Vol.6 No.3 December 2013

ISSN 1883-0978 (Print)
ISSN 1883-2318 (Online)

Synthesiology
English edition

Synthesiology editorial board

2013 3

Synthesiology-English edition ❸ 2013

National Institute of Advanced Industrial Science and Technology (AIST)

MESSAGES FROM THE EDITORIAL BOARD

There has been a wide gap between science and society. The last three hundred years of the history of modern science indicates to us that many research results disappeared or took a long time to become useful to society. Due to the difficulties of bridging this gap, this stage has been recently called the valley of death or the nightmare stage (Note 1). Rather than passively waiting, therefore, researchers and engineers who understand the potential of the research should actively try to bridge the gap.

To bridge the gap, technology integration (i.e. *Type 2 Basic Research* – Note 2) of scientific findings for utilizing them in society, in addition to analytical research, has been one of the wheels of progress (i.e. *Full Research* – Note 3). Traditional journals, have been collecting much analytical type knowledge that is factual knowledge and establishing many scientific disciplines (i.e. *Type 1 Basic Research* – Note 4). Technology integration research activities, on the other hand, have been kept as personal know-how. They have not been formalized as universal knowledge of what ought to be done.

As there must be common theories, principles, and practices in the methodologies of technology integration, we regard it as basic research. This is the reason why we have decided to publish "*Synthesiology*", a new academic journal. *Synthesiology* is a coined word combining "synthesis" and "ology". Synthesis which has its origin in Greek means integration. Ology is a suffix attached to scientific disciplines.

Each paper in this journal will present scenarios selected for their societal value, identify elemental knowledge and/or technologies to be integrated, and describe the procedures and processes to achieve this goal. Through the publishing of papers in this journal, researchers and engineers can enhance the transformation of scientific outputs into the societal prosperity and make technical contributions to sustainable development. Efforts such as this will serve to increase the significance of research activities to society.

We look forward to your active contributions of papers on technology integration to the journal.

Addendum to Synthesiology-English edition,

"Synthesiology-English edition" is a translated version of "Synthesiology", which is published quarterly, ISSN 1882-6229, by AIST.

Papers or articles published in "Synthesiology-English edition" appear approximately four months after the publication of the original "Synthesiology". Those published in Japanese are translated into English, so the views expressed in translated versions are exclusively those of the Japanese authors and editors. The Japanese authors are generally consulted regarding the translation of their papers, but are not responsible for the published English version.

Papers or articles in the "Synthesiology" originally submitted in English are also reproduced just as they were published in "Synthesiology". Some papers or articles in "Synthesiology" are not translated due to the authors' or editors' judgement.

Synthesiology Editorial Board
(written in January, 2008)

Note 1 : The period was named "nightmare stage" by Hiroyuki Yoshikawa, the then President of AIST, and historical scientist Joseph Hatvany. The "valley of death" was used by Vernon Ehlers in 1998 when he was Vice Chairman of US Congress, Science and Technology Committee. Lewis Branscomb, Professor emeritus of Harvard University, called this gap as "Darwinian sea" where natural selection takes place.
Note 2 : *Type 2 Basic Research*
This is a research type where various known and new knowledge is combined and integrated in order to achieve the specific goal that has social value. It also includes research activities that develop common theories or principles in technology integration.
Note 3 : *Full Research*
This is a research type where the theme is placed within the scenario toward the future society, and where framework is developed in which researchers from wide range of research fields can participate in studying actual issues. This research is done continuously and concurrently from *Type 1 Basic Research* (Note 4) to *Product Realization Research* (Note 5), centered by *Type 2 Basic Research* (Note 2).
Note 4 : *Type 1 Basic Research*
This is an analytical research type where unknown phenomena are analyzed, by observation, experimentation, and theoretical calculation, to establish universal principles and theories.
Note 5 : *Product Realization Research*
This is a research where the results and knowledge from *Type 1 Basic Research* and *Type 2 Basic Research* are applied to embody use of a new technology in the society.

Synthesiology – English edition Vol.6 No.3 (Dec. 2013)

Contents

A proposal for setting electric power saving rate to avoid risk of electric power shortage occurrence

— Probability evaluation system of electric power shortage occurrence under tight electric power supply —

Ikuo ARIZONO[1]* and Yasuhiko TAKEMOTO[2]

[Translation from *Synthesiology*, Vol.6, No.3, p.140-151 (2013)]

Japan has to urgently build a new system for securing electric power supply including renewable energy and for saving electric power. The electricity demand and the electricity supply based on renewable energy are influenced by the weather. Thermal power generation may also be affected by equipment failure. Therefore, plotting of a plan is required to avoid electric power shortage under inaccurate prediction for supply and demand of electricity. In this article, we propose a probability evaluation system to avoid electricity shortage. We also propose a method for setting the electricity saving rate to avoid electricity shortage while maintaining the present level of electricity shortage occurrence risk.

Keywords: Electric power demand-and-supply balance, electric power shortage probability evaluation system, Chebychev probability inequality, Bennett probability inequality, Hoeffding probability inequality

1 Introduction

Prospects for new constructions and resumptions of nuclear power plants are uncertain. Considering the present situation, securing electricity supply from the new electric generating system based on renewable energy in addition to the conventional electric generating systems, e.g. thermal plants, is an urgent issue. At the same time, it goes without saying that a system for planning electric power savings should be developed.[1][2]

From the summer of 2011, the Tokyo Electric Power Company, Inc. and the Kansai Electric Power Company, Inc. have begun to offer electricity demand-supply balance information about the ratio of the expected maximum electricity demand against the expected electricity supply of the electricity consumption peak period of any given day and the next day on the website. It seems that the expected maximum electricity demand and the expected electricity supply in the electricity consumption peak period are estimated by the past data and experience accumulated in each electric power company.

On the website of autumn, 2011, a regression model of the peak electricity demand according to atmospheric temperatures was published for the purpose of enlightening the community on electricity consumption. On this website, the regression models of temperature and the maximum electricity demand of the summers of 2010 and 2011 were illustrated. From this illustration, the difference between electricity consumption behaviors in 2011 and 2010 was quite apparent. Furthermore, it could also be seen that the electricity demand has an uncertainty under the respective regression models. However, because of the change of the electricity consumption behaviors for the present situation of the electricity supply, it is not necessarily easy to grasp the stochastic distribution of the electricity demand precisely.

Yamamoto[3] has presented a research report about the influence of the electricity power shortage caused by the East Japan Great Earthquake disaster to the Japanese economy. In this report, Yamamoto insisted that the temporary electricity savings under tight electric power supply of the last summer did not influence the production and the employment so much. Yamamoto has concluded that although the employment rate has worsened by the prolongation of the electric power savings, not the voluntary electric power savings but rather the enforced reduction of the electric power supply decreases the production and employment. This fact suggests the necessity of showing an appropriate target for electric power savings.

The Kansai Electric Power Company made an announcement requesting for a 15 % reduction in electricity consumption for the summer of 2011, after the earthquake disaster. At that time, Mr. Hashimoto who was the Governor of Osaka Prefecture demanded for a reason for the request to the Kansai Electric Power Company. However, the Kansai Electric Power Company made no reply to this query and remained silent. The summer of 2011 passed and it was

1. Graduate School of Natural Science and Technology, Okayama University 3-1-1 Tsushima-naka, Okayama 700-8530, Japan
* E-mail: arizono@et6500.mech.okayama-u.ac.jp, 2. Faculty of Management and Information Systems, Prefectural University of Hiroshima 1-1-71 Ujina-higashi, Hiroshima 734-8558, Japan

Original manuscript received June 15, 2012, Revisions received February 20, 2013, Accepted February 26, 2013

rumored that the reason for the 15 % reduction in electricity consumption was not necessarily based on a scientific background. The possibility of intentional information control was also suspected. It may be said that this indicates insufficient information disclosure by the electric power companies including the Tokyo Electric Power Company and the Kansai Electric Power Company. In the present situation, it is necessary that each individual behaves so as not to create big societal confusion. However, this can only be done if some kind of convincing information is released that can induce people to reduce electricity consumption

At the same time, as one conclusion to the decarburization of energy, an electric generating system based on renewable energy is considered. The purchase price of electricity based on renewable energy was decided under the Act on Special Measures Concerning Procurement of Renewable Electric Energy by Operators of Electric Utilities. However, since renewable energy is natural energy, the electricity supply based on renewable energy is affected by uncertain elements, e.g. weather and climatic conditions. In addition, the electricity demand is also influenced by weather and climatic conditions, which shows that the electricity demand also has much uncertainty. Moreover, because of the possibility of facility trouble and the need of maintenance check for the aging fatigue of existing facilities, the fluctuation in the electricity supply by the existing thermal power generating system should be considered.

Therefore, when we consider the present situation in our country, both the expansion of electric generating facilities and the planning of electric power saving are required in order to evade electricity shortage outbreaks. In such cases, the uncertainties about the electricity supply and demand have to be put into consideration. Furthermore, considering the electricity demand-supply balance, the construction of a valid system to call for appropriate reductions in the electricity consumption is urgent.

This paper addresses the evaluation of the electricity shortage outbreak probability of a case where there are stochastic fluctuations in the electricity demand and supply, keeping the current situation where there is no elbow room in electricity demand-supply balance in mind. It is supposed that the stochastic distributions of the electricity supply and demand are not exactly known, and that the limited information about the electricity supply and demand, such as the expectation and variance, are given.

In this paper, the system for evaluating the electricity shortage outbreak probability is presented first. As one of the contributions of the electricity shortage outbreak probability evaluation system, a procedure for deciding the electric power saving rate for avoiding electricity shortage outbreaks is presented. The reasonableness of the decided request value of the electric power saving rate can be explained using the considered system.

2 Description of the problem

The greater part of generated electricity is produced in conventional facilities, e.g. thermal power generating systems and others. In addition to this, under the present situation, generated electricity based on renewable energy has become an urgent subject. The ratio of the electricity supply based on renewable energy among all of the electricity supply is around 3 % at present and the target in 2020 is 10 %.

It is appropriate to consider that all of electricity produced by conventional electric generating systems and new generating systems based on natural energy fluctuates as mentioned above. The electricity supply based on renewable energy depends on the weather and/or climate conditions and may not necessarily bring a stable electricity supply. Accordingly, the electricity supply based on renewable energy can be understood as a random variable. Furthermore, since the temporary halts such as those caused by facility troubles or due to maintenance checks are supposed in the conventional generating systems like the thermal power generating system, electricity supply of conventional systems should also be understood as a random variable. The stochastic distributions of these random variables are not known exactly.

Similarly, as mentioned above, by the voluntary reduction in electricity consumption of consumers, the current electricity consumption behaviors have certainly changed from conventional electricity consumption behaviors. Therefore, it is considered that the stochastic distribution of the electricity demand is also unknown.

Under this situation, let us assume that each expectation and variance of the above random variables for the electricity demand and the electricity supply are available as limited information based on the forecast of the climate and weather of the next day. In this paper, the construction of the electricity shortage outbreak probability evaluation system is attempted based on the limited information about the electricity demand and the electricity supplies.

Suppose the three random variables as follows:

- electricity supply in conventional electric generating systems: e_0 ($E[e_0] = \mu_0$ and variance $V[e_0] = \sigma_0^2$),
- electricity supply based on renewable energy: e_1 ($E[e_1] = \mu_1$ and variance $V[e_1] = \sigma_1^2$),
- electricity demand: e_2 ($E[e_2] = \mu_2$ and $V[e_2] = \sigma_2^2$),

where the distributions for e_0, e_1 and e_2 are unknown. Furthermore, the independency among the random variables e_0, e_1 and e_2 is assumed. In this paper, first priority is to construct a system for evaluating the electricity shortage outbreak probability based on the limited information

mentioned above, in the present situation where there is no elbow room in electricity demand-supply balance.

Under the assumption mentioned above, we simply define the relationship of $e_0+e_1 \geq e_2$ as the situation that the electricity supply satisfies the electricity demand. Therefore, a system for evaluating the probability $\Pr\{e_0+e_1<e_2\}$ on the safe side is constructed. The phrase, "the safe side," means that the actual electricity shortage outbreak probability is definitely less than the electricity shortage outbreak probability evaluated in the system. In other words, a system for evaluating the electricity shortage outbreak probability in the worst situation under an assumed scenario is intended.

3 Proposal of a system based on probability inequalities

There are some probability inequalities to evaluate the upper bound of the upper probability of the average and sum of random variables based on limited information such as expectations and variances of individual random variables without the information about the distribution. Recently, Takemoto *et al.*[4] have considered the decision making problem of the reorder point in an inventory system by utilizing the probability inequality. Moreover, Shinzato and Kaku[5] have argued for an analysis method for finding safety inventory using large deviation principles.

In this paper, by utilizing three probability inequalities, that is, the one-sided Chebychev probability inequality,[6] the Bennett probability inequality[7] and the Hoeffding probability inequality,[8] the construction of a system for evaluating the probability $\Pr\{e_0+e_1<e_2\}$ on the safe side is proposed.

3.1 Evaluation based on the one-sided Chebychev probability inequality

Consider the upper probability $\Pr\{D>v+k\delta\}$, where D is the random variable following an unknown distribution with expectation v and variance δ^2, and k is a positive number. Then, we have the following inequality according to the one-sided Chebychev probability inequality:[6]

$$\Pr\{D > v + k\delta\} \leq \frac{1}{1+k^2}.$$

We can make the relation of $e_2-(e_0+e_1)>0$ equivalent to the relation of $D>v+k\delta$ for the purpose of evaluating $\Pr\{e_2-(e_0+e_1)>0\}$ by utilizing the one-sided Chebychev probability inequality. Then, the following equations are derived:

$$v=\mu_2-(\mu_0+\mu_1), \quad (1)$$

$$\delta^2=\sigma_0^2+\sigma_1^2+\sigma_2^2, \quad (2)$$

$$k = \frac{(\mu_0+\mu_1)-\mu_2}{\sqrt{\sigma_0^2+\sigma_1^2+\sigma_2^2}}, \quad (3)$$

where it is obvious that $k>0$ because it is natural that the planned generation of electricity should be larger than the assumed demand of electricity. Therefore, the upper bound of the electricity shortage outbreak probability can be evaluated by utilizing the one-sided Chebychev probability inequality as follows:

$$\Pr\{e_0+e_1<e_2\} \leq \frac{\sigma_0^2+\sigma_1^2+\sigma_2^2}{(\mu_0+\mu_1-\mu_2)^2+\sigma_0^2+\sigma_1^2+\sigma_2^2}. \quad (4)$$

3.2 Evaluation based on the Bennett probability inequality

Let us adopt the Bennett probability inequality[7] for a similar problem. In the case of utilizing the Bennett probability inequality, the lower limits a_0 and a_1 for e_0 and e_1, and the upper limit b_2 for e_2 are considered in addition to the expectation and variance for each e_i. It is defined as follows:

$$B = \max\{(\mu_0-a_0),(\mu_1-a_1),(b_2-\mu_2)\}. \quad (5)$$

Actually, the values of a_0, a_1 and b_2 might be given as the maximum values and the minimum values based on the past results.[10] However, in the case where those results cannot be obtained as exact values, we can evaluate these values based on the three-sigma method or the two-sigma method. Under the three-sigma method, the followings are obtained:

$a_0=\mu_0-3\sigma_0$, $a_1=\mu_1-3\sigma_1$, $b_2=\mu_2+3\sigma_2$.

Similarly, we have the followings under the two-sigma method:

$a_0=\mu_0-2\sigma_0$, $a_1=\mu_1-2\sigma_1$, $b_2=\mu_2+2\sigma_2$.

The upper bound of the electricity shortage outbreak probability can be evaluated by utilizing the Bennett probability inequality as follows:

$$\Pr\{e_0+e_1<e_2\} \leq \exp\left\{-\left(\frac{\delta}{B}\right)^2 h\left(\frac{kB}{\delta}\right)\right\}, \quad (6)$$

where δ and k are equivalent to equations (2) and (3), respectively, and the function $h(u)$ is defined as

$h(u)=(1+u)\ln(1+u)-u$.

3.3 Evaluation based on the Hoeffding probability inequality

We can evaluate the electricity shortage outbreak probability by utilizing the Hoeffding probability inequality.[8] The Hoeffding probability inequality gives the evaluation of the upper bound for the electricity shortage outbreak probability as follows:

$$\Pr\{e_0+e_1<e_2\} \leq \left(1+\frac{kB}{\delta}\right)^{-\left(\frac{\frac{\delta^2}{B}+k\delta}{B+\frac{\delta^2}{3B}}\right)}\left(1-\frac{k\delta}{3B}\right)^{-\left(\frac{3B-k\delta}{B+\frac{\delta^2}{3B}}\right)}, \quad (7)$$

where δ, k and B are defined as equations (2), (3) and (5), respectively, and the value of "3" in the right hand of the equation (7) indicates the number of random variables e_0, e_1 and e_2 in the considered system.

4 Specification of range for each random variable

The expectation and variance of the random variable is commonly required in the one-sided Chebychev, Bennett and Hoeffding probability inequalities. The one-sided Chebychev probability inequality is defined only on the expectation and variance. On the other hand, the Bennett and Hoeffding probability inequalities require the range for each random variable in addition to the expectation and variance. Therefore, when we adopt the Bennett and Hoeffding probability inequalities, the range for each random variable needs to be specified.

With the information about the electricity supply and demand, only the expectation and variance for each random variable is considered as mentioned above. It is thought that the lower limit and upper limit for each random variable are specified in conformity with the two-sigma or three-sigma methods. In this paper, the two-sigma method is employed for specified lower limit and upper limit for each random variable.

5 Relation between electricity shortage outbreak possibility and electricity supply

In this chapter, based on the one-sided Chebychev, Bennett and Hoeffding probability inequalities, the behavior of the upper bound of the electricity shortage outbreak probability for the changes of electricity supply is evaluated. Then, the influence on the electricity shortage outbreak probability by the ratio of the electricity supply based on renewable energy in the total electricity supply is examined.

At first, the expectation of the electricity demand e_2 is fixed as $E[e_2]=\mu_2=94.0$. Furthermore, the variance of e_2 is set as $V[e_2]=\sigma_2^2=(0.015\times\mu_2)^2$, because the fluctuation range of the electricity demand was illustrated as about ±3 % against the expectation of the electricity demand on the previously published website of the Kansai Electric Power Company. The total of the electricity supplies is fixed as $E[e_0+e_1]=\mu_0+\mu_1=100$. By changing μ_1 from 0.5 to 10, the fluctuation of the electricity shortage outbreak probability is examined. In this case, the variances for e_0 and e_1 are given as $V[e_0]=\sigma_0^2=(0.01\times\mu_0)^2$ and $V[e_1]=\sigma_1^2=(0.30\times\mu_1)^2$.

The combination of (μ_0, μ_1)=(97.0, 3.0) is corresponding to the present situation where the electricity supply derived from renewable energy is approximately 3 %. On the other hand, the combination of (μ_0, μ_1)=(90.0, 10.0) is corresponding to the target situation where the electricity supply derived from renewable energy will be approximately 10 % in 2020.

The result based on three probability inequalities mentioned above is illustrated in Fig. 1. In Fig. 1, the electricity shortage outbreak probability evaluated by simulation is also shown. In this case, the simulation was carried out under the situation where the distributions of the electricity supplies and demand are assumed as the log-normal distributions, respectively. The iteration number was 1,000,000.

From Fig. 1, it is found that the electricity shortage outbreak probability by simulation is less than the electricity shortage outbreak probabilities evaluated by the probability inequalities. This result indicates that the electricity shortage outbreak probability can be evaluated on the safe side. Similar results are also confirmed in the cases where the beta distribution, normal distribution and so on are assumed as the distributions of the random variables e_0, e_1 and e_2. Therefore, it can be said that the electricity shortage outbreak probability evaluated in each probability inequality is evaluated on the safe side.

For reference, in addition to the results in Fig. 1, Fig. 2 shows

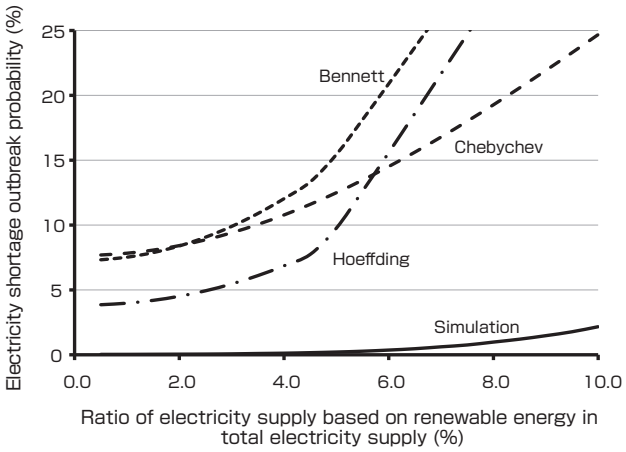


Fig. 1 Fluctuation of electricity shortage outbreak probability in the change of (μ_0, μ_1)

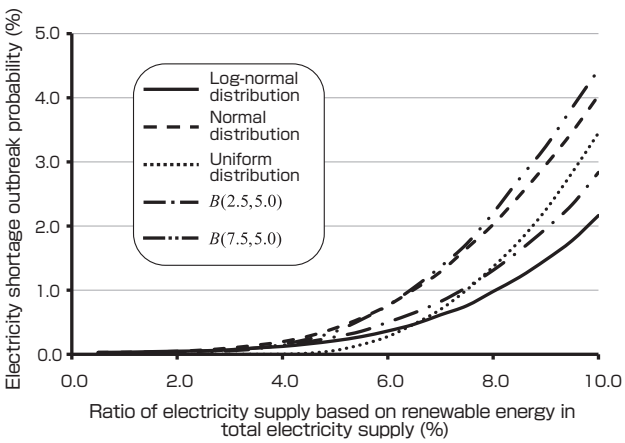


Fig. 2 Results of simulation under assumed distributions

the simulation results in the case that all the distributions for e_0, e_1 and e_2 are assumed as the normal distributions, uniform distributions and beta distributions, respectively. In these simulations, the conditions in the expectations and variables of e_0, e_1 and e_2 are corresponding to the conditions in Fig. 1.

As a matter of course, the difference of the assumed distribution of each random variable brings the difference in the electricity shortage outbreak probability. However, it is confirmed that the electricity shortage outbreak probabilities estimated under the assumed distributions are certainly less than the electricity shortage outbreak probabilities evaluated by the probability inequalities from the comparison with the results of Fig. 1. Accordingly, it is understood that the evaluation system based on the probability inequalities considered in this paper promises decision-making on the safe side.

In Fig. 1, remark that the relationship among the evaluation values of the electricity shortage outbreak probability are varied by the situation. From this fact, we consider that the electricity shortage outbreak probability is evaluated as the minimum value among them based on the one-sided Chebycehv, Bennett and Hoeffding probability inequalities.

In addition, notice that the electricity shortage outbreak probability based on the probability inequality is considerably larger than the value by simulation. Then, since the electricity shortage outbreak probability based on the probability inequality is given as a pessimistic value, the unnecessary confusion by this value should be avoided.

For reference, the electricity shortage outbreak probability by simulation in Fig. 1 is estimated as 0.0717 % , in the case where the electricity supply based on renewable energy is given as 3 % as at present. In addition, it is estimated as 2.180 % in the case where the electricity supply is 10 % in 2020. This fact means that the risk in the electricity shortage increases only by replacing the electricity supply from the conventional electric generating systems with the electricity supply based on renewable energy.

6 Relation between electricity shortage outbreak possibility and electric power saving rate

In the present situation where there is no elbow room in electricity demand-supply balance and it is difficult to increase the electricity supply, the reduction in electricity consumption might be required in order to avoid an electricity shortage outbreak, and the electricity demand-supply balance should be considered. However, excessive savings of electricity consumption without argument suppresses the economic activities and may threaten the social system.[3] In the following section, we illustrate the role of the proposed evaluation system using the probability inequality.

Suppose the stable condition for (e_0, e_1) as $(\mu_0, \mu_1)=(97.0, 3.0)$, $V[e_0]=\sigma_0^2=(0.01\times\mu_0)^2$ and $V[e_1]=\sigma_1^2=(0.30\times\mu_1)^2$, where this stable condition is interpreted as the condition in which the electricity demand-supply balance is in a stable state from the viewpoint of the electricity shortage outbreak probability. Thereafter, assume that the electricity supply by the conventional electric generating systems decreases 15 %. Then, we consider the required electric power saving rate under the condition of $(\mu_0, \mu_1)=(97.0\times0.85, 3.0)$. In this case, from Fig. 1 it is found that the electricity shortage outbreak probability based on the probability inequality is evaluated greatly on the safe side. It is not suitable to decide on the electric power saving rate by setting the value requested in the real world against the electricity shortage outbreak probability evaluated by the probability inequality.

In this paper, a stable condition mentioned above is interpreted as the condition that the electricity demand-supply balance is in a stable state from the viewpoint of the electricity shortage outbreak probability. We investigate the appropriate electric power saving rate in order to guarantee that the electricity shortage outbreak probability in a situation where the electricity supply with the conventional electric generating systems decreases 15 % is equal to that of a stable condition. The electricity shortage outbreak probability in the stable condition $(\mu_0, \mu_1)=(97.0, 3.0)$ is evaluated as 5.462 % based on the Hoeffding probability inequality.

Under the condition that the electric power saving rate is achieved as γ, the expectation and variance of the electricity demand e_2 can be described as $((1-\gamma)\mu_2, (1-\gamma)^2\sigma_2^2)$. Then, we can evaluate the electricity shortage outbreak probability in the situation of $(\mu_0, \mu_1)=(97.0\times0.85, 3.0)$ as the function of the electric power saving rate γ by the probability inequality. This probability is described as $\Pr\{e_0+e_1<e_2|\gamma\}$.

Figure 3 shows the behavior of the electricity shortage outbreak probabilities in each electric power saving rate.

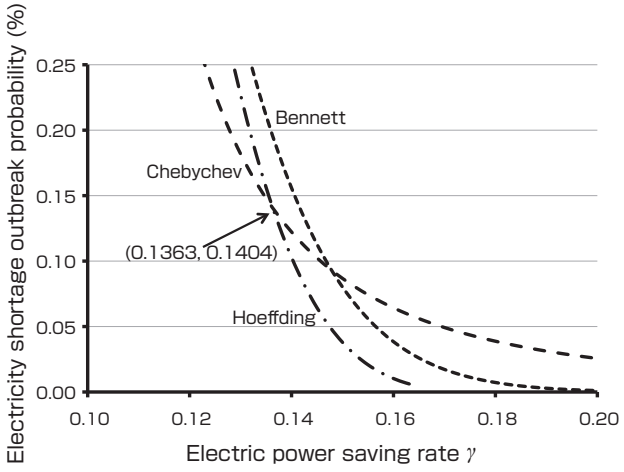


Fig. 3 Electricity shortage outbreak probabilities in each electric power saving rate

We can obtain the electricity shortage outbreak probability in the situation of $(\mu_0, \mu_1)=(97.0\times0.85, 3.0)$ as the minimum value among three values from the reason mentioned above. From Fig. 3, it is found that the evaluation by the probability inequality is shifted to the Hoeffding probability inequality from the Chebychev probability inequality after γ=13.63(%).

The result about the minimum value is illustrated in Fig. 4. In Fig. 4, the appropriate electric power saving rate for ensuring the value (5.462 %) of the electricity shortage outbreak probability is derived as γ=14.66(%).

When the electricity supply with the conventional electric generating systems decreased by 15 %, 14.55 % of the total electricity supply was lost from the viewpoint of the average. Therefore, it is found that, for the purpose of ensuring the value (5.462 %) of the electricity shortage outbreak probability in a stable condition, the electric power saving rate of 14.66 % exceeding the lost total electric power rate of 14.55 % is required. In other word, it can be interpreted that to decide on the electric power saving rate from the viewpoint of expectation is not necessarily enough. The proposed evaluation system concludes that excessive electric power saving is not necessary from the comparison of 14.66 % and 14.55 %. This is the effect of having considered the information of each variance in the electricity supplies and demand. Based on this effect, we can say that the proposed evaluation system for the electricity shortage outbreak probability has the appropriate security-oriented property.

Similar results have been observed under other loss ratios of the electricity supply with the conventional electric generating systems. Therefore, it is understood that the required electric power saving rate can be obtained under the security-oriented property by utilizing the proposed evaluation system for the electricity shortage outbreak probability. Moreover, it is concluded that the proposed evaluation system contributes to the accountability of the electric power saving rate.

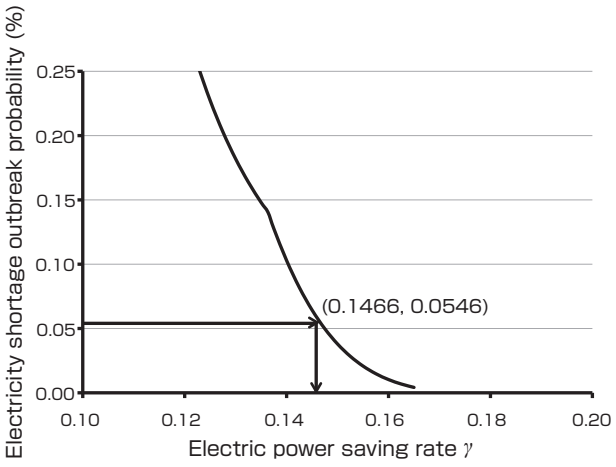


Fig. 4 Evaluation based on proposed system

7 Conclusion

At the moment, the electricity demand-supply balance is in a tight situation. Although renewable energy as a source of electricity supply is anticipated, the electricity supply based on renewable energy contains a lot of uncertainty. In addition, there is also uncertainty in the electricity demand. In view of the present situation, we have considered a system for evaluating the electricity shortage outbreak probability based on the limited information concerning the electricity supply and demand. Concretely, under the uncertainty concerning the electricity demand and supply, an evaluation system for electricity shortage outbreak probability in the worst-case scenario has been proposed by utilizing the probability inequality. Furthermore, the procedure for achieving appropriate accountability for a certain rate in the reduction of the electricity demand has been discussed by using the proposed evaluation system.

In deciding on the required electric power saving rate and the construction planning of a new electric generating system based on renewable energy using the proposed evaluation system, the features of the probability inequality should be fully explained. Basically, the information about the electricity supplies e_0 and e_1, and the electricity demand e_2 should be sufficiently disclosed in order to estimate the expectation and variance of them. We desire more information disclosure by the existing electric power companies and the Japanese government. We can, in fact, request for more information disclosure to the electric power companies and the government on the basis of using the proposed evaluation system.

Recently, the Kansai Electric Power Company has made an effort to disclose information in order to answer many questions from the local inhabitants.[11] From this information disclosure, it is found that the electricity supply and demand fluctuate every day as assumed in this paper. At the same time, the Kansai Electric Power Company announces the estimation of the electricity demand-supply balance as part of the information disclosure. However, it seems that the estimation of the electricity demand-supply balance by the Kansai Electric Power Company depends only on the expectation of the electricity supply and demand. Therefore, we desire more information disclosure for the purpose of making more useful decisions.

In addition, we consider that some new technical innovations in the case of adopting the probability inequality might be required. For example, improvement of forecast precision of the electricity demand directly influences the required electric power saving rate. Therefore, accurate estimation of the expectation and variance based on historical data accumulated in the electric power companies will be an important innovation. Furthermore, considering that the

probability inequality is a pessimistic evaluation, more effective policy decision-making is enabled by devising a higher-performance probability inequality which gives tighter probability.

Here, we give some explanations concerning the probability inequalities adopted in this paper. Because the electricity shortage should not happen, the electricity shortage outbreak probability has to be evaluated as a relatively small value. Therefore, some probability inequalities with the feature of giving a pessimistic evaluation have been adopted in this paper. Concretely, we employ three probability inequalities of one-sided Chebychev, Bennett and Hoeffding probability inequalities. The one-sided Chebychev probability inequality[6] which is a well-known and basic probability inequality, gives an evaluation based on the information about the expectation and variance of the random variable. Both the Bennett and Hoeffding probability inequalities need the information about the range in addition to the expectation and variance of the random variable. This information is observable in actuality. The device to give the range using the expectation and variance is presented in this paper. Talagrand[12] and Bentku[13] have mentioned that the Hoeffding probability inequality is extremely useful among the existing probability inequalities evaluated under the same conditions. The Bennett probability inequality is the basis of the derivation of the Hoeffding probability inequality. Therefore, both the Bennett and Hoeffding probability inequalities are also employed in this paper.

There are other probability inequalities not adopted in this paper, for example, the Markov probability inequality, the Chernoff probability inequality and another Hoeffding probability inequality. Although the Markov probability inequality[9] is a basic probability inequality shown in various textbooks about the probability theory, evaluation by the Markov probability inequality based on information of the lower limit and expectation of the random variables is not exactly practical. There is another Hoeffding probability inequality[8] which can evaluate by using the information on only the range of random variables. However, since this Hoeffding probability inequality gives a larger value than the Hoeffding probability inequality in this paper, this Hoeffding probability inequality has not been employed here. There is the Chernoff probability inequality which is considered a well-known probability inequality. The Chernoff probability inequality uses information of probability distributions of random variables.[14][15] Therefore, in the situation considered in this paper, it is not suitable to adopt this Chernoff probability inequality.

Although there may be some critical comments, we consider that the system proposed in this paper is presently of a certain completed form under the available information in order to evaluate the electricity shortage outbreak probability. However, it is important to improve the performance of the probability inequalities. By deriving probability inequalities with better performance, we can make more fruitful decisions. In this sense, the authors would like to pursue the improvement of probability inequality.

The results of this paper are summarized as follows:

1. An electricity shortage outbreak probability evaluation system under the worst-case scenario has been constructed by using probability inequality in the case where limited information about the expectation and variance of electricity supplies and demand is only given.
2. The fact that the disclosure of the past data for the electricity demand and supply is not necessarily enough has been explained. At the same time, if this past data is disclosed, in order to use it effectively, the development of the estimation method of the expectation and variance of the electricity demand and supply is needed and is a future subject to be explored.
3. It has been exhibited that the performance improvement of probability inequality is a subject for more effective and efficient decision-making in using the proposed system based on probability inequality.

From the above, authors pray that this proposed evaluation system is supplemented and upgraded by more researchers to meet social requests. For example, there are many young and energetic researchers in the field of data analysis. If the electric power companies disclose more information, a method for estimating precisely the expectation, variance and range might be developed by such researchers. The proposed evaluation system satisfies the requirements to be at the least a basic system, and it has been suggested with this intention.

References

[1] The Asahi Shimbun: The Tokyo Electric Power Company, Inc., toward the re-operation of thermal plants, the morning newspaper on March 18 (2011) (in Japanese).

[2] The Asahi Shimbun: The trying winter with no electricity supply from nuclear power plants is coming soon, the morning newspaper on December 18 (2011) (in Japanese).

[3] S. Yamamoto: Electricity shortage and Japanese economy affected by the East Japan Great Earthquake disaster – influence on production/employment caused by electricity savings and electricity supply reduction by sign restriction VAR –, *Discussion Paper of the Graduate School of Economics, Kobe University*, 1119, 1-13 (2011) (in Japanese).

[4] Y. Takemoto, F. Iwamoto and I. Arizono: Proposal of reorder point satisfying allowable shortage rate under limited demand information, *Journal of Japan Industrial Management Association*, 62 (1), 21-24 (2011) (in Japanese).

[5] T. Shinzato and I. Kaku: Large deviation approach for safety stock management for correlated demands, *Journal of Japan Industrial Management Association*, 62 (4), 164-173 (2011) (in Japanese).

[6] J. R. Birge and F. Louveaux: *Introduction to Stochastic Programming*, Springer (1997).

[7] G. Bennett: Probability inequalities for the sum of independent random variables, *J. Am. Stat. Assoc.*, 57, 33-45 (1962).
[8] W. Hoeffiding: Probability inequalities for sums of bounded random variables, *J. Am. Stat. Assoc.*, 58, 13-30 (1963).
[9] M. J Cloud and B. C. Drachman: *Inequalities with Applications to Engineering*, Springer Verlag (1998).
[10] The Kansai Electric Power Company, Incorporated: http://www.kepco.co.jp/setsuden/graph/index.html, browsed on June 12, 2012.
[11] The Kansai Electric Power Company, Incorporated: http://www.kepco.co.jp/setsuden/graph/pop/pop_pdf/forecast.pdf, browsed on November 15, 2012.
[12] M. Talagrand: The missing factor in Hoeffding's inequalities, *Ann. Inst. H. Poincaré Probab. Statist.*, 31, 689-702 (1995).
[13] V. Bentku: On Hoeffding's inequalities, *Ann. Probab.*, 32, 1650-1673 (2004).
[14] C. H. Papadimitriou: *Computational Complexity*, Addison-Wesley (1994).
[15] M. Mitzenmacher and E. Upfal: *Probability and Computing: Randomized Algorithms and Probabilistic Analysis*, Cambridge University Press (2005).

Authors

Ikuo ARIZONO

Received doctorate degree of engineering from Osaka Prefecture University in 1988. Research Associate (1985 to 1990), Assistant Professor (1990 to 1994), Associate Professor (1994 to 2011) of the Graduate School of Engineering, Osaka Prefecture University. From 2011, Professor of the Graduate School of Natural and Technology, Okayama University. His research interests center on statistical quality control. In this paper, he was in charge of the whole design, scenario construction and system construction.

Yasuhiko TAKEMOTO

Received doctorate degree (Engineering) from Osaka Prefecture University in 2004. Research Associate (2004 to 2007) of Department of Strategic Management, School of Business Administration, University of Hyogo. From 2007, Associate Professor of Faculty of Management and Information Systems, Prefectural University of Hiroshima. His research interests center on statistical quality control and supply chain management. In this paper, he was in charge of system construction, mathematical verification and numerical analysis.

Discussions with Reviewers

1 Significance of this paper

Comment (Hiroshi Tateishi, AIST, Itaru Ishii, National Museum of Nature and Science)

Because the operation of nuclear power plants almost stopped under the influence of the East Japan Great Earthquake disaster, restriction of electricity supply have become severe, and a large-scale blackout is considered as a real risk. On the other hand, all the information about the electricity supply and demand is stashed under the control of the electric power companies. In addition, an objective tool for risk management cannot be found except for the regression model using past data published by electric power companies.

This paper deals with a procedure for evaluating the electricity shortage outbreak probability based on probability inequality using the limited information about the uncertain electricity demand and supply. The objective explanation of the required power saving rate is addressed based on the evaluated electricity shortage outbreak probability. When we consider the background mentioned in the previous paragraph, we conclude that the scenario of this paper is more or less persuasive. Although it is slightly different in content from the journal, *Synthesiology*, which sets the creation of social values as its goal, we conclude that the paper is significant as it shows a rational methodology that leads to value creation.

However, if such an evaluation system does not play a concrete role in real decision-making processes, it only becomes an impractical theory, and might not be received socially. In such a case, it is incomplete in terms of the purpose of *Synthesiology*.

In the case of applying the contents of this paper to a real electric power system, there are some future subjects to be considered. For instance, the authors evaluate the electricity shortage outbreak probability by using the expectation and variance of the electricity demand and supply, without supposing any probability distribution from limitations of available information. How much difference will this simplification cause in the results? Can the fluctuation of the electricity supply from natural energy caused by climatic conditions be handled equally with the fluctuation caused by the influence of artificial factors such as the stop of operation for maintenance?

The authors should explain their intentions of submitting this paper to *Synthesiology* including such future issues.

Answer (Ikuo Arizono)

Under the present situation about the electricity supply and demand, we intend to give some kind of contribution from the viewpoint of our area of specialization such as industrial engineering, operations research and applied statistics. In this sense, we also consider that the decision-making process and the interpretation of decisions based on the proposed evaluation system need to be persuasive in order to be accepted socially. For this purpose, we have arranged the points of argument so that decision-making using the proposed evaluation system could be accepted socially.

On the other hand, we thank the reviewers for their understanding of this study. With that in mind, I explain "our intentions in submitting the paper to *Synthesiology*".

The main intention is in the policy of the academic journal "*Synthesiology*", that is, instead of a passive attitude that the results of research become understood naturally by society, the researcher who understands the possibility and limit of the results of research should popularize the result of research in a positive manner by himself//herself. This research focuses on an extremely contemporary problem. We would like to suggest this research as a starting point for discussions based on a new sense of values

after the earthquake disaster and the nuclear power plant accident. Therefore, we believe that this research is suitable for publication in Synthesiology and we submitted this paper. In this sense, there are some future issues in applying the content of this paper to a real electric power generating system.

Under the uncertainty of the electricity demand and supply, an evaluation system for electricity shortage outbreak probability in the worst-case scenario has been proposed by utilizing probability inequality. In addition, the present issues in utilizing this evaluation system have been clarified, and the necessity of adding further knowledge of researchers has been described. We believe the description mentioned above also corresponds to the publication policy of "the journal to discuss together", and therefore, we think this paper is suitable for *Synthesiology*.

There are some future issues such as the acquisition of data which should be offered in the proposed evaluation system and the performance improvement of the probability inequality. These future issues have been summarized in chapter 7.

2 Development of the model

Comment (Hiroshi Tateishi)

In the introduction, the expectation for renewable energy and the problems in electricity demand predictions are pointed out, and an evaluation model of the electricity shortage outbreak probability is formulated. However, this paper seems to reason that the uncertainty of electricity supply and demand is an essential element of electric power shortage, and the existence of renewable energy is not an essential element. Therefore, I suggest that through the evaluation based on only the balance between the electricity demand and the electricity supply from the conventional electric generating systems, the validity of the proposed procedure should be first shown more logically. Next, I suggest that the effect and the influence of the electricity supply based on renewable energy be shown.

I also think that although the sensitivity analysis for variance is inspected, the sensitivity analysis for the quantity of renewable energy is necessary as the first step.

Answer (Ikuo Arizono)

At the time that the initial manuscript of this study was submitted, the electricity buyback program of renewable energy was just being discussed. The system to purchase at a fixed price started, and it is possible to assume that the electricity from the conventional electric generating systems including the nuclear power plants will be substituted by the electricity from renewable energy at some future date. In this study, we proactively pushed forward the investigation keeping such a situation in mind.

In the revised manuscript, we present the electricity supply based on renewable energy from the present situation to the goal in 2020.

Furthermore, in the revised manuscript, the sensitivity analysis for the quantity of renewable energy has been investigated according to the reviewer's opinion. Fig. 1 in the revised manuscript shows the influence of the change in the ratio of the electricity supply of renewable energy.

3 Interpretation and utilization of the evaluation results

Comment (Hiroshi Tateishi)

Because the concept behind how to understand and utilize the electricity shortage outbreak probability that is the output of the proposed system is not explained explicitly, it is not obvious how to utilize the proposed system in the real world. In the last part of chapter 4, it is remarked that the results must be used carefully. However, the procedure for use of the results is not sufficiently explained. I think there is no room to be doubted about the logical validity of the proposed model. Rather, it is important how the user is able to make decisions from the results of the proposed system. For reference, if the outbreak probability is less than what percentage rate do the authors think that there is not any problem?

Answer (Ikuo Arizono)

We have considered that this instructed point was the most important content. However, it was vague in the previous manuscript. We can interpret the electricity shortage outbreak probability by the probability inequality as the worst probability. We avoided the explanation in the previous manuscript about how to decide the allowable level of this probability.

In this revised manuscript, it has been added that the allowable level of this probability is decided from the viewpoint of maintaining the present level. In this way, the authors think that the implications of decision-making based on the proposed evaluation system has been made apparent.

4 Definition of the statistical distribution

Comment (Hiroshi Tateishi)

Expression of "the distribution" in the quantity of electricity supply or demand was used. However, it is unknown what "the distribution" means.

Answer (Ikuo Arizono)

The regression model about relations between the highest temperature in the daytime and the quantity of electricity demand was previously published on the website of the Kansai Electric Power Company. Even if the highest temperature in the daytime is the same, the quantity of electricity demand is not constant. In other words, there is some uncertainty in the electricity demand.

The regression model captures the stochastic fluctuation and catches the average feature of the data. Similarly, in reality, the electricity supply derived from renewable energy is also affected by the weather and has some uncertainty. In addition, all conventional electric generating systems are not always functioning due to failure and maintenance.

In this paper, the uncertainty in the quantities of the electricity supply and demand is assumed. Although, in reality, the information such as the expectation and the variance of the quantities of the electricity demand and supply is accumulated in the electricity companies as past data, these data are not always formally disclosed. Therefore, in the numerical examination about the proposed evaluation system, the calculation results based on artificial data have been illustrated. Naturally, the expectation and variance of the quantities of the electricity demand and supply ought to be obtained based on real accumulated data. Moreover, a novel method to obtain the expectation and variance may be developed. In either case, the disclosure of the accumulated data in the electric power companies is a required precondition.

The accumulated information in the electric power companies is necessary in order that the proposed evaluation system functions in practice. Therefore, it is one of objectives of this paper to paradoxically press the electric power companies for more information disclosure by presenting this fact.

The Kansai Electric Power Company is making an effort to disclose information in order to answer to many questions of the local inhabitants (http://www.kepco.co.jp/setsuden/graph/pop/pop_pdf/forecast.pdf). From this information on the website, it is found that the quantities of the electricity demand and supply fluctuate every day as assumed in this paper, and it is estimated that the electricity power saving rate is requested based on these predicted values. From the disclosed information, it is revealed that there is a cause for the uncertainty of the electricity supply in the existing generation facilities. However, although the information about the expectation of the quantities of the electricity demand and supply can be obtained, the information about the variance of them cannot be known.

Therefore, we have changed the quantity of the electricity supply of the conventional electric generating systems treated as a fixed value in the previous manuscript to a random variable in this revised manuscript.

5 Characteristic and selection of the probability inequality

Question (Hiroshi Tateishi)

Three probability inequalities are used without explanation. It is supposed that each probability inequality has an advantage and disadvantage. The authors should explain them. Furthermore, is there an inequality which seems to be usable other than these three inequities?

Answer (Ikuo Arizono)

The authors have represented the reasons for the three probability inequalities. The Bennett and Hoeffding probability inequalities require the range for each random variable that the one-sided Chebychev probability inequality does not need. In this case, this domain information is given based on the two-sigma method using expectation and variance only. The advantage and disadvantage of each probability inequality cannot be definitely shown. Note that the Hoeffding probability inequality, in particular, is recognized as a probability inequality with superior performance. The paper with the probability inequality by Hoeffding[8] was called a "celebrated paper" by Talagrand[12] and Bentkus.[13] From this fact, we consider that the combination of these three probability inequalities is valid. In addition, we are attempting various developments including the performance improvement of the Hoeffding probability inequality.

6 Influence of simulation by the difference in stochastic distribution

Comment (Hiroshi Tateishi)

In chapter 5, a simulation result using the log-normal distribution is shown. However, the simulation results under other stochastic distributions, e.g., the beta distribution and normal distribution should be presented for persuasiveness.

Answer (Yasuhiko Takemoto)

For reference, in Fig. 2, we have illustrated the simulation results in the case where all stochastic distributions for e_0, e_1 and e_2 are assumed as the normal distributions, uniform distributions and beta distributions, respectively. In these simulations, the conditions in the expectation and variance of e_0, e_1 and e_2 are corresponding to those in Fig. 1.

For the beta distribution, the authors have taken the linear conversion because the range of beta distribution is usually from 0 to 1. Considering that the beta distribution greatly changes the shape of distribution by the setting of the parameters, the authors have utilized both situations where the peak of the density is on the left side and on the right side of the center.

From comparisons with the results in Fig. 1, it is confirmed that the electricity shortage outbreak probabilities in Fig. 2 are definitely less than those evaluated based on the probability inequalities in Fig. 1. The authors have added the descriptions mentioned above.

7 Interpretation of the power saving rate

Comment (Hiroshi Tateishi)

The description in chapter 6 is somewhat incomprehensible. For example, when the quantity of the electricity supply decreased 15 %, is it correct to understand that the electric power saving rate is enough at 14.66 % in order not to increase the electricity shortage outbreak probability? If it is true, I think that the authors should show more extensive calculation results.

Answer (Ikuo Arizono)

That is not true and is a misunderstanding. As mentioned in the revised manuscript, when the electricity supply with the conventional electric generating systems decreased 15 %, 14.55 % of the total electricity supply was lost from the viewpoint of the average. It is found that, for the purpose of ensuring the value (5.462 %) of the electricity shortage outbreak probability in a stable condition, the electric power saving rate of 14.66 % exceeding the lost total electric power rate of 14.55 % is required. In other word, it is interpreted that the electric power saving from the viewpoint of expectation is not necessarily enough. At the same time, the proposed evaluation system shows that the excessive electric power saving is not required from the comparison of 14.66 % and 14.55 %. This is the effect of having considered the information of each variance in the electricity supply and demand. Based on this effect, the proposed evaluation system for the electricity shortage outbreak probability has the appropriate security-oriented property.

Since the information disclosure of each electric power company is not enough, the numerical value of the analysis result is not necessarily important. However, it is meaningful to indicate the effect by having considered the information of each variance in the electricity supply and demand. Furthermore, through the existence of the proposed evaluation system, we can demand more information disclosure from the electricity companies and government. We think that this study is also meaningful in this aspect.

Development of diamond-based power devices

— Verification of its superiority as the ultimate power device —

Shinichi SHIKATA * and Hitoshi UMEZAWA

[Translation from *Synthesiology*, Vol.6, No.3, p.152-161 (2013)]

Diamond is expected to be an excellent material exceeding SiC for producing low loss power devices because of its superior material characteristics. We have developed series of elemental technologies including killer-defect free epitaxial growth, refractory Schottky contact, Schottky barrier height control associated with low leakage current and termination structure. As a result, we have developed a refractory Schottky barrier diode with fast switching capability, which can operate for over 300,000 hours at 250 °C. R&D of large scale wafers and large power devices are required to realize low-loss devices with a new concept of "cooling system free."

Keywords : Diamond, power switching device, refractory, low loss, Schottky diode

1 Objective of the research and its outcome

Diamond is a material with the highest performance among all materials in terms of heat conductivity and electrical breakdown field. It can be called the "super material." Although there are several applications for diamond, it is best known as the material for wide-gap semiconductors. For power semiconductor devices, its expectation as low-loss power conversion device surpassing SiC is high.[1]-[4] The related material parameters are shown in Fig. 1. The thermal conductivity is one order higher than Si, overwhelmingly higher than AlN, Cu, Al and other heat spreader materials commonly used. It can be easily inferred that diamond may alter the fundamental thermal management of a device. The electrical breakdown field is one order higher compared to other materials, and high breakdown voltage is expected. The high hole mobility is advantageous for high-speed and high-output operations. Also, with increased carrier at self-heating temperatures of 200~250 °C, there is no decrease in output at high temperature, and this property can be used to create an innovative device module without a cooling system unit. Figure 2 shows the correlation between the on-resistance and the breakdown voltage of the Schottky diode at room temperature and at 250 °C. For the property of SiC, the incremental effect of the drift layer[Term 2] due to temperature increase was applied to the optimal structure at room temperature.[5] In diamond, the increase in carrier due to temperature increase supplements the decrease in mobility due to scattering. The current increases to about 200 °C and becomes low on-resistance, and become constant to about 250 °C. Therefore, in case of the diamond, low-loss, high-current, high-voltage, and ultra downscaling are realizable as long as the device that has reached high temperature due to self-heating is not "cooled on purpose."[6] This property can be applied to power devices such as electrical vehicles, trains, and vessels, as well as industrial devices and for power distribution. Compared to SiC, the CO_2 reduction of 2.34 million ton/year (2040) and 4.93 million ton/year (2050) can be expected. It is mentioned as one of the ultimate devices that may support power electronics in the Cool Earth Innovative Energy Technology Plan[Note)] of the Japan Ministry of Economics, Trade and Industry.

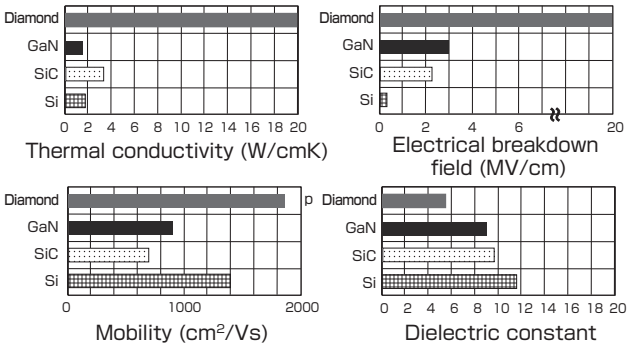


Fig. 1 Comparison of parameters of various materials that affect the power device
(Mobility for diamond is p type)

Because it is composed entirely of carbon, diamond has a major advantage that there is no natural resource problem such as raw material procurement and remaining reserves. It is also highly safe, as it can be synthesized using safe gases such as methane and CO_2, is extremely stable all the way to high temperature, and does not emit harmful substances upon combustion, and is safe at nano size.

In conducting the fundamental researches and various application researches for diamond, in February 2005, we

Diamond Research Laboratory, AIST Tsukuba Central 2, 1-1-1 Umezono, Tsukuba 305-8568, Japan
* E-mail: s-shikata@aist.go.jp
(current affiliation: Research Institute for Ubiquitous Energy Devices, AIST 1-8-31 Midorigaoka, Ikeda 563-8577, Japan)

Original manuscript received August 28, 2012, Revisions received January 16, 2013, Accepted February 7, 2013

started for the first time in the world on the research of its use in wafers and devices for application in power devices. For wafers, there is a report on part of the developmental process (direct wafer technology where the single crystals are fabricated as if being copied, and the realization of crystals with 12 mm sides).[7] This was followed by the achievement of mosaic crystal,[8] and recently the 20×40 mm^2 dimension has been achieved.[9] In this paper, we report Phase 1 of an R&D where the superiority of diamond was verified from the vantage point of devices, taking the example of the Schottky barrier diode (SBD).

2 Research scenario

To realize diamond as a next-generation power semiconductor device, there are, of course, various issues in each phase. The following points must be verified to establish superiority over other materials in Phase 1 (superiority verification).

1) High breakdown voltage (verification of property that surpasses other materials)
2) Operation in high current (density) (verification that high output can be achieved in high temperature)
3) Operation in high temperature (verification of property that enables new concept)
4) Verification of high-speed switching operation

Among the above points, 1) and 3) can be verified using the pseudo vertical device (to match the explanation in the figure) where the process can be carried out relatively easily, but for 2) and 4), a vertical structure[Term 3] that enables practical use is necessary.

The above points were summarized from the perspective of synthesiology in Fig. 3. These are like the combination of the aufheben and breakthrough types that are basic synthesis methods,[10] and it can be concluded that the accumulation of elemental technologies and the breakthrough that enables that are necessary. Figure 4 supplements the explanation of the pseudo vertical and vertical devices shown in Fig. 3. In this synthesis diagram, the low-defect epitaxial growth in the active layer of device (elimination of killer defect in Phase 1) and the heat resistant Schottky formation for high-temperature operation are considered very difficult issues. As shown in Fig. 5, there are defects present due to abnormal growth of diamond in the epitaxial film. In this example, the defects in the growth hillock appear as holes, and these are “killer defects” that are fatal to device operation. This was determined since we detected what seemed like a superimposition of the ohmic flow-through current when we conducted property assessment after fabricating the diode. By studying the relationship between the device yield and the surface area, it was shown quantitatively that such defects directly affect the device yield as shown in Fig. 6. In the example of this epi film, the defect density reached 10^5 defect/cm^2.

3 Example of the elemental technology development

In this paper, the items that were breakthroughs for solving the issues of fundamental technology of the devices will be outlined.

1) Elimination of killer defects

First, pertaining to the low-defect epitaxial film growth in the drift layer that is the active layer of the device, it is widely known that low defect can be obtained by step flow growth in the normal semiconductor material. Since the diamond has bond energy three times the strength of SiC, arbitrary polishing was difficult, creating reproducible steps on the crystal surface was difficult, and experiments could not be carried out easily. Therefore, we conducted the R&D of polishing technology for obtaining a flat surface in arbitrary direction on the diamond crystal and then forming steps. It became clear that this was totally impossible with the

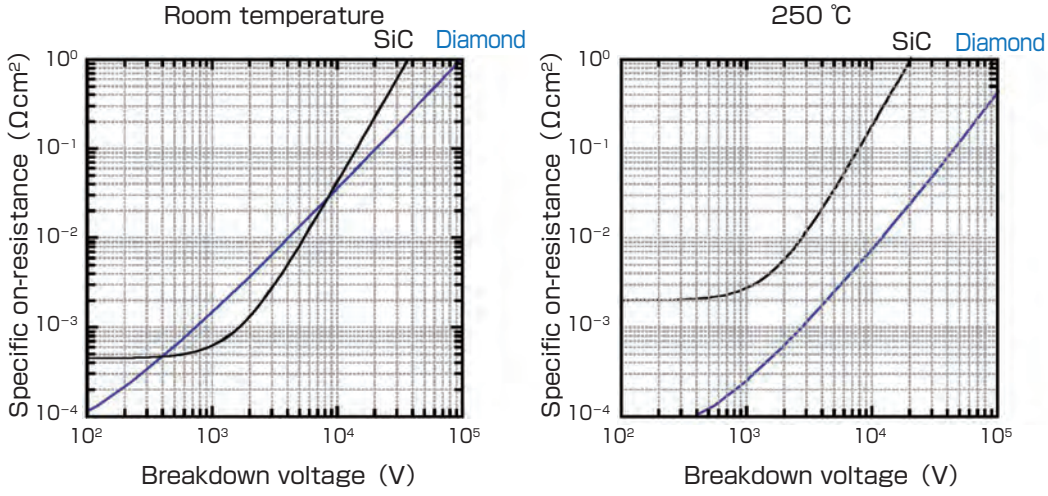


Fig. 2 Comparison of the relationship of on-resistance and breakdown voltage at room temperature and 250 °C

conventional polishing technology. We decided to take this to the basics, and started from the design and fabrication of the polishing device. The two points of the polishing device development were as follows.

(1) An x-ray Laue goniometer was mounted on the polishing head to measure the off angle and off direction by x-ray analysis, to enable polishing in any arbitrary direction.
(2) A weight was placed on the high-rigidity arm for weight adjustment, and the lap was designed with a low vibration structure.

By developing the polishing plate and polishing process as well as the polishing device, we were able to achieve step formation after applying ultra flat processing (arithmetical mean roughness of Ra < 1 nm) on substrates with various off angles and off directions. Using such formations, we investigated the epitaxial layer growth. The epitaxial layer was formed using the CH_4 and H_2 gases with trimethylboron (TMB) as B dopant gas, using the 2.45 GHz microwave chemical vapor deposition (CVD) that is employed normally. While the details will be abbreviated, it was found that in the microwave CVD growth using low density plasma, the abnormal particle defects did not decrease even by changing the off angles and off directions, step flow did not occur well, and there were some variations depending on plasma density. Therefore, we remodeled the CVD equipment to use high-powered plasma. The dependence of the off direction was studied by increasing the power of microwave from 0.75 kW to 4 kW.

As a result, it was found that a giant growth hillock tended to form between <110> and <100>. There were no such hillocks at directions <110> and <100>, nor were there abnormal particles, and an extremely flat surface could be obtained at 2 degrees or more, without dependence on the off angle.[11] Particularly for direction <110>, it was easily estimated that the step flow growth was readily formed since the carbon atoms on the surface formed the dimer row. Figure 7 shows the dependence of the defect formed by the epitaxial growth and the off angles. The situation obtained when the plasma density was changed is also shown. Hence, we succeeded in reducing the killer defect of 10^5 cm^{-2} to almost zero.[11] The flatness Ra obtained by measuring the epitaxial film by AFM was 1.1 nm. When the mobility of the holes in the diamond was measured by hole effect measurement, it was high at 1540 cm^2/Vs, and it was found to be a high quality film. The rate of epitaxial growth in this session (4 kW) was high

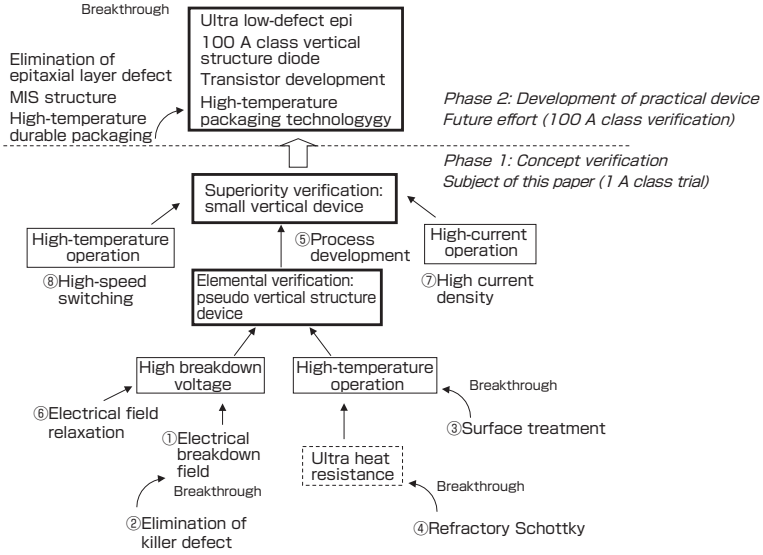
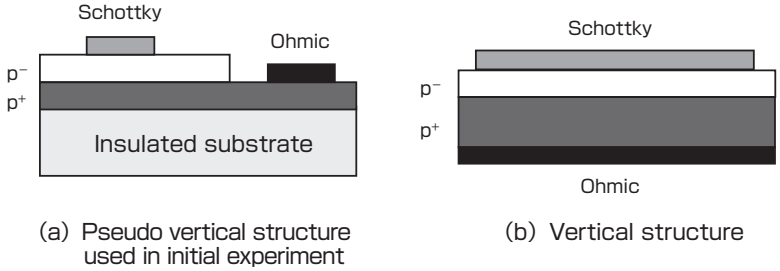


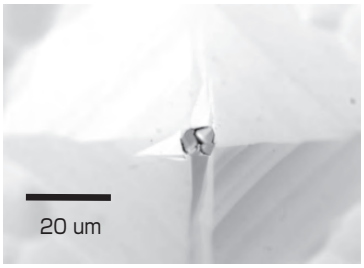
Fig. 3 Synthesiology tree diagram for the superiority verification of the diamond power device
(Numerals are the order of researches conducted)



(a) Pseudo vertical structure used in initial experiment

(b) Vertical structure

Fig. 4 Structural diagram of the device



(Killer defect)

Fig. 5 Killer defect present in the epi layer of diamond

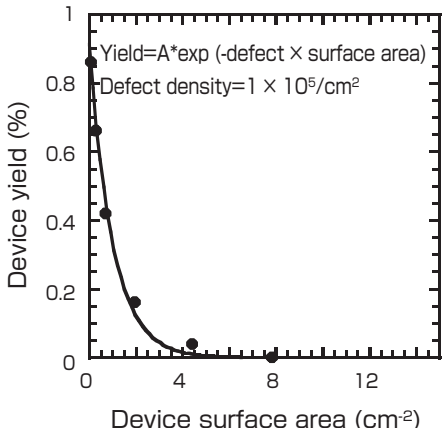


Fig. 6 Relationship between the defect in device and its yield

from 0.8 to 3 μm/hr, or over five times, compared to the 0.2 μm/hr or less of the conventional plasma density (750 W). To maintain the breakdown voltage of the power device, a thick drift layer is necessary as the active layer, so the drift layer epitaxial growth of 10 μm/hr or more is required. In diamond, since the electrical breakdown field is high and only one order less thickness is necessary compared to Si, the epitaxial growth rate obtained in this research is thought to be sufficient for practical application.

As described above, the technology for flat-polishing the wafer to obtain arbitrary crystal off angle and off direction was established, and this enabled nano step control as well as epitaxial growth without killer defects. Prior to the researches of devices and crystal epitaxial growth, we were able to develop the technology by returning all the way to the polishing technology. Thus, we pursued the *Full Research* that involved basic research to application.

2) Schottky interface formation to enable high-temperature operation

Even the mechanism of the reverse-biased leakage of Schottoky interface was unknown in 2005, and we had to start from basic research. To simplify the process, the investigation at this stage was conducted using the pseudo vertical strucutre[Term 3] shown in Fig. 3.[12] The diamond Schottky barrier diode (SBD) was fabricated and the temperature dependence of the reverse leakage current was analyzed. The leakage current increased with the increase in temperature. For example it increased from 10 μA/cm^2 (@2 MV/cm) at 23 °C, to 10 mA/cm^2 at 120 °C. Such figures for the current density level were several digits less than the leakage current observed for SiC SBD in the same electric field. It is difficult to analyze this leakage current according to the model of decreased barrier induced by electric field that is used generally to understand the reverse-biased leakage in Si SBC and GaAs SBD. It was found that the behavior of current voltage property could be explained mostly by using the TFE model[Term 4] taking into consideration the tunnel process by the application high electric field.[13][14] It was necessary to increase the barrier height because the device operation limit was reached by the thermal heat emission current, before the operation limitation due to current amplification led by the avalanche breakdown.[Term 5] Of course, the operating voltage increases if the barrier height is raised, but this was not a problem assuming the high-temperature operation in this case. Therefore, we attempted the method of introducing the localized level for pinning the Fermi level, by applying surface treatment to the Schottky interface. In considering the dry treatment of the diamond surface, we found a way to maintain the high barrier height by introducing the localized level stably through the UV/O_3 treatment.[15] We were also able to observe the reverse field that reached 3.1 MV/cm. Although this localized level has not been identified, we decided to utilize it for engineering purposes. When the Schottky diode was fabricated using this method, the reverse leakage current three order less compared to SiC at high temperature,[16] good forward-biased properties (forward voltage that does not decrease too much at high temperature and low on-resistance due to increased carrier) were observed[17] (Fig. 8).

3) Refractory metal

The next explanation is the breakthrough in the search of heat refractory Schottky electrode. At the time, the heat resistant ohmic junction was already developed, and it was known that TiAu materials including TiPtAu and TiMoAu presented extremely high heat resistance.[18] The difficulty was the Schottky junction. The hurdle was high for the simultaneous achievement of Schottky property, low resistance, adhesiveness, simple process (wafer process and wire bond), as well as heat resistance, and the feasibility of the research was unknown. Investigations were done from both aspects of materials that formed carbide by reacting with diamond at high temperature and those that do not form carbides, but the most prospective stable carbide WC had high resistance and sufficiently high heat resistance could not be obtained.[19] Therefore, we shifted the focus to non carbide forming metals with high melting points. Various metals were tested, and Mo was found to have

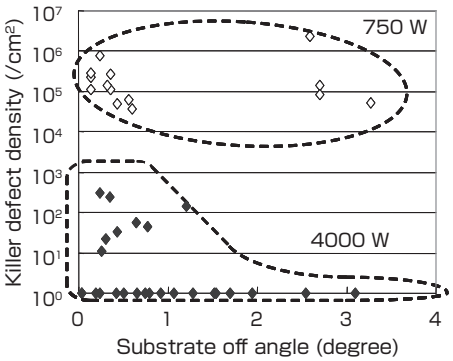
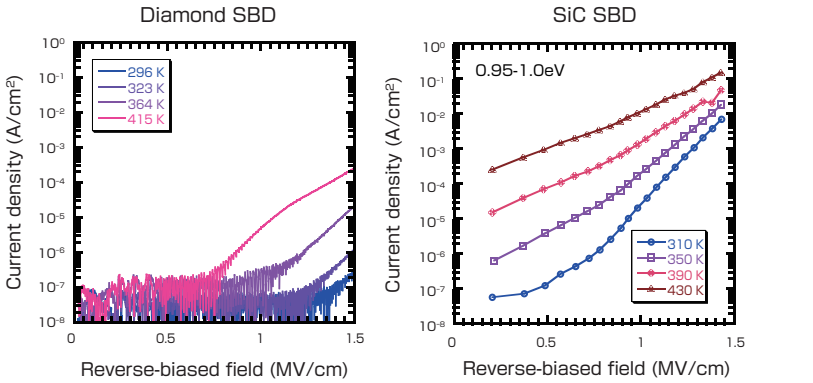


Fig. 7 Dependence of killer defect, substrate off angle, and plasma density



(a) Diamond
(device with high barrier height after surface treatment)

(b) Example of SiC
(from Reference [16] T. Hatakeyama *et al.*)

Fig. 8 Reverse leakage current of the Schottky junctio

excellent properties in various items. The development was continued with Mo as the prime candidate. However, when studying the deterioration in high temperature using various devices, it was found that although excellent property was observed in the Schottky junction that was formed in the no-defect area of the epitaxial layer, the reverse leakage current increased depending on the annealing time in the defective epi layer region. This is shown in Fig. 9. The defective area of epi layer had lost the sp^3 bond state, and the carbide was formed as γMoC_{1-x}. Since the reverse leakage current increased in the epi defect region with increased high temperature time, it could not be used practically. Amidst such situation, a young post-doctorate researcher suggested Ru that was successfully used in some previous research in which he was involved, and a test was done by borrowing a sputtering equipment from a different section. As a result, it was found that the above five properties, from heat resistance to ease of processing, were simultaneously satisfied using this metal. In the accelerated deterioration test, there were no changes over 1500 hours at 400 °C as shown in Figure 10, regardless of the presence or absence of defects.[20] It was estimated that ultra high thermal resistance of over 300 thousand hours at 250 °C should be obtained when the activated energy of deterioration by surface graphitization was assumed to be l eV. The search for such heat resistant Schottky metal was far from the originally planned R&D. However, by conducting the high-temperature deterioration test at an early stage, we were able to overcome the issue early so it would not be a major problem after the development had progressed for some time. It is also the reality of R&D that progress occurs on a whim as in the Ru suggestion. I mentioned this incidence because I feel that it is very important to maintain some degree of freedom in conducting the R&D.

4 Technological syntheses that were verified

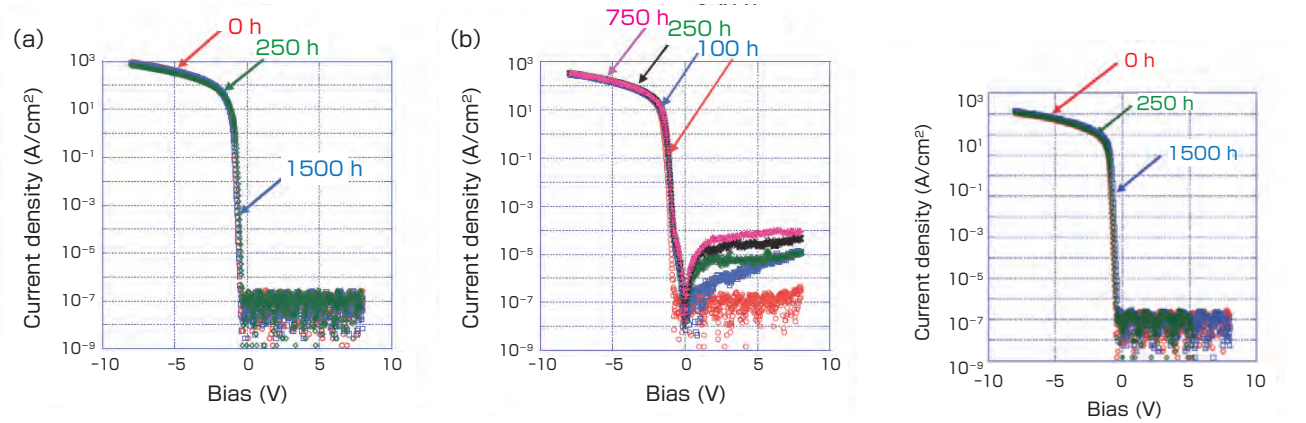
The developments of breakthroughs were explained, among the several research process of using diamond as power devices. For the verification for diamond advantage, various properties were demonstrated using the pseudo vertical structure as shown in Fig. 3. After the development of the process, device, and implementation technology, the operating properties were investigated using the vertical structure, and the following overall superiority of diamond was demonstrated. Although the details will be abbreviated due to space limitations, the properties can be divided in to the following categories.

(1) Electrical breakdown field: verified 3.5 MV/cm with Schottky junction, way surpassing SiC[21]
(2) Elimination of killer defects by improving the epitaxial growth of the drift layer (described in this paper)
(3) Achievement of low leakage current by surface treatment technology and high ϕ_B (described in this paper)
(4) Achievement of ultra high thermal resistant Schottky junction (described in this paper)
(5) Development of vertical device process[22]
(6) Development of field termination structure[23]-[25]
(7) Verification of high current density at high temperature (5 KA/cm^2 @250 °C using small pseudo vertical device)[26]

Additional tests other than mentioned above included observations of property unique to diamonds, such as observing that no hotspots would be formed in diamond through temperature mapping of the device in operation.[27]

The diamond diode that could achieve both high temperature operation at 250 °C and high current density was developed, and this opened the possibility for a power device that does not require cooling, as well as with low loss at high temperature and high breakdown voltage. This is a concept where the device that reaches high temperature through self-heating does not have to be cooled by a large cooling module using energy, but instead, heat is utilized as is.

A prototype of a vertical structure diode was fabricated using



(a) Region without epi defect
No change in property after 1500 hr at 400 °C

(b) Region with epi defect
Increase in reverse leakage current

Fig. 9 Property of Mo Schottky junction maintained at high temperature
(From Reference [20] K. Idea *et al.*)

(a) Maintained for 1500 hr at 400 °C

Fig. 10 Property of Ru Schottky junction maintained at high temperature
(From Reference [20] K. Idea *et al.*)

the Al_2O_3 insulating film as the field relaxing structure. As shown in Fig. 11(a), this is a structure in which the Al_2O_3 was set around the Schottky electrode. The prototype of the first ampere class device is shown in Fig. 11(b).[28]

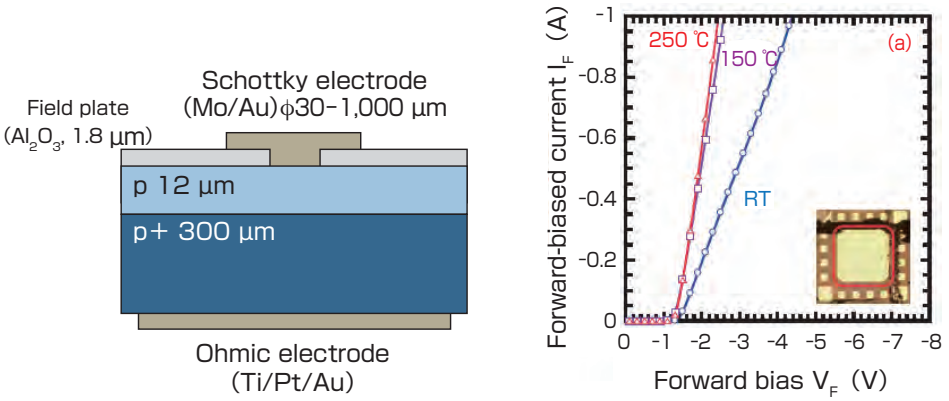
For the high-speed operation property, joint research was done with Professor Funaki of the Graduate School of Engineering, Osaka University. The switching characteristics of the diamond diode was measured, as the recovery of the diamond Schottky diode was measured using the "double pulse method" after constructing the driving circuit using the Si MOSFET. Figure 12 shows the switching property. This corresponds to (8) in the synthesiology tree in Fig. 3.

For the high-speed switching of (8), the high-speed switching of 0.01 μsec and small reverse recovery current (low loss) of 40 A/cm^2 were confirmed for the high-speed operation at 225 °C in small vertical diode that was our first prototype. The operation at 250 °C was achieved in a 1 A class device.[28][31]

By demonstrating that the diamond diode could operate in high temperature at high speed and with low loss in a structure that is actually used, even in a small vertical device, it can be said that Phase 1 (superiority verification) of this research was cleared.

5 Future prospects and roadmap

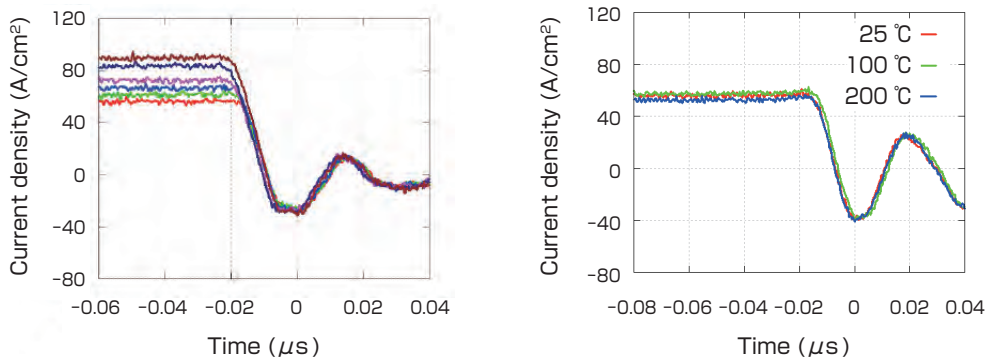
First of all, the main issue is the growth of epitaxial film with low defects. While we were able to eliminate the killer defects, it is known that the leakage current increases significantly if the device size is increased,[32]-[34] and the most important issue is to decrease the defects. At present, we have started to work on identifying the defect types, effects on the device characteristics, and the ways to reduce them. The research from this perspective has not been done intensively for diamond, and it is necessary to return to basic research. Currently, through various analysis such as x-ray topography, the presence of edge dislocation and mixed type dislocation



(a) Schematic diagram of vertical device structure using field plate as the field termination

(b) Example of forward-biased property of diodes

Fig. 11 Ampere class diamond Schottky diode with field relaxing structure
(From Reference [28] H. Umezawa *et al.*)

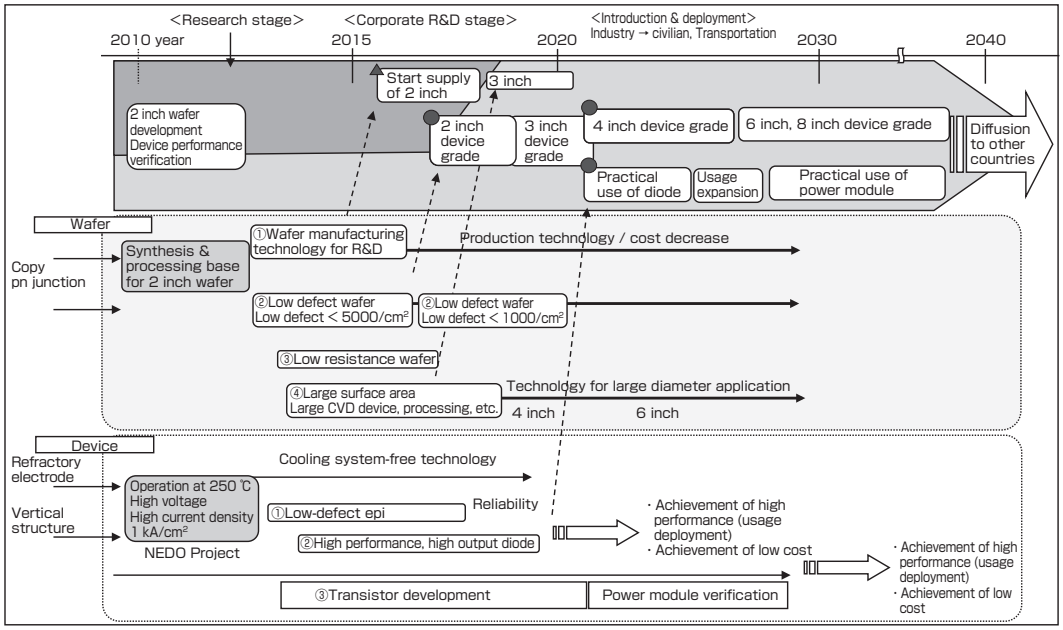


(a) Comparison at various current levels (show same high-speed recovery property)

(b) Comparison at various temperatures (show same recovery property)

Fig. 12 Recovery property of the diamond Schottky diode
(From Reference [29] K. Kodama *et al.*)

Table 1. Roadmap for the diamond power device and wafer



as main defect types and rough defect density are being discerned,[35][36] and detailed investigation of defects' influence to the device characteristics is being done. We aim to achieve the practical vertical structure device and the verification of several to 100 A devices.

For transistors, many researches have been studying diamond to achieve high speed and high frequency application using the lateral device structure.[37]-[39] However, vertical device structure with high breakdown voltage and high output current is mandatory for the power device, and it is necessary to speed up research based on past findings. We plan to investigate the superiority quantitatively, including the technology to achieve cooling free operation at high temperature through device implementation.

Table 1 shows the roadmap of the wafer and device created through surveying industry and academia, based on the technological strategy map of METI. For wafers, the supply system for 2-inch wafers is built jointly with companies to help promote the device research at the companies and universities. Also, the developments of practical wafers such as low-resistance and low-defect wafers are planned. For devices, the researches for low-defect epitaxial growth and

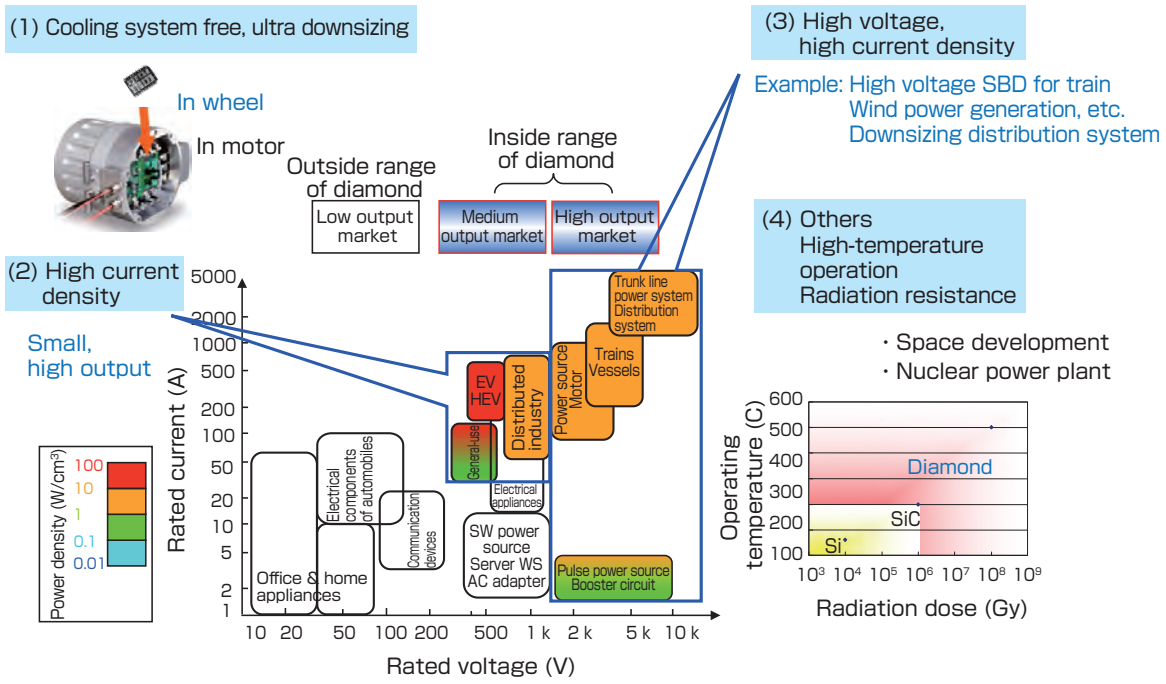


Fig. 13 Prospect of diamond power device application

others will be conducted toward the practical use of Schottky diode, to promote the practical utilization of high-output, high-performance diodes. At the same time, the research for MIS (MOS) type field effect transistors (FET) and pn junction transistors will be done jointly with several universities. As an application, development will be done with prospects in mind as shown in Fig. 13 through interviews with companies.

We have just started the *Full Research* that may require a long time. However, we wish to speed up the development to enable this material to become the main material and device of the 21st century, to meet the national interest of Japan in terms of resource and safety, and also to help solve the issue of global warming.

Acknowledgement

We are deeply thankful to the researchers who worked with us at the time: Hiromichi Yoshikawa, Researcher, AIST (currently, Tomei Diamond Co., Ltd.); Kazuhiro Ikeda, Special Researcher, AIST (currently, Sumitomo Electric Industries, Ltd.); Ramanujam Kumaresan (currently, Kobe University); A. M. M. Omer (currently, Sumitomo Chemical Co., Ltd.); Natsuo Tatsumi (dispatched from Sumitomo Electric Industries, Ltd.); Masanori Nagase, Researcher (currently, Nanosystem Research Institute, AIST); Hideyuki Watanabe, Senior Researcher, Diamond Research Lab; Yukako Kato, Researcher; as well as the members of the Wafer Development Team (Akiyoshi Chayahara, Deputy Director; Yoshiaki Mokuno, Senior Researcher; Nobuteru Tsubouchi, Senior Researcher; and Hideaki Yamada, Senior Researcher). We are also deeply thankful to Professor Funaki of Osaka University, with whom we engaged in joint research on the switching property.

Part of this research was conducted with the grant from "Project for Developing Innovative Energy-Saving Technology" of the New Energy and Industrial Technology Development Organization (NEDO).

Note) http://www.enecho.meti.go.jp/policy/coolearth_energy/coolearth-hontai.pdf

Terminologies

Term 1. Field relaxing structure: The structure of the device is made to maintain breakdown voltage by dispersing and avoiding the concentration of electric field. Field plate and junction termination structures are well known.

Term 2. Drift layer: This is the active layer that operates as the power device.

Term 3. Vertical structure and pseudo vertical structure: Since large current flows through the power device, the current is led through the whole surface using a structure with vertical current route, rather than through a lateral structure device used in LSI and high-frequency devices. The pseudo vertical device is a test device with insulated substrate, and only its active layer is vertical, while the extraction of current is done from the top. See Fig. 3.

Term 4. Themionic field emission (TFE) model: Of the three models of carrier conduction in the Schottky barrier junction, this model incorporates both the effects of thermo electron and field emission.

Term 5. Avalanche breakdown: The phenomenon that leads to destruction as massive current flows like an avalanche, as free electrons are accelerated in the field and collision ionization occurs repeatedly.

References

[1] B. J. Baliga: Semiconductors for high-voltage, vertical channel field-effect transistors, *J. Appl. Phys.*, 53, 1759 (1982).

[2] H. Ohashi: Pawa debaisu no genjo to shorai tenbo (Current situation and future prospect of power devices), *FED Journal*, 11 (2), 3-7 (2000) (in Japanese).

[3] W. Saito, I. Omura, T. Ogura and H. Ohashi: Theoretical limit estimation of lateral wide band-gap semiconductor power-switching device, *Solid-State Electron.*, 48, 1555-1562 (2004).

[4] A. Q. Huang: New unipolar switching power device figures of merit, *IEEE Electron. Device Lett.*, 25 (5), 298-301 (2004).

[5] K. Arai and S. Yoshida: Dai 5 Sho Debaisu Sekkei Hyoka (Chapter 5 Device Design and Assessment), *SiC Soshi No Kiso To Oyo* (Foundation and Application of SiC Elements), Ohmsha (2003) (in Japanese).

[6] H. Umezawa and S. Shikata: Diamond high-temperature power devices, *Int'l Symp. Power Semiconductor Devices*, 259-262 (2009).

[7] A. Chayahara, Y. Mokuno, N. Tsubouchi and H. Yamada: Development of single-crystalline diamond wafers - Enlargement of crystal size by microwave plasma CVD and wafer fabrication technology, *Synthesiology*, 3 (4), 272-280 (2010) (in Japanese) [*Synthesiology English edition*, 3 (4), 259-267 (2010)].

[8] H. Yamada, A. Chayahara, Y. Mokuno, H. Umezawa, S. Shikata and N. Fujimori: Fabrication of 1 inch mosaic crystal diamond wafers, *Appl. Phys. Express*, 3, 051301 (2010).

[9] H. Yamada, A. Chayahara, Y. Mokuno, N. Tsubouchi, H. Umezawa, Y. Kato and S. Shikata: Inchi saizu no tankessho daiyamondo setsugo ueha no sakusei to daimensekika ni muketeno torikumi (Fabrication of inch-size monocrystal diamond juction wafer and effort toward increasing the surface area), *25th Diamond Symposium*, 8 (2011) (in Japanese).

[10] N. Kobayashi, M. Akamatsu, M. Okaji, S. Togashi, K. Harada and N. Yumoto: Analysis of synthetic approaches described in papers of the journal *Synthesiology* - Towards establishing synthesiological methodology for bridging the gap between scientific research results and society, *Synthesiology*, 5 (1), 36-52 (2012) (in Japanese) [*Synthesiology English edition*, 5 (1), 37-52 (2012)].

[11] N. Tatsumi, H. Umezawa and S. Shikata: Reduction of epitaxial defects in diamond for high power device, *Int'l*

Conf. SiC and Related Materials, Th-P-33 (2007).
[12] R. Kumaresan, H. Umezawa and S. Shikata: Parasitic resistance analysis of pseudovertical structure diamond Schottky barrier diode, *Phy. Status Solidi A*, 207 (8), 1997-2001 (2010).
[13] H. Umezawa, T. Saito, N. Tokuda, M. Ogura, S. G. Li, H. Yoshikawa and S. Shikata: Leakage current analysis of diamond Schottky barrier diode, *Appl. Phys. Lett.*, 90 (7), 073506 (2007).
[14] H. Umezawa, N. Tokuda, M. Ogura, S.G. Li and S. Shikata: Characterization of leakage current on diamond Schottky barrier diodes using thermionic-field emission modeling, *Diamond Relat. Mater.*, 15, 1949-1953 (2006).
[15] H. Umezawa, N. Tatsumi, S. Shikata, K. Ikeda and R. Kumaresan: Increase in reverse operation limit by barrier height control of diamond Schottky barrier diode, *IEEE Electron. Device Lett.*, 30 (9), 960-962 (2009).
[16] T. Hatakeyama, M. Kushibe, T. Watanabe, S. Imai and T. Shinohe: Optimum design of a SiC Schottky barrier diode considering reverse leakage current due to a tunneling process, *Mater. Sci. Forum*, 433-436, 831-834 (2003).
[17] H. Umezawa, K. Ikeda, R. Kumaresan and S. Shikata: High temperature characteristics of diamond SBDs, *Mater. Sci. Forum*, 645-648, 1231-1234 (2010).
[18] Y. Nishibayashi, N. Toda, H. Shiomi and S. Shikata: Thermally stable ohmic contact to boron doped diamond films, *4th Int'l Conf. New Diamond Science and Technology*, 717-720 (1994).
[19] M. Liao, J. Alvarez and Y. Koide: Tungsten carbide Schottky contact to diamond toward thermally stable photodiode, *Diamond Relat. Mater.*, 14 (11-12), 2003-2006 (2005).
[20] K. Ikeda, H. Umezawa, K. Ramanujam and S. Shikata: Thermally stable Schottky barrier diode by Ru/Diamond, *Appl. Phys. Express*, 2, 011202 (2009).
[21] H. Umizawa, N. Tatsumi, H. Yamaguchi, T. Kato, K. Ikeda, R. Kumaresan and S. Shikata: The observation of the defects in epitaxial diamond film and its influence to SBD characteristics, *17th Meeting on SiC and Related Wide Bandgap Semiconductors*, P-76 (2008) (in Japanese).
[22] R. Kumaresan, H. Umezawa, N. Tatsumi, K. Ikeda and S. Shikata: Device processing, fabrication and analysis of diamond pseudo-vertical Schottky barrier diodes with low leakage current and high blocking voltage, *Diamond Relat. Mater.*, 18, 299-302 (2009).
[23] K. Ikeda, H. Umezawa and S. Shikata: Edge termination techniques for p-type diamond Schottky barrier diodes, *Diamond Relat. Mater.*, 17 (4-5), 809-812 (2008).
[24] K. Ikeda, H. Umezawa, N. Tatsumi, R. Kumaresan and S. Shikata: Fabrication of a field plate structure for diamond Schottky barrier diodes, *Diamond Relat. Mater.*, 18 (2-3), 292-295 (2009).
[25] H. Umezawa, M. Nagase, Y. Kato and S. Shikata: High temperature application of diamond power device, *Diamond Relat. Mater.*, 24, 201-205 (2012).
[26] S. Shikata, K. Ikeda, R. Kumaresan, H. Umezawa and N. Tatsumi: Recent progress of diamond device toward power application, *Mater. Sci. Forum*, 615-617, 999-1002 (2009).
[27] H. Umezawa and S. Shikata: Characterization of temperature distribution of forward biased Schottky barrier diode on diamond wafer, *Eur. Conf. SiC and Related Materials*, Tue P-15 (2010).
[28] H. Umezawa, Y. Kato and S. Shikata: 1 Ω On-resistance diamond vertical-Schottky barrier diode operated at 250 °C, *Appl. Phys. Express*, 6, 011302 (2013).
[29] K. Kodama, T. Funaki, H. Umezawa and S. Shikata: Switching characteristics of a diamond Schottky barrier diode, *IEICE Electron. Express*, 7 (17), 1246-1251 (2010).
[30] T. Funaki, K. Kodama, H. Umezawa and S. Shikata: Characterization of fast switching capability for diamond Schottky barrier diode, *Mater. Sci. Forum*, 679-680, 820-823 (2011).
[31] T. Funaki, M. Hirano, H. Umezawa and S. Shikata: High temperature switching operation of a power diamond Schottky barrier diode, *IEICE Electron. Express*, 9 (24), 1835-1841 (2012).
[32] H. Umezawa, K. Ikeda, R. Kumaresan, N. Tatsumi and S. Shikata: Device characteristics dependence on diamond SDBs area, *Mater. Sci. Forum*, 615-617, 1003-1006 (2009).
[33] H. Umezawa, Y. Mokuno, H. Yamada, A. Chayahara and S. Shikata: Characterization of Schottky barrier diodes on a 0.5-inch single-crystalline CVD diamond wafer, *Diamond Relat. Mater.*, 19 (2-3), 208-212 (2010).
[34] R. Kumaresan, H. Umezawa and S. Shikata: Vertical structure Schottky barrier diode fabrication using insulating diamond substrate, *Diamond Relat. Mater.*, 19 (10), 1324-1329 (2010).
[35] H. Umezawa, Y. Kato, H. Watanabe, A.M.M. Omer, H. Yamaguchi and S. Shikata: Characterization of crystallographic defects in homoepitaxial diamond films by synchrotron X-ray topography and cathodoluminescence, *Diamond Relat. Mater.*, 20 (4), 523-526 (2011).
[36] Y. Kato, H. Umezawa, H. Yamaguchi and S. Shikata: X-ray topography used to observe dislocations in epitaxially grown diamond film, *Jap. J. Appl. Phys.*, 51, 090103 (2012).
[37] H. Taniuchi, H. Umezawa, T. Arima, M. Tachiki and H. Kawarada: High-frequency performance of diamond field-effect transistor, *IEEE Electon. Device Lett.*, 22 (8), 390-392 (2001).
[38] K. Hirama, H. Sato, Y. Harada, H. Yamamoto and M. Kasu: Diamond field-effect transistors with 1.3 A/mm drain current density by Al_2O_3 passivation layer, *Jap. J. Appl. Phys.*, 51, 090112 (2012).
[39] T. Iwasaki, Y. Hoshino, K. Tsuzuki, H. Kato, T. Makino, M. Ogura, D. Takeuchi, T. Matsumoto, H. Okushi, S. Yamasaki and M. Hatano: Diamond junction field-effect transistors with selectively grown n+-side gates, *Appl. Phys. Express*, 5, 091301 (2012).

Authors

Shinichi SHIKATA

Graduated from the Faculty of Engineering, Kyoto University in 1978. Completed the masters program at the Graduate School of Engineering, Kyoto University in 1980. After working at a company, joined AIST in 2004. Currently, Principal Research Manager at the Research Institute of Ubiquitous Energy Devices, AIST. Engaged in R&D for wide-gap semiconductor device, SAW device, and diamond material and its device application. Conferred doctorate from the Osaka University (Engineering). Visiting Professor at the Graduate School of Engineering, Chiba University. Senior member of IEEE; member of the Japan Society of Applied Physics; and member of the Institute of Electronics, Information and Communication Engineers. Created the basic long-term plan for this research in December 2004. In this paper, headed the development of the material.

Hitoshi UMEZAWA

Graduated from the Faculty of Science and Engineering, Waseda University in 1998. Completed the master's course at the Graduate School of Science and Engineering, Waseda University in 2000. Assistant at the Waseda Research Institute of Science and Engineering; assistant at the Research Institute for Advanced Science and Medical Care, Waseda University; and joined AIST in 2005. Currently, Senior Researcher at the Research Institute of Ubiquitous Energy Devices. Engages in R&D of synthesis technology, assessment, and device application of diamond material. Conferred doctorate at the Waseda University (Engineering). Member of Japan Society of Applied Physics and IEEE. After joining AIST, has been the main personnel in charge of this research. In this paper, was in charge of whole research except polishing.

Discussions with Reviewers

1 General

Question and comment (Naoto Kobayashi, Center for Research Strategy, Waseda University)

This paper reports the results of the comprehensive research for superiority verification of diamond used in power semiconductor devices. It presents the general outcomes starting from the individual elemental technology that the authors have accumulated over the years to the actual verification, and it is a significant paper to be published in *Synthesiology*. Particularly, I think it can provide an effective guideline and direction to readers who may be working on the practical utilization and realization of diamond power devices. However, there are ambiguous expressions that are somewhat difficult to understand, and careful revision is necessary.

Question and comment (Toshimi Shimizu, AIST)

This research shows the result of the superiority verification of next-generation power semiconductor device that uses diamond materials which possess optimal performance among several substances. Its content is equivalent to *Full Research* as the four synthesis elements were solved along with the reference to breakthroughs. It is indeed appropriate as a *Synthesiology* paper. Although there is no major problem in the logical composition, I think you need to work on making it more understandable to the general reader. If this point is supplemented, it will be a more satisfying paper.

2 Research scenario and specific application

Question and comment (Naoto Kobayashi)

Figure 3 shows the scenario (synthesiology tree diagram) for the superiority verification research of diamond power devices. This is the important main focus of this paper in terms of synthesiology. However, the meaning of the numbered items such as (1) electrical breakdown, (2) killer defect elimination, etc. and their relationships are hard to understand. There are some explanations in chapter 4, but it is unclear whether they show the passage of time or the order of research conducted, and you need some explanation in the text or in the caption of the figure.

Answer (Shinichi Shikata)

The numbers indicate the order in which the researches were ultimately conducted. I added a note in the figure. They more or less follow the basic plan that was created in December 2004, and combined with the wafer development for which the research was done concurrently, they lead up to the roadmap shown in Table 1. The future issues are the breakthroughs needed for practical use as shown in the upper left of Fig. 3, and we hope to accomplish them in Japan with cooperation from various organizations.

Question and comment (Naoto Kobayashi)

There is a brief description of the application of diamond power devices in chapter 1. Since this is the most important part for enabling practical use of the results of this paper, I recommend that it be discussed in detail by using a diagram (such as that you have shown on http://www.chubu.meti.go.jp/jisedai_jidoushiya/chiubu/pdf/sansoken/sansoken_8.pdf), which will help the readers' understanding.

Answer (Shinichi Shikata)

I added the figure that I left out due to space limitations. I added the names of specific application devices. In the ENERGY OUTLOOK of IEA, 67 % of the CO_2 reduction is accomplished by energy-saving technology, and I wish to attain practical use as soon as possible to meet this demand. Looking at the example of SiC, the Schottky diode that we took up as an exemplary device in this paper has more merit compared to the Si pn diode, and I think there is good possibility for the medium output devices. Also, diamond has excellent resistance to gamma rays and neutron rays, and I think there is potential in small current devices.

3 Comparison of the performances of low-loss power devices and status of the R&D of the diamond device

Question and comment (Toshimi Shimizu)

You compare various property values for substances including diamond, SiC, GaN, and Si, but I would like to know the benchmark information of the devices to which such substances are actually implemented. In other words, in future power device applications, how will diamond exert its characteristics? What are the evidences and reasons for such claims? Please describe them. In the *Synthesiology* paper written by Kazuo Arai, "R&D of SiC semiconductor power devices and strategy towards their practical utilization - The role of AIST in developing new semiconductor devices" [*Synthesiology English edition*, Vol. 3, No. 4, p. 245-258 (2011)], there is a conceptual diagram that clearly shows the relationship between the application of power semiconductor and device performance in demand (p. 256). For easier understanding, I think you need to create a similar figure by superimposing the performance of diamond on this diagram.

Answer (Shinichi Shikata)

I created a new figure. I showed the specific applications according to the categories of current and voltage. In fact, by adding the cooling free and high temperature axes, it shows the characteristic merit of diamond that can be used without decreasing output.

Question and comment (Naoto Kobayashi)

In this paper, there are detailed explanations of the content and significance of the elemental technologies that the authors have accumulated over the years, but there is no explanation on the ongoing R&D in Japan and overseas, and this gives an obscure impression of the positioning of this research. I hope you address other R&Ds such as, for example, T. Iwasaki *et al.* [*Appl. Phys. Express*, 5, 091301 (2012)]. You should also cite the patent information, since your results have been utilized as patents.

Answer (Shinichi Shikata)

I added the prospects by citing the papers on transistors. The recent paper that you indicated is a research on the device based on pn junction, and ultra high breakdown voltage is assumed for its use. However, over 10 order improvement from nA to 100 A class is needed. In diamond, n+ doping has not been achieved, and further material research is necessary. Currently, I think the unipolar device that can be driven at low voltage will take the

lead, just as it happened in SiC. Since the device in this paper is already 1 A class, we are aiming for double-digit increase by reducing the defects. For patents, there are several that have been registered including the patent unique to diamonds.

4 Advantage verification

Question and comment (Toshimi Shimizu)

At the end of "1 Objective and outcome of research," you write, "Phase 1 of R&D was conducted to verify the advantage…." For example, drug discovery starts from basic research, nonclinical trial using animals, and clinical trial in humans to see the efficacy and safety of the drug (Phase 1~3). Here, there is a giant difference between the research phases of whether the subjects of verification are animals or humans. In device research, what is the major synthesis element or technological element that separates Phase 1 research for concept verification and Phase 2 for practical device verification, as shown in Fig. 3? Is it a difference perceived by the author, or is it a generally accepted difference? Even if it is common sense to device researchers, the positioning of Phase 1 and 2 is not clear to the general readers.

Answer (Shinichi Shikata)

The concept verification of Phase 1 is an animal experiment in the sense that confirmation is done, for example, at 1 A class for whether the principle is realizable or not. The device development of Phase 2 is an efficacy check in humans in the sense that it is verification of 100 A class that can be actually implemented. The reliability test is Phase 3 or the safety test. After this, the phase proceeds to engineering samples and products. Although the names are different by companies, this is a common concept. I added supplementary explanation in Fig. 3.

5 Performance verification of transistor

Question and comment (Toshimi Shimizu)

To aim for power device verification using the diamond semiconductor, I think the verification of not only diode but also transistor performance is essential. Recently, there was a paper published by an AIST research group about the success of verification of operating junction type field transistor for the first time. Your paper does not address the future prospect of transistor operation using the diamond semiconductor. If you are aiming for an ultimate power device, I think you must comment on the latest technological trend on the transistor development using diamond materials.

Answer (Shinichi Shikata)

There are mountains of trial results from way back, but unfortunately they involve only the lateral structure device that aims for high frequency, and there is no success with prototypes with vertical structure that may lead to the future 100 A class. However, as you say, there is a lack of reference to transistors in this paper, so I added some comments. I think this item must be studied with the participation of multiple organizations.

Marine geological mapping project in the Okinawa area

— Geoinformation for the development of submarine mineral resources —

Kohsaku ARAI*, Gen SHIMODA and Ken IKEHARA

[Translation from *Synthesiology*, Vol.6, No.3, p.162-169 (2013)]

AIST has been conducting marine geological surveys in the Okinawa area to construct geological maps since 2008. The chain of islands extending from Kyushu to Taiwan in the Okinawa area is called the Ryukyu Arc, and was formed with the subduction of the Philippine Sea Plate beneath the Eurasian Plate along the Ryukyu Trench. The Okinawa Trough is a back-arc basin formed behind the Ryukyu Arc. Active submarine volcanoes and hydrothermal phenomena are known to exist in the trough. Because large scale mineral deposits may exist in relation to the geological structures, collecting the marine geological information around the area where submarine mineral resources are expected is very effective for grasping the location of resource-rich zone. Being surrounded by sea, Japan is expected to increase marine utilization within the Exclusive Economic Zone (EEZ) in the future. Methods for developing submarine mineral resources based on the geological phenomena are presented as tools for exploiting fundamental geological information.

Keywords : Marine geology, geological structures, Okinawa Trough, back-arc basin, marine mineral resources

1 Introduction

"Marine Geological Investigations on the Continental Shelves and Slopes around Japan" is a special research program of the Agency of Industrial Science and Technology started in FY 1974. As part of this project, marine geological surveys were conducted to obtain geological information on ocean regions around Japan and create 1:200,000 marine geological maps. Surveys of the four main islands of Japan (Honshu, Hokkaido, Kyushu, and Shikoku) were completed in FY 2006. The marine geological survey for the region around Okinawa, for which there was no basic geological information, was started in 2008 (hereinafter referred to as the Okinawa Project). In the Okinawa Project, the region around Okinawa-jima Island was surveyed in 3 years from FY 2008 to 2010, and the northern part of the Okinawa Trough was surveyed during the GH11 cruise in FY 2011. The names of the AIST survey cruises are derived from the name of the organization (G stands for Geological Survey of Japan), the name of the survey ship (H for *Hakurei Maru No. 2*), and the western calendar year in which the survey was conducted. A survey of the ocean region around Okinoerabu-jima, Tokuno-shima, and Amami-oshima islands in Kagoshima Prefecture which began in FY2012 is planned to continue for 4 years. After completion of the large-scale survey of the southern Okinawa Trough, a survey is scheduled of the area around the islands of Southern Ryukyu (Miyako-jima, Ishigaki-jima, and Yonakuni-jima islands).[1]

The planned duration of the Okinawa Project overlaps with a major change in policies for marine development and use in Japan. The Basic Act on Ocean Policy was established in 2007, followed by the Ocean Policy Basic Plan and the Marine Energy and Mineral Resources Development Plan in 2008. Under the Marine Energy and Mineral Resources Development Plan, the commercialization of submarine hydrothermal mineral deposits was set for 2018. Also, the situation of the mineral resources changed greatly because of the worldwide increases in resource prices after the global financial crisis in 2007. With such a background, the importance of submarine mineral resource development increased dramatically. The future utilization of these resources depends on the provision of geological information that contributes to the management, maintenance, and development of Japan's vast exclusive economic zone (EEZ).

In April 2012, the United Nations approved the majority of Japan's application for governance over an extended continental shelf area,[2] which was widely reported by the media. This approval covered an area of approximately 310,000 km^2 (Fig. 1), and included the ocean regions of Shikoku Basin, Ogasawara Plateau, Minami-Io-jima Island, and Southern Oki-Daito Ridge. It is expected that these areas will hold significant mineral resources, and sufficient marine geological information is required to identify potential zones of concentration within existing geological structures. Conducting surveys effectively and accelerating the organization of data will therefore serve the national interests of Japan.

In the present study, we report the significance and current practices of organizing basic geological information from

Geological Survey of Japan, AIST Tsukuba Central 7, 1-1-1 Higashi, Tsukuba 305-8567, Japan
* E-mail: ko-arai@aist.go.jp

Original manuscript received October 2, 2012, Revisions received January 31, 2013, Accepted February 15, 2013

the Okinawan ocean region. The survey area of the Okinawa Project includes the Okinawa Trough, an active back-arc basin that contains the Tokara Islands and continuous submarine volcanoes that extend from Kyushu. The basin is renowned for volcanic and submarine hydrothermal activities.[3]-[5] We also discuss the current situation and recent issues facing AIST in the development of submarine mineral resources.

2 Marine geological surveys, and organization and use of geological information

The marine geology map series, published at the end of September 2012, includes 76 sheets based on marine geological surveys (Fig. 2), eight of which show the marine geology around Japan at a 1:1,000,000 scale. The more detailed 1:200,000 marine geology map series was also published, separated into sedimentological and geological maps, the latter of which include magnetic and gravity anomaly maps.

To utilize the research vessel efficiently during AIST marine geological surveys, geophysical observations were primarily recorded during nighttime and sediment samples were taken from the stationary ship during the day (Fig. 3). In these surveys, the aim was to obtain 'uniform data,' defined as data that are systematically and comprehensively collected without any major variation in methods and equipment and of sufficient quality for geological interpretation. The sedimentological maps are based on seafloor surface samples collected using a grab sampler or columnar sampler, and they show the materials being deposited on the sea floor determined from sediment grain size and composition. The grab sampler was equipped with the conductivity depth profiler (CTD), turbidimeter, water sampler, and a submarine camera. Analyses conducted to produce these maps included sedimentology, geochemistry, and oceanography. The marine geological maps are based on seismic reflection profiling and the age of the sampled sediments. These maps display geological structure and stratification, and were created through integrated interpretations of structural geology, seismic stratigraphy, geophysics, sedimentology, etc.

Figure 4 shows the scenario of the flow for basic geological information from data collection to data use. The various data collected during the offshore surveys are published as a database and marine geological maps, and are an important part of the available intellectual infrastructure. Figure 4 provides examples of potential uses for the data and maps, including assessments of geological hazards and submarine resource. The marine geological maps indicate, for example, the presence of faults and their activity, which may be used to assess geological hazards affecting oceanfront buildings. The sedimentological maps may be used for understanding the

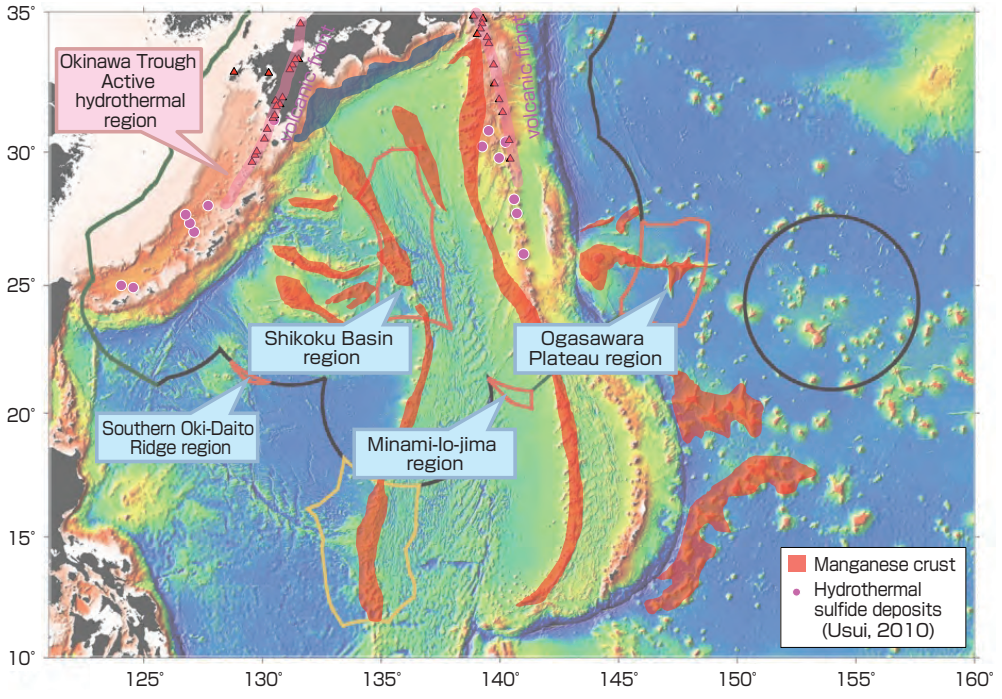


Fig. 1 Map of the sea floor geography around southwestern Japan showing major active hydrothermal areas and approved EEZ extension over the continental shelf

The black line shows the open sea and the green line shows the boundary with neighboring countries. The orange area marks the approved EEZ extension, and the yellow region indicates where the judgment has been postponed [Headquarters for Ocean Policy: *Heisei 24 Nen Ban Kaiyo No Jokyo Oyobi Kaiyo Ni Kanshite Kojita Shisaku* (2004 Situations of the Ocean and the Policies Taken for the Ocean)]. The Okinawa Trough is known for its active hydrothermal activities.[3]

distribution of potential aggregate materials such as sand and gravel, as well as for identifying submarine hydrothermal deposits, as discussed below.

3 Geology and structure of the active Ryukyu Arc and Okinawa Trough back-arc basin

Geological information regarding the islands of the Ryukyu Arc was obtained during the Okinawa Project. Previous studies of the geological stratigraphy of the Ryukyu Arc have concentrated on field surveys of a small land area of the arc, and consequently much of its tectonic history remains unclear. However, marine geological data provided by the Okinawa Project are expected to provide a more detailed understanding.

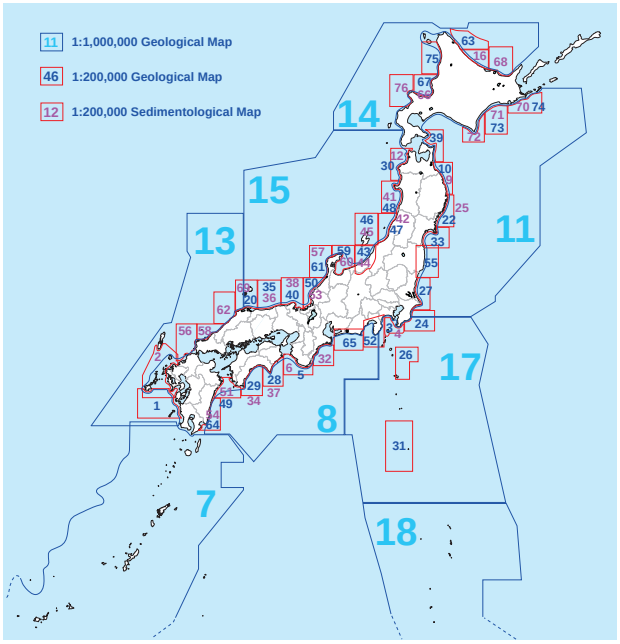


Fig. 2 Publication status of the marine geology maps for ocean regions around Japan
The areas within blue lines are those for which 1:1,000,000 marine geology maps have been published, and the red blocks are areas covered by published 1:200,000 marine geology maps (from AIST URL).

The Ryukyu Arc is a chain of islands that extends for approximately 1,200 km between Kyushu and Taiwan. It is an arc-trench system created as a result of subduction of the Philippine Sea Plate along the Ryukyu Trench. The Ryukyu Trench runs in a northeast-southwest direction, almost parallel to the Ryukyu Island Arc, and reaches a maximum depth of over 6,000 m. The orientation of the Ryukyu Arc shifts to east-west in the southern region (Fig. 5). In contrast to the Nankai Trough subduction zone offshore of Shikoku and Honshu, the fore-arc slope of the Ryukyu Trench is extremely limited, and there is almost no fore-arc basin, and no significant outer-arc ridge. This is possibly due to the difference in the subduction mechanism of the Philippine Sea Plate. The lack of the outer-arc ridge is more conspicuous on the slopes of the Ryukyu Trench north of Okinawa-jima Island than in the middle of the northern region.[7] The Ryukyu Arc can be divided into three regions, based on differences in zonal geological structure: North Ryukyu, Central Ryukyu, and South Ryukyu.[8] The borders of these regions are defined by Tokara Strait and Kerama Gap, a depression over 1,000 m deep that runs northwest-southeast. These structures were formed by normal faulting oriented perpendicular to the axis of the Ryukyu Arc. A number of active normal faults were identified east of Okinawa-jima Island from data collected during the GH08 cruise,[9] with subsequent analysis demonstrating that they developed in shallow areas close to land in the Ryukyu Arc and its upper fore-arc slope. Given that activity on these faults may cause tsunamis, it is necessary to investigate their distribution and activity in more detail. Historical records from Okinawa reveal little evidence of an earthquake and tsunami that caused significant damage. However, the Yaeyama Earthquake and Tsunami of Meiwa 8 (1771) caused major damage in the Yaeyama and Miyako Islands.[10] This emphasizes the importance of evaluating the geological hazards present in the Ryukyu Arc as part of the Okinawa Project.

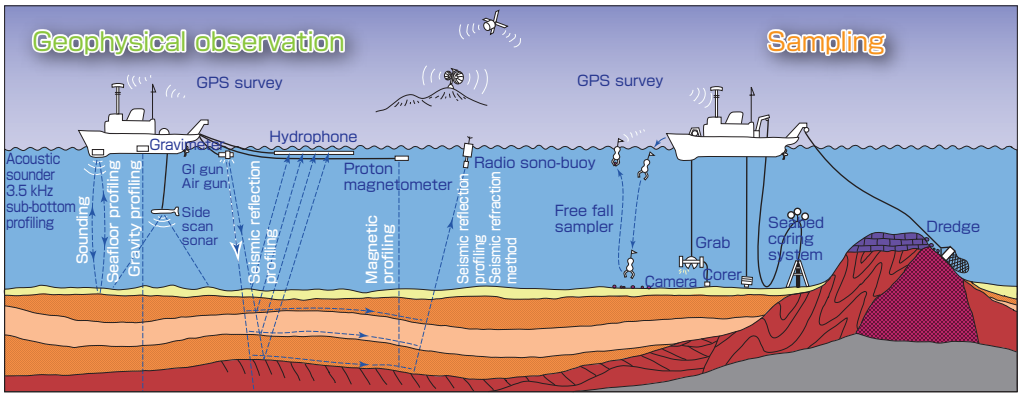


Fig. 3 Schematic diagram of the marine geological survey methods (from Reference [6])
Bathymetric, sub-bottom profiling, seismic reflection profiling, gravity, and magnetic surveys were conducted for creation of the 1:200,000 marine geology maps. Sampling mainly included grab sampling, core sampling, and dredging.

An active back-arc basin, known as the Okinawa Trough, runs almost parallel to the Ryukyu Arc on its northwestern side.[11] The trough is 1,000 km long and 200 km wide, with a depth that gradually increases along the axis from north to south, reaching a maximum of 2,000 m. Although there is some disagreement over when formation of Okinawa Trough began, it is generally considered to have been formed during the Pleistocene, based on evidence from seismic stratigraphy.[12] A volcanic front, including submarine volcanoes, runs from Kyushu to the offshore area northwest of Okinawa-jima Island in the Okinawa Trough.[4][13] While several previous studies have examined the Cenozoic tectonics that formed the Ryukyu Arc and the back-arc basin,[11][14] there is a paucity of data from the northern region, and the tectonics of rifting are not well understood. Therefore, data were collected from the northern Okinawa Trough during the GH11 cruise. The Okinawa Trough is thought to be in an active rifting stage, in which the continental crust is being extended. The northern Okinawa Trough is filled with stratified sediments, with several normal faults cutting the trough (Fig. 6). Rotated fault blocks dip northwest on the northwest side of the trough and toward the southeast on the southeast side,[15] and the sedimentary layer is thinnest in the axial region. The axis of rifting does not necessarily correspond to the areas of deepest bathymetry. In general, the axis of rifting is northeast-southwest, crossing the Okinawa Trough, but it is intersected by en echelon faults.[16] These observations demonstrate the importance of examining underlying geological structure, in addition to bathymetry, to gain a full understanding of the geology of these marine areas.

4 Development of submarine mineral resources

As an example of the use of the marine geological maps, we shall discuss the development of submarine mineral resources. AIST has developed techniques and processes for the sampling and analysis of surface sediments and geological structure below the seafloor. It is believed that geological structures control the area in which minerals are deposited.[17] Therefore, these processes aid the organization of the geological information, which can then be used to identify potential areas of mineral deposits. In particular, marine geological surveys performed over uniform grids by AIST may help discover potential deposits in previously overlooked areas.

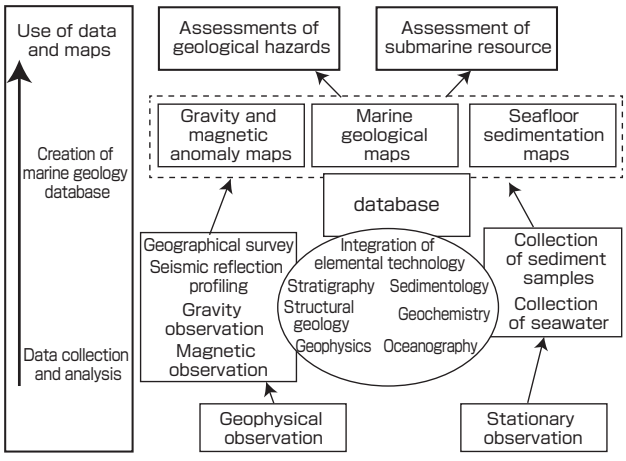


Fig. 4 Scenario for the data collection, creation, and use for the 1:200,000 marine geological maps

Multiple national organizations complete submarine mineral resources assessments using a variety of equipment and technology. The Japan Agency for Marine Earth Science and Technology (JAMSTEC) and various university organizations have conducted submarine mineral surveys, focusing on particular resources and gaining an understanding of formation processes. For example, the Integrated Ocean Drilling Program (IODP) undertook scientific drilling for seabed bacteria in the Iheya-North hydrothermal field of the Okinawa Trough.[18] Japan Oil, Gas and Metals National Corporation (JOGMEC) completed core sampling using the Benthic Multicoring System (BMS), targeting prospective regions for resource development and evaluating deposit sizes. These studies have focused on target resources, whereas AIST studies focus on promising locations. To assess submarine mineral resouces effectively, both strategies are required, and must be conducted with mutual collaboration and cooperation.

The following descriptions are the examples of surveys done in the Okinawa Project. The survey for the development of submarine mineral resources based on the marine geological surveys of AIST and the issues will be explained.

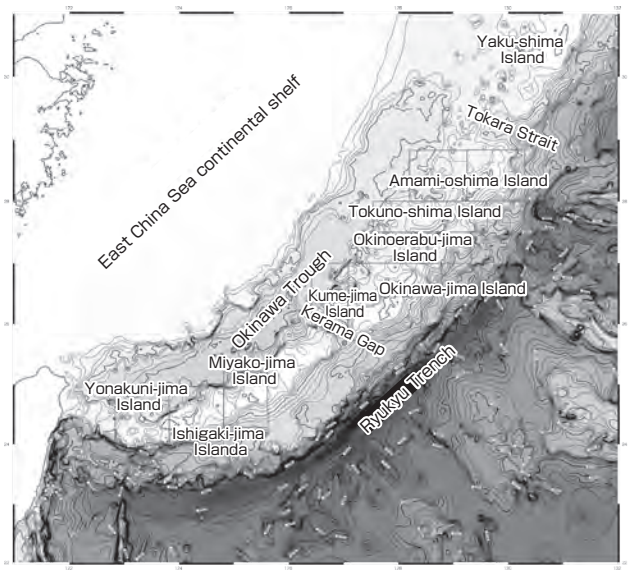


Fig. 5 Maps of the survey area covered in the Okinawa Project, and associated seafloor geography (from Reference [1])

The blocks depict the scheduled survey area for geological maps. As part of the Okinawa Project, ten 1:200,000 geological maps will be created for areas around the island.

4.1 Investigating potential sites in the Okinawa Trough

For this study, we defined potential sites as areas in which the hydrothermal activities currently occur or may have occurred in the past. In the Okinawa Trough, hydrothermal activity may occur at the juncture of the rift axis and intercepting faults, as well as in the calderas of the submarine volcanic front associated with the arc-trench system.[5] Previous surveys around Japan have noted the presence of hydrothermal deposits around submarine calderas and structural depressions in the volcanic fronts of back-arc rifting zones in the Izu-Ogasawara Arc and Okinawa Trough (Fig. 1). Examining the subsurface geological structure, the distribution of fault systems, and the distribution of submarine volcanoes and calderas, may reveal previously unknown hydrothermal deposits in the Okinawa Trough. Moreover, identifying oceanic regions with a similar geological history may help locate mineral deposits in areas that are no longer hydrothermally active. The survey area for the 1:200,000 marine geology maps (Fig. 5) does not extend to the trough surveyed in the Okinawa Project. Therefore, to identify potential sites, it is necessary to expand the survey area to include the back-arc basin of the Okinawa Trough.

4.2 Significance of uniform grid data for discovering potential sites

Marine geophysical surveys are conducted along survey lines perpendicular to the strike of the geological structure or deformation. For the 1:200,000 marine geological maps, survey lines were spaced approximately two nautical miles apart. Data were collected using a narrow multi-beam echo sounder and parametric sub-bottom profiler (SBP), while simultaneously conducting seismic reflection profiling, gravity surveys, and magnetic surveys. The cross line was set at intervals of four nautical miles. By doing this, it was possible to capture geological structures such as faults and fold axes with lengths of 5 km or more. Sediment sampling was conducted at the intersections of survey lines and cross lines. The collection and analysis of such uniform data sets are essential for understanding the whole region, and in limiting the possibility of overlooked structures.

4.3 Current situation and issues affecting the survey of potential sites

4.3.1 Geophysical surveys

The seismic reflection profiling survey is one of the basic methods to know the marine geological structure. The Izena Hole is one potential site for submarine hydrothermal deposits in the juncture of the rift axis and intersecting faults of the Okinawa Trough.[5] Identification of the geological structure of such sites within the back-arc region can be completed using seismic reflection profiling. Using this technique, we succeeded in obtaining cross-sections showing the geological structure of several submarine calderas of the Okinawa Trough during GH09-12 cruises. By combining seismic reflection profiling with rock sampling, gravity profiling, and magnetic profiling, we were able to determine the age, tectonics, and formation mechanisms of the calderas.

However, identifying hydrothermal deposits requires vertical and horizontal resolutions down to several meters, since deposits are composed of mixed sediments from the caldera wall and surrounding area. Also, potential deposits in back-arc basin are generally located in areas with complex topography near caldera walls, and imaging these conventional reflection profiling is difficult. Therefore, additional methods with greater accuracy, such as high-resolution acoustic surveys combined with gravity and magnetic profiling, are required to locate hydrothermal deposits.

4.3.2 Stationary observation surveys

For the conventional sampling, the stationary surveys we conducted included surface sediment sampling over survey grids using a grab sampler, columnar core sampling, and rock sampling using a dredge in steep areas with exposed rocks. The surface sediment samples we collected have not previously been used to search for indications of hydrothermal activity. However, it can be achieved by leaching the sediment samples using a weak acid, and

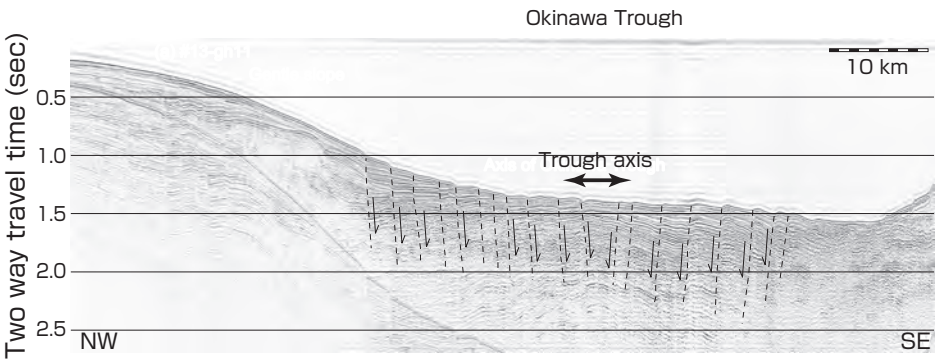


Fig. 6 Cross-section of the seismic profile obtained in the GH11 cruise (from Reference [16])
The seismic profile cross-section perpendicular to the Okinawa Trough. The internal reflectors clearly display stratified sediments, which are intersected by normal faults (dashed line).

selectively dissolving and analyzing sulfides released by hydrothermal activity. We conducted surveys during the GH12 cruise in 2012, using a remotely operated vehicle (ROV) owned by JOGMEC (Fig. 7). The ROV conducted seafloor observations at two outcrops over a distance of approximately 2 km, and collected a total of three samples. The work took approximately 5 hours, including launch and retrieval time. During the ROV survey, seafloor images can be observed in real time, and decisions on sample collection can be made on the spot. Using ROVs for outcrop observation could be the next effective step for identifying potential sites of hydrothermal deposits, although the number of ships capable of undertaking ROV surveys is currently limited.

5 Summary and future prospects

In the present study, we have discussed the current state of the Okinawa Project, using it as an example of how the results of marine geological surveys can be utilized within intellectual infrastructures. We have focused on the contribution of the Okinawa Project to the development of submarine mineral resources.

The Okinawa Project, started in FY 2008, aims to obtain geological information and to contribute to organization of geological information around Japan.[19] The survey of the region around Okinawa-jima Island, one of the most important islands of the Ryukyu Arc, was completed in the first 3 years of the project, and the survey of the region around Okinoerabu-jima Island of Kagoshima Prefecture was started in FY 2012. The Okinawa Project is producing important results that allow for detailed submarine mineral exploration, including an understanding of caldera structure and active submarine faults.

Fig. 7 Remotely operated vehicle (ROV) system on *Hakurei*, the vessel used for the GH12 cruise
In this ROV system, the ROV itself can be released in the ocean using a tether cable, allowing for operation with little preparation time. The ROV allows real-time observation of the seafloor, and the manipulator can be used to collect rock samples from the seafloor.

In the future, the survey range of the Okinawa Project may be extended to include the Okinawa Trough, greatly increasing the possibility of discovering new mineral deposits. However, there are a few issues that may limit this expansion. The most pressing issue is the procurement of vessels capable of conducting surveys along fixed lines and at set sampling points. A wide-ranging survey for submarine mineral resources will also face efficiency and technical issues. To advance national interest, the development of submarine mineral resources must be conducted efficiently and effectively across the boundaries of agencies, ministries, and institutions. It is therefore necessary to construct an efficient research system through collaboration and cooperation that enables mutual utilization of technology and knowledge amongst institutions, including AIST.

Acknowledgement

Marine geological investigations around Japan were continuously carried over to AIST from its preceded organization, the Division of Marine Geology, Geological Survey of Japan, Agency of Industrial Science and Technology. They represent the accumulation of scientific discussions and the development of marine survey methods by both of these organizations. We are grateful for the cooperation of all those involved with the marine geological surveys and research vessels, particularly JOGMEC and its precursor, Metal Mining Agency of Japan.

References

[1] K. Arai and A. Nishimura: Okinawa kaiiki no chosa ni mukete – Tokushugo no hajime ni (Toward the survey of Okinawa ocean region – Introduction to Special Edition), *Chishitsu News*, 633, 10 (2007) (in Japanese).
[2] A. Nishimura, M. Yuasa, K. Kisimoto and K. Iizasa: A scientific challenge to the delineation of Japan's continental shelf - Contribution to validating the Japan's rights over marine areas based on earth science, *Synthesiology*, 6 (2), 103-117 (2013) (in Japanese) [*Synthesiology English edition* in print].
[3] A. Usui: *Kaitei Kobutsu Shigen: Miriyo Rea Metaru No Tansaku to Kaihatsu* (Submarine mineral resources – Exploration and Development of Unused Rare Metals), Ohmsha (2010) (in Japanese).
[4] H. Yokose, H. Sato, Y. Fujimoto, M. H. T. Mirabueno, T. Kobayashi, K. Akimoto, H. Yoshimura, Y. Morii, N. Yamawaki, T. Ishii and E. Honza: Mid-Pleistocene submarine acidic volcanism of the Tokara Islands, Japan, *Journal of Geography*, 119, 46-68 (2010) (in Japanese).
[5] S. Haraguchi and T. Kodama: Hydrothermal deposits in the Okinawa Trough, *Chishitsu News*, 634, 10-14 (2007) (in Japanese).
[6] K. Ikehara: Examining the Seabed, The Earth's Messages from the Sea, English version of the Japanese article in *AIST Today*, 5 (8), 4 (2005).
[7] S. Kato: A geomorphological study on the classification and

evolution of trenches around Japan, *Rep. Hydr. Res.*, 27, 1-57 (1991).
[8] K. Konishi: Geotectonic framework of the Ryukyu Islands (Nansei-shoto), *Journal of the Geological Society of Japan*, 71, 437-457 (1965) (in Japanese).
[9] K. Arai, T. Inoue, T. TsuZino, F. Murakami and K. Ikehara: Okinawa-jima toho oki no onpa tansa (Seismic surveys of eastern Okinawa Island –preliminary results of GH08 cruise-, Marine Geological and Geophysical Studies around Okinawa Islands –eastern off of Okinawa Island- (Preliminary Reports on Researches in the 2008 Fiscal Year)), *GSJ Interim Report*, 46, 29-39 (2009) (in Japanese).
[10] H. Watanabe: *Nihon Higai Tsunami Soran (Comprehensive List of Tsunami to Hit the Japanese Islands, Second Edition)*, University of Tokyo Press (1998) (in Japanese).
[11] J. Letouzey and M. Kimura: The Okinawa Trough: Genesis of a back-arc basin developing along a continental margin, *Tectonophysics*, 125 (1-3), 209-230 (1986).
[12] J. O. Park, H. Tokuyama, M. Shinohara, K . Suyehiro and A. Taira: Seismic record of tectonic evolution and back-arc rifting in the southern Ryukyu island arc system, *Tectonophysics*, 294 (1), 21-42 (1998).
[13] R. Shinjo: Geochemistry of high Mg andesites and the tectonic evolution of the Okinawa Trough-Ryukyu arc system, *Chem. Geol.*, 157 (1-2), 69-88 (1999).
[14] J. C. Sibuet, B. Deffontaines, S. K. Hsu, N. Thareau, J. P. Le Formal, C. S. Liu and ACT Party: Okinawa Trough back-arc basin: Early tectonic and magmatic evolution, *J. Geophys. Res.*, 103 (B12), 30245-30267 (1998).
[15] C. S. Lee, G. G. Shor, L. D. Bibee, R. S. Lu and T. W. C. Hilde: Okinawa Trough: Origin of a back-arc basin, *Marine Geology*, 35 (1-3), 219-241 (1980).
[16] T. Sato, K. Arai and T. Inoue: GH11 kokai deno hanshaho onpa tansa gaiyo (Seismic survey of GH11 cruise: Spreading axis of the Okinawa Trough and gradient of shelf slope, Marine Geological and Geophysical Studies East China Sea and Okinawa Trough –Northen Okinawa Trough- (Preliminary Reports on Reseaches in the 2011 Fiscal Year)), *GSJ Interim Report*, 58, 46-53 (2012) (in Japanese).
[17] F. J. Sawkins: Sulfide ore deposits in relation to plate tectonics, *Jour. Geol.*, 80 (4), 377-397 (1972).
[18] Expedition 331 Scientists: Deep hot biosphere, *IODP Preliminary Report*, 331 (2010).
[19] K. Arai and K. Ikehara: Okinawa-jima shuhen no kaiyo chishitu chosa - Ryukyu Retto oyobi Higashi Shinakai no chishitsu joho seibi o mezashite (Marine geological survey around Okinawa-jima - Toward the geological information organization for Ryukyu Islands and East China Sea), *AIST TODAY*, 11 (6), 27 (2011) (in Japanese).

Authors

Kohsaku ARAI

Completed doctoral course at the Division of Material Sciences, Graduate School of Natural Science and Technology, Kanazawa University in 1994. Joined the Geological Survey of Japan, Agency of Industrial Science and Technology, Ministry of International Trade and Industry in 1997. Senior Researcher of the Institute for Marine Resources and Environment, AIST in 2001; Senior Researcher of the Institute of Geology and Geoinformation, AIST in 2004; and Leader of the Marine Geology Research Group, IGG, AIST from 2010. Engaged in marine geological surveys since joining AIST, and including creation and publication of marine geological maps such as Enshunada Geological Map. Led the survey since the inception of the Okinawa Project. In this paper, summarized the current state of the Okinawa Project and discussed its potential contribution to the development of submarine mineral resource.

Gen SHIMODA

Completed doctoral course at the Graduate School of Human and Environmental Studies, Kyoto University in 1996 (Doctor of Human and Environmental Studies). Joined Kyoto Fission-Track Co., Ltd. in 1997. Lecturer of the Institute for Geothermal Sciences, Graduate School of Science, Kyoto University in 1990 (researcher of research institution). Supporting Staff for Priority Research of the Institute of Geology and Geoinformation, AIST in 2001; Researcher of the IGG, AIST in 2005; and Leader of the Tectonics and Resources Research Group, IGG, AIST from 2012. Specialty is solid geochemistry. In this paper, described the marine surveys conducted at the potential sites of submarine mineral resources, as well as proposing solutions to survey issues.

Ken IKEHARA

Graduated from the Department of Education, Tokyo Gakugei University in 1982. Joined the Geological Survey of Japan, Agency of Industrial Science and Technology, Ministry of International Trade and Industry in 1982. Leader of the Marine Geology Research Group, Institute of Geology and Geoinformation, AIST from 2005; and Leader of the Marine Geological Map Project; and Deputy Director of the IGG, AIST from 2009. Engaged in marine geological survey of the ocean regions around Japan since joining AIST. Specialty is sedimentology. In this paper, as the leader of the Marine Geological Map Project, proposed the ways in which AIST should concentrate efforts to advance the development of submarine mineral resources.

Discussions with Reviewers

1 Overall

Comment (Shigeko Togashi, AIST)

This paper sheds light on the current situation and issues of the geological marine survey, an AIST effort to organize the geological information in the ocean regions around Japan, carried on by the Geological Survey of Japan, especially focusing on the Okinawa Project. Its content is appropriate for a *Synthesiology* paper, as a discussion of the methodology for organizing the national intellectual infrastructure. In the first draft, there were some insufficiencies in the methodology development, but these were improved in the revised version.

Comment (Masahiro Seto, AIST)

This is a very interesting paper that discusses the significance of the marine geological survey in the Okinawa region from the perspectives of earth science, disaster prevention, and assessment of potential mineral resource sites. I think the content and composition are appropriate as a *Synthesiology* paper. I also hope

more surveys will be conducted in the Okinawa region in the future.

Answer (Kohsaku Arai)

The survey around Okinawa region has produced new geoscientific findings. Based on the situation with surrounding countries of Japan in recent years, I believe it is necessary to organize the basic geological information quickly. I hope to improve the efficiency of the organization while maintaining the quality of the AIST survey.

2 Flow from collection to use of basic land information data

Comment (Shigeko Togashi)

For the "flow from collection to use of basic geological information data" and Fig. 4, I think you should add detailed information as a *Synthesiology* paper. Particularly, to the people outside the field, it is necessary to carefully explain the process by which the collected data become sedimentological or geological maps. For example, please add the explanation about the necessity of employing the latest knowledge of sedimentology, structural geology, geophysics, geochemistry, mineralogy, seismology, and others, to conduct interpretations of the sedimentation unique to the region, geological structure, or mineral deposition process. Please state clearly that sedimentological or geological maps are compiled by clarifying the geological phenomena of the target region by "synthesizing" the various "elemental technologies" based on a scientific scenario. Also, in Fig. 4, please indicate the process for integrating the disciplines you deem most important among the aforementioned "ologies" that are the keywords. For the "development of the submarine mineral resources," please clarify what was the objective, how the method was selected, and what you found out. Please show the flow of what is necessary to be known in the future, what selection of methods must be made to achieve this, and what are the issues involved.

Answer (Kohsaku Arai)

I have added details of the flow of geological information from collection to use in marine geological maps. During survey cruises, many researchers are involved in the collection of data and samples, and a variety of academic specialties are required to analyze and interpret these data. Samples do not stay within AIST, but are distributed to the specialists in various universities and other institutions. The marine geological map series is the grand culmination of such efforts.

3 "Uniform data"

Comment (Shigeko Togashi)

You use the expression "uniform data," and since this is an important keyword of this paper, please elaborate on this point. When you say uniform, do you mean, for example, "the data is collected spatially in a systematic and comprehensive manner, the selection and collection methods of the data are done in some standardized way, or a certain level of quality is maintained"?

Answer (Kohsaku Arai)

I have added an explanation of this in section 2.

4 Survey method of fault activity in the the seabed

Comment (Masahiro Seto)

You mention that there are faults that intersect the island arc in the Ryukyu Arc and the upper part of its fore-arc slope. You also indicate the importance of the detailed survey of the fault activity. I think the methods for the survey and assessment of the submarine fault activities must be different from the methods on land. Is there technology and methodology established for surveying the submarine faults? If so, what are they?

Answer (Kohsaku Arai)

Many of the earth's plate boundaries are in oceanic areas, along with associated faults that cause major earthquakes. Activity on these submarine faults may also cause tsunamis. AIST studies that assess these active faults consider them from this perspective. First, the distribution and form of active submarine faults are investigated using the seismic reflective profiler. However, estimating the activity and activity history of these faults may be more important than describing their distribution. Previous research investigating faults activity includes studies in which cores were collected on both sides of the active fault, allowing the history of fault activity to be inferred through comparative changes in sediment layer thicknesses. The activity history of submarine faults can also be derived from the frequency of seismic-related sediment structure (turbidites) occurring in columnar core samples. It is important to use the method appropriate for the individual regions for these surveys, and necessary to accumulate case studies on active submarine faults.

5 Restriction caused by geological structures in locations of mineral deposits

Comment (Masahiro Seto)

In general, which structure or phenomenon do you mean when you say, "the geological structure restricts the potential mineral deposition"?

Answer (Kohsaku Arai)

Potential hydrothermal activity is concentrated in the island arc volcano and the back-arc basin. In the back-arc basin, hydrothermal activity accompanies underground magmatic activity due to the formation of the back-arc rift zone in response to the tensile stress field. It is thought that the locations of structures that are continuous to considerable depths underground (e.g., faults) have high potential for mineral deposits.

6 Characteristics of the marine geological survey of the Okinawa region and future development

Comment (Masahiro Seto)

For the marine geological survey of the Okinawa region that started in 2008, what are the future plans for organizing and publishing the geological maps, and by when will they be done? Also, in organizing the geological maps, I think the originality of the researchers in charge is expressed. What differences in characteristics can we expect for the Okinawa region survey compared to the conventional marine geological survey?

Answer (Kohsaku Arai)

The survey is planned to continue until FY 2019. For the production of the geological maps, we are starting from the regions around Okinawa-jima and Kume-jima islands, where the surveys have already been completed. We hope to publish the maps as they are completed. The primary difference between this region and the other surveys conducted to date is the variation in geological structure, as described in this report. One particularly interesting characteristic that distinguishes this region from the four main islands is the lack of major rivers. Instead of land-derived siliciclastic material, this region is dominated by high bioclastic productivity and carbonate particles derived from coral reefs.

Measurement of input resources for standardization activities in basic research and applied and development research, and the difference of the measuring results between the research types

— Case studies of universities and technology licensing organizations, and the electric machinery industry —

Suguru TAMURA

[Translation from *Synthesiology*, Vol.6, No.3, p.170-179 (2013)]

This study explores the methods for measuring standardization activities in basic research and applied and development research. Such methods are supposed to enable more sophisticated management of innovation in organizations. This paper focuses on standardization activities relating to intellectual property, because such activities are thought to be strongly linked to innovation. Universities and technology licensing organizations were chosen as examples of basic research institutions. Companies in the electric machinery industry and information and communication industry were selected as examples of the applied and development research institutions. First, the stability of data over multiple years and the validity of the definition of standardization activities are discussed. Then, the difference in measurement results between basic research, and applied and development research is described. A hypothesis is proposed that the ratio of standardization activities in basic research is as high as that in applied and development research.

Keywords : Basic research, applied research, development research, standardization activities, university

1 Outline

The objective of this research is to clarify whether the measurement method for quantitative data pertaining to the standardization activities in basic research and applied and development research is appropriate or not, and to set the clarified method as a foundation to advance innovation management. In addition, to construct an evaluation method for standardization policy, the elemental activities of standardization activity and the re-synthesis of various elements are investigated through the quantification of outcomes and invested resources in the standardization activity. Until now, while the quantification of outcome was possible to some extent through statistics such as ISO, there was no sufficient quantification of the invested resources.

In this paper, the usability of the definitions pertaining to the standardization activity in research analysis (hereinafter, will be called efficacy), and whether the data measured over several fiscal years stay roughly within a certain range will be investigated (note: the situation in which the data collected over several fiscal years fall roughly in a certain range will be described as being “stable”). Based on the data obtained, the difference of the standardization activity between the universities that engage in basic research and the companies that engage in applied and development research will be evaluated. Also, the management of the standardization activity in basic research institutions will be discussed. In addition, the social foundation where the standardization activities for innovation are quantitatively managed is established as a long-term outcome goal, and proposals will be made for research processes necessary for its achievement, and the point of achievement at the time this research paper was written is described.

Although the importance of standardization strategy is emphasized in recent years, surprisingly, the method for measuring the quantitative data pertaining to standardization activities in companies and organizations is still in the research stage. The *Monbu Kagaku Tokei Benran* (Statistical Abstract for Education, Culture, Sports, Science and Technology) carries data pertaining to patents, but there are no data for standardization activities.[1] The quantitative data for standardization activities collected officially focus heavily on the results, and are limited to the number of de jure standards offered by ISO or IEC, and the number of staff in the office.[2]

In such a situation, the Japan Patent Office (JPO) added the survey items pertaining to the standardization activities in intellectual property (IP) activities in the *Chiteki Zaisan Katsudo Chosa Hokokusho* (Results of the Survey of Intellectual Property-Related Activities) that is conducted for all industries in Japan.[3]-[6] Compared to the whole

Research institute of Economy, Trade and Industry (RIETI) 1-3-1 Kasumigaseki Chiyoda-ku 100-8901, Japan Tel: 03-3501-1363, Fax: 03-3501-8577

Original manuscript received December 12, 2012, Revisions received February 18, 2013, Accepted February 18, 2013

standardization activities, the standardization activity in IP activity has recently gained attention, because there are many patents related to standards and its importance in policymaking has increased.[7] By narrowing down the range to IP activities, the possibility of unintentionally including the activities unrelated to standardization planning, such as resource investment for the verification activity pertaining to ISO 14000 series, will be reduced. The data thus obtained will accurately represent the effect of the amount of resource investment for the standardization activities in IP activities.

In case of Japan, about 60 % of the research funds are spent on basic research in the research institutions such as universities. On the other hand, nearly 90 % of the research funds are used for applied and development research in companies.[1] Considering this point, the data in the category, "education, Technology Licensing Organization (TLO), public research institutions, and public service," will be used to evaluate the standardization activities in basic research. This category includes basic research institutions such as universities. The data in the category of "electric machinery industry" and "information communication industry" will be used to evaluate the standardization activities in applied and development research. Focusing on these standardization activity data, investigation will be done on whether the collected data are adequate and stable, and whether they are adequate enough to be used in future policy analysis. In addition, the collection and use of data pertaining to the standardization activities that may contribute to an evaluation method for innovation activities in both research fields will be discussed. The differences and the reasons will be considered for the standardization activities by different research objectives. Moreover, based on the results obtained, the management of standardization activities in basic research institutions such as universities will be considered.

Comparing the data for the standardization activities in IP activities for the four years between 2008 and 2011, we obtained results that indicated that the data had certain reliability and stability in terms of continuity. The number of people in standardization activities was higher in the IP activities for education, TLO, and others that represent basic research. In the aspect of policy, it was pointed out that the universities had insufficient management of standardization activities in the IP activities.

In this paper, chapter 2 explains the previous researches. chapter 3 describes the hypotheses and their background. Explanation of the method and data are provided in chapter 4, results in chapter 5, discussion including the scenario for realization in chapter 6, future issues in chapter 7, and conclusion in chapter 8.

2 Previous researches

Since there are very few previous researches in this discipline, I shall describe the literature necessary for understanding the framework of this research.

2.1 Collection method for the number of standardization activity personnel and the definitions

2.1.1 Collection method

For the collection of the number of researchers and personnel, the full-time equivalent (FTE) method is recommended in the OECD's Frascati Manual.[8] FTE is a counterpart to the method based on per capita count. The per capita counting method counts the actual number of people. On the other hand, FTE is a method of counting the number of people by the percentage of working hours. Therefore, if one works half a day on a certain job, the count will be 0.5 person. The FTE is a method appropriate for understanding the amount of labor invested in cases where people engage in both education and research, as in the case of university faculty members. This is because this method prevents overvaluation of the actual research activity that may occur by counting the actual number of people. In the *Chiteki Zaisan Katsudo Chosa Hokokusho* (Results of the Survey of Intellectual Property-Related Activities), the Japan Patent Office has conventionally used the FTE method to count the number of people engaging in IP activities. Therefore, the FTE method was employed in this research to count the number of standardization activity personnel in the overall IP activities.

2.1.2 Definition

The definitions of the standardization activity often use the keyword "specialization" by focusing on technology.[9] However, this is a definition for products, and is not intended for use in the collection of quantitative data for standardization activities. In the OECD Frascati Manual that sets out the evaluation method for innovation activities around the world, there is no definition of the standardization activity.

However, some clues have been offered recently in considering the definitions for the standardization activities in companies. In this paper, the following definitions were used in the JPO's IP activity survey.[3]-[6]

Standardization activity personnel:
Standardization is the process of establishing or revising the rules (standard) such as the evaluation method for technical specs and tests, unification of terms and symbols, or simplification in certain technological field, through deliberation by several people.

Intellectual property (IP) activity personnel:
This is a person who engages in the work including exploration of industrial property rights, obtainment of rights, and maintenance of rights. It also includes people engaging in the work pertaining to the management, assessment, transaction,

licensing, and dispute of IP activities, as well as people engaging in the planning, research, education, accounting, clerics, and other work necessary to support the IP activities.

Standardization activity personnel of IP activity personnel: This is a person who engages in research of patents for standardization, assessment of essential patent and license negotiations, writing and submission of patent statements for standardization, response to patent violations of technology in standardization, and other works to manage the intellectual properties related to standardization. It also includes persons engaging in planning, proposals, and deliberations, as well as people engaging in education, diffusion, accounting, clerics, and other works necessary to support the standardization activities of the IP personnel.

2.2 International comparison of the existing data

Internationally, there is hardly any attempt to collect data for standardization activities. One of the main reasons is because there is the lack of effort to collect data by the related international institutions. In the annual reports of the ISO and IEC that are organizations that set the international standards, there are data on the number of people at the government organizations of various countries and the number of standards established, but there is no report of the number of standardization activity personnel in each country.[12] It is indicated that the objective of ISO and IEC is to create international standards in document form, and the collection of statistical data pertaining to the actual state of standardization activities around the world is not considered their organizational goal. On the other hand, the international intellectual property organizations such as the World Intellectual Property Organization (WIPO) collect economic data pertaining to patents, but do not have the function to collect statistical data for standardization activities. The lack of institutions that conduct data collection systematically for standardization activities results in the lack of data that allows international comparison.

Another reason is that the amount of resource invested in standardization activities is not recognized as part of science and technology data. Frequent discussions are conducted in OECD and UNESCO on how to set the range of science and technology activities. However, the activities for technological standards have been positioned as “related activities” to R&D, and are not considered as science and technology activities. They are positioned merely as activities related (or pertaining) to science and technology. Therefore, even to this day, they are not included in the official statistical data for science and technology.[10]

As a result, the question of which quantity should be considered as policy variable in order to evaluate standardization activities remains unsolved.

As another practical reason, it is difficult to collect such data. In many cases, the standardization activities are not established as independent work, and they are often conducted as additional work adjunct to the main work of R&D or IP activities. Therefore, they are less likely to be recognized within the organization.

2.3 Relationship between basic research, applied and development research, and standardization activities

For the number of standardization activities in universities that primarily engage in basic research disciplines, real data cannot be found internationally, as mentioned above. A similar situation can be seen for the real data of companies that mainly engage in applied and development research.

2.4 Effect of standardization activities on technological innovation

It is reported that in electric machinery manufacturing in the US, there is a clear positive correlation between the number of people involved in the standard development organization and the number of patents obtained by the companies. The results indicate that the standardization activities of the standard setting organizations may have a cause-and-effect relationship with the IP activities as represented by the corporate patents.[9]

3 Hypotheses

In this paper, the following hypotheses will be investigated.

3.1 Hypothesis 1a

There is no internationally established method for collecting data on the number of people engaging in standardization activities within an organization, and it is currently under investigation. First, it is necessary, as an assumption for utilizing the data, to check the collection method and to see whether the data can actually be collected stably.

Hypothesis 1a: The collected data of the number of standardization activity personnel is stable in terms of recovery rate, etc.

3.2 Hypothesis 1b

In collecting the number of standardization activity personnel in IP activities, the collection is based on the definition for standardization activities that spread out within the organization, rather than on the definition considering only the work of standardization negotiation. Since whether the collection of data based on this definition is actually possible has never been verified in the previous researches, the verification of this hypothesis will be conducted.

Hypothesis 1b: The definition is effective in the data collection of the number of standardization activity personnel.

Figure 1 shows the hypotheses and the relationship to the research synthesis of research.

4 Method

Using the data from the JPO *Chiteki Zaisan Katsudo Chosa Hokokusho* (Results of the Survey of Intellectual Property-Related Activities), observations were made from 2008 to 2011 on the number of IP activity personnel by industrial field, and the number of standardization activity personnel in IP activities. The comparisons were made among research fields to see the percentage of the standardization activities in IP activities.

4.1 Outline of the Chiteki Zaisan Katsudo Chosa Hokokusho

4.1.1 Objective of the survey

The objective of the survey was: "To understand the situation of the IP activities of individuals, corporate bodies, research institutions such as universities in Japan, to organize basic materials for planning and proposing the IP policy of Japan." This statistical survey was started in FY 2002.

4.1.2 Subject year

The subject years of the survey for standardization activities are FY 2008 and after.

4.1.3 Survey subject

The subjects are the companies and others with five or more patent applications, utility model applications, design registrations, or trademark registrations in the previous fiscal year. Specifically, this includes companies, corporate laboratories, universities, and public research institutions. The data collection for IP activity survey was started in 2002. Since it is conducted as a general statistical survey based on the Statistics Act of Japan, the subjects are required to respond honestly, unlike regular questionnaire surveys, and it is believed that highly reliable results are obtained for the standardization activities in companies.

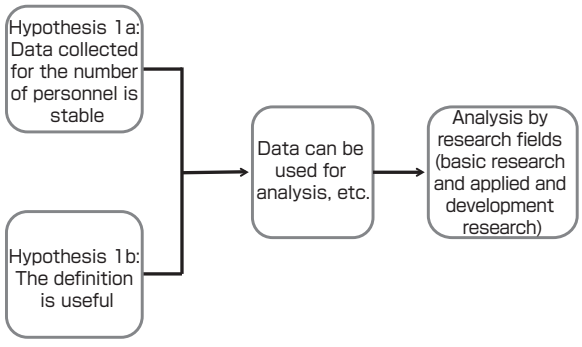


Fig. 1 Flow of the hypothesis to the composition of research

Table 1. Number of standardization personnel in IP activity and number of IP personnel that serves as parameter

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Number of standardization personnel in IP activity (persons)	Non-surveyed	Non-surveyed	Non-surveyed	Non-surveyed	Non-surveyed	Non-surveyed	2,296	2,298	2,336	1,826
Number of IP personnel that serves as parameter (persons)	17,679 (Reference value)	9,234 (Reference value)	17,569 (Reference value)	17,700	18,658	19,589	18,458	19,227	17,106	18,583
Percentage (%)	—	—	—	—	—	—	12.4 %	12.0 %	13.7 %	9.9 %

Source: Data of the JPO *Chiteki Zaisan Katsudo Chosa Hokokusho* (Results of the Survey of Intellectual Property-Related Activities). The numbers of IP personnel for 2002, 2003, and 2004 are reference values, because they were measured using measurement method that was different from the current method.

5 Results

5.1 Number of IP activity personnel and the number of standardization activity personnel in IP activities

The recovery rate of the JPO survey over the years has been about 50 %, and the responses are obtained from the majority of those surveyed. Of the companies and others that responded, about 90 % entered information about the standardization activities for IP activities. It is thought that there is a low possibility of sampling bias due to response or no response.

The data collection for the number of IP personnel has been done since 2002 (Table 1). The numbers fall in the range of 17,000 to 19,000 persons. For 2003, the number dropped to half of about 9,000 persons, due to the changes in collection method, and this figure is considered as reference value. In contrast, the number of standardization activity personnel in IP activities that is used as the alternative index of the standardization activities remained around 2,000 persons between 2008 and 2011. The percentage of standardization activities was approximately 10 %. For 2011, the percentage was 9.9 %, and the percentage of standardization activities was lowest in the past four years.

5.2 Comparison of data over the years by industrial category

The changes in the figures by industrial category are shown (Table 2, Fig. 2). At one glance, one can see that the fields of "electrical machinery manufacturing" and "education, TLO, public research institution, and public service" have the highest number of personnel. However, because this number may be affected by the number of companies and the number of working people that serve as the parameter, the high-low of numbers cannot be simply compared. Yet, it is appropriate to overview the level of activities in each industry. Also, by looking at the variation of numbers for each year, it can be used to determine the appropriateness of the collection method and data reliability.

Table 2. Number of standardization personnel among IP personnel and the percentage (total by industry)

	Number of samples				Number of IP personnel				Number of in-company patent attorney in IP personnel			
	2011	2010	2009	2008	2011	2010	2009	2008	2011	2010	2009	2008
Total	3,030	4,805	3,663	3,231	18,538	17,106	19,227	18,457	1,352	1,055	1,202	998
Education, TLO, public research institute, public service	256	515	252	251	1,246	1,549	1,412	1,524	46	54	62	47
Electric machinery industry	328	425	378	389	6,600	4,806	6,711	5,953	563	336	491	337
Information & communication industry	108	254	170	149	431	653	687	568	39	42	38	21
Construction	107	190	110	126	286	360	242	345	15	12	5	10
Food manufacturing	164	200	228	161	465	501	531	493	47	30	39	41
Textile, pulp, papermaking	53	98	66	72	238	260	244	263	23	22	22	24
Drug manufacturing	88	82	86	85	626	565	610	551	106	94	101	89
Chemical industry	211	261	227	227	1,743	1,844	1,912	1,725	128	132	125	109
Oil & coal, plastic, rubber, ceramics	192	262	224	208	990	1,039	944	955	76	76	65	51
Iron & steel, non-iron metal manufacturing	75	79	82	84	667	603	697	633	52	50	41	33
Metal product manufacturing	109	190	149	133	271	335	320	329	4	10	6	7
Machinery manufacturing	215	266	219	294	905	872	1,156	865	58	40	59	39
Transportation machine manufacturing	137	166	139	145	1,581	1,207	1,272	1,468	71	46	47	53
Commercial machinery & equipment manufacturing	104	108	90	100	1,023	667	852	845	61	37	50	48
Other manufacturing	209	291	236	229	699	804	703	1,133	33	35	25	66
Wholesale, retail, etc.	323	594	528	296	329	380	389	314	10	15	4	6
Other non-manufacturing	226	446	317	281	337	512	385	472	15	18	15	18
Individual, others	125	378	162	91	147	149	161	19	6	6	7	-

	Number of IP personnel				Number of standardization personnel in IP personnel				(Number of standardization personnel)/(IP personnel)			
	2011	2010	2009	2008	2011	2010	2009	2008	2011	2010	2009	2008
Total	18,538	17,106	19,227	18,457	1,826	2,336	2,298	2,296	9.9%	13.7%	12.0%	12.4%
Education, TLO, public research institute, public service	1,246	1,549	1,412	1,524	161	402	386	390	12.9%	26.0%	27.3%	25.6%
Electric machinery industry	6,600	4,806	6,711	5,953	421	465	461	484	6.4%	9.7%	6.9%	8.1%
Information & communication industry	431	653	687	568	34	63	73	35	7.9%	9.6%	10.6%	6.2%
Construction	286	360	242	345	40	62	36	41	14.0%	17.2%	14.9%	11.9%
Food manufacturing	465	501	531	493	115	120	80	85	24.7%	24.0%	15.1%	17.2%
Textile, pulp, papermaking	238	260	244	263	20	31	21	19	8.4%	11.9%	8.6%	7.2%
Drug manufacturing	626	565	610	551	129	133	127	65	20.6%	23.5%	20.8%	11.8%
Chemical industry	1,743	1,844	1,912	1,725	98	161	204	180	5.6%	8.7%	10.7%	10.4%
Oil & coal, plastic, rubber, ceramics	990	1,039	944	955	109	103	149	173	11.0%	9.9%	15.8%	18.1%
Iron & steel, non-iron metal manufacturing	667	603	697	633	44	37	35	26	6.6%	6.1%	5.0%	4.1%
Metal product manufacturing	271	335	320	329	63	66	73	84	23.2%	19.7%	22.8%	25.5%
Machinery manufacturing	905	872	1,156	865	159	220	153	192	17.6%	25.2%	13.2%	22.2%
Transportation machine manufacturing	1,581	1,207	1,272	1,468	113	106	123	164	7.1%	8.8%	9.7%	11.2%
Commercial machinery & equipment manufacturing	1,023	667	852	845	63	50	66	77	6.2%	7.5%	7.7%	9.1%
Other manufacturing	699	804	703	1,133	122	154	143	148	17.5%	19.2%	20.3%	13.1%
Wholesale, retail, etc.	329	380	389	314	82	88	85	66	24.9%	23.2%	21.9%	21.0%
Other non-manufacturing	337	512	385	472	32	54	55	63	9.5%	10.5%	14.3%	13.3%
Individual, others	147	149	161	19	21	23	28	6	14.3%	15.4%	17.4%	31.6%

Source: Modified data of the JPO *Chiteki Zaisan Katsudo Chosa Hokokusho* (Results of the Survey of Intellectual Property-Related Activities) for 2011, 2010, 2009, and 2008.

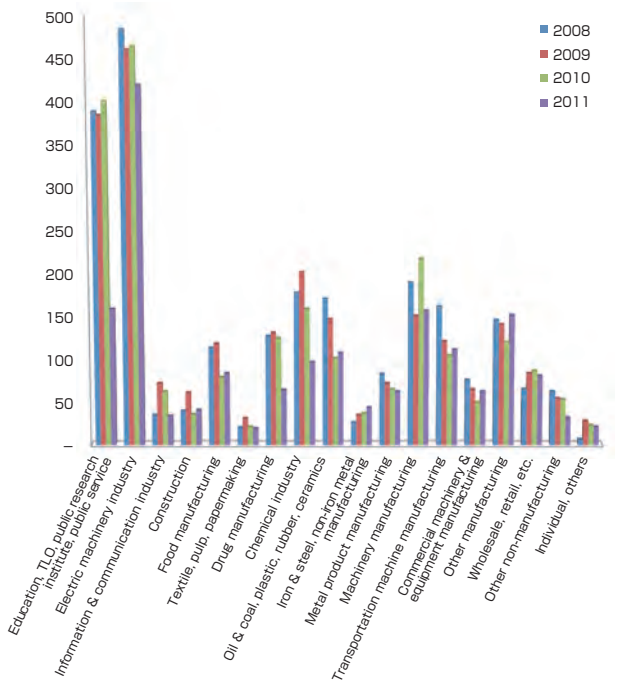


Fig. 2 Number of personnel involved in standardization among the IP personnel by industrial category (2008-2011)

5.2.1 Education, TLO, public research institution, and public service

This category includes the advanced research institutions such as universities. Therefore, the data can be used to understand the trend of basic research. Looking at the data by category, the number of personnel involved in standardization activities is second after the electric machinery industry. In 2010, the number was highest at 402 persons, and lowest with 161 persons in 2011. The percentage of the standardization activities among IP activities was lowest at 12.9 % in 2011. In other years, the percentage was about 26 % to 27 %. The reason for the shift in the data, other than the decrease in the actual number of personnel, was because the amount of standardization activities decreased in work. Other factors include the fact that this data was not panel data but targeted the companies with five or more patent applications in the previous year, and the sample companies might have been replaced.

5.2.2 Electric machinery industry

The highest number was 484 persons in 2008, and the lowest number was 421 persons in 2011. While the percentage of the

number of standardization activity personnel in IP activities was lowest at 6.4 % in 2011, the percentage was highest at 9.7 % in 2010.

5.2.3 Information and communication industry

The lowest number was 34 persons in 2011, and highest number was 73 persons in 2009. For the percentage in IP activity personnel, it was lowest at 6.2 % in 2008, and highest at 10.6 % in 2009.

6 Discussion

6.1 Verification of the hypotheses

From the above results, the Hypotheses 1a and 1b were evaluated. In verifying the hypotheses, we looked at: 1) the recovery rate of the questionnaire, 2) the response rate to the number under investigation among the recovered data, and 3) the changes observed when the data were compared by year. Currently, since the statistical index that may serve as precedent data is not internationally available for the number of standardization activity personnel, adequacy cannot be verified by international comparison. Therefore, the investigation of the data usability was based on the stability of collection.

For Hypothesis 1a, it was observed that the number of standardization personnel among IP activities fell in a certain range each year. Also, the recovery rate of the questionnaire for each year was approximately 50 %. Of the recovered questionnaires, it was found that there was about 90 % response for the item under investigation, and it was determined that the data collection was stable and could be used for secondary analysis. For Hypothesis 1b, based on the results of Hypothesis 1a, it was indicated as possible to collect data that captured the wide range of standardization activities that included back office work and planning, as well as the negotiation for establishing the standard. Combining the results of Hypotheses 1a and 1b, it could be determined that there was low probability for the collected data to be subject to sampling bias, and the data could be used for various analyses (Fig. 1).

Considering both the inside and outside of an organization, there was ambiguity in how to understand the range of the standardization activities related to the innovation activities. The reason is because in establishing the international standard, the involvement in the committee that is the ultimate place for decision-making and vote execution was considered most important. Therefore, the standardization activities meant the activities in the standardization bodies that actually drafted the standards outside the organization. The concept was formed where the standardization activities represented the number of people who participated in the committee for standard establishment, and as a reflection, there was a recognition that it was difficult to survey and count the standardization activities in places other than in the negotiation activities such as participation in the committees. On the other hand, the standardization activities within the organization assumed the developmental strategy of new products accompanying the development of the new technological standards, in addition to the negotiations. The definition of the survey pertaining to the patent activities that may serve as the subject of comparison is not limited to the conventional negotiations including those of patent disputes and licensing, but includes a wide range of activities as in the expanded definition for standardization activities in this research.[3]-[6]

The standardization activities that were the subject of this study was the standardization activities related to the IP activities within the organizations, but it could be construed as the general trend of the data for standardization activities. Therefore, the obtained data are expected to be a meaningful finding in the discussion of whether to position the data for resource investments related to the standardization activities as part of science and technology data. Also, it may allow evaluation of the effect of the expanded standardization activities including the negotiation work on the innovation activities.

6.2 Comparison among research fields

The hypothesis was formed that the standardization activities in IP activities for basic research activities may be conducted at the same percentage as the applied and development research. The category, “education, TLO, public research institution, and public service,” was set as a representative field of basic research, and “electric machinery industry” and others were set as representatives of applied and development research. When the two were compared to see which was higher in degree of standardization activities in IP activities, the result showed that the basic research disciplines were higher. On the other hand, in total, both fields were higher than average, and showed approximately the same figures.

Figure 3 shows the changes of the average percentage of standardization activities related to IP activities during the four years from 2008 to 2011 in basic research of “education, TLO, public research institution, and public service” and in applied and development research of “electric machinery industry” and “information and communication industry” to see the trend of standardization activities by types of research.

Looking at the ratio of basic and applied and development researches, the average percentage was higher for basic research, at approximately 20 %. On the other hand, the results showed that applied and development research was around 10 %. One reason for the higher percentage of basic research than applied and development research can be that the percentage shifted due to the change in the number of

IP activity personnel, because the data was collected for the standardization activities of IP activity personnel. Looking at the "electric machinery industry" that represents the applied and development research, the number of IP personnel was approximately 5,000 persons. In the category "education, TLO, public research institution, and public service" that represents basic research, it was about 1,500 persons (Table 2). This can be considered as one reason the percentage of standardization activities increased in "education, TLO, public research institution, and public service" that represent basic research. The reason the number of IP activity personal was higher in "electric machinery industry" than in "education, TLO, public research institution, and public service" was because the number of patents filed was higher compared to the basic research institutions such as universities, and there were more work related to patent application. For example, in NEC Corporation, Fujitsu Ltd., and Hitachi Ltd., which are major Japanese companies, there are 100 to 300 persons assigned to the intellectual property division, and this matches the result of this study.[11] In basic research institutions, there was also the reason that the percentage of personnel belonging to the IP division engaging in both the IP and standardization activities increased since the researchers contributed less to the IP or standardization activities.

In Japan, the activities to establish the international technological standards to utilize the developed technologies are done at AIST and the National Institute of Information and Communications Technology (NICT) that engage mainly in basic research. AIST actively publishes papers on international standardization. Also, development of standards is done by university researchers, and the researches on communication protocol are done at the science and engineering departments of universities. It is thought that the activities related to the establishment of the technological standards are included in this category. The public service category is thought to include the public or governmental institutions that function as the secretariat for establishing the de jure standard. The above activities are thought to represent the standardization activities in basic research disciplines.

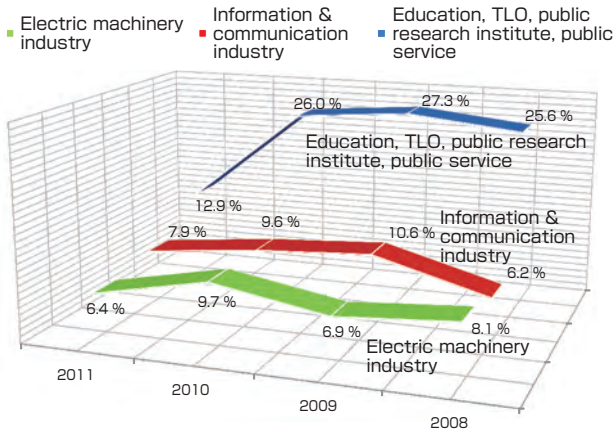


Fig. 3 Change over the years of the percentage of personnel involved in standardization among the IP personnel

The "electric machinery industry" and "information and communication industry" are thought to represent the applied and development research. It is essential to standardize the interface to commercialize technologies and to create development strategies of products. Therefore, the research disciplines in the applied and development fields include the activities related to technological standards, because they are extremely important in product innovations for today's electrical machinery manufacturing industry.

The above results lead to the hypothesis that there is a possibility that the standardization activities related to IP activities in basic research discipline may be conducted at the same level as the applied and development research of the companies.

6.3 Problems in the standardization activities in basic research

The universities file a number of patent applications, and it is necessary to confirm whether the technological standards born from the standardization activities by universities are related to the patent groups that they possess. Looking at the handling of the technological standards in the IP policies of the universities that ranked top for the number of patents published in Japan (Tohoku University, the University of Tokyo, Tokyo Institute of Technology, and Osaka University), it was found that no universities had any rules.[12]-[15] This means that a clearance system within the organization for patents and standards that exists in Japanese companies, does not exists in the divisions that handle intellectual properties at universities. The reason is because the basic research institutions such as universities have no production facility, and therefore do not execute patents themselves. Unlike the companies that engage in applied and development research, the universities do not have to pay attention to the presence of the patented technologies in the technological standards.

The comparison of the standard management and patent management by different research objectives is shown in Table 3. In the private companies of the information and communication industry, the system for collaboration between patent management and standard establishment is established, as the execution of IP strategies is integrated and the framework is solid. NEC Corporation, Fujitsu Ltd., and Hitachi Ltd. have standard committees that integrate standard strategies and standardization activities of the companies. In the applied and development research, the effort to integrate patents and standardization activities is in progress.[11] Considering the result of this paper, in the future, similar effort to manage the effect of patents owned by research institutions in establishing the technological standards will become necessary in basic research institutions such as universities.

Table 3. Differences in the standardization activities related to IP activities in basic research and applied and development research

Research objective	Percentage	Number of people	Degree of integrated management of standardization activities and patent management activities (Drafting of internal guideline, etc.)	Remarks: Representative industrial categories, etc.
Basic research	High	Higher than average	Hardly any cases (No description in IP policy)	Education, TLO, public research institute, public service
Applied and development research	Low	Higher than average	Some companies with advanced policies	Electric machinery industry

6.4 Goal to be achieved: viewpoint of synthesiology

Figure 4 shows the scenario of the flow and introduction of research from the synthesiology viewpoint. To establish the management method for the standardization activities in innovation activities that may serve as the index of long-term outcome, it is necessary to establish the method for data collection and usage in basic research as well as applied and development research. To do so, it is necessary to establish ways to collect data in companies and universities as well as evaluation methods for the effect of standardization activities in universities that are basic research institutions and in company organizations that are applied and development research institutions. In this research, some accomplishment was made to establish the foundation of data collection for companies and universities. On the other hand, for the evaluation of the situation that may occur between basic research and applied and development research, this paper only introduced the hypotheses. Further research will be necessary in the future.

7 Future research topics

For the commercialization of technology for information and communication device, or product innovation, addressing interface standards is essential today to obtain network externality. The collection and evaluation methods for statistical data pertaining to IP activities centering on patents are described in the OECD Frascati Manual[8] and the Oslo Manual,[16] but there is no description of the standardization activities. Therefore, it is difficult to conduct the check of adequacy through international comparison at this point. The precision will increase if comparison of international data becomes possible through data collection in various countries. The advancement in international research is desired in the future.

To verify the hypotheses for the degree of standardization activities in IP activities for basic research and applied and development research as developed in this paper, the understanding of actual situations of the standardization activities of basic research discipline is awaited.

8 Conclusion

It was confirmed that it was possible to stably collect data for the standardization activities in the IP activity survey, and that the data are reproducible. From the investigations of the rate of data recovery and others, it was concluded that the adequacy was supported. While it is necessary to continue investigation on whether the data can be stably collected and that they are reproducible from 2012 onward, from the result of the investigation in this paper, the reliability as primary data was mostly confirmed. This result is expected to advance innovation management through the visualization of

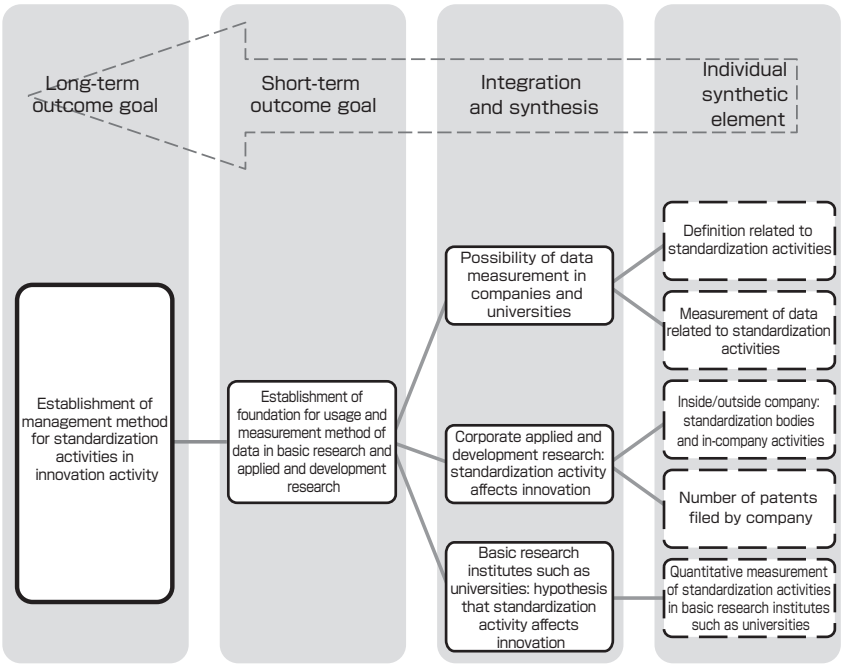


Fig. 4 Scenario for the development and introduction of the methods for standardization acidities to improve innovation activity management

standardization activities in organizations. In addition, from the analysis of the total data, the hypothesis was established that there is a possibility that standardization activities related to IP activities are being conducted in basic research institutions at the same level as the applied and development research. Aside from the precision, at least, the presence of standardization activities in basic research was confirmed from the quantitative data.

As an implication on policy, although an equivalent or higher percentage was observed compared to applied and development research of companies for standardization activities, the management of the standardization activities is not sufficiently organized in IP management at universities, and the standardization and patent activities are not sufficiently coordinated. The universities need the integrated management of standards and patents as in the electric machinery industry, and it is necessary for the divisions for industry-academia collaboration promotion at universities that currently handle patent information to play the role of transmitting information on standardization. Also, standardization activities must be considered when universities set IP policies as internal rules.

As an implication on research, in short-terms, the results indicate the usability of the number of people involved in technological standard activities to the quantitative analysis of evaluation of the innovation activities in basic and applied and development research. In long-terms, using the findings of this paper, the establishment of the system to collect similar data internationally is expected.

For establishing the evaluation method for innovation activities, considering the qualitative changes that the standardization activities confer on the IP activities, further advancement in the measurement method of the quantitative data for standardization activities will be demanded. Assuming the evolving network society, the standardization activities will become a factor that cannot be ignored in evaluating the innovation activities in the future.

Acknowledgement

I am thankful to the Research Institute of Economy, Trade and Industry (RIETI), the Waseda University, and the staff members of the institutions, for offering us the opportunity to conduct this research. I am also thankful to Mr. Nagano and Mr. Sakamoto of the Standard Certification Unit, Ministry of Economy, Trade and Industry. I am grateful to Professor Nagaoka, Institute of Innovation Research, Hitotsubashi University, for his useful advice in the research.

This paper was written under the responsibility of the author, and the contents including the mistakes are the responsibility of the author.

References

[1] Ministry of Education, Culture, Sports, Science and Technology: *Monbu Kagaku Tokei Benran* (Statistical Abstract for Education, Culture, Sports, Science and Technology) (2009) (in Japanese).

[2] International Organization for Standardization (ISO), *ISO Members 2006*, ISO, Geneva (2006).

[3] Japan Patent Office: *Heisei 20 Nen Chiteki Zaisan Katsudo Chosa Hokokusho* (2008 Results of the Survey of Intellectual Property-Related Activities), Japan Patent Office (2009) (in Japanese).

[4] Japan Patent Office: *Heisei 21 Nen Chiteki Zaisan Katsudo Chosa Hokokusho* (2009 Results of the Survey of Intellectual Property-Related Activities), Japan Patent Office (2010) (in Japanese).

[5] Japan Patent Office: *Heisei 22 Nen Chiteki Zaisan Katsudo Chosa Hokokusho* (2010 Results of the Survey of Intellectual Property-Related Activities), Japan Patent Office (2011) (in Japanese).

[6] Japan Patent Office: *Heisei 23 Nen Chiteki Zaisan Katsudo Chosa Hokokusho* (2011 Results of the Survey of Intellectual Property-Related Activities), Japan Patent Office (2012) (in Japanese).

[7] Mitsubishi Research Institute, Inc.: *Sentan-Gijutsu Bunya Ni Okeru Gijutsu Kaihatsu To Hyojunka No Kankei Mondai Ni Kansuru Chosa Hokokusho* (Report on Technological Development for State-of-the-Art Field and Relationships/ Issues in Standardization), Ministry of Economy, Trade and Industry (2009) (in Japanese).

[8] OECD: *Frascati Manual 2002: Proposed Standard Practice For Surveys on Research and Experimental Development*, OECD, Paris (2002).

[9] N. Gandal, N. Gantman and D. Genesove: Intellectual property and standardisation committee participation in the US modem industry, *Standards and Public Policy* (S. Greenstein and V. Stango (eds.)), 208-230, Cambridge University Press (2007).

[10] B. Godin: Neglected scientific activities: The (non) measurement of related scientific activities, Montreal (2001). <http://www.csiic.ca/pdf/godin_4.pdf> [accessed 26 Sept. 2012].

[11] S. Tamura: Effects of integrating patents and standards on intellectual property management and corporate innovativeness in Japanese electric machine corporations, *Int. J. of Technology Management*, 59 (3/4), 180-202 (2012).

[12] Tohoku University: *Kokuritsu Daigaku Hojin Tohoku Daigaku Chiteki Zaisan Porishi* (Intellectual Property Policy of Tohoku University). <http://www.rpip.tohoku.ac.jp/files/chipo.pdf> [accessed 11 Dec. 2012] (in Japanese).

[13] The University of Tokyo: *Tokyo Daigaku Chiteki Zaisan Porishi* (Intellectual Property Policy of The University of Tokyo) (2004). <http://www.ducr.u-tokyo.ac.jp/jp/rules_and_forms/index.html#policy> [accessed 11/12/2012] (in Japanese).

[14] Tokyo Institute of Technology: *Tokyo Kogyo Daigaku Chiteki Zaisan Porishi* (Intellectual Property Policy of Tokyo Institute of Technology) (2004). <http://www.sangaku.titech.ac.jp/policy/pdf/property.pdf> [accessed 11 Dec. 2012] (in Japanese).

[15] Osaka University: *Osaka Daigaku Chiteki Zaisan Porishi* (Intellectual Property Policy of Osaka University) (2010). <http://www.ipo.osaka-u.ac.jp/> [accessed 11 Dec. 2012] (in Japanese).

[16] OECD: *Oslo Manual: Guidelines for Collecting and*

Interpreting Innovation Data, 3rd Edition, OECD, Paris (2005).

Author

Suguru TAMURA

Joined the Ministry of International Trade and Industry, and worked at the Technology Evaluation and Research Division, Industrial Science and Technology Policy and Environment Bureau, and at the Council for Science and Technology Policy, Cabinet Office. Associate Professor of the Faculty of Science and Engineering, Waseda University from 2009 to 2012. Senior Fellow of the Research Institute of Economy, Trade and Industry (RIETI) from 2012. Main accomplishments include publication in the *Journal of the American Ceramic Society* and others. Research topics include the innovation management and the R&D evaluation method. In this paper, Tamura was in charge of all contents.

Discussions with Reviewers

1 Point that the measurement was not done for the whole standardization activities, but was limited to the standardization activities within IP activities

Comment (Hiroo Matsuda, International Standards Promotion Division, AIST)

You mention as your research goal is "to consider the method for measuring standardization activities." However, you only considered the numerical fluctuation (stability?) of the standardization activity survey in the "Results of the Survey of Intellectual Property-Related Activities" conducted by the Japan Patent Office (JPO), and concluded that the hypothesis is adequate. Since the result of this JPO survey is an important "element" for the synthesis of this paper, I think you need deeper consideration for adequacy. Looking at the details, in the basic research that was the subject of this paper, the percentage of the standardization personnel in FY 2011 was reduced to half compared to the past fiscal years. You mention this in subchapter 5.1 but do not offer consideration of the fluctuation in the survey method.

Answer (Suguru Tamura)

I described that the reason for the reduction in 2011 was due to the replacement of companies that were subjects of the survey, as this was not a panel survey. For the reliability of data, I added the reasons that the recovery of the questionnaire data was about 50 % and the response on standardization was provided in 90 % of the recovered questionnaires. These two points were given as reasons that the sampling bias could be eliminated and the data could be considered reliable. (5 Result; 5.1 Number of IP activity personnel and the number of standardization activity personnel in IP activities; 5.2 Comparison of data over the years by industrial category)

2 Reliability of data

Comment (Mitsuru Tanaka, AIST)

Your discussion relies greatly on an evaluation index based on the fact it uses the basic data from the statistics of the Japanese IP activities. In particular, you address the comprehensible nature of the data based solely on the fact that the data is public data. For the readers who are not familiar with data reliability, they will be skeptical of how to view the changes from 2008 to 2011, or have trouble in understanding the comparison of basic and applied and development researches. I recommend you to supplement the explanations for such readers.

Answer (Suguru Tamura)

I explained that because the rate of response to the questionnaire was about 50 %, and because the percentage of response to the question related to this research was 90 % among the recovered questionnaire, it was possible to eliminate the bias in response. It can be concluded that the reliability of data is high. In ordinary questionnaire survey, though it depends on the situation, the reliability of a data source is thought to be high if there is 20 % to 30 % response. For the conclusion, I added the point that we cannot deny that a certain level of standardization activities related to IP activities is present in the basic research field. (5 Result; 5.1 Number of IP activity personnel and the number of standardization activity personnel in IP activity; 6 Discussion; 6.1 Verification of the hypothesis; 6.2 Comparison among the research fields; 8 Conclusion)

3 Description of the importance of definition for standardization

Question (Mitsuru Tanaka)

In relation to your description, "the verification method of the hypothesis that the new definition for standardization is adequate," I wonder if the fact, "…It was possible to collect data that captured the wide range of standardization activities that included back office work and planning, as well as the negotiation for establishing the standard" is critically essential for the new definition. It looks quite obvious that "taking up a wide range of items for standardization activity provides" makes the definition clear with "more accurate index." Instead of picking up specific examples for broader items, you should provide a simple discussion on the support of the scope of items for standardization. Or, is the main point of this paper, "one can obtain data" because there is stability? I recommend you to clarify this point.

Answer (Suguru Tamura)

I have added that the definition was matched to the patent activities for which surveys have already been done, and that the count of the standardization activity personnel was almost the same as the count of the negotiator. Also, I added the description on the reflective disadvantage such counting method may bring forth. No quantification of the standardization activities has ever been done using the expanded definition, so I indicated that, the fact that data can be collected is meaningful. In a sociological survey, unlike the measurements using measuring devices as done in natural sciences, there are many cases where responses may not be obtained in a questionnaire survey. (6 Discussion; 6.1 Verification of the hypothesis; and 6.2 Comparison among research fields)

4 Verification of the hypothesis on the standardization trend in basic research

Question (Mitsuru Tanaka)

Quantitative study is presented on the contribution of basic research to standardization compared with that of applied and development research. However, the reliability of the process of the study has to be explained taking into account the applied evaluation index and the definition of standardization. Since the evaluation index will be no more than one of the consequences of assumed contributions of basic research, the author will be allowed to explain his own speculation explaining the difference in the contributions of the two different research fields, which is of great interest to the readers.

Answer (Suguru Tamura)

I revised the text to state that there is a possibility that the standardization activities related to IP activities may be done at similar levels in the basic and applied and development researches. (6 Discussion; 6.2 Comparison among research fields; and 8 Conclusion)

Question (Hiroo Matsuda)

In the abstract you write that you "obtained the conclusion that the percentage of standardization activities is higher in basic research compared to applied and development research." The reviewer feels this conclusion is extremely dangerous as it can mislead the readers. The JPO survey used in this paper merely uses the personnel engaging in IP activities as a parameter, and the standardization activity personnel is counted as an included number. In subchapter 2.4 you mention the positive correlation between the participation to standardization organization and the number of patents, and it can be estimated that there are many of the standardization activity personnel who do not belong to the IP division in the applied and development research. On the other hand, the researchers contribute little to IP or standardization in basic research institutions such as universities. As a result, the personnel who belong to the IP division must cover both fields, and therefore, the percentage of the standardization activity personnel included in the IP activity personnel increased. Isn't this the case?

Answer (Suguru Tamura)

The handling of the conclusion was changed to an introduction of the hypothesis. Also, I changed the description to there is a possibility that about the same level of standardization activities may be done in basic research as in applied and development research. (6.2 Comparison among the research fields)

I added a discussion on the factors in the basic field. (6.2 Comparison among the research fields)

Portfolio structuring and social implementation in the development of complex technology

— Case study of the development of GERAS and its evolution —

Takeshi KOMAI

[Translation from *Synthesiology,* Vol.6, No.3, p.180-186 (2013)]

A portfolio analysis of composing elements using a synthesiological method has been carried out for complex technology development, which involves fusion of various technology systems and elemental technologies. To assess the method's effectiveness, a case study was conducted on GERAS (Geo-environmental Risk Assessment System), a system for soil contamination diagnosis. The analysis spanned the entire development phase, from the generation of research ideas to the dissemination of results to society. The benefit of using this method was greater ease in system design and social implementation, through the analysis of critical components in the developmental process. I also discuss applying this method to novel areas, such as the development of technology for reconstruction after The Great East Japan Earthquake disaster.

Keywords : Environmental risk, risk assessment, soil contamination, synthesiology, portfolio structure

1 Introduction

Various reactions have been received since the publication of the paper on the Geo-environmental Risk Assessment System (GERAS) published in *Synthesiology* Volume 1 Number 4 (2008)[1] four years ago. There are direct requests from companies and local governments for the use of GERAS in environmental measures, and the paper has played a major role in its social diffusion. The paper has also been cited in many researches on risk assessment. However, more essentially, there were many comments on the methodology for establishing and diffusing the process and on the synthetic thinking that led to the development of GERAS. In another series of comments, constructive proposals and new viewpoints were provided, such as the optimal scenario as well as ways to fuse the elemental technologies in order to promote such complex technological development.

Most of the environmental technologies are clusters of diverse technological elements, and they realize products or social systems through analyses and processing of vast amounts of information. Although there are numerous R&Ds for technological elements, the technique to combine them is lacking. Ultimately it is necessary to integrate them and to fix them into society by maintaining the socioeconomic perspective. After the Great East Japan Earthquake of March 2011, there were high expectations for new developments for helping disaster restoration efforts by diffusing environmental technologies quickly in society.

In this paper, I shall discuss the scientific and sociological methods for developing GERAS further and for diffusing it in the industrial field. Also, since the combination and fusion of the complex technological elements are important, the discussion will be from new viewpoints including the drafting of whole scenarios in R&D, improvement of vulnerability of the system, and the construction of a portfolio and social implementation. Also, the author currently belongs to the environmental science department of a university, and would like to state the basic concept on the role and collaboration of industry, government, and academia in a technological development, mainly from the academic stance.

2 Current situation and future of technological development

In the development of GERAS, various types of analysis models were created in the past 10 years, and were applied to the actual environmental pollution problems. It is now employed in over 1,500 Japanese companies and organizations, and it has been established as a standard risk management tool. The users suggest various future developments, such as making it usable for economic risk evaluation in addition to environmental risks, or incorporating risk evaluations to social systems for soil environment and possibly to legal systems. As the next step, we are developing the economic model to quantify the cost-effectiveness of the remediation measures. We are also developing a submodel for the impact of soil pollution measures on the living environment and the ecosystem. In the new development, risk based decision-making and investigations of environmental economy are necessary, and the introduction of a methodology to fuse the humanities and

Graduate School of Environmental Studies, Tohoku University 6-6-20 Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan
* E-mail: komai@mail.kankyo.tohoku.ac.jp

Original manuscript received May 10, 2013, Revisions received June 18, 2013, Accepted June 19, 2013

sciences is mandatory. The efforts of industry, government, and academia are extremely important to actively employ human resources from social sciences. Specifically, AIST is working on difficult socioeconomic problems by conducting several joint researches with the environment divisions of local governments and public research institutions. Since universities harbor abundant human resources in social and environmental sciences, the amalgamation of academic fields that specializes in risk assessment is important. By conducting researches on soil contamination risk assessment through collaborative lectures and joint researches with universities as well as innovation school systems of companies, we obtained composite results unseen before. Joint researches on risk assessments of radioactive materials and new mathematical statistics methods are being conducted with universities. Also, through questionnaire surveys on the use and diffusion of GERAS, much know-how was accumulated such as functions that are truly needed in the assessment system, methods to feedback various data, and ways of securing reliability of the assessment results.

3 Development scenario and portfolio analysis

3.1 Composition of the portfolio

In order to achieve research goals in a short time, to realize products, and to implement the results in society in efficient ways, the most important point is the management of the processes including the composition of portfolios for individual elements as well as designing R&D scenarios. Indeed, it is extremely rare to be able to realize a product with only a single technology or a single technological system. The overwhelming majority of the cases are achieved by combining and fusing multiple technological elements. In such scenarios, the key to success is to perform preliminary portfolio analysis for what are the elemental technologies essential for technological development, what is the optimal combination of the technologies, and which elements are lacking within the team.

Figure 1 shows the portfolio of the technological elements (research topics) that were considered necessary for the development of GERAS. This figure shows the qualitative relationship in terms of the maturity of R&D and society (market). While the goal of the technological development for both is to show the upward vector, appropriate fusion is important in addition to the improvement of various technological elements such as of soil surveys, chemical analyses, environmental restorations, risk assessments, information analyses, physical explorations, and others. For example, although soil contamination information is deeply related to all elements, the possibility of fusion is determined by how such elements can be linked organically from the perspective of "risks." In addition, it was necessary to respond to the social demands for assessment of tsunami deposits and radioactive materials. That is, not only basic research and product realization research shown in the legend of the figure, but also the combination of the integration and demand-response researches based on social demand become important. In fact, there were no clear images from the beginning of the development, and only some technological elements were clearly positioned and defined. However, in the course of the development, methods were devised to accelerate the development when we hit the stage of the "valley of death." As discussed here, the construction of the portfolio provides important implications for the fusion and integration of technologies by clarifying the goals to be achieved. In addition to the advancement of the core technological elements, the dynamics of the technologies that must be newly deployed and those that must be accelerated become clear.

3.2 Weakness of elemental technologies and its reinforcement

The great mistake one tends to fall into in R&D is to focus on technological elements with high priority and lose sight of the peripheral technologies. This may be the disadvantage of the R&D in Japan, and there are many cases

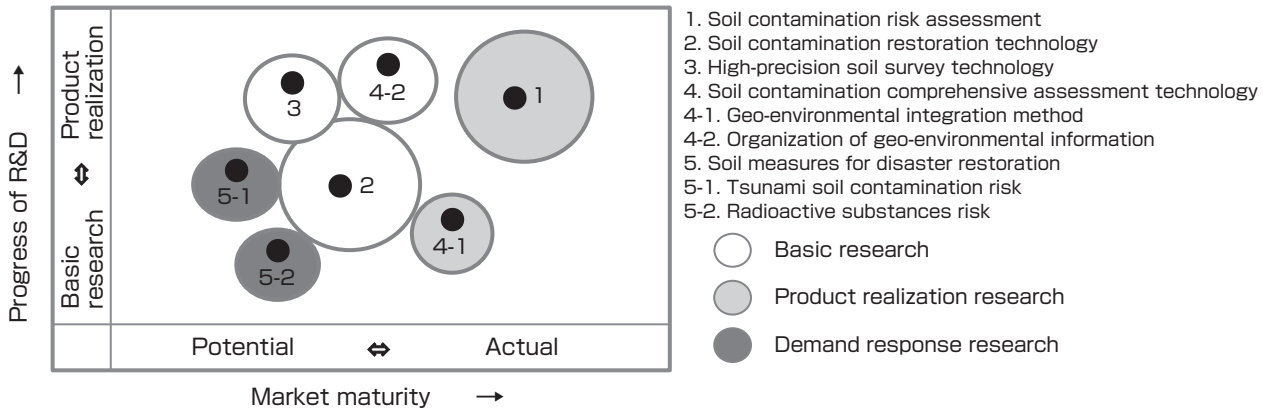


Fig. 1 Portfolio analysis in the development of GERAS
Shown in the diagram are the positioning of individual elements from the perspectives of the progress of R&D and maturity of market for soil contamination countermeasures, for the various technological elements that comprise GERAS.

in which the overview analysis of the technological system to be developed is lacking. It is important to discern the weakest technological element in a system, in addition to concentrating on the technological development that must be nurtured, after carefully analyzing the property of the whole system. Even if an excellent technology is completed, if the related peripheral technologies and the relationships are not maintained, the system may be unusable. In the development of GERAS, the initial researches on which we concentrated were soil surveys, soil contamination restorations, and mathematical statistics methods, and these were mainly handled by the researchers in the engineering field. Later, exposure assessment methods and system development were strengthened, as they were considered weak, and the researchers of different fields such as physical exploration and geochemistry joined the project. About ten years were spent to complete GERAS. The research development that involved field fusion and leadership in R&D were important.

Another important point was the construction of a database and analysis parameters that were essential for GERAS. To enable interactive risk assessment by the model creators and the users, the actual measurements of the contamination on site and the measurements of geology and groundwater were necessary. Since it was impossible for AIST alone to compile these data, the valuable on-site data and geological information were collected through joint researches with universities, local governments, and private companies. In such industry-government-academia collaborations, the Soil Contamination Working Group (the author was the chairman) of the Industrial Technology Cooperative Promotion Committee played a major role. For example, the studies included: survey and analysis of naturally-derived heavy metals conducted jointly with the Geological Survey of Hokkaido; risk assessment of organic compounds performed jointly with the Tokyo Metropolitan Research Institute for Environmental Protection; clarification of groundwater contamination by volatile organic compounds (VOC) done jointly with the Environmental Science Research Center of Yamagata Prefecture; and development of a geo-environmental informatics system conducted jointly with the Graduate School of Environmental Studies, Tohoku University.

3.3 Fusion of the technological development and its continuous development

The methods that were used to construct multiple components or elements and to fuse the elements in the development stage of GERAS are shown using several composition diagrams (Fig.2). First, with the conventional fields of environmental geology or geological contamination only, practical risk assessments could not be provided by these fields alone. Therefore, in the next stage (II), the fields of geochemistry and environmental sciences (biology, ecology, etc.) were introduced to fuse the fields and to enable scientific interpretation of the assessment results. Since it also became clear that the developments of exposure analysis and numerical simulation methods were bottlenecks (or weak elements) in the entire system, the technological fusion was attempted using the exposure and risk as integration scale, by incorporating the findings of risk science. Fortunately, these elements were highly compatible, and in stage (III), they served as the glue to hold the elements together, and played an important role in creating a new method of information processing based on information sciences and statistics. Also, for the social implementation of technology, sociology and the efforts in industry-academia collaboration were essential. In addition to the synthesis phase of technological

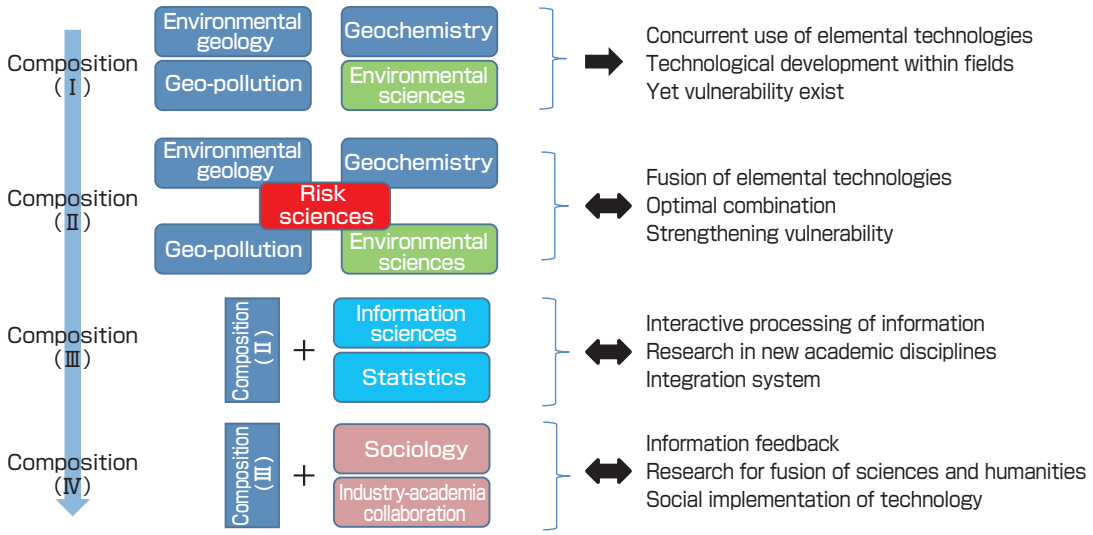


Fig. 2 Changes in the composition in the GERAS development
The characteristics of the composition in the four phases from beginning, during, and to maturity are shown, according to the research fields necessary for the development of GERAS and their composition. In addition to technical development, the final phase of social implementation is important.

development, it was most important to incorporate the final stage (IV) for social implementation. We believe that the optimal system design would not have been possible if any of the elements were lacking. One of the factors of success was the smooth linkage of the elements using risks as a scale (rate of occurrence of a phenomenon), and the by-product included the establishment of sociogeology (the author is the chairman of the Japanese Society of Geo-Pollution Science, Medical Geology and Urban Geology) that links geology to medicine (health).

4 Diffusion of the developed technology and realization of social implementation

4.1 Collaboration with society and industry and the feedback

The mechanism to diffuse the various types of GERAS developed in industry and society is also an important element. The aforementioned activities of the Soil Contamination WG, efforts in the academic activities for geo-pollution and urban geology, committee activities such as in councils and research groups in local governments, and involvement in businesses for soil surveys and environmental restorations with private companies were good opportunities to attract attention to GERAS. The activity on which we spent the most effort was the feedback of the assessment data from users that actually used the system. Normally, GERAS risk assessment is a forward analysis based on input data, but it is also possible to simultaneously conduct backward analysis from real contamination data. By repeating the two-way operation, not only did the reliability of the assessment results increase, but also the system efficiency increased. Moreover, good results were obtained in the communication with interested parties. By conducting risk assessments in realistic conditions rather than in a virtual environment, the risk awareness increased and the assessment results could be better understood. Therefore, researches in new academic disciplines are being done on optimizing prior and posterior distributions of risks using the sparse Bayesian modeling.[Term 1]

4.2 Public utilization of technology and its standardization

As a mechanism to diffuse a technology, utilization of public institutions of the government and local governments is effective. Since the release in 2008, the GERAS-1, 2 versions have been used in over 200 government and local government institutions. Using this name recognition, we made appeals to the persons in charge of the soil contamination measures at major government agencies whenever we had opportunities. It was officially employed as follows. GERAS-1, 2 were employed as risk assessment methods for the Site Assesser, which is a certification system to diagnose land use, in the Ministry of Economy, Trade and Industry. The improved new versions of GERAS-1, 2 were deployed as risk assessment tools for soil and sand from construction work at the Ministry of Land, Infrastructure, Transport and Tourism. Also, the thinking of GERAS was introduced into the risk assessment methodology at the Ministry of Environment and Tokyo Metropolitan Government. Recently, through joint research with the Environment Bureau of Tokyo, the new version of GERAS is being developed with added life cycle assessment (LCA). In the risk assessment of remediation measures, it is important to establish a comprehensive assessment method for individual life cycles from the perspective of environmental energy as well as environmental burden. Therefore, as shown in Fig. 3, the general assessment is done for total environmental impact, including those on the surrounding environment and ecosystem as well as the external environmental burden (CO_2 emission). To evaluate

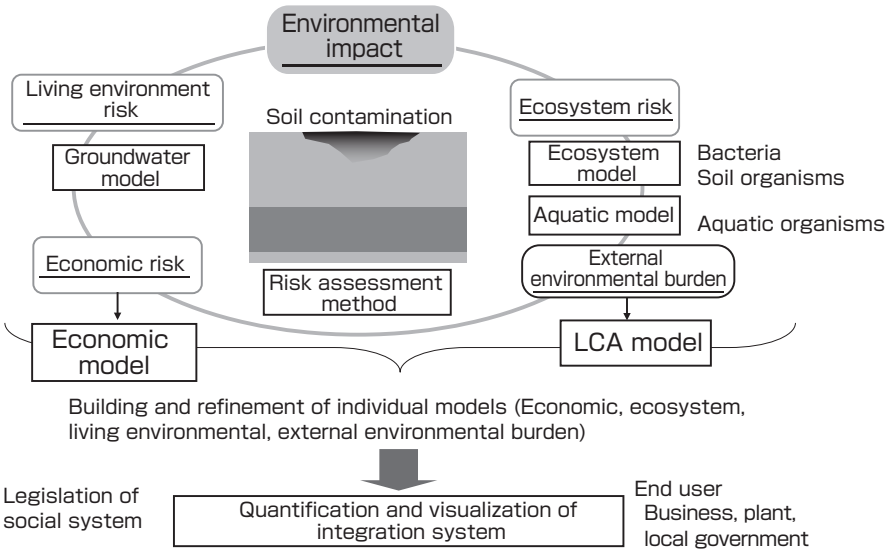


Fig. 3 Composition of the integration system in the development of GERAS
In addition to the assessments of soil contamination risk and environmental load, the integration system including economic model, groundwater model, ecosystem model, LCA model, etc. is developed.

risks on the living environment and ecosystem in addition to conventional soil contamination risks, the development of specific groundwater models, ecosystem models, and aquatic modes are in progress.

Moreover, there are moves toward international standardization of risk assessment methods for soil contamination. GERAS is widely used in advanced nations as well as in Asian countries, and there are efforts to standardize the methodology for exposure and risk assessment incorporated in GERAS, by creating a new framework in the International Standard Organization (ISO). Also, the standardization of the domestic risk assessment technology looking at international standardization is important, and there are efforts across the agencies and ministries toward JIS standardization. In the future, the research results will be opened to the world, and international efforts to diffuse and expand risk assessment technologies will be done, mainly for the Asian countries.

4.3 Social implementation and contribution to earthquake disaster restoration

Since the Great East Japan Earthquake and Tsunami of March 2011, the ways of R&D have been questioned. There emerged an attitude that the results obtained by research must be recognized by society as usable products and systems, and must be applicable to immediate issues that society faces. The environmental pollution that is the subject of GERAS was mainly geared for heavy metals and organic compounds that are regulated by the Soil Contamination Countermeasures Act, but after the earthquake, the R&D was accelerated for applications to tsunami deposits, debris of the earthquake and tsunami, and also for radioactive substances. This was done to enable social implementations by establishing risk assessment methods for diverse environmental pollution problems, and also in hopes of helping the disaster restoration.

Due to the giant tsunami that hit the coasts of East Japan, voluminous amount of tsunami deposits and debris were generated. Since some of the deposits and debris contained harmful chemical substances such as arsenic and lead, risk control was necessary. The author and co-researchers spent about a year from 2011 surveying the physicochemical properties of the tsunami deposits, and conducted environmental risk assessment using GERAS. As a result, it was found that there were some regions with high risk of arsenic in the coastal area from Miyagi to Iwate Prefectures, and there was a need for risk management of groundwater.[2] Also, it was found that the environment risk of heavy metals was small for about 95 % of the region, and the deposited sand and gravel could be reused as building materials for reconstruction efforts. This research received an award of the Japan Society of Civil Engineers in 2013, as an important research for social implementation.

The issue of soil contamination by radioactive substances such as caesium 137 is another extremely important issue from a social standpoint. Currently, new researches are being done to incorporate radioactive substances in GERAS, and we are now collecting observations on the behavior of radioactive caesium and other substances in the environment. Since the physicochemical properties of radioactive substances are known, it is possible to introduce them into GERAS at this point, but to improve the accuracy of risk assessment, it is necessary to clarify the interactions with soil particles and the migration properties according to their existence form. We are now organizing the parameters necessary for the GERAS analysis, such as building the database for soil properties in the East Japan region and monitoring the soil, water, and river sediments in Fukushima Prefecture.

5 Summary

In the development of the geo-environmental risk assessment system (GERAS), we went through valuable experiences from escaping the valley of death of R&D to the diffusion of results to society. As mentioned in this paper, new versions of GERAS have been developed with new viewpoints, and the results are being transmitted widely to society. Blessed with the efforts and good luck (serendipity) of the research team, the research seemed to progress smoothly. However, immediately after the earthquake, it felt as if we had entered the second valley of death, with added responsibility of supporting the reconstruction. Although still in the research stage, the course has been laid down for the completion of the assessment system that can handle assessment of tsunami deposits, earthquake debris, and radioactive substances. To overcome the difficulties and to fix the technology in society, sufficient understanding of the elemental technologies that comprise the system and the ability to fuse them are necessary.

Finally, I have learned that the following commitments are necessary for the research leader.

- Have many possessions in the attaché case (or drawer), meaning, accumulate various kinds of knowledge.
- Optimize the combinations of the things inside the drawer, meaning, optimize the combinations of knowledge.
- Clarify what are weak (and what are strong).
- Take on society and industry and navigate the great sea or venture out.
- Finally, show strong leadership.

Terminology

Term 1. Sparse modeling is one of the information analysis methods using the Bayes' theorem. Recently in geosciences, it has been utilized for the extraction

of main information in big data and for the restoration of images. In the field of risk assessment, it is gaining attention as a new numerical method for estimating the preliminary risk from posterior occurrence rates, and it has been applied to few complex systems such as the ecosystem. The author and co-researchers are engaging in the research to apply the Bayesian statistics to the geochemical identification of the surface horizon and tsunami deposits.

References

[1] T. Komai, Y. Kawabe, J. Hara, Y. Sakamoto and H. Sugita: Development of a risk assessment system for soil contamination and the application to the social system – Processes in *Synthesiology* for practicing an advanced environmental risk management, *Synthesiology*, 1 (4), 276-286 (2008) (in Japanese) [*Synthesiology* English edition, 1 (4), 251-262 (2009)].

[2] Y. Kawabe, J. Hara, T. Yasutaka, Y. Sakamoto, M. Zhang and T. Komai: Heavy metals in tsunami sediment by the Great East Japan Earthquake and their risks to human, *Journal of Japan Society of Civil Engineers, Ser. G (Environmental Research)*, 68 (3), 195-202 (2012) (in Japanese).

Author

Takeshi KOMAI

Has been in charge of research management from the planning, production, and diffusion of GERAS, and has spent effort in the diffusion of GERAS to industry and society at the Research Institute for Geo-Resources and Environment, AIST. Innovation Coordinator from April 2010; and Director, Research Institute for Geo-Resources and Environment, AIST from April 2012. Specialties are environmental engineering and environmental geology. Has worked on the solutions of various issues that lie between resources and environment, and on the diffusion of environmental technologies to industry. To diffuse the research results, served as member of the Tokyo Environment Council, member of the Chiba Prefecture Pollution Committee, specialist member of the Ibaraki Prefecture Environment Council, and others. Retired from AIST in March 2013. Currently in charge of the lectures for Geo-resources and Energy Science as professor, Graduate School of Environmental Studies, Tohoku University.

Discussions with Reviewers

1 Overall

Comment (Chikao Kurimoto, Evaluation Department, AIST; and Hiroaki Tao, Research Institute for Environmental Management Technology, AIST)

This article shows the synthesiological process of GERAS, a risk diagnosis system for soil and groundwater contamination, from its conceptualization to the diffusion into society. Based on the research paper [*Synthesiology*, 1(4), 276-286 (2008)] that discussed the process from its development to social provision, this article discusses the scientific and social measures for further technological development and diffusion into industry, as well as the role and collaboration of industry, academia, and government. Particularly, focus was placed on the overall scenario and portfolio to combine and fuse the technological elements, to clarify the elements that should be emphasized and those that are weak, and to outline the importance of utilizing them in system design and social implementation. The content of the article is synthesiological, and we think that it is appropriate for publication in *Synthesiology*.

2 Portfolio analysis

Comment (Chikao Kurimoto)

In this paper, you discuss the technologies for soil surveys, chemical analyses, environmental restorations, risk assessments, information analyses, and geophysical explorations, but in Fig. 1, you present the technologies and measures that integrate multiple technologies such as "1. Soil contamination risk assessment, 2. Soil contamination remediation technology, etc." Please organize the terminologies such as the elemental technologies in the legend of Fig. 1 and the technological elements (research topics). Please explain the fusion and integration of the technologies in this article.

Answer (Takeshi Komai)

The legend of Fig. 1 and the terminologies in this paper were organized, and the details of the method of fusion and integration and the process composition were added to the article. I consider the portfolio shown in Fig. 1 as one expression of using the maturity of technology and society as an index. The three categories in the legend were revised to basic research, product realization research, and demand-response research, and the terminologies were organized to enable better understanding of the overall image. Throughout the paper, instead of an explanatory content, revisions and additions were made to present theoretical discussions that indicate synthesiological thinking.

3 Composition of the GERAS development

Comment (Chikao Kurimoto)

The three-phase composition of GERAS development and their characteristics are well organized and easy to understand in Fig. 2. In chapter 4, the activities for collaboration with industries and for social implementation are explained. I think the understanding will be enhanced if you can clearly show the flow from industrial collaboration to social implementation in Fig. 2. How about setting sociology and industry-academia collaboration of Fig. 2 as the composition stage IV and position it as the next phase?

Answer (Takeshi Komai)

I think the composition where the objective is the diffusion to society is the next step of these R&Ds or the final stage of the loop. I realized it was very important to add the process for social implementation, not just the technological development, in the synthesiological process. Therefore, based on the changes in the three phases in Fig. 2, I added a new process through social

activities such as sociology and industry-government-academia collaboration as stage IV. Figure 2 was revised to show the four stages to make it understandable.

4 Sparse Bayesian modeling

Comment (Hiroaki Tao)

I think the "sparse Bayesian modeling" in risk assessment is a very important analysis method. I think it will help the readers' understanding if you provide a brief explanation in the terminology section.

Answer (Takeshi Komai)

Sparse modeling is one of the information analysis methods using the Bayes' theorem. Recently in geosciences, it is utilized for the extraction of main information in big data and for the restoration of images. In the field of risk assessment, it is gaining attention as a new numerical method for estimating prior risks from posterior occurrence rates, and it has been applied to some complex systems such as the ecosystem. The author and co-researchers are engaging in research to apply the Bayesian statistics to geochemical identification of tsunami deposits. I added a terminology section.

5 Public utilization of the technology and its standardization

Comment (Hiroaki Tao)

In "subchapter 4.2 Public utilization of the technology and its standardization," you write, "Recently, through the joint research with the Environment Bureau of Tokyo, the new version of GERAS is being developed with added LCA." I think you can indicate the potential of the new development if you describe the significance of adding LCA to the components. Perhaps LCA is included partially in the statistics and information science in Fig. 2, but can you add LCA to the components?

Answer (Takeshi Komai)

In the risk assessment up to now, the chronological analysis of the frequency or probability of phenomena or events was not done. However, in soil contamination measures, it is necessary to conduct chronological and spatial analysis for environmental load and energy balance of the various processes from survey to decontamination. Therefore, we developed a method to comprehensively evaluate the life cycles of countermeasures, from the perspective of environmental energy, and not just the environmental burden. The objective is to conduct general assessment of the environmental impact as a whole, including the effects on the surrounding environment, ecosystem, and earth environment (CO_2 emission). Figure 3 was newly added to explain these points.

Comment (Hiroaki Tao)

In "subchapter 4.2 Public utilization of the technology and its standardization," you write about international standardization. Please describe if there are any actions toward JIS standardization.

Answer (Takeshi Komai)

For the international framework, we are already proposing the risk assessment model to ISO. In Japan, the introduction of the risk assessment method is considered within the legal system of individual agencies and ministries, and some have already employed it as the official framework. The next step is the standardization of the domestic risk assessment technology, with international standardization in mind. I think it is about time we begin the efforts across various ministries and agencies for standardization including JIS.

6 Integration system for GEARS development

Comment (Chikao Kurimoto)

For the synthesis of academia and research in Fig. 2, I think it is appropriate that you added Fig. 3 that presents integration and provides comprehensive discussion of the geo-environment. It shows the course for conducting assessments of the environmental risks that exist in the geo-environment, and for integrating the groundwater model, aquatic model, and the economic and LCA model that lie ahead. Please check the uniformity of the terminologies such as the economic model, ecosystem model, LCA model, and others in the figures, captions, and text of the article.

Answer (Takeshi Komai)

Figure 3 shows the scenario where the groundwater and aquatic models are developed in addition to the soil contamination, the economic and LCA models are developed in relation to the individual models, and the entire integrated system that links with the individual models is delivered to the end user. The terminologies were organized and revised so they would be uniform in the text and in the figure caption.

Editorial Policy

Synthesiology Editorial Board

Objective of the journal

The objective of *Synthesiology* is to publish papers that address the integration of scientific knowledge or how to combine individual elemental technologies and scientific findings to enable the utilization in society of research and development efforts. The authors of the papers are researchers and engineers, and the papers are documents that describe, using "scientific words", the process and the product of research which tries to introduce the results of research to society. In conventional academic journals, papers describe scientific findings and technological results as facts (i.e. factual knowledge), but in *Synthesiology*, papers are the description of "the knowledge of what ought to be done" to make use of the findings and results for society. Our aim is to establish methodology for utilizing scientific research result and to seek general principles for this activity by accumulating this knowledge in a journal form. Also, we hope that the readers of *Synthesiology* will obtain ways and directions to transfer their research results to society.

Content of paper

The content of the research paper should be the description of the result and the process of research and development aimed to be delivered to society. The paper should state the goal of research, and what values the goal will create for society (Items 1 and 2, described in the Table). Then, the process (the scenario) of how to select the elemental technologies, necessary to achieve the goal, how to integrate them, should be described. There should also be a description of what new elemental technologies are required to solve a certain social issue, and how these technologies are selected and integrated (Item 3). We expect that the contents will reveal specific knowledge only available to researchers actually involved in the research. That is, rather than describing the combination of elemental technologies as consequences, the description should include the reasons why the elemental technologies are selected, and the reasons why new methods are introduced (Item 4). For example, the reasons may be: because the manufacturing method in the laboratory was insufficient for industrial application; applicability was not broad enough to stimulate sufficient user demand rather than improved accuracy; or because there are limits due to current regulations. The academic details of the individual elemental technology should be provided by citing published papers, and only the important points can be described. There should be description of how these elemental technologies are related to each other, what are the problems that must be resolved in the integration process, and how they are solved (Item 5). Finally, there should be descriptions of how closely the goals are achieved by the products and the results obtained in research and development, and what subjects are left to be accomplished in the future (Item 6).

Subject of research and development

Since the journal aims to seek methodology for utilizing the products of research and development, there are no limitations on the field of research and development. Rather, the aim is to discover general principles regardless of field, by gathering papers on wide-ranging fields of science and technology. Therefore, it is necessary for authors to offer description that can be understood by researchers who are not specialists, but the content should be of sufficient quality that is acceptable to fellow researchers.

Research and development are not limited to those areas for which the products have already been introduced into society, but research and development conducted for the purpose of future delivery to society should also be included.

For innovations that have been introduced to society, commercial success is not a requirement. Notwithstanding there should be descriptions of the process of how the technologies are integrated taking into account the introduction to society, rather than describing merely the practical realization process.

Peer review

There shall be a peer review process for *Synthesiology*, as in other conventional academic journals. However, peer review process of *Synthesiology* is different from other journals. While conventional academic journals emphasize evidential matters such as correctness of proof or the reproducibility of results, this journal emphasizes the rationality of integration of elemental technologies, the clarity of criteria for selecting elemental technologies, and overall efficacy and adequacy (peer review criteria is described in the Table).

In general, the quality of papers published in academic journals is determined by a peer review process. The peer review of this journal evaluates whether the process and rationale necessary for introducing the product of research and development to society are described sufficiently well.

In other words, the role of the peer reviewers is to see whether the facts necessary to be known to understand the process of introducing the research finding to society are written out; peer reviewers will judge the adequacy of the description of what readers want to know as reader representatives.

In ordinary academic journals, peer reviewers are anonymous for reasons of fairness and the process is kept secret. That is because fairness is considered important in maintaining the quality in established academic journals that describe factual knowledge. On the other hand, the format, content, manner of text, and criteria have not been established for papers that describe the knowledge of "what ought to be done." Therefore, the peer review process for this journal will not be kept secret but will be open. Important discussions pertaining to the content of a paper, may arise in the process of exchanges with the peer reviewers and they will also be published. Moreover, the vision or desires of the author that cannot be included in the main text will be presented in the exchanges. The quality of the journal will be guaranteed by making the peer review process transparent and by disclosing the review process that leads to publication.

Disclosure of the peer review process is expected to indicate what points authors should focus upon when they contribute to this journal. The names of peer reviewers will be published since the papers are completed by the joint effort of the authors and reviewers in the establishment of the new paper format for *Synthesiology.*

References

As mentioned before, the description of individual elemental technology should be presented as citation of papers published in other academic journals. Also, for elemental technologies that are comprehensively combined, papers that describe advantages and disadvantages of each elemental technology can be used as references. After many papers are accumulated through this journal, authors are recommended to cite papers published in this journal that present similar procedure about the selection of elemental technologies and the introduction to society. This will contribute in establishing a general principle of methodology.

Types of articles published

Synthesiology should be composed of general overviews such as opening statements, research papers, and editorials. The Editorial Board, in principle, should commission overviews. Research papers are description of content and the process of research and development conducted by the researchers themselves, and will be published after the peer review process is complete. Editorials are expository articles for science and technology that aim to increase utilization by society, and can be any content that will be useful to readers of *Synthesiology.* Overviews and editorials will be examined by the Editorial Board as to whether their content is suitable for the journal. Entries of research papers and editorials are accepted from Japan and overseas. Manuscripts may be written in Japanese or English.

Required items and peer review criteria (January 2008)

	Item	Requirement	Peer Review Criteria
1	Research goal	Describe research goal ("product" or researcher's vision).	Research goal is described clearly.
2	Relationship of research goal and the society	Describe relationship of research goal and the society, or its value for the society.	Relationship of research goal and the society is rationally described.
3	Scenario	Describe the scenario or hypothesis to achieve research goal with "scientific words".	Scenario or hypothesis is rationally described.
4	Selection of elemental technology(ies)	Describe the elemental technology(ies) selected to achieve the research goal. Also describe why the particular elemental technology(ies) was/were selected.	Elemental technology(ies) is/are clearly described. Reason for selecting the elemental technology(ies) is rationally described.
5	Relationship and integration of elemental technologies	Describe how the selected elemental technologies are related to each other, and how the research goal was achieved by composing and integrating the elements, with "scientific words".	Mutual relationship and integration of elemental technologies are rationally described with "scientific words".
6	Evaluation of result and future development	Provide self-evaluation on the degree of achievement of research goal. Indicate future research development based on the presented research.	Degree of achievement of research goal and future research direction are objectively and rationally described.
7	Originality	Do not describe the same content published previously in other research papers.	There is no description of the same content published in other research papers.

Instructions for Authors

"Synthesiology" Editorial Board
Established December 26, 2007
Revised June 18, 2008
Revised October 24, 2008
Revised March 23, 2009
Revised August 5, 2010
Revised February 16, 2012
Revised April 17, 2013

1 Types of contributions

Research papers or editorials and manuscripts to the "Readers' Forum" should be submitted to the Editorial Board. After receiving the manuscript, if the editorial board judges it necessary, the reviewers may give an interview to the author(s) in person or by phone to clarify points in addition to the exchange of the reviewers'reports.

2 Qualification of contributors

There are no limitations regarding author affiliation or discipline as long as the content of the submitted article meets the editorial policy of *Synthesiology*, except authorship should be clearly stated. (It should be clearly stated that all authors have made essential contributions to the paper.)

3 Manuscripts

3.1 General

3.1.1 Articles may be submitted in Japanese or English. Accepted articles will be published in *Synthesiology* (ISSN 1882-6229) in the language they were submitted. All articles will also be published in *Synthesiology - English edition* (ISSN 1883-0978). The English edition will be distributed throughout the world approximately four months after the original *Synthesiology* issue is published. Articles written in English will be published in English in both the original *Synthesiology* as well as the English edition. Authors who write articles for *Synthesiology* in Japanese will be asked to provide English translations for the English edition of the journal within 2 months after the original edition is published.

3.1.2 Research papers should comply with the structure and format stated below, and editorials should also comply with the same structure and format except subtitles and abstracts are unnecessary. Manuscripts for "Readers' Forum" shall be comments on or impressions of articles in *Synthesiology*, or beneficial information for the readers, and should be written in a free style of no more than 1,200 words. Editorials and manuscripts for "Readers' Forum" will be reviewed by the Editorial Board prior to being approved for publication.

3.1.3 Research papers should only be original papers (new literary work).

3.1.4 Research papers should comply with various guidelines of research ethics.

3.2 Structure

3.2.1 The manuscript should include a title (including subtitle), abstract, the name(s) of author(s), institution/contact, main text, and keywords (about 5 words).

3.2.2 Title, abstract, name of author(s), keywords, and institution/contact shall be provided in Japanese and English.

3.2.3 The manuscript shall be prepared using word processors or similar devices, and printed on A4-size portrait (vertical) sheets of paper. The length of the manuscript shall be, about 6 printed pages including figures, tables, and photographs.

3.2.4 Research papers and editorials shall have front covers and the category of the articles (research paper or editorial) shall be stated clearly on the cover sheets.

3.2.5 The title should be about 10-20 Japanese characters (5-10 English words), and readily understandable for a diverse readership background. Research papers shall have subtitles of about 15-25 Japanese characters (7-15 English words) to help recognition by specialists.

3.2.6 The abstract should include the thoughts behind the integration of technological elements and the reason for their selection as well as the scenario for utilizing the research results in society.

3.2.7 The abstract should be 300 Japanese characters or less (125 English words). The Japanese abstract may be omitted in the English edition.

3.2.8 The main text should be about 9,000 Japanese characters (3,400 English words).

3.2.9 The article submitted should be accompanied by profiles of all authors, of about 200 Japanese characters (75 English words) for each author. The essential contribution of each author to the paper should also be included. Confirm that all persons who have made essential contributions to the paper are included.

3.2.10 Discussion with reviewers regarding the research paper content shall be done openly with names of reviewers disclosed, and the Editorial Board will edit the highlights of the review process to about 3,000 Japanese characters (1,200 English words) or a maximum of 2 pages. The edited discussion will be attached to the main body of the paper as part of the article.
3.2.11 If there are reprinted figures, graphs or citations from other papers, prior permission for citation must be obtained and should be clearly stated in the paper, and the sources should be listed in the reference list. A copy of the permission should be sent to the Publishing Secretariat. All verbatim quotations should be placed in quotation marks or marked clearly within the paper.

3.3 Format

3.3.1 The headings for chapters should be 1, 2, 3…, for subchapters, 1.1, 1.2, 1.3…, for sections, 1.1.1, 1.1.2, 1.1.3, for subsections, 1.1.1.1, 1.1.1.2, 1.1.1.3.
3.3.2 The chapters, subchapters, and sections should be enumerated. There should be one line space before each paragraph.
3.3.3 Figures, tables, and photographs should be enumerated. They should each have a title and an explanation (about 20-40 Japanese characters or 10-20 English words), and their positions in the text should be clearly indicated.
3.3.4 For figures, image files (resolution 350 dpi or higher) should be submitted. In principle, the final print will be in black and white.
3.3.5 For photographs, image files (resolution 350 dpi or higher) should be submitted. In principle, the final print will be in black and white.
3.3.6 References should be listed in order of citation in the main text.

Journal – [No.] Author(s): Title of article, *Title of journal* (italic), Volume(Issue), Starting page-Ending page (Year of publication).

Book – [No.] Author(s): *Title of book* (italic), Starting page-Ending page, Publisher, Place of Publication (Year of publication).

4 Submission

One printed copy or electronic file of manuscript with a checklist attached should be submitted to the following address:

Synthesiology Editorial Board
c/o Website and Publication Office, Public Relations Department, National Institute of Advanced Industrial Science and Technology(AIST)
Tsukuba Central 2 , 1-1-1 Umezono, Tsukuba 305-8568
E-mail: synthesiology-ml@aist.go.jp

The submitted article will not be returned.

5 Proofreading

Proofreading by author(s) of articles after typesetting is complete will be done once. In principle, only correction of printing errors are allowed in the proofreading stage.

6 Responsibility

The author(s) will be solely responsible for the content of the contributed article.

7 Copyright

The copyright of the articles published in "*Synthesiology*" and "*Synthesiology English edition*" shall belong to the National Institute of Advanced Industrial Science and Technology(AIST).

Inquiries:

Synthesiology Editorial Board
c/o Website and Publication Office, Public Relations Department, National Institute of Advanced Industrial Science and Technology(AIST)
Tel: +81-29-862-6217 Fax: +81-29-862-6212
E-mail: synthesiology-ml@aist.go.jp

Letter from the editor

Recently, the demands on the R&D results are becoming diversified. Just decades ago, the main mission of R&D was to produce research results that will help create products with better functions because we had a belief that "products with excellent functions will sell." However, today, it is said that the demand is not only for the functionality of the products or services, but is for the "values at a higher dimension." On the other hand, after the Great East Japan Earthquake and Tsunami of 2011, the demands for "specific applications (implementations) of the research results to society" have increased, and the ways in which the research results "realize values in society" are under scrutiny.

Synthesiology sets the following as requirements for its papers: to set specific values and goals of R&D in society; to create scenarios to realize the goals; and to select and integrate the elemental technologies necessary to achieve the goals. One of the most important requirements is how to set the "goals and values in society." It is very interesting to see how the researchers have tackled this issue. In this issue of *Synthesiology*, there are four papers and one article, and I shall write my thoughts from this perspective.

The paper by Arai *et al*., "Marine geological mapping project in the Okinawa area," provides the methodology for exploring submarine mineral resources, based on geological phenomena. It should be noted that the paper presents the synthesis process of the methodology to generate "higher values," that is, resource development, without staying in the bounds of organizing the basic land information.

The paper by Shikata *et al*., "Development of diamond-based power devices," is a verification research of the diamond material that has the highest performance and overwhelming superiority among the power semiconductors, and this is taken to the stage of practical use. The goal is the realization of "higher environmental and energy values" for the "low-loss electric conversion" by combining the various excellent properties of diamond.

Tamura's paper, "Measurement of input resources for standardization activities in basic research and applied and development research, and the difference of the measuring results between the research types," is also interesting. Here, a hypothesis is set that there may be a possibility that the standardization activity is conducted in the basic research disciplines, at the same level as the application and developmental researches. The focus is placed on the activities to generate "higher added values" for the research results of the standardization activities.

In the paper by Arizono *et al*., "A proposal for setting electric power saving rate to avoid risk of electric power shortage occurrence," the method for setting the power conservation rate to avoid power shortage is proposed, using the probability inequality as the main elemental technology. As there is a concern for the shortage of electricity, it is an interesting paper from the perspective of aiming for "a solution of a difficult issue that must be solved" in avoiding the risk of electricity shortage based on the current power demand-supply balance.

In all papers, we can see the efforts to create new values, and the unique insight of the researchers can be discerned in all cases.

Finally, we published an article, "Portfolio structuring and social implementation in the development of complex technology." by Dr. Komai. Here, the portfolio analysis was conducted for a complex technological development using the synthetic method. It is a report of a method and diffusion of the analysis results of the geo-environmental risk assessment system (GERAS). This article is a recommended reading as it presents an example of the new way of applying synthesiology that goes all the way to social implementation as mentioned in the beginning.

Executive Editor
Naoto KOBAYASHI

Synthesiology - English edition Vol. 6 No. 3, Dec. 2013
Edited by *Synthesiology* Editorial Board
Published by National Institute of Advanced Industrial Science and Technology (AIST)

Contact: *Synthesiology* Editorial Board
c/o Website and Publication Office, Public Relations Department, AIST
Tsukuba Central 2, Umezono 1-1-1, Tsukuba 305-8568, Japan
Tel: +81-29-862-6217 Fax: +81-29-862-6212
E-mail: synthesiology-ml@aist.go.jp
URL: http://www.aist.go.jp/aist_e/research_results/publications/synthesiology_e

Synthesiology Vol.6 No.3 December 2013
-English edition

Messages from the editorial board

Research papers

Article

Editorial policy
Instructions for authors

"Synthesiology-English edition" is a translated version of "Synthesiology," which is published quarterly, ISSN 1882-6229, by AIST. Papers or articles published in "Synthesiology-English edition" appear approximately four months after the publication of the original "Synthesiology."

AIST11-A00005-10 Published by AIST