Report of the 2nd Advisory Council

on

RIKEN Center for Emergent Matter Science (CEMS)

September 27 – 29, 2016

The second Advisory Council meeting on RIKEN Center for Emergent Matter Science (CEMSAC) was held from September 27 to 29, 2016 at the RIKEN Wako Campus and Hotel Metropolitan Tokyo Ikebukuro. The introduction of RIKEN was first presented by Dr. Yoichiro Matsumoto, Executive Director of RIKEN. Then CEMS brief introduction, response to CEMSAC2014 and Terms of Reference were presented by Dr. Yoshinori Tokura, Director of RIKEN Center for Emergent Matter Science (CEMS). Research presentations are provided by total fifteen PIs, including Division and Group Directors, Team and Unit Leaders. On the third day of the meeting, Center Director Tokura presented about management, current activities, and collaborations of CEMS. In addition, we had a chance to hear some opinions from CEMS young scientists. The report by the CEMS Advisory Council is presented from the next page on the Terms of References for the CEMS.

Members of the CEMSAC2016

Dr. Sadamichi Maekawa, Director General, Advanced Science Research Center, Japan Atomic Energy Agency (chair)
Dr. Makoto Gonokami, President, the University of Tokyo
Dr. Koichi Mizushima, Executive Fellow, Toshiba Research & Consulting Corporation
Dr. Junsaku Nitta, Professor, Graduate School of Engineering, Tohoku University
Dr. Samuel I. Stupp, Director, Simpson Querrey Institute for BioNanotechnology, Northwestern University
Dr. Atsushi Takahara, Director, Institute for Materials Chemistry and Engineering, Kyushu University
Dr. Jean-Marc Triscone, Vice-rector, University of Geneva
Dr. Robert M. Westervelt, Director, Center for Nanoscale Systems, Harvard University

1. ***Evaluate whether the Center possesses research achievements and human resources that meet international standards, produces world-leading research in its field, and engages in research that contributes to society. Also, elucidate the Center's standing within its field, and strengths and weaknesses with respect to the Center's areas of focus (sub-theme). In formulating the fourth five-year plan, the Advisory Council is asked to propose a well-defined policy for the mid- to long-term (5 to 10 years) and suggest the direction for the Center to take within its area of focus in order to achieve rapid progress.***

Strengths/world standard

CEMS is a unique center that brings together physics, chemistry and electronics with the vision that top scientists from these different fields are able to work more "broadly" and bring long-term solutions to some of the important problems of our society. CEMS has about 40 research groups and 200 scientists. The center has very many talented researchers in three areas: "Strong correlation physics", "Supramolecular chemistry" and "Quantum information electronics". CEMS is without any doubt performing at the highest international level. At the core of this project, the "emergence" goes very well, namely, the idea that when putting together a number of elements, the properties will be "more" than what would be expected by considering the simple "addition" of these elements.

Strong Correlation Physics Division:

Here are some of the impressive recent achievements of the Strong Correlation Physics Division. These results, which for many come from collaborations between the different research areas, are certainly at the highest scientific international level and cover a broad spectrum of research areas.

- The role of strain was demonstrated on the real space structure of skyrmions (Tokura).
- Large magnetoelectric effect was reported on a new multiferroic material $Fe_2Mo_3O_8$ with a ten times larger magnetoelectric coupling than conventional multiferroics (Tokura).
- Skyrmions and antiskyrmions were studied, in particular their time evolution. Ways to create and annihilate skyrmions were found and theses ideas successfully tested theoretically. Memory concepts were also developed and patented (Nagaosa).
- Mobility of polarons has been calculated in organic systems – resolving a long-standing question (Nagaosa).
- Quantum Hall effect has been observed in delta-doped $SrTiO_3$ and the observed behavior related to the electronic structure of the material and role of the d_{xy} and $d_{xz,}$ d_{yz} bands (Kawasaki).
- Interesting photovoltaic effects have been observed in polar – non-polar structures containing $LaFeO_3$ and $SrTiO_3$ (Kawasaki).

- Skyrmion crystal structures have been observed at room temperature (Taguchi).
- Large thermoelectric effects have been investigated in skutterudite compounds (Taguchi).
- High-pressure studies of Hg-based cuprates revealed record-high T_c with zero resistance (Tokura).
- A multiferroic phase of $DyFeO_3$ has been observed under uniaxial strain (Arima).
- Nanoscale magnetic bubbles and skyrmions have been observed in zero field in bilayer manganites (Arima).
- Two different electronic structures have been revealed in the vortex core of high T_c superconductors (Hanaguri).
- A quantum spin liquid state has been theoretically explored (Furusaki).
- Negative thermal expansion, a rare phenomenon, has been studied in $BiNiO_3$ (Furusaki).
- The ground state of Sr_2IrO_4 has been studied in detail (Yunoki).
- Ab-initio calculations for predicting the superconducting critical temperature of novel compounds have been developed and applied to sulfur hydrides with record high T_c. The pressure dependence of T_c was theoretically studied for this compound (Arita).
- A new model based on hidden composite fermions has been developed to explain high T_c superconductivity (Arita).

This list is not exhaustive and shows an amazing productivity.

Supramolecular Chemistry Division:

The topics under investigation in the Supramolecular Chemistry Division by 8 PIs are uniformly of the highest quality and innovative, and this group under the leadership of Dr. Takuzo Aida is recognized worldwide as working on the frontiers of supramolecular materials. One important direction pursued by this group is the development of dynamic soft materials (organic-inorganic hybrid materials). In this particular work they have developed materials with autonomous motion using highly creative mechanisms. This work has received a lot of attention internationally, and it is considered an important goal in soft matter. There has been excellent progress in the development of hydrogels (aqua material) reinforced by charged titanium oxide nano-sheets, particularly in identifying both the mechanisms of dynamic behavior driven by temperature changes as well as the possibility of generating “photonic water-based materials”, using stress-driven changes in well defined spacing between charged titanium oxide nano-sheets. Other excellent work involves organic photovoltaics (OPV), exploring multiple challenging goals such as, the achievement of defined molecular orientation in active layers to maximize efficiency, the development of ultrathin wearable solar cells, and the mechanisms of exciton splitting. In an effort to understand mechanisms and maximize efficiency in charge generation within organic solar cells, the Division is developing planar model heterojunctions that will be of great interest to the OPV community. There are many other areas being pursued by the

Division, including the development of self-healing organic glasses using supramolecular structure, the synthesis of novel n-type organic semiconductors, and the development of block copolymers in which electron donor and acceptor functions are covalently integrated. Overall the quality of publications being generated by the Division is absolutely outstanding, and all indications are that the Division will continue on a great scientific trajectory.

The Supramolecular Chemistry Division has achieved great balance between fundamental science and a vision for technological translation of the concepts they explore. Having said this, the Division is pursuing emergent matter opportunities, and they should not be judged by the level of interest of their work to industry. The field of dynamic soft matter is in many ways at early stages and industrial interest is still not well established. With regard to organic photovoltaics, the level of interest in industry fluctuates but there is a lot of critical and interesting basic science to do in this field which could provide a great future for this area. In addition to the excellent work in this area by Tajima team, one of the great things being done by the Division is the work by Someya team which in parallel is exploring completely new applications for organic photovoltaics. In this work, the concept of using them as energy sources in wearable stretchable devices, possibly for biomedical applications is a very interesting direction that may even cross fertilize new areas in emergent matter. Also given the strong presence of biology and medicine at RIKEN, this area may in the future become a very fertile interface for interdisciplinary research. The current efforts in the Supramolecular Chemistry Division are definitely on the right track for a successful 5 to 10 year plan focusing on world class innovation in basic soft matter materials science that is relevant to multiple potential technologies in the areas of sustainable energy, advanced manufacturing, and novel biomedical platforms for advanced medicine.

Quantum Information Electronics Division:

In Quantum Information Electronics Division (QIE-D), research activities using spins of semiconductor quantum dots lead by Tarucha group, and using superconductors lead by Nakamura and Tsai teams are world-class quality and leading in this research field. Within last two years, several excellent progresses were done. In Tarucha group, four spin qubits operation with quadruple quantum dots and exchange and phase control of entanglement with triple quantum dots were realized with GaAs quantum dots. 99.9 % high fidelity was achieved in Si qubit. The high fidelity in qubit is crucial for multiplication of qubits. Tarucha group also first demonstrated non-local quantum entanglement in solids in a scalable manner. In collaboration with Ishibashi team, Majorana-Andreev bound states were detected in HgTe Josephson junction. Majorana spin hybrid qubit as a new scheme for implementing quantum circuits was theoretically proposed by Loss team. The Majorana quasi-particle is expected to be useful for fault tolerant quantum computation. Nakamura and Tsai teams made superconducting parametron utilizing superconducting quantum interferometer (SQUID) and superconductor resonator. This is an essential technology for quantum computer with quantum error correction. By using superconducting circuit, single microwave photon was detected by single-shot. They also started a new approach on quantum simulation which can be applied to solve problems in many-body systems. Nori group theoretically proposed quantum spin Hall effect in light.

Otani team successfully realized very high current-spin conversion efficiency by using high quality topological insulating material (BiSbTe) which was made by Tokura and Kawasaki groups. This is an excellent collaborative example between Strong Correlation Physics Division (SCP-D) and QIE-D. Tatara team theoretically formulated Dzyaloshinskii-Moriya interaction, which plays an important role for formation of skyrmion. Kono team developed a new technique to detect a tiny magnetization by using quantum point contact. Shindo team first realized three-dimensional observation of magnetic vortex cores by using electron holographic vector-field electron tomography. Technical supports for nano-fabrications from Akimoto team were very helpful in QIE-D activity for producing nano-scale devices.

As is described above, it is clear that QIE-D produced world-leading researches. The strength of QIE-D is that a variety of solid state systems are studied for future electronics. Each group is doing very well to perform the world-top science and based on it, collaborations and integration among QIE-D and SCP-D have been starting. Further effort in this direction will enhance the strength and will lead to technological breakthrough.

Managements:

CEMS has established a leading position in the research of materials science (both in physics and chemistry) and quantum information electronics, as is objectively evident from a numbers of statistics such as Nature Index.

The most important factor that has enabled the excellence of CEMS is recruiting the best PIs through a very competitive selection process from worldwide. This set of PIs promises continuing success for the mid-term of the next 5 years.

One clear evidence of as well as another important driving force for success is the weekly research meeting that is organized by the Center Director. Regardless of their division, position, nationality, or interests, as many as 50 people get together to discuss research for 3 hours. The important thing is that this meeting is not intended to be a collection of talks for finished research topics but to be a platform to discuss deeply the preliminary results of on-going research and near future plans. The AC members highly evaluate and appreciate the effort of PIs who run such an important meeting. It is very likely that in other institutes such a weekly meeting would become inactive in a short period of time. The AC members presume that there are numbers of reasons that make the meeting possible. Among those, (i) the coordinating force of the Center Director, (ii) the motivation held by numbers of PIs of high caliber who actually activate the discussion, and (iii) the well shared recognition of the high value that such interdisciplinary meetings bring in raising their research to higher level. It is a clear evidence of the excellence of CEMS that the meetings keep providing such a high quality opportunity to the CEMS researchers. It is usually impossible in universities to pack many of internationally recognized researchers with various interests in a room to share unpublished research results for high-level discussion. Not only gathering PIs with high caliber, but also set up such an environment to create synergy between PIs is the most important mission of a top level research center, which apparently has been realized in CEMS.

Weaknesses

CEMS is a world unique center that is merging three different fields of research: physics, chemistry and electronics. Managing such a center and trying to push people to work together are a formidable task that is taking a lot of time. In this sense CEMS is already somehow like three centers working together and one can see that many collaborative projects are developing. There is however still progress to do and the management is working in this direction. To further develop the links between physics, chemistry and electronics, efforts to bring all these activities "under one roof" should be pursued. This might be a key step to favor such collaborations.

The following is some additional comments:

- One issue to be noted is the limited contract time for research scientists. Since most of them are not linked to universities, this situation is creating uncertainties for their career. One should imagine a way to stabilize a fraction of them.
- More PhD students would be a plus for CEMS.
- Although the number of foreign scientists is rather high in CEMS, a continuous effort to attract more foreigners is important and should be pursued. It would be great to better advertise for RIKEN allowing everyone in Japan but also abroad to know RIKEN and its unique facilities. That would also help when recruiting new personal, in particular, when looking for foreign scientists.
- CEMS is lacking technicians who are keys for maintaining sophisticated equipment such as molecular beam epitaxy systems.
- Although CEMS is collaborating with other institutions outside of RIKEN such as the University of Tokyo, NIMS and AIST, most researchers working in industries are not in intimate relation with CEMS. The industry researchers would be more familiar to CEMS to grade up their science levels.
- "Nano-Science Joint Laboratory" (clean room facility) for nano-fabrications is crucial for QIE-D experimental groups and teams. Sharing common equipment in this facility is effective to save research budget. The support team consists of a team leader, 3 technical staffs and an assistant. However, their duties for maintenance of many machines and

education for users seem to be heavy, so they may not afford to accept all requests of nano-fabrication. If the budget is permitted, it might be worth considering to hire additional staff to support nano-fabrication.

Suggestions for mid/long-term

The vision at the origin of CEMS is a long-term fundamental research, but not a short-term “applied” research that should lead to immediate deliverables. The CEMS research program is an investment for the next decades and should allow new knowledge to be developed that will lead to disruptive technologies in several important areas for the development of our society. It is important to stress that studies show that investment in fundamental research has a payback that is higher than the one in applied research. In that sense, the pressure to go to more innovation and short-term views is not very good and should not be slowing down the developments of CEMS.

One could add to this general statement that CEMS should continue developing collaborations between physics, chemistry and electronics. Efforts to bring all the CEMS activities “under one roof” that would help developing synergies should be pursued.

The AC would like to emphasize the significance of CEMS weekly research meetings. The AC would also like to stress that the weekly meeting held in CEMS is quite exceptional and important even from a world-wide viewpoint and this gives tremendous opportunity for CEMS to expand and strengthen research activity.

To maintain strength and sustainability of CEMS, it will be very effective and is necessary to collaborate with other institutions outside of RIKEN. The President of the University of Tokyo (one of the AC members) would like to suggest following two schemes with the University of Tokyo (UTokyo): expand the existing RIKEN-UTokyo collaborative network in the near future, and UTokyo-NIMS-AIST-RIKEN collaboration on materials science that has been just launched. For the latter, the UTokyo plans to create a new research center in Kashiwa-II campus for the collaborative research activities. The UTokyo certainly expects the tight relationship on this regard with RIKEN. This suggestion is related with the comments given in TOR3-(3) and TOR3-(5).

One important goal for the Supramolecular Chemistry Division is to add more PIs to its programs, paying particular attention to scientists that could help solidify the integration with the physics oriented groups. One example would be to add efforts in soft matter physics and computation to establish interfaces between the chemical side of supramolecular systems and physics as a whole within the Center. One possible way of approaching this issue is to create a new group under the banner of supramolecular physics since this will facilitate interactions.

2. Not applied for CEMS

3. A significant change in RIKEN's top management took place when Hiroshi Matsumoto became the president in April, 2015. Under the RIKEN Initiative for Scientific Excellence put forth by the new president, we place special emphasis on the five strategies shown below. The Advisory Council is asked to evaluate whether the Center's activity follows this Initiative, and whether such activity is achieving the intended results. We also ask for recommendations on any new policies to be implemented by the Center.

(1) Pioneer a research management model for maximizing research and development results

・Initiatives to manage the center at optimum efficiency so as to maximize research and development results

・Initiatives to optimize budget allocations within the center and secure external research funds

The management of CEMS is rather simple with two high-level deputy directors, i.e., Deputy Director Kawasaki is in charge of the budget, and Deputy Director Nagaosa leads the CEMS human resources and advises the director on the hiring of PI's and researchers. These are very important aspects.

The Center Director Tokura has some budget flexibility to allocate money directly when judged necessary and when fitting the defined priorities.

The SCP-D is a top runner in the field of materials science, e.g. topological insulators (TI) materials. Quantum computation using topologically protected states is now very hot topic in the world. *The advantage of CEMS is that materials science and quantum information electronics are integrated.* One of theoretical group in quantum information division (Loss team) is working on this direction to make promising theoretical proposals. High quality of TI will certainly play a crucial role in these proposals. CEMS is a suitable center to combine quantum information (QI) technology (lead by Tarucha-Nakamura-Tsai groups) with TI materials (lead by Tokura-Kawasai groups). It is expected that the collaboration between QI and TI will enhance their advantage and strength and will lead to a new research horizon.

Human resources such as young researchers are a most important issue in order to continue high level of research. Systems such as JRA should be advertised in order to get good students with a collaboration.

A number of CEMS PIs have joint appointments with universities; mainly with the University of Tokyo, but also with Tsinghua University, Tohoku University, Basel University, Tokyo University of Science, and Ochanomizu University. This is an ideal situation, because it allows CEMS to pull in established researchers, with excellent reputations, as well as top young

PIs. The visibility of CEMS at the University of Tokyo will also attract postdocs, as well as graduate students. In the US, collaborations between the DOE National Laboratories and universities are highly productive. For example, Lawrence Berkeley National Laboratory is right next to UC Berkeley, many faculty members have joint appointments, and graduate students and postdocs go back and forth to carry out their research. Likewise, Argonne National Laboratory is closely connected with the University of Chicago. By contrast, Sandia National Laboratories is far from top universities, and suffers as a result.

(2) Lead the world in preeminent research and development achieved through scientific excellence

・Initiatives based on the research achievements of the centers to pioneer new research areas that transcend existing research fields (Evaluation of the centers' research capabilities are covered by item 1)

One can simply add here that the idea of bringing together physics, chemistry and electronics by itself is generating new "cross-fields" research areas.

Recently, the concept of quantum computation is applied to "quantum simulations", which makes many-body problems solvable. The quantum simulation is one example and Nakamura-Tsai teams started this direction. Although a major task of QIE-D in CEMS is to make significant contributions and approaches to a quantum computer, it is recommended to extend their scope to contribute fundamental physics as well by using quantum information technologies. Especially, young researchers should have a wide scope based on their own researches. Budget allocation for young researcher's proposals, especially interdisciplinary topics between different groups and divisions should be recommended as well.

As noted above CEMS has an exciting vision, aimed at the production of quantum devices made from new quantum materials, the creation of quantum information processing systems, and the development of complex new types of soft matter with exceptional properties. The researchers include some of the best people in the world, and CEMS is in a position to set the agenda.

(3) Become a hub for science and technology innovation

・ The role of the centers in transforming RIKEN into a hub for science and technology innovation (such as initiating industry, government, and academia collaborations)
・ Initiatives for interdisciplinary research involving multiple centers throughout RIKEN

In this direction, one should mention the "Joint Research Laboratory for Materials Science" initiative is being planned to allow several laboratories, i.e. CEMS (RIKEN), ISSP (Univ

Tokyo), IMS (Okazaki), ICR (Kyoto Univ), and IMR (Tohoku Univ), to work closer and form a hub for a better “brain circulation”. Also, in this context, a Forum of Materials Science mostly for young PIs is being planned.

One should also mention the RIKEN-AIST initiative to bring closer researchers coming from different horizons and working on related fields of research.

The strong links with Tsinghua University and the Indian Institute of Science are expected. Also important in this context is the collaboration with industries. There is a program has been launched with many industries (among them Intel, NEC, HITACHI….) with industry scientists on a 2-3 years project in CEMS.

One can finally mention here the foreseen developments of sensing technologies for future society needs including environmental sensors and bio-sensors. These developments will strengthen collaborations within CEMS but also with other RIKEN centers.

For playing a role of a hub function on materials science as suggested in CEMSAC2014, CEMS has continued its effort to discuss with the University of Tokyo central administration. In order to strengthen the RIKEN-UTokyo collaboration at Quantum Phase Electronics Center (QPEC) of the University of Tokyo, QPEC has succeeded in getting a support of about $100k from the University of Tokyo, which should be evaluated highly.

Budget and human resources on quantum computer research in abroad are getting one-order larger than those in Japan. It should be emphasized that big companies such as Intel, Google, IBM, and Microsoft are strongly supporting quantum computation researches.

The quantum information research groups including spin and superconducting qubits in QIE-D of CEMS form a world-leading center in Japan. In order to compete with the rapid progress on quantum computing in the world, *it is recommended that Tarucha-Nakamura-Tsai Groups should take an initiative to organize a national project including AIST and some related Japanese companies*. It is also recommended to consider making an international collaboration if possible.

Each division of CEMS can be a hub for science and technology such as electronics, soft functional devices and biomaterials. Since RIKEN has the one of the world most powerful K-computer for simulation (in Kobe), the world most high-performance synchrotron/X-ray free electron laser at SPring-8/SACLA for characterization (in Harima), each division of CEMS or CEMS can initiate innovative project with these centers including industrial development as well as academic collaboration.

(4) Serve as a focal point for global brain circulation

・Initiatives to improve recruiting methods, particularly regarding the ratio of non-Japanese to Japanese researchers and men to women

・Initiatives to improve the research environment and bring it up to international standards

One should first note the two first female PIs who joined CEMS, Dr. Ishizaka (ARPES) and Dr. Furukawa (neutrons).

Analyses of the statistics show that the strongest effort to have more women and non-Japanese has to be done at the PI level. Notice also that female PIs are an example for the next generation of female scientists. Regarding non-Japanese PIs, a substantial help (which may exist already) for administrative related issues is probably necessary to try attracting more foreigners.

Although CEMS already took measure to provide comfortable circumstances for foreign researchers, further support might be necessary. It is very helpful to form a special team in RIKEN to support solving foreigner’s problems in daily life in Japan.

This is a request from a young foreign researcher during interview:

To encourage foreign researchers,

I. Improve English on the administrative side (This might be a request to whole RIKEN not to CEMS.) Now, secretaries and researchers need to help their communication.

II. Prepare a team (or a person) to support solving their problems in daily life in Japan.

(5) Foster world-class leaders in scientific research

- Contributing to global brain circulation through initiatives to foster and train excellent researchers and send them out into the world
- Initiatives to provide researchers and engineers in industry and academia with opportunities for research and training to improve their skills

Many activities of CEMS are directed towards helping young scientists to profile themselves and become more self-confident – very important issues. Indeed, some education and research systems with different hierarchical levels often “block” young people in their progression.

Important efforts in the good directions can be mentioned: One can note events allowing more interactions; open discussions on on-going research followed by the young scientists (every week), research camps (organized 4 times) – notice here that the topics of the camps are chosen to attract people from the three CEMS research areas, topical meetings whose subjects are selected by the young scientists that allow presentations of ongoing work (organized 5 times) and weekly coffee/tea parties, which is called “Tea time”, as well as monthly colloquium. Important too is the creation of CEMS awards (up to 5 a year) allowing young researchers to get profiled and the organization of International Symposium Workshops.

Also very important is the Cross-Divisional Materials Research Program where young researchers organize their units under the supervision of senior PIs.

One should notice here that many scientists left CEMS and found a permanent position in the university system or in industries. Still, one worry is the small number of permanent position in RIKEN – this is not a good incentive for young researchers.

Issues discussed with young scientists:

- there is a very few perspective as permanent scientist in RIKEN
- for women, a Japanese model is to stay for 5-10 years in a University and then move, but this is not well adapted for a woman having children
- there is more freedom in RIKEN than in Universities in terms of choosing his research
- advertising more for RIKEN is a good idea
- it would be good to get more foreigners in RIKEN
- lack of technicians is an issue
- journal access is sometime a problem

It should be highly appreciated that CEMS had introduced Cross-Divisional Materials Research Program, Topical Meeting organized by young researchers, and also Forum of Materials Science by young PIs is being planned. These programs are very effective to foster next-generation top researchers. Many excellent works are coming out from Cross-Divisional Materials Research Program.

Actually, researchers in CEMS were promoted to be higher positions; e.g. one group director became program manager, two senior scientists became professors, 7 researchers and scientists became associate professors.

Collaboration with Tsinghua University and Indian Institute of Science is effective to promote international hub for research personal exchange/ brain circulation. It is recommended to introduce an internship system for young researchers to stay abroad to experience other cultures and environment. It should be an important period to think about their future research topics and to make an international collaboration.

4. Evaluate how appropriate and effective the Center's activities are towards maximizing RIKEN's achievements as a whole, including collaboration between centers.

As described above, CEMS is a world unique center that is merging three different fields of research: physics, chemistry and electronics. Managing such a center and trying to push people to work together is a formidable task that is taking a lot of time. In this sense CEMS is already somehow like three centers working together and one can see that many collaborative projects are developing. There is however still progress to do and the management is working in this direction.

In view of the CEMS structure ("three centers in one") it may not be too reasonable to push too much CEMS to collaborate with other RIKEN centers – CEMS will however certainly do this if necessary to achieve its goals.

Multiplication of qubits to build up fault tolerant or scalable quantum systems, including quantum computation and quantum simulation is getting more and more challenging. Not only CEMS but also all institutes in the world are now facing this problem. For the solid-state qubits including spins and superconducting states integration techniques can be applied to overcome this problem but in order to make a breakthrough in this challenge, it will be necessary to collect technical expertise from not only quantum information but also computer science and electrical engineering. Maybe even a new concept of quantum computation is necessary. (The original concept of "Quantum Annealing" was made by a Japanese researcher.) In this context it would be helpful for CEMS or RIKEN to take an initiative to organize a national project as described before in 3-(3).

A newly established "Center for Advanced Integrated Intelligence Research (AIP)" in RIKEN seems to consist of computer scientists. If "AIP" and Quantum Information Electronics Division will have common research directions, it might be very helpful AIP researchers give advices and supports to experimental researchers in Quantum Information Electronics Division.

CEMS is demonstrating to be a unique center inside RIKEN in its ability to reach out to the significant strengths of this national laboratory in life sciences. This is clearly demonstrated by the new initiative proposed to utilize achievements in supramolecular chemistry combined with new engineering efforts to generate biomedical and environmentally relevant devices.

As one of missions of CEMS asked by RIKEN headquarters, CEMS pays effort to realize the collaboration between centers in RIKEN, such as "Innovative Quantum Technology" running from FY2015 and "Sensing Technology for Society 5.0" to be launched from FY2017. We hope their activity will contribute the excellence of CEMS. However, we have to mention again to the RIKEN headquarters that focusing too much on RIKEN internal collaboration may be harmful to keep the excellence of CEMS.

It has been already very clear that CEMS has established its presence, importance and role in RIKEN as basic research center on materials science. It is now the time for the decision makers of the Japanese national initiative on science and technology of advanced materials to consider how Japan can benefit through the achievements of CEMS.

It has been said that AI and IoT are the key drivers for near future technology, industry and society. In order to leverage Japan's strengths, it is necessary to link these technologies with most advanced materials science in Japan. CEMS keeps producing exceptionally outstanding research among world-wide top institutions in the field of functional materials science driven by novel concepts. On the other hand, the ecosystem for supporting the birth of new start-ups based on the cutting edge research on materials science is not yet established in Japan. It is highly desired to organize a system in Japan that can carry efficiently and effectively the CEMS-born knowledge and materials to real-world applications in society.

Society and technology have been changing in a very dynamic way. It is very important to have an organization in RIKEN that can keep up with and forecast those trends. There should be individuals who have an excellent view of this dynamically-changing world in decision making sectors both in Japan and RIKEN so that appropriate decisions are made in a timely manner.