Report of

The 3rd RIKEN Center for Advanced Photonics Advisory Council

(RAPAC2019)

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I. Executive Summary

1) Progress of RAP

The RIKEN Center for Advanced Photonics (RAP), which was started in 2013, is in the second year of its second term (2018-2025). The Advisory Council (AC) is impressed that RAP is making remarkable progress in the second term in many directions; world-leading research in basic science, development of fore-front technologies, and collaboration with domestic and international R&D activities at universities, government labs, industry and also RIKEN. We believe that these activities are well in line with the 4th Mid- to Long-term Plans of RIKEN (2018-2025).

2) RAP Organization

The organization of RAP has been changed in the second phase as follows. With these reorganizations, we find that the research and management of RAP are working very smoothly as described in this Report.

- The Center Director's Office has been newly created to support the RAP Director mainly on management of scientific activities.
- The Extreme Photonics Research Group, which was composed of 7 research teams, 1 joint research team and 1 joint research unit in the first phase, has been divided into two research groups: Extreme Photonics Research Group (composed of 4 research teams) and a newly formed Subwavelength Photonics Research Group (composed of 5 research teams).
- In this reorganization, a new Quantum Optoelectronics Research Team has been created in the Extreme Photonics Research Group, and the Advanced Laser Processing Research Team has been formed (from the RIKEN-SIOM Joint Research Unit in the first phase) in the Subwavelength Photonics Research Group.
- The Cloud-Based Eye Disease Diagnostics Joint Research Team for RAP-Topcon collaboration is continued as an independent team with cooperation of 3 research teams of RAP. The organizations of the Terahertz-wave Research Group and Advanced Photonics Technology Development Group are not changed.

3) Progress both in basic science and engineering

After reorganization in the second phase composing 4 Research Groups, two research groups are working mainly on basic science and another two groups mainly on engineering. This reorganization reflects the vision of the RAP management that strong R&D both in basic science and engineering are required in order to generate excellent outcome in both directions and also to explore new fields by strong support of science and engineering. This RAP vision has been successfully implemented, resulting in many outcomes both in basic science and engineering.

Since R&D activities of RAP have reached a significantly high level, we would suggest if RAP can consider starting a "Grand Challenge" of scientific and societal importance as its own initiative, which can be pursued only by a well-organized research center of high research capability such as RAP.

4) RAP management

We found that the vision of RAP management is well shared by the research members in implementing various activities. This sharing is realized by intensive effort of the RAP management for smooth communication among the researchers and the management; for example by holding the RAP meeting every month at the location of each research team in turn. This approach turned out to be very effective for understanding the detailed aspects of the research of each team. We were impressed at the poster session that various cooperation and collaboration are emerging among young scientists through these interactions.

5) RAP technical accomplishments and worldwide visibility

The RAP teams have impressive records of high-quality publications. Similarly, their findings have been presented at national and international conferences, as invited and contributed talks. In some cases, the research themes are the center of conferences.

II. Report on RAPAC2019 Terms of Reference

1. ToR 1: Evaluation of the research of RAP

(1) Does the research of RAP meet international standards and is it regarded as world-leading?

The scientific research of RAP meets international standards and can be regarded to be world-leading in many areas as shown in the following examples, where they are not only excellent as scientific research but also expected to give high impacts to society. Further examples are described in Section III.

(a) Generation of coherent high harmonic radiation in the water-window region

There is strong competition worldwide to extend the wavelength of high-order harmonic radiation in the soft X-ray water-window region, where observation of biological specimen in living condition becomes possible. The Attosecond Science Research Team has developed a novel scheme to generate high-power ultrashort pulses in the mid-infrared region, with which they have succeeded in generating high power coherent radiation in the water-window. Furthermore, synthesis of phase-controlled ultrashort laser pulses of three different wavelengths has been realized to generate a single attosecond-pulse in the water-window and also to further extend high harmonics into the keV X-ray region. The Attosecond Team is definitely leading the world on this subject.

(b) Development of optical lattice super clocks and their applications

Under the concept “From curiosity-driven research to practical devices”, the Space-Time

Engineering Team is developing an optical lattice super clock toward achieving 10^{-19} uncertainty, which is at the forefront of research towards determining the new definition of SI second. At the same time, this team is developing transportable optical clocks which can be used to detect the earthquakes from the gravitational redshift of the clocks. They have tested this portable lattice clock under real world conditions for the first time in the world at the Tokyo SKYTREE.

(c) Visualization of secretory cargo transport within the Golgi apparatus

For observing living cells with high spatial and temporal resolutions, "Super-resolution Confocal Live Imaging Microscopy" (SCLIM) has been developed by the Live Cell Super-Resolution Imaging Research Team. This team has been investigating the intracellular membrane traffic with SCLIM, and discovered for the first time that cargo stays in a Golgi cisterna during maturation from *cis*-Golgi to *trans*-Golgi and further to the *trans*-Golgi network (TGN). With further development of the second generation of SCLIM, i.e., SCLIM-2M (extremely fast super-resolution imaging) and SCLIM-2K (user friendly model), this team is leading the world in live cell imaging and expected to make important contributions to biology.

(2) Have the research results of RAP contributed to society?

RAP has been developing many technologies which will make significant contributions to the society as evidenced by the following examples. Since their technology readiness level (TRL) is 6-7, they could be used in real world applications if proper systems are engineered for commercialization.

(a) Early detection of gastric cancer with limited endoscope images by AI-assistance

By working with the National Cancer Center East, the Image Processing Research Team has developed a new method to detect gastric cancer in early stage with limited number of endoscope images by assistance of AI with an accuracy of 86.2 % and a processing time rate of 4 ms/image. If this method is officially approved, it might replace the present gastric cancer screening by X-ray radiography and may become a *de fact* standard. Due to active development of various advanced methods of image processing, this team is becoming a research HUB of image processing with participation of many universities and research institutes in Japan, Asia, and Europe.

(b) Development of an accelerator-driven compact neutron source for non-destructive inspection of infrastructures and industrial structures

Accelerator-driven compact neutron source (RANS), being developed by the Neutron Beam Technology Team, has been shown to be very useful to detect fatigues of the infrastructures and also to inspect the crystalline structures of iron alloys used for automobiles. A transportable RANS is being developed with Japanese companies for *in-situ* inspection of bridges. This team is a forerunner of neutron applications to public and industrial uses.

(c) Fast, noncontact inspection of tunnels

For maintenance of many infrastructures such as tunnels and bridges in Japan, that were constructed almost 50 years ago, new methods are required for fast and accurate inspection of these infrastructures. By collaboration with other institutes under Cross-Ministerial Strategic Innovation Promotion Program (SIP), the Photonics Control Technology Team has developed a prototype of a new inspection system to detect various types of defects on and under surfaces of tunnels using optical technologies. Since the field tests have been implemented already, it will not take many years to make this system applicable to daily inspections.

(3) Do the up-to-date activities and strategies of RAP meet the aims of RIKEN's fourth mid- to long-term plan?

Followings are evaluation of the activities and strategies of RAP in terms of the six items listed as Major Initiatives in 4th Mid- to Long-term plan.

(a) Promoting the creation of new scientific fields and pioneering new research fields

RAP as a whole, especially the Extreme Photonics Research Group and Subwavelength Photonics Research Group, are attaching much importance for creating new scientific research fields in up-to-date activities, as described in II-1-(1).

(b) Strategic research and development to meet national and social needs.

- Data science for Society 5.0

  Image processing is one of the core technologies in data science. The Image Processing Research Team is working very actively on scientific-image processing by integrating advanced image processing techniques into science. This team is driving "Imaging Network" of RIKEN, where 7 campuses and 13 PIs are participating. Also, with this team as the core organization, "Image Processing Research HUB" composed of domestic and international researchers is being formed.

- Life Science for understanding human

  Bio-photonics is becoming a key technology in life science. The Biotechnological Optics Research Team has developed an engineered bioluminescence light source (named AkaBLI), which is 100-1,000 times brighter than the conventional D-luciferin/Fluc, and demonstrated its effectiveness by observing the striatum *in vivo* of freely moving marmoset. For medical applications, this team is developing bilirubin-inducible fluorescent protein (named UnaG) which can be used for screening neonatal jaundice in early stage.

- Research for SDGs and social needs

  For early detection of defects in social infrastructures, remote sensing methods have been developed in the Advanced Photonics Technology Development Group, such as rapid optical inspection of tunnels and non-destructive inspection of bridges with a transportable compact neutron source.

(c) Development, maintenance, shared use and applications of top-grade, world-class research infrastructure

Although RAP does not have large infrastructures, various activities in RAP are supporting the world-class research infrastructures such as J-PARC and Paul Scherrer Institute (PSI, Switzerland) with neutron focusing mirror, TAO telescope (U. Tokyo) with mirror arrays for 2D spectrograph, and GroundBIRD telescope with superconducting mm-wave detector.

2. ToR 2: Evaluation of the management of RAP

The RAP Director has presented the following SWOT analyses.

(1) Strengths

- The research level of the 4 research groups is high.
- Many interdisciplinary activities by researchers from a broad range of fields.
- Creation of the new "Subwavelength Photonics Research Group".
- Large amount of external funds.
- Smooth communication within RAP (PI meetings, RAP seminars and RAP symposia).

(2) Weakness

- Dependence on external and private funds (51%) -> Insecure employment
- Due to budget limitations, difficulties in securing HR/expanding teams for advancing research to the social implementation.
- No non-Japanese PIs in RAP (Lack of budget necessary to recruit PIs from overseas)

(3) Opportunities

- Research projects in (IT) Bio and light/quantum technologies covered by the government's Integrated Innovation Strategy.
- Engineering-oriented policies in RIKEN.

(4) Threats

- Reduction of Japan's total R&D expenditure
- Declining number of PhD students
- Difficulty in recruiting female researchers

The followings are the comments and advices by the AC

(a) We find that this SWOT analysis is very well argued and honest. In general we are very impressed by the Director's leadership and his ability to steer the vision of the Center to deliver first-class basic science coupled to emerging applications. Although some of the weaknesses and threats presented above are outside of local control, nevertheless mitigations might still be sought through carefully designed local actions.

(b) We find that smooth communication within RAP has been implemented very well, resulting in various collaborations within and across the groups in RAP. This smooth communication is also an important factor for pursuing the research in two different directions of scientific excellence and enhancing societal benefits.

(c) We think that RAP should make more efforts to publicize its research internationally to gain more visibility for their works. There will be room for increasing the number of publications in high impact journals, since there are many high-level research outcomes in RAP. In this context, w*riting in the style* required in these journals may be an issue. We would like to recommend to work with a specialist consultant with experience with high impact journals and their required style. We also note the press releases appear rather technically dense compared to what is the norm – it may help in promoting the work if a more "journalistic" style is adopted.

(d) We believe that it is important for RIKEN (and the Governmental institutes in general) to work more closely with universities for research and education, since RIKEN has excellent researchers and major facilities which could offer unique opportunities for research and education of graduate students. Since it is difficult to change the present situation at the researchers level, we would like to recommend RIKEN to take positive actions to form formal cooperation agreements to make joint appointments for university professors to work at RIKEN in a larger scale than the present numbers so that the research done at RIKEN by Ph.D. students is beneficial to both universities and RIKEN. This action will contribute to send positive messages to university students for pursuing Ph.D. degrees and engaging in advanced research.

(e) As analyzed by the Director, RAP is not highly diversified; the fraction of female researchers is small and there are no non-Japanese PIs. It may be possible to improve this situation however, since we met many active post-docs and graduate students, females and non-Japanese, during the poster session. We hope that the excellent RIKEN system such as JRA, IPA and SPDR are expanded to provide more opportunities for young researchers.

(f) One of the threats in RAP is that some senior PIs and staffs are approaching retirement ages, creating the concerns of program continuity. This needs immediate attention, especially in the Advanced Manufacturing Supporting Team.

3. ToR 3: Evaluation on the center's initiatives on the following items

(1) Center's achievements in collaborative activities, including those belonging to the Science and Technology Hub

RAP is very actively engaged in collaboration in Japan, with 4 national research institutes and 10 universities. RAP is taking major roles in many of these collaborations: for example, formation of the "Image Processing Research HUB" composed of domestic and international researchers, and EUV mask inspection as a part of national program on EUV lithography with *at wavelength* coherent scatterometry microscope by high-order harmonic EUV radiation.

RAP is also collaborating with several (>5) companies. In Topcon collaboration, which started in the first term and continued in the second term, a machine-learning model for automatic diagnostics of glaucoma from the ophthalmoscopy image has been developed. Now 1 senior scientist and 3 researchers of Topcon are working on this Program. During this research, 1 company researcher has obtained his Ph.D. degree and several more are working towards their Ph.D. degrees. Thus, RAP is contributing to higher education of the company employees.

Although RAP is very active in various activities in RIKEN, the AC thinks that it is important to carefully select the collaborative partners in order to keep proper balance between the collaborative activities and the individual R&Ds of the researchers. Successful outcome will result from the collaboration when the collaborative works are undertaken with the initiatives of the individual researchers.

(2) Initiatives on the internationalization of the center

RAP is engaged in collaboration with many universities and research institutes abroad. In terms of research initiatives, the THz Sensing and Imaging Research Team is taking an important role for microwave sensing in the GroundBIRD experiment located in Spain for measurement of polarization of cosmic microwave background (CMB) which is regarded to be the key parameter to support the inflation cosmology. Collaboration with Huazhong University of Science and Technology in China on the generation of intense attosecond pulses is a good example of RAP to be an international S&T Hub.

These collaborations are also important for young researchers to work as post-docs and Ph.D. students in RAP, leading to their academic careers.

We believe that it will be useful to increase interactions with the central EU countries where we can find talented young researchers and Ph.D. students with great intellectual potential, as it is not easy to recruit scientists in West Europe and North America mainly due to the wage difference between these countries and Japan.

4. ToR 4: Evaluation of PI

The PIs at RAP have strong sense of responsibility for fulfilling their duties in accordance with the mission of the center and performing high-level research of international standards. They are also capable of laboratory management and supporting early-carrier researchers, as described in a separate sheet. We were much impressed by the enthusiastic presentations by many researchers at the poster session, young and senior and foreign and Japanese, showing their active involvements in each team.

III. Evaluation and Advice on Research Activities

A. Extreme Photonics Research Group

This research group is composed of 4 research teams, each actively challenging on different and important fields of “Extreme Photonics”.

A-1 Attosecond Science Research Team

(1) Focus of research

- Generation of intense high-order harmonic radiation in water-window and X-ray regions.
- Generation and applications of atto-second pulses.

(2) Major achievements

- Generated high energy few cycle mid-IR laser pulses by developing a new Dual-Chirped OPA scheme. This MIR laser is the core technology for the water window X-ray generation, and also for many high-power laser applications in future.
- This team is further extending this approach to world-leading stage by developing multi-color field synthesizer with complete CEP stabilization for generation of isolated, high-power attosecond pulses in the X-ray region.
- The high-power MIR laser developed by the team was also applied to the laser wake-field electron acceleration and proven that the number of the accelerated electrons is 10 times higher than that with the 0.8 μm laser which is currently used worldwide.

(3) Evaluation

- This team has world-class attosecond beamlines and capabilities; high-intensity isolated attosecond pulses at 10 Hz, 100 Hz attosecond pulse trains, and 3 MHz high-harmonic radiation source. These are rather unique in the world, especially in the high-power activity with the only emerging rival at ELI ALP and in the MHz area with Pupeza’s intracavity scheme.
- Among various investigations on high-order harmonic generation worldwide, this team is world-leading for generating intense radiation in the water-window and even shorter X-ray regions.
- We were impressed by the posters and enthusiastic young scientists presenting them.

(4) Recommendation

- We very much like the vision of particle acceleration with MIR and synthesized fields. This is a direction actively pursued in the US/UK MURI project where they share strong common interests – perhaps ideal for future collaborations.
- We hope that the X-ray beam in the water-window region is generated with sufficient energy for single-shot measurement of transient phenomena in biological systems.
- Compared with the X-ray FELs, HHG has advantages in terms of pulse duration and synchronization. But we recommend to make careful analysis of the recent results from LCLS and their implications for future developments in attosecond science.

A-2 Ultrafast Spectroscopy Research Team

(1) Focus of research

- Development of new spectroscopic methods for fundamental studies of chemical reactions and material functions.

(2) Major achievements

- Developed deep UV stimulated Raman scattering which will have an important impact on biochemical understanding (Cerullo 320-520 nm in 2011, RIKEN now 240-290 nm). This team has chosen bacteriorhodopsin as an example for the method, where UV excites the protein backbone of the aromatic amino acids. A chromophore is pumped in vis and amino acid response is probed in UV, uncovering 30 ps time-constant decay in Raman features. This suggests events faster than chromophore isomerization and implies that they are playing an important role in the system, i.e. large dipole changes protein environment which may promote isomerization. This is a very interesting work.
- Studied ultrafast spectroscopy at interfaces using 2nd order nonlinear response due to broken symmetry at the interfaces. This team has developed an elegant and important method to measure the phase of the sum frequency signal together with the amplitude by heterodyning the signal. They have applied this method to photochemistry of phenol at the water surface and discovered that the excited state of phenol autoionizes within 100 fs, which is far shorter than the previously known autoionization time of 5 ns of this excited state in water.

(3) Evaluation

- The discovery of very fast decay at the water surface has revealed a unique feature of reaction dynamics at the interfaces. This work will lead to exciting developments toward buried interfaces.
- Although this group is not large in numbers, its scientific quality is very high.
- We were impressed by the enthusiastic young researchers presenting at the poster session.

(4) Recommendation

- We support the future plan of this team to visualize multi-dimensional reactive potential energy surface of complex molecules and interfaces by utilizing the novel methods this team has developed.
- The impact of this research will increase if the relation of this work to the biological systems like human bodies is shown.

A-3 Space-Time Engineering Research Team

(1) Focus of research

- Realization of optical lattice clocks with extreme precision of 10^{-19} uncertainty.
- Development of transportable clocks as practical devices for infrastructure of society.

(2) Major achievements

- Published the operational magic intensity for Sr for realizing the optical lattice clock of 10^{-19} precision.

- Developed transportable optical lattice clocks and tested at Tokyo SKYTREE under the real-world conditions by operating the clock for half a year at 450 m above the ground. This test has shown that α, violation of the gravitational redshift, is less than 2×10^{-5}.

(3) Evaluation

- Dr. Katori is a real pioneer of the optical lattice clocks, both in science and in real-world applications.
- Responding to the request of TV reporter, this team has measured the frequency difference of the two clocks with height difference of 1 m. (The Japanese TV reporters are really smart, and this team is very flexible!.)
- The SKYTREE experiment is very adventurous – not only challenging the technology with real world issues but highly effective in engaging the public in science.

(4) Recommendation

- In order to realize "Internet of Clocks", it is important to show a model system with performance and cost. Then people will start thinking seriously toward its realization.

A-4 Quantum Optoelectronics Research Team

(1) Focus of research

- Development of single photon sources at room temperature and near field electroluminescence devices using individual carbon nanotubes.

(2) Major achievements

- Lab and team rapidly built up in 3 years.
- Developed clean materials with well-defined chirality by spectroscopic determination for a single nanotube, presenting a special opportunity in reproducible and quantitative research.
- An impressive automated set-up to achieve this spectroscopic selectivity is already operational – this will overcome the lack of chirality control in the synthesis.

(3) Evaluation

- A good example of a PI of Japanese birth who was brought back to Japan having built his early career in USA. This is a strong model for future recruitment that optimizes the international connections in RAP.
- Beautiful experiments were implemented to demonstrate photon antibunching with a carbon nanotube and cavity-enhancement of single-photon emission, showing the possibility of a single-photon source at room temperature.

(4) Recommendation

- This team is proving an excellent area to be developed with a really talented young scientist in charge.
- This team started in RAP three years ago and grew smoothly by the help of relatively large starting budget from RIKEN. Taking this as a successful example, we recommend that RIKEN continues this system to support new and talented PIs.

B. Subwavelength Photonics Research Group

This new group was created with teams of complementary expertise. The group leader emphases on creating an open environment conductive to smooth communications and easy collaboration, which has significantly improved the research efficiency and quality.

B-1 Live Cell Super-Resolution Imaging Research Team

(1) Focus of research

- Development of cutting-edge super-resolution light microscopy for live cell imaging to understand molecular mechanism of life.

(2) Major achievements

- Developed state-of-the-art, second-generation super-resolution confocal live imaging microscopy (SCLIM2).
- This system revealed the dynamics of the Golgi and *trans*-Golgi network membranes in living cells, leading to the notion that organelles are not homogeneous entities but differentiate into different zones to perform different functions.

(3) Evaluation

- SCLIM2 has the best performance in the world for observing protein dynamics on organelle membrane in a living cell.

(4) Recommendation

- We recommend SCLIM2 to be used as a platform for bio-imaging research in RIKEN and other organizations to maximize the valuable outcomes.

B-2 Biotechnological Optics Research Team

(1) Focus of research

- Development of genetically encoded probes to better understand the spatio-temporal regulation of biological functions in a variety of biological systems.

(2) Major achievements

- Succeeded in developing AkaBLI, an all-engineered in vivo bioluminescence imaging system which has 1-2 orders of magnitude increased emission, using a luciferase mutant and a red-shifted luciferin.
- Succeeded in monitoring bioluminescence at a video rate from the striatum of naturally behaving marmoset.
- Activity of the entire dorsal surface of the mouse cerebellar cortex was visualized at a video rate with an AkaBLI-based calcium probe.
- For medical applications, the team has developed a novel fluorescent protein, UnaG, from vertebrate eel. It can be used as a diagnostic probe for neonatal jaundice.

(3) Evaluation

- The contribution of the team to life science through bioimaging is great. The team is certainly the top runner of bioimaging field.

(4) Recommendation

- We support the plan of this team to continue developing new fluorescent proteins which will become the useful tools for life sciences.

B-3 Image Processing Research Team

(1) Focus of research

- Development of novel image acquisition and processing techniques and their applications to scientific research.
- Forming infrastructure of image processing for research.

(2) Major achievements

- Working on new algorithms and computational methods for image processing.
- Developed an image processing platform (VCAT5) and an image processing cloud. These are used as an image processing platform for RIKEN and Japanese researchers.
- Developed a novel framework for automatic detection of early gastric cancer in endoscopic images using convolutional neural networks. It will assist endoscopists to find cancer.

(3) Evaluation

- Digital image processing for scientific applications and technology is currently a very active and fast-moving field internationally.
- Research achievements of this team are highly evaluated in the field of image processing.
- The team is also serving RIKEN as an image processing support center.

(4) Recommendation

- We expect this team to demonstrate originality by developing new algorithms and computational methods for image processing, especially for scientific research.

B-4 Innovative Photon Manipulation Research Team

(1) Focus of research

- This research team has been working on metamaterials (manmade subwavelength structures) for controlling optical properties of materials, including full color pixel using visible metamaterial absorber, application of metamaterial absorber for IR spectroscopy, and sub-nanometer resolution TERS (Tip-enhanced Raman scattering) in ambient

(2) Major achievements

- The team has made a few major achievements: including 1) metamaterial absorbers, 2) full-color pixel using visible metamaterial absorbers, 3) metamaterial absorber for IR spectroscopy, 4) nano-fluidic device with metamaterial absorbers, and 5) subnanometer resolution TERS in ambient with an astonishing resolution of 0.7 nm.

(3) Evaluation

- The team has a strong background both in fundamental research and applications. The research quality is high, as has been published in a number of high-impact journals.
- The research is original, with potential in applications.

(4) Recommendation

- The TERS resolution of 0.7 nm is astonishing. This could be a major breakthrough with more systematic evidence and analyses. The team should continue the work, obtain systematic results, carry out more thorough analyses, and submit the results to a major scientific journal.

B-5 Advanced Laser Processing Research Team

(1) Focus of research

- Development of advanced laser processing, with focus on flexibility, precision, and functional processing and fabrication of materials in 3D.
- Fabricating 3D highly functional photonic, electronic, chemical and biomedical microsystems.

(2) Major achievements

- This team has made major achievements in a number of areas. Particularly,

(a) Fabrication of functional biochips by femtosecond (fs) laser 3D glass micromachining to study cancer cell invasion and metastasis.

(b) Fabrication of 3D microfluidic SERS chips with ultrahigh sensitivity by fs-laser-processing for real-time sensing of trace substances.

(c) 3D printing of proteinaceous micro/nanostructures for biomedical applications.

(d) Synthesis of nanomaterials and formation of hierarchical micro/nanostructures.

(e) Fundamental research on using spatiotemporally tailored laser beams for super-resolution material processing and fabrication.

(3) Evaluation

- Top lab internationally in the areas of laser-based micro/nanofabrication in 3D.
- Major contributions and significant impacts on areas of biomedicine, photonics, electronics, and material science. This team is highly respected in international communities of laser applications.
- The quality of their work has been evidenced by a large number of high-quality papers published in top journals. The PI and the researchers have been invited for plenary, keynote, and invited presentations in major international conferences.
- The team is unique in RAP in a way that it has been supporting the strategic areas the center is pursuing in biomedicine and photonics, by working on using lasers to make 3D micro/nanoscale functional structures.
- The study on cancer cell migration in narrow channels is strategic and groundbreaking. It promises to support major breakthroughs in quantitative study of cancer cell activities, templates for regenerative medicine in which Japan is a leading country, as well as the templates for artificial cancers for molecule-targeted chemotherapy.

(4) Recommendation

- Chemotherapy is the important field.
- Make a strategic plan which could push the current discoveries/achievements to solutions and breakthroughs in biomedical areas.
- Collaborate more closely with biomedical researchers.
- Increase the number of postdoc researchers and PhD students.

C. Terahertz-wave Research Group

This group has been one of the major research centers in the world for developing unique technologies on generation, detection and applications of THz radiation.

C-1 Terahertz Sensing and Imaging Research Team

(1) Focus of research

- The purpose of this team is to explore the undeveloped fields of terahertz (THz) sensing, imaging and applications.
- The team especially focuses on activation of soft materials by intense THz wave, optical pump-THz-probe measurement of graphene, and spectroscopy of soft materials.
- Another work of this team is on superconductor microwave detector to measure the Cosmic Microwave Background (CMB) with international collaboration.

(2) Major achievements

- <u>Structural changes and controls of macromolecules by intense THz radiation</u>.

  Discovered that the intense THz irradiation activates actin filamentation remarkably. In the cytoplasm, actin is an integral component of the cytoskeleton, which plays crucial roles in a variety of cell functions, including cell migration, adhesion, polarity and shape change. Therefore, the manipulation technology of actin dynamics is expected in a variety of research fields. They showed that THz irradiation enhances actin filamentation without denaturing its molecular structures.
- Development of a rotating telescope and superconducting detectors for <u>CMB polarization observations</u>.

  CMB radiation is the oldest light we can observe in the deepest universe. The observations of its 2.7 K blackbody spectrum and its anisotropy was used to verify the Big Bang hypothesis as well as the "inflation" before the bang cosmological theories. One of the ways to prove the presence of the inflation stage is to look for the specific rotational polarization patterns of THz 2.7K blackbody radiation. The group was developing the rotational telescope system named "GroundBIRD". The telescope has been successfully mounted in Canarian Islands in Spain.

(3) Evaluation

- The results of the research on structural changes of macromolecules by THz radiation are extremely important because they show that THz radiation illumination can be a physical method for regulating protein dynamics. This research could indicate how to modify biological processes with THz radiation, which can be extremely useful in new drag production or even direct curing of certain diseases.

- The research on CMB detection is important from the basic science point of view. The human knowledge about the origin of the universe is still not complete and many high-level research institutes are competing to bring a new, complementary information concerning the Big Bang or other origin of the Universe theories. It is a very important task for the Japanese science to participate in this challenging research.

(4) Recommendation

- Concerning the THz radiation influence on the bio-matter we strongly advice to take a close collaboration with medical centers or biophysical institutions to check if and how practical THz radiation can be used – in disease detection or curing. Search for other resonance THz frequencies can also be of interest; for example, 1.6THz was reported as the frequency of curing cancerous DNA chains.
- Cosmology related research should be maintained as this is long term research and only now Japanese scientists will be able to obtain the data from the first observations. Surely RIKEN scientists' participation will be required in maintenance and improvement of the telescope. Continuation of the RIKEN effort in this domain is necessary to profit an important time, human and budget investment made up to now.

C-2 Tera-Photonics Research Team

(1) Focus of research

- The objective of this team is to realize widely tunable and high-power pulsed THz sources and investigate sensitive THz detection using nonlinear optical methods.

(2) Major achievements

- Achieved remarkable advances in the THz source by constructing <u>Backward THz-wave parametric oscillator.</u> With a slant-strip-type periodically-poled lithium niobate (PPLN), they have newly identified a backward phase-matching condition in THz-wave parametric oscillation (TPO) with continuous tunability. This mirrorless backward-TPO is promising for wider use because the size is palmtop dimension with robustness. This is the main scientific achievement which can be recognized by the highest ranked journals.
- Very important achievement for applications is a <u>gas-sensing system</u>, developed using the originally developed injection-seeded THz-wave parametric generator. The very important characteristic of the system is its rapidity allowing the real time screening of passengers in train station or airports.

(3) Evaluation

- Backward THz-wave parametric oscillator is very compact and robust. The generation scheme is very interesting and unique from the view of laser science and technology.
- The demonstration of highly sensitive detection and identification of gas molecules is a clear evidence that the <u>spectroscopic study in THz region comes to the real world</u>.
- This group has a big historical advantage on the THz generation and detection using nonlinear

coherent process. This gives them a very strong world-leading position.

(4) Recommendation

- Advised future direction of development are to: i) work on the ways of lowering costs of the laser pumping parametric oscillator and ii) work on broadening of the spectral range of operation of the backward THz wave parametric oscillator.
- Both actions will allow to have cost efficient and small-size THz systems for wide society use like for example – post, train, airports security screening, nondestructive quality control, health monitoring by exhausted air analysis.

C-3 Terahertz Quantum Device Research Team

(1) Focus of research

- The purpose of this team is to develop advanced terahertz emitting devices based on the inter sub-band optical transitions of semiconductor quantum cascade structures.
- They aim to design and fabricate novel quantum cascade superlattice (SL) structures for high-efficiency terahertz transitions and develop terahertz quantum cascade lasers (THz-QCLs) with a frequency range between 0.5-30 THz.
- Through these researches, they hope to construct what will become the base of the next-generation advanced terahertz imaging system.

(2) Major achievements

- Achieved <u>high-output-power operation of GaAs/AlGaAs THz-QCL</u> (350mW at 4K and 50mW at 80K at 3.45 THz) by introducing a QC design with reduced leakage current. They expect it is possible to obtain several-tens-mW operation at 5—10 THz at liquid-nitrogen temperature – which is crucial for practical applications.
- The second important activity is on <u>GaN-based QCL</u>. The group has conducted advanced simulations on the optical gain and designed a low-loss waveguide for GaN/AlGaN THz-QCL, where the optical gain is high enough for <u>laser action at room temperature</u>. It is expected that the experimental results of this type will be obtained in the Sendai –RIKEN group.

(3) Evaluation

- The THz-QCL is essential for future THz applications.
- <u>Material development</u> is not an easy work. Today young people do not like such type of "dirty work". According to Ryoichi Ito (Prof. Emeritus of Univ. of Tokyo), the success of semiconductor industry in Japan in 1980s was the result of high-quality crystal growth technique. We strongly support such a work in RAP.
- New design of GaAs/AlGaAs for the operation at liquid nitrogen temperature (77K) will be possible. The new waveguide design is quite reasonable. We hope that the room temperature oscillation of GaN THz-QCL will be achieved soon.

(4) Recommendation

- Extensive research efforts should be made on GaN-based QCL because this is a kind of “quality mark” of Japanese THz-related research. THz emission from GaN-based QCLs can not only confirm the scientific leadership of the RIKEN QCL group but also can lead to room-temperature operating high-power compact THz sources. Such sources are crucial for large-scale THz technology applications in security, nondestructive quality control, and health monitoring.

- A good strategy would be trying low-density-dislocation bulk GaN substrates that can be obtained in collaborative research with the Warsaw GaN group or commercially from AMONO or TOPGAN companies.

D. Advanced Photonics Technology Development Group

The Advanced Photonics Technology Development Group has an impressive portfolio of research projects which support the demonstration of practical devices and have significant societal impact at the same time. Each of the teams has a well-defined focus.

D-1 Photonics Control Technology Team

(1) Focus of research

- This team is developing new solid-state laser materials, including crystals and fibers, to extend laser operation into near infrared.
- The growth capabilities span from YAG to doped chalcogenides and ZBLAN fibers.
- Developing novel diagnostics tools for a number of applications, including lidar systems for tunnel inspections.

(2) Major achievements

- Demonstrated lasing in Cr:ZnSe by electrical tuning and extended its operation to a broad range spanning from 2100 to almost 3000 nm using a composite gain media.
- Demonstrated frequency domain interferometer for remote measurement of small cracks and spectroscopic detection of water in the concrete wall of tunnels.

(3) Evaluation

- The work of this team is of excellent quality. The applications demonstrated are impressive.
- Planned research activities are well thought out: development of continuous-wave, pulsed and ultrafast lasers for applications in particle physics, biomedical research and precise measurements.
- This team involves a good number of graduate students.

(4) Recommendation

- This team supports a large number of collaborative projects which require significant manpower. We recommend this team to be selective on engaging in collaborations.
- Increasing internal collaborations with other RAP groups will be beneficial for RAP.
- Combined active media of Cr:ZnSe + Cr:CdSe has been tested for broad bandwidth mid-IR laser. How about Cr:CdSe + Co:MgF2, which has broader spectral emission?.

D-2 Ultrahigh Precision Optics Technology Team

(1) Focus of research

- This team has specialized tools and capabilities to support the development of neutron optics and other sophisticated optical components.

(2) Major achievements

- Realized precision mirrors using metallic substrates for neutron focusing for RANS (RIKEN), J-PARC (BL-16, BL-06), PSI (Switzerland) and a few others.
- Realized special precision optics for 2D spectrograph of TAO telescope (U. Tokyo) and for slicing mirror for ultrafast imaging (U. Tokyo).

(3) Evaluation

- Collaborative research targets well selected to enhance the performance of this group.
- Developed many fabrication techniques to realize ultrahigh-precision components. Especially a method to remove mid-frequency figure errors to realize high reflectivity in neutron optics should be highly evaluated.
- Making important contribution to neutron science at RANS, J-PARC and others.
- A sub-nanometer resolution machine tool has been newly installed and tested in collaboration with a machine-tool company. Continuous effort to improve the fabrication capability is very important.

(4) Recommendation

- Collaboration partners should be well selected to enhance the activity of this team, especially in cutting-edge optics manufacturing.

D-3 Neutron Beam Technology Team

(1) Focus of research

- The objective of this team is to develop compact accelerator-driven neutron sources for practical uses such as non-destructive test of infrastructures and inspection of industrial materials.

(2) Major achievements

- Developed compact moderators for RANS to cover the neutron spectrum from MeV for imaging to 50 meV for diffraction analyses.
- Applied the RANS diffractometer to analyses of steels (austenite phase evaluation and texture evolution under pressure) and shown that RANS data are consistent with J-PARC data within 1 % accuracy. With these data, this team has demonstrated the applicability of RANS for development of new materials at industrial laboratories.
- Developed new methods for non-destructive inspection of bridges: reflection neutron imaging and chloride damage detection.
- Developed RANS-II as a smaller system of floor standing type for industrial applications.

(3) Evaluation

- Excellent work with clear goal of reducing the size of the neutron source.

(4) Recommendation

- This is unique work with high societal impact that merits support.

- Support development of RANS-III, a compact, transportable neutron source.
- Securing the financial support is critical to pursue these endeavors. Encouraging to know that there is already interest from a foreign company for commercializing this neutron source, although we hope this is commercialized in Japan.

D-4 Advanced Manufacturing Support Team

(1) Focus of research

- This team is playing a key role in realizing many apparatus and parts for RAP and throughout RIKEN.
- The manufacturing support includes design, mechanical machining, wire EDM, laser machining, brazing/welding and metrology. The experts in electronics and glassware have retired.

(2) Major achievements

- This team has manufactured a variety of components and systems with high precision.
- About 600 requests are processed each year, with ~40% for RAP and ~60% for other groups in RIKEN (24% CEMS, 20% CPR, 10% CBS) in FY2018.
- With newly introduced 3D printers, various complicated structures are now fabricated for biology and medicine.
- Ultrahigh precision machining of organic BNA crystal, which is difficult to fabricate, has been realized for efficient generation of THz radiation.

(3) Evaluation

- The performance of the group is excellent.
- Significant amount of research activities of whole RIKEN is strongly depending on the efforts of this group.

(4) Recommendation

- The critical issue on this team is the discontinuity of the skilled technologies due to retirement of all permanent staffs within 7 years. In order to keep manufacturing support in RIKEN, it is important to promote the present young (under 40) fixed term staffs to more stable positions and also hire more technical staffs to this team.
- Since the activities of this team are extended across RIKEN, the labor cost and equipment of this team have better be financially supported by RIKEN. Timely installations of cutting-edge machine tools are quite important to maintain and improve the performance of this group.
- In order to increase motivation of the technical staff, their standpoints had better be clarified by preparing some criteria such as to include their names in acknowledgement and/or author list in publication when their contributions are very significant.
- It will be reasonable to increase the user fee (1,700 Y/hour), if this is necessary to continue the activities of this team.

RAPAC2019 Program

Sept. 4, Wed., day 1st @Hotel Metropolitan Tokyo, Ikebukuro			
16:30	- 16:50	20	Opening remarks (Center Director) , AC members & RAP PIs' introduction
16:50	- 17:20	30	RIKEN's introduction and Terms of Reference from President (Dr. Koyasu, Executive Director)
17:20	- 17:25	5	RAPAC Terms of Reference, Response to RAPAC2016 recommendations
17:25	- 17:30	5	RAPAC Program/Schedule announcement
17:30	- 17:50	20	AC member discussion about role-sharing
17:50	- 19:20	90	Buffet dinner (RAPAC members, Executive Director, RAP PIs)

Sept. 5, Thu., day 2nd @ RIKEN Wako campus			
9:00	- 9:40	40	About RAP (Dr. Midorikawa)
9:40	- 9:50	10	A Extreme Photonics Research Group (Dr. Midorikawa)
9:50	- 10:20	30	A-2 Ultrafast Spectroscopy (Dr. Tahara)
10:20	- 10:50	30	A-1 Attosecond Science (Dr. Midorikawa)
10:50	- 11:10	20	Coffee break
11:10	- 11:40	30	A-3 Space-Time Engineering (Dr. Katori)
11:40	- 12:10	30	A-4 Quantum Optoelectronics (Dr. Kato)
12:10	- 12:30	20	Brief Discussion for Extreme Photonics Group
12:30	- 13:20	50	Closed lunch (AC members only)
13:20	- 13:30	10	B Subwavelength Photonics Research Group (Dr. Nakano)
13:30	- 14:00	30	B-1 Live Cell Super-Resolution Imaging (Dr. Nakano)
14:00	- 14:30	30	B-2 Biotechnological Optics (Dr. Miyawaki)
14:30	- 15:00	30	B-3 Image Processing (Dr. Yokota)
15:00	- 15:20	20	Coffee break
15:20	- 15:50	30	B-4 Innovative Photon Manipulation (Dr. Tanaka)
15:50	- 16:20	30	B-5 Advanced Laser Processing (Dr. Sugioka)
16:20	- 16:40	20	Brief discussion for Subwavelength Photonics Group
16:40	- 18:10	90	Poster session
18:10	- 18:50	40	Move to Hotel Metropolitan, Ikebukuro
18:50	- 20:50	120	Working dinner (AC members, and Dr. Midorikawa, Dr. Nakano, Dr. Otani and Dr. Wada)

Sept. 6, Fri., day 3rd @ RIKEN Wako campus				
9:00	-	9:10	10	C Terahertz-wave Research Group (Dr. Otani)
9:10	-	9:40	30	C-1 Terahertz Sensing and Imaging (Dr. Otani)
9:40	-	10:10	30	C-2 Tera-Photonics (Dr. Minamide)
10:10	-	10:40	30	C-3 Terahertz Quantum Device (Dr. Hirayama)
10:40	-	11:00	20	Brief discussion for Terahertz-wave Group
11:00	-	11:20	20	Coffee break
11:20	-	11:30	10	D Advanced Photonics Technology Development Group (Dr. Wada)
11:30	-	12:00	30	D-1 Photonics Control Technology (Dr. Wada)
12:00	-	12:30	30	D-3 Neutron Beam Technology (Dr. Otake)
12:30	-	13:00	30	D-2&4 Ultrahigh Precision Optics Technology & Advanced Manufacturing Support (Dr. Yamagata)
13:00	-	13:20	20	Brief discussion for Advanced Photonics Tech. Group
13:20	-	14:50	90	Closed Lunch (AC members only)
14:50	-	15:50	60	Discussion (AC members and RAP PIs)
15:50	-	16:20	30	Closed Discussion (AC members, Dr. Midorikawa, Dr. Nakano, Dr. Otani, Dr. Wada)
16:20	-	17:50	90	Closed discussion (AC members, only)
17:50	-	18:20	30	General briefing (AC members, Dr. Koyasu and Dr. Kotera, Executive Directors, and RAP PIs)
18:20	-	18:50	30	Closing remarks
18:50	-	19:00	10	Move to Hirosawa Club
19:00	-	20:30	90	Opinion exchange with dinner (AC members, RAP PIs)