JAEA-Evaluation
2012-002

平成 24 年度　研究開発・評価報告書
評価課題「先端原子力科学研究」（中間評価）

Assessment Report on Research and Development Activities
Activity: “Advanced Science Research” (Interim Report)

先端基礎研究センター
Advanced Science Research Center

November 2012
Japan Atomic Energy Agency
日本原子力研究開発機構

JAEA-Evaluation

本レポートは独立行政法人日本原子力研究開発機構が不定期に発行する成果報告書です。
本レポートの入手並びに著作権利用に関するお問い合わせは、下記あてにお問い合わせ下さい。
なお、本レポートの全文は日本原子力研究開発機構ホームページ（http://www.jaea.go.jp）
より発信されています。

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平成 24 年度　研究開発・評価報告書
評価課題「先端原子力科学研究」（中間評価）

日本原子力研究開発機構
先端基礎研究センター

（2012 年 9 月 14 日　受理）

独立行政法人日本原子力研究開発機構（以下、「原子力機構」という）は、「国の研究開発評価に関する大綱的指針」（平成 17 年 3 月 29 日内閣総理大臣決定）及びこの大綱的指針を受けて作成された「文部科学省における研究及び開発に関する評価指針」（平成 17 年 9 月 26 日文部科学大臣決定）、並びに原子力機構の「研究開発課題評価実施規程」（平成 17 年 10 月 1 日制定、平成 18 年 1 月 1 日改正）等に基づき、平成 24 年 4 月 20 日に先端基礎研究センターの先端原子力科学研究に関する第二期中期計画期間中の実績に対する中間評価を先端基礎研究・評価委員会に諮問した。（26 ページ「研究開発課題の中間評価について（諮問）」参照）

これを受けて、先端基礎研究・評価委員会は、委員会において定められた評価方法に従い、原子力機構から提出された先端基礎研究センターの運営及び先端原子力科学研究の実施に関する説明資料の検討及び先端基礎研究センター長並びに研究グループリーダーによる口頭発表と質疑応答を実施した。

本報告書は、先端基礎研究・評価委員会より提出された中間評価の内容をまとめるとともに、7 ページ以降に「評価結果（答申書）」を添付したものである。

本報告書は、研究開発・評価委員会（先端基礎研究・評価委員会）が「国の研究開発評価に関する大綱的指針」等に基づき実施した外部評価の結果を取りまとめたものである。

日本原子力研究開発機構 先端基礎研究センター（事務局）
原子力科学研究所（駐在）：〒319-1195 茨城県那珂郡東海村白方白根 2-4

JAEA-Evaluation 2012-002

Assessment Report on Research and Development Activities Activity: "Advanced Science Research" (Interim Report)

Advanced Science Research Center

Japan Atomic Energy Agency
Tokai-mura, Naka-gun, Ibaraki-ken

（Received September 14, 2012）

Japan Atomic Energy Agency (hereinafter referred to as "JAEA") consulted an assessment committee, "Evaluation Committee of Research Activities for Advanced Science Research" (hereinafter referred to as "Committee") for interim assessment of "Advanced Science Research," in accordance with "General Guideline for the Evaluation of Government Research and Development (R&D) Activities" by Cabinet Office, Government of Japan, "Guideline for Evaluation of R&D in Ministry of Education, Culture, Sports, Science and Technology" and "Regulation on Conduct for Evaluation of R&D Activities" by JAEA.

In response to the JAEA's request, the Committee assessed the research programs and activities of the Advanced Science Research Center (hereinafter referred to as "ASRC") for the period of two years from April 2010. The Committee evaluated the management and the research programs of the ASRC based on the explanatory documents prepared by the ASRC and the oral presentations with questions-and-answers by the Director and the research group leaders.

This report summarizes the result of the assessment by the Committee with the Committee report attached from page 7.

This evaluation report presents the result of third-party evaluation conducted based on "General Guideline for Evaluation of Government R&D Activities" by Japanese Cabinet Office, etc.

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１．概要

独立行政法人日本原子力研究開発機構（以下、「原子力機構」という）は、「国の研究開発評価に関する大綱的指針」（平成 17 年 3 月 29 日内閣総理大臣決定）及びこの大綱的指針を受けて作成された「文部科学省における研究及び開発に関する評価指針」（平成 17 年 9 月 26 日文部科学大臣決定）、並びに原子力機構の「研究開発課題評価実施規程」（平成 17 年 10 月 1 日制定、平成 18 年 1 月 1 日改訂）等に基づき、先端基礎研究センター（以下、「センター」という）の先端原子力科学研究に関する中間評価を先端基礎研究・評価委員会（以下、「委員会」という）に諮問した。

これを受けて、委員会は、委員会において定められた評価方法に従い、原子力機構から提出されたセンターの運営及び先端原子力科学研究の実施に関する説明資料の検討及び先端基礎研究センター長並びに研究グループリーダーによる口頭発表と質疑応答を実施した。

その結果、諮問された第二期中期計画期間中におけるセンターの運営、及び事前評価における委員会からの提言に対する対応、ならびに各グループの研究活動について全て『適切』であると評価された。特に、事前評価における委員会の意見を真摯に受け止め、プロジェクトに反映している点は高く認められ、また、以下の点が評価された。

- 革新的な研究を通して科学のフロンティアを開拓するという原子力機構とセンター共通の任務を達成すべく邁進し、全てのプロジェクトが良好に進んでいる。
- センターは世界レベルの研究拠点の一つであり、その国際的認知度が、原子力機構に対する高い評価にも大きく貢献している。
- 黎明研究制度は改善され、主に国際研究協力を推進するための制度として新しい目標に向けてうまく機能している。

２．先端基礎研究・評価委員会の構成

本委員会は平成 18 年 1 月 1 日に設置され、平成 22 年 4 月 1 日及び平成 23 年 11 月 1 日の委員改選により、以下の 10 名の委員により構成されている。

委員長	Takeshi Egami	UT-ORNL Distinguished Scientist/Professor, Department of Materials Science and Engineering, the University of Tennessee, USA
委員	阿部　勝憲	八戸工業大学工学部　教授／エネルギー環境システム研究所長
	Albert Fert	Scientific Director at the CNRS/Thales Joint Physics Unit, Professor of Physics, University of Paris-Sud, Orsay, France　（Nobel Prize Winner in Physics 2007）
	藤田　大介	物質・材料研究機構　先端的共通技術部門長
	Peter S. O. Fulde	Director and Scientific Member at Max Planck Institute for the Physics of Complex Systems, Germany, Director of Asia-Pacific Center for Theoretical Physics
	家　泰弘	東京大学　物性研究所長
	小安　重夫	慶応義塾大学　医学部　教授
	玉尾　皓平	理化学研究所　基幹研究所長
	土岐　博	大阪大学　核物理研究センター　名誉教授
	Norbert G. Trautmann	Honorary Professor at the University of Mainz, Germany

（アルファベット順）

３．審議経過

（１）第 5 回委員会開催（事前評価）：平成 22 年 4 月 22 日～23 日
- 先端基礎研究センターの運営方針に関する報告と意見交換
- 各研究グループの研究計画についての報告と意見交換
- 現場訪問
- 評価内容の検討、報告書作成に関する審議
- 事前評価結果の答申（平成 22 年 6 月 7 日）

（２）第 6 回委員会開催（中間評価）：平成 24 年 4 月 23 日～24 日
- 先端基礎研究センターの運営及び事前評価における提言に対する対応に関する報告と意見交換
- 各研究グループの研究成果についての報告と意見交換
- 評価内容の検討、報告書作成に関する審議

（３）中間評価結果の取りまとめ：平成 24 年 4 月下旬～6 月

（４）答申：平成 24 年 7 月 4 日

４．評価方法

以下の評価作業手順及び評価項目に従い、先端基礎研究センターより提出された先端基礎研究センターの運営及び先端原子力科学研究の実施に関する説明資料を検討するとともに、先端基礎研究センター長及び各研究グループリーダーによる口頭発表と質疑応答・意見交換を行った。

（１）評価作業手順

① 評価方法、評価基準についての議論
② 先端基礎研究センターの運営及び事前評価における提言に対する対応についての先端基礎研究センター長による口頭発表及び質疑応答
③ 各研究グループの事前評価への対応、ならびに研究進捗状況について各研究グループリーダーによる口頭発表及び質疑応答
④ 提出資料及び口頭発表に基づき、評価意見を整理
⑤ 答申書の取り纏め方針の検討

（２）評価項目

１）先端基礎研究センター
先端基礎研究センターの運営及び事前評価における提言に対する対応について評価

２）先端原子力科学研究の実施（11 研究グループ）
以下の 11 研究グループの事前評価への対応、ならびに研究進捗状況について評価

・量子物性理論研究グループ
（新機能材料の創出に関する研究）
・分子スピントロニクス研究グループ
（分子・スピントロニクス材料・デバイスにおけるスピン伝導機構の解明）
・力学的物質・スピン制御研究グループ
（スピントロニクス、スピンメカトロニクス及び NMR 手法によるスピン流制御及び材料設計）
・重原子核反応フロンティア研究グループ
（重原子核の殻構造の解明）
・超重元素研究グループ
（超重元素の価電子状態と超重核の殻構造の解明）
・アクチノイド物質開発研究グループ
（アクチノイド化合物の物質開発）
・重元素系固体物理研究グループ
（重元素化合物のための新たな固体物理コンセプトの開拓）
・ハドロン物理研究グループ
（ストレンジネスを含む原子核とハドロンの構造解明）

・バイオアクチノイド化学研究グループ
（バイオ反応場におけるアクチノイドのナノ粒子化機構の解明）
・放射場生体分子科学研究グループ
（放射場における生体分子の変異と生体応答の解明）
・スピン偏極陽電子ビーム研究グループ
（スピン偏極陽電子ビーム技術の開発とスピントロニクス研究への応用）

（３）評価の基準
１）先端基礎研究センター
先端基礎研究センターが示した研究方針及び戦略並びに事前評価における提言に対する対応の適否を判断し、評価意見をまとめる。
２）先端原子力科学研究の計画（11 研究グループ）
各グループの事前評価への対応、ならびに研究進捗状況について適否を判断し、科学的視点により、長所及び短所を考慮した具体的な評価意見をまとめる。

中間評価スケジュール

場所：いばらき量子ビーム研究センター　多目的ホール

第 1 日目　平成 24 年 4 月 23 日（月）

10：00～10：15　　センター長挨拶
委員長、委員の紹介
諮問事項の説明

先端基礎研究センターの運営方針について

10：15～11：00　　先端基礎研究センター運営及び事前評価における提言に対する対応について報告

各研究グループの事前評価への対応、ならびに研究進捗状況について
（発表 15 分＋質疑 10 分）

11：00～11：25　　量子物性理論研究グループ
11：30～11：55　　分子スピントロニクス研究グループ
12：50～13：15　　力学的物質・スピン制御研究グループ
13：20～13：45　　重原子核反応フロンティア研究グループ
13：50～14：15　　超重元素研究グループ
14：20～14：45　　アクチノイド物質開発研究グループ
14：50～15：15　　重元素系固体物理研究グループ
15：40～16：05　　ハドロン物理研究グループ
16：10～16：35　　バイオアクチノイド化学研究グループ
16：40～17：05　　放射場生体分子科学研究グループ
17：10～17：35　　スピン偏極陽電子ビーム研究グループ

第 2 日目　平成 24 年 4 月 24 日（火）

議論のまとめ

9：30～11：30　　議論のまとめ、報告書の作成について

評価委員会の総括

11：30～12：00　　委員会及びアドバイザーからのコメント

５．評価結果（答申書）

平成 24 年 7 月 4 日

独立行政法人 日本原子力研究開発機構
理事長　鈴木　篤之　殿

研究開発・評価委員会
（先端基礎研究・評価委員会）
委員長　Takeshi Egami

研究開発課題の評価結果について（答申）

当委員会に諮問〔２４原機（先）０１１〕のあった下記の研究開発課題の中間評価について、その評価結果を別紙のとおり答申します。

記

研究開発課題「先端原子力科学研究」

以上

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（別紙）

Evaluation Report

Evaluation Committee of Advanced Science Research Center
Mid-term Review

Date of the Meeting: April 23rd – 24th, 2012

Submittion of the Report : July 4th, 2012

Members :

Name	Title / Institute
Katsunori Abe	Professor, Laboratory for Energy, Environment and Systems, Hachinohe Institute of Technology,
Takeshi Egami [Chairperson]	UT-ORNL Distinguished Scientist/Professor, Department of Materials Science and Engineering, the University of Tennessee, USA
Albert Fert	Nobel Prize Winner in Physics 2007, Scientific Director at the CNRS/Thales Joint Physics Unit, Professor of Physics, University of Paris-Sud, Orsay, France
Daisuke Fujita	Director, Advanced Key Technologies Division, National Institute for Materials Science
Peter S. O. Fulde	Director and Scientific Member at Max Planck Institute for the Physics of Complex Systems, Germany, Director of Asia-Pacific Center for Theoretical Physics.
Yasuhiro Iye	Director, The Institute for Solid State Physics of the University of Tokyo
Shigeo Koyasu	Professor, School of Medicine, Keio University
Kohei Tamao	Director, Advanced Science Institute, RIKEN
Hiroshi Toki	Professor Emeritus, Research Center for Nuclear Physics, Osaka University
Norbert G. Trautmann	Honorary Professor at the University of Mainz, Germany

1. The research policy and the response to the pre-review of the ASRC

Evaluation Result : **appropriate**

Comments and suggestions
The evaluation committee is very much pleased by the impressive progress made by the ASRC in spite of the major setback suffered because of the earthquake. In particular we deeply appreciate the response by the ASRC to the pre-evaluation suggestions made earlier by this committee. The ASRC took our suggestions seriously and made significant modifications to the projects, including total change in research direction in some cases. Partly because of these changes, all of the ASRC projects are now in an excellent state and jointly fulfilling the goals of the ASRC to extend the scientific frontier in basic science through innovative research consistent with the mission of JAEA. The ASRC is now one of the world-class research centers, and is contributing significantly to the prestige of JAEA through its international visibility. It is important for JAEA to strongly support the ASRC with sufficient budget consistent with its significance to the mission of JAEA in spite of financial difficulties the Japanese government is facing.
The purpose of the REIMEI program has been modified and is now used primarily to promote international collaborations. It is working well for the new goal, given the fiscal limitations.

2. The research subject No.1, 'Study on New Functional Materials' (Research Group for Condensed Matter Theory)

Evaluation Result : **appropriate**

Comments and suggestions
This group has achieved important advances in the field of spintronics, such as the elegant theoretical elucidation of the spin Seebeck effect and magnetomechanical effect. Collaboration with experimental groups, Saitoh group in particular, was crucial to the success. In addition they work on various topics of current interest. They are a leading group in the ASRC and are making significant contribution to the synergy within the ASRC. Their output is excellent, and the group is internationally highly visible.

3. The research subject No.2, 'Study for Spin-Transport Mechanisms in Molecular Spintronics Materials and Devices' (Research Group for Molecular Spintronics)

Evaluation Result : **appropriate**

Comments and suggestions

This group succeeded in producing high-quality graphene sheets through UHV-CVD and obtained very unique and interesting experimental results. Even though the field of graphene research is quite competitive, they were able to distinguish themselves through original contributions. Their effort should be highly commended. However, they should collaborate more with other research groups, in Japan or abroad, for instance in nano-scale characterization and in theory, in order to grow into a true leader in the field.

4. The research subject No.3, 'Spin manipulation and material design by combining Spintronics, mechanical engineering and NMR method'
（Research Group for Mechanical Control of Materials and Spin Systems）

Evaluation Result : **appropriate**

Comments and suggestions
This group is one of the most successful experimental groups in the ASRC. They demonstrated the spinmechatronic effect by utilizing the unique technical capability of the JAEA group and the expertise in spintronics by the Saitoh group in Sendai combined with theory by the Mori/Maekawa group. The experiment with liquid Hg droplets impacting Pt thin film to demonstrate the inverse spin-Hall effect is highly innovative. The energetic and effective leadership by Saitoh is highly appreciated.

5. The research subject No.4, 'Research in exotic shell evolution of heavy nuclei'
（Research Group for Reactions Involving Heavy Nuclei）

Evaluation Result : **appropriate**

Comments and suggestions
Following the suggestion by the committee, this group changed the direction of the research to a more adventurous one. The change was highly successful, and they discovered unexpected asymmetry in nuclear reactions of Hg, a major achievement with huge impact to the field. Development of a new field of research is expected from this discovery with this group taking the leadership. This is a textbook case of the way the ASRC should operate.

6. The research subject No.5, 'Study of Valence Electronic Structure and Nuclear Shell Structure of Superheavy Elements' （Research Group for Superheavy Elements）

Evaluation Result : **appropriate**

Comments and suggestions

This group also followed the suggestion by the committee and totally revamped the research program, now focusing on truly innovative projects. They opened up a new field of research on metal-organic compounds of super-heavy elements and are making unique and interesting observations on the atomic, chemical, and nuclear properties of these compounds. The group is led by Dr. Schädel and has a wide network of national and international collaboration. This group represents an excellent case of internationalization of the ASRC.

7. The research subject No.6, 'Preparation of New Actinide Compounds with Exotic Behavior' (Research Group for Actinide Materials Science)

Evaluation Result : **appropriate**

Comments and suggestions
This is another case of excellent research and very successful international collaboration. Prof. Fisk, the group leader, constantly communicates with the group via internet and is very effectively running the group. This group is unique in the capability of producing high-quality 5*f* compounds, which are in high demand. They have already produced a number of outstanding results, in part through the wide network of collaboration, and have a good chance of producing major discoveries. This group represents another textbook case of the way research should be done at the ASRC.

8. The research subject No.7, 'Foundation of New Concept in Condensed Matter Physics for Heavy Element Systems'
(Research Group for Condensed Matter Physics of Heavy Element Systems)

Evaluation Result : **appropriate**

Comments and suggestions
This group studies the magnetism and superconductivity of 5*f* compounds, making use of the unique features of the J-PARC facilities and focusing on extreme conditions. Even though the J-PARC facilities suffered a major setback by the earthquake, this group is making excellent progress and producing important results. This group has an excellent potential to deliver highly impactful research results. They collaborate effectively with the Fisk group.

9. The research subject No. 8, 'Research on the Structure of Nuclei and Hadrons Containing Strangeness' (Research Group for Hadron Physics)

Evaluation Result : **appropriate**

Comments and suggestions
This group carries out pioneering studies of hypernuclei with strangeness. The group was expanded, as recommended in the pre-review. The use of the J-PARC facility is essential to this research. A unique use of the J-PARC facility and scientific novelty of the subject make this group ideal for the ASRC. In spite of the major setback caused by the earthquake, they are making excellent progress.

10. The research subject No. 9, 'Study of Formation of Actinides Nano-Particles in Biological Reaction Environments' (Research Group for Bioactinide)

Evaluation Result : **appropriate**

Comments and suggestions
This group was criticized by us two years ago for not being sufficiently innovative. However, they dramatically and very successfully responded to the Fukushima disaster by demonstrating the contamination in biological systems. This success greatly contributed to raising the visibility of the ASRC and JAEA. As a consequence, a majority of their activity is now supported by outside funding. This is another way of responding to our recommendation, and their success should be commended.

11. The research subject No. 10, 'Biophysical Study for Molecular and Cellular Responses to Radiation' (Research Group for Radiation and Biomolecular Science)

Evaluation Result : **appropriate**

Comments and suggestions
This group also changed the direction of research by changing the subject of research from DNA to living cells, cancer cells in particular, in good response to our recommendation in the pre-review. Their research is now more relevant and exciting. They have already obtained unexpected results on irradiation damage on cells, which could lead to valuable findings on the effects of irradiation, particularly at low doses, which is not well understood but is obviously very important.

12. The research subject No.11, 'Development of Spin-Polarized Positron Beam and its Applications to Spintronics Study' (Research Group for Spin-Polarized Positron Beam)

Evaluation Result : **appropriate**

Comments and suggestions

This is an ambitious and exciting pioneering project which uses the TIARA. They have already produced 40% spin-polarized positron beam and succeeded in studying the spin-polarized electronic structure and directly measuring the spin-Hall effect. They have an excellent prospect of opening up a new field of research and attaining a new level of understanding in magnetic phenomena in thin films or near surface using spin-polarized positrons. This project is also ideally suited to the ASRC.

≪和訳≫

評価結果

先端基礎研究・評価委員会
中間評価

開催日：平成 24 年 4 月 23 日、24 日

報告書提出日：平成 24 年 7 月 4 日

委員：

氏名	所属・職位
阿部　勝憲	八戸工業大学工学部機械情報技術学科　教授 エネルギー環境システム研究所長
Takeshi Egami [委員長]	UT-ORNL Distinguished Scientist/Professor, Department of Materials Science and Engineering, the University of Tennessee, USA
Albert Fert	Nobel Prize Winner in Physics 2007, Scientific Director at the CNRS/Thales Joint Physics Unit, Professor of Physics, University of Paris-Sud, Orsay, France
藤田　大介	物質・材料研究機構　先端的共通技術部門　部門長
Peter S. O. Fulde	Director and Scientific Member at Max Planck Institute for the Physics of Complex Systems, Germany, Director of Asia-Pacific Center for Theoretical Physics.
家　泰弘	東京大学　物性研究所長
小安　重夫	慶応義塾大学　医学部　教授
玉尾　晧平	理化学研究所　基幹研究所長
土岐　博	大阪大学　核物理研究センター　名誉教授
Norbert G. Trautmann	Honorary Professor at the University of Mainz, Germany

※本和文は先端基礎研究センターにて和訳を行ったものであり、先端基礎研究・評価委員会より提出された英文を正とする。

1. センターの方針及び事前評価結果に対する対応

評価結果：適切

意見・提案
震災による大打撃を受けながらも、ASRC が目覚ましい発展を遂げていることを、評価委員一同大変うれしく思う。特に、事前評価における委員会の提言への対応は高く評価したい。ASRC は我々の意見を真摯に受け止めてプロジェクトに反映した。中には研究の方向性を大幅修正したグループもある。その効果もあり、ASRC の全てのプロジェクトの進捗は良好で、革新的な研究を通して科学のフロンティアを開拓するという JAEA と ASRC 共通の任務を達成すべく邁進している。ASRC は世界レベルの研究センターのひとつであり、その国際的認知度は JAEA に対する高い評価にも大きく貢献している。日本政府が直面している難しい経済状況においても、JAEA はその貢献に相応しい十分な予算を ASRC のために確保することが重要である。
黎明研究制度の目的は改善され、現在は主に国際研究協力を推進するための制度となっている。予算的な制約があるものの、新しい目標に向けてうまく機能していると言える。

2. 研究課題 No.1：新機能材料の創出に関する研究 （量子物性理論研究 Gr.）

評価結果：適切

意見・提案
このグループはスピントロニクスの分野において、スピンゼーベック効果や磁気メカトロニクスの理論的解明などで重要な進展を遂げている。この成功は、実験グループ、特に齋藤グループとの研究協力が不可欠であった。さらにこのグループは、目下関心を集めている様々なトピックにも取り組んでいる。彼らは ASRC をリードするグループであるとともに、ASRC 内での研究協力の進展にも大きく貢献している。彼らの発信する成果は秀逸で、グループの国際的知名度も高い。

3. 研究課題 No.2：分子スピントロニクス材料・デバイスにおけるスピン伝導機構の解明 （分子スピントロニクス研究 Gr.）

評価結果：適切

意見・提案
このグループは UHV-CVD 法を用いて高品質のグラフェンを作製することに成功し、非常に興味深い独自の実験結果を得た。グラフェン研究の分野は競争が激しいが、彼らは創造的な成果によって確固たる地位を築いている。その努力は大いに評価されるべきである。しかし彼らがこの研究分野の真のリーダーへと成長するためには、ナノスケール解析や理論に関する国内外の研究グループともっと連携を深めるべきである。

4. 研究課題 No.3：スピントロニクス、メカトロニクス及び NMR 手法によるスピン流制御及び材料設計
（力学的物質・スピン制御研究 Gr.）

評価結果：適切

意見・提案
このグループは ASRC において最も成功している実験グループである。JAEA グループのもつ独自の技術的能力に加え、仙台（東北大）の齋藤研究室がもつスピントロニクスの専門知識と森／前川グループの理論を融合させることによって、スピンメカトロニクスを実証した。白金薄膜への液体水銀の吹き付け手法を用いて逆スピンホール効果を実証する実験は非常に革新的である。積極的かつ効果的な齋藤氏のリーダーシップは高く評価できる。

5. 研究課題 No.4：重原子核の殻構造の解明 （重原子核反応フロンティア研究 Gr.）

評価結果：適切

意見・提案
このグループは事前評価での提言を受けて、より挑戦的な取り組みへと研究を方向転換した。この修正が功を奏し、彼らは Hg の核分裂において従来の理論からは予期せぬ非対称分裂を発見した。この重要な成果は関連分野に大きな反響をもたらした。この発見により、新たな研究分野が、このグループの牽引によって開拓されることを期待する。これは ASRC の運営において模範的なケースである。

6. 研究課題 No.5：超重元素の価電子状態と超重核の殻構造の解明 （超重元素研究 Gr.）

評価結果：適切

意見・提案
このグループも事前評価の提言に基づき、研究計画の抜本的改革を行い、現在は非常に革新的なプロジェクトに焦点を当てている。彼らは超重元素の有機金属化合物に関する新たな研究を開拓するとともに、それら化合物の原子・化学・原子核に関して独自の興味深い特性評価を行っている。Schädel 博士をリーダーとし、国内外に広く協力のネットワークがあり、ASRC の国際化の素晴らしい成功例である。

7. 研究課題 No.6：アクチノイド化合物の物質開発 （アクチノイド物質開発研究 Gr.）

評価結果：適切

意見・提案
これは、国際協力に基づき素晴らしい研究成果が得られた、もう一つの成功例であろう。グループリーダーの Fisk 教授は、インターネットを使って頻繁にグループとの意思疎通を図り、効果的にグループを牽引している。このグループは、この分野の研究に広く必要とされている高品質の 5f 電子化合物を作製する技術をもち、独自性に富んでいる。彼らは既に幅広い協力ネットワークを駆使して傑出した成果を出しており、さらに大きな発見をする可能性が高い。このグループもまた、ASRC における研究活動の模範を示している。

8. 研究課題 No.7:重元素化合物のための新たな固体物理コンセプトの開拓 （重元素系固体物理研究 Gr.）

評価結果：適切

意見・提案
このグループは、J-PARC などの施設を活用して、特に極限状態に焦点を絞り、5f 電子化合物の磁性と超伝導に関する研究を行っている。先の震災による J-PARC 施設の深刻な被災状況においても優れた成果を生み出しつづけている。このグループはインパクトの強い研究成果をあげる潜在能力がある。Fisk グループとの協力が効果的に行われている。

9. 研究課題 No.8:ストロンジネスを含む原子核とハドロンの構造解明 （ハドロン物理研究 Gr.）

評価結果：適切

意見・提案
このグループはストレンジネスを含んだハイパー核に関するパイオニア的研究を進めており、事前評価で推奨されたとおり人員が補充された。J-PARC の利用はこの研究には欠かせない。独自性のある J-PARC 施設の活用や研究テーマの科学的新規性という点で、ASRC にとって理想的な研究グループである。J-PARC の深刻な被災状況にもかかわらず、すばらしい躍進をしている。

10. 研究課題 No.9:バイオ反応場におけるアクチノイドのナノ粒子化機構の解明 （バイオアクチノイド化学研究 Gr.）

評価結果：適切

意見・提案
このグループは 2 年前の事前評価時に新規性が乏しいと評価された。しかし彼らは生物系における汚染状況を適切に把握することでみごとに福島の危機に対応した。この成果

はASRCとJAEAの知名度を高めることに大いに貢献した。福島除染に関する研究成果が認められた結果として、現在彼らの活動の大部分は外部資金によって支えられている。彼らは違った方法で我々の提案に応えた形になり、この成功は評価されるべきである。

11. 研究課題 No.10:放射場における生体分子の変異と生体応答の解明 （放射場生体分子科学研究 Gr.）

評価結果：適切

意見・提案
このグループも事前評価の提言に応えて、研究の方向性をDNAから生体細胞、特にガン細胞へと変更した。よって彼らの研究はさらに適切で興味深いものとなり、すでに細胞の照射損傷に関する予想外の結果を得ている。この結果は、重要であるにも関わらずあまり解明されていない低線量の照射効果について、価値ある発見につながる可能性がある。

12. 研究課題 No.11:スピン偏極陽電子ビーム技術の開発とスピントロニクス研究への応用（スピン偏極陽電子ビーム研究 Gr.）

評価結果：適切

意見・提案
これはTIARAを利用した、意欲的かつ興味深い先進的なプロジェクトである。彼らはすでに40%のスピン偏極した陽電子ビームを生成し、スピン偏極した電子構造の解明とスピンホール効果の直接測定に成功している。これらの成果は、新しい研究分野の開拓や、スピン偏極陽電子を用いた薄膜や表面近傍における磁気現象をこれまでにないレベルで解明することへの大いなる展望を有している。このプロジェクトもASRCの理念に相応しいものと言える。

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添付資料

添付資料１　研究開発課題の事前評価について（諮問）

添付資料２　中間評価資料

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添付資料１

研究開発課題の事前評価について（諮問）

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２４原機（先）０１１
平成２４年４月２０日

先端基礎研究・評価委員会
　委員長　Takeshi Egami　殿

独立行政法人日本原子力研究開発機構
　理事長　鈴木　篤之

研究開発課題の中間評価について　（諮問）

「研究開発・評価委員会の設置について」(17(達)第42号)第3条第1項に基づき、次の事項について諮問します。

記

〔諮問事項〕

「先端原子力科学研究」に関する中間評価

以　上

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添付資料２

中間評価資料

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先端基礎研究センター中間評価資料目次

Research Program in Advanced Science Research Center (ASRC), JAEA
Introduction, Summary of the pre-review, Response, Organization and administration, References

Research Subject (1)
Study on New Functional Materials
(Research Group for Condensed Matter Theory)

Research Subject (2)
Study for Spin-Transport Mechanisms in Molecular Spintronics Materials and Devices
(Research Group for Molecular Spintronics)

Research Subject (3)
Spin manipulation and material design by combining Spintronics, mechanical engineering and NMR method
(Research Group for Mechanical Control of Materials and Spin Systems)

Research Subject (4)
Research in exotic shell evolution of heavy nuclei
(Research Group for Reactions Involving Heavy Nuclei)

Research Subject (5)
Study of Valence Electronic Structure and Nuclear Shell Structure of Superheavy Elements
(Research Group for Superheavy Elements)

Research Subject (6)
Preparation of New Actinide Compounds with Exotic Behavior
(Research Group for Actinide Material Science)

Research Subject (7)
Foundation of New Concept in Condensed Matter Physics for Heavy Element Systems
(Research Group for Condensed Matter Physics of Heavy Element Systems)

Research Subject (8)
Research on Structure of Nuclei and Hadrons Containing Strangeness
(Research Group for Hadron Physics)

Research Subject (9)
Study of Formation of Actinides Nano-Particles in Biological Reaction Environments
(Research Group for Bioactinide Chemistry)

Research Subject (10)
Biophysical Study for Molecular and Cellular Responses to Radiation
(Research Group for Radiation and Biomolecular Science)

Research Subject (11)
Development of Spin-Polarized Positron Beam and its Applications to Spintronics Study
(Research Group for Spin-Polarized Positron Beam)

Research Program in Advanced Science Research Center (ASRC), JAEA
April 1, 2010 - March 31, 2015

Introduction

The Advanced Science Research Center (ASRC) has been conducting the state-of-the-art research to discover new principles and phenomena, and to explore yet-undiscovered research fields for the future of atomic and nuclear sciences. To achieve the goal, ASRC has engaged in important tasks in the fields of advanced materials research, frontier research on heavy element systems, and research on radiation field effects. The Great East Japan Earthquake left a serious damage in some parts of the laboratories and experimental equipments belonging to ASRC, as well as large facilities in JAEA, such as J-PARC and the JAEA tandem accelerator, and so on. Fortunately, the damage on the equipments was non-fatal. As a result of management effort, such as allocating budget in an effective way at the Director General's discretion, and the prompt restoration action of staff researchers, experiments have been restarted by autumn in the same year except those by J-PARC related groups. Some groups received offers from overseas institutes, and managed to carry out their research activities abroad. Despite the severe damage due to the earthquake, ASRC achieved substantial results maximizing human interaction which had long been cultivated. In response to the accident in Fukushima Daiichi nuclear power plant, ASRC has made contributions in various aspects of restoration by using its expertise in implementation of research themes related to the issues aroused.

Summary of the pre-review

The committee has a high opinion of the research program of ASRC. It says that ASRC is a world-class center of basic research with goals far transcending the core mission of JAEA. ASRC is also leading the wave of internationalization of JAEA. ASRC now has an excellent opportunity to become one of the most prominent world-leading research institutions. Yet, to achieve further growth, the committee gives suggestions to organization and administration of ASRC as follows.

(1) The committee recommends an increase of budget and securing a source of manpower to maintain the international competitive edge. The administration should restrain itself from weakening ASRC by restricting its freedom and financial agility in an attempt to save a small amount of funding. It is also desirable to improve the working environment including a condition of the visiting group leaders for their active participation.

(2) With regards to the research subjects, although they are scientifically excellent and are fully consistent with the mission of JAEA, a number of projects currently supported by ASRC are technically demanding and require long preparation and commitment. There are also projects which have weak interaction and synergy with the rest of the projects. These projects may be continued outside ASRC.

(3) The REIMEI program is an excellent avenue for bringing young talents into ASRC. It is, however, not clear how each project has been evaluated after the completion of the project and how successful the program as a whole has been. An increase of budget of the REIMEI program, which has been proposed to open to international competition, is essential.

(4) The committee strongly recommend for ASRC to maintain close contact with the rest of JAEA, so that ASRC truly becomes the gateway for JAEA to the outside scientific community.

Response

(1) Although ASRC has continuously requested a budget based on funding requirement, the annual budget of ASRC does not increase due to the financial stringency of JAEA. ASRC positively has employed young post doctoral fellows and temporary staff scientists including foreign researchers to maintain and to enhance the international competitive edge of ASRC. Also ASRC strongly encourages staff scientists to give invited talks in international conferences. The working environment including a condition of the visiting group leaders has been greatly improved. Acquirement of outside fund has been encouraged.

(2) Progress of each research theme has been strictly and continuously reviewed by the Director for not only the suggested themes but also the all ones. Taking the evaluations into account, one of the groups has decided to change the subject to a current highlight-topic that has been discovered by the group through the international collaboration, and some other groups have overhauled and refocused the research programs. Accordingly, ASRC has decided to accept their newly proposed subjects.

(3) The effective operation of the REIMEI program has been conducted internationally as shown in the following. Several international workshops based on this program have been organized in FY2010 and 2011. The completed themes have been strictly reviewed by the Evaluation Committee of the REIMEI program. The reports of the programs have been issued in a JAEA-review.

(4) Each group actively and continuously exchanges scientific information with outside communities as well as related other divisions in JAEA.

Organization and administration

In addition to the above response, we have been conducting the following organization and management at ASRC to achieve the ASRC research policy: implementation and creation of frontier researches using unique JAEA facilities, establishment of a world-class center (COE) of basic research, and contribution to human resource development.

(1) Meetings consisting of the executive members of ASRC have been periodically held to discuss the ASRC organization and management. To encourage the staffs of ASRC, the Director's interviews with all members of ASRC have been conducted every year at the end of FY. The Director's awards have been presented to researchers who achieved remarkable results and/or great progress in each FY. The award winners were obtained the support of attending international conferences.

(2) As mentioned above, the REIMEI research program has been conducted to cultivate forefront and frontier researches in the diverse fields of atomic and nuclear sciences and its related fields on an international basis. Five research themes adopted in FY2010 included three international collaborations, while in FY 2011, all of the five adopted themes were based on proposals from overseas. The conducted subjects in collaboration with ASRC in the two FYs are as follows.

1. Theoretical studies in spintronics and multifunctional materials - Institut Laue-Langevine (ILL) by T. Ziman *et al*.
2. New approach to the exotic phases of actinides compounds under unconventional experimental conditions - Institut Laue-Langevine (ILL) by G. H. Lander *et al*.

3. Synthesis, magnetic and transport studies of Li(Zn,Mn)As and other doped I-II-V magnets - Columbia University, USA by Y. Uemura *et al*.
4. Biological assessment of radiation damage of ATP by soft x-rays - The University of Tokyo by N. Akimitsu *et al*.
5. Time-resolved neutron contrast method by pulsed-high-magnetic-field nuclear polarization - Tohoku University by Y. Narumi *et al.*
6. New fission mechanism peculiar to proton-rich nuclei - University of the West Scotland by A. Andreyev *et al*.
7. Exploration of new biological specific function by heavy elements stimulus - University of Birmingham by L. Macaskie *et al*.

The five international workshops based on the REIMEI programs were hosted by ASRC:

1. New approach to the exotic phases of actinides compounds under unconventional experimental conditions, February 18-18, 2011, Tokai, Japan
2. Magnetic materials and nanostructures, January 10-13, 2012, Tokai, Japan
3. New approach to the exotic phases of actinides compounds under unconventional experimental conditions, January 31-February 3, 2012, Grenoble, France
4. Transformation of radionuclides by microorganism, clays and plants: Implication for migration and remedation, March 12-13, 2012, Tokai, Japan
5. Perspectives in nuclear fission, March 14-16, 2012, Tokai, Japan

In addition to the REIMEI workshops, ASRC organized the following international workshop and school:

1. Spin caloritronics III, May 9-13, 2011, Leiden, The Neitherland
2. International school on hadron physics, February 12-18, 2012, Tokai and Sendai, Japan

In FY2012, the following 7 REIMEI programs will be cooperated with ASRC:

1. Gas-phase chemistry of $Sg(CO)_6$ - Establishing novel metal-organic chemistry for superheavy elements - Johannes Gutenberg University of Mainz by C. E. Düllmann *et al.*
2. Theory for spin engine - Tohoku University by G. E. W. Bauer *et al.*
3. Heavy fermion superconductivity explored by anisotropic magnetic fluctuations in actinide compounds - Tohoku University by D. Aoki *et al*.
4. Muon spin relaxation studies of Skyrmion Spin Systems and magnetic semiconductors - Paul Scherrer Institute by E. Morenzoni *et al*.
5. Initial processes of radiation effects on genomic stability - Universite Pierre et Marie Curie by M. H. du Penhoat *et al*.
6. New island of asymmetric fission in proton-rich nuclei - University of the West Scotland by A. Andreyev *et al*.
7. Exploration of new biological specific function by heavy elements stimulus - University of Birmingham by L. Macaskie *et al*.

(3) To increase scientific exchange, ASRC invites two distinguished scientists as the research advisors. A number of scientists frequently have visited ASRC and given current highlight talks at the ASRC seminars. Furthermore ASRC invites two foreign world-wide leading scientists as the

group leaders. They occasionally visit ASRC and periodically communicate with the group members through the net meeting to discuss progress of their research groups. ASRC has also organized the ASRC meeting/colloquium every month to enhance mutual scientific communications among the ASRC members.

Based on not only the REIMEI research program, and the assigned International collaboration programs with DOE, USA on nuclear physics and with CEA, France on transuranium solid state physics but also individual collaboration, ASRC actively cooperates with foreign institutes. Two of the ASRC members were invited to foreign research institutes as the guest professors through the above collaboration programs: Universite Pierre et Marie Curie and Institut Laue-Langevine (ILL).

(4) ASRC has positively accepted many post-doctoral fellows, sabbatical fellows and students to contribute human resource development. Almost all of them have got their academic positions after leaving ASRC.

(5) ASRC has encouraged the young staffs to submit their manuscripts to the prestigious journals and to participate in international conferences. A number of young scientists received external awards as well as the JAEA president award.

(6) The brochure of ASRC, Annual Report of ASRC 2010 ▸ 2011, and Notes on Basic Science, Vol. 18, No. 1 (2010) and Vol. 19, No. 1 (2011) were issued to introduce research activities of ASRC.

References

1. Annual budget
   FY2010: 275,571 MJPY, outside budget: 296,054 MJPY, total: 571,625 MJPY
   FY2011: 341,128 MJPY, outside budget: 204,095 MJPY, total: 545,223 MJPY
2. Personnel
   FY2010: permanent staff: 43, post-doctoral fellows: 36, total: 79
   FY2011: permanent staff: 44, post-doctoral fellows: 35, total: 79
3. Press release
   FY2010: 5
   FY2011: 7
4. Publication
   FY2010: published articles: 111, selected papers: 5, invited talks:
   FY2011: published articles: 125, selected papers: 5, invited talks:
5. Award
   FY2010: 8
   FY2011: 4

Research Subject (1)

Study on New Functional Materials

Group **Condensed Matter Theory Group**

Member (Leader) Michiyasu Mori
(Researcher) Katsunori Kubo, Hiroaki Onishi, Hiroto Adachi, Bo Gu, Jun'ichi Ieda, Mamoru Matsuo
(Post doc.) Takanori Sugimoto, Zhuo Xu
(Student) Yuta Yamane, Yuichi Ohnuma

Summary of the Pre-review

The condensed matter theory group was launched to study new functional materials emerging from the electron internal degrees of freedom (spin, charge and orbital) and the electrons correlation. New principle and new function of devices are also important targets of this group. For example, the spintronics device is not simply derived from the conventional electronics. In order to achieve those purposes, various numerical calculation techniques such as quantum Monte Carlo method, density matrix renormalization group method, density functional theory, finite element method are used fully and flexibly. Furthermore, a new concept of condensed matter physics is set to be the premier goal.

Regarding our plans, the evaluation committee claimed that the theory group needed to focus on a few important subjects, since the listed matter was rather broad. In addition, they strongly encouraged that we would take every opportunity to interact with the experimentalists not only within ASRC but also those in the Quantum Beam Physics group at J-PARC.

Response

So far we have focused on (i) thermoelectric phenomena originating from the electron inertial degrees of freedom and the electrons correlation and (ii) new principle of spin current generation. Our research resources have been mainly allocated to those two topics, which are closely related each other. Details of our results will be summarized in the next section. Note that the other topics are also progressing soundly, e.g., *spinmotive force, magnetic domain wall, ferromagnetic Josephson junction, enhanced spin Hall effect, high-Tc cuprate,diluted magnetic semiconductors, heavy fermion* and so on.

About the collaboration with experimental groups, we started to discuss frequently with the following ones in ASRC; Molecular Spintronics Gr, Spin Manipulation and Material Design by Combining Spintronics and High-Speed Rotation Technique Gr, Actinide Material Science Gr, Condensed Matter Physics of Heavy Element Systems Gr, and Spin-Polarized Positron Beam Gr. A few projects will be published in near future, and the other ones are still under discussion. Concerning the collaboration with the Quantum Beam Physics group at J-PARC, we created a joint seminar among J-PARC, KEK, Ibaraki University, CROSS, and ASRC. In this seminar, we discuss the latest interesting topics of various material sciences by using the video conference system. This is a good occasion to know each other and to start new collaborations among the five institutes. We are now

planning some new projects. In addition, we ask an expert of the neutron scattering experiment to be invited researcher in the theory group. It is also working well to establish the collaboration with the Quantum Beam Physics group at J-PARC. In fact, one project is progressing by getting a grant from MEXT.

Progress

Out of our results, three topics are summarized below.

(i) Theory of Spin Seebeck Effect

The Seebeck effect is the conversion of temperature difference into the electricity in metals or semiconductors. Such thermoelectric phenomena is one of recent hot topics in the condensed matter physics, since the thermoelectric device has fascinating features necessary for future technologies. In practice, however, the efficiency of the devices is limited by the energy loss due to conduction electrons' heat transport. On the other hand, the spin Seebeck effect is the conversion of temperature difference in a ferromagnet into the electricity via the spin current (see Fig. 1) [24]. The spin current injected into the Pt electrode is transformed into the electric one by the inverse spin Hall effect. Surprising is that this effect is possible in the insulating ferromagnet such as yttrium iron garnet (YIG). The insulator-based thermoelectric devices have never been considered so far, and would lead to new

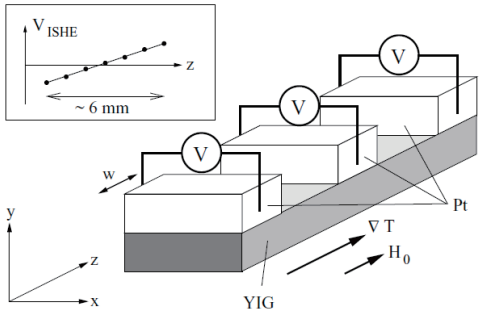

Fig. 1 Experimental setup for the spin Seebeck effect. Magnetic field, H_0, is applied in a direction parallel to the temperature gradient, ∇T. Inset: The spatial profile of observed voltage, V. [Ref. 24]

thermoelectric devices with high efficiency. We have developed a theory of spin Seebeck effect based on the linear response theory, in which magnon and phonon play a role to mediate the heat energy. Conceptually important is that those collective modes induce some amount of deviation from the local equilibrium state depending on the temperature profile. Such deviation is the origin of spin injection by the temperature gradient. This result, in particular by phonon, is enhanced in a low temperature regime [Ref. 34] and is experimentally observed [Refs. 2-3] (See also Fig. 2).

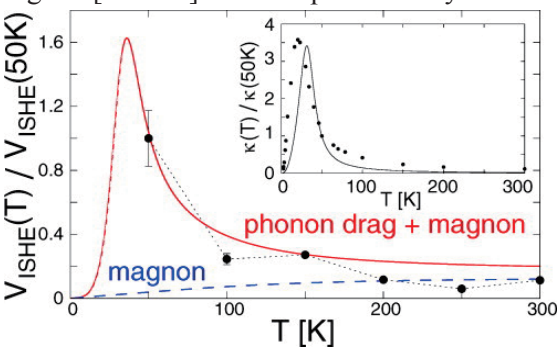

Fig. 2 The enhanced spin Seebeck effect by the phonon drag effect (solid line: theory, solid circles: experiment) in YIG [Ref. 34]. The magnon contribution is shown by broken line. Inset: Thermal conductivity of YIG.

(ii) Non-monotonic temperature dependence of thermopower in correlated electron systems

Since the discovery of unusually large thermopower in Na_xCoO_2, transition-metal oxides with strong electron correlation have attracted much attention as promising candidates for

high-performance thermoelectric materials. Thermopower is none other than the amount of entropy flow along with the electric current. The consideration on the entropy in thermodynamics tells us the low and high temperature (T) limits of the thermopower: In the metallic systems, the thermopower goes to zero as T goes to 0 K. On the other hand, the high-temperature limit of thermopower is given by the entropy consideration in the atomic limit. In the strongly correlated systems, the spin and orbital degrees of freedom can enhance the high-temperature thermopower in principle.

We studied the role of strong Coulomb interaction on thermopower, whose temperature dependence is particularly examined in detail [Ref. 9]. For this purpose, the single- and multi-band Hubbard models are adopted as a minimum model and the strong Coulomb interaction is treated in the dynamical mean field theory (DMFT), which can capture the coherent-to-incoherent crossover due to the strong Coulomb interaction, U. This method based on the local picture is useful to understand the overall behavior of thermopower as a function of temperature. It is found that the Coulomb interaction gives rise to a non-monotonic temperature-dependence, which is well described by the entropy consideration at high temperatures. In the light of our theoretical results, the thermoelectric response in the transition metal oxides, $La_{1-x}Sr_xVO_3$ seems to be well explained [Ref. 12].

(iii) New principle of spin current generation by mechanical rotation

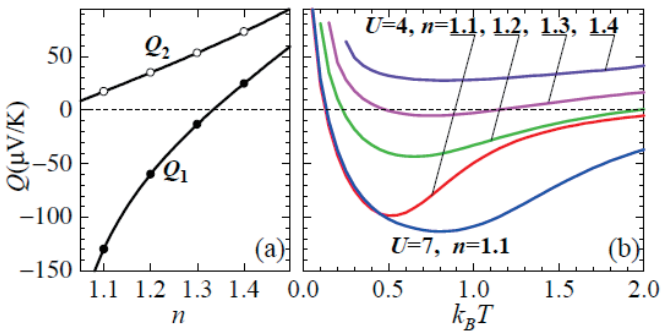

Fig. 3 (a) Thermopower in the high temperature limit, Q_1 ($T\rightarrow\infty$ with $k_BT<U$) and Q_2 ($T\rightarrow\infty$ with $U<k_BT$), vs. electron density, n in the single band Hubbard model. (b) Temperature dependence of the thermopower calculated by DMFT with the non-crossing approximation as impurity solver, for various parameter sets of U and n. [Ref. 9]

In 1915, Albert Einstein made two important discoveries known as the general relativity and the Einstein-de Haas effect. The former describes phenomena in accelerated systems such as a rotating body, and the latter provides a bridge between magnetism and mechanical rotational. The quantum mechanics established in 1926 tells us that electron spin is the origin of magnetism. Recent progress of nanotechnology enables us to manipulate the flow of electron spins, i.e. “spin current”. The interplay of spin current and magnets has been well studied for nano-device applications. Then, a question arises: Is it possible to generate the spin current by the mechanical rotation as classical angular momentum?

We studied theoretically the generation of the spin current in both rotationally and linearly accelerating systems [Refs. 10,18,22]. The spin-dependent inertial force acting on electrons in the rotating frame was derived from the generally covariant Dirac equation in the presence of electromagnetic fields. We have shown that the force is responsible for the generation of spin currents by mechanical rotation in the first order of the spin-orbit coupling. It is found that the mechanical rotation causes a circular (pure) spin current in a rotating frame (See Fig.4). The framework proposed in this study provides a new route to study the inertial effects on electron transport phenomena, leading to an innovative combination of microelectromechanical systems (MEMS) and spintronics.

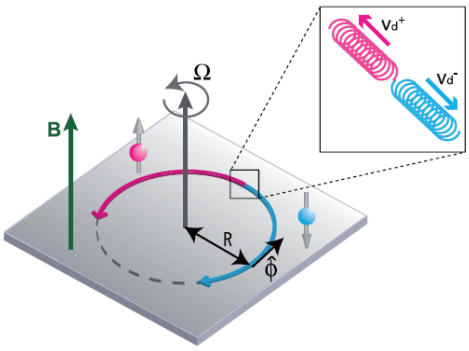

Fig. 4 Schematic illustration of electrons' trajectories under mechanical rotation Ω and a magnetic field B. The generation of the circular spin currents can be interpreted as an analogy of the drift of charged particles in electromagnetic fields [Ref. 22]

Goal

We try to clarify physics behind the electrons correlation, and to develop new functional materials. New principles and new functions applied to spintronics devices, such as, "non-local spin- and charge current converter at room temperature", "ferromagnetic Josephson device", and "spin Seebeck device" will be proposed. Our numerical simulation techniques will overcome various theoretical difficulties. Then, we will discover new functional materials and its application to new devices.

Originality

Numerical studies on the spintronics- and the correlated-electronic materials have been done by another group as well, while our simulation technique such as quantum Monte Carlo, exact diagonalization and density matrix renormalization group, which are useful for the quantum many body problems, come up to the highest standard in the world. In addition, uniqueness is that the material development and the device design are simultaneously carried out in this study. By using the next generation supercomputer, a-not-yet-realized numerical simulation will be done.

Scientific and Social Outcome

The conventional electronics have been developed by controlling the charge degree of freedom. By including the remaining internal degrees of freedom, spin and orbital, and the electron correlation, we can expect new technology beyond the conventional one.

International Cooperation

The international collaboration programs by Japan Society for the Promotion of Science, Japan Science and Technology Agency, and Tohoku University as well as JAEA, help us to obtain successfully many results in collaboration with the following institutes: University of Miami (USA), Max Plank Institute (Germany), Institute de Laue Langevin (France), Zaragosa University (Spain), Josef Stephan Institute (Slovenia), Institute of Physics Zagreb (Croatia), Polish Academy of Sciences (Poland), University of New South Wales (Australia). We will keep these collaborations and develop much further.

The followings are a part of collaborations.

- REIMEI Project by JAEA
  1) "Theory of Materials for Spin Electronics and Dynamics of Magnetic Nanostructures" (Prof. T. Ziman, ILL, France), 2010

2) "Theory of Materials for Spin Electronics and Dynamics of Magnetic Nanostructures" (Prof. T. Ziman, ILL, France), 2011

- Invited Researchers by JAEA,
  Prof. G. Khaliullin (Max Planck Institute, Germany) 2010
  Prof. S, E, Barnes (Univ. of Miami, USA) 2010
  Prof. O. P. Sushkov (Univ. of New South Wales) 2011
  Prof. J. Martinek (Polish Academy of Sciences, Poland) 2012
- Invitation fellowship program by Japan Society for the Promotion of Science (JSPS),
  Prof. Veljko Zlatic, Institute of Physics, Zagreb (Croatia), 2012 (No.S-11030)
- Bilateral collaboration program by (JSPS),
  Prof. Janez Bonca, Jozef Stefan Institute, Ljubljana (Slovenia), 2010-2012

Publication List (2010-2011 FY)

Nature Mat.	**5**
Nature Comm.	**1**
Phys. Rev. Lett.	**7**
Phys. Rev. B	**6**
J. Phys. Soc. Jpn.	**5**
J. Appl. Phys.	**5**
Appl. Phys. Lett.	**3**
etc.	**4**

2011 FY

1) M. Hayashi, J. Ieda, Y. Yamane, J. Ohe, Y. K. Takahashi, S. Mitani, and S. Maekawa
Time-domain observation of spinmotive force in permalloy nanowires
Phys. Rev. Lett. in press.

2) K. Uchida, H. Adachi, T. An, H. Nakayama, M. Toda, B. Hillebrands, S. Maekawa, and E. Saitoh
Acoustic spin pumping: Direct generation of spin currents from sound waves in Pt/$Y_3Fe_5O_{12}$ hybrid structures
J. Appl. Phys. **111**, 053903 (2012).

3) K. Uchida, H. Adachi, T. An, T. Ota, M. Toda, B. Hillebrands, S. Maekawa, and E. Saitoh
Long-range spin Seebeck effect and acoustic spin pumping
Nature Materials **10**, 737 (2011).

4) Y. Fukuma, L. Wang, H. Idzuchi, S. Takahashi, S. Maekawa, and Y. Otani
Giant enhancement of spin accumulation and long-distance spin manipulation in metallic lateral spin valves
Nature Materials **10**, 527 (2011).

5) K. Ando, S. Takahashi, J. Ieda, H. Kurebayashi, T. Trypiniotis, C. Barnes, S. Maekawa, and E. Saitoh
Electrically tunable spin injector free from the impedance mismatch problem
Nature Materials **10**, 655 (2011)

6) Z. Deng, C.Q. Jin, Q.Q. Liu, X.C. Wang, J.L. Zhu, S.M. Feng, L.C. Chen, R.C. Yu, C. Arguello, T. Goko, Fanlong Ning, Jinsong Zhang, Yayu Wang, A.A. Aczel, T. Munsie, T.J. Williams,

G.M. Luke, T. Kakeshita, S. Uchida, W. Higemoto, T.U. Ito, Bo Gu, S. Maekawa, G.D. Morris, and Y.J. Uemura
Li(Zn,Mn)As as a new generation ferromagnet based on a I-II-V semiconductor
Nature Commun. **2**, 422 (2011)

7) L. Vidmar, J. Bonca, T. Tohyama, and S. Maekawa
Quantum Dynamics of a Driven Correlated System Coupled to Phonons
Phys. Rev. Lett. **107**, 246404 (2011).

8) Y. Yamane, K. Sasage, T. An, K. Harii, J. Ohe, J. Ieda, S. E. Barnes, E. Saitoh, and S. Maekawa
Continuous Generation of Spinmotive Force in a Patterned Ferromagnetic Film
Phys. Rev. Lett. **107**, 236602 (2011).

9) M. Matsuo, S. Okamoto, W. Koshibae, M. Mori, and S. Maekawa
Nonmonotonic temperature dependence of thermopower in strongly correlated electron systems
Phys. Rev. B **84**, 153107 (2011)

10) M. Matsuo, J. Ieda, E. Saitoh, and S. Maekawa
Spin-dependent inertial force and spin current in accelerating systems
Phys. Rev. B **84**, 104410 (2011).

11) K. Ishii, S. Ishihara, Y. Murakami, K. Ikeuchi, K. Kuzushita, T. Inami, K. Ohwada, M. Yoshida, I. Jarrige, N. Tatami, S. Niioka, D. Bizen, Y. Ando, J. Mizuki, S. Maekawa, Y. Endoh
Polarization-analyzed resonant inelastic x-ray scattering of the orbital excitations in $KCuF_3$
Phys. Rev. B **83**, 241101(R) (2011) (PRB Editors' Suggestion)

12) M. Uchida, K. Oishi, M. Matsuo, W. Koshibae, Y. Onose, M. Mori, J. Fujioka, S. Miyasawa, S. Maekawa, and Y. Tokura
Thermoelectric response in the incoherent transport region near Mott transition: the case study of $La_{1-x}Sr_xVO_3$
Phys. Rev. B **83**, 165127 (2011)

13) S. Hikino, M. Mori, S. Takahashi, and S. Maekawa,
Composite excitation of Josephson phase and spin waves in Josephson junctions with ferromagnetic insulator
J. Phys. Soc. Jpn, **80**, 074707 (2011).

14) K. Kubo
Gutzwiller Method for an Extended Periodic Anderson Model with the c-f Coulomb Interaction
J. Phys. Soc. Jpn. **80**, 114711 (2011).

15) K. Kubo
Mass Enhancement in an Intermediate-Valent Regime of Heavy-Fermion Systems
J. Phys. Soc. Jpn. **80**, 063706 (2011).

16) H. Onishi
Multipole Correlations of t2g-Orbital Hubbard Model with Spin-Orbit Coupling
J. Phys. Soc. Jpn. **80** Suppl. A, SA141 (2011).

17) K. Kubo and P. Thalmeier
Correlation Effects on Antiferromagnetism in Fe Pnictides
J. Phys. Soc. Jpn. **80** Suppl. A, SA121 (2011).

18) M. Matsuo, J. Ieda, E. Saitoh, and S. Maekawa

Spin current generation due to mechanical rotation in the presence of impurity scattering
Appl. Phys. Lett. **98**, 242501 (2011).

19) Y. Yamane, J. Ieda, J. Ohe, S. E. Barnes, and S. Maekawa
Spinmotive force due to intrinsic energy of ferromagnetic nanowires
Applied Physics Express, **4,** 093003 (2011).

20) K. Ando, S. Takahashi, J. Ieda, Y. Kajiwara, H. Nakayama, T. Yoshino, K. Harii, Y. Fujikawa, M. Matsuo, S. Maekawa, and E. Saitoh
Inverse spin-Hall effect induced by spin pumping in metallic system
J. Appl. Phys. **109**, 103913 (2011).

21) Y. Yamane, J. Ieda, J. Ohe, S. E. Barnes, and S. Maekawa
Equation-of-motion approach of spin-motive force
J. Appl. Phys. **109**, 07C735 (2011)

2010 FY

22) M. Matsuo, J. Ieda, E. Saitoh, and S. Maekawa
Effects of mechanical rotation on spin currents
Phys. Rev. Lett. **106**, 076601 (2011) (PRL Editors' Suggestion)

23) J. Ohe, H. Adachi, S. Takahashi, and S. Maekawa
Numerical study on the spin Seebeck effect
Phys. Rev. B **83**, 115118 (2011)

24) H. Adachi, J. Ohe, S. Takahashi, and S. Maekawa
Linear-response theory of spin Seebeck effect in ferromagnetic insulators
Phys. Rev. B **83**, 094410 (2011)

25) Bo Gu, T. Ziman, G-Y. Guo, N. Nagaosa, and S. Maekawa
Giant spin Hall effect of Au films with Pt impurities: Surface-assisted skew scattering
J. Appl. Phys. **109**, 07C502 (2011)
(Virtual Journal of Nanoscale Science and Technology, vol. 23, issue 13 (2011))

26) M. Ichimura, T. Hamada, H. Imamura, S. Takahashi, and S. Maekawa
Spin transfer torque in MTJs with synthetic ferrimagnetic layers by the Keldysh approach
J. Appl. Phys. **109**, 07C906 (2011)
(Virtual Journal of Nanoscale Science and Technology, vol. 23, issue 13 (2011))

27) S. Hikino, M. Mori, S. Takahashi, and S. Maekawa
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28) H. Yang, S.H. Yang, S. Takahashi, S. Maekawa, S.S.P. Parkin
Extremely long quasiparticle spin lifetimes in superconducting aluminium using MgO tunnel spin injectors
Nature Materials **9**, 586 (2010).

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Nature Materials **9**, 894 (2010).

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Quantum Renormalization of the Spin Hall Effect

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Surface-assisted spin Hall effect in Au films with Pt impurities
Phys. Rev. Lett **105**, 216401 (2010).
32) G. Khaliullin, M. Mori, T. Tohyama, and S. Maekawa
Enhanced pairing correlations near oxygen dopants in cuprate superconductors
Phys. Rev. Lett **105**, 257005 (2010).
33) K. Uchida, H. Adachi, T. Ota, H. Nakayama, S. Maekawa and E. Saitoh
Observation of longitudinal spin-Seebeck effect in magnetic insulators
Appl. Phys. Lett **97**, 172505 (2010).
34) H. Adachi, K. Uchida, E. Saitoh, J. Ohe, S. Takahashi, and S. Maekawa
Gigantic enhancement of spin Seebeck effect by phonon drag
Appl. Phys. Lett. **97**, 252506 (2010).
35) M. Okumura, H. Onishi, S. Yamada, and M. Machida
Dynamics of attractively interacting fermi atoms in one-dimensional optical lattices: Non-equilibrium simulations of fermion superfluidity
Physica C **470**, S949 (2010).
36) M. Okumura, H. Onishi, S. Yamada, and M. Machida
Anomalous non-equilibrium electron transport in one-dimensional quantum nano wire at half-filling: time dependent density renormalization group study
J. Phys.: Conf. Ser. **248**, 012031 (2010).

Invited Talk

2011 FY

1) APS March Meeting
Boston, U.S.A., February 29, 2012
"Magnons, Spin Current and Spin Seebeck Effect"
S. Maekawa
2) ILL Colloquium
Grenoble, France, January 31, 2012
"Heat and Spin"
S. Maekawa
3) RIKEN-APW-APCTP Jpint Workshop "Recet trend in condensed matter physics"
Wako, Japan, January 15, 2012
"Spin-Motive Force"
S. Maekawa
4) SpinCaT conference
Bonn, Germany, January 5, 2012
"Theory on spin current generation"
S. Maekawa
5) FIRST-QS2C Workshop on "Eergent Phoenomena of Carrelated Materials"
Okinawa, Japan, December 13, 2011

"Heat and Spin"
S. Maekawa

6) Joint Polish-Japanese Workshop on "Spintronics-from new materials to applications"
Warsaw, Poland, November 17, 2011
"Spin-Motive Force in Magnetic Nanostructures"
S. Maekawa

7) 2011 Gordon Godfrey Workshop on Spins and Strong Correlations
Sydney, Australia, October 24-28, 2011
"Magnetic resonance appeared in ferromagnetic Josephson junction"
M. Mori

8) Spin Currents 2011
Sendai, Japan, July 28, 2011
"Conservation Laws and Spin Motive Force in Magnetic Nanostructures"
S. Maekawa

9) 2nd International Workshop on Magnonics: From Fundamentals to Applications
Recife, Brazil, August 22, 2011
"Non-Equilibrium Magnons, Spin Current and Spin Seebeck Effect"
S. Maekawa

10) Moscow International Symposium on Magnetism
Moscow, Russia, August 22, 2011
"Conservation Laws and Spin Motive Force in Magnetic Nanostructures"
S. Maekawa

11) The 2nd International Symposium on Hybrid Materials and Processing 2011
Busan, Korea, October 28, 2011
"Seebeck Effect, Spin Seebeck Effect and Spin-Electronics"
S. Maekawa

12) 56th Annual Conference on Magnetism & Magnetic Materials
Arizona, U.S.A., October 31, 2011
"Magnons, Phonons, and Spin Seebeck Effect"
S. Maekawa

13) ARW Workshop Hvar 2011
Hvar, Croatia, September 18-25, 2011
"Thermopower in correlated electron systems revisited: non-monotonic temperature dependence"
M. Mori

14) Vortex matter in nanostructured superconductors (VORTEX VII)
Rhodes, Greece, September 10-17, 2011
"Influences of magnetic-fluctuation, resonance, and oscillation on Josephson current in superconductor/ferromagnet/superconductor junction"
M. Mori

15) The 4th annual showcase of materials-allied research at The Ohio State University
Columbus, Ohio, USA, September 12-14, 2011
"Theory of phonon-drag spin Seebeck effect"

H. Adachi

16) The 26th International Conference on Low Temperature Physics (LT26)
Beijing, China, August 10-17, 2011
"Dynamics of Josephson-phase coupled with spin waves"
M. Mori

17) Coma-ruga 2011, 7th International Workshop on Nanomagnetism and Superconductivity
Tarragona, Spain, July 3rd-7th, 2011
"Spin current generation arising from mechanical rotation"
M. Matsuo

18) PM'11
Poznan, Poland, June 27-30, 2011
"Spin-Wave, Spin Current and Spin Seebeck Effect"
S. Maekawa

19) Spin Caloritronics III
Lorentz Center, Leiden, Netherlands, May 9-13, 2011
"Spin Current from Mechanical Motion"
J. Ieda

20) Spin Caloritronics III
Lorentz Center, Leiden, Netherlands, May 9-13, 2011
"Are only phonons relevant to the long-range nature of the spin Seebeck effect?"
H. Adachi

21) Intermag 2011
Taipei, Taiwan, April 26-28, 2011
"Theory on pure spin current"
S. Maekawa

2010 FY

22) The 34th Spin-electronics Workshop
Hongo, Japan, March 7th, 2011
“Thory of spin current generation by mechanical rotation”
M. Matsuo

23) NASCES 2011
Tokai, Japan, February 23-25, 2011
"Materials Design of Magnetic Semiconductors -Quantum Monte Carlo Study-"
S. Maekawa

24) The 9th Asia Pacific Workshop on Materials Physics (APW2010), Hanoi, Vietnam, December 12-15, 2010
"Possible mechanisms of enhanced pairing gap near apical and dopant oxygens in cuprate"
M. Mori

25) The 9th Asia Pacific Workshop on Materials Physics (APW2010), Hanoi, Vietnam, December 12-15, 2010
"Spin Current, Charge Current and their Interaction in Magnetic Nanostructures"
S. Maekawa

26) KIST Spintronics workshop, Seoul, Korea, December 9-10, 2010
"Spin-wave spin current in non-equilibrium systems"
J. Ohe
27) International Conference of AUMS (ICAUMS2010), Jeju, Korea, December 5-8, 2010
"Spin motive force induced by the magnetic vortex core motion"
J. Ohe
28) International Conference of AUMS (ICAUMS2010), Jeju, Korea, December 5-8, 2010
"Spin-Wave Spin Current as a Transmission Tool of Electric Signal and Thermal Energy"
S. Maekawa
29) CRP Workshop on Oxide Electronics, Singapore, November 8, 2010
"Spin-Wave Spin Current as a Transmission Tool of Electric Signal and Thermal Energy"
S. Maekawa
30) Super-PIRE/REIMEI workshop, Knoxville, USA, October 28-31, 2010
"Enhanced pairing correlation near oxygens in cuprate"
M. Mori
31) ARW Workshop Hvar 2010, Hvar, Croatia, October 2-7, 2010
"Quantum transport in nano-structure of superconductor and ferromagnet"
M. Mori
32) APW Workshop Hvar 2010, Hvar, Croatia, October 2-7, 2010
"Seebeck Effect, Spin Seebeck Effect and Spin-Electronics"
S. Maekawa
33) RIKEN Opening Symposium of QS2C Theory Forum, Wako, Japan, September 27-30, 2010
"Seebeck Effect, Spin Seebeck Effect and Spin-Electronics"
S. Maekawa
34) The 34th conference of The Magnetic Society of Japan, Tsukuba, Japan, September 4-7, 2010
"Spin Current, Charge Current and their Interaction in Magnetic Nanostructures"
S. Maekawa
35) Spin Age 2010, California, USA, August 27-31, 2010
"Spin-Wave Spin Current as a Transmission Tool of Electric Signal and Thermal Energy"
S. Maekawa
36) Shanghai Workshop on Spintronics and Low Dimensional Magnetism, Shanghai, China, June 16-18, 2010
"Spin injection into a superconductor"
S. Maekawa
37) KITPC 2010, Beijing, China, May 31-June 4, 2010
"Spin Current, Charge Current and their Interaction in Magnetic Nanostructures"
S. Maekawa
38) Workshop on High Performance Ceramic Hangzhou, China, May 27-30, 2010
"Seebeck Effect, Spin Seebeck Effect and Spin-Electronics"
S. Maekawa
39) SNS 2010, Shanghai, China, May 23-28, 2010
"Ferromagnetic Josephson Resonance"
S. Maekawa

40) ESF-NES Workshop 2010, Salzburg, Austria, May 4-8, 2010
"Spin injection into a superconductor in a magnetic double tunnel junction"
S. Maekawa

Press Release & Remarked Papers

Press Release

1) Jun. 27, 2011
Discovery of a new spin injection method available into all types of materials
-The significant progress for development of next-generation energy-saving devices-
2) Jun. 13, 2011
Improvements to specialized valves that separate spin and electron currents
-The significant progress for development of higher-density magnetic media-
3) Feb. 15, 2011
A flow of spins from rotational bodies
4) Sep. 27, 2010
Thermoelectric power generation using insulators
5) Jun. 7, 2010
First observation of very long-lived spins in superconductors
-Opening the way to novel superconducting quantum computing devices-

Remarked Papers

6) PRB Editors' Suggestion
K. Ishii, S. Ishihara, Y. Murakami, K. Ikeuchi, K. Kuzushita, T. Inami, K. Ohwada, M. Yoshida, I. Jarrige, N. Tatami, S. Niioka, D. Bizen, Y. Ando, J. Mizuki, S. Maekawa, Y. Endoh
Polarization-analyzed resonant inelastic x-ray scattering of the orbital excitations in KCuF3
Phys. Rev. B **83**, 241101(R) (2011)
7) PRL Editors' Suggestion
M. Matsuo, J. Ieda, E. Saitoh, and S. Maekawa
Effects of mechanical rotation on spin currents
Phys. Rev. Lett. **106**, 076601 (2011)
8) Highlighted by NGP Asia Materials.
B. Gu, I. Sugai, T. Ziman, G. Y. Guo, N. Nagaosa, T. Seki, K. Takanashi, and S. Maekawa
"Surface-assisted spin Hall effect in Au films with Pt impurities"
Phys. Rev. Lett. **105**, 216401 (2010).
9) Selected in Virtual Journal of Nanoscale Science and Technology, vol. 23, issue 1 (2011)
H. Adachi, K. Uchida, E. Saitoh, J. Ohe, S. Takahashi, and S. Maekawa
"Gigantic enhancement of spin Seebeck effect by phonon drag"
Appl. Phys. Lett. **97**, 252506 (2010)
10) Selected in Virtual Journal of Nanoscale Science and Technology, vol. 23, issue 13 (2011)
Bo Gu, T. Ziman, G-Y. Guo, N. Nagaosa, and S. Maekawa
Giant spin Hall effect of Au films with Pt impurities: Surface-assisted skew scattering
J. Appl. Phys. **109**, 07C502 (2011)
11) Selected in Virtual Journal of Nanoscale Science and Technology, vol. 23, issue 13 (2011)

M. Ichimura, T. Hamada, H. Imamura, S. Takahashi, and S. Maekawa
Spin transfer torque in MTJs with synthetic ferrimagnetic layers by the Keldysh approach
J. Appl. Phys. **109**, 07C906 (2011)

Awards

- H. Adachi and Bo Gu, ASRC AWARD 2010, Apr. 2011
- H. Adachi, J. Ieda, and Bo Gu, JAEA Director Award 2011, Oct. 2011

Promotions

- Jun-ichiro Ohe, Lecturer (Toho University), Apr. 2011
- Bo Gu Foreign Researcher (JAEA), Apr. 2012

Research Subject (2)

Study for Spin-Transport Mechanisms in Molecular Spintronics Materials and Devices

Group Members **Research Group for Molecular Spintronics**
(Leader) Seiji Sakai
(Scientist) Yoshihiro Matsumoto
Shiro Entani
(Research fellow) Pavel V. Avmorav
(Post Doc.) Manabu Ohtomo

Summary of the pre-review

Molecular spintronics is an exciting, highly competitive research field. This group has an excellent opportunity to make significant contributions to this field through the use of graphene as spin injector. Although a number of technical difficulties can be imagined, this project is exemplary as the high-risk high-return project of ASRC.

Response

Reflecting the pre-review results, our group has elaborated a plan to make considerable achievements through the five-year scheme.

Progress

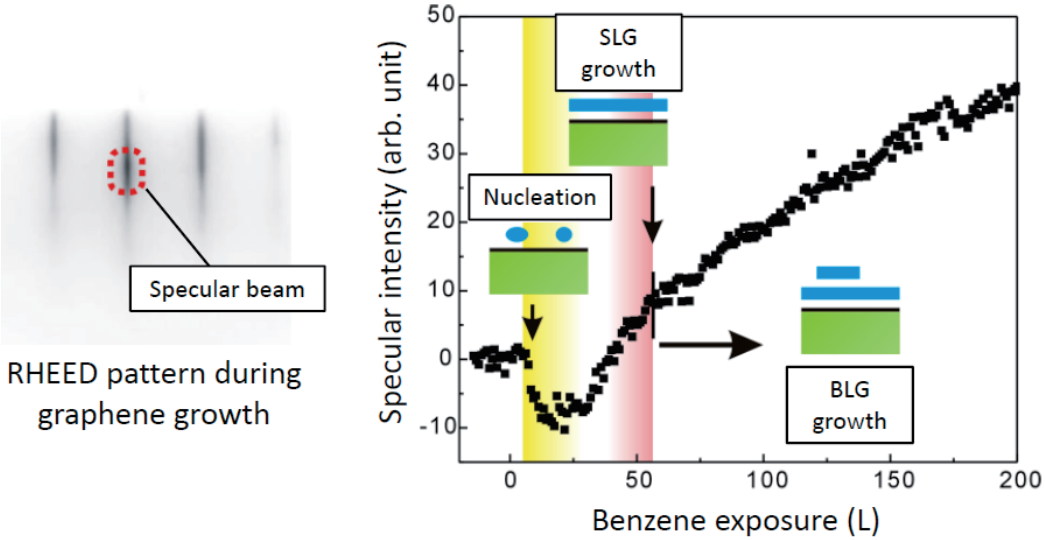
Studies have been conducted for function designs of molecular spintronic devices specially focusing on graphene as a key material which attracts growing attention as a prominent spin-transport medium.

The main themes of our group in the 2010 and 2011 fiscal years were 1) the development of a new growth method of the large area and layer-number controlled graphene on ferromagnetic metal thin films and 2) the spectroscopic investigations of the electronic and magnetic states of the graphene / ferromagnetic metal hybrid structures. The obtained insights through these studies enabled us to fabricate well-defined graphene-based spintronic devices with the tailored atomic and electronic structures. Such techniques are believed to be indispensable to functionalize graphene for spintronic devices by overcoming the difficulties that have been encountered in earlier studies with the use of exfoliated graphene.

Our achievements during the 2010-2011 fiscal years are listed below.

- **Success in the precise control of the atomic layer epitaxy of single and bi-layer graphene (SLG and BLG) on the Ni(111) thin film surface by the ultra-high vacuum (UHV) chemical vapor deposition** [25]. The following issues were clarified. The layer number of graphene can be controlled associated with the self-limiting layer-by-layer growth reflecting the change in the graphene growth-rate by three orders of magnitude in between the first and

second layer. Remarkably high uniformity of the degree of electron-doping compared with that in exfoliated graphene can be realized under a specific deposition condition at which the growth of the respective graphene layers are completed in the UHV-CVD process.

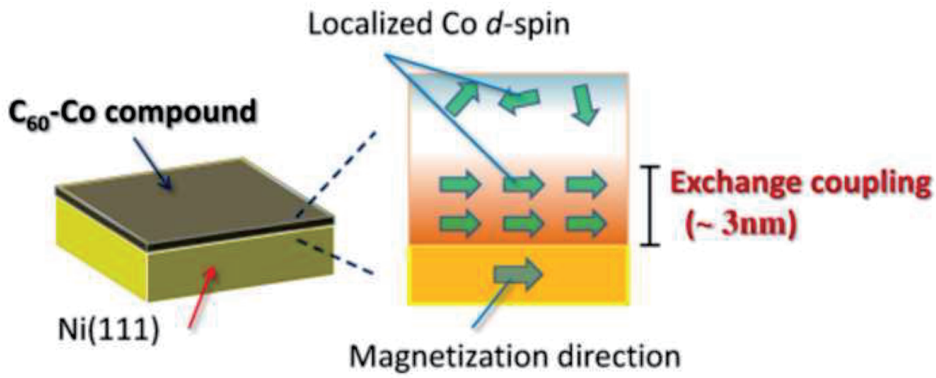


The layer number of graphene and its uniformity were successfully controlled by in-situ monitoring of the evolution of the RHEED (reflection high energy electron diffraction) specular intensity from the graphene/Ni(111) surface during the UHV-CVD growth. Benzene was used as a precursor molecule. (L: Langmuir)

- **Finding of the layer number dependent changes in chemical and electronic interactions at the interfaces of the graphene / magnetic metal (Ni and Co) and graphene / noble metal (Ag and Au) structures** [6, 14]. It was demonstrated that the covalent interaction with Ni at the gaphene / magnetic metal interface is reduced significantly by replacing SLG with multilayer graphene thicker than SLG. The similar reduction was also observed in the case of graphene / noble metal structures. In addition, the characteristics of charge carrier doping from metals into MLG was clarified. That is the carrier doping within the critical thickness of a few graphene layers from the graphene / metal interface independent of metal species and, meanwhile, the type of the doped carriers (electron or hole) is governed by the interfacial interactions depending on metal species.
- **Elucidation of the most accurate density functional theory (DFT) calculation method of the atomic structures of graphene (SLG, BLG, trilayer-graphene, tetralayer-graphene) and graphene-based materials** [15]. It was found that the long-corrected HSE scheme demonstrates the best performance in determination of the C-C bond lengths. It was demonstrated that the PBC HSE approach satisfactorily does not only reproduces the interlayer distances but also conserves the symmetry of the layer stacking sequence, and hence it can be judged to be a reliable DFT-based approximation.
- **The first demonstration of very high spin polarization generated at the fullerene-transition metal compound ($C_{60}Co_5$) / magnetic metal (Co) interface** [16, 24] Magnetotransport properties of granular C_{60}-Co films composed of the C_{60}-Co compound ($C_{60}Co_5$) matrix and Co nanoparticles were investigated at low temperatures. It was suggested that the transport process is dominated by the long-range cooperative tunneling (cotunneling) in

the Coulomb blockade regime. By taking account of the enhancement of the tunneling magnetoresistance (TMR) by cotunneling, the tunneling electrons generated at the C_{60}-Co compound / Co nanoparticle interface were shown to possess a remarkably higher spin polarization (80%) than that in Co nanoparticles (35%).

- **Finding of the interlayer exchange coupling in the C_{60}-Co compound / ferromagnetic metal bilayer structures** [19] Co and Ni *L*-edge XMCD spectroscopies were employed to investigate the electronic and magnetic structures of the C_{60}-Co compound / Ni bilayers. A few-several nm thick C_{60}-Co compound layer on the Ni(111) surface was found to show intense XMCD signals attributed to the localized Co *d*-electron spins even under the remanent magnetization of the Ni layer. It was suggested that the region of the C_{60}-Co compound within 3 nm from the interface is ferromagnetically coupled with Ni due to the indirect exchange interactions mediated by C_{60}, possibly relevant to the interlayer charge transfer. The long-range ferromagnetic coupling firstly reported on this study would offer a promising route for the efficient control of spin-transport in molecule- and nanocarbon-based media.



Schematic drawings of the C_{60}-Co compound / Ni(111) bilayer structure and the long-range ferromagnetic coupling at the C_{60}-Co compound / Ni interface. The long-range coupling is associated with the exchange interaction in the C_{60}-Co compound and also the charge transfer from Ni to the C_{60}-Co compound.

- **Prediction of the spin-filtering effect according to the C_{60}-Co compounds by the X-ray absorption near edge structure and magnetic circular dichroism (XANES and XMCD) analyses** [17, 23] Co *K*- and *L*-edge XANES and Co *L*-edge XMCD calculations were carried out in order to analyze the atomic and electronic structures of the C_{60}-Co compounds ($C_{60}Co_x$). It was clarified that the microstructure develops with the Co concentration, x. In the Co dilute region ($x < 2$), each Co atom is surrounded by three C_{60} and has the spin magnetic moment in the range 0.5–0.9μ_B. In the Co dense region ($4 < x$), the $4C_{60}$-4Co model; one Co_4 tetragonal cluster is surrounded by four C_{60}, gives the good agreement with the XANES. It was shown that spin quintet ($4\mu_B$) with the ferromagnetic order is in the lowest energy and the band gap for the minority spin is smaller than that for the majority spin. From this reason, one can expect the spin-filtering effect as a possible origin of the high spin polarization in the granular C_{60}-Co films.

Goals

- Realization of highly efficient spin-injection into graphene sheet employing the graphene- / molecule-ferromagnetic metal hybrid structures as electrodes.
- Establishments of new growth methods of the large area graphene sheets on ferromagnetic metals and semiconductors.
- Elucidation of the spin-transport processes and mechanisms in the molecular spintronic devices by using quantum beams.

Originality

Our studies are based on original and advantageous viewpoints for the materials and device designs. As for the designs of graphene spin devices, we propose the hybrid structures of graphene / molecules and ferromagnetic metals as a new promising electrode to realize highly efficient spin-injection into and spin-manipulation on the graphene sheet. We have conceived the present idea stimulated by our recent studies on the electronic / spin states in the hybrid structures or at the interfaces of molecules and ferromagnetic metals, and also on the mechanism of the giant TMR effect. In materials designs, we will challenge to establish a novel growth method of graphene sheets on ferromagnetic metal thin films with large area together with controlling the layer number. This method can facilitate to develop graphene spin devices composed of a well-defined graphene sheet as an ideal spin-transport medium and the hybrid structured electrodes for the well-controlled spin-transport.

Our idea concerning the hybrid structures of graphene / molecule and ferromagnetic metals stems from our own pioneering approach into the molecule-level materials science in the boundary between organic and inorganic substances. Our research procedure to investigate the spin-transport properties with the originally designed spectroscopic techniques will provide us original and unique opportunities for the cutting-edge scientific discoveries. We have already demonstrated the validity of this procedure on ascertaining the spin-transport process about the fullerene-cobalt films.

Our challenges based on the unique ideas and approach will achieve a breakthrough against the problems in the control of spin-transport properties facing the molecular spintronics study and will lead the way to the further functionalization.

Feasibility

Our research group has a unique potential based on the abundant experiences on materials science, especially about the investigation of structure evolutions in the molecule-metal hybrid systems, their electronic structures and the device properties as represented by the study on the C_{60}-Co systems (e.g., S. Sakai et al., *Appl. Phys. Lett.* **89**, 113118-1-3 (2006) and ref. 19). This allows us to conduct challenging studies in the field of molecular spintronics with a remarkable contrast to other studies in this field where investigations have been conducted being almost biased toward the device properties without knowledge on the microscopic materials states which would be indispensable to discuss the process and electronic origin of spin-transport.

Before the 2010 fiscal year, our group has firstly established an original experimental system to perform comprehensive investigations on the microscopic electronic / spin states and also the

spin-dependent transport properties of the graphene- / molecule-based hybrid structures or devices in the field of molecular spintronics. This system is composed of **i) the UHV molecular beam (MBE) apparatus** with the inorganic and organic MBE, UHV-CVD, *in-situ* micro-device fabrication systems and the Auger and electron-energy loss electron spectroscopy system for sample characterization, and **ii) the synchrotron soft X-ray absorption (XAS) and XMCD spectroscopy apparatus** equipped with a UHV sample transfer system from the MBE apparatus. This UHV sample transfer system can be connected to the soft X-ray beam lines in Photon-Factory (KEK, Tsukuba) and makes it possible to study the structure and property of samples in the atomistic scale without unintentional contamination and degradation by the atmosphere. In the 2010 and 2011 fiscal years, we have further developed **a new apparatus for the depth-resolved XAS and XMCD spectroscopy**. This apparatus enables us a comprehensive investigation not only on the electronic and spin states but also on the local atomic structures at and near the interface in the layered hybrid structures (e.g., graphene / ferromagnetic metal) with angstrom depth-resolution. We have also developed **iii) a high-vacuum magnet microprobe station** equipped with two pairs of the electromagnets for applying the parallel and perpendicular magnetic fields which are necessary for analyzing the spin-dynamics and properties of carriers in devices and with the UHV sample transfer system from the MBE apparatus also.

Scientific and social outcomes

Molecular spintronics study is reasonably believed to contribute to the advancement of information technologies in the future by developing highly functional and high density spintronics devices beyond the present limits. From the fundamental viewpoint, the success in large area growth of the graphene sheet with a well-defined microstructure will contribute to widely ranged applications of graphene as a foundational electronic substance like silicon.

International cooperation

Our group is ready to open for international cooperation at any time, and we have already cooperated with two research groups in Russia and India concerning the studies on the ion-irradiation effects to the fullerene-related materials and the structural characterizations of oxide nanoparticles. From the 2010 fiscal year, one Russian theoretical scientist (Dr. Pavel V. Avramov) belongs to our group as a research fellow and deals with the calculations for the graphene-related nanomaterials and graphene-based hybrid structures aimed at applications for spintronics. Our proposal for the FY 2012 JSPS Postdoctoral Fellowship (Short-Term) is also approved by Japan Society for the Promotion of Science (JSPS) and a young Russian theoretical scientist (Dr. Pavel B. Sorokin) will join our group in the 2012 fiscal year. Furthermore, we intend to consider new cooperation particularly about spectroscopic study on molecular spintronics.

Publication list, Invited talks, Awards, Press release, etc.

Papers

1) Thermal Effect on Structure Organizations in Cobalt-Fullerene Nanocomposition, V. Lavrentiev, J. Vacik, H. Naramoto, S. Sakai, *J. Nanosci. & Nanotech.* **10**, 2624-2629 (2010).
2) RBS study of diffusion under strong centrifugal force in bimetallic Au / Cu thin films, T. Hao, M.

Ono, S. Okayasu, S. Sakai, K. Narumi, Y. Hiraiwa, H. Naramoto, Y. Maeda, *Nucl. Instr. and Meth. in Phys. Res. B* **268**, 1867-1870 (2010).

3) Composition dependence of magnetic and magnetotransport properties in C_{60}-Co granular thin films, I. Sugai, S. Sakai, Y. Matsumoto, H. Naramoto, S. Mitani, K. Takanashi, Y. Maeda, *J. Appl. Phys.* **108**, 063920-1-6 (2010).
4) Effect of ion irradiation on structure and thermal evolution of the Ni-C_{60} hybrid systems, J. Vacik, V. Lavrentiev, V. Vorlicek, L. Bacakova, K. Narumi, *Nucl. Instr. and Meth. in Phys. Res. B* **268**, 1976-1979 (2010).
5) Observation of intermolecular N-I interaction during the growth of a 4-cyano-4'-iodobiphenyl molecular crystal on GeS(001), R. Sumii, M. Sakamaki, Y. Matsumoto, K. Amemiya, K. Kanai, K. Seki, *Surf. Sci.* **604**, 1100-1104 (2010).
6) Interface Properties of Metal / Graphene Heterostructures Studied by Micro-Raman Spectroscopy, S. Entani, S. Sakai, Y. Matsumoto, H. Naramoto, T. Hao, Y. Maeda, *J. Phys. Chem. C* **114**, 20042-20048 (2010).
7) Comparison of secondary ion emission yields for poly-tyrosine between cluster and heavy ion impacts, K. Hirata, Y. Saitoh, A. Chiba, K. Yamada, Y. Takahashi, K. Narumi, *Nucl. Instr. and Meth. in Phys. Res. B* **268**, 2930-2932 (2010).
8) Atomic Structure and Energetic Stability of Complex Chiral Silicon Nanowires, P. V. Avramov, S. Minami, S. Irle, L. A. Chernozatonskii, K. Morokuma, *J. Phys. Chem. C* **114**, 14692-14696 (2010).
9) Theoretical Study of Atomic Structure and Elastic Properties of Branched Silicon Nanowires, P. B. Sorokin, A. G. Kvashnin, D. G. Kvashnin, J. A. Filicheva, P. V. Avramov, A. S. Fedorov, *ACS Nano* **4**, 2784-2790 (2010).
10) Theoretical Study of Elastic Properties of SiC Nanowires of Different Shapes, P. B. Sorokin, D. G. Kvashnin, A. G. Kvashnin, P. V. Avramov, L. A. Chernozatonskii, *J. Nanosci. & Nanotech.* **10**, 4992-4997 (2010).
11) Beta-phase silicon nanowires: structure and electronic properties, P. B. Sorokin, P. V. Avramov, V. A. Demin, L. A. Chernozatonskii, *JETP Letters* **92**, 352-355 (2010).
12) Determination of silicon vacancy in ion-beam synthesized β-$FeSi_2$, Y. Maeda, T. Ichikawa, T. Jonishi, K. Narumi, *Physics Procedia* **11**, 83-86 (2011).
13) Size-derived effects in electronic and elastic properties of diamanes, L. A. Chernozatonskii, P. B. Sorokin, A. A. Kuzubov, B. P. Sorokin, A. G. Kvashnin, D. G. Kvashnin, P. V. Avramov, B. I. Yakobson, *J. Phys. Chem. C* **115**, 132-136 (2011).
14) Interface Properties of Ag and Au / Graphene Heterostructures Studied by Micro-Raman Spectroscopy, S. Entani, S. Sakai, Y. Matsumoto, H. Naramoto, T. Hao, Y. Maeda, *Jpn J. Appl. Phys.* **50**, 04DN03-1-5 (2011).
15) Ab initio LC-DFT study of graphene, multilayer graphenes and graphite, P. V. Avramov, S. Sakai, S. Entani, Y. Matsumoto, H. Naramoto, *Chem. Phys. Lett.* **508**, 86-89 (2011).
16) Effect of cotunneling and spin polarization on the large tunneling magnetoresistance effect in granular C_{60}-Co films, S. Sakai, S. Mitani, I. Sugai, K. Takanashi, Y. Matsumoto, S. Entani, H. Naramoto, P. Avramov, Y. Maeda, *Phys. Rev. B* **83**, 174422-1-6 (2011).
17) Multiplet Scattering Approach to XAS for Co-C_{60} Films, I. Hojo, Y. Matsumoto, T. Maruyama, S. Nagamatsu, S. Entani, S. Sakai, T. Konishi, T. Fujikawa, *Photon Factory News* **29**, 20-25 (2011).

(*in Japanese*)
18) Thermo-dynamical contours of electronic-vibrational spectra simulated using the statistical quantum–mechanical methods, V. Pomogaev, A. Pomogaeva, P. Avramov, K. J. Jalkanen, S. Kachin, *Theor. Chem. Acc.* **130**, 609-632 (2011).
19) Ferromagnetic interlayer coupling in C_{60}-Co compound / Ni bilayer structure, Y. Matsumoto, S. Sakai, S. Entani, Y. Takagi, T. Nakagawa, H. Naramoro, P. Avramov, T. Yakoyama, *Chem. Phys. Lett*. **511**, 68-72 (2011).
20) Ion channeling study of epitaxy of iron based Heusler alloy films on Ge(111), Y. Maeda, K. Narumi, S. Sakai, Y. Terai, K. Hamaya, T. Sadoh, M. Miyao, *Thin Solid Films* **519**, 8461-8467 (2011).
21) Determination of silicon vacancy in ion-beam synthesized β-$FeSi_2$, Y. Maeda, T. Ichikawa, T. Jonishi, K. Narumi, *Physics Procedia* **11**, 83-86 (2011).
22) Relative Isomer Abundance of Fullerenes and Carbon Nanotubes Correlates with Kinetic Stability, A. S. Fedorov, D. A. Fedorov, A. A. Kuzukov, P. V. Avramov, Y. Nishimura, S. Irle, H. A. Witek, *Phys. Rev. Lett.* **107**, 175506-1-5 (2011).
23) Local structures and magnetic properties of fullerene-Co systems studied by XAFS and XMCD analyses, I. Hojo, A. Koide, Y. Matsumoto, T. Maruyama, S. Nagamatsu, S. Entani, S. Sakai, T. Fujikawa, *J. Electro. Spec. Relat. Phenom* **185**, 32-38 (2012).
24) Bias voltage dependence of tunneling magnetoresistance in granular C_{60}-Co films with current-perpendicular-to-plane geometry, S. Sakai, S. Mitani, Y. Matsumoto, S. Entani, P. Avramov, M. Ohtomo, H. Naramoto, K. Takanashi, *J. Magn. Magn, Mater.* **324**, 1970-1974 (2012).
25) Precise control of single- and bi-layer graphene growths on epitaxial Ni(111) thin film, S. Entani, Y. Matsumoto, M. Ohtomo, P. V. Avramov, H. Naramoto, S. Sakai, *J. Appl. Phys.*, *in press and preparing a press release April 2012.*
26) Structure determination of self-assembled monolayer on oxide surface by soft-X-ray standing wave, Y. Baba, A. Narita, T. Sekiguchi, I. Shimoyama, N. Hirao, S. Entani, S. Sakai, *e-Journal of Surf. Sci. Nanotech.*, *in press*.
27) Quasi-monochromatic pencil beam of laser-driven protons generated using a conical cavity target holder, M. Nishiuchi, A. S. Pirozhkov, H. Sasaki, K. Ogura, T. Esirkepov, T. Tanimoto, M. Kanasaki, A. Yogo, T. Hori, A. Sagisaka, Y. Fukuda, Y. Matsumoto, S. Entani, S. Sakai, C. Brenner, D. Neely, T. Yamauchi, S. V. Bulanov, K. Kondo, *Physics of Plasmas*, *in press*.

Books & Reviews

1) The elastic properties of branched silicon nanowires: the theoretical study, P. B. Sorokin, A. G. Kvashnin, D. G. Kvashnin, P. V. Avramov, L. A. Chernozatonskii, *Handbook of Chemistry, Biochemistry and Biology: New Frontiers*, 331-336, Nova Publishers (2010).
2) The study of the atomic structure and elastic properties of the silicon carbide nanowires, P. B. Sorokin, A. G. Kvashnin, D. G. Kvashnin, P. V. Avramov, L. A. Chernozatonskii, *Handbook of Chemistry, Biochemistry and Biology: New Frontiers*, 325-330, Nova Publishers (2010).
3) Spin polarization of graphene on Ni single crystal substrate (Chapter 10), Y. Yamauchi, S. Entani, *Functions of Graphene and Its Prospects on Applications*, CMC books (2010). (*in Japanese*)

Invited Talks

1) Spin polarization of organic molecules on magnetic surfaces probed by a metastable helium beam, Y. Yamauchi, *18th International Workshop on Inelastic Ion-Surface Collisions*, Gatlinburg, USA (2010).
2) Spintronic applications and structure designs of molecules and nanocarbons by quantum-beams, S. Sakai, *5th Takasaki Advanced Radiation Research Symposium*, Takasaki, Japan (2010). (*in Japanese*)
3) Spin-dependent transport and electronic / magnetic structures in fullerene-magnetic metal systems, S. Sakai, *The 32th Special Meeting on Spin-electronics of the Magnetic Society of Japan*, Kyoto, Japan (2010). (*in Japanese*)
4) Ion-Beam Analysis of Bombardment Effect of 10-to-100-keV C_{60} Ions on a Si Surface, K. Narumi, *11th Special Meeting on Surface and Interface Analysis by Ion-Beam*, Nagoya, Japan (2010). (*in Japanese*)
5) Spin states of molecules and nanocarbons analyzed by X-ray magnetic dichroism spectroscopy, Y. Matsumoto, *Photon Factory Meeting*, Tsukuba, Japan (2011). (*in Japanese*)
6) Analysis of electronic and spin states in nanocarbon- and molecule-magnetic metal systems for spintronic applications, Y. Matsumoto, *17th Meeting on Silicide Semiconductors and Related Materials*, Tokyo, Japan (2011). (*in Japanese*)
7) Growth of graphene on magnetic metal surface and its spin polarization measurements, S. Entani, *17th Meeting on Silicide Semiconductors and Related Materials*, Tokyo, Japan (2011). (*in Japanese*)
8) Spin states of molecules and nanocarbons analyzed by X-ray magnetic dichroism spectroscopy, Y. Matsumoto, *Photon Factory Meeting*, Tsukuba, Japan (2012). (*in Japanese*)

Awards

1) Theoretical analysis of geometrical and magnetic structures of C_{60}-Co thin films based on XAS, I. Hojo, Student Incentive Award, *13th meeting of the Japanese XAFS society*, Shiga, Japan (2010).
2) Self organization of FeGe/FeSi/FeGe layered structures on Ge and their electrical conduction properties, B. Matsukura, Y. Hiraiwa, T. Nakajima, K. Narumi, S. Sakai, T. Sadoh, M. Miyao, Y. Maeda, Best Poster Award, *Asian School-Conference on Physics and Technology of Nanostructured Materials*, Vladivostok, Russia (2011).

Research Subject (3)

Spin manipulation and material design by combining Spintronics, mechanical engineering and NMR method

Group: Research Group for Mechanical Control of Materials and Spin Systems

Member (Visiting Leader) Eiji Saitoh
(Researchers) Satoru Okayasu (Sub Leader),
Masao Ono,
Rie Haruki, Hiroyuki Chudo

Objective

Expand spintronics frontier using mechanical motion and NMR method.

Summary of the Pre-review

This group utilizes the unique expertise in high-speed rotors at JAEA with the spintronics to develop a totally novel idea of studying the coupling between electron spin and mechanical rotation. The idea is excellent and quite exciting. It is very important, however, that Prof. Saitoh becomes much more closely engaged in the ASRC research effort with appropriate financial compensation. The current level of two days a month is hardly sufficient to ensure the success. Without his leadership and expertise in spintronics this group will not be able to fulfill its promise.

Response

The following procedures will be taken to maintain a close contact between GL and other members, such as utilizing e-mail, video meeting, on-site visit to Tohoku Univ., in addition to the periodical meeting.

We also keep a close contact to Mori's group to discuss our experimental results.

Progress

Novel method for spin-current generation

In past studies, spin current generation relies on the injection of a spin-polarized current across junctions. We found spin pumping method before starting this JAEA project. Spin pumping exploits angular-momentum conservation of electron spin, which allows spin-current generation from a variety of angular momentum: magnetization, nuclear spin, and lattice (body) motion. In this project, we explore this mechanism to integrate the variety of angular momentum into spintronics.

We began with examining the versatility of spin pumping; the result shows that the spin pumping is basically free from impedance mismatching problem. This is a crucial piece of information since we can use various materials ranging from insulators to metals as a spin-current receiver (Nature

materials (2011), Nature communications (2012)).

By using this knowledge, then, we moved to spin-current generation from lattice motion. Lattice motion is categorized into(1) internal lattice dynamics (k≠0):mechanical vibration, and (2) a k=0 motion accompanying a motion of the center of gravity. First, we showed the spin injection from (1) internal lattice dynamics (k≠0) (Nature materials (2011)) and moved to that from (2) a k=0 motion accompanying a motion of the center of gravity (unpublished). We summarize the main results in the following.

1. Versatile spin current injection using spin pumping

We began with examining the versatility of spin pumping. Injection of spin currents into solids is crucial for exploring spin physics and spintronics. There has been significant progress in recent years in spin injection into semiconductors, which uses tunnel barriers to circumvent the impedance mismatch problem; the impedance mismatch between ferromagnetic metals and high-resistivity materials drastically limits the spin-injection efficiency. However, because of this problem, there is no route for spin injection into semiconductors through low resistivity interfaces, i.e., ohmic contacts, even though it promises easy and versatile pathway for spin injection into high resistivity materials.

The impedance mismatch problem arises from the fact that spins are injected by carrier transport across a ferromagnetic metal / semiconductor (FM/SC) interface. Thus, it seems natural to consider that this problem disappears when spins are injected directly into the SC layer without using charge transport across the interface; the driving force for the spin flow (not the charge carrier flow) is expected to offer a way for versatile spin injection free from the impedance mismatch problem. In this work, we experimentally demonstrate efficient spin injection into semiconductors through ohmic contacts using dynamical spin injection. The spin pumping, generation of pure spin currents from magnetization precession provides a powerful way for direct spin injection. The spin-angular momentum of the precessing magnetization in the FM layer is transferred to the carriers in the SC layer via dynamical exchange interaction at the FM/SC interface, inducing a pure spin voltage, the potential acting on spins not on charges, in the SC layer. This enables spin injection into both p- and n-type GaAs from NiFe through both ohmic and Schottky contacts in a NiFe/GaAs interface even at room temperature. Furthermore, we demonstrate that the spin exchange interaction can be controlled electrically by applying a bias voltage across a NiFe/GaAs interface, enabling electric tuning of the spin-pumping efficiency. The result means that we can use various materials

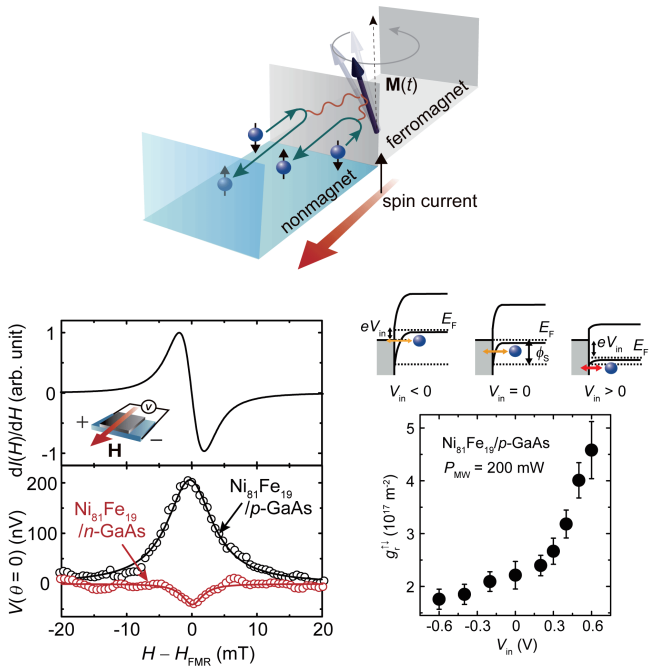


Fig. 1. Dynamical spin injection.

ranging from insulators to metals and also liquids as a spin-current receiver (Nature materials (2011), Nature communications (2012)).

2. Spin current injection from mechanical vibration

Lattice motion is categorized into(1) internal lattice dynamics (k≠0):mechanical vibration, and (2) a k=0 motion accompanying a motion of the center of gravity. By using the spin pumping, we measured spin-current generation from (1) lattice vibration.

A spin pumping effect refers to the transfer of spin-angular momentum from magnetization dynamics in a ferromagnet to conduction-electron spins in an attached paramagnet; when a magnetization motion in the ferromagnet is excited, a spin current is pumped out of the ferromagnet into the paramagnet. The spin pumping is of immense importance in spintronics since it allows the generation of pure spin currents using a simple ferromagnetic/paramagnetic bilayer structure.

The conventional spin pumping has been operated by microwaves under ferromagnetic resonance or spin-wave resonance conditions, where a steady magnetization motion is maintained in a ferromagnet. This microwave-driven spin pumping has been observed in a variety of sample systems ranging from magnetic metals and semiconductors to magnetic insulators covered with paramagnets.

Here, we have demonstrated a new type of spin pumping: acoustic spin pumping (ASP) (Nature materials (2011)). We showed that spin currents are generated by an external injection of sound waves into a ferromagnet and that the sound-wave-driven spin currents can be detected electrically by means of the inverse spin-Hall effect (ISHE) in a paramagnetic metal attached to the ferromagnet (Figs. 2(a) and 1(b)). The ISHE induced by the ASP was found to be detected by measuring a voltage in the Pt layer at the piezoelectric resonance frequency of the actuator coupled with the paramagnetic metal (Pt)/ferrimagnetic insulator ($Y_3Fe_5O_{12}$: YIG) hybrid structures. The frequency-dependent measurements enable us to separate the ASP-induced signals from extrinsic heating effects (Figs. 2(c) and 1(d)). Our model calculation based on the linear response theory provides us with a qualitative and quantitative understanding of the ASP in the Pt/YIG system; the ASP is operated by thermal energy transfer from sound waves to spin waves, or magnons, in a ferromagnet.

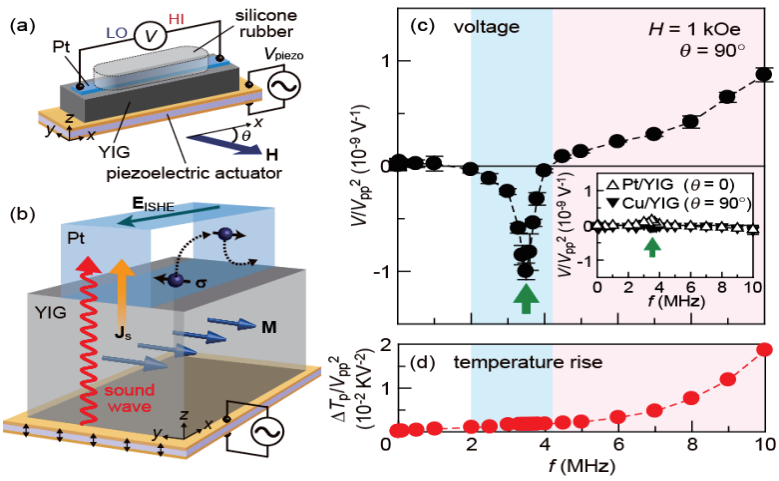


Fig. 2(a) A schematic illustration of the Pt/YIG sample. (b) The ASP and the ISHE in the Pt/YIG sample. (c) Frequency dependence of the ISHE voltage in the Pt/YIG sample. (d) Frequency dependence of the temperature rise of a piezoelectric actuator.

By using a Pt/YIG lateral structure combined with a piezoelectric wedge transducer, we also show that the ASP can be driven not only by bulk sound waves but also by surface acoustic waves (Fig. 3).

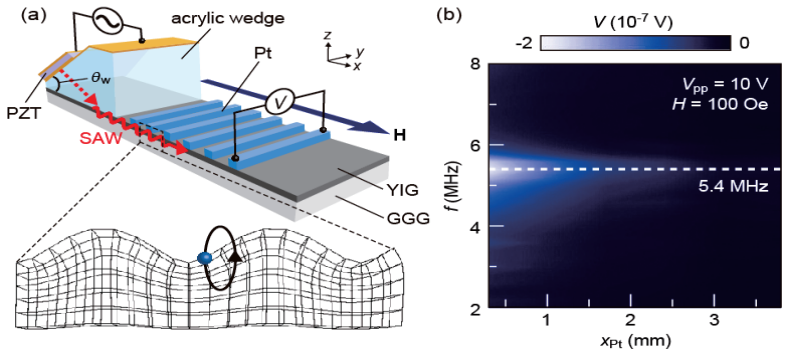


Fig. 3 (a) A schematic illustration of the Pt/YIG lateral structure. (b) The contour plot of the voltage signal in the Pt/YIG sample as functions of the Pt-wire position and the frequency.

Since the ASP enables simple and versatile spin-current generation from sound waves, it will be useful in basic spintronics researches and spin-based device applications.

3. Spin current injection from mechanical motion accompanying a center of gravity motion

Now we moved to the exploration of spintronic effects combined with a k=0 motion accompanying a motion of the center of gravity. The study was running in the following two-stage approach to realize the transferring mechanical angular momentum to spin angular momentum.

a) In a rotational frame, spin pumping is equivalent in part to the Barnett effect. The concept of the Barnett effect is simply described in figure 4; an inverse effect of the Einstein - de Hass effect. As a first stage, we explored the Barnett effect in magnets utilizing our high-speed rotation system, where we exploit the critical enhancement of magnetic susceptibility near a magnetic transition point. The aim of this experiment is to see the feasibility of transferring mechanical angular momentum to magnetic angular momentum using our rotation system.

b) As a second stage, by using the above knowledge of the spin pumping, we designed an implementation that enables a spin current injection from a mechanical motion accompanying a center of gravity motion into solid, which is the utilization of solid/liquid interface.

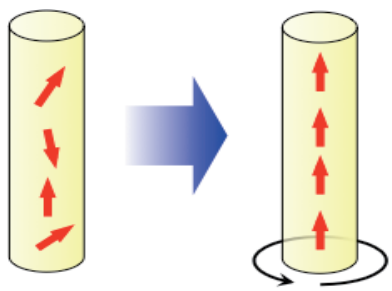


Fig. 4 The concept of the Barnett effect.

We measured deference of magnetization between rotated and non-rotated samples which had been annealed across a magnetic transition where the magnetic susceptibility is critically enhanced.

Figure 5 shows the present experimental equipment. The system comprises a high-speed rotation system and an infrared introduction-heating unit. A sample can be heated up to 600℃ at a rotational speed up to 2kHz. The sample is a ferrite magnet, which has a column shape with a diameter of 1mm and a height of 5mm. The magnitude of environmental magnetic field was controlled to be less than 0.01 Oersted.

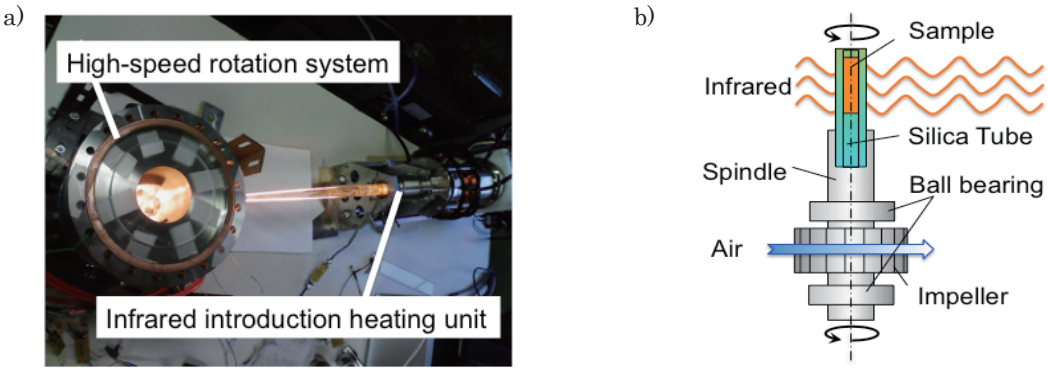


Fig. 5 The equipment for Barnett effect observation experiment. a) photograph, b) schematic.

Figure 6 is a plot of magnetization of a single sample after the series of experiments to observe the Barnett effect. The measurement of the magnetization of the sample was carried out using a gauss meter. Square plots are the magnetization of the sample in the case only after heat treatment, in which the sample is cooled after heated to 500℃ above Curie point of 480℃. Circular plots are the magnetization of the sample in the case heat treatment while rotating, in which the sample is cooled after heated up to 500℃ above Curie point of 480℃ in the rotational speed of 0.5kHz. The values of most of all circular plots are smaller than those of square plots. This implies that the rotation-induced-effective magnetic field modulates the net magnetization, consistent with the Barnett effect affected by the magnetic transition instability.

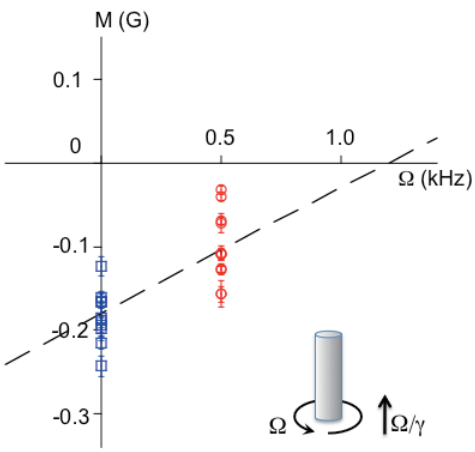


Fig. 6 Magnetization of a sample by a series of the experiment to observe Barnett effect. The dotted line represents $M=\chi(\Omega/\gamma+H_{env.})$. (Sample: anisotropic ferrite magnet ϕ 1 x 5mm, $H_{env.}$: -0.01Oe, Ω:0.5kHz)

We also carried out a spin injection experiment using a fluid motion, which is an experiment based on a theoretical prediction that is a collaboration with Mori group. We have predicted that spin currents are injected from a mechanical motion of a fluid into a film attached to the fluid if it has vorticity gradient, e.g. it is yielded in Stokes flows.

We have developed a method in which large vorticity can be yielded in a fluid using a gas actuator on a Pt thin film that is put on a substrate. By using this method, we have observed spin current signals in the thin film by using the inverse spin-Hall effect (ISHE). Figure 7 shows the alteration of voltage in the fluid spin injection experiment using a liquid metal. The voltage appears when a liquid metal flows on the Pt thin film pattern on a substrate and the polarity of the voltage changes with the direction of the flows. The correlation between the flow direction and the polarity is consistent with the above prediction and ISHE.

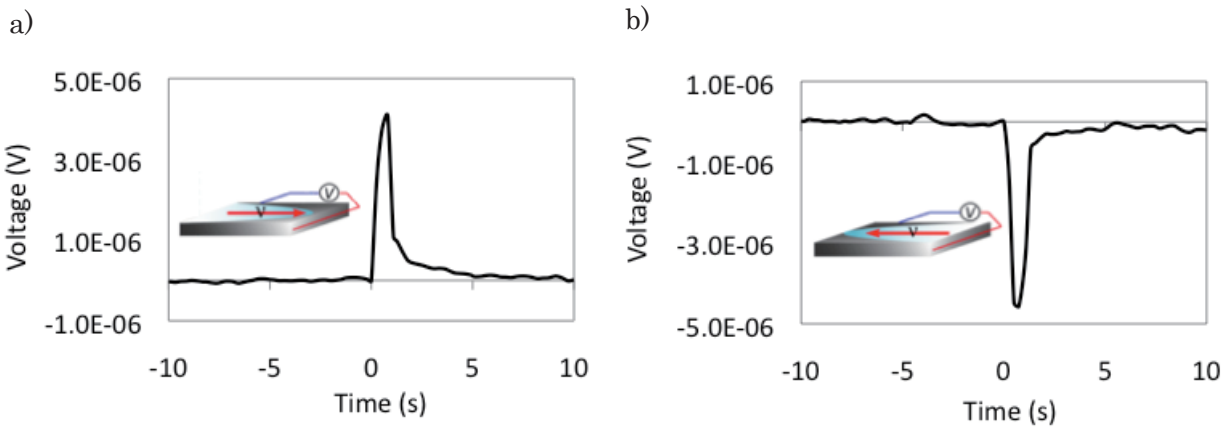


Fig. 7 Alteration of voltage in the fluid spin injection experiment using a liquid metal. (Flow direction of the liquid: a) minus to plus terminal of nano-voltmeter, b) plus to minus terminal of nano-voltmeter.

4. Nuclear Spintronics by Ferromagnetic Nuclear Resonance (FNR)

a) Spin pumping stimulated by the FNR in Pt/Co_2MnSi hetero junction

The transfer of spin angular momentum from the precessing localized spin to the conduction electron is a spin pump. The spin pump method from a ferromagnetic magnetization has already been established, and it is used as a basic technique of the spin current generation. Nonetheless, the microscopic mechanism has not elucidated yet, particularly underlying physics near the interface. In order to go further step to understand the phenomena, we have been trying to generate a spin current using the spin pumping from resonating nuclear spins.An experimental strategy in this category is a rather simple minded, namely we try to detect a current in the nonmagnetic metallic layer attached to a ferromagnetic layer via the ISHE. Here the spin pumping proceeds by resonating nuclear spin (Ferromagnetic Nuclear Resonance (FNR)) which coupled strongly to the magnetic moment of electrons via the hyperfine coupling in the order of 10~100 T/μ_B.

The ferromagnetic layer was chosen on Heusler compounds Co_2MnSi, because it contains ^{59}Co and ^{55}Mn nucleus whose natural abundances are 100%, good for FNR. A spin current generated by the

spin pumping that is driven either by the ^{59}Co and ^{55}Mn FNR is detected by the ISHE in the Pt layer.

Figure 8 shows the schematic illustration of the setup for the measurement of spin pumping using ^{59}Co and ^{55}Mn FNR. The sample is an array of Pt(7nm)/Co_2MnSi(20nm) thin rectangular with width of 0.8×9mm in size. These films were wired in series fashion in order to obtain larger voltage arising from the ISHE. The sample assembly was inserted into a RF-coil, where the RF field for FNR was applied parallel to the electrodes on the Pt layer. In order to align the ferromagnetic domains, 270 Oersted fields were applied within the film plane and were rotate with respect to the direction of the RF field.

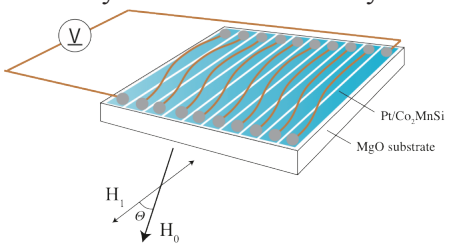


Fig. 8 Schematic image of the sample set-up for spin pump measurement.

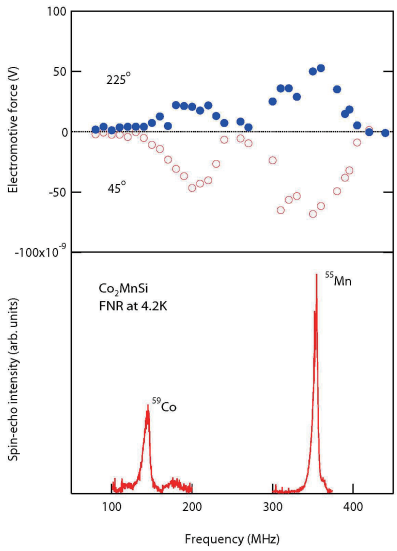


Fig. 9 Frequency dependence of the potential difference between electrodes on Pt film (upper panel). ^{59}Co and ^{55}Mn FNR spectra in Co_2MnSi (lower panel).

Figure 9 displays the FNR spectra associated with the ^{59}Co and ^{55}Mn nuclei in Pt(7nm)/Co_2MnSi(20nm) and the fractional change in the voltage across the FNR frequencies for θ=45° and 225° (θ being angle between the external field and the RF field). The electromotive force has two broad peaks over the frequency range between 100 and 500 MHz, corresponding to the ^{59}Co and ^{55}Mn FNR spectra. Although these peaks are broaden compared with the FNR spectrum and the peak frequency is shifted from the FNR spectrum especially in ^{59}Co FNR, this is assuring that FNR is really inducing a spin current into the Pt layers.

In Fig. 10, we show the angular dependence of the FNR driven electromotive force at 350 MHz (center for ^{55}Mn FNR frequency). In general, the angular dependence of electromotive force due to the spin pumping is expected to be maximum at π/2×(2n+1) (n being an integral number) degrees on this setup. Nevertheless, the observed one has the maxima at the π/4+π/2×n.

This unusual angular dependence may come from a special shape of the film or interplay between unique angular dependence of FNR excitation and the spin pumping. We plan to do the same kind of measurements using a disc shape sample to avoid any geometrical shape anisotropy that may obstruct the analysis.

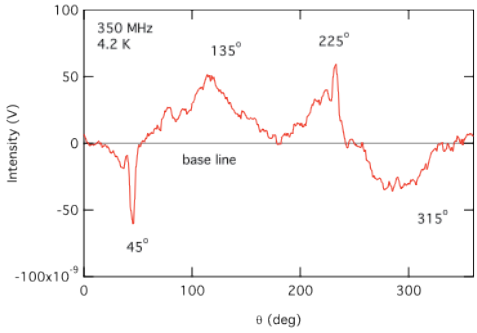


Fig. 10 Angular dependence of the potential difference between electrodes on Pt film.

b) FNR detection of induced magnon current in Pt/YIG bilayer system.

In this project, we aimed to obtain an evidence for the spin injection from nonmagnetic metals to

ferromagnetic metals or insulators by measuring a change in the FNR parameters such as the nuclear magnetic relaxation time. To do this, we have attempted a feasible experiment using a bilayer metal/ferromagnetic insulator system. The reason for this is being the following.

The most important fact to be taking into account for designing the experiment is that the FNR relaxation is to be sensitive to a small change of the magnetic excitations during the spin injection. This can be realized in the FNR in ferromagnetic insulators where the only three magnon realization process is involved, free form a relaxation through the conduction electrons. On the other hand, it is well established by now that a spin current in the insulating ferromagnets (so called "magnon current") can be injected from the electron current in a metallic layer. This magnon current is expected to create a new relaxation channel in the ferromagnetic insulating layer.

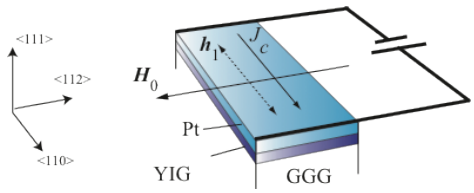


Fig. 11 Schematic illustration of the sample set-up for FNR relaxation measurement.

Under the above mentioned scenario in mind, we have started to the ^{57}Fe FNR measurements in Pt(15nm)/YIG(2.4um) bilayer system. The single crystal of the YIG was grown on (111) surface of Gadolinium Gallium Garnet (GGG) and on top of that a Pt layer was deposited current though. The sample schematic is shown in Fig. 11. The typical ^{57}Fe FNR spectra for d- and a- sites in YIG are shown in Fig. 12 where all the detailed structures are well accounted for the anisotropic hyperfine interaction in the ferromagnetic state.

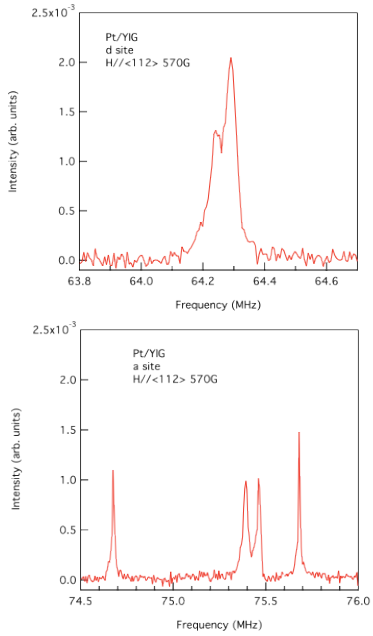


Fig. 12 ^{57}Fe FNR spectrum for d- site (upper panel) and a- site (lower panel) in YIG.

The nuclear spin-lattice relaxation time T_1 has been measured with and without current on the Pt layer for the ^{57}Fe FNR associated with the d-site. The decays of the nuclear magnetization in different values of current are shown in Fig. 13. Despite of the expectation of a large change in T_1 due to the injected magnon current, there exists essentially no effect. Nonetheless, we observed a large change in the spin-echo decay time T_2 when an electric current is applied on the Pt layer (Fig. 14). This is a rather unexpected and surprising result.

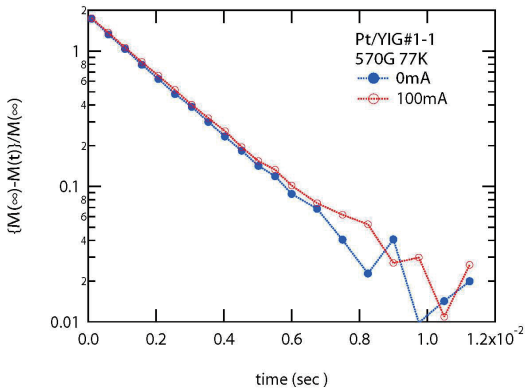


Fig. 13 Decay curves for T_1 measurement.

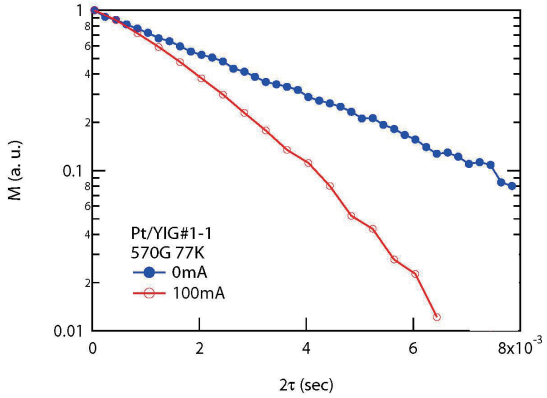


Fig. 14 Spin-echo decay curves for T_2 measurement.

In general, T_1 proves a relaxation accompanied with an energy transfer from the nuclear spin system to the electron spin (in the present case it is magnon) and the energy scale is an order of 10~100MHz. While T_2 is governed without any energy transfer, meaning the neighboring nuclear spin-spin coupling creating a virtual magnon is important. At the same time, the spin echo decay may proceed by a fluctuating random field that looses the phase memory during the FNR signal formation.

Although we do not have a plausible account for the present findings, we believe that this opens a new field to be explored in the "nuclear spintronics". We plan to continue the experiments under more controlled way.

Goals

1. Magnetization manipulation using mechanical rotation.

2. Detection of spin current generation from rotating objects.

3. Detection of spin transfer between nonmagnetic and ferromagnetic layers by NMR.

Originality

This is the first trial to expand the physics of spin current into non-inertial frame.

Feasibility

The classical Barnett effect was already established. We are now developing the theory on quantum mechanical Barnett effect with Mori's group. We design our experiments using the results of this theory.

Scientific and social outcomes

A novel direction of spintronics theory is triggered by present study, and a new experimental concept in which spintronics and nano fluid mechanics is combined is constructed. As a result, the following two effects are born in electronics, the spintronics, and the nano mechanics.

1) The generation technique with new spin current that grips the key to the spintronics application is achieved.

2) The basic data desired in nanotechnology for the efficient drive of the movement in a minute area is obtained.

International cooperation

Collaborative researches with Cavendish Laboratory in University of Cambridge (U.K.), Delft University (Netherlands), Zaragoza University (Spain), TU Kaiserslautern (Germany), Fudan University (China) are running.

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45) Temporal evolution of inverse spin Hall effect voltage in a magnetic insulator-nonmagnetic metal structure, M.B. Jungfleisch, A.V. Chumak, V.I. Vasyuchka, A.A. Serga, B. Obry, H. Schultheiss1, P. A. Beck, A.D. Karenowska, E. Saitoh and B.Hillebrands, *Appl. Phys. Lett.* **99**, 182512_1-182512_3 (2011).

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49) Strong Correlation among Structural, Electronic, and Magnetic Properties of $Sr_2Fe_{1+x}Mo_{1-x}O_6$ ($0 < x < 1$), K. Yoshida, S. Ikeuchi, H. Shimizu, S. Okayasu and T. Suzuki, *J. Phys. Soc. Jpn* **80**, 044716 (2011).
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52) Fast scintillation detectors for high-energy X-ray region, S. Kishimoto, F. Nishikido, R. Haruki, K. Shibuya, M. Koshimizu, Hyperfine Interact., in press.
53) All-oxide system for spin pumping, Z. Qiu,Y. kajiwara, K. Ando, Y. Fujikawa, K. Uchida, T. Tashiro, K. Harii, T. Yoshino, and E. Saitoh, *Appl. Phys. Lett.* **100**, 022402_1-022402_3 (2012).
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55) Radiation effects on film formation and nanostructural changes of iron disilicide thin film, M. Sasase, H. Yamamoto and S. Okayasu, *Nucl. Inst. Method* **B**, **272**, 318-321 (2012).
56) Observation of inverse spin-Hall effect in silicon, K. Ando, and E. Saitoh, *Nature communications* **3**, 629_1-629_6 (2012).
57) Scaling fit of spin pumping in various ferromagnetic materials, T. Yoshino, K. Ando, Y. Kajiwara, H. Nakayama, and E. Saitoh, *J. Appl. Phys.,* **111** 07C502_1-07C502_3 (2012).
58) Electrical determination of spin mixing conductance at metal/insulator interface using inverse spin-Hall effect, R. Takahashi, R. Iguchi, K. Ando, H. Nakayama, T. Yoshino, and E. Saitoh, *J. Appl. Phys.*, **111**, 07C307_1-07C307_3 (2012).
59) Acoustic spin pumping: Direct generation of spin currents from sound waves in $Y_3Fe_5O_{12}$/Pt hybrid structures, K. Uchida, H. Adachi, T. An, H. Nakayama, M. Toda, B. Hillebrands, S. Maekawa, and E. Saitoh, *J. Appl. Phys.,* **111,** 053903_1-053903_8 (2012).
60) Thermal artifact on the spin Seebeck effect in metallic thin films deposited on MgO substrates S. Bosu, Y. Sakuraba, K. Uchida, K. Saito, W, Kobayashi, E. Saitoh, and K. Takanashi, *J. Appl. Phys.,* **111**, 07B106_1-07B106_3 (2012).

Invited Talks

1) Spin Hall and spin Seebeck effects, E.Saitoh, Third International Conference on Nanospintronics Design and Realization, Osaka , Japan (2010).
2) Spin current generation and detection, E.Saitoh, Progress in Spintronics and Graphene Research,

Kavli Institute for Theoretical Physics China at the Chinese Academy of Sciences, Beijing, China (2010).

3) Spin current detection and generation using spin-Hall effect, E.Saitoh, Ninth International Workshop on Surface, Interface and Thin Film Physics, Shanghai , China (2010).
4) Spin Seebeck effect, E.Saitoh, 3rd International Conference on Spintronics Materials and Technology,Illinois, USA (2010).
5) Spintronics and spin current, E. Saitoh, 3rd International Conference on Spintronics Materials and Technology, 29th Electronic Materials Symposium, Shizuoka, Japan (2010).
6) Spin Seebeck Effect, E. Saitoh, MSJ 173th Workshop, Tokyo, Japan (2010).
7) Spin Seebeck effect, E.Saitoh," Gordon Research Conferences, Magnetic Nanostructures, Lewiston, USA(2010).
8) Spin and Heat, E. Saitoh, JPS Science Seminar 2010 "Spintronics", Tokyo, Japan (2010).
9) Spin Current Physics, E.Saitoh, 4th IMR-Korea University Seminar, Seoul, Korea (2010).
10) Spin Hall and spin torque effects in metal and insulator films, E.Saitoh, The 34th Annual Conference on MAGNETICS in Japan, Tsukuba, Japan (2010).
11) Development of dielectric spintronic materials and spin optical function, E. Saitoh, The 71st JSAP Fall Meeting, Nagasaki, Japan (2010).
12) Spintronics in Mott insulators, E. Saitoh, The 71st JSAP Fall Meeting, Nagasaki, Japan (2010).
13) (Plenary Talk)Spin current coupled with charge and heat currents, E. Saitoh, The IEEE 7th International Symposium on Metallic Multilayers MML2010, Berkeley (2010).
14) Spin current generation from insulators and metals, E. Saitoh, Magnetism and Magnetic Materials Conference 2010 , Atlanta, USA (2010).
15) Spin current generation and measurements, E. Saitoh, Surface Science Society of Japan, Hamamatsu, Japan (2010).
16) Spin current physics, E. Saitoh , Spintronics Introductory Seminar JSAP Spintronics workshop, Tokyo, Japan (2010).
17) Spin Seebeck effect in metallic materials, E. Saitoh, SORST Symposium, Tokyo, Japan (2011).
18) Spin current generation from metals and insulators, E.Saitoh, International Symposium "Nanoscience and Quantum Physics 2011",Tokyo, Japan (2011).
19) Spintronics and spin current, E. Saitoh, The 20th young forum for Advanced material science, Funabashi, Japan (2011).
20) Spin current generation from insulators and metals, E.Saitoh, The 3rd Scienceweb GCOE International Symposium ,Sendai, Japan (2011).
21) Spintronics in Mott Insulators, E. Saitoh, PF Workshop, Tsukuba, Japan (2011).
22) Spin pumping and spin Seebeck effects in insulators and metals, E. Saitoh, 2011 Materials Research Society Spring Meeting, San Francisco, USA (2011).
23) Spin Hall effect and its application, E. Saitoh, International Center for Quantum Materials (ICQM), Beigin, China (2011).
24) Spin current generation from magnetic dynamics and heat, E. Saitoh, JSPS York-Tohoku Research Symposium on "Magnetic Materials and Spintronics, York, UK (2011).
25) Spin current generation from magnetic dynamics and heat, E. Saitoh, 5th International Workshop on Spin Current, Sendai, Japan (2011).
26) Spin current and heat: Development for new functional devices using spin currents, E. Saitoh, JST,

Tokyo, Japan (2011).

27) Physics and applications for spin current, E. Saitoh, Science summer seminor, Nagano, Japan (2011).
28) Spin Seebeck effect, E. Saitoh, ASPIMATT school on "Advanced spintronic materials and transport phenomena, Diemerstein, Germany (2011).
29) Spin current generation using heat and magnetic dynamics, E. Saitoh, 2011 OSU Materials Week, Ohio, USA (2011).
30) Fundamental physics on spin current, E. Saitoh, JPS Autumn meeting 2011, Toyama, Japan (2011).
31) Spin current generation using heat and magnetic dynamics E. Saitoh, 2011 International Conference on Solid State Devices and Materials (SSDM), Nagoya, Japan (2011).
32) Possibility of realization for electronic devices using spin current, E. Saitoh, TECH Biz EXPO 2011, Nagoya, Japan (2011).
33) Spin current generation using heat and magnetic dynamics, E. Saitoh, Magnetism and Magnetic Materials Conference 2011, Scottsdale, Arizona (2011).
34) Spin seebeck effect, E. Saitoh, JSAP spintronics seminor, Sendai, Japan (2011).
35) Spin current physics and application, E. Saitoh, Joint Polish-Japanese Workshop: Spintronics-from new materials to applications, Warsaw, Poland (2011).
36) (Plenary Talk) Spin current physics and application, E. Saitoh, The 7th International Conference on Advanced Materials and Devices (ICAMD2011), Jeju, Korea (2011).
37) Spin Current in Metals and Insulators, E. Saitoh, The FIRST-QS2C Workshop on Emergent Phenomena of Correlated Materials, Okinawa, Japan (2011).
38) Spin current and spintronics, E. Saitoh, 15th NAISTSeminor, Nara, Japan (2011).
39) Spin current generation and utilization, E. Saitoh, Spin Caloric Transport, Bad Honnef, Germany (2012).
40) Spin current generation from heat and magnetic dynamics, E. Saitoh, The 2nd ASRC International Workshop on Magnetic Materials and Nanostructures (JAEA), Tokai, Japan (2012).
41) Physics and applications on spin current, E. Saitoh, Sendai, Japan (2012).
42) Spin pumping and spin Seebeck effect, E. Saitoh, American Physical Society March Meeting, Boston, USA (2012).
43) Thermo – acoustic effect in spin current, E. Saitoh, Japan Physical Society Annual Meeting, Kobe, Japan (2012).

Awards

E. Saitoh

Young Scientist Award of the Physical Society of Japan (2011).

The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, The Young Scientists' Prize (2011).

10th FFIT Award (2011).

7th (FY2010) JSPS Prize (2011)

7th Japan Academy Medal Prize (2011).

25th IBM Japan Science Award (2011).

Press Release

2011/08/22

Spin current generation through acoustic wave injection - A path toward the development of new energy-saving electronic devices -

2011/06/27

Discovery of a new spin injection method available into all types of materials -The significant progress for development of next-generation energy-saving devices -

2010/09/27

Thermoelectric Generation from Insulators - Pave the way for the development of green and energy-saving devices -

Research Subject (4)

Research in exotic shell evolution of heavy nuclei

Group Name: **Research Group for Reactions involving Heavy Nuclei**

Members: (GL) S. Chiba (Visiting researcher)
(Researchers) K. Nishio (SL), S. Mitsuoka, I. Nishinaka, H. Koura, Y. Utsuno, H. Makii
(PD, JSPS) S. Ota
(Student) T. Nagayama

Summary of the pre-review

Special techniques which enable the measurement of neutron cross section of unstable heavy nuclei will be developed. The science is excellent and the subject it of great importance to JAEA. However, this project requires long-time commitment to the development of special technique. Acutually it is a continuation of an existing project. In spite of its technical excellencde this project does not sit well with the goal of ASRC as an agile cutting-edge research institute, and should be moved to other technical division within JAEA.

Responce

We have followed the results of the pre-review sincerely, and decided to change our research subject to "exploring shell effects which will appear during exotic shape evolution of the fission process". We have organized a workshop to discuss its physical significance by inviting a number of specialists in nuclear physics. Equipments developed for the surrogate project (our original research subject) can be used effectively for the purpose of the new subjects.

Progress

We have published a total of 23 papers in the 1st FY and 21 in the 2nd FY. Five papers were published on the theoretical foundation of the surrogate method:

[1] S. Chiba and O. Iwamoto, "Verification of the surrogate ratio method", Phys. Rev. C **81**, 044604-1-6 (2010).

[2] Y. Utsuno and S. Chiba, "Multiparticle-multihole states around ^{16}O and correlation-energy effect on the shell gap", Phys. Rev. C **83**, 021301(R)-1-5 (2011).

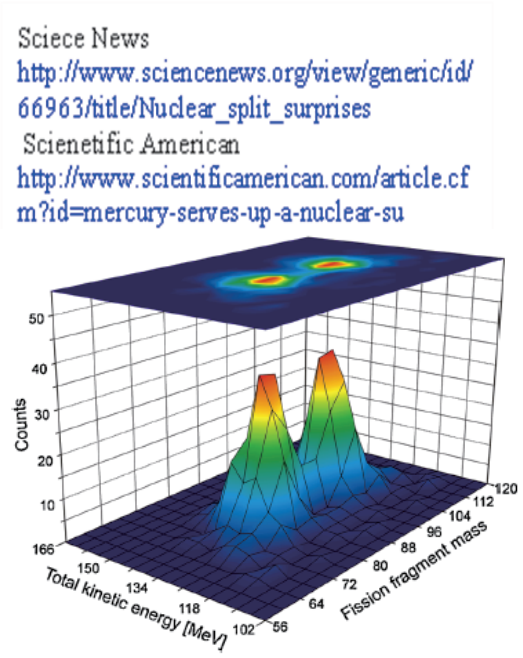
[3] Y. Aritomo, S. Chiba, and K. Nishio, "Dynamical model of surrogate reaction", Phys. Rev. C **84**, 024602-1-10 (2011).

[4] S. Chiba, O. Iwamoto, and Y. Aritomo, "Spin-dependent observables in surrogate reactions", Phys. Rev. C **84**, 054602-1-5 (2011).

[5] K. Ogata, S. Hashimoto, and S. Chiba, "Three-Body Model Calculation of Spin Distribution in Two-Nucleon Transfer Reaction",
J. Nucl. Sci. Technol. **48**, 1337-1342 (2011).

Papers on surrogate experiments were not published yet due to inturruption by the east-Japan earthquake, but many will follow shortly. Besides, we have contributed to a number of subjects in the basic nuclear physics and nuclear astrophysics. A couple of them are introduced in the followings:

1) K. Nishio has proposed to measure fission properties of neutron-deficient mercury isotope in cooperation with Prof. A. Andreyev (University of West Scotland). The observed distribution of fission fragment mass turned out to be a big surprise (PRL 105, 252502(2010)), and it was introduced in nature news shown as below. It was also introduced in web pages of Science news and Asicnetific American. This result shows that there is still much to be understood in the physics of fission.



This topic will be one of our main subjects in the next 3 years.

2) Y. Utsuno has studied the evolution of the shell structure from normal to exotic nuclei. It has been found that a very neutron-rich isotope ^{42}Si has a strongly oblate deformed shape despite of the N=28 magic nucleus due to the change of the shell structure caused by the tensor force. Concerning the shell structure of nuclei, it has been also clarified that the N=Z=8 shell gap in the doubly-magic nucleus ^{16}O is strongly reduced from the widely accepted value based on the independent particle picture because of a sizable breaking of the doubly closed-shell configuration (PRC 83, 021301(R) (2011)).

Research Subject

Fission process will be studied for nuclei located far from the stable isotopes. Fission properties such as fragment mass distributions are strongly influenced by the motion of nucleons involved in a nucleus at an extremely deformed shape. In other words, fission study gives an opportunity to study the nuclear structure appearing at a deformed nuclear matter. Potential energy of a nucleus is largely determined by the number of protons and neutrons and their energy levels, so that new phenomenon and/or new principle in fission would be found by investigating fission for nuclei located far from the stable isotopes. We focus on the fissions of proton-rich nucleus, neutron-rich nucleus and heavy elements. The new principle and phenomenon which is found in the proposed study would be used to develop a theoretical description in fission, which should be then applied to predict nuclear properties relevant for, e.g., r-process nucleosynthesis and nuclear data required by nuclear engineering.

Significance of the Research (Advantage of it in ASRC)

Finding new phenomenon and new principle in fission will have a large impact on the practical application and science: In a fundamental research in nuclear physics, fission process is widely used to produce neutron-rich nuclei at the radioactive nuclear-beam facilities. The fission process is a fundamental phenomenon in atomic energy to generate electric power. Associated nuclear data such as fission cross section, neutron multiplicity and fission fragment mass distribution are important to understand the physical process of the fission phenomena. We believe that new findings in fission which will be brought by our approach will make it possible to study properties of nuclei located far from the stable isotopes; proton-rich and neutron-rich heavy nuclei. In these exotic region, shell-structures different from those of typical actinides must rule the fission process.

At the ASRC, we have developed a system for in-beam fission measurement at the JAEA tandem facility. By taking advantage of the wide variety of available beams with precisely controlled energy and the infrastructure to use actinide target materials at the facility, we will use nucleon transfer and fusion reactions to populate the neutron-rich, proton-rich nucleus at desired excited energies and measure the fission properties. We will investigate β^+-delayed fission to study also proton-rich nucleus under the collaboration with the international facilities.

The fission data obtained in the new region gives strong constraints in fission model, thus such a model calculation can yield a reliable fission properties for nuclei whose data is difficult to take experimentally.

Furthermore, the JAEA has strong infrastructure. For example, J-PARC can promote the fission research activity in another domain. Strong neutron and muon beams are available as trigger sources for fission. We will also start fission measurements at J-PARC using intense neutron beams. This will be the starting point of the activity in fission research at J-PARC. In future, fission of hypernuclei we have proposed may be even possible. The JAEA Tokai campus has a potential to be the center of fission research program in the world.

Uniqueness and Advantage of the Research

We will use nucleon-transfer reactions to produce rich amount of neutron-rich nucleus and measure variery of observables which carry information on different aspects of the exotic shape of nuclei appearing during fission, namely, fission fragment mass and kinetic energy distributions, number of

prompt fission neutrons and their energy spectra, and fission γ-ray spectra. For the proton-rich nucleus, combination of the target and projectile nucleus in fusion reaction will allow us to measure wide variety of nucleus. β^+-delayed fission of nuclei located in the proton-rich region in the chart of nuclei will be a first challenge in our collaborative work. Mapping of the fission property on the chart of nuclei and on the excitation energy allows us to reveal the change of the nuclear structure relevant to fission process.

Specific Goals to be Achieved During the Assigned Period and Expected Breakthrough

We will find a structure to rule fission of proton-rich nucleus. We have already found that ^{180}Hg fissions asymmetrically, which means that shells of fragments (semi-magic nucleus ^{90}Zr in this case) do not regulate fission. This contradicts the current understanding in fission of typical actinides that the mass partition is determined such that nuclei with closed shells are preferentially formed. The experimental and theoretical investigation will be promoted by extending other proton-rich isotopes. Experimental study of fusion-fission reaction will be performed at the JAEA tandem facility, and β^+-delayed fission measurement at the CERN-ISOLDE facility. All these measurement will be planned under the international collaboration.

It is known that sharp transition from asymmetric to symmetric fission have been observed in the spontaneous fission of fermium isotopes : ^{256}Fm fissions asymmetrically but ^{258}Fm fissions symmetrically. One possible explanation is the formation of the large cluster ^{132}Sn in the elongated nuclear matter. The phenomenon will be investigated more deeply by taking fission data for wide variety of neutron-rich nuclei using nucleon transfer reactions between projectile and actinide target nuclei. Such a sharp transition is also predicted in the proton-rich nucleus. The experiment will be carried out using a newly developed in-beam fission setup at the JAEA tandem facility.

In the in-beam fission study at the JAEA tandem facility, we will also measure the neutron multiplicity emitted from individual fragment to know the deformation of the nascent fission fragments. The data sets of mass distribution, total kinetic energy and deformation of fission fragments at the scission points have information on the fission path on the potential energy structure. These data will be used to develop a theoretical model using fluctuation-dissipation model.

Impact of the research results to society and other fields

Understanding in fission and new phenomenon and principle in the fission process has been one of the remaining big issues in nuclear physics as a matter of large-amplitude collective motion of finite nucleon systems. It will give impact on the production mechanism of radioactive beam and is also directly connected to the nuclear data for application (fission yields, decay heat, delayed neutron yield.). The developed model can also predict the role in fission in the astrophysical nucleosynthesis.

Toward International Research Center

(1) International Collaboration

University of the West Scotland (Fission of proton-rich nucleus)

IKS, KU Leuven (Fission of proton-rich nucleus)

CERN-ISOLDE (Fission of proton-rich nucleus)

Flerov Laboratory of Nuclear Reactions, Dubna (Theoretical model)
GSI Helmholz center (Fission heavy element)
China Institute of Atomic Energy (Development of new detector)
Joint Institute for Power and Nuclear Research, Belarus (Theoretical model)

(2) Foreign Collaborators

Prof. A. Andreyev, University of the West Scotland (Experimental study of fission of proton-rich nucleus)

Prof. V. Zagrebaev, Deputy Director of Flerov Laboratory of Nuclear Reactions , (Theoretical study of nucleon transfer reaction

Efrem Soukhovitskij, Head of nuclear data group, Joint Institute for Power and Nuclear Research (Belarus): Theoretical research in nucleon-induced reaction mechanisms

List of publication

Research Group for Reactions Involving Heavy Nuclei

FY2010

Papers in Refereed Journals

[6] In-beam γ-ray spectroscopy of ^{248,250,252}Cf by neutron-transfer reactions using a Cf target
R. Takahashi, T. Ishii, M. Asai, D. Nagae, H. Makii, K. Tsukada, A. Toyoshima, Y. Ishii, M. Matuda, A. Makishima, T. Shizuma, T. Kohno, and M. Ogawa
Phys. Rev. C **81**, 057303-1-4 (2010).

[7] Experimental Study of the ^{238}U(^{36}S,3-5n)$^{269-271}$Hs reaction leading to the observation of ^{270}Hs
R. Graeger, D. Ackermann, M. Chelnokov, V. Chepigin, Ch.E. Duellmann, J. Dvorak, J. Even, A. Gorshkov, F,P. Hessberger, D. Hild, A. Huebner, E. Jaeger, J. Khuyagbaatar, B. Kindler, J.V. Kratz, J. Krier, A. Kuznetsov, B. Lommel, K. Nishio, H. Nitsche, J.P. Omtvedt, O. Petrushkin, D. Rudolph, J. Runke, F. Samadani, M. Schaedel, B. Schausten, A. Tueler, A. Yakushev, and Q. Zhi
Phys. Rev. C. **81**, 061601(R)-1-5 (2010).

[8] Verification of the surrogate ratio method
S. Chiba and O. Iwamoto
Phys. Rev. C **81**, 044604-1-6 (2010).

[9] New estimate for the time-dependent thermal nucleosynthesis of ^{180}Ta^{m}
T. Hayakawa, T. Kajino, S. Chiba, and G.J. Mathews
Phys. Rev. C **81**, 052801(R)-1-4 (2010).

[10] Fusion-fission and quasi-fission process in reactions using actinide target nuclei
Y. Aritomo,
Int. J. Mod. Phys. E **19**, 813-824 (2010).

[11] Nuclear orientation in the reaction ^{34}S+^{238}U and synthesis of the new isotope ^{268}Hs
K. Nishio, S. Hofmann, F. P. Heßberger, D. Ackermann, S. Antalic, Y. Aritomo, V. F. Comas, Ch. E. Düllmann, A. Gorshkov, R. Graeger, K. Hagino, S. Heinz, J. A. Heredia, K. Hirose, H. Ikezoe, J. Khuyagbaatar, B. Kindler, I. Kojouharov, B. Lommel, R. Mann, S. Mitsuoka, Y. Nagame, I. Nishinaka, T. Ohtsuki, A.G. Popeko, S. Saro, M. Schädel, A. Türler, Y. Watanabe, A. Yakushev,

and A. V. Yeremin
Phys. Rev. C **82**, 024611-1-9 (2010).

[12] Neutron drip line and the equation of state of nuclear matter
K. Oyamatsu, K. Iida, and H. Koura
Phys. Rev. C **82**, 027301-1-4 (2010).

[13] Cross-shell excitations near the "island of inversion": Structure of ^{30}Mg
A. N. Deacon, J. F. Smith, S. J. Freeman, R. V. F. Janssens, M. P. Carpenter, B. Hadinia, C. R. Hoffman, B. P. Kay, T. Lauritsen, C. J. Lister, D. O'Donnell, J. Ollier, T. Otsuka, D. Seweryniak, K.-M. Spohr, D. Steppenbeck, S. L. Tabor, V. Tripathi, Y. Utsuno, P. T. Wady, and S. Zhu
Phys. Rev. C **82**, 034305-1-7 (2010).

[14] Multi-layered parallel plate ionization chamber for cross-section measurement of minor actinides
K. Hirose, T. Ohtsuki, Y. Shibasaki, N. Iwase, J. Hori, K. Takamiya, H. Yashima, K. Nishio, and Y. Kiyanagi
Nucl. Instrum. Meth. In Phys. Res. A **621**, 379-382 (2010).

[15] Extraction chromatographic behavior of Rf, Zr, and Hf in HCl solution with styrene-divinylbenzene copolymer resin modified by TOPO (trictylphosphine oxide)
A.Toyoshina, Y. Kasamatsu, K. Tsukada, M. Asai, Y. Ishii, H. Toume, I. Nishinaka, T. K. Sato, Y. Nagame, M. Schaedel, H. Haba, S. Goto, H. Kudo, K. Akiyama, Y,. Oura, K. Ooe, A. Shinohara, K. Sueki, and J. V. Kratz
J. Nucl. Radochem. Sci. **11**, 7-11 (2010).

[16] A new Type of Asymmetric Fission in Proton-Rich Nuclei
A.N. Andreyev, J. Elseviers, M. Huyse, P. Van Duppen, S. Antalic, A. Barzakh, N. Bree, T.E. Cocolios, V.F. Comas, J. Diriken, D. Fedorov, V. Fedosseev, S. Franchoo, J.A. Heredia, O. Ivanov, U. Koester, B.A. Marsh, K. Nishio, R.D. Page, N. Patronis, M. Seliverstov, I. Tsekhanovich, P. Van den Bergh, J. Van De Walle, M. Venhart, S. Vermote, M. Veselsky, C. Wagemans, T. Ichikawa, A. Iwamoto, P. Moeller, and A.J. Sierk
Phys. Rev. Lett. **105**, 252502-1-5 (2010).

[17] Evidence for quasifission in the sub-barrier reaction of ^{30}Si+^{238}U
K. Nishio, H. Ikezoe, I. Nishinaka, S. Mitsuoka, K. Hirose, T. Ohtsuki, Y. Watanabe, Y. Aritomo, and S. Hofmann
Phys. Rev. C **82**, 044604-1-5 (2010).

[18] The new isotope ^{236}Cm and new data on ^{233}Cm and ^{237,238,240}Cf
J. Khuyagbaatar, F.P. Hessberger, S. Hofmann, D. Ackermann, V.S. Comas, S. Heinz, J.A. Heredia, B. Kindler, I. Kojouharov, B. Lommel, R. Mann, K. Nishio, and A. Yakushev
Eur. Phys. J. A **46**, 59-67 (2010).

[19] Proton resonance elastic scattering in inverse kinematics on the medium heavy nucleus ^{68}Zn
N. Imai, Y. Hirayama, H. Ishiyama, S.C. Jeong, H. Miyatake, Y.X. Watanabe, H. Makii, S. Mitsuoka, D. Nagae, I. Nishinaka, K. Nishio, and K. Yamaguchi
Eur. Phys. J A **46**, 157-160 (2010).

[20] Neutrino reactions on ^{138}La and ^{180}Ta via charged and neutral currents by the quasiparticle random-pahse approximation
M.-K. Cheoun, E. Ha, T. Hayakawa, T. Kajino, and S. Chiba
Phys. Rev. C **82**, 035504-1-7 (2010).

[21] Reanalysis of the (J=5) state at 592 keV in ^{180}Ta and its role in the ν-process nucleosynthesis of ^{180}Ta in supernovae
T. Hayakawa, P. Mohr, T. Kajino, S. Chiba, and G.J. Mathews
Phys. Rev. C **82**, 058801-1-4 (2010).

[22] Multiparticle-multihole states around ^{16}O and correlation-energy effect on the shell gap
Y. Utsuno and S. Chiba
Phys. Rev. C **83**, 021301(R)-1-5 (2011).

[23] Matter radii of $^{32-35}$Mg
R. Kanungo, A. Prochazka, W .Horiuchi, C. Nociforo, T. Aumann, D. Boutin, D. Cortina-Gil, B. Davids, M. Diakaki, F. Farinon, H. Geissel, R. Gernhauser, J. Gerl, R. Janik, B. Jonson, B. Kindler, R. Knobel, R. Krucken, M. Lantz, H. Lenske, Y. Litvinov, B. Lommel, K. Mahata, P. Maierbeck, A. Musumarra, T. Nilsson, C. Perro, C. Scheidenberger, B. Sitar, P. Strmen, B. Sun, Y .Suzuki, I. Szarka, I. Tanihata, Y. Utsuno, H .Weick, and M. Winkler
Phys. Rev. C **83**, 021302(R)-1-4 (2011).

[24] JENDL-4.0: A New Library for Nuclear Science and Engineering
K. Shibata, O. Iwamoto, T. Nakagawa, N. Iwamoto, A. Ichibhara, S.Kunieda, S. Chiba, K. Furutaka, N. Otsuka T. Ohsawa, T. Murata, H.Matsunobu, A. Zukeran, S. Kamada, and J. Katakura
J. Nucl. Sci. Tech. **48**, 1-30 (2011)

[25] Decay studies of K isomers in ^{254}No
F.P. Hessberger, S. Antalic, B. Sulignano, D. Ackermann, S. Heinz, S. Hofmann, B. Kindler, J. Khuyagbaatar, I. Kojouharov, P. Kuusiniemi, M. Leino, B. Lommel, R. Mann, K. Nishio, A.G. Popeko, S. Saro, B. Streicher, J. Uusitalo, M. Venhart, and A.V. Yeremin
Eur. Phys. J. A **43**, 55-56 (2010).

[26] Novel extrapolation method in the Monte Carlo shell model
N. Shimizu, Y. Utsuno, T. Mizusaki, T. Otsuka, T. Abe, and M. Honma
Phys. Rev. C **82**, 061305(R)-1-5 (2010)

[27] Nuclear-charge polarization at scission in proton-induced fission of ^{233}U
I. Nishinaka, M. Tanikawa, Y. Nagame, and H. Nakahara
Eur. Phys. J. A. **47**, 1-8 (2011).

[28] Neutron one-quasiparticle states in $^{251}Fm_{151}$ populated via the α decay of ^{255}No
M. Asai, K. Tsukada, H. Haba, Y. Ishii, T. Ichikawa, A. Toyoshima, T. Ishii, Y. Nagame, I. Nishinaka, Y. Kojima, and K. Sueki
Phys. Rev. C **83**, 014315-1-15 (2011).

Invited Talks

[1] Shell-model approach to exotic nuclei—description by monopole-based universal interaction and development of a new MCSM code
Y. Utsuno, T. Otsuka, B.A. Brown, M. Honma, T. Mizusaki, and N. Shimzu
ECT* Workshop "Reactions and Nucleon Properties in Rare Isotopes", Trento, Italy, Apr. 6-10, 2010.

[2] Multiplicity and energy of neutrons from ^{233}U(n_{th},f) fission fragments
K. Nishio,

Workshop of the Espace de Structure Nucleaire Theorique, The scission process : the last stage of nuclear fission, Cedex, France, Apr. 12-16, 2010.

[3] Effects of nuclear orientation on fusion and fission process for reactions using ^{238}U target nucleus
K. Nishio
24th International Nuclear Physics Conference 2010, Vancouver, Canada, Jul. 4-9, 2010.

[4] Alchemy in the universe—Origin of atoms and nuclei
H. Koura
Waseda University Summer Seminar "Lecture for Future Scientists", Kamogawa, Japan, Jul. 26-28, 2010.

[5] Nuclear Physics Contributions to Nuclear Energy
S. Chiba
The 9th CNS-EFES International Summer School (CNS-EFES10), Wako, Japan, Aug. 18-24, 2010.

[6] Fission dynamics in heavy ion collisions on ^{238}U
K Nishio, H. Ikezoe, I. Nishinaka, S. Mitsuoka, K. Hirose, T. Ohtsuki, Y. Watanabe, Y. Aritomo, S. Hofmann
Scientific Workshop on Nuclear Fission and Dynamics and the Emission of Prompt Neutrons and Gamma Rays, Sinaia, Romania, Sep. 27-29, 2010.

[7] Measurement of the E1 and E2 cross sections of the ^{12}C(α,γ)^{16}O reaction
H. Makii
The 3rd Meeting of OMEG Institute on ^{12}C(α,γ)^{16}O Reaction, Nov. 1, 2010.

[8] Surrogate-Reaction Research Project in JAEA
S. Chiba
The 3rd Japan Forum of Nuclear Astrophysics Workshop, Tokyo, Japan, Nov. 4-5, 2010.

[9] Measurement of Neutron-Capture Cross Sections in Unstable Nuclei with the Surrogate Reaction
H. Makii
The 3rd Japan Forum of Nuclear Astrophysics Workshop, Tokyo, Japan, Nov. 4-5, 2010.

[10] Theory of Surrogate Reaction
Y. Aritomo
The 3rd Japan Forum of Nuclear Astrophysics Workshop, Tokyo, Japan, Nov. 4-5, 2010.

[11] Study for fusion-fission and quasifission in reactions using ^{238}U target nucleus
K. Nishio, I. Nishinaka, S. Mitsuoka, H. Makii, H. Ikezoe, K. Hirose, T. Ohtsuki, Y. Watanabe, and S. Hofmann
International Symposium on Quasifission Process in Heavy Ion Reactions, Messina, Italy, Nov. 8-9, 2010.

[12] Surrogate-Reaction Research Project in JAEA
S. Chiba
2010 Symposium on Nuclear Data, Fukuoka, Japan, Nov. 25-26, 2010.

[13] Shell-model study on the island of inversion: what has been clarified and what should be
Y. Utsuno
RIBF-ULIC Symposium on Further Understanding of "Island of Inversion" via Nuclear Moments and Inelastic Reactions, Wako, Japan, Dec. 20-21, 2010.

[14] Towards petascale nuclear-structure calculation: shell-model case
Y. Utsuno
French-Japanese Symposium on Nuclear Structure Problems, Wako, Japan, Jan. 5-8, 2011.
[15] Basic Research about the Nuclear Fission Process with Neutrons
K. Nishio
Workshop Celebrating the Completion of Construction of ANNRI, Tokai, Japan, Feb. 24, 2011.
[16] Interconnection between Atomic Energy and Nuclear Physics
S. Chiba
Workshop on Nuclear Physics and Atomic Energy, Tokyo, Japan, Mar. 10, 2011.

Press Release
[1] On the origin of ^{180}Ta that is the rarest in the solar system
T. Hayakawa, S. Chiba, and T. Kajino
Released in May 12, 2010.

FY2011

Papers in Refereed Journals
[1] Dynamical model of surrogate reaction
Y. Aritomo, S. Chiba, and K. Nishio
Phys. Rev. C **84**, 024602-1-10 (2011).
[2] Effective radii of deuteron induced reactions
S. Hashimoto, M. Yahiro, K. Ogata, K. Minomo, and S. Chiba
Phys. Rev. C **83**, 054617-1-11 (2011).
[3] Spin-dependent observables in surrogate reactions
S. Chiba, O. Iwamoto, and Y. Aritomo
Phys. Rev. C **84**, 054602-1-5 (2011).
[4] Radiochemical study of sub-barrier fusion hindrance in the ^{19}F +^{209}Bi reaction
I. Nishinaka, Y. Kasamatsu, M. Tanikawa, S. Goto, and M. Asai
Proc. Radiochim. Acta **1**, 117-121 (2011).
[5] Three-Body Model Calculation of Spin Distribution in Two-Nucleon Transfer Reaction
K. Ogata, S. Hashimoto, and S. Chiba
J. Nucl. Sci. Technol. **48**, 1337-1342 (2011).
[6] Systematic description of ^{6}Li(n,n')dα reactions with the microscopic coupled-channels method
T. Matsumoto, D. Ichinkohorloo, Y. Hirabayashi, K.Katō, and S. Chiba
Phys. Rev. C **83**, 064611-1-6 (2011).
[7] Fission of actinide nuclei with double Λ particles within the Skyrme-Hartree-Fock method
F. Minato and S. Chiba
Nucl. Phys. A **856**, 55-67 (2011).
[8] In-beam γ -ray spectroscopy of ^{35}Mg and ^{33}Na
A. Gade, D. Bazin, B.A. Brown, C.M. Campbell, J.M. Cook, S. Ettenauer, T. Glasmacher, K.W. Kemper, S. McDaniel, A. Obertelli, T. Otsuka, A. Ratkiewicz, J.R. Terry, Y. Utsuno, and D. Weisshaar
Phys. Rev. C **83**, 044305-1-5 (2011).

[9] Production and Decay Properties of ^{264}Hs and ^{265}Hs
N. Sato, H. Haba, T. Ichikawa, D. Kaji, Y. Kudou, K. Morimoto, K. Morita, K. Ozeki, T. Sumita, A. Yoneda, E. Ideguchi, H. Koura, A. Ozawa, T. Shinozuka, T. Yamaguchi, and A. Yoneda
J. Phys. Soc. Jpn. **80**, 094201-1-7 (2011).

[10] Isomeric states in ^{253}No and ^{253}Fm
S. Antalic, F.P. Hessberger, D. Ackermann, S. Heinz, S. Hofmann, Z. Kalaninova, B. Kindler, J. Khuyagbaatar, I. Kojouharov, P. Kuusiniemi, M. Leino, B. Lommel, R. Mann, K. Nishio, S. Saro, B. Streicher, B. Sulignano, and M. Venhart
Eur. Phys. J. A **47**, 62-1-12 (2011).

[11] Covariance Evaluation for Actinide Nuclear Data in JENDL-4
O. Iwamoto, T. Nakagawa, S. Chiba, and N. Otuka
J. Korean Physical Society **59**, 1224-1229 (2011).

[12] Self-consistent Analyses of Nuclear Level Structures, and Nucleon Interaction Data of Even-even Sn Isotopes
J.-Y. Lee, E.Sh. Soukhovitskij, Y. Kim, R. Capote, S. Chiba, and J.M. Quesada
J. Korean Physical Society **59**, 1019-1022 (2011).

[13] Status of JENDL High Energy File
Y. Watanabe, K. Kosako, S. Kunieda, S. Chiba, R. Fujimoto, H. Harada, M. Kawai, F. Maekawa, T. Murata, H. Nakashima, K. Niita, N. Shigyo, S. Shimakawa, N. Yamano, and T. Fukahori
J. Korean Physical Society **59**, 1040-1045 (2011).

[14] JENDL-4.0: A New Library for Innovative Nuclear Energy Systems
K. Shibata, O. Iwamoto, T. Nakagawa, N. Iwamoto, A. Ichihara, S. Kunieda, S. Chiba and J. Katakura
J. Korean Physical Society **59**, 1046-1051 (2011).

[15] Measurements of Inelastic Neutron Scattering at 96 MeV from Carbon, Iron, Yttrium and Lead
A. Ohrn, C. Gustavsson, M. Blann, V. Blideanu, J. Blomgren, S. Chiba et al.
J. Korean Physical Society **59**, 1817-1820 (2011).

[16] Neutron production in the lunar subsurface from alpha particles in galactic cosmic rays
S. Ota, S. Kobayashi, L. Sihver, N. Yamashita, and N. Hasebe
Earth Planets Space **63**, no. 1, 25-35 (2011).

[17] Charge resolution of CR-39 plastic nuclear track detectors for intermediate energy heavy ions
S. Ota, N. Yasuda, L. Sihver, S. Kodaira, M. Kurano, S. Naka, Y. Ideguchi, E. R. Benton, and N. Hasebe
Nucl. Instr. Meth. B **269**, 1382-1388 (2011).

[18] Spin-polarization of radioactive ^{123}In$_{g.s.}$ by the tilted-foil method
Y. Hirayama, M. Mihara, Y.X. Watanabe, S.C. Jeong, N. Imai, K. Matsuta, H. Miyatake, T. Hashimoto, H. Ishiyama, S. Ichikawa, T. Ishii, T. Izumikawa, I. Katayama, H. Kawakami, I. Nishinaka, K. Nishio, H. Makii, S. Mitsuoka, S. Momota, A. Osa, Y. Otokawa, T.K. Sato, and Y. Wakabayashi
Eur. Phys. J. A **47**, 138-1-5 (2011).

[19] Analysis of n + ^{6}Li reactions in three-body model
D. Ichinkhorloo, T. Matsumoto, Y. Hirabayashi, K. Katō, and S. Chiba
J. Nucl. Sci. Technol.**48**, 1357-1360 (2011).

[20] Shell structure of even-even nickel isotopes containing twenty to forty neutrons
O.V. Bespalova, I.N. Boboshin, V.V. Varloamov, T.A. Ermakova, B.S. Ishkhanov, A.A. Klimochkina, S.Yu. Komarov, H. Koura, E.A. Romanovsky, and T.I. Spasskaya
Phys. Atom. Nucl. **74**, 1521-1535 (2011).

[21] Proton-proton phase shifts calculations in momentum space by a rigorous Coulomb treatment
S. Oryu, Y. Hiratsuka, S. Nishinohara, and S. Chiba
J. Phys. G **39**, 045101-1-12 (2012).

Invited Talks

[1] Surrogate Reaction and Nuclear Data
S. Chiba
Workshop on Strategy for Nuclear Data Research in RCNP, Osaka, Japan, Jun. 28-29, 2011.

[2] Surrogate-Reaction Research Project in JAEA
S. Chiba
YITP Workshop on Physics of Microscopic Nuclear Reaction Theory, Kyoto, Japan, Aug. 1-3, 2011.

[3] Evolution of Shell Structure Probed by RIBF and RCNP Experiments
Y. Utsuno
2011 Fall Meeting of the Physical Society of Japan, Hirosaki, Japan, Sep. 16-19, 2011.

[4] What Is Learned from Environmental Radiation Monitoring for the Fukushima-Daiichi Accident
S. Mitsuoka
2011 Fall Meeting of the Atomic Energy Society of Japan, Kita-Kyushu, Japan, Sep. 19-22, 2011.

[5] Nuclear orientation in fusion and synthesis of heavy element at sub-barrier energy
K. Nishio
7th. International Conference on Dynamic Aspects of Nuclear Fission, Smolenice, Slovakia, Oct. 17-21, 2011.

[6] Recent development in the shell model: shell evolution and methodology
Y. Utsuno
ECT* Workshop “Nuclear Structure Seen through Ground-State Properties of Exotic Nuclei”, Trento, Italy, Oct. 17-21, 2011.

[7] Long-term Needs for Nuclear Data Development
S. Chiba
Technical meeting on long-term needs for nuclear data development, IAEA Headquarters, Vienna, Austria Nov. 2-4, 2011.

[8] Current status of nuclear mass formulae
H. Koura
RIKEN RIBF-ULIC-Symposium “Physics of Rare-RI Ring”, Wako, Japan, Nov. 10-12, 2011.

[9] Surrogate Reaction
S. Chiba
2011 Symposium on Nuclear Data, Tokai, Japan, Nov. 16-17, 2011.

[10] Surrogate Reaction and Nuclear Data Research in the Future
S. Chiba

The 1st International Symposium on the Science with KoRIA, Sejong, Korea, Dec. 1-2, 2011.

[11] Nuclear-Physics Point of View about the Fukushima-Daiichi Accident
Y. Utsuno
The 44th Annual Meeting of the Japan Society of Safety Engineering, Yonezawa, Japan, Dec. 1-2, 2011.

[12] Considering an Algorithm of Nuclear Shell-Model Calculations Suitable for Massively Parallel Computers
Y. Utsuno
HPCI Workshop Field 5 Workshop on Frontier of Nuclear Study with Large-Scale Calculations—Nuclear Many-Body Systems, Wako, Japan, Jan. 24-25, 2012.

[13] Towards Establishing the Evolution of the Shell Structure
Y. Utsuno
RCNP Workshop on Demonstrative Nuclear Physics, Osaka, Japan, Feb. 22-23, 2012.

Research Subject (5)

Study of Valence Electronic Structure and Nuclear Shell Structure of Superheavy Elements

Group: **Research Group for Superheavy Elements**

Member

(Leader)	Matthias Schädel
(Researcher)	Kazuaki Tsukada, Masato Asai, Tetsuya Sato
(Senior Post doc.)	Atsushi Toyoshima
(Post doc.)	Zijie Li (- March, 2011), Nozomi Sato (- March, 2012), Kazuhiro Ooe (April, 2011 -), Sunao Miyashita (April, 2012 -)
(MEXT Nuclear Research Exchange Program)	Xiao Fu Liang (from CIAE, - May, 2010)

Summary of the pre-review

The review committee acknowledged the internationally well recognized role of this group in performing very impressive, innovative atom-at-a-time studies of chemical and nuclear properties of superheavy elements (SHE) and its world-wide leading role in specific areas. The experimental program benefits from advancing it to heavier elements beyond rutherfordium, Rf. Critics arose from the fact that several topics in this program, despite of their scientific and technical excellence, were continuations of old projects, partially with long commitments to technical developments, making them borderline with respect to the mission of the ASRC. The role of a new group leader from abroad and attempts towards a change of the research program was positively accepted.

Response

Taking the recommendation from the evaluation committee seriously into account, and keeping in mind the mission of the ASRC to support genuinely new and innovative high-risk projects in world-class basic science, we totally overhauled and refocused our research program. To achieve, within this 5-year period, most exciting and challenging results we abandoned several long-term projects and concentrated our resources on a small number of completely new and innovative projects well beyond the scope of the former program. Most of these world-wide unique, high-risk experiments will be performed in international collaborations with the ASRC group playing a crucial role. Opening up the completely new field of metal-organic compounds of SHE with the first synthesis and investigation of $Sg(CO)_6$, testing predictions of fully-relativistic theory calculations in redox reactions of seaborgium, Sg, and exploring the nuclear structure of superheavy nuclei in the vicinity of doubly-magic ^{270}Hs are our central topics. In addition, we will finish measuring the first ionization potential (IP) of lawrencium, Lr. All of these experiments are performed in close contact with theoreticians.

Progress

(1) Ionization potential measurement of lawrencium (Lr)

Important advancement was made towards the measurement of the first IP of Lr. The performance of our surface-ionization-type ion-source was significantly improved. In experiments with different ionizers, surprisingly high efficiencies were measured for short-lived lanthanides. Deduced ionization potentials showed unwanted boiling point dependences when compared with literature values. A different, very promising approach is now pursued in the analysis to eliminate this effect. Optimization of temperature distributions along the ionizer and the choice of the best ionizer are coming to an end. In March, we are planning to begin our experimental program with Lr.

(2) Electrochemistry of superheavy elements

Our successful electrochemistry program was modified and is focusing now on a very unique case among superheavy elements. In a first step, we finished the measurement of the mendelevium reduction potential (Md^{3+} => Md^{2+}) in 0.1 M HCl with a newly developed flow electrolytic column. The measured potential of -0.18 V sheds more light on the relative stability of Md oxidation states. This experiment demonstrated the capability of our world-wide unique technique to perform redox experiments on single atoms and it provides a basis for our new program focusing on Sg. In a newly established collaboration with the group of Prof. J.P. Omtvedt (Univ. Oslo) work is under way to adapt and couple our flow electrolytic column technique with the fast and continuously working liquid-liquid extraction system SISAK.

(3) Nuclear structure of superheavy nuclei

Proton single-particle configurations in Lr isotopes have been identified through a newly developed high-resolution α fine-structure spectroscopy technique. It enables nuclear structure studies in a very unique and unprecedented way. For the first time, nuclear structure details can be determined even if no γ ray is emitted following the α-decay. Using this technique as well as α-γ-coincidences, we will establish excited states and single-particle configurations in our reshaped nuclear structure program now aiming for the region around doubly-magic ^{270}Hs. In a step in this direction we have started α–γ spectroscopy of ^{261}Db.

It was a great relief to the group that "The 2011 off the Pacific coast of Tohoku Earthquake" left no major damage to the Tandem accelerator and that operation resumed about half a year later. At about this time also access to controlled areas for radiochemical studies was possible again. Fortunately enough, the experimental equipment of the group did not suffer any major damage. For several months, the group used its expertise and equipment and shifted its main task contributing to a survey of radioactivity dispersed from the nuclear reactor accident at Fukushima. By end of 2011, we fully resumed our SHE research program.

Goals

(1) In our research subject "Atomic Properties" we will determine the first ionization potential of Lr. This provides direct information on the stability of valence electrons in Lr and a test of fully-relativistic atomic theory predictions.

(2) Our reshaped research subject "Chemical Properties" is now focusing on Sg and Hs. The experiment in the aqueous phase aims at measuring the redox potential of Sg^{6+} to Sg^{4+}. It

exploits our experience with flow electrolytic column reduction coupled with the extraction and detection system SISAK of the Oslo group. Sg is unique as it is the first SHE which can be reduced. This experiment will challenge quantitative theoretical predictions of the stability of oxidation states in SHE. The collaborative experiment in the gas phase will study the formation of $Sg(CO)_6$. With this experiment we will open up the completely new and exciting field of metal-organic SHE chemistry.

(3) In our reshaped research subject "Nuclear Properties" the doubly-magic nucleus $^{270}Hs_{162}$, and neighboring nuclei in this deformed neutron shell region, are now in the focus. High-resolution α fine structure and α-γ-coincidence spectroscopy of ^{265}Sg and ^{270}Hs will give access to the proton and neutron single-particle structure in these neutron-excess nuclei. This elucidates the deformation and the shell structure of SHE and provides a test for nuclear models at the limit of stability. As a first a step, we began a study of ^{261}Db.

Originality

Beyond actinides, the 6*d* and *7p* elements 104 to 118 constitute today's limit of existence of matter. Shell effects and strong relativistic effects are influencing chemical properties. Experiments elucidate the architecture of the Periodic Table at its extreme limit and challenge modern fully-relativistic atomic and molecular theories. IP and redox potential measurements yield quantitative information on the valence electronic structure of SHE. These results test the validity of fully-relativistic models. Electrochemical studies of Sg provide a unique approach to reveal chemical properties of 6*d* elements. The electrochemistry apparatus we are developing, a combination of flow electrolytic columns with a SISAK system, has a world-wide unique ability to measure the Sg^{6+} to Sg^{4+} redox potential. For the first time, an oxidation state lower than the maximum one will be reached for a *6d* element.

Recent test experiments at Mainz and Darmstadt show that the completely new class of metal-organic compounds is most likely accessible for a large number of SHE after physical pre-separation. In a ground-breaking collaborative experiment, within the *Reimei* program, we plan to synthesize and chemically separate $Sg(CO)_6$.

Nuclear structure information at the frontier of known nuclei helps refining nuclear models. Consequently, a more trustable insight into limits of our matter can be obtained. Energy spacing and the order of proton and neutron single-particle orbitals are sensitive probes to elucidate shell structures. Our studies of $^{259,261}Rf$ mark the limits of today's knowledge of level energies and spin-parities. α-γ spectroscopy of Db and Sg nuclei will reveal the proton and neutron single-particle structure in this heaviest frontier region. The ultimate goal is an investigation of the doubly-magic deformed ^{270}Hs located at the center of this entire shell stabilized region of SHN.

Feasibility

SHEs can only be produced at heavy-ion accelerators. While concentrating our experimental program on the JAEA tandem, if necessary or advantageous, we use the world-wide best suited facility; e.g., RIKEN or GSI. The atom-at-a-time situation in SHE experiments requires dedicated automated apparatuses. At the JAEA tandem, we gained large experience and have mastered the development of several world-wide unique techniques and devices to cope with this situation. For IP measurements, we have improved and optimized the surface ionization technique in tests with

lanthanides. Rates higher than expected were obtained. Our experience with a gas-jet coupled ISOL system enables us to apply this technique to determine the IP of Lr.

Our research activities in electrochemistry and in the aqueous phase chemistry of SHE are technically and scientifically leading on a global scale. Redox experiments with No and Md demonstrated that our electrochemistry apparatus is applicable for single atoms. Presently we develop a dedicated system to measure the redox potential of Sg^{6+} to Sg^{4+}. To chemically separate and detect both Sg oxidation states, in collaboration with the University of Oslo, we opted for the SISAK system.

Technically and scientifically, our spectroscopic studies to unravel the nuclear structure of SHE are at the forefront. Our technique provides crucial nuclear structure data not accessible with other techniques. This was demonstrated in α–γ spectroscopy of No and Rf nuclei; the heaviest and most neutron-rich nuclei whose neutron single-particle configurations have been established experimentally. A specialty of our technique is that it allows studies of these neutron-rich nuclei produced in hot-fusion reactions with highly-radioactive actinide targets. Experiments are performed coupling gas-jets with an α–γ detection systems. A similar technique will be applied for Db, Sg, and especially Hs with and without physical and chemical pre-separation.

Scientific and social outcomes

This program advances our knowledge of basic properties of the heaviest know elements and it helps determining the limits of existence of matter in Nature.

International cooperation

In our newly focused research program we have close international cooperation with the following partners in the field of (1) Atomic Properties, (2) Chemical properties, (2a) Electrochemical determination of the first SHE redox potential in Sg, (2b) Establishing novel metal organic SHE chemistry with $Sg(CO)_6$, and
(3) Nuclear properties (numbers below relate to these programs):
- GSI Helmholtz Center for Heavy-Ion Research, Darmstadt, (2a, 2b, 3)
- Helmholtz-Institute Mainz (2b)
- University of Mainz (1, 2a, 2b)
- University of Oslo (2a)
- University of Bern (2b)
- Paul Scherrer Institute (PSI), Villigen (2b)
- Lawrence Berkeley National Laboratory (LBNL), Berkeley (2b)
- University of California, Berkeley (2b)
- Institute of Modern Physics, Lanzhou (2b)
- University of Jyväskylä (JYFL), Jyväskylä (3)

In addition, we are closely collaboration with Dr. Thierry Stora from the CERN ISOLDE group on specific aspects of surface ionizers.

We plan to organize the renowned International Workshop on the Chemistry of Superheavy Elements in 2013 and the 5th International conference on the chemistry and physics of transactinide in 2015.

Publication list

[1] Extraction chromatographic behavior of Rf, Zr, and Hf in HCl solution with styrene-divinylbenzene copolymer resin modified by TOPO (trioctylphosphine oxide)
A. Toyoshima, Y. Kasamatsu, K. Tsukada, M. Asai, Y. Ishii, H. Toume, I. Nishinaka, T. K. Sato, Y. Nagame, M. Schädel, H. Haba, S. Goto, H. Kudo, K. Akiyama, Y. Oura, K. Ooe, A. Shinohara, K. Sueki, and J. V. Kratz
J. Nucl. Radiochem. Sci. **11**, 7-11 (2010).

[2] In-beam γ-ray spectroscopy of ^{248,250,252}Cf by neutron-transfer reactions using a Cf target
R. Takahashi, T. Ishii, M. Asai, D. Nagae, H. Makii, K. Tsukada, A. Toyoshima, Y. Ishii, M. Matuda, A. Makishima, T. Shizuma, T. Kohno, and M. Ogawa
Phys. Rev. C **81**, 057303-1-4 (2010).

[3] Nuclear orientation in the reaction ^{34}S + ^{238}U and synthesis of the new isotope ^{268}Hs
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Y. Ishii, A. Toyoshima, K. Tsukada, M. Asai, Z. J. Li, Y. Nagame, S. Miyashita, T. Mori, H. Suganuma, H. Haba, S. Goto, H. Kudo, K. Akiyama, Y. Oura, A. Shinohara, M. Schädel, V. Pershina, and J. V. Kratz
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R. Takayama, K. Ooe, W. Yahagi, H. Fujisawa, Y. Komori, H. Kikunaga, T. Yoshimura, N. Takahashi, K. Takahisa, H. Haba, Y. Kudou Y. Ezaki, A. Toyoshima, M.Asai, Y. Nagame, T. Saito, T. Mitsugashira and A. Shinohara
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H. Haba, D. Kaji, Y. Kudou, K. Morimoto, K. Morita, K. Ozeki, R. Sakai, T. Sumita, A. Yoneda, Y. Kasamatsu, Y. Komori, and A. Shinohara, H. Kikunaga, H. Kudo, K. Nishio, K. Ooe, N. Sato, and K. Tsukada
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U. Forsberg, P. Golubev, L.G. Sarmiento, J. Jeppsson, D. Rudolph, L.-L. Andersson, D. Ackermann, M. Asai, M. Block, K. Eberhardt, J. Even, Ch.E. Düllmann, J. Dvorak, J.M. Gates, K.E. Gregorich, R.-D. Herzberg, F.P. Heßberger, E. Jäger, J. Khuyagbaatar, I. Kojouharov, J.V. Kratz, J. Krier, N. Kurz, S. Lahiri, B. Lommel, M. Maiti, E. Merchán, J.P. Omtvedt, E. Parr, J. Runke, H. Schaffner, M. Schädel, and A. Yakushev
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Z. J. Li, A. Toyoshima, M. Asai, K. Tsukada, T. K. Sato, N. Sato, T. Kikuchi, Y. Nagame, M.

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Radiochim. Acta (in press).

[18] Adsorption behavior of ^{181}W and ^{93m}Mo as lighter homologues of seaborgium (Sg) in HF/HNO_3 on anion-exchange resin
X. H. Liang, K. Tsukada, A. Toyoshima, Z. J. Li, M. Asai, T. K. Sato, N. Sato, and Y. Nagame
J. Radioanal. Nucl. Chem. (in press).

Invited talks

[1] Strategy for approaching superheavy-nucleus spectroscopy
M. Asai
Fall Meeting of the Physical Society of Japan, Kitakyushu, Japan, September 11-14, 2010.

[2] Chemistry of superheavy elements – Experimental achievements and perspectives
M. Schädel
The 54th Symposium on Radiochemistry, Suita, Japan, September 27-29, 2010.

[3] The Recent Superheavy Element Chemistry at JAEA
Y. Nagame
The 2nd International Conference on Application of Radiotracers in Chemistry, Environment and Biological Science, Kolkata, India, November 7-13, 2010.

[4] Chemistry of superheavy elements: Experimental achievements and perspectives
M. Schädel
International Chemical Congress of Pacific Basin Societies (Pacifichem 2010), Honolulu, Hawaii, USA, December 15-20, 2010.

[5] Electrochemistry of the heaviest elements
A. Toyoshima
International Chemical Congress of Pacific Basin Societies (Pacifichem 2010), Honolulu, Hawaii, USA, December 15-20, 2010.

[6] Liquid Phase Experiments with the Heaviest Elements
Y. Nagame
The 4th International Conference on the Chemistry and Physics of the Transactinide Elements (TAN11), Sochi, Russia, September 5-11, 2011.

[7] Chemistry and Physics of (Super-)Heavy Elements
M. Schädel
Summer School on Actinide Science and Applications 2011, Institute for Transuranium Elements (ITU), Karlsruhe, Germany, June 16, 2011.

Awards

[1] Study on oxidation-reduction properties of the heaviest elements using a newly developed electrochemistry apparatus
A. Toyoshima
JAEA President Awards on Research and Development (October, 2010)

[2] Fluorido Complex Formation of Element 104, Rutherfordium (Rf)

Y. Ishii, A. Toyoshima, K. Tsukada, M. Asai, Z. J. Li, Y. Nagame, S. Miyashita, T. Mori, H. Suganuma, H. Haba, S. Goto, H. Kudo, K. Akiyama, Y. Oura, A. Shinohara, M. Schädel, V. Pershina, and J. V. Kratz
Bull. Chem. Soc. Jpn. 84, 903-911 (2011).
Selected paper in the issue (September, 2011)

Research Subject (6)

Preparation of New Actinide Compounds with Exotic Behavior

Group **Research Group for Actinide Materials Science**

Member

(Leader)	Zachary Fisk
(Researcher)	Yoshinori Haga, Etsuji Yamamoto, Naoyuki Tateiwa, Tatsuma Matsuda Hidehito Asaoka
(Post-doctoral Fellow)	Yuji Matsumoto
(Senior Scientist)	Akio Nakamura

Summary of the pre-review

"This is a truly outstanding exciting project which fits perfectly well to the mission of ASRC. Having Prof. Fisk as a leader renders tremendous boost to the team. His deep knowledge and sharp intuition will most likely guide the team to a great height of international prominence, if he dedicates enough time and effort to this project. ASRC and JAEA should make every effort to make this international collaboration a success and a showcase for the future projects."

Response

Group leader and the members well communicate each other for scientific discussions using a variety of opportunities including a weekly video meeting over internet, leader's visit to Tokai, member's visit to US, discussion meeting at international workshops/conferences and daily communication using Email. These activities, combined with ultra-high quality single crystal growth and hydrostatic pressure experiments, lead to the scientific outcomes, particularly on the long-standing issues in heavy fermion uranium compound.

Progress

Electron degree of freedom plays essential role, in general, in the exotic phenomena in condensed matter. When 5f electrons of actinide atoms with spin/orbital moments and partial delocalization characteristics are confined in a crystal lattice and cooled down, electron system exhibit a variety of ordering phenomena to release their entropy. Among them, an unidentified order parameter in the phase transition of a uranium-based heavy fermion superconductor URu_2Si_2 is a long-standing problem. Since its discovery in 1986, any experimental / theoretical attempts failed to identify the order parameter. Therefore it is now called a "hidden order" phase. Our approach to tackle with this is to prepare extremely clean sample, which is essentially important to study electron system with large degree of freedom at low temperature. Our sample has a world-highest residual resistance ratio enabling the detection of anomalous electron scattering in URu_2Si_2[48]. The study was further extended to the high-pressure investigation using a hydrostatic condition. A careful measurement of resistivity at low temperature and high pressure lead to a discovery of the clear

relationship between an 'anomalous' scattering component with the superconducting transition temperature[63,73]. It was also found that the 'anomalous' scattering only exists in the hidden order phase. On the other hand, recent developments in measurement techniques were applied to our clean single crystals. A high sensitivity magnetic torque measurement detected a rotational symmetry breaking in the hidden order state.[54] (collaboration with Kyoto University) Ultra-high-resolution photoemission found a formation of narrow quasi-particle band and relevant super-cell formation.[25,70,71] (collaboration with ISSP, Univ. Tokyo)

Transuranium compounds were also prepared including a heavy fermion compound $PuCoIn_5$ and related compounds. Although a part of transuranium experiments are suspended after the earthquake, collaboration with Los Alamos lead was successfully performed. An intermetallic compound $PuIn_3$, which is considered as a building block of superconducting $PuCoIn_5$ was investigated. A possible antiferromagnetic ordering was observed.

Further international collaborations are in progress: field-induced electronic transition in uranium compound at NHMFL, optical investigation of pressure-induced ferromagnet US_2 at MPI Dresden, and single crystal growth in LANL.

A new attempt to prepare and characterize a surface state and thin-film of correlated materials was initiated. MBE equipments in an ultra high vacuum chamber were built in a laboratory building where actinide materials can be handled.

Scientific/technical merit

5f electrons in actinides show a variety of phenomena that attract scientists' interests. However, because of the radioactivity and toxicity of transuranium elements, such materials can only be handled in atomic energy research facilities. In Japan, JAEA and Tohoku University can perform actinide research using a macroscopic amount of sample. We also have a large advantage in high-quality single crystal growth techniques that are indispensable to the study strongly correlated phenomena at low temperatures. Hydrostatic pressure will be used to modify the electronic state by tuning the interatomic distances.

Goals

The importance of actinide materials in the condensed matter physics of metals lies in their correlated electronic properties arising from the establishing and development of the 5f electronic shell with Z increasing from Uranium. 5f electrons have larger radial extension than the 4f's and this fact makes the properties of 5f materials intermediate in many respects between those of the more localized 4f's and the d-band transition intermetallics. This leads to essentially new phenomena in some cases justifying the study of the actinide intermetallics in their own right. But more importantly, the 5f's provide a route for understanding how correlated electron physics evolves as the very narrow bands characterizing 4f Ce materials are broadened and participate in the bonding as well as magnetic properties seen in 3d materials.

One particular path for thinking about this is that of the exotic superconductors. The original exotic superconductors were the heavy Fermions, of which the 4f $CeCu_2Si_2$ and the 5f's UBe_{13} and UPt_3 were the first identified. The discovery of the class of high T_c cuprate superconductors raised immediately the question whether the cuprate and the heavy Fermions shared at some deep level similar physics. This remains a not well explored subject due apparently to a lack of

any clear vision as to how to make the connection other than suggesting pairing from a similar magnetic mechanism. But the discovery of superconductivity first in $PuCoGa_5$ and subsequently in $NpAl_2Pd_5$ hinted strongly at the deeper connection, particularly in view of the 18K T_c of $PuCoGa_5$.

The first observation of ^{139}Pu NMR signal by Yasuoka at Los Alamos in 2011 now gives real direction to making this connection, with the possibility to track the NMR signal of the active 5f nucleus through T_c in $PuCoGa_5$. this can provide direct comparison with the behavior of Cu in the cuprates, where Cu NMR has been a probe of first importance. We now have a route via the actinides to examine at the microscopic level the evolution and origin of high T_c from its highly correlated electron progenitors. The materials' goal from such study is the design and discovery of new materials through the new and at present missing understanding of the chemistry of correlated electron materials to be gained through the connected chain of NMR investigations.

A specific chemical avenue for pursing a close connection between the 4f and 5f materials is the comparison between Sm and Pu intermetallics. Both are trivalent entities in most cases and so have formally f^5 configuration. We have identified a number of cubic Sm materials where the f-electron spin degrees of freedom become entangled with those of the conduction electrons in the compounds. These give the opportunity for a direct comparison between 4f and 5f correlated electron properties wihin the same f-configuration which is not present with Uranium or other actinide element intermetallics. We have not as yet found highly correlated electron Sm based superconductors, but this is an avenue being pursued.

Originality

Our group can grow the best high-quality single crystals in the world. We can also access transuranium facilities.

Feasibility

We have developed the sample preparation facilities for a variety of samples from intemetallics to insulators. The techniques involve arc-melting, Bridgman method, vapor transport and flux growth. The characterization facilities like EPMA and single-crystal XRD enable us to determine the composition and structure of new compounds. The high-pressure apparatus is ready for 10 GPa and cryogenic temperatures. Transuranium facilities are also accessible. All these infrastructures make the systematic actinide research possible.

Scientific and social outcomes

Condensed matter science has been developed through discoveries of new phenomena in new materials. We will promote actinide science by providing the samples to researchers working in this field including neutron reactor and SPring-8 groups in JAEA and universities.

International cooperation

We promote international collaboration among JAEA, ITU (Karlsruhe, Germany) and CEA (Grenoble, France).

Group Leader, Guest Scientist

Zachary Fisk (Professor, University of California, Irvine)

Publication list, Invited talks, Awards

[1] ^{105}Pd NQR study on $NpPd_5Al_2$ and $CePd_5Al_2$, H. Chudo, H. Sakai, Y. Tokunaga, S. Kambe, D. Aoki, Y. Haga, T.D. Matsuda, Y. Homma, Y. Nakano and F. Honda, J. Phys.: Conf. Ser. **200** 012020 (2010).

[2] Anisotropic Spin Fluctuations in Heavy-Fermion Superconductor $NpPd_5Al_2$, H. Chudo, H. Sakai, Y. Tokunaga, S. Kambe, D. Aoki, Y. Homma, Y. Haga, T.D. Matsuda, Y. Ōnuki and H. Yasuoka, J. Phys. Soc. Jpn. **79** 053704-1-4 (2010).

[3] Angle Resolved Photoemission Study on Uranium Compounds, S.-i. Fujimori, T. Ohkochi, T. Okane, Y. Saitoh, A. Fujimori, H. Yamagami, Y. Haga, E. Yamamoto and Y. Onuki, IOP Conf. Ser.: Mater. Sci. Eng. **9** 012045-1-8 (2010).

[4] Magnetism and Superconductivity in the new Family of Actinide Compounds : $AnPd_5Al_2$, Y. Haga, Y. Homma, D. Aoki, S. Ikeda, T.D. Matsuda, N. Tateiwa, E. Yamamoto, A. Nakamura, K. Nakajima, Y. Arai, F. Honda, R. Settai and Y. Ōnuki, IOP Conf. Ser.: Mater. Sci. Eng. **9** 012046-1-7 (2010).

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[8] Quantum criticality in a uranium heavy fermion system revealed with NMR spin-spin relaxation, S. Kambe, H. Sakai, Y. Tokunaga, T.D. Matsuda, Y. Haga, H. Yasuoka, H. Chudo and R. Walstedt, J. Phys.: Conf. Ser. **200** 012076 (2010).

[9] One-Component Description of Magnetic Excitations in the Heavy-Fermion Compound $CeIrIn_5$, S. Kambe, Y. Tokunaga, H. Sakai, H. Chudo, Y. Haga, T.D. Matsuda and R.E. Walstedt, Phys. Rev. B **81** 140405(R)-1-4 (2010).

[10] Molecular and Crystal Structures of Plutonyl(VI) Nitrate Complexes with N-Alkylated 2-Pyrrolidone Derivatives: Cocrystallization Potentiality of U^{VI} and Pu^{VI}, S.-Y. Kim, .K. Takao, Y. Haga, E. Yamamoto, Y. Kawata, Y. Morita, K. Nishimura and Y. Ikeda, Crystal Growth & Design **10** 2033-2036 (2010).

[11] Anisotropic transport properties of $NpPd_5Al_2$, T.D. Matsuda, Y. Haga, D. Aoki, Y. Homma, N. Tateiwa, E. Yamamoto and Y. Ōnuki, J. Phys.: Conf. Ser. **200** 012113 (2010).

[12] Fermi Surface Properties of Ferromagnet UCu_2Si_2, T.D. Matsuda, S. Ikeda, E. Yamamoto, Y. Haga, H. Shishido, H. Yamagami, R. Settai and Y. Ōnuki, J. Phys. Soc. Jpn. **79** 114712-1-4 (2010).

[13] Huge upper critical field in the superconductor with non-centrosymmetric crystal structure $CeCoGe_3$, M.-A. Measson, H. Muranaka, T.D. Matsuda, T. Kawai, Y. Haga, G. Knebel, D. Aoki, G. Lapertot, F. Honda, R. Settai, J.-P. Brison, J. Flouquet, K. Shimizu and Y. Onuki, Physica C **470** S536–S538 (2010).

[14] Neutron Scattering Study on U-Dichalcogenides, N. Metoki, K. Kaneko, S. Ikeda, H. Sakai, E. Yamamoto, Y. Haga, Y. Homma and Y. Shiokawa, IOP Conf. Series: Mater. Sci. Eng. **9** 012088-1-8 (2010).

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[20] Crystal Structure and Physical Properties of Uranium-Copper Oxyphosphide UCuPO, H. Sakai, N. Tateiwa, T.D. Matsuda, T. Sugai, E. Yamamoto and Y. Haga, J. Phys. Soc. Jpn. **79** 074721-1-5 (2010).

[21] New Surprises "Down Below": Recent Successes in the Synthesis of Actinide Materials, J.L. Sarrao, Y. Haga and R.C.C. Ward, MRS Bulletin **35** 877-882 (2010).

[22] Metamagnetic Behavior in Heavy-Fermion Compound $YbIr_2Zn_{20}$, T. Takeuchi, S. Yasui, M. Toda, M. Matsushita, S. Yoshiuchi, M. Ohya, K. Katayama, Y. Hirose, N. Yoshitani, F. Honda, K. Sugiyama, M. Hagiwara, K. Kindo, E. Yamamoto, Y. Haga, T. Tanaka, Y. Kubo, R. Settai and Y. ŌNuki, J. Phys. Soc. Jpn. **79** 064609-1-15 (2010).

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[24] Electronic structure analysis of UIr using soft x-ray photoemission spectroscopy and band calculation, H. Yamagami, T. Ohkochi, S. Fujimori, T. Toshimitsu, A. Yasui, T. Okane, Y. Saitoh, A. Fujimori, Y. Haga and E. Yamamoto, J. Phys.: Conf. Ser. **200** 012229 (2010).

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Invited Talks

[1] New compounds in actinide-based intermetallic system and physical properties
Y. Haga
The Third International Workshop on Dual Nature of f-Electrons
Dresden, Germany, May 27, 2010

[2] Unconventional magnetism and superconductivity in the ternary actinide compounds $AnPd_5Al_2$
Y. Haga, Y. Homma, D. Aoki, T. D. Matsuda, N. Tateiwa, H. Sakai, S. Yoshio, T. Sugai, A. Nakamura, E. Yamamoto, Y. Onuki
International Conference on Strongly Correlated Electron Systems, Santa Fe, USA, July 1, 2010.

[3] Thermodynamic study on anomalous magnetism and superconductivity in actinide compounds
Y. Haga
The North American Calorimetry Conference, Colorado Springs, USA
July 20, 2010

[4] Potholes on the heavy Fermion Road : Electronic inhomogeniety in doped $CeCoIn_5$
Z. Fisk
On the Heavy Fermion Road, Paris, France
August 30, 2010

[5] New Defect-Crystal-Chemistry Model for Non-Vegardianity and Non-Random Defect Structure of Defect-Fluorite MO_2–$LnO_{1.5}$ Solid Solutions (M^{4+} = Ce, Th; Ln^{3+} = Lanthanide)
A. Nakamura
21st IUPAC International Conference on Chemical Thermodynamics (ICCT-2010), Tsukuba, August 1-6, 2010

[6] New Defect-Crystal-Chemical Approach to non-Vegardianity and Complex Defect Structure of Fluorite-Based MO_2–$LnO_{1.5}$ Solid Solutions (M^{4+} = Ce, Th; Ln^{3+} = Lanthanide)

A. Nakamura
3rd International Symposium on Materials Chemistry (ISMC-2010), Mumbai, India, December 7-11, 2010

[7] Single crystal growth of strongly correlated uranium and transuranium compounds
Y. Haga
The 1st ASRC International Workshop : New Approach to the Exotic Phases of Actinides Compounds under Unconventional Experimental Conditions
Tokai, Japan, February 16-18, 2011

[8] High-pressure studies on actinide compound in Tokai
N. Tateiwa
The 1st ASRC International Workshop : New Approach to the Exotic Phases of Actinides Compounds under Unconventional Experimental Conditions
Tokai, Japan, February 16-18, 2011

[9] Strong Correlation between Anomalous Quasiparticle Scattering and Unconventional Superconductivity in Hidden Order Phase of URu_2Si_2
N. Tateiwa
Heavy Fermion Physics: Perspective and Outlook
Beijing, Jan 7-9, 2012

[10] Unconventional superconducting characteristics of heavy fermion actinide superconductors
Y. Haga
Heavy Fermion Physics: Perspective and Outlook
Beijing, Jan 7-9, 2012

Press release, etc.

Press release

[1] "Rotational symmetry breaking in the hidden-order state of URu_2Si_2"
Jan. 28, 2011 (with Kyoto University and Osaka University)

[2] "Anomalous quasiparticle scattering in the heavy fermion superconductor URu_2Si_2"
Mar. 1, 2012 (with Osaka University)

(Scheduled) "Superconducting symmetry revealed by the angle-resolved thermal transport in UPt_3"
March, 2012 (with Tokyo Inst. Tech., Tohoku Univ., Osaka Univ. and Okayama Univ.)

JAEA President's award

[1] N. Tateiwa
"High-Pressure Research in Actinide Compounds", 2011

ASRC award

[1] N. Tateiwa
"High-Pressure Research in Actinide Compounds", 2011

[2] T.D. Matsuda
"High quality single crystal growth and characterization of URu_2Si_2", 2012

J. Phys. Soc. Jpn. Editors' Choice

[1] Details of Sample Dependence and Transport Properties of URu_2Si_2, T.D. Matsuda, E. Hassinger, D. Aoki, V. Taufour, G. Knebel, N. Tateiwa, E. Yamamoto, Y. Haga, Y. Ōnuki, Z. Fisk and J. Flouquet, J. Phys. Soc. Jpn. **80** 114710-1-10 (2011).

Patent

[1] N. Tateiwa, and Y. Haga, Japanese Patent Tokugan No .2011-054153 (pending)

Research Subject (7)

Foundation of New Concept in Condensed Matter Physics for Heavy Element Systems

Group **Research Group for Condensed Matter Physics of Heavy Element Systems**

Member (Leader) Shinsaku Kambe
(Researcher) Wataru Higemoto, Yo Tokunaga, Hironori Sakai, Takashi U. Ito
(Post doc.) Kazuhiko Ninomiya, From April 2012, assistant professor at Osaka University
(MS student) Yo Saito, From April 2011, Sandisk (Co)

Summary of pre-review

This is an exciting project to investigate the complex condensed matter physics of heavy elements in the new intermediate regime of spin-orbit coupling. The goal of creating new concepts fits very well with the ideal of ASRC. Also their ambitious target of creating new high temperature superconductors should be commended.

Response

It is delightful for us that our project has been accepted positively. According to suggestions of reviewers and advisers, we have programmed our research in April 2010. Although all measurements are stopped for 8 months in 2011 due to the disaster in Japan, we have made concrete progresses for our purpose.

Progress

1) **Unconventional superconductivity and Magnetic fluctuations:** A correlation between the strength of XY anisotropy for antiferromagnetic (***q***=***Q***) fluctuations and the superconducting transition T_c has been found in *d*-wave unconventional superconductors of 4*f* and 5*f* heavy fermion systems based on systematic NMR and μSR studies (see Fig. 1). This anisotropy of pseudo-spin is certainly related with the spin-orbit coupling. Since no correlation is found between Tc and anisotropy of static (***q***=0) susceptibility, this correlation appears only magnetic fluctuations around antiferromagnetic wave vector. A determination of anisotropic fluctuations by neutron scattering is difficult in compounds of central issue such as $CeCoIn_5$, $NpPd_5Al_2$ and $PuCoIn_5$ due to large neutron-absorption of In and/or strong radio-activities of Np or Pu atoms. Thus NMR is unique method to determine the anisotropy of spin fluctuations. Certain compounds does not seem to obey the above correlation, however, there is an interesting physical reason for the exception in appearance, which is also investigated in order to understand the correlation deeply. Among these exceptions, for example, a superconductor $CeIrSi_3$ shows the Ising magnetic

anisotropy. In $CeIrSi_3$, *d*- and *p*-wave superconductivity can be mixed since the crystal structure has no-inversion symmetry, which is considered to be the origin of the exception as the correlation is only found for *d*-wave superconductivity. It is also revealed that the Ising anisotropy is favorable for *p*-wave superconductivity. Using μSR, we have determined that superconductivity under pressure is at least unconventional in $CeIrSi_3$ (Fig. 2). An exact determination of the superconducting symmetry is now in progress.

From third year, we try to understand this correlation based on more microscopic point of view in terms of spin-orbit coupling on collaborations with theoretical colleagues. In addition, we start to search high T_c *f*-electron compound based on the correlation as a working hypothesis.

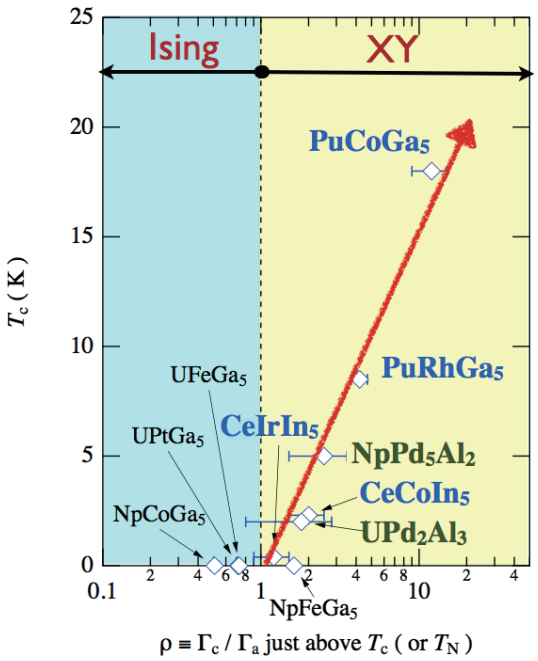

Fig. 1 Plot of T_c vs anisotropy factor of antiferromagnetic spin fluctuations.

2) **Multipolar ordering:** Multipolar degree of freedom is a characteristic of *f*-electron systems due to the spin-orbit coupling. In order to understand the basic character and excitation of multipole, simple cubic systems AmO_2 and SmX_3 (X=Sn, In) are investigated. Actinides dioxides series AnO_2 (An: U, Np, Pu, Am…) provide rich examples of multipolar ground states. We have already investigated UO_2 (dipolar+quarudpolar ordering), NpO_2 (quadrupolar+octupolar ordering), PuO_2 (paramagnetic) systems. AmO_2 shows a transition at 8.5 K but the character of ordering has not been been identified. Using ^{17}O-NMR in AmO_2, we have clarified that there is a 2nd order phase transition at 8.5 K with a distributed internal magnetic field, which may indicate spin density wave ordering. A new measurement using fresh sample without μ-damages is programmed to confirm this observation.

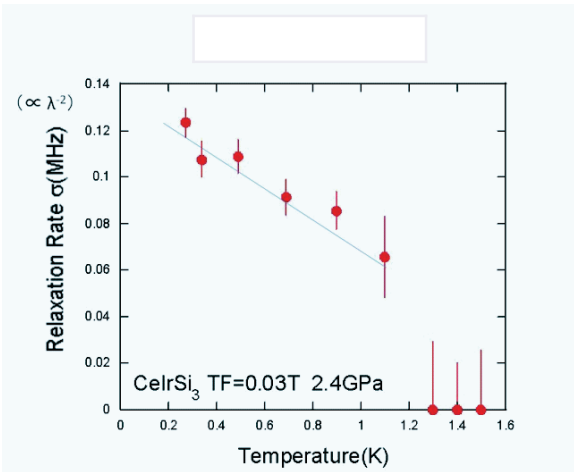

Fig. 2 T-dependence of penetration depth in CeIrSi3 under 2.4GPa,indicating line-node of superconducting gap.

Sm-based compounds provide an important aspect as these systems shows not only magnetic but also valance transitions. In contrast, a multipolar transition has never been reported. There may be a competition between valance and multipolar instabilities. However, because of large neutron-absorption of Sm, a microscopic investigation by neutron scattering was difficult. Here we start to study it using μSR. The intermetallic cubic compounds SmX_3 (X=Sn, In) are currently the only candidate for pure quadrupole ordering among existing Sm-based compounds. However, we have found that a spontaneous local magnetic field appears in the ordered state, which

undoubtedly rules out the pure quadrupole ordering. Comparing dipole-dipole and quadrupole-quadrupole interactions in trivalent lanthanide systems on the basis of a de Gennes theory, we indicate that the former tends to dominate in Sm intermetallics. This result provides a general guideline for future searches of quadrupole-related phenomena in trivalent lanthanide systems.

Superconductivity induced by multipolar fluctuation is also an important subject. For this purpose, cubic superconductor $PrIr_2Zn_{20}$ with quadrupolar degree of freedom has been studied. $PrIr_2Zn_{20}$ with T_c=0.05 K shows another transition at 0.11 K. Temperature independent μSR spectra in $PrIr_2Zn_{20}$ below 1 K indicate that a phase transition at 0.11 K is of a non-magnetic origin, most probably pure quadrupole ordering, i.e. the superconducting transition occurs in the quadrupolar ordered state. The relation between quadrupolar fluctuation and superconductivity will be investigated.

3) **Development of J-PARC and μSR techniques:** Most of muon works are performed at J-PARC. For these studies, we have developed the muon experimental instruments at the D-line of J-PARC muon facility. For example, we have developed muon beam slicer, which gives narrow muon beam pulse. By using this "muon-slice mode," we have obtained a pulse width less than 37 ns (FWHM).

   Using negative muon source, we also measured muonic X-ray in molecular samples to elucidate relation between chemical state of molecule and muonic atom formation process. Characteristic muonic X-ray measurement for nitrogen oxide samples (NO, N_2O and NO_2) were performed. The experimental capture ratios are compared with these from previous empirical models that muon capture ratios are strongly influenced by the number of localized electrons in each atom. The calculated values fail to produce the experimental result. From the molecular orbit calculation, we found a correlation between the numbers of most loosely bound electrons and muon capture ratio. This fact implies muon capture phenomena proceeds interaction between free muon and most loosely bound electrons. Application of negative muon for investigation of electronic state in solid state is planned.
4) **Development of measurements under extreme conditions:** In addition to μSR under high pressure mentioned above, NMR measurements under 2 GPa have been developed. Measurement under 10 GPa is planned on collaboration with CEA-Grenoble. Concerning high magnetic field, NMR in URu_2Si_2 up to 30 T is performed at NHMFL in USA, and magnet time up to 45 T has been approved in this year. Scientific reports based on these measurements are planned.

<u>Goals</u>

1) A: Complementary studies using different microscopic measurements (NMR, μSR, and neutron scattering).

   B: To achieve world leadership in development of the above measurements under extreme environments (high pressure, strong magnetic field, and intense radioactivity).

Based on these two strategies, elucidation and understanding of excitation spectra in exotic states will be achieved, creating a conceptually novel and unified picture of correlated electrons in 3*d* to 5*f* systems.

2) Development of μSR: The pulsed μSR spectrometer at J-PARC, currently with the highest pulse

strength in the world, will be further optimized. Advanced experimental techniques will be implemented for the new spectrometer.

Originality

Order parameter fluctuations are enhanced in the vicinity of a phase transition. Therefore, clarifying the properties of such fluctuations is essential for the understanding of related exotic behaviors. Because the static and dynamic properties of both the spin and orbital degrees of freedom can be detected, NMR is especially effective for the investigation of fluctuations. Moreover, μSR can detect the static and dynamic behaviors of small internal magnetic fields with high sensitivity on a time scale that is complementary to NMR. Using neutron scattering, magnetic correlations can be investigated over wide ranges of space and time.

Research on the microscopic physical properties of actinide compounds, including transuranium systems, is a unique capability that very few groups, including our group, possess in the world today. In addition, our ability to perform experiments under extreme environmental conditions will also be unique throughout the world.

Feasibility

Experimental facilities for NMR and μSR have been developed during the first 5-year project. Thus, basic measurement techniques are on hand for achieving scientific results and for developing experiments under extreme conditions. With our extensive experience in handling radioactive samples, all measurements can be performed safely. Due to damages from the disaster, NMR facility has been shut down until November 2011, but now is almost recovered. Since μSR facility in J-PARC accelerator has been seriously damaged, no scientific results can be obtained by μSR spectrometer in J-PARC which has not been damaged itself. Last December, the accelerator has been recovered and the first muon beam after disaster has been obtained 24th January. In next fiscal year, μSR measurements are planned to restart.

Scientific and social outcomes

Magnetic fluctuation-induced superconductivity with a high critical temperature may be realized in an unconventional superconductor. Therefore, clarification of the relation between magnetic fluctuations and unconventional superconductivity is an important step in the development of a high temperature superconductor. Understanding basic physical properties of actinide compounds, especially of the actinide dioxides, is essential for the fundamental engineering of nuclear power using, e.g., MOX fuel development. After the accident in Fukushima, technical developments in this field become crucial for future strategy of nuclear engineering in Japan.

International cooperation

In terms of REIMEI research project coordinated by G.H. Lander, A. Hiess (Institute Laue-Langevin) and S. Kambe (JAEA), international research project is organized from 2010 to 2012. In addition to CEA-Grenoble, Institute Laue-Langevin (ILL) and Institute for Transuranium (ITU) which have the official treaty with JAEA, Los Alamos laboratory (LANL), National High Magnetic Field Lab. (NHMFL), Laboratoire National des Champs Magnetiques Intenses (LNCMI), European Synchrotron Radiation Facility (ESRF) have participated. The collaborations

are quite successful. Achievements and future plan have been discussed in workshops held at ASRC in 2011 and at ILL in 2012. All participants agree to continue the collaborations.

Concerning μSR, research project, which is leading by Y. J. Uemura (Columbia University), is in progress as another REIMEI research project from 2010 to 2012. TRIUMF, Institute of Physics, Beijing, China (IOP), National Institute for Advanced Industrial Science and Technology, Tsukuba (AIST), University of Tokyo and JAEA have participated to elucidate the nature of magnetic semiconductors. Achievements and future plan have been discussed in workshops held at ASRC in 2012.

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Invited talk in international conferences

1. “Solid-state NMR study of Actinide Dioxides”, Y. Tokunaga (MRS Spring Meeting, San-Francisco, April, 2012)
2. “Spin Fluctuation, Orbital States and Non-conventional Superconductivity in Actinides Compounds”, S. Kambe (MRS Spring Meeting, San-Francisco, April. 2012)
3. "Anisotropy of Spin Fluctuations in the Heavy Fermion Systems: Nuclear Magnetic Resonance Study", H. Sakai (TOKIMEKI2011 International Workshop on Heavy Fermions, Osaka, Japan, Nov., 2011).
4. "Ligand and Actinide NMR Studies in Actinide Oxides and Intermetallic Compounds", S. Kambe (American Chemical Society Fall Meeting, Denver, Colorado, Aug., 2011)

5. “Coherence between localized and itinerant excitations in heavy fermion $CeIrIn_5$”:, S. Kambe (International workshop “Dual Nature of *f*-electrons” Dresden, May 2010)
6. “Magnetic fluctuations around quantum critical point in heavy fermion systems”, S. Kambe（International workshop “Heavy fermion road”, Paris, France, Aug. 2010）
7. “Dynamical coherence in heavy fermion superconductor $CeIrIn_5$”, S. Kambe (International conference on heavy electron 2010 Tokyo, Japan, Sep., 2010)
8. “NMR studied of actinide dioxides”: Yo Tokunaga (International conference “Pu futures 2010”, Keystone, USA, Sep., 2010)
9. “Magnetic fluctuations and Unconventional superconductivity in Actinide compounds”, S. Kambe (International conference “Pu futures 2010”, Keystone, USA, Sep., 2010)
10. "NMR study of exotic magnetism and superconductivity in actinide compounds", S. Kambe (International and Interdisciplinary Workshop on Novel Phenomena in Integrated Complex Sciences: from No-living to Living Systems, Coop-Inn Kyoto, Kyoto, Japan, Oct., 2010)
11. "NMR studies in actinide dioxides", Y. Tokunaga, (6th Workshop on Speciation, Techniques, and Facilities for Radioactive Materials at Synchrotron Light Sources and Other Quantum Beam Sources (AnXAS2011), Harima Science Garden City, Hyogo, Japan, April. 2011)
12. "NMR Studies in Actinide Oxides and Intermetallic Compounds", Y. Tokunaga, (The 1st ASRC International Workshop - New Approach to the Exotic Phases of Actinides compounds under Unconventional Experimental Conditions, Tokai, Ibaraki, Japan, Feb., 2011)
13. "Our Recent Progress of NMR Measurements Under High Pressures in Our Research Group of ASRC-JAEA", H. Sakai, (The 1st ASRC International Workshop - New Approach to the Exotic Phases of Actinides compounds under Unconventional Experimental Conditions, Tokai, Ibaraki, Japan, Feb., 2011)
14. "Our Recent Progress of NMR Measurements Under extreme condition in Our Research activity in ASRC-JAEA", H. Sakai, (The 3rd ASRC International Workshop - New Approach to the Exotic Phases of Actinides compounds under Unconventional Experimental Conditions, Grenoble, France Feb., 2012)
15. "No-collinear antiferromagnetic structure in $TbCoGa_5$", Y. Tokunaga, (The 3rd ASRC International Workshop - New Approach to the Exotic Phases of Actinides compounds under Unconventional Experimental Conditions, Grenoble, France Feb., 2012)

Press release

2011 September “Magnetic fluctuations in $CeCoIn_5$”
2011 August “Li(Zn,Mn)As as a new generation ferromagnet based on a I–II–V. Magnetic semiconductor”

Research Subject (8)

Research on Structure of Nuclei and Hadrons Containing Strangeness

Group **Hadron Physics Research Group**

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Susumu Sato,
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(Research Fellow) Kenneth Hicks (Ohio U.) (2012.3.5 ~ 6.5)
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Summary of the pre-review

"This is an exciting project which makes excellent use of J-PARC. This project has a high potential to grow into a major project. The current level of support at ASRC is inadequate to fully exploit the subject. It should be seen as a seed project, which, upon initial successes, will attract major external support."

Response

We were very much encouraged by the comments above given to our group in the summary of the pre-review. The member of the hadron group has been increased from the time of the pre-review (4 staff scientists and 2+1 phD students) to present (5 staffs, 1 posdoc and 4 phD students) thanks to the comments above and the effort of the ASRC headquarter. In spite of the delay due to the damage of J-PARC by the earthquake, we have been trying hard to carry out the planned experiments at J-PARC and get physics results. All of the staff members have applied for various research funds of MEXT. We have also been trying to expand the international collaboration to establish a global center for hadron physics at JAEA. In addition to the collaboration with a hadron physics group lead by K.Tanida of Seoul National University, we collaborate with a group of J.K.Ahn of Pusan National University for a new proposal to J-PARC.

Progress

FY2010

1. Set up of a new laboratory (two rooms (One is a clean room) for detector R&D etc.).
2. Pentaquark (Theta+) search experiment with 1.9 GeV/c pions at J-PARC (E19) was performed. We obtained the null result and upper limit of the production cross section as 300 nb/sr which gives a strong constraint on the Pentaquark.
3. R&D of silicon strip detectors was performed and high resolution and high efficiency was obtained up to 100MHz beam rate.
4. A prototype Time Projection Chamber (TPC) with GEM readout was constructed for R&D of a large acceptance hyperon spectrometer (HypTPC) for coming experiments at J-PARC.
5. We joined PHENIX experiment at RHIC and installed vertex detectors in order to study exotic hadrons and charmed nuclei produced from QGP phase. The data was taken for p+p and Au+Au collisions at 200 GeV.
6. Theoretical study of multi-kaonic nuclei. We have found a saturation of the matter density with increase of the number of kaons in a nucleus.
7. Theoretical study of liquid-gas phase transition of low-density nuclear matter which is relevant to the supernova matter. We have clarified the origin of the congruence of symmetric nuclear matter and the non-congruence of asymmetric nuclear matter.

FY2011

1. We have worked for the recovery of K1.8 beam line and SKS spectrometer from damages due to the March-11 earthquake and completed in time
2. We have performed Pentaquark (Theta+) search experiment with 2.0 GeV/c pions at J-PARC (E19).
3. A proto-type TPC was tested with proton beams at RCNP, and we have confirmed that the TPC works well up to 5MHz beam rate without losing efficiency or resolution.
4. A proto-type scintillating fiber tracker (SFT) with MPPC readout was constructed and tested with the proton beams at RCNP, and we have confirmed the SFT works up to 50 MHz beam rate with 100% efficiency.
5. After the success of the detector R&D of SSD and SFT, the new beam line detectors have been designed to enable J-PARC E10 (search for neutron rich hypernuclei) which needs a 10 MHz pion beam.
6. Based on the study of the proto-type TPC, we have submitted a new proposal of H-dibaryon search experiment (P42) which needs a large acceptance hyperon spectrometer with TPC.
7. Theoretical study of kaonic nuclei. We have pointed out the possibility of disappearance of kaonic nuclei in the ground state by a strong process $K^{-}+N \rightarrow Y$.
8. Theoretical study of low-density nuclear matter with inhomogeneous structures. We have confirmed the appearance of “nuclear pasta” structures by an *a priori* calculation without assuming any geometry.

Goals

Our goal is to discover new hypernuclei and new exotic hadrons to expand the frontier of nuclear and hadronic physics by fully utilizing world highest-intensity kaon and other hadron beams at J-PARC.

To achieve the goal, more specifically, we plan;

To observe X-rays from Ξ-atoms for the first time (E03).

To identify the existence of Ξ-nuclei, and to determine its potential (E05).

To discover as many double Λ hypernuclei as possible and to clarify their systematic feature (E07).

To discover neutron rich Λ hypernuclei such as $^{6}H_{\Lambda}$ and $^{9}He_{\Lambda}$.(E10)

To complete γ-spectroscopy for lighter hyper nuclei, and also to make γ-spectroscopy for some medium/heavy hyper nuclei in order to determine their structure (E13).

To confirm the existence of Pentaquark Θ^{+} by the high-resolution and high-statistics experiment (E19).

To discover the H-dibaryon near ΛΛ threshold with a hyperon TPC spectrometer (P42).

To explore the structure of Λ (1405) particle, which is relevant to K-meson nuclei (E27).

To get consistency of hyperon interaction with observed properties of compact stars.

To develop experimental devices for the studies above.

To make a plan of the hadron physics at J-PARC phase-2.

Originality

Recent studies of hypernuclei have been led by Japanese groups. In J-PARC, many new discoveries such as Ξ-nuclei etc. are expected by utilizing the world-highest intensity of K-meson beams. The hadron physics group at ASRC has an advantage to do experiments and play an important role in hadron physics at J-PARC as an “in-house” research group. We can host and collaborate with many scientists from foreign countries as well as from Japanese Universities.

It is our originality to install new detectors such as SSD and SFT to K1.8 Beam line to accept higher rate beams (10MHz) in order to enable several important experiments in a reasonable beam time.

It is also our originality to construct a large hyperon spectrometer with TPC which enable high sensitivity search for H-dibaryon and also make various measurements possible which need a large acceptance.

Feasibility

The technical feasibility of the experiments at J-PARC has been reviewed by PAC and stage-2 approval is given if the experiment is considered to be feasible. Many experiments above were already in stage-2 approval. The feasibility largely depends on the intensity improvement of the slow extracted beam from the J-PARC Main Ring and scheduling. We have finished E19 and will carry out E27, E10, E13 in FY2012 (J-PARC operation is well funded). After a long shutdown due to the upgrade of LINAC during FY2013, we will carry out E07, E03, E05 and P42 one by one with high intensity kaon beams.

Scientific and social outcomes

Understanding and progress of theoretical treatments of nuclei and hadrons with strangeness as many-body systems, have ripple effects on material science and the related fields, as well as astrophysics. Developing new measurement devices for radiation will contribute to medical applications and to environmental affairs.

International cooperation

(1) Approach for internationalization

1. We made a contruct with a group of Seoul National University to carry out joint research for s=-2 strangeness nuclear physics experiments at J-PARC and detector R&D for those. Under this collaboration, 4 people (2 staffs and 2 phD students) have been working at ASRC.

2. We collaborate with a group of Pusan National University (J.K.Ahn) for a new proposal to search for H-dibaryon submitted to J-PARC PAC (P42).

3. We participated PHENIX experiment at RHIC (BNL) and worked for vertex detector installation and its data analysis in collaboration with RIKEN group. It is under JAEA-DOE agreement which is under the process of revision.

4. We have so far visiting physicists from Italy, USA and Korea as below and plan to expand the collaboration with Jlab and GSI which are major facilities for hadron physics in the world.

5. We organized the 1st international school on strangeness nuclear physics from Feb.12-14 at Tokai and 15-18 at Sendai in cooperation with Tohoku University. We have 64 participants including 32 from abroad. We plan to organize the international school for hadron physics at Tokai every year.

(2) Visitors from Foreign Institutes (Name, Affiliation, Title, Role in the research)

K. Tanida: Seoul National Univ., Professor.
Experiments at K1.8 beam-line and detector R&D and preparation for s=-2 nuclear physics experiments (E03, E05 and E07).

R.Kiuchi: Seoul National Univ., Post Doc.
Experiments at K1.8 beam-line and detector R&D and preparation for s=-2 nuclear physics experiments (E03, E05 and E07).

J.C.Woo: Seoul National Univ., phD student.
Experiments at K1.8 beam-line and detector R&D and preparation for s=-2 nuclear physics experiments (E03, E05 and E07).

Y.S.Bhe: Seoul National Univ., phD student.
Experiments at K1.8 beam-line and detector R&D and preparation for s=-2 nuclear physics experiments (E03, E05 and E07).

S. Marcello: Torino Univ., Associate Professor.
Pentaquark search (E19) at J-PARC.

J.K.Ahn: Pusan National Univ., Professor.
Detector R&D and planning for the experimental search for H-dibaryon at J-PARC.

Andrei Ni: Pusan National Univ., Post doc.
Detector R&D and planning for the experimental search for H-dibaryon at J-PARC.

S.H.Hwang: Pusan National Univ., phD student.

Detector R&D and planning for the experimental search for H-dibaryon at J-PARC.

B.Bassalleck: New Mexico Univ., Professor.
Experiments at K1.8 beam-line and detector R&D and preparation for H-dibaryon search experiment (P42)

K.Hicks: Ohio University, Professor and spokesman of CLAS at Jlab.
Planning for hadron spectroscopy at J-PARC in collaboration with Jlab.

Publications (2010～2011)

Refereed papers (41)

1. Enhanced Production of Direct Photons in Au + Au Collisions at $(s_{NN})^{1/2}$ = 200 GeV and Implications for the Initial Temperature
   A.Adare, K.Imai, S.Sato, K.Tanida *et al*., *Phys. Rev. Lett.* **104**, 13231-1-6 (2010).
2. Near Threshold Λ (1520) Production by the γp -> K^+Λ (1520) Reaction at Forward K^+ Angles
   H.Kohri, K.Imai, *et al*., *Phys. Rev. Lett.* **104**, 172001-1-5 (2010).
3. Measurement of Spin-Density Matrix Elements for ϕ-Meson Photoproduction from Protons and Deuterons Near Threshold.
   W.C. Chang, K.Imai, *et al. Phys. Rev.* C **82**, 015205-1-25 (2010).
4. Transverse momentum dependence of η meson suppression in Au+Au collisions at $(s_{NN})^{1/2}$ = 200 GeV.
   A. Adare, K.Imai, K.Tanida, *et al. Phys. Rev.* **C82**, 011902-1-7 (2010).
5. Transition in Yield and Azimuthal Shape modification in Dihadron Correlations in relativistic Heavy Ion Collisions
   A.Adare, K.Imai, K.Tanida *et al*., *Phys. Rev. Lett.* **104**, 252301-1-7
6. Transverse momentum dependence of J/φ polarization at midrapidity in p+p collisions at $s^{1/2}$ =200GeV.
   A.Adare, K.Imai, K.Tanida, *et al. Phys. Rev.* D **82**, 012001-1-17 (2010).
7. Measurement of transverse single-spin asymmetries for J/φ polarization in polarized p + p collisions at $s^{1/2}$ = 200 GeV.
   Adare, K.Imai, K.Tanida, *et al. Phys. Rev.* D **82**, 112008-1-13 (2010).
8. The HypHI Phase 0 experiment
   T.R.Saito,H.Sugimura et al,.*Nucl. Phys.* A **835**, 110-116 (2010).
9. Elliptic and Hexadecapole flow of Charged Hadrons in Au + Au Collisions at $(s_{NN})^{1/2}$ = 200 GeV
   A.Adare, K.Imai, K.Tanida *et al*., *Phys. Rev. Lett.* **105**, 062301-1-6 (2010).
10. Azimuthal anisotropy of neutral pion production in Au+Au collisions at $s^{1/2}$ = 200 GeV: Path-length dependence of jet quenching and the role of initial geometry.
    Adare, K.Imai, K.Tanida *et al*., *Phys. Rev. Lett.* **105**, 142301-1-7 (2010).
11. High P_T direct photon and π^0 triggered azimuthal jet correlations and measurement of k_T for

isolated direct photons in p+p collisions at $s^{1/2}$ = 200 GeV.
A.Adare, K.Imai, S.Sato K.Tanida *et al*., *Phys. Rev.* D **82**, 072001-1-18 (2010).

12. Equation of State of Structured Matter at Finite Temperature
T.Maruyama, N.Yasutake and T.Tatsumi, *Prog. Theor. Phys. Suppl.***186** (2010) 69.

13. Nuclear modification factors of ϕ mesons in d + Au, Cu + Cu, Au + Au collisions at $(s_{NN})^{1/2}$ = 200 GeV
A.Adare, K.Imai, K.Tanida, *et al*., *Phys. Rev.* C **83**, 024909-1-10 (2011).

14. Cross section and double helicity asymmetry for η meson and their comparison to π^0 production in p + p collisions at $s^{1/2}$ = 200 GeV.
A.Adare, K.Imai, S.Sato, K.Tanida, *et al*., *Phys. Rev.* D **83**, 032001-1-11 (2011).

15. Cross Section and Parity-Violating Spin Asymmetries of $W^{+/-}$ Boson Production in Polarized p+p Collisions at $s^{1/2}$=500 GeV.
A.Adare, K.Imai, K.Tanida, *et al. Phys. Rev. Lett.* **106**, 062001-1-6 (2011).

16. Unified Beam Control System of J-PARC Linac
H. Sako, C. K. Allen, H. Ikeda, and G. Shen, *IEEE Transactions and Nuclear Science* **57**, No. 3, 1528-1535 (2010)

17. Suppression of Beam Loss at the First Arc Section in the J-PARC Linac
H. Sako and M. Ikegami, *IEEE Transactions and Nuclear Science* **57**, No. 5, 2783-2789 (2010)

18. Effects of the Λ (1405) on the Structure of Multi-Antikaonic Nuclei
T. Muto, T. Maruyama and T. Tatsumi, *Nucl. Phys.* A **835**, 370-373 (2010).

19. Current Status and Performance of the J-PARC Accelerators
Hiroyuki Sako, Journal of Power and Energy Systems, Vol.4, No. 1, pp. 218-233, (2010)

20. Liquid-gas phase transition in asymmetric nuclear matter at finite temperature.
T. Maruyama, T. Tatsumi and S. Chiba, *Nucl. Phys.* A **834**, 561 (2010)

21. Multi-antikaonic nuclei and kaon condensation in dense matter.
T. Muto, T. Maruyama, T. Tatsumi, *AIP Conf. Proc*. **1269**, 233 (2010)

22. Cooling of compact stars with quark-hadron mixed phase in the color superconductive state.
T. Noda, M. Hashimoto, N. Yasutake, T. Maruyama, T. Tatsumi and M. Fujimoto, *AIP Conf. Proc.* **1269**, 384 (2010)

23. Quark-hadron mixed phase with hyperons in protoneutron stars
N. Yasutake, T. Maruyama and T. Tatsumi, *Proc. of Sci.* **NIC XI**, 041 (2010)

24. Signatures of hadron-quark mixed phase in gravitational waves
H. Sotani, N. Yasutake, T. Maruyama and T. Tatsumi, *Phys. Rev.* D **83**, 024014 (2011)

25. Identified Charged Hadron Production in p+p collisions at sqrt{s}=200 and 62.4 GeV
A.Adare, K.Imai, S.Sato, K.Tanida et al., Phys. Rev. C **83,** 064903-1-29 (2011).

26. Azimuthal correlations of electrons from heavy flavor decay with hadrons in p+p and Au+Au collisions at sqrt{S_{NN}}=200 GeV
A.Adare, K.Imai, K.Tanida, et al., Phys. Rev. C83, 044912-1-16 (2011).

27. Measurement of neutral mesons in p+p collisions at sqrt{s}=200 GeV and scaling properties of hadron production

A.Adare, K.Imai, S.Sato, K.Tanida, et al., Phys. Rev. D83, 052004-1-26 (2011).

28. Event structure and double helicity asymmetry in jet production from polarized p+p collisions at sqrt{s}=200 GeV
A.Adare, K.Imai, S.Sato, K.Tanida, et al., Phys. Rev. D84, 012006-1-16 (2011).
29. Suppression of away-side jet fragments with respect to the reaction plane in Au+Au collisions at sqrt(s_{NN})=200 GeV
A.Adare, K.Imai, K.Tanida, et al., Phys. Rev. C84, 024904-1-12 (2011).
30. Production of omega meson in p+p, d+Au, Cu+Cu, and Au+Au collisions at sqrt{s_{NN}}=200 GeV
A.Adare, K.Imai, S.Sato, K.Tanida, et al., Phys. Rev. C84, 044902-1-11 (2011).
31. Cold nuclear matter effects on J/psi yields as a function of rapidity and nuclear geometry in d+A collisions at sqrt{s_{NN}}=200 GeV
A.Adare, K.Imai, K.Tanida, et al., Phys. Rev. Lett. 107, 142301-1-7 (2011).
32. Heavy-quark production in p+p and energy loss and flow of heavy quarks in Au+Au collisions at sqrt{s_{NN}}=200 GeV
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33. Suppression of back-to back hadron pairs at forward rapidity in d+Au collisions at sqrt{s_{NN}}=200 GeV
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34. Development of a tracking detector system with multichannel scintillation fibers and PPD
R.Honda, S.Callier, S.Hasegawa, M.Ieiri, Y.Matsumoto, K.Miwa, I.Nakamura, L.Raux, C. DeLaTaille, M.Tanaka, T.Uchida,K.Yoshimura
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment In Press, Corrected proof.
35. Multi-antikaonic nuclei and in-medium kaon properties in dense matter
T. Muto, T. Maruyama and T. Tatsumi, *J. Phys. Conf. Ser.* 312, 022018 (2011)

36. Liquid-gas mixed phase in nuclear matter at finite temperature
T. Maruyama and T. Tatsumi, *J. Phys. Conf. Ser.* 312, 042015 (2011)
37. Pasta Structures of Quark-Hadron Phase Transition in Proto-Neutron Stars
N. Yasutake, T. Maruyama and T. Tatsumi, *J. Phys. Conf. Ser.* 312, 042027 (2011)
38. Effect of Λ(1405) on the structure of multi-antikaonic nuclei
T. Muto, T. Maruyama, T. Tatsumi, *AIP Conf. Proc.* 1374, 197 (2011).
39. Search for Θ^+ via the pion induced reaction at J-PARC : J-PARC E19
K. Shirotori, R. Honda, K. Imai, H. Sako, S. Sato, Sugimura, et al., Few-Body Systems (2011) in press.
40. J-PARC Facilities and Physics,
S.Sato, Nucl. Phys. A 862, 238 (2011).
41. CANGAROO-III Observation of TeV Gamma Rays from the Unidentified Gamma-Ray Source HESS J1614-518”,
T.Mizukami, R.Kiuchi, et al., Astrophysical Journal, 740, 78 (2011)

Papers without referee (7)

1) Development of silicon strip detector for the measurement of the Xi-atom X-rays.
H. Sugimura, K. Imai, H. Sako, S. Sato, S. Adachi, K. Tanida, R. Kiuchi, C.W. Joo,
AIP Conf.Proc.1388:602-604, 2011.
2) Measurement of Beam Loss Tracks by Scintillating Fibers at J-PARC Linac,
H. Sako, T. Maruta, A. Miura, Proceedings of International Particle Accelerator Conference (IPAC2011), pp 1251, San Sebastian, Spain, Sep 2011
3) Beam Loss Detected by Scintillation Monitor,
A. Miura, T. Maruta, H. Sako et. al, Proceedings of International Particle Accelerator Conference (IPAC2011), pp 1257, San Sebastian, Spain, Sep 2011
4) Longitudinal Beam Profile Measurement at J-PARC Separated Drift Tube Linac
T. Maruta, A. Miura, H. Sako, G. Wei, M. Ikegami, Proceedings of International Particle Accelerator Conference (IPAC2011), pp 1245, San Sebastian, Spain, Sep 2011.
5) Longitudinal Beam Acceptance of J-PARC Drift Tube Linac
T. Maruta, A. Miura, H. Sako, G. Wei, M. Ikegami, Proceedings of International Particle Accelerator Conference (IPAC2011), pp 2592, San Sebastian, Spain, Sep 2011.
6) J-PARC Status, Nuclear and Particle Physics"
S.Sato, AIP Conf. Proc. Vol. 1336, pp. 560-564 (2011)
7) J-PARC and its prospect of nuclear and particle physics
K.Imai, AIP Conf. Proc. Vol. 1342 pp. 32-36 (2011)

Invited talks (13)

1) K. Imai,
Search for H resonance and other exotics at J-PARC,
YIPQS workshop on Exotics from Heavy Ion Collisions, Kyoto, Japan (2010).
2) T. Muto, T. Maruyama, and T. Tatsumi,
Effect of Λ(1405) on structure of multi-antikaonic nuclei,
12th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon, Williamsburg, USA (2010).
3) K. Imai,
J-PARC and its prospects of nuclear and particle physics,
2nd International Ulaanbaatar Conference on the Nuclear Physics and Applications (UBC2010), Ulaanbaatar, Mongolia (2010).
4) Susumu Sato,
Status of J-PARC, Hadron and Particle Physics,
International Conference on the Application of Accelerator in Research and Industry, Fort Worth, USA, (2010).
5) K. Imai,
Nucleons and Nuclear Interactions Studied with Spin and Strangeness,
The Autumn Meeting 2010 of Physical Society of Japan, Kita Kyushu, Japan (2010).
6) S. Sato,
J-PARC Facility and Physics,
6th International Conference on Physics and Astrophysics of Quark Gluon Plasma, Goa, India

(2010).

7) M. Okamoto, T. Maruyama, K. Yabana and T. Tatsumi,
Three-dimensional calculation of inhomogeneous structure in low-density nuclear matter
15th Research Workshop Nucleation Theory and Applications, Dubna, Russia, 2011.4

8) K.Imai,
Strangeness nuclear physics at J-PARC
Hadron physics meeting, Pohang, Korea 2011.5

9) K.Imai,
Hadron Physics at J-PARC
ECT Workshop on Strange Hadronic Matter, Trento, Italy 2011.9.26-30.

10) S.Sato,
Search for H-dibaryon at J-PARC
ECT Workshop on Strange Hadronic Matter, Trento, Italy 2011.9.26-30.

11) R.Honda,
Experimental investigation of baryon-baryon interaction through Sigma-p scattering at J-PARC.
8th Postgraduate Academic Forum of Beihang University. Beijing, China. Oct, 16-19th, 2011.

12) K.Shirotori,
Search for Θ^+ via the pion induced reaction at J-PARC: J-PARC E19
The Fifth Asia-Pacific Conference on Few-Body Problems in Physics 2011 (APBF2011), Seoul, Korea, 22-26 August 2011.

13) K.Shirotori,
Search for Θ^+ pentaquark baryon at the J-PARC K1.8 beam line: First result and current status
Hadron Physics Meeting (Strangeness Physics at J-PARC), Pohang, Korea, 27-28 May 2011.

Oral presentations at international conferences (4)

1) T. Maruyama and T. Tatsumi
Non-congruence of liquid-gas phase transition of asymmetric nuclear matter
The 19th Particles and Nuclei International Conference, Cambridge, USA, 24-29 July 2011

2) H.Sugimura,
"Development of GEM-TPC with gating grid for J-PARC hadron experiment."
International Conference on Micro Pattern Gaseous Detectors (MPGD2011)
Kobe, Aug. 2011

3) Y.Ichikawa
“Search for a nuclear kaon bound state K-pp at the J-PARC K1.8 beam line.”
Korea-Japan workshop on nuclear and hadron physics at J-PARC Seoul, 2011

4) R.Honda
Development of a tracking detector system with multichannelscintillation fibers and PPD
6th international conference on New Developments In Photodetection (NDIP2011).
Lyon, France. July, 4-8th, 2011.

Awards;

Kotaro Shirotori
Outstanding Young Scientist Presentation Award,
5th Asia-Pacific Conference on Few-Body Problems in Physics, 22-26 Aug. 2011

Ryotaro Honda
Master Thesis Award 2011, J-PARC Hadron Hall Users' Association

Research Subject (9)

Study of Formation of Actinides Nano-Particles in Biological Reaction Environments

Group: Research Group for Bioactinides chemistry

Members: (Leader) Toshihiko Ohnuki
(Researchers) Naofumi Kozai, Fuminori Sakamoto
(Post doc) Kazuya Tanaka(2009-2011),
Shinya Yamasaki (2011-)
(Student) Mingyu Jiang (2009-2011),
Shousuke Igarashi (2010-)

Summary of the pre-review

The goal of this project is to study the biological implications of actinide nano-particles. The detailed comments by Prof. Trautmann and by Prof. Koyasu will be of great value to this project. Although this project is an important component for the mission of JAEA, according to the committee member who is an expert in this field, this project is not truly expanding a novel scientific territory. Then this project can be justified only within the broad mission of JAEA, but is not consistent with the goal of ASRC. This project could be another candidate to be relocated to outside ASRC.

Objectives

This research subject is focused on the formation of actinides nano-particles (NP) in the biological reaction environments. The central objectives are to elucidate the biological and chemical processes of the NPs formation by analyzing change on chemical states of acitinides by advanced analytical methods.

Progress

For the study on the formation of actinides NPs in biological reaction environments, we have first challenged to form rare earth elements (REEs) NPs on the cell surface of *Saccharomyces cerevisiae* (yeast). It is believed in long time that cell surface of microorganisms adsorbs dissolved cations from solution because of the carboxyl and phosphoryl functional groups presented on the cell surface. The adsorption of REE ions on the cell surface attained to be equilibrium within one hour. So, the many scientists have studied the adsorption behavior of REEs. For the estimation of environmental behavior of cations including long lived radionuclides, long term behavior of adsorbed cations (post adsorption) should be elucidated. However, the post adsorption has not been understood.

We have investigated the mechanism underlying light REE of Ce sequestration by yeast *S. cerevisiae* after exposure to Ce(III) solution without nutrients for 4-120 h at pH 3, 4, or 5. A variety

of analytical techniques have been employed, including field-emission scanning electron microscopy equipped with energy-dispersive X-ray spectroscopy (FESEM-EDS), transmission electron microscopy (TEM), and inductively coupled plasma atomic emission spectrometry (ICP-AES).

Cerium concentration in solutions decreases as a function of exposure time and more rapidly at pH 5 than at pH 3 or 4. Analyses of the yeast cells by FESEM, TEM, and XAFS show that needle-shaped Ce(III) phosphate nanocrystals with a monazite structure formed on the yeast cells by exposure to Ce(III) for 42 h (Fig. 1), even though the initial solutions did not contain any P species. The Ce(III) phosphate nanocrystals grew from about 50 nm to hundreds of nanometers when pH increased from 3 to 5. Lower pH resulted in higher P concentration in the solution after the yeast cells were inoculated, indicating the release of P from the yeast cells. These results indicate that the sorbed Ce on the cell surfaces reacted with P released from inside the yeast cell, resulting in the formation of Ce(III) phosphate nanocrystallites.

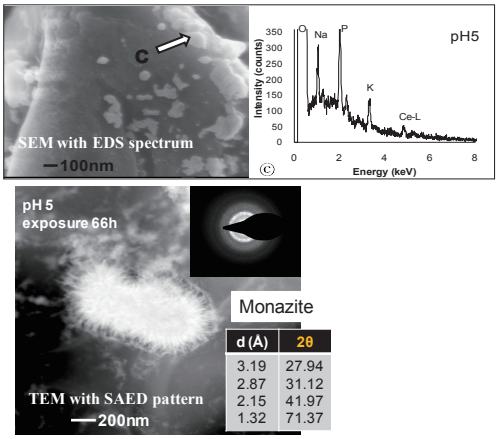

Fig. 1 SEM and TEM images of yeast exposed to Ce solution for 42 h at pH 5. EDS spectrum showed Ce and P are contained in the precipitates formed on cell surface shown by c with arrow . TEM and SAED showed clear fringe indicating that monazite is developed directly from the cell surface.

When the yeast cells are exposed to the solution containing 1.44×10^{-4} mol/L Yb(III) (heavy REE) for 2-120 h, and two months at 25 ± 1 °C at an initial pH of 3, 4, or 5, Yb concentrations in solutions decreased as a function of exposure time. Field-emission scanning electron microscopy equipped with energy-dispersive X-ray spectroscopy (FESEM), and transmission electron microscopy (TEM) analyses revealed that nano-sized blocky Yb phosphate with an amorphous phase formed on the yeast cells surfaces in the solutions with Yb (Fig. 2). These nano-sized precipitates that formed on the cell surfaces remained stable without changing their size even after two months of exposure at 25 ± 1 °C around neutral pHs.

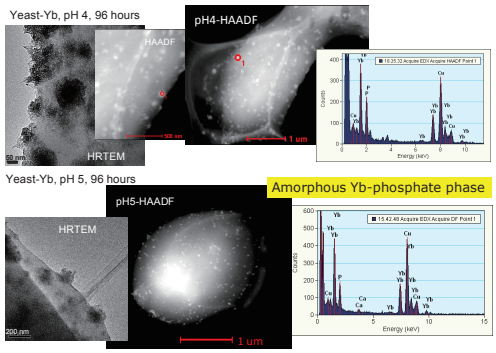

Fig. 2 TEM images of yeast exposed to Yb solution for 96 h at pH 4 and 5. EDS spectrum showed Yb and P are contained in the precipitates formed on cell surface shown by circles. SAED (not shown) showed no fringe indicating that amorphous Yb-phosphate precipitates are developed directly from the cell surface.

The synchrotron-based extended X-ray absorption fine structure (EXAFS) analysis (Fig. 3) revealed that the chemical state of the accumulated Yb on the cell surfaces changed from the adsorption on both phosphate and carboxyl sites at 30 min to Yb phosphate precipitates at 5 days, indicating the Yb-phosphate precipitation as a major post-adsorption process. In addition, the precipitation of Yb phosphate occurred on cell surfaces during 7 days of exposure in Yb-free solution after 2 h of exposure (short-term Yb adsorption) in Yb solution. These results suggest the

transformation of the adsorbed Yb to Yb phosphate precipitates on cell surfaces, even though no P was added to the exposure solution. In an abiotic system, the EXAFS data showed that the speciation of sorbed Yb on the reference materials, carboxymethyl cellulose and Ln resin, did not change even when the Yb was exposed to P solution, without forming Yb phosphate species. This result strongly suggests that the cell surface of the yeast plays an important role in the Yb-phosphate precipitation process, not only as a carrier of the functional groups but also as a substrate inducing the nucleation of phosphate nanoparticles.

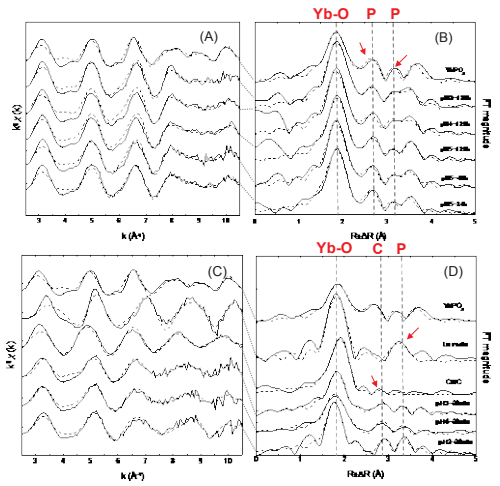

Fig. 3 (A) The EXAFS function, $k^3\chi(k)$, where k is the wave number. (B) The radial structural function (RSF) at the Yb L_{III}-edge for the chemical standard of $YbPO_4$, for Yb sorbed on the reference materials of CMC and Ln resin for 2 h in P-free solution, and for sorbed Yb on CMC and Ln resin with continuing exposure in 1.0×10^{-4} mol/L of P solution for 24 h after 2 h of sorption, respectively. The dotted lines show simulation data of EXAFS spectra using the parameters extracted by FEFF.

These results indicate that light and heavy REEs behave different manner at the biological reaction environments. This fact stimulates us to investigate the behavior of series of REEs at the biological reaction environment. We have a plan to study on the behavior of series of REEs by yeast.

We have demonstrated the effect of biological reaction environments on the behavior of series of REEs using biogenic Mn oxides. We have conducted sorption experiments of REEs on biogenic Mn oxide produced by *Acremonium* sp. strain KR21-2. The distribution coefficients, K_d(REE), between biogenic Mn oxide (plus hyphae) and 10 mmol/L NaCl solution showed large a positive Ce anomaly at pH 3.8, which was consistent with previous works using synthetic Mn oxide. The positive Ce anomaly was caused by oxidation of Ce(III) to Ce(IV) by the biogenic Mn oxide, which was confirmed by analysis of the Ce L_{III}-edge XANES spectra. With increasing pH, the positive Ce anomaly became less pronounced. Furthermore, negative Ce anomalies were observed at a pH of more than 6.5, suggesting that Ce(IV) was stabilized in the solution (< 0.2 μm) phase, although Ce(III) oxidation to Ce(IV) on the biogenic Mn oxide was confirmed by XANES analysis. We demonstrated that no Ce(III) oxidation occurred during sorption on the hyphae of strain KR21-2 by the K_d(REE) patterns and XANES analysis. Then we analyzed the organic-molecules in the solution by size exclusion HPLC-ICP-MS , and found that some fractions of REEs in the filtrates (< 0.2 μm) after sorption experiments were bound to organic molecules (40 kDa and < 670 kDa fractions), which were possibly released from hyphae. A line of our data indicates that the negative Ce anomalies under circumneutral pH conditions arose from Ce(III) oxidation on the biogenic Mn oxide and subsequent complexation of Ce(IV) with organic ligands. The results of this study demonstrate that the coexistence of the biogenic Mn oxide and hyphae of strain KR21-2 produces a specific redox chemistry which cannot be explained by inorganic species.

A negative Ce anomaly in the adsorption of REEs by *Pseudomonas fluorescens* was observed in the presence of desferrioxamine B (DFO). The higher Kd of REEs was obtained at lower pHs on *P. fluorescens* cells, and decreased with increasing pH of solution (Fig. 4). This is different tendency from the adsorption of REEs on γ-Al_2O_3, where lower Kd was obtained at lower pH, and increased

with increasing pH. Degree of negative anomaly of Ce compared to its neighboring REEs, La(III) and Pr(III) decreased with increasing pH. XAFS analysis showed that Ce exists as the Ce(IV)-DFO complex in higher pH than 6. Thus, the pH dependence of Ce anomaly is predominantly dependent on the stability of Ce(IV)-DFO complex. And we believe at present that siderophore like DFO is one of the candidates of the organic-molecules to dissolve Ce(IV) from the biogenic Mn oxides.

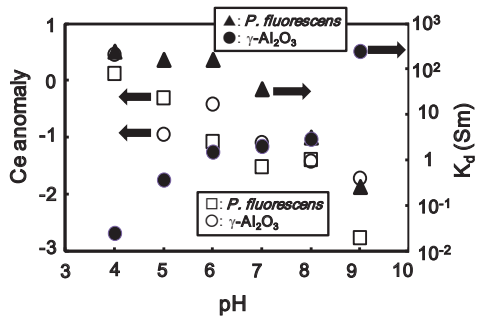

Fig. 4 Degrees of Ce anomaly and K_d(Sm) on *P. fluorescens* cells and g-Al_2O_3 as a function of pH. Ce anomaly in adsorption on *Pseudomonas fluorescens* cells and on g-Al_2O_3 enhanced with increasing pH, even though the pH dependence of adsorption (K_d) of REE of Sm differs between the solid phases.

After the accident of Fukushima Daiichi Nuclear Power Plant (FDNPP), we first sampled the soils, plants, and paddy area at Iitate-mura, Fukushima on June, 2011 to estimate environmental behavior of radioactive Cs in the fallout from the accident of FDNPP. We have measured radioactive Cs's spatial distribution on/in trees, plants, and surface soil beneath the plants using autoradiography analysis. The autoradiography analyses (Fig. 5) showed that radioactive Cs was distributed on the branch and leaves of trees that were present at the accident and that only small fraction may be transported to new branch and leaves grown after the accident. Radioactive Cs was present on the grass and rice stubble on the soils, but not in the soils beneath the grass and rice stubble, indicating that the radioactive Cs was deposited on the grass and the rice plant. In addition the ratio of the radioactive Cs penetrated into soil layer by weathering was very small for two months after the accident. These results indicate that trees and plant would be the reservoir of the fallout Cs and function for retardation of the fallout Cs migration with rain water.

Fig. 5 Autoradiograph image and optical photograph of *Torreya nucifera*. Sampled at Iitate, Fukushima, about 30 km from FDNPP.

We start to develop bio-remediation method using microorganisms. Chemical behavior of Cs resembles to K. Some microorganisms accumulate dissolved Cs, i.e. *Rodcoccus erisroporis*. In addition, mashroom is known to accumulate radioactive Cs in Fukushima. We have atarted to examine the accumulation of Cs by basidiomycete during the growth. So far, we have examined the effect of Cs on the growth of basidiomycete using *Pleurotaceae* species. The fruiting body was formed in the medium containing 500 ppm and 1000 ppm Cs. The size of the fruiting body is smaller in the medium containing higher amounts of Cs. The X-ray fluorescence spectrometry analysis of the fruiting body indicates that the fruiting body contains Cs. These results indicate that the *Pleurotaceae* species accumulates Cs in the cells. The quantitative analysis is planned in the

future. The accumulation ability of microorganisms can be applied to the remediation of the contaminated land. The biological technique is eco-friendly one, so that we have planned to develop a biological technique for remediating the contaminated land.

Originality

The research subject is based on our findings of the formation of NPs of heavy elements on the cell surface of microorganisms, showing high originality. The analytical techniques to examine the chemical states of actinides transformed by the interaction with microorganisms and bio molecules are well established in this research group, and the analytical apparatus are equipped in JAEA.

Although several studies have already reported the biogenic nanoparticle formation (Moreau et al., 2007; Bargar et al., 2008), our study clearly demonstrated that the post-adsorption process forms biogenic nanoparticles as small as ~100 nm. The present study is unique in the point that the compounds inside the cell are manipulated and the cell's bioactivity was utilized to synthesize the nanoparticles, of which the compounds do not exist in the surrounding solution. As highlighted in Science Editor's choice (2010, Vol 329), this is a new protocol of synthesizing nanoparticles, featured by "Inside out synthesis". This unique method to synthesize nano-sized biomaterial may have some applications in a broaden area of nanotechnology.

Goals

The NPs of REE and actinides are formed on the microbial cells and bio molecules. The physico-chemical properties of the nano-particles are characterized by using advanced analytical techniques of XAFS, SANS, SAXS, SEC-ICPMS, SEM-TEM, and UV/VIS spectroscopy.

Goal of this study is as follows:

1. Understanding of mechanism of all REE phosphate nano-particles formed on yeast. We showed monazite structure of light REE of Ce and amorphous one of heavy REE of Yb. It is question which REE between light and heavy REEs occurs structure change in REE phosphate NPs formation. We will analyze the structure of each of all REEs phosphate NPs formed on the cell surface. Then we elucidate the mechanism of REE phosphate mineralization using synthetic organic materials having functional group of carboxyl or phosphate. The REE adsorbed synthetic organic material embeds on the membrane filter. Phosphate solution of different P concentration is provided through the filter, and change of the local structure of REE on the synthetic material is monitored by EXAFS. The bio molecules to accumulated actinides and to be template for developing NPs are identified.
2. Understanding of mechanism of actinides of U, Np, Pu, Am, and Cm phosphate nano-particles formation on the cell surface of microorganisms.
3. For the contribution to remediation of Fukushima, we challenge to develop biological remediation system. In this study, we understand mechanism of Cs accumulation by basidiomycete. We also challenge to explore specific microorganism to accumulate high amounts of Cs.

Finally, the biological and chemical processes of the formation of the NPs in the biological reaction environments are elucidated.

Scientific and social outcomes

The results would advance to understand actinides solution chemistry especially in environmental neutral pH solution, and to explore a new function of microorganisms and bio molecules. The research of biological NP formation is developing new research area of actinides bio-geo chemistry, where the effects of microorganisms on the environmental behavior of actinides are elucidated. The research results lead to develop new techniques of environmental remediation and waste treatments. In addition the results also contribute to develop economical methods of formation of NP.

International cooperation

International collaboration

At present, we have collaborated with University of Birmingham through REIMEI research to explore new function of microorganisms.

Foreign research scientists involved in the research are

Lynne Macaskie, Professor of University of Birmingham, Birmingham, UK., biology.

Publication

1 Y. Suzuki, K. Tanaka, N. Kozai, T. Ohnuki, Effects of citrate, NTA and EDTA on the reduction of U(VI) by *Shewanella putrefaciens*, Geomicrobiology J. 27, 245-250, 2010.

2 T. Ohnuki, N. Kozai, F. Sakamoto, T. Ozaki, T. Nankawa, Y. Suzuki, A. J. Francis, Association of actinides with microorganisms and clay: Implications for radionuclide migration from waste-repository sites, Geomicrobiology J. 27, 225-230, 2010.

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of Yeast in Migration of Radioactive Co-, J. Nucl. Sci. Technol., 48, 1206-1213(2011).
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11 K. Tanaka, Y. Tani, T. Ohnuki, Specific Sorption Behavior of Actinoids on Biogenic Mn Oxide, Chemistry Letters, 40 (2011), pp.806-807.
12 T. Ohnuki, T. Yoshida, Interactions of the rare earth elements - desferrioxamine B complexes with *Pseudomonas fluorescens* and γ-Al_2O_3, Chemistry Letters, (2011) pp98-100.
13 F. Sakamoto, T. Ohnuki, N. Kozai, S. Igarashi, S. Yamasaki, Z. Yoshida, S. Tanaka, Local area distribution of fallout radionuclides from Fukushima Daiichi Nuclear Power Plant by autoradiography analysis,

Invited and key note talk

1. K. Tanaka, Y. Suzuki, M. Jiang, S. Utsunomiya, T. Ohnuki, Mineralization of heavy elements by microbial transportation, 2010 Japanese Geochemical Society Meeting, Higashi-Hiroshima, Hiroshima, Japan, Sep. 7-9, 2010.(Invited talk)
2. T. Ohnuki, Mineralization of actinides on the surface of microorganisms and minerals. Pacifichem 2010, Honolulu, USA, Dec. 150-20, 2010. (Invited talk and selected as highlighted talk)
3. T. Ohnuki, Biotransformation of rare earth elements. Goldschmidt Conference 2011, Prague, Czech Republic , June, 2011. (Keynote talk)

Award:
2011 ASRC Director General Award: Mingyu Jiang
2011 ASRC Director General Award: Kazuya Tanaka

Research Subject (10)

Biophysical Study for Molecular and Cellular Responses to Radiation

Group **Research Group for Radiation and Biomolecular Science**

Members	(Leader)	Akinari Yokoya
	(Researchers)	Kentaro Fujii, Miho Noguchi, Ayumi Urushibara (fixed-term employment), Naoya, Shikazono (additional post)
	(Post doctoral fellows)	Ayumi Narita
	(Students)	Takuya Shiina (master course), Iyo Shiraishi (master course), Yuki Sugaya (master course), Yuka Sakamoto（undergraduate）, Kiichi Kaminaga (undergraduate), Yukiko Kanari (undergraduate)
	(Technical staff)	Keiko Hagiya

Summary of the pre-review

Use of chemical molecules, such as purified DNA, may not reveal the mechanisms happening in the cell irradiated. Introduction of modified plasmid DNA may replicate or be repaired quickly. In mammalian cells, it is likely that the introduced DNA is properly modified by histone proteins etc. to form a chromatin structure. Since these have been a lot of studies on DNA repairing mechanism in both bacteria and mammalian cells, it is not clear what is a frontier contributing in the field of radiation biology. Based on these facts the committee was not convinced that this project is a cutting-edge research.

Response

In response to the suggestions of the committee, we have substantially changed our research subject from the studies using simple model DNA molecules to studies using living cells. The previous projects using the simple model DNA molecules have been finalized by 2012 March.

The aim of our new research program is to understand the epigenetic cellular responses to radiation by which ionizing radiation causes trans-generational effect such as radiation-induced carcinogenesis. The proposed study consists of two approaches to address the main objective:

1) Clarify the mechanism of mutation induction or genomic instability of irradiated or non-irradiated chromosomes in mammalian cells induced by irradiation.
2) Explore novel radiation effects which become persistent after cell division. Effects on subcellular organelle, such as mitochondria, will be examined using a combination of micro-X-ray or ion beams and a time-lapse micro-imaging technique in terms of epigenetic effects such as histone modifications. Furthermore we will address the role of non-coding long RNAs in cellular responses to radiation, particularly the regulation of cell cycle by working cooperatively with stress response proteins such as p53.

Progress

The progress of the studies using simple model DNA molecules is shown in the several publications listed below.

The other noteworthy progress relating to our new project using living cells, particularly in respect to Approach (2) (see above), is as follows.

1) To examine whether genomic instability is induced by non-DSBs types of damage such as oxidative base damage, we transferred an UVA-irradiated human chromosome 21 into **unirradiated** mouse cells derived from mouse fibroblasts using a microcell-mediated chromosome transfer (Figure 1). The transferred chromosomes were analyzed by the whole chromosome painting fluorescence in situ hybridization (WCP-FISH). Most of mouse cells that were transferred with unirradiated chromosomes remained diploid. However, in cells that were transferred with the UVA-irradiated chromosome, we found that the recipient mouse cells became polyploidy and induction of chromosomal instability. The results suggest that the DNA damage induced by the UVA-irradiation causes chromosomal instability in **unirradiated** cells. This is a noteworthy result suggesting that some potential contributory factors play a very important role in the induction of instability in not only an irradiated genome but also **unirradiated** ones. We are preparing a paper to publish these results.

2) We determined the mutagenicities of complex DNA damage sites containing a nucleotide gap and a base lesion (8-oxo-guaine). We have found that the mutation frequencies observed as point mutation at the damage sites in several DNA repair defficient strains significantly depend on the relative positional relation of the lesions. Particularly these lesions are located in both strands (Figure 2). On the other hand, the mutation frequencies of lesions on the same strand

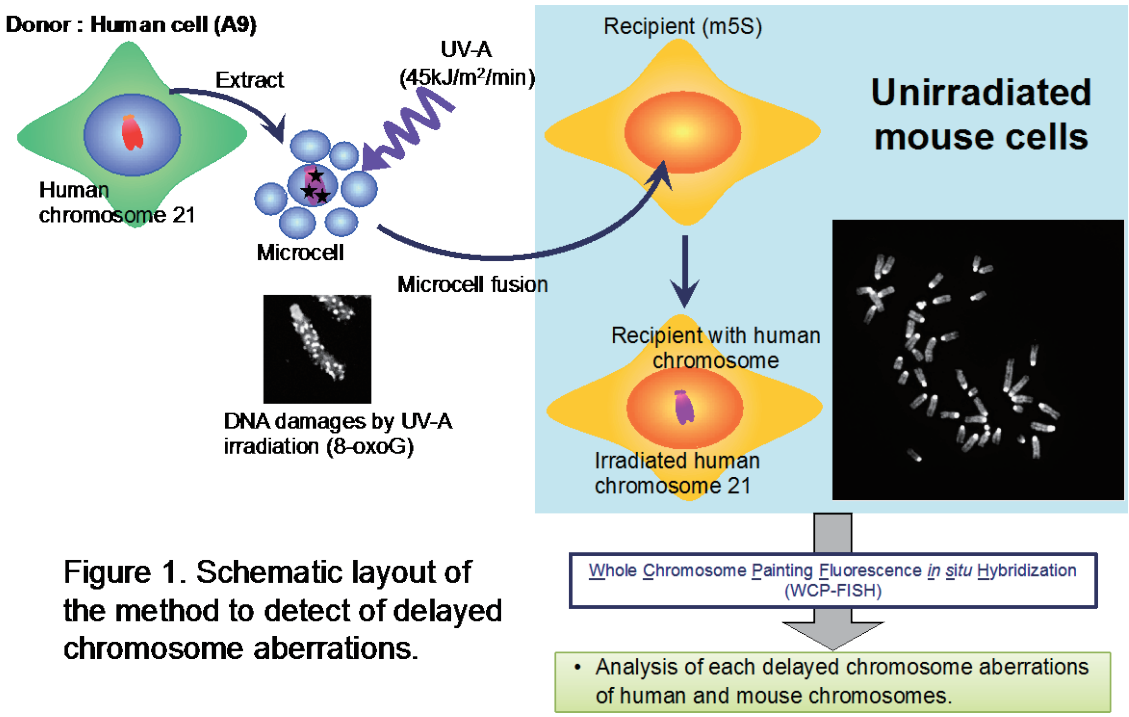

Figure 1. Schematic layout of the method to detect of delayed chromosome aberrations.

were comparable to or less than the frequency of a single 8-oxoG. Our observation indicates that the repair of a specific lesion is retarded by an opposing lesion, but not by the lesion on the same strand. The extent of the damage repair determines the following biological consequences. This study has been published in Mutation Research (online) in the end of 2011.

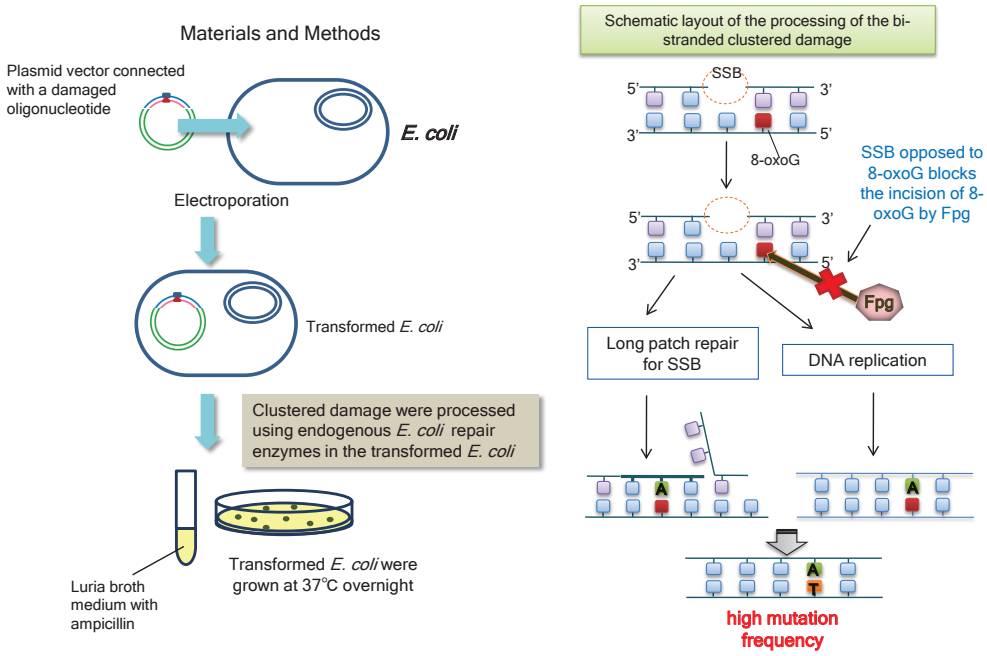

Figure 2 Experimental method of transformation of artificial clustered DNA damage into *E. coli* cells, and proposed processing scheme of the clustered damage.

Goals

The ultimate goal of this study is to ascertain the mechanism of trans-generational radiation effects, which are thought to induce radiation carcinogenesis. Particularly we address the cellular responses that continue through whole cell cycle as indicated above (Approach (2)).

Originality

One of the noteworthy originality of the newly planned research is that we are finding the fact that the genetic instability, which may finally lead radiation-induced carcinogenesis, is caused in not only an irradiated chromosome but also in a non-irradiated one. The mechanism has not been understood yet, because most of the previous studies have tended to concentrate on DNA damage and its repair. In the recently-progressing field of genomic sciences, except classical radiation biology, it has been recognized that genome in a living cell is highly controlled by epigenetic mechanism, as typified by modification of histone modifications. Another regulation of genome activation is by using long non-coding RNAs that have been thought not to have any functional roles in cells for a long time. Recently these RNAs have been revealed to form a domain structure in a cell nucleus, called a nuclear speckle, which works as a factor to regulate gene expressions. There has been no approach so far to study these genetic regulations in terms of radiation effects.

Feasibility

We have been restored our biological laboratories after the disaster on March 11th, last year, and have prepared the basic facilities necessary for mammalian cell cultures. Moreover, we have put in place a fluorescence microscope that enables us to successive observation of specific cells after irradiation. We also have started feasibility experiments at the Photon Factory, KEK in Japan to perform partial irradiation to cytoplasm or nucleus in a cell using an X-ray micro-beam.

Scientific and social outcomes

It has been well known that genomic stability of living organisms is seriously affected by ionizing radiation. Understanding of the radiation effects has been recognized as one of very important subjects in order to not only reveal evolution of life in terms of adaptation to radiation-stresses from the environment during geological age, but also to provide practical aspects on the low-dose effect by nuclear accidents such as the case seen in **"Fukushima"**.

International collaboration

We are currently engaged in two lines of international collaborative research projects. The first project involves the analysis of radiation-induced genomic instability. We are collaborating with Professor Peter O'Neill of Oxford University, U.K., who is highly skilled in the use of several biochemical techniques for the study of modification of biological molecules in respect of radiation chemistry. We will advance our collaboration program by incorporating the study of complex DNA damage sites, as shown in Progress 2 (see above).

The second program is a new collaboration with Dr. Evelyne Sage of the CNRS-Institut Curie, and Dr. Marie-Anne Hervé du Penhoat of Université Pierre et Marie Curie in France, who are also extremely capable of applying a variety of both molecular biological techniques and physicochemical techniques to analyze the effects of radiation in living cells. They are interested in the application of synchrotron radiation to this research area and Dr. Sage has visited our laboratory through the Invitation Fellowship Program by Japan Society for the Promotion of Science (JSPS). A possible collaboration at the new French synchrotron facility SOLEIL between our two research groups has also been proposed which would give us access to the two beamlines dedicated to biology. These beamlines would provide us with soft X-rays in lower energy regions (from a few to 1,000 eV) than those available at SPring-8. Using these low energy photons, circular dichroism method will be applied to study structural changes of complex of functional macromolecules upon radiation impact. The dedicated irradiation system that we have in place at SPring-8 could be also used for the collaboration project when we need to use higher energy region of X-rays. We have proposed to *Reimei* Research 2012, with the research theme entitled "Initial processes of radiation effects on genomic stability".

Publication list (Peer-reviewed papers)

1. Hata, K., Lin, M., Katsumura ,Y., Muroya, Y., Fu, H., Yamashita, S. and Nakagawa, H., Pulse Radiolysis Study on Free Radical Scavenger Edaravone (3-methyl-1-phenyl-2-pyrazolin-5-one). 2: A Comparative Study on Edaravone Derivatives. *J. Radiat. Res.* **52**, 15-23 (2011).
2. Maeyama, T., Yamashita, S., Baldacchino, G., Taguchi, M., Kimura, A., Katsumura, Y., Murakami, T. Fluorescent probe for steady-state radiolysis with heavy ions 1: LET effects and

time dependence of OH yields. *Radiat. Phys. Chem.* 80, 535-539 (2011).

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4. Oka, T., Oshima, A., Motohashi, R., Seto, N., Watanabe, Y., Kobayashi, R., Saito, K., Kudo, H., Murakami, T., Washio, M., and Hama, Y. Changes to the chemical structure of isotactic-polypropylene induced by ion-beam irradiation, *Radiat. Phys. Chem.* 80, 248-280 (2010).
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10. Gowa, T., Shiotsu, T., Urakawa, T., Oka, T., Murakami, T., Oshima, A., Hama, Y. and Washio, M., Study on depth profile of heavy ion irradiation effects in poly(tetrafluoroethylene-co-ethylene), *Radiat. Phys. Chem.* **80**, 264-267 (2011).
11. Hirade, T., Oka, T. and Lee, J. J., Ortho-positronium reactions in water studied by positron annihilation age-momentum correlation, *Materials Science Forum* **666**, 103-108 (2011).
12. Oka, T., Yokoya, A. and Fujii, K. Electron paramagnetic resonance study of unpaired electron species in thin films of pyrimidine bases induced by nitrogen and oxygen K-shell photoabsorption. *Appl. Phys. Lett.* **98**, 103701-1- 103701 -3 (2011).
13. Yokoya, A., Shikazono, N., Fujii, K., Noguchi, M. and Urushibara, A. A novel technique using DNA denaturation to detect multiply induced single-strand breaks in a hydrated plasmid DNA molecule by X-ray and 4He2+ ion irradiation. *Radiat. Protect. Dosim.* **143**, 219-225 (2011).
14. Shikazono, N., Yokoya, A., Urushibara, A., Noguchi, M. and Fujii. K. A model for analysis of the yield and the level of clustering of radiation-induced DNA strand breaks in hydrated plasmids. *Radiat. Protect. Dosim.* **143**, 181-185 (2011).
15. Fumiya Shiraki, Yoshikawa Taeko, Akihiro Oshima, Yuji Oshima, Yuya Takasawa, Naoyuki Fukutake, Tomoko Gowa Oyama, Tatsuya Urakawa, Hajime Fujita, Tomohiro Takahashi, Toshitaka Oka, Hisaaki Kudo, Takeshi Murakami, Yoshimasa Hama, Masakazu Washio, Development of Function-graded Proton Exchange Membrane for PEFC Using Heavy Ion Beam Irradiation, Nucl. Instrum. Methods Phys. Res. Sect. B-Beam Interact. *Mater. Atoms*, 269, 1777-1781 (2011)
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Induction of DNA DSB and its rejoining in clamped and non-clamped tumours after exposure to carbon ion beams in comparison to X rays, *Radiat. Protect. Dosim.* 143, 508-512, (2011)

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19. Ushigome, T., Shikazono, N., Fujii, K., Watanabe, R., Suzuki, M., Tsuruoka, C., Tauchi, H. and Yokoya, A. Yield of single-, double-strand breaks and nucleobase lesions in fully hydrated plasmid DNA films irradiated with high-LET charged particles. *Radiat. Res.* in press.

Publication list (Invited papers, book chapters)

1. Yamashita, S. Prologue: Untapped capabilities of radiation chemistry and radiation biology. *Radiat. Chem*.89, 2 (2010). (in Japanese)
2. Yokoya, A. Epilogue: Pivotal issues of chemistry and biology in radiation sciences. *Radiat. Chem*.89, 36-37 (2010) . (in Japanese)
3. Yokoya, A., Fujii, K., Shikazono, N. and Ukai, M. Chap. 20: Spectroscopic study of radiation-induced DNA lesions and their susceptibility to enzymatic repair. In Charged Particle and Photon Interactions with Matter - Recent Advances, Applications, and Interfaces -, ed. by Hatano, Y., Katsumura, Y. and Mozumder, A., pp. 543-574, CRC Press, Boca Raton/New York/Abingdon, Dec. 2010.
4. Yamashita, S., Taguchi, M., Baldacchino, G., and Katsumura, Y. Chap. 13: Radiation chemistry of liquid water with heavy ions: steady-state and pulse radiolysis studies. In Charged Particle and Photon Interactions with Matter - Recent Advances, Applications, and Interfaces -, ed. by Hatano, Y., Katsumura, Y. and Mozumder, A., pp. 325-354, CRC Press, Boca Raton/New York/Abingdon, Dec. 2010.
5. Fujii, K. Selective damage induction of DNA induced by monochromatic soft X-rays. *Radiat. Chem*.90, 11-16 (2010). (in Japanese)
6. Yamashita, S., Radiation chemical reactions in water radiolysis with therapeautic heavy ion beams. *Radiat. Chem*.90, 17-22 (2010). (in Japanese)

Invited talks

1. Kobayashi, Y., Oka, T. and Hama, Y., Improvement of radiation resistance of polymers by inorganic coating, International Workshop on Radiation Effects in Nuclear Technology, 2011/3/9-10, Tokyo, Japan.
2. Washio, M., Shiraki, F., Oshima, Y., Takasawa, Y., Fujita, H., Gowa, T., Kudo, H., Oka, T., Hama, Y., Murakami, T. and Oshima, A., Fabrication of functionally gradient PEM using heavy ion beams grafting, The 2010 International Chemical Congress of Pacific Basin Societies (Pacifichem 2010), 2010/12/15-20, Hawaii, USAYamashita, S., Maeyama, T. and Katsumura, Y. Water Radiolysis with Steady-state Heavy-ion Beams from HIMAC. 15èmes Journées d'Etudes de la Chimie sous Rayonnement (JECR-2010), Bordeaux, France, May 26-28, 2010.

3. Hirade, T., Oka, T. and Lee, J. J., Ortho-positronium reactions in water studied by positron annihilation age-momentum correlation, 39th Polish Seminar on Positron Annihilation (PSPA10), Kazimierz Dln., Poland, June 20-25, 2010
4. Yokoya, A. Spectroscopic studies of DNA damage using synchrotron radiation. The 1st Seminar of the Tokyo Radiation Biology Communications in 2010, Tokyo, Japan, July 17, 2010.
5. Yokoya, A. Physical and biological studies of unrepairable DNA damage. IDAC Seminar, Institute of Development, Aging and Cancer, Tohoku University, Sendai, Japan, August 11, 2010.
6. Yamashita, S., Katsumura, Y., Maeyama, T., Baldacchino, G., Murakami, T., Meesungnoen, J., and Jay-Gerin, J.-P. Water radiolysis with heavy ions of energies up to 28 GeV. 3rd Asia-Pacific Symposium on Radiation Chemistry (APSRC-2010) / DAE-BRNS 10th Biennial Trombay Symposium on Radiation & Photochemistry (TSRP-2010), Lonavala, India, September 14-17, 2010.
7. Muroya, Y., Lin, M., Yan, Y., Han, Z., Yamashita, S., Ueda, T., Mostafavi, M., Katsumura, Y. Ultra-fast pulse radiolysis study on spur reaction: kinetics in water at elevated temperatures from room temperature up to supercritical state. 3rd Asia-Pacific Symposium on Radiation Chemistry (APSRC-2010) / DAE-BRNS 10th Biennial Trombay Symposium on Radiation & Photochemistry (TSRP-2010), Lonavala, India, September 14-17, 2010.
8. Yokoya, A. Various modes of DNA damage formation by the direct effect of radiation. The 56th Annual Meeting of the Radiation Research Society, Hawaii, USA, September 25-29, 2010.
9. Yamashita, S., Katsumura, Y., Meesungnoen, J., Jay-Gerin, J.-P., Lin, M., Muroya, Y., and Murakami, T. Water radiolysis with high-energy heavy ions: conversion of transient water radicals into stable product inside heavy-ion tracks. The 56th Annual Meeting of the Radiation Research Society, Maui, HI, USA, September 25-29, 2010.
10. Yokoya, A. Physical and biological studies of unrepairable DNA damage. IDAC Seminar, Institute of Development, Aging and Cancer, Tohoku University, Sendai, Japan, August 11, 2010.
11. Yokoya, A. Various modes of DNA damage induction by ionizing radiation. The second seminar of Research Laboratory for Quantum Beam Science Institute of Scientific and Industrial Research Osaka University in 2010, Osaka、Japan, November 30, 2010.
12. Oka, T. Unpaired electron species in DNA and DNA-base thin films induced by K-shell photoabsorption. Photon Factory Seminar: Prospect on Synchrotron Radiobiology focusing on Inhomogeneous Energy Deposition, Tsukuba, Japan, July 14-15 (2011).
13. Fujii, K. Study of DNA damage using soft X-ray absorption technique. Photon Factory Seminar: Prospect on Synchrotron Radiobiology focusing on Inhomogeneous Energy Deposition, Tsukuba, Japan, July 14-15 (2011).
14. Yokoya, A., Usami, N. and Maeda, M. DNA base lesions induced by phosphorus K-ionization and its Auger decay. Photon Factory Seminar: Prospect on Synchrotron Radiobiology focusing on Inhomogeneous Energy Deposition, Tsukuba, Japan, July 14-15 (2011).
15. Yokoya, A., Spectroscopic studies of genome damage induced by ionizing radiation. Summer school of the radiation section of the Japan Society of Applied Physics, Sendai, Japan, August 1-3 (2011).
16. Yokoya, A. EU educational program, Lecture title: Introduction to Synchrotron Radiation and Radio-biological Studies, Orsay, France, October 11-26 (2011).
17. Yokoya, A., Physicochemical processes of radiation damage to genomic DNA and its enzymatic

repair. 67th Annual meeting of the Physical Society of Japan, Nishinomiya, Japan, March 24-27 (2012).

Awards

1. Fujii, K. Encouragement award of the Japanese Society of Radiation Chemistry, Selective damage induction of DNA induced by monochromatic soft X-ray. 2010.
2. Yamashita, S. Encouragement award of the Japanese Society of Radiation Chemistry, Radiation chemical reactions in water radiolysis with therapeautic heavy ion beams. 2010.
3. Oka, T. Unpaired electron species in DNA film and DNA modification induced by nitrogen and oxygen K-shell photoabsorption. Award for excellent posters, 54th Annual meeting of the Japanese Society of Radiation Chemistry, Osaka, Japan, September 28-30 (2011).

Research Subject (11)

Development of Spin-Polarized Positron Beam and its Applications to Spintronics Study

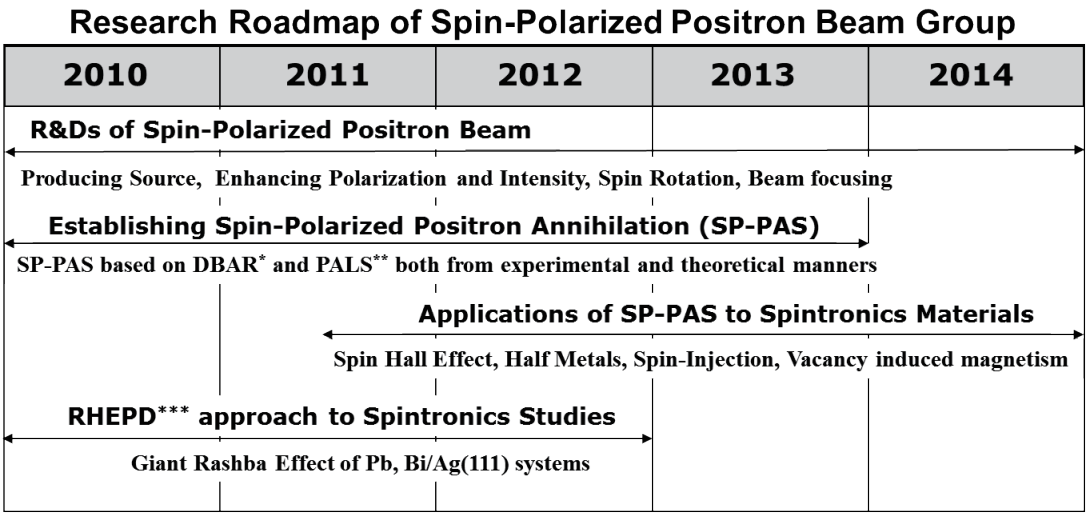
Group Research group for Spin-Polarized Positron Beam

Member

(Group leader)	A. Kawasuso
(Researcher)	Y. Fukaya, M. Maekawa
(Post-doctoral researcher)	H. Zhang, I. Mochizuki

Research contents

We promote a research project on "***Development of Spin-Polarized Positron Beam and its Applications to Spintronics Study***". We construct a highly spin-polarized positron beam by producing a ^{68}Ge-^{68}Ga source which emits highly polarized positrons as compared to the conventional sources. We apply this beam to the various spintronics studies. Behind these applications, we also reconstruct the fundamental aspects of spin-polarized positron annihilation both in experiment and theory. In addition to spin-polarized positron beam, we have two more positron beam techniques that are the reflection high-energy positron diffraction (RHEPD) and the positron annihilation microscope (PAM). We will also utilize these techniques in our spintronics studies. Our research roadmap is shown below:



*DBAR, Doppler broadening of annihilation radiation giving rise to electron momentum distribution.
**PALS, Positron annihilation lifetime giving rise to electron density.
***RHEPD, Reflection high-energy positron diffraction

Summary of the pre-review by the evaluators

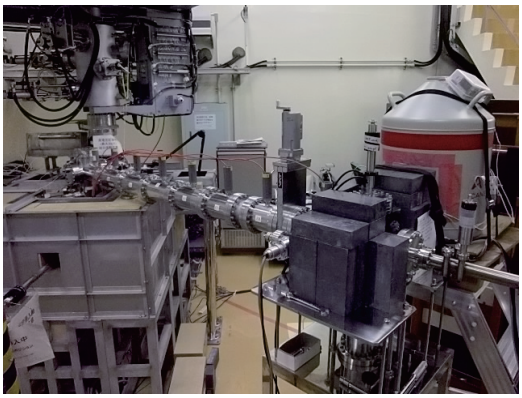
Spin-polarized positron beam has a potential to be a unique tool in the condensed matter research. It will be enable direct observation of the spin-polarized electronic bands in solids. Exploring this possibility is an exciting project, consistent with the mission of ASRC.

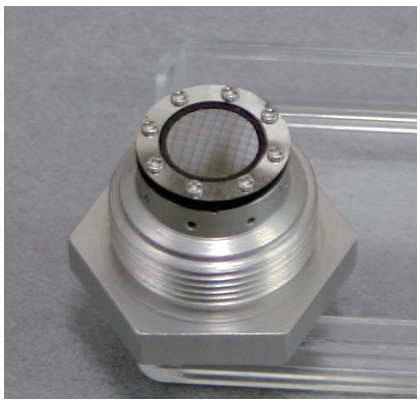
Response for the pre-review from the group

We concentrate on our research and development of spin-polarized positron beam and attempt to obtain outstanding outcomes.

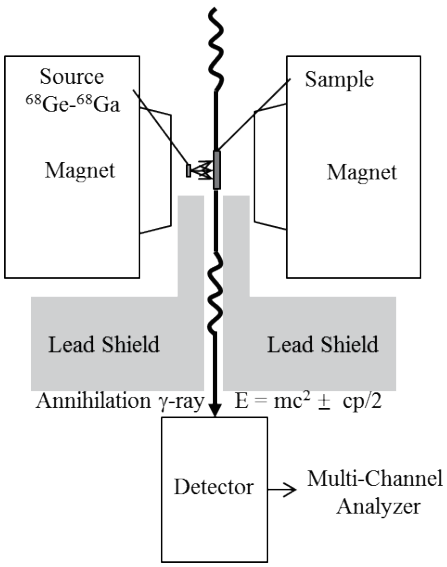
Progress in the project from 2010 to 2011

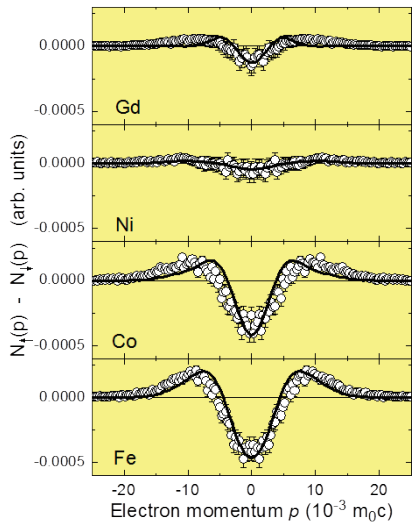
- We succeeded in safely and stably producing a ^{68}Ge-^{68}Ga source with more than 200 MBq through a nuclear reaction of ^{69}Ge(p, 2n)^{68}Ge in our facility [P1, I1].
- Using the above source, we succeeded in generating a low-energy spin-polarized positron beam with a polarization of at least 40% and a flux of 4x10^{3} positrons /sec. Pictures of the spin-polarized positron beam line and the source are shown below.



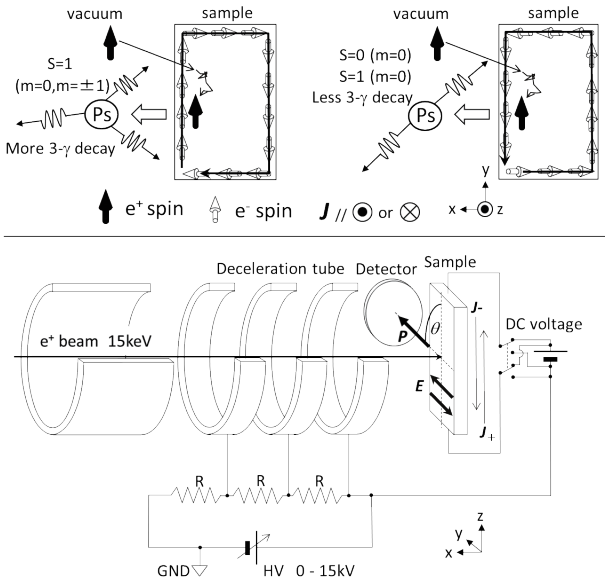


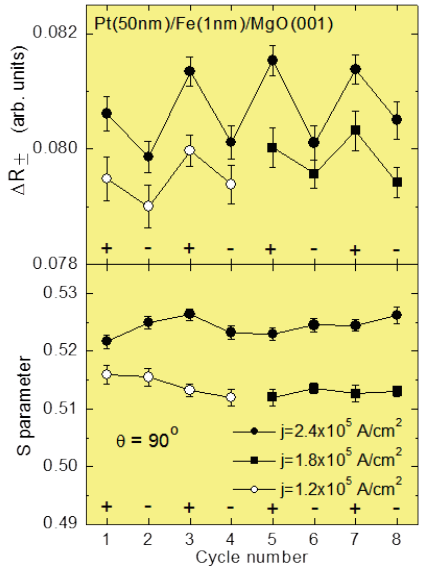
- Using the above spin-polarized positron beam, we found that the Doppler broadening of annihilation radiation (DBAR) spectra of various ferromagnets, e.g., 3d and 4f metals and some Heusler alloys exhibits the polarized band structures [P3, P4]. Principle of SP-DBAR and an example of experimental data are shown below.





- Using the above spin-polarized positron beam, we have started the direct observation of spin Hall effects for Pt and Au thin films. We found some changes of positron annihilation intensity at the topmost surfaces where excess spins may be accumulated upon current reversal [A paper submitted]. Experimental details and an example of experimental data are shown below.





- Using the RHEPD method, we found that the spin-splitting of surface bands of Pb/Ag(111) system due to the Rashba effect are controllable by adjusting the Pd position.

Goals of the project

The goal of this research project is to accomplish our R&D study of spin-polarized positron beam and to promote spintronics study using spin-polarized positron beam.

Originality of the project

Positron spectroscopy is generally used for the investigations of defects in metals and semiconductors and of free volumes in polymers. Positron beam extends those kinds of studies from bulk to surface, interface and thin films. A world-wide research trend of positron community is to explore intense positron beam. Only a limited number of researches have so far been carried out using spin-polarized positrons. Thus, the present research provides a unique research axis in the world. All the R&D contents that we plan to conduct in this project are new and challenging works.

Feasibility of the project

We have a confidence to complete a spin-polarized beam having the highest performance in the world. We believe that we obtain important and intriguing results on spintronics materials using the above spin-polarized positron beam.

Scientific and social outcomes of the project

In the spintronics study, development of new probe is always required. This is because conventional techniques are not necessarily adequate to reveal new phenomena. Through spin-polarized positron annihilation spectroscopy (SP-PAS) measurements, polarized electron momentum distributions are observed. This spectroscopic feature is analogous to that of the

magnetic Compton scattering. One advantage of SP-PAS may be the depth selectivity by employing a spin-polarized positron beam. Some important magnetic effects, such as giant magnetoresistance and tunneling magnetoresistance, occur near the interface between magnetic and nonmagnetic layers. Spin-injection electrodes, which will be used in spin devices, are normally thin films. Novel spin phenomena such as the spin Hall effect and the giant Rashba effect occur near surfaces. These are potential applications of SP-PAS. Taking advantage of the fact that PAS is a powerful tool to detect vacancy defects, SP-PAS might be used in studying vacancy-induced magnetism. In the 1960s, a few studies were performed on magnetic substances using spin-polarized positrons. However, thereafter, only a limited number of works have been carried out. Potential of polarized positrons was not well developed. Spintronics study using spin-polarized positron beam is very important and the obtained results will have high impacts in both fundamental physics and spintronics industry.

Cooperation through the project

(1) Internationalization
- Accept foreign researchers
- Dispatch researchers to abroad
- Promote international collaborations
- Host international meetings

(2) Foreign researchers (will be invited for short-term if enough budgets is provided.)
- Prof. P. Coleman, Bath Univ., Spin-polarized positron beam
- Prof. Z. Q. Chen, Wuhan Univ., Diluted magnetic semiconductor

Publication list (only published), Invited talks, Awards, Press release, etc.

Spin-polarized positron beam R&D study

[P1] Development of spin-polarized positron beam using high energy proton beam,
M. Maekawa, A. Kawasuso, Y. Fukaya, A. Yabuuchi
J. Phys. Conf. Ser. **262**(2011)012035.

[P2] Defect Structure of MBE-grown GaCrN Diluted Magnetic Semiconductor Film
A. Yabuuchi, M. Maekawa, A. Kawasuso, S. Hasegawa, Yi-Kai Zhou and H. Asahi
J. Phys. Conf. Ser. **262**(2011)012066.

[P3] Spin-polarized positron annihilation measurements on polycrystalline Fe, Co, Ni and Gd based on Doppler broadening of annihilation radiation
A. Kawasuso, Y. Fukaya, M. Maekawa, A. Yabuuchi, I. Mochizuki
Phys. Rev. B **83**(2011)100406(R).

[P4] Doppler broadening of annihilation measurements on 3d and 4f ferromagnets using polarized positrons
A. Kawasuso, Y. Fukaya, M. Maekawa, A. Yabuuchi, I. Mochizuki
Phys. Rev. B **85**(2012)024117(6).

[I1] New Positron Beam Studies of Surface Low-Dimensional Systems and Magnetic Substances
A. Kawasuso, Y. Fukaya, M. Maekawa, A. Yabuuchi, I. Mochizuki
12th International Workshop on Slow Positron Beam Techniques (SLOPOS-12),

1st to 6th August, 2010.

Other studies using conventional positron beams

[P5] A study of defects in electron- and ion-irradiated ZrCuAl bulk glassy alloy using positron annihilation techniques
F. Hori, N. Onodera, Y. Fukumoto, A. Ishii, A. Iwase, A. Kawasuso, A. Yabuuchi, M. Maekawa and Y. Yokoyama
J. Phys. Conf. Ser. **262**(2011)012025.

[P6] Positron microbeam study on vacancy generation caused by stress corrosion crack propagation in austenitic stainless steels
A. Yabuuchi, M. Maekwa and A. Kawasuso
J. Phys. Conf. Ser. **262**(2011)012067.

[P7] Vacancy defects in a stress-corrosion-cracked Type 304 stainless steel investigated by positron annihilation spectroscopy
A. Yabuuchi, M. Maekawa, A. Kawasuso
J. Nucl. Matt. **419**(2011)9-14.

[P8] Microstructure of nearly stoichiometric ZrC coating layers for advanced high temperature gas cooled reactor fuel and positron annihilation spectroscopy of various ZrC coating layers
J. Aihara, M. Maekawa, S. Ueta, A. Kawasuso and K. Sawa
J. Am. Ceram. Soc. **94**(2011)4516-4522.

[P9] Development of pulsed positron beam line with compact pulsing system
M. Maekawa and A. Kawasuso
Nucl. Inst. Meth. in Phys. Res. B**270** (2012) 23-27.

[P10] Positron annihilation study of 4H-SiC by Ge implanted and subsequent thermal annealing
R. S. Yu, M. Maekawa, A. Kawasuso, B. Y. Wang and L. Wei
Nucl. Inst. Meth. in Phys. Res. B**270** (2012) 47-49.

[A1] Structures and phase transitions of surface super-structures by using reflection high-energy positron diffraction
Y. Fukaya
Awards for the Encouragement of Young Physicists 2011(The Physical Society of Japan)

P: Papers, I: Invited talks, A: Awards, PR: Press announcements

参考資料

先端基礎研究センターアドバイザーによる意見※

※先端基礎研究センターの研究運営に国際的な視野を導入し、国際共同研究拠点形成のために、センター長直属のアドバイザー（東京大学 永長直人教授、ANL Dr. S.D. Bader）をおいた。両アドバイザーが第 6 回先端基礎研究・評価委員会に参加し、提出した意見を参考資料として掲載する。

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Comments and Suggestions

Review Dates : 23-24 April 2012
Submission Date : 28 April 2012
Advisor : Samuel Bader and Naoto Nagaosa

1. The research policy and the strategy of the ASRC

Evaluation Result : **appropriate**

Comments and suggestions
The overall progress across the entire ASRC is very impressive under the leadership of Prof. Maekawa, as measured by objective scientific metrics, such as quality and quantity of publications, and invited talks at major international meetings. This is especially noteworthy given the major disasters that struck Japan in the time period under evaluation. The three sections of ASRC, condensed matter physics, nuclear physics, and actinide biochemistry, that superficially appear to be disparate, are actually becoming increasingly related. The synergies between these fields are beginning to emerge as a healthy interplay and collaboration amongst the different groups. The common issue is the importance of relativistic effects that permeate spintronics, actinides and nuclear matter. Many new developments within ASRC are anticipated by these cross-disciplinary collaborations.

Suggestions to further strengthen and consolidate the scientific leadership role of ASRC

1. Emphasize synergies between the eleven groups and three thematic sections of the ASRC. This can be begun, for example, by having group leaders prepare slides of their connections with the other groups/themes. Ways to reward creative cross-fertilization of ideas and programs should be found, such as joint funding, synergy awards, and promotions. Synergies already exist but were somewhat downplayed during the review. Further synergies could be developed. The whole must be shown to be greater than the sum of the parts, otherwise what is the reason to co-locate these groups within the ASRC? Future presentations should utilize a common template across the ASRC to show the unity and coherence of the organization. As it stands now, each group has its own style of presentation that sends the message of a lack of communication, coordination and sense of unity. Find additional ways that communication across group lines can be strengthened to further improve the scientific standing of the ASRC.
2. A plan is needed to incentivize staff diversity. For example, all group leaders presently are male. Is this the best model for promoting scientific excellence? How will outstanding women researchers be incorporated into leadership positions to more fully utilize the human intellectual capacity of Japan?

2. The research subject No.1, 'Study on New Functional Materials' (Research Group for Condensed Matter Theory)

Evaluation Result : **appropriate**

Comments and suggestions
This theory group is guiding the experimental activities in ASRC and has achieved many important results, including the theory of the spin Seebeck effect, spin mechatronics, and the spin motive force. This group also promotes collaborations within and outside of the ASRC by organizing seminars and related activities. In the future the group is encouraged to focus on the challenge of materials and phenomena by design. The group should articulate its strategy are moving forward. The group should not feel the need to stress possible applications. The overarching strength of their work is in the great interest and insights they generate from the perspective of fundamental science.

3. The research subject No.2, 'Study for Spin-Transport Mechanisms in Molecular Spintronics Materials and Devices' (Research Group for Molecular Spintronics)

Evaluation Result : **appropriate**

Comments and suggestions
This group is aiming at graphene as a material for spintronics. This is definitely a promising direction although the field is highly competitive. Their work on the epitaxial growth utilizing Ni(111) substrates along with Raman and XMCD experiments represent important steps toward their goal. We suggest that they communicate with Mori's group and also with other research groups involved with graphene internationally to gain more information and perspectives on the problem. In the second half of the project, this group should make concerted efforts to explicitly show promising routes to applications. We are following the development of this research with great interest.

4. The research subject No.3, 'Spin manipulation and material design by combining Spintronics, mechanical engineering and NMR method' (Research Group for Mechanical Control of Materials and Spin Systems)

Evaluation Result : **appropriate**

Comments and suggestions
This is a showcase group for expanding the frontiers of spintronics into the areas of classical mechanics, and bridging the coupling of electronic and nuclear spin systems. The group leader, Prof. E. Saitoh, has the advantage of a productive joint appointment between the ASRC and the IMR at Sendai. This is to the scientific advantage of both

institutions and should be nurtured by ASRC management. World-class research being pursued within this group has historical underpinnings in the Einstein-de Hass and Barnett effects circa 1915, as so aptly pointed out in the presentation. Many of the efforts within the group are motivated by a desire to observe, explore and understand unconventional phenomena, such as thermal, acoustic, fluid or NMR spin pumping, rather than to create viable new technologies. Thus, technological terminology like "spin mechatronics" unnecessarily raises expectations of imminent applications, and thus could be avoided.

5. The research subject No.4, 'Research in exotic shell evolution of heavy nuclei' (Research Group for Reactions Involving Heavy Nuclei)

Evaluation Result : **appropriate**

Comments and suggestions
At the pre-review, the Review Committee recommended that this group be transferred to another division. In response, the group changed its research focus. Fortunately, it seems this was very successful. The group found a remarkable new phenomenon that fission of the proton-rich nucleus 180Hg occurs in an asymmetric manner. This is quite unexpected based on conventional wisdom, and sheds new light on fission physics. The group is encouraged to further pursue this new field. There is now no need to transfer this successful group to another division.

6. The research subject No.5, 'Study of Valence Electronic Structure and Nuclear Shell Structure of Superheavy Elements' (Research Group for Superheavy Elements)

Evaluation Result : **appropriate**

Comments and suggestions
Responding to the pre-review's comments, this group changed its focus to more challenging problems, including the study of metal-organic compounds and the electrochemistry of super heavy elements, and specifically the ionization potential measurement of lawrencium (Lr). These are all new and promising areas of interest. The topics are also of relevance to condensed matter physics from the perspective of relativistic effects in materials. It would be fruitful if this group and the spintronics group communicate with each other in order to see if some new ideas emerge from the interaction.

7. The research subject No.6, 'Preparation of New Actinide Compounds with Exotic Behavior' (Research Group for Actinide Materials Science)

Evaluation Result : **appropriate**

Comments and suggestions
This is an outstanding condensed matter physics group that focuses on creating new materials based on systems that have 5f electrons. The new materials are of the highest quality, including single crystals, and also there are expanded plans for thin film growth. It is widely appreciated that the best samples yield the clearest physical insights, thus this group also serves as a highly sought after resource worldwide for their outstanding samples. The physical phenomena being pursued include topics associated with correlated electron systems, which is the central contemporary topic within condensed matter research. Efforts include the study of exotic superconductivity, quantum criticality, Kondo and heavy Fermion physics, metamagnetic transitions, materials under extreme conditions, including high magnetic fields, high pressure, low temperature, and damaging radiation environments. This group supplies samples to the (Subject No. 7) heavy element group. It could be to the advantage of the two groups to transparently coordinate and develop their priorities.

8. The research subject No.7, 'Foundation of New Concept in Condensed Matter Physics for Heavy Element Systems'
（Research Group for Condensed Matter Physics of Heavy Element Systems）

Evaluation Result : **appropriate**

Comments and suggestions
This is another outstanding condensed matter physics group that focuses on systems that have 5f electrons. The unique strength of this group is that it possesses a battery of advanced techniques to explore the underlying physics of correlated electron systems with strong relativistic effects, especially systems with unconventional superconductivity, quantum criticality and complex Fermi surfaces. The techniques include NMR, μSR and neutron scattering. The group has a sterling publication record, half of the papers utilizing access to samples prepared by the companion (Subject No. 6) group. As mentioned in the comments for that group, the two groups can readily expand their synergies, and, hence, their collective impact, by explicitly coordinating their future research objectives.

9. The research subject No. 8, 'Research on the Structure of Nuclei and Hadrons Containing Strangeness' （Research Group for Hadron Physics）

Evaluation Result : **appropriate**

Comments and suggestions

This nuclear physics group is a pioneer in the experimental study of hadron physics. Its mission is to explore new nuclei and hadrons, including those that possess strangeness. It continues to develop an impressive array of major tools to accomplish its mission, including novel spectrometry approaches and new spectrometers, detectors and tests at J-PARC and RCNP (Osaka). In addition, the group concurrently pursues theoretical and computational approaches to understand astrophysical phase transitions and the symmetry of phase separated states of nuclear matter, such as with relevance to supernovas and neutron stars. The structures simulated (called pasta structures) bear a resemblance to structures familiar in soft condensed matter physics systems. It could be beneficial for this group and the condensed matter theory/computational (Subject No.1) group to cross-pollinate ideas transparently in the interest of advancing the commonality of physics at vastly different length scales.

10. The research subject No. 9, 'Study of Formation of Actinides Nano-Particles in Biological Reaction Environments' (Research Group for Bioactinide)

Evaluation Result : **appropriate**

Comments and suggestions
This actinide biochemistry group made a stunning comeback after weathering a critical pre-review two years ago. The group re-invented itself in the study of nanoparticle formation on cell surfaces. In the aftermath of the great disaster at Fukushima, the group emerged as the one within the ASRC that was of the most immediate importance to the Japanese people, due to its work in the 3D mapping of radioactive 137Cs. The group is now due great praise for the relevance of its work. This illustrates that although peer review is the best process of evaluation we know of, it is not a perfect system. Unanticipated events can rapidly and dramatically change perceptions.

11. The research subject No. 10, 'Biophysical Study for Molecular and Cellular Responses to Radiation' (Research Group for Radiation and Biomolecular Science)

Evaluation Result : **appropriate**

Comments and suggestions
This bio-molecular science group studies the response to radiation at the molecular and cellular levels. This group was faced with a similar situation as that of Subject No. 9 after the pre-review two years ago of needing to reinvent itself in response to criticism. The group focused on trans-generational effects in radiation-induced cancer. Most interestingly, it adopted the new FUCCI cell techniques to image the time evolution of x-radiation effects. This is cutting edge research that is yielding new insights into the

biochemistry of cell division and the role of cell repair in the timing of the cell cycle. Results to date are specific to a human epithelial cancer, but can be generalized to other experimental cell types in future research. This group is also the most diverse in terms of gender representation within the ASRC, and, thus, might be the best place to start to cultivate female scientific leadership.

12. The research subject No.11, 'Development of Spin-Polarized Positron Beam and its Applications to Spintronics Study' (Research Group for Spin-Polarized Positron Beam)

Evaluation Result : **appropriate**

Comments and suggestions

This group is aiming at a new and interesting goal, the spin physics studied by means of spin polarized positron beams to study annihilation processes and related spectroscopy and scattering techniques. To our knowledge, this is the only group working in this area. It is to the credit of the group and to the leadership and encouragement of Prof. Maekawa that the group can be regarded as a prime example of successful synergies within the ASRC. The spin and momentum resolution achieved by the group is very impressive and the measurements can be performed even under magnetic field conditions, which is not the case for ARPES, for example. The research is very promising. Also the giant spin Hall effect that is under experimental investigation by this group and others within the ASRC offers a challenge for theory, and thus for the ASRC theorists. Many interesting advances are expected.

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意見と提案

評価実施日：平成 24 年 4 月 23 日、24 日
報告書提出日：平成 24 年 4 月 28 日
アドバイザー：Samuel Bader、永長　直人

1. センターの研究活動に関する方針と戦略

評価結果：適切

意見・提案
発表論文ならびに主要な国際会議での招待講演の数や質などの客観的学術的基準からみて、前川センター長の指揮の下で ASRC 全体が遂げている発展は実に目覚ましい。さらに注目すべきことは、この評価対象期間が、東日本大震災が日本を襲った時期であるということである。固体物理、核物理、アクチノイド生物化学という、一見全く異なる ASRC の 3 つの分野は、かなり連携がとれてきている。これら異なる分野による相乗効果は、グループ間の協力と相互作用として現れ始めている。共通の課題は、スピントロニクス、アクチノイド、核物質の分野をまたぐ相対論的効果の重要性である。多くの新たな展開が、これら複数分野間の協力から生れることを期待する。

ASRC の科学界におけるリーダーシップをさらに強化し確固とするための提案

1. ASRC の 3 つの分野間や 11 のグループ間の相乗効果に重点をおく。例えば手始めに、グループリーダーが他のグループや研究テーマと自身の研究との関連をスライドで示すことなどができるだろう。アイディアや研究計画で創造的な相互作用があるものは、協同研究資金の提供、”シナジー賞”、昇進などで評価するべきである。相乗効果はすでに存在するが、委員会ではあまり認められなかった。さらなる展開が可能であろう。全員で取り組むことで、個々の成果の集合以上の成果が得られるはずであり、それでこそ ASRC にこれらのグループが共存する意義がある。今後のプレゼンテーションは ASRC 共通のテンプレートを使用し、組織のまとまりと一貫性を示すべきである。現在は、それぞれのグループが各自のスタイルでプレゼンテーションを行っており、コミュニケーション、協調性及び一貫性の不足を露呈するものである。ASRC の科学的水準のさらなる向上を図るためにも、グループ間コミュニケーションの強化を模索するべきである。
2. 人員の多様化を図る策が必要である。一例をあげると、現在、グループリーダーは全員男性であるが、これが科学的卓越を展開するのに最適な状態とは思えない。日本の英知を余すところなく活かすために、優れた女性研究者を指導的地位に配置してはいかがか。

2. 研究課題 No.1：新機能材料の創出に関する研究 （量子物性理論研究 Gr.）

評価結果：適切

意見・提案
この理論グループは ASRC の実験グループの活動を牽引し、スピンゼーベック効果、スピンメカトロニクス、スピン起電力の理論を含む重要な成果を出している。さらに、セミナーの開催等をとおして ASRC 内外との研究協力を推し進めている。このグループは将来的に“（理論に基づく）素子やその機能の設計”に焦点をあてることを推奨する。彼らは、戦略が前向きに進展していることを明示するべきである。また、応用の可能性を強調する必要もない。彼らの研究の強みは、基礎科学の本質を見抜く上で大きな利益をもたらすものである。

3. 研究課題 No.2：分子スピントロニクス材料・デバイスにおけるスピン伝導機構の解明（分子スピントロニクス研究 Gr.）

評価結果：適切

意見・提案
このグループの研究目的はグラフェンをスピントロニクスの材料にすることである。この研究分野は非常に競争が激しいが、前途有望なことは明らかである。Ni(111)基板を用いたエピタキシャル成長の研究は、ラマン法や XMCD 測定の実験とともに、彼らの目標達成への重要な布石となることを示している。彼らが森グループや、国外の他のグラフェン研究グループとコミュニケーションを図り、さらに多くの情報や新たな見識を得ることを推奨する。期間の後半では、応用への明確な道筋を描くための組織的な努力が必要である。この研究の今後の展開に大いに注目している。

4. 研究課題 No.3：スピントロニクス、メカトロニクス及び NMR 手法によるスピン流制御及び材料設計（力学的物質・スピン制御研究 Gr.）

評価結果：適切

意見・提案
スピントロニクス研究の未開拓分野を古典力学にまで広げ、電子と核スピン機構の結合を導き出すことに成功しており、模範的なグループである。グループリーダーの齊藤教授には ASRC と仙台（東北大）IMR の兼任という強みがある。これは双方の機関にとって科学的にも有利であり、ASRC の運営によって発展させるべきである。プレゼンテーションで適切に表現されたように、このグループが行っている世界レベルの研究にはアインシュタイン・ドハース効果やバーネット効果（1915 年）の歴史的基盤がある。このグループの取り組みの大部分は、目に見える新しい技術の開発よりも、熱・音・流体・NMR

スピンポンピングのような今までにない現象の探求と解明に動機づけられている。したがって、不要に目先の応用を示唆する“スピンメカトロニクス”などという技術専門用語の使用は避けてはいかがだろうか。

5. 研究課題 No.4:重原子核の殻構造の解明 （重原子核反応フロンティア研究 Gr.）

評価結果：適切

意見・提案
事前評価において評価委員会は、このグループを別の部門に移すことを勧めた。グループは研究の焦点を変更することで対応したが、それがみごとに成功したようだ。彼らは陽子過剰核 180Hg の核分裂が非対称に起こる新現象を発見した。これは既存の理論では予期できなかったことで、核物理界に光明を投じた。新たに開拓したこの分野で、研究をさらに遂行することが望まれる。現在では、成功を収めたこのグループを別部門に移す必要はない。

6. 研究課題 No.5:超重元素の価電子状態と超重核の殻構造の解明 （超重元素研究 Gr.）

評価結果：適切

意見・提案
このグループは事前評価の提言を受けて、有機金属化合物、超重元素の電気化学、特にローレンシウム(Lr)のイオン化ポテンシャル測定を含む、より挑戦的なテーマに取り組むことになった。これらは全て新規的で将来性があり、興味深い分野である。この課題は、物質における相対論的効果という視点から、固体物理とも関連がある。スピントロニクスのグループと情報交換し、新しいアイディアを模索することも有益かもしれない。

7. 研究課題 No.6:アクチノイド化合物の物質開発 （アクチノイド物質開発研究 Gr.）

評価結果：適切

意見・提案
5f 電子系のもつ特性を基に新材料を創出することに焦点をあてた、優秀な固体物理研究グループである。単結晶を含むこれらの新材料は最高品質で、さらに薄膜成長へ広げる計画もある。最高品質の試料によって明瞭な物理的洞察を生み出し、それによりこのグループが質の高い試料の供給源として世界中から求められるようになることが望ましい。追求する物理現象は、現代固体物理学の主要課題である相関電子系関連のものだけでなく、非従来型超伝導、量子臨界、近藤効果、重フェルミオン物理、メタ磁性転移、高磁場・高圧・低温・放射線環境下など極限状態における物質の研究を含む。このグループは固体物理グループ(研究課題 7）への試料提供を行っている。両グループ間の垣根を越

えた協力関係と独自性の確立は、双方にとって有益と思われる。

8. 研究課題 No.7:重元素化合物のための新たな固体物理コンセプトの開拓 （重元素系固体物理研究 Gr.）

評価結果：適切

意見・提案
5f 電子系を研究するもうひとつの優れた固体物理研究グループである。このグループ特有の強みは、非従来型超伝導、量子臨界、複雑なフェルミ面の研究といった強い相対論的効果を伴う相関電子系の基礎物理を探索するための最先端技術の蓄積があるということである。その技術には NMR、 μSR、中性子散乱を含む。また、このグループは素晴らしい数の論文発表を行っており、その半数は前述のグループ(研究課題 6)が提供した試料を活用したものである。前述のグループへの意見として述べたとおり、両グループが今後の研究目標策定において積極的な連携を図ることで、相乗効果とそれにともなう大きな影響力を発揮することができるだろう。

9. 研究課題 No.8:ストロンジネスを含む原子核とハドロンの構造解明 （ハドロン物理研究 Gr.）

評価結果：適切

意見・提案
この核物理のグループはハドロン物理実験研究のパイオニアである。彼らの使命は、ストレンジネスを含む新しい原子核とハドロンの研究である。目的達成のために、分光分析手法や新しい分光測定器の整備、J-PARC と RCNP(大阪大　核物理研究センター)での検出器のテストなど、主要な装置・手法の開発を進めている。同時に、理論的・計算的手法により、超新星や中性子星とも関連する天体物理学的相転移や相分離に関する核物質の対称性の解明にも取り組んでいる。シミュレーションされた機構(パスタ構造と呼ばれる)は、ソフトマター物理でよく知られる構造と類似している。違ったスケールで物理の共通性を追究するために、固体物理の理論/計算グループ(研究課題 1)とアイディアを交換し合うことも、このグループにとって有益かと思われる。

10. 研究課題 No.9:バイオ反応場におけるアクチノイドのナノ粒子化機構の解明 （バイオアクチノイド化学研究 Gr.）

評価結果：適切

意見・提案
このバイオアクチノイド化学グループは、2 年前の厳しい事前評価からみごとに立て直しを果たした。彼らは細胞表面におけるナノ粒子形成の研究でグループを再構成した。彼

らは大震災後の福島支援において放射性 137Cs の 3 次元マッピングを行い、ASRC の中でも、日本国民にとって直接的に最も重要な存在となった。この事実は、ピア・レビュー（外部専門家による評価）は私たちが知り得る限り最良の評価方法とはいえ、完全ではないということを示している。評価の観点は予期せぬ出来事によって、突如劇的に変わり得るということである。

11. 研究課題 No.10：放射場における生体分子の変異と生体応答の解明 （放射場生体分子科学研究 Gr.）

評価結果：適切

意見・提案
この生体分子科学のグループは、分子・細胞レベルでの放射線影響を研究している。2 年前の事前評価では改革を求められ、前述のグループ(研究課題 9)と同様の状況にあった。放射線で誘発した癌におけるトランス生成効果に焦点を当てて研究を進めている。X 線照射効果の時間経過にともなう影響を理解するため、新しい FUCCI 技術を採用している点は非常に興味深い。これは細胞分裂の生体化学や細胞周期における細胞修復の役割解明に新しい知見をもたらす最先端の研究である。現在の成果は人間の上皮癌に限定されるが、今後の研究で他の型の細胞にまで一般化され得る。またこのグループの男女比率は ASRC 内でもっとも緩やかであるので、女性指導者の育成を始めるのに最適かもしれない。

12. 研究課題 No.11：スピン偏極陽電子ビーム技術の開発とスピントロニクス研究への応用（スピン偏極陽電子ビーム研究 Gr.）

評価結果：適切

意見・提案
陽電子消滅過程の解明や、それに関する分光法ならびに散乱技術を開拓するという新奇的かつ興味深い研究を行うグループである。私たちが知る限り、彼らはこの研究を行う唯一のグループである。前川センター長のリーダーシップにより、このグループは ASRC 内での相乗効果を最大限に発揮できている。このグループが達成したスピンと運動量の分解能分布は実にみごとで、磁場環境下でも有効である。これは ARPES（高電子分光）では不可能なことである。この研究は非常に将来性が高い。また、このグループや ASRC 内の他のグループが行っている巨大スピンホール効果の実験は、理論構築という課題を生み出しており、それはすなわち ASRC の理論家たちの課題ともなり得る。多くの興味深い進展が期待できる。

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国際単位系（SI）

表１．SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表２．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m^{-1}
密度，質量密度	キログラム毎立方メートル	kg/m^3
面積密度	キログラム毎平方メートル	kg/m^2
比体積	立方メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
量濃度[a]，濃度	モル毎立方メートル	mol/m^3
質量濃度	キログラム毎立法メートル	kg/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率[b]	（数字の） 1	1
比透磁率[b]	（数字の） 1	1

(a) 量濃度（amount concentration）は臨床化学の分野では物質濃度（substance concentration）ともよばれる。
(b) これらは無次元量あるいは次元１をもつ量であるが、そのことを表す単位記号である数字の１は通常は表記しない。

表３．固有の名称と記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン[b]	rad	1 [b]	m/m
立体角	ステラジアン[b]	sr[c]	1 [b]	m^2/m^2
周波数	ヘルツ[d]	Hz		s^{-1}
力	ニュートン	N		$m\ kg\ s^{-2}$
圧力，応力	パスカル	Pa	N/m^2	$m^{-1}\ kg\ s^{-2}$
エネルギー，仕事，熱量	ジュール	J	N m	$m^2\ kg\ s^{-2}$
仕事率，工率，放射束	ワット	W	J/s	$m^2\ kg\ s^{-3}$
電荷，電気量	クーロン	C		s A
電位差（電圧），起電力	ボルト	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
静電容量	ファラド	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
電気抵抗	オーム	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
コンダクタンス	ジーメンス	S	A/V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
磁束	ウエーバ	Wb	Vs	$m^2\ kg\ s^{-2}\ A^{-1}$
磁束密度	テスラ	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
インダクタンス	ヘンリー	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
セルシウス温度	セルシウス度[e]	℃		K
光束	ルーメン	lm	cd sr[c]	cd
照度	ルクス	lx	lm/m^2	$m^{-2}\ cd$
放射性核種の放射能[f]	ベクレル[d]	Bq		s^{-1}
吸収線量, 比エネルギー分与, カーマ	グレイ	Gy	J/kg	$m^2\ s^{-2}$
線量当量, 周辺線量当量, 方向性線量当量, 個人線量当量	シーベルト[g]	Sv	J/kg	$m^2\ s^{-2}$
酸素活性	カタール	kat		$s^{-1}\ mol$

(a)SI接頭語は固有の名称と記号を持つ組立単位と組み合わせても使用できる。しかし接頭語を付した単位はもはやコヒーレントではない。
(b)ラジアンとステラジアンは数字の１に対する単位の特別な名称で、量についての情報をつたえるために使われる。実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号である数字の１は明示されない。
(c)測光学ではステラジアンという名称と記号srを単位の表し方の中に、そのまま維持している。
(d)ヘルツは周期現象についてのみ、ベクレルは放射性核種の統計的過程についてのみ使用される。
(e)セルシウス度はケルビンの特別な名称で、セルシウス温度を表すために使用される。セルシウス度とケルビンの単位の大きさは同一である。したがって、温度差や温度間隔を表す数値はどちらの単位で表しても同じである。
(f)放射性核種の放射能（activity referred to a radionuclide）は、しばしば誤った用語で"radioactivity"と記される。
(g)単位シーベルト（PV,2002,70,205）についてはCIPM勧告2（CI-2002）を参照。

表４．単位の中に固有の名称と記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	Pa s	$m^{-1}\ kg\ s^{-1}$
力のモーメント	ニュートンメートル	N m	$m^2\ kg\ s^{-2}$
表面張力	ニュートン毎メートル	N/m	$kg\ s^{-2}$
角速度	ラジアン毎秒	rad/s	$m\ m^{-1}\ s^{-1}=s^{-1}$
角加速度	ラジアン毎秒毎秒	rad/s^2	$m\ m^{-1}\ s^{-2}=s^{-2}$
熱流密度，放射照度	ワット毎平方メートル	W/m^2	$kg\ s^{-3}$
熱容量，エントロピー	ジュール毎ケルビン	J/K	$m^2\ kg\ s^{-2}\ K^{-1}$
比熱容量，比エントロピー	ジュール毎キログラム毎ケルビン	J/(kg K)	$m^2\ s^{-2}\ K^{-1}$
比エネルギー	ジュール毎キログラム	J/kg	$m^2\ s^{-2}$
熱伝導率	ワット毎メートル毎ケルビン	W/(m K)	$m\ kg\ s^{-3}\ K^{-1}$
体積エネルギー	ジュール毎立方メートル	J/m^3	$m^{-1}\ kg\ s^{-2}$
電界の強さ	ボルト毎メートル	V/m	$m\ kg\ s^{-3}\ A^{-1}$
電荷密度	クーロン毎立方メートル	C/m^3	$m^{-3}\ sA$
表面電荷	クーロン毎平方メートル	C/m^2	$m^{-2}\ sA$
電束密度，電気変位	クーロン毎平方メートル	C/m^2	$m^{-2}\ sA$
誘電率	ファラド毎メートル	F/m	$m^{-3}\ kg^{-1}\ s^4\ A^2$
透磁率	ヘンリー毎メートル	H/m	$m\ kg\ s^{-2}\ A^{-2}$
モルエネルギー	ジュール毎モル	J/mol	$m^2\ kg\ s^{-2}\ mol^{-1}$
モルエントロピー, モル熱容量	ジュール毎モル毎ケルビン	J/(mol K)	$m^2\ kg\ s^{-2}\ K^{-1}\ mol^{-1}$
照射線量（X線及びγ線）	クーロン毎キログラム	C/kg	$kg^{-1}\ sA$
吸収線量率	グレイ毎秒	Gy/s	$m^2\ s^{-3}$
放射強度	ワット毎ステラジアン	W/sr	$m^4\ m^{-2}\ kg\ s^{-3}=m^2\ kg\ s^{-3}$
放射輝度	ワット毎平方メートル毎ステラジアン	$W/(m^2\ sr)$	$m^2\ m^{-2}\ kg\ s^{-3}=kg\ s^{-3}$
酵素活性濃度	カタール毎立方メートル	kat/m^3	$m^{-3}\ s^{-1}\ mol$

表５．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	μ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^{9}	ギガ	G	10^{-12}	ピコ	p
10^{6}	メガ	M	10^{-15}	フェムト	f
10^{3}	キロ	k	10^{-18}	アト	a
10^{2}	ヘクト	h	10^{-21}	ゼプト	z
10^{1}	デカ	da	10^{-24}	ヨクト	y

表６．SIに属さないが、SIと併用される単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86 400 s
度	°	1°=(π/180) rad
分	’	1’=(1/60)°=(π/10800) rad
秒	”	1”=(1/60)’=(π/648000) rad
ヘクタール	ha	$1ha=1hm^2=10^4m^2$
リットル	L，l	$1L=1=1dm^3=10^3cm^3=10^{-3}m^3$
トン	t	$1t=10^3\ kg$

表７．SIに属さないが、SIと併用される単位で、SI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位で表される数値
電子ボルト	eV	$1eV=1.602\ 176\ 53(14)\times10^{-19}J$
ダルトン	Da	$1Da=1.660\ 538\ 86(28)\times10^{-27}kg$
統一原子質量単位	u	1u=1 Da
天文単位	ua	$1ua=1.495\ 978\ 706\ 91(6)\times10^{11}m$

表８．SIに属さないが、SIと併用されるその他の単位

名称	記号	SI 単位で表される数値
バール	bar	$1\ bar=0.1MPa=100kPa=10^5Pa$
水銀柱ミリメートル	mmHg	1mmHg=133.322Pa
オングストローム	Å	$1\ Å=0.1nm=100pm=10^{-10}m$
海里	M	1 M=1852m
バーン	b	$1\ b=100fm^2=(10^{-12}cm)2=10^{-28}m^2$
ノット	kn	1 kn=(1852/3600)m/s
ネーパ	Np	SI単位との数値的な関係は、対数量の定義に依存。
ベル	B	
デジベル	dB	

表９．固有の名称をもつCGS組立単位

名称	記号	SI 単位で表される数値
エルグ	erg	$1\ erg=10^{-7}\ J$
ダイン	dyn	$1\ dyn=10^{-5}N$
ポアズ	P	$1\ P=1\ dyn\ s\ cm^{-2}=0.1Pa\ s$
ストークス	St	$1\ St=1cm^2\ s^{-1}=10^{-4}m^2\ s^{-1}$
スチルブ	sb	$1\ sb=1cd\ cm^{-2}=10^4cd\ m^{-2}$
フォト	ph	$1\ ph=1cd\ sr\ cm^{-2}\ 10^4lx$
ガル	Gal	$1\ Gal=1cm\ s^{-2}=10^{-2}ms^{-2}$
マクスウェル	Mx	$1\ Mx = 1G\ cm^2=10^{-8}Wb$
ガウス	G	$1\ G =1Mx\ cm^{-2} =10^{-4}T$
エルステッド[c]	Oe	$1\ Oe \triangleq (10^3/4\pi)A\ m^{-1}$

(c) ３元系のCGS単位系とSIでは直接比較できないため、等号「 ≙ 」は対応関係を示すものである。

表10．SIに属さないその他の単位の例

名称	記号	SI 単位で表される数値
キュリー	Ci	$1\ Ci=3.7\times10^{10}Bq$
レントゲン	R	$1\ R = 2.58\times10^{-4}C/kg$
ラド	rad	$1\ rad=1cGy=10^{-2}Gy$
レム	rem	$1\ rem=1\ cSv=10^{-2}Sv$
ガンマ	γ	1 γ =1 nT=10-9T
フェルミ		1フェルミ=1 fm=10-15m
メートル系カラット		1メートル系カラット = 200 mg = 2×10-4kg
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	1cal=4.1858J（「15℃」カロリー），4.1868J（「IT」カロリー）4.184J（「熱化学」カロリー）
ミクロン	μ	$1\ \mu =1\mu m=10^{-6}m$

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この印刷物は再生紙を使用しています