improvements or changes to the consortium management?

In a consortium that crosses over several industries (materials, apparatuses, and photovoltaic cells) as described in this article, total management that takes into consideration the vertical and horizontal relationships is extremely important. You write that setting of the technical advisory committee, which was positioned horizontally regardless of the membership categorization of the participating companies in both Consortiums I and II, was effective in determining the direction of research with a wide-ranging view. What situational analysis did the authors make in setting up the technical advisory committee? Also, can you explain in more detail what kind of function you expected from the committee?

Answer (Atsushi Masuda)

In Consortium I, there was no categorization of the participating organizations, but I think this was the reason for the differences in interest among the members. The greatest reason we set the member categorization in Consortium II was, as described in Chapter 4, to smooth out the consortium management by resolving the differences in interest among the members.

Since the Consortium was established by the demand of material manufacturers, the Consortium members were composed mainly of the material manufacturers. Many photovoltaic manufacturers kept the module reliability secret as know-how to themselves, and it was difficult to have them participate as organizations. On the other hand, the management was concerned that the findings of the photovoltaic manufacturers could not be utilized if the research was conducted only by the material manufacturers and collaboration between the two did not occur. Therefore, we asked for the participation of people who could provide wisdom to the Consortium as individuals rather than organizations. I added this aim in Chapter 2. The management, the invention review, and the technical advisory committees were not equal. The technical advisory committee was a permanent committee set under the management committee. The invention review committee was a temporary committee that convened only when there was a request from the inventors and was deemed necessary.

4 Results of the Consortium and future prospect

Question (Akira Kageyama)

In the first draft, you write, "This article explains only about the establishment and management of the Consortium, and please refer to the Reports for the results." However, people would be curious to know what results were obtained under the support of your management. Therefore, can you list the titles of five or six major results and add a few lines of explanation?

I think the reliability evaluation and lifetime prediction technologies will contribute greatly to the future photovoltaic industry. Can you describe, as much as you can, the specific movements on how the results obtained will be carried on and developed further?

Answer (Atsushi Masuda)

As you indicated, I described the six representative research results of the Consortium in Chapter 6. The utilization of academic and fundamental findings obtained in this Consortium in application R&D such as the "Next-Generation Crystalline Silicon Photovoltaic Consortium," whose objective is to develop high-quality crystalline silicon photovoltaic cells using thin wafers, is highly significant, and there is much potential. I added the cases where our results led to a new government project and where we obtained a result worthy of a press release in the succeeding individual joint research, to make Chapter 8 more complete. This Consortium was conducted with the intention to academically systematize the research backed by scientific evidence, and I think this led to the next development.