・本資料は、ワークショップ当日に配布したものです。
・一部プログラムと予稿集のタイトルが異なるものがあります。また、予稿または日本語訳のないものがあります。
・日本語訳は、当機構で翻訳したものにつきましては、仮訳となっております。

Program and Abstracts

廃炉に向けた耐放射線性センサー及び関連研究に関する国際ワークショップ(R2SRT2016)

International Workshop on Radiation Resistant Sensors and Related Technologies for Nuclear Power Plant Decommissioning 2016 (R2SRT2016)

平成 28 年 4 月 19 日-20 日
いわき産業創造館（LATOV）6 F
（福島県・いわき市）

April 19－20, 2016
Iwaki Business Innovation Center “LATOV” 6 F
（Iwaki-city, Fukushima）

Organized by
Collaborative Laboratories for Advanced Decommissioning Science
(CLADS)
JAPAN ATOMIC ENERGY AGENCY (JAEA)
廃炉国際共同研究センター（CLADS）
日本原子力研究開発機構

International Workshop on Radiation Resistant Sensors and Related Technologies for Nuclear Power Plant Decommissioning 2016

(R2SRT2016)

Thank you for your participation in the "International Workshop on Radiation Resistant Sensors and Related Technologies for Nuclear Power Plant Decommissioning 2016 (R2SRT2016)". The purpose of this workshop is to provide the place and occasion to contact the decommissioning, radiation resistance and related technologies. This is the first attempt after the Great East Japan Earthquake. We expect the active discussion of all participants.

Purpose

In the decommissioning work for TEPCO Holdings Fukushima Daiichi Nuclear Power Station, the remote maintenance operations under intense gamma-ray irradiation conditions are inevitable. Developing radiation-tolerance robots or remote monitoring and handling systems is going to be an important issue.

These technologies can also form a good foundation for future development in innovative technologies such as the Gen-IV reactors, Fast Reactors, fusion power, etc. JAEA has evaluated radiation resistance of electronics parts, sensor and other devices and developed related basic and generic research. , In addition, this basic and generic research on radiation resistance of electronic parts and sensors, etc. is expected to be the spin-off to innovate visualization technologies in the future.

In this workshop, we invite many professionals around the world to discuss radiation resistance to improve the robot technology and sensor technology needed for the decommissioning work and related research. This discussion wills strength information exchange and cooperation between the people involved in decommissioning and domestic and foreign researchers. We expected that this workshop will accelerate the decommissioning work and promote the relevant basic research.

In this workshop, we focus on the following topics:

Session Overview

Session – 1 :　R&D on robot-related electronics

Session – 2 :　R&D on decommissioning technologies

Session – 3 :　R&D on new materials

Session – 4 :　R&D on innovation concept - spintronics -

Session – 5 :　R&D on sensorning technology

Program

<DAY 1 : 19 APRIL>

12:00- RECEPTION

13:00-13:10 OPENING REMARKS

13:10- SESSION-1 : ROBOT-RELATED ELECTORONICS

"EVALUATION AND CHARACTERIZATION OF ELECTRONIC PARTS FOR THE EUROPA CLIPPER MISSION"

California Institute of Technology Jet Propulsion Lab.(JPL)
MR. S. McCLURE

"R&D ON ROBOTS FOR THE DECOMMISSIONING OF FUKUSHIMA DAIICHI NPS"

International Research Institute for Nuclear Decommissioning(IRID)
/Hitachi-GE Nuclear Energy Ltd.
MR. H. KINOSHITA

"RADIATION TOLERANCE OF COMPONENTS ON THE SHELF"

Japan Atomic Energy Agency(JAEA)
MR. S.KAWATSUMA

"ELECTRONIC RADIATION HARDENING, A SYSTEM APPROACH"

Laboratoire Fiabilité et Intégration Capteurs
Commissariat à l'énergie atomique et aux énergies alternatives(CEA)
DR. A. DUPRET

15:10- Break (20 MIN.)

15:30- Session-2 : DECOMMISSIONING TECHNOLOGIES

"DECOMMISSIONING EXPERIENCES AT THE USDOE SAVANNAH RIVER NATIONAL LABORATORY"

Savannah River National Laboratory(SRNL)
DR. K. KOSTELNIK

"R&D AND INNOVATION IN INSTRUMENTATION AND MEASUREMENT FOR IMPROVED CORE SAFETY, PERFORMANCE AND CONTROL"

International Expert in Nuclear Measurement / Prof. of radiation detection
/Scientific Director of LIMMEX join Lab.(CEA)
DR. A. LYOUSSI

"OECD NEA Activity in the Area of the Use of Robotic and Remote Systems in Radioactive Waste Management and Decommissioning"

Organisation for Economic Co-operation and Development / Nuclear Energy Agency（OECD/NEA）

DR. V. LEBEDEV

17:10- ADJOURN

18:00- WELCOME RECEPTION (PLACE : IWAKI WASHINGTON HOTEL)

<DAY 2 : 20 APRIL>

8:50- RECEPTION

9:00-9:10 GENERAL INFORMATION

9:10- SESSION-３ : NEW MATERIALS

"SILICON-CARBIDE BASED THERMAL AND FAST NEUTRON DETECTORS FOR NUCLEAR REACTOR MONITORING"

Aix-Marseille Univ.

DR. L. OTTAVIANI

"DEVELOPMENT OF DIAMOND RADIATION DETECTORS AND FETS FOR NUCLEAR POWER PLANTS"

Hokkaido Univ.

ASSOC. PROF. J. KANEKO

10:10- BREAK (20 MIN.)

10:30- (SESSION-３ CONTINUATION)

"4H-SIC MOSFETS AND LOGIC INVERTERS FOR RADIATION-HARDENED ELECTRONICS"

Hiroshima Univ.

ASSOC. PROF. S. KUROKI

"POSSIBILITY FOR AN IMAGE CAPTURING OF NUCLEAR DEBRIS MATTERS"

Tohoku Univ.

DR. K. KUMANO

"DEVELOPMENT OF SUPER RADIATION RESISTANT METAL-OXIDE-SEMICONDUCTOR TRANSISTOR BASED ON SILICON CARBIDE"

National Institutes for Quantum and Radiological Science and Technology (QST)

DR. T. OHSHIMA

12:00- LUNCH

13:30- SESSION-4 : INNOVATION CONCEPT : SPINTRONICS

"EFFECTS OF SWIFT HEAVY ION BOMBARDMENT ON THE FUNCTIONAL PROPERTIES OF MAGNETIC TUNNEL JUNCTION AND EXAMPLES OF RADIATION HARD CIRCUITS DESIGN BASED ON THESE ELEMENTS"

Commissariat a l'energie atomique et aux energies alternatives(CEA)

DR. B. DIENY

"APPLICATION OF SPINTRONICS TO NUCLEAR TECHNOLOGY"

Japan Atomic Energy Agency(JAEA)

DR. S. MAEKAWA

14:30- BREAK (20 MIN.)

14:50- SESSION-5 : SENSORNING TECHNOLOGIES

"ADVANCED CMOS IMAGE SENSORS DEVELOPMENT FOR HIGH SENSITIVITY, HIGH SPEED AND WIDE SPECTRAL RESPONSE"

Tohoku Univ.

ASSOC. PROF. R. KURODA

"HIGH RADIATION RESISTANT VISUALIZATION TECHNOLOGIES USING SILICA BASED GLASS IMAGEFIBER"

Fujikura Ltd.

MR. T. TORIYA

15:50- BREAK (20 MIN.)

16:10- (SESSION 5: SENSORNING TECHNOLOGIES) CONTINATION

"PHOTONICS APPROACHES FOR PLANT DECOMMISSIONING"

Hamamatsu Photonics Ltd.

DR. Y. TAKIGUCHI

"DEVELOPMENT OF ONSITE/IN-SITU, RAPID AND RADIO-RESISTANCE REMOTE ANALYSIS BY OPTICAL FIBER BASED LASER INDUCED BREAKDOWN SPECTROSCOPY"

Japan Atomic Energy Agency(JAEA)

DR. I.WAKAIDA

17:10- CLOSING REMARKS

17:20 ADJOURN

廃炉に向けた耐放射線性センサー及び関連研究に関する国際ワークショップ(R2SRT2016)

この度は、「廃炉に向けた耐放射線性センサー及び関連研究に関する国際ワークショップ(R2SRT2016)」にご参加頂きまして誠にありがとうございます。 本ワークショップは、東日本大震災以降、初めての試みとして、廃炉と耐放射線性及びその関連研究を繋ぐ場として開催するものであります。皆様の活発なご議論をお願い申し上げます。

目　的

東京電力ホールディングス福島第一原子力発電所事故の廃炉作業では、現場作業における被ばく等のリスクを低減するため、遠隔技術が多く活用されています。このため、遠隔技術であるロボットや計測機器等の耐放射線の向上は、今後、重要なますます課題となってきます。また、これらの耐放射線性の向上は、廃炉以外の原子力研究開発（Gen-IV、高速炉、核融合等）の分野でも、その適用が大いに期待される技術です。

日本原子力研究開発機構では、これまでエレクトロニクス部品やセンサー等の耐放射線性の評価や関連する基礎基盤的な研究開発を実施しております。また、ここで必要となる電子機器等の耐放射線性に関する基礎研究は、将来的の革新的な可視化技術等へのスピンオフも期待されています。

本ワークショップでは、国内外の専門家にご参加を頂き、廃炉作業に必要なロボット技術やセンサー技術の向上に必要な耐放射線性、及びその関連研究に関する議論を行い、廃炉関係者や国内外の研究者間の情報交流と連携を強化することで、廃炉作業を加速するとともに、関連する基礎基盤研究の促進を図ることを目的としています。

セッション概要

セッション- 1 ：ロボット関連エレクトロニクス
セッション- 2 ：廃止措置（廃炉）技術
セッション- 3 ：新材料
セッション- 4 ：革新概念　-スピントロニクス-
セッション- 5 ：検知・検出技術

プログラム内容

＜１日目：４月１９日＞

12:00-　受付

13:00-13:10　開会挨拶

13:10-　セッション-１：ロボット関連エレクトロニクス

SESSION-1：ROBOT-RELATED ELECTRONICS

「EVALUATION AND CHARACTERIZATION OF ELECTRONIC PARTS FOR THE EUROPA CLIPPER MISSION（エウロパ探査ミッション用電子部品の評価と特性分析（仮訳））」

カリフォルニア工科大学ジェット推進研究所（JPL）　S. McCLURE　氏

「R&D ON ROBOTS FOR THE DECOMMISSIONING OF FUKUSHIMA DAIICHI NPS（福島第一原子力発電所の廃炉に向けたロボット技術開発）」

国際廃炉研究開発機構（IRID）/日立 GE　木下 博文　氏

「RADIATION TOLERANCE OF COMPONENTS ON THE SHELF（市販半導体の耐放射線性）」

日本原子力研究開発機構（JAEA）　川妻 伸二　氏

「ELECTRONIC RADIATION HARDENING, A SYSTEM APPROACH（システムアプローチによる電子回路の耐放射線化（仮訳））」

仏国原子力・代替エネルギー庁（CEA）　A. DUPRET 博士

15:10-　休憩（20 分），Break (20min)

15:30-　セッション-２：廃止措置（廃炉）技術

Session-2：DECOMMISSIONING TECHNOLOGIES

「DECOMMISSIONING EXPERIENCES AT THE USDOE SAVANNAH RIVER NATIONAL LABORATORY（米国エネルギー省サバンナリバー国立研究所における廃止措置の実績（仮訳））」

米国サバンナリバー国立研究所（SRNL）　K. KOSTELNIK　博士

「R&D AND INNOVATION IN INSTRUMENTATION AND MEASUREMENT FOR IMPROVED CORE SAFETY, PERFORMANCE AND CONTROL（改良炉心の安全、性能及び制御に向けた計測機器と測定法に関する研究開発と革新（仮訳））」

仏国原子力・代替エネルギー庁（CEA）　A. LYOUSSI　博士

「OECD NEA Activity in the Area of the Use of Robotic and Remote Systems in Radioactive Waste Management and Decommissioning（放射性廃棄物の処理

及び廃炉におけるロボット及び遠隔システムに関する OECD NEA の活動（仮訳））」

経済協力開発機構原子力機関（OECD/NEA）　V. LEBEDEV　博士

17:10-　１日目終了

18:00-　懇親会（いわきワシントンホテル）

＜2日目：４月２０日＞

8:50-　受付

9:00-9:10　一般連絡・案内

9:10-　セッション-３：新材料

SESSION-３：NEW MATERIALS

「SILICON-CARBIDE BASED THERMAL AND FAST NEUTRON DETECTORS FOR NUCLEAR REACTOR MONITORING（炭化ケイ素材料を基にした原子炉監視用の熱中性子及び高速中性子検出器（仮訳））」

エクス-マルセイユ大学　L. OTTAVIANI　博士

「DEVELOPMENT OF DIAMOND RADIATION DETECTORS AND FETS FOR NUCLEAR POWER PLANTS（原子炉プラント用ダイヤモンド放射線検出器とダイヤモンド電界効果トランジスタの開発）」

北海道大学大学院　金子 純一　准教授

10:10-　休　憩　（20 分）

10:30-　（セッション-３：新材料）継続

「4H-SIC MOSFETS AND LOGIC INVERTERS FOR RADIATION-HARDENED ELECTRONICS（耐放射線エレクトロニクスのための 4H シリコンカーバイド MOSFETs と論理インバータ）」

広島大学　黒木 伸一郎　准教授

「POSSIBILITY FOR AN IMAGE CAPTURING OF NUCLEAR　DEBRIS MATTERS（燃料デブリ撮像の可能性について）」

東北大学　熊野 勝文　博士

「DEVELOPMENT OF SUPER RADIATION RESISTANT METAL-OXIDE-SEMICONDUCTOR TRANSISTOR　BASED ON SILICON CARBIDE（炭化ケイ素を基板とした超耐放射線性金属－酸化膜－半導体トランジスタの開発）」

量子科学技術研究開発機構（QST）　大島 武　博士

12:00-　昼　休

13:30-　セッション-４：革新概念　-スピントロニクス-

SESSION-4 : INNOVATION CONCEPT : SPINTRONICS

「EFFECTS OF SWIFT HEAVY ION BOMBARDMENT ON THE FUNCTIONAL PROPERTIES OF MAGNETIC TUNNEL JUNCTION AND EXAMPLES OF RADIATION HARD CIRCUITS DESIGN BASED ON THESE ELEMENTS（磁気トンネル接合の機能特性に与える高速重イオン衝撃効果とそれを用いた及び元素に起因する耐放射線性硬化回路設計例（仮訳））」

仏国原子力・代替エネルギー庁（CEA）　B. DIENY　博士

「APPLICATION OF SPINTRONICS TO NUCLEAR TECHNOLOGY（スピントロニクスの原子力への応用（仮））」

日本原子力研究開発機構（JAEA）　前川 禎通　博士

14:30-　休　憩　（20 分）

14:50-　セッション-５：検知・検出技術

SESSION-5 : SENSORNING TECHNOLOGIES

「ADVANCED CMOS IMAGE SENSORS DEVELOPMENT FOR HIGH SENSITIVITY, HIGH SPEED AND WIDE SPECTRAL RESPONSE（東北大学における先進 CMOS イメージセンサの開発：高感度化・高速化・広光波長帯域化）」

東北大学大学院　黒田 理人　准教授

「HIGH RADIATION RESISTANT VISUALIZATION TECHNOLOGIES USING SILICA BASED GLASS IMAGEFIBER（石英ガラスイメージファイバを用いた高耐放射線性視覚化技術）」

株式会社フジクラ　鳥谷 智晶　氏

15:50-　休　憩　（20 分）

16:10-　（セッション-５：検知・検出技術）継続

「PHOTONICS APPROACHES FOR PLANT DECOMMISSIONING（廃炉における光技術によるアプローチ）」

浜松ホトニクス株式会社　瀧口 義浩　博士

「DEVELOPMENT OF ONSITE/IN-SITU, RAPID AND RADIO-RESISTANCE REMOTE ANALYSIS BY OPTICAL FIBER BASED LASER INDUCED BREAKDOWN SPECTROSCOPY（光ファイバを用いたレーザー誘起発光分光法によるその場、迅速、耐放射線性遠隔分析手法の開発）」

日本原子力研究開発機構　若井田 育夫　博士

17:10-　閉会挨拶

17:20　閉　会

Purpose

In the decommissioning work for TEPCO's Fukushima Daiichi Nuclear Power Station, the remote maintenance operations under intense gamma-ray irradiation conditions are inevitable. Developing radiation-tolerance robots or remote monitoring and handling systems is going to be an important issue.

These technologies can also form a good foundation for future development in innovative technologies such as the Gen-IV reactors, fusion power, etc., and have spin-off potential.

Japan Atomic Energy Agency (or JAEA) has ever carried out radio-resistance evaluations for electronic components or sensors as well as R&D on related basic technologies.

The purpose of the 2-day workshop is to bring together researchers from around the world who are interested in exploring the link between decommissioning work and sensor hardening-related technologies. In this workshop, we focus on the following topics:

- R&D on sensor/measuring technologies available under radiation environments
- R&D on radiation-resistant devices
- R&D on spintronics
- R&D on robot-related electronics

JAEA, Cobalt- 60 Irradiation Facilities

Iwaki Marine Tower

Marine Science Museum, (Aquamarine Fukushima)

LATOV Iwaki Business Innovation Center
120 Aza-Tamachi Taira,
Iwaki-city, Fukushima 〒970-8026

R2SRT2016

" International Workshop on Radiation Resistant Sensors and Related Technologies for Nuclear Power Plant Decommissioning 2016 "

19-20 April, 2016

Iwaki Japan

Venue :

LATOV, Iwaki city, Fukushima

Conference Language : English

Host organization is Japan Atomic Energy Agency (JAEA)

JAEA-R2SRT2016@jaea.go.jp

Contact :
Japan Atomic Energy Agency
Tokai Research and Development Center,
http://www.jaea.go.jp/english/04/ntokai/access/

Program   " R2SRT2016 "   19-20 April, 2016 Iwaki Japan

<DAY1 : 19 APRIL>

12:00- RECEPTION

13:00- OPENING REMARKS

SESSION- 1 (ROBOT-RELATED ELECTRONICS)

13:10- " EVALUATION AND CHARACTERIZATION OF ELECTRONIC PARTS FOR THE EUROPA CLIPPER MISSION "
MR. S. McCLURE (JPL)

" R&D ON ROBOTS FOR THE DECOMMISSIONING OF FUKUSHIMA DAIICHI NPS "
MR. KINOSHITA (IRID)

" RADIATION TOLERANCE OF COMPONENTS ON THE SHELF "
MR. S.KAWATSUMA (JAEA)

" ELECTRONIC RADIATION HARDENING, A SYSTEM APPROACH "
DR. A. DUPRET (CEA)

15:10- BREAK (20 MIN.)

SESSION- 2 (DECOMMISSIONING TECHNOLOGIES)

15:30- " DECOMMISSIONING EXPERIENCES AT THE USDOE SAVANNAH RIVER NATIONAL LABORATORY "
DR. K.KOSTELNIK (SRNL)

" R&D AND INNOVATION IN INSTRUMENTATION AND MEASUREMENT FOR IMPROVED CORE SAFETY, PERFORMANCE AND CONTROL "
DR. A. LYOUSSI (CEA)

" OECD NEA ACTIVITY IN THE AREA OF THE USE OF ROBOTIC AND REMOTE SYSTEMS IN RADIOACTIVE WASTE MANAGEMENT AND DECOMMISSIONING "
DR. V. LEBEDEV (OECD/NEA)

17:10 ADJOURN

18:00- WELCOME RECEPTION
(PLACE: IWAKI WASHINGTON HOTEL)

<DAY2 : 20 APRIL>

8:50- RECEPTION

9:00- GENERAL INFORMATION

SESSION - 3 (NEW MATERIALS)

9:10- " SILICON-CARBIDE BASED THERMAL AND FAST NEUTRON DETECTORS FOR NUCLEAR REACTOR MONITORING "
DR. L.OTTAVIANI (AIX-MARSEILLE UNIV.)

" DEVELOPMENT OF DIAMOND RADIATION DETECTORS AND FETS FOR NUCLEAR POWER PLANTS "
ASSOC.PROF. J.KANEKO (HOKKAIDO UNIV.)

10:10- BREAK (20 MIN.)

10:30- " 4H-SIC MOSFETS AND LOGIC INVERTERS FOR RADIATION-HARDENED ELECTRONICS "
ASSOC.PROF. S.KUROKI (HIROSHIMA UNIV.)

" POSSIBILITY FOR AN IMAGE CAPTURING OF NUCLEAR DEBRIS MATTERS "
DR. K.KUMANO (TOHOKU UNIV.)

" DEVELOPMENT OF SUPER RADIATION RESISTANT METAL-OXIDE-SEMICONDUCTOR TRANSISTOR BASED ON SILICON CARBIDE "
DR. T.OHSHIMA (QST)

12:00 LUNCH

SESSION - 4 (INNOVATION CONCEPT:SPINTRONICS)

13:30- " EFFECTS OF SWIFT HEAVY ION BOMBARDMENT ON THE FUNCTIONAL PROPERTIES OF MAGNETIC TUNNEL JUNCTION AND EXAMPLES OF RADIATION HARD CIRCUITS DESIGN BASED ON THESE ELEMENTS"
DR. B.DIENY (CEA)

" APPLICATION OF SPINTRONICS TO NUCLEAR TECHNOLOGY "
DR.S.MAEKAWA (JAEA)

14:30- BREAK (20 MIN.)

SESSION - 5 (SENSORNING TECHNOLOGIES)

14:50- " ADVANCED CMOS IMAGE SENSORS DEVELOPMENT FOR HIGH SENSITIVITY, HIGH SPEED AND WIDE SPECTRAL RESPONSE "
ASSOC.PROF. R.KURODA (TOHOKU UNIV.)

" HIGH RADIATION RESISTANT VISUALIZATION TECHNOLOGIES USING SILICA BASED GLASS IMAGEFIBER "
MR. T.TORIYA (FUJIKURA LTD.)

15:50- BREAK (20 MIN.)

16:10- " PHOTONICS APPROACHES FOR PLANT DECOMMISSIONING "
DR. Y.TAKIGUCHI (HAMAMATSU PHOTONICS)

" DEVELOPMENT OF ONSITE/IN-SITU, RAPID AND RADIO-RESISTANCE REMOTE ANALYSIS BY OPTICAL FIBER BASED LASER INDUCED BREAKDOWN SPECTROSCOPY "
DR. I.WAKAIDA (JAEA)

17:10- CLOSING REMARKS

17:20- ADJOURN

Abstract

Europa Clipper Mission: Designing for Radiation Survival

S. McClure*, G. Arakaki, R. Pappalardo, D. Brinza, I. Jun, W. Kim,

M. Pich, L. Scheick, S. Guertin, F. Irom, P. Willis, N. Low, K. Stanford

Jet Propulsion Laboratory, California Institute of Technology

*Email: steven.mcclure@jpl.nasa.gov

Keyword(s): Radiation hardened electronics, Spacecraft, Materials, Electronic parts

Introduction

The Europa mission will conduct detailed reconnaissance of Jupiter's moon Europa and investigate whether the icy moon could harbor conditions suitable for life. The mission will place a spacecraft in orbit around Jupiter in order to perform a detailed investigation of the giant planet's moon Europa -- a world that shows strong evidence for an ocean of liquid water beneath its icy crust and which could host conditions favorable for life [1]. The mission will send a highly capable, radiation-tolerant spacecraft into a long, looping orbit around Jupiter to perform repeated close flybys of Europa.

Trapped by Jupiter's strong magnetic field, the high energy electron environment poses a significant challenge. The design of the Europa Clipper mission addresses this challenge through a) minimizing encounters with the radiation field, b) system and subsystem shielding, c) maximum use of radiation hardened parts and materials, and d) mitigation of effects in electronic design.

Mission and Spacecraft Design

The high energy electron environment is particularly intense near Europa (over 1.0 krad, 10 Gray per hour at 100 equivalent mils Al). To mitigate this environment, the spacecraft will orbit Jupiter, outside of the radiation belt a majority of the time and make approximately 50 flybys of Europa to perform its science observations. The mission dose will be limited to approximately 3 Mrad at 100 mil eq. Al. Further the majority of the electronics will be within a vault shielded to approximately 300 krad (Fig. 1).

Hardened Parts, Materials and Design

Preferred parts and materials lists have been developed based on significant characterization and testing efforts. During this effort it was found that the majority of the subsystems could be hardened to required levels. In most cases, hardened space grade parts are used, some with additional testing at low dose rate to extend capability. Though the system includes some commercial memories and sensor ROICs, most commercial grade electronics will not survive in this environment [2]. In a few cases, including sensors, additional shielding to about 50 krad is required.

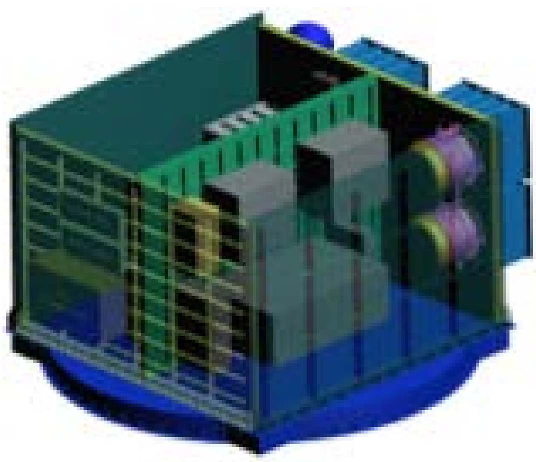


Fig. 1 Spacecraft shielding vault design.

Hardened circuit design approaches are also employed to mitigate radiation effects. These include but are not limited to building in parametric margin for analog circuits, rewriting bulk storage memory, subsystem redundancy, and ability to account for time/temperature annealing of devices.

References

[1] P.D. Fischer *et al.*, "Spatially Resolved Spectroscopy of Europa: The Distinct Spectrum of Large-scale Chaos, Astronomical Journal", 150 (5). Art. No. 164. ISSN 0004-6256.

[2] S. Guertin *et al.*, "TID Test Results for 4th Generation Ipad," IEEE Radiation Effects Data Workshop (2013) p.55.

Title: R&D on Robot for the Decommissioning of Fukushima Daiichi NPS

Hirofumi Kinoshita

International Research Institute for Nuclear Decommissioning, Tokyo, Japan

Abstract:

The International Research Institute for Nuclear Decommissioning (IRID) is a technology research association consisting of 18 member corporations that focus on R&D required for decommissioning the Fukushima Daiichi Nuclear Power Station (NPS). We have tied up with TEPCO's Fukushima Daiichi Decontamination and Decommissioning (D&D) Engineering Company to identify the needs of the Fukushima Daiichi site and are engaged in the integrated management on the development of various decommissioning technologies.

In the session, I will introduce some examples of IRID's R&D activities for preparation of fuel debris retrieval that is a core operation of decommissioning. Various kinds of remote controlled equipment and robots have been developed so far for decontamination and investigation inside the reactor building.

In 2012 and 2013, we investigated the dose rate and contamination distribution at each floor of the Units 1-3. Therefore, the conditions inside the reactor buildings are still very severe. We have developed three types of remote decontamination equipment: suction/blast type, high pressure water jet type and dry ice blast type.

Submersion method is the most favorable approach from the standpoint of minimizing radioactive exposure of workers. To realize this method, whole water leakage from the PCV needs to be found and stopped. Although the point to be investigated on the PCV is very hard to access with usual vehicle, we have to have developed various remotely controlled robots for water leakage investigation.

As the most recent example, we have developed a shape changing robot that can go through a penetration to investigate the PCV to grasp the damage situation inside the PCV, and also the location and condition of the fuel debris. We also developed a technology for detection of fuel debris in the reactor. Remote sensing technology utilizing cosmic ray muon is one of the methods to identify location of fuel debris.

The important process by the final stage of robot development prior to the application to Fukushima Daiichi is the evaluation in the mock-up facilities equal to the environment of the application place in the PCV. Not only examining the performance of the robot, but also training the workers to carry out the mission safely and certainly is executed sufficiently.

In the development of technologies for fuel debris retrieval, in addition to the method in which PCV is submerged, we are evaluating retrieval in the air, partial or full in air, as an applicable method. Because the status differs from unit to unit, we should consider the applicability of each method.

As the result of our R&D activities, IRID has acquired some useful outcome, but at the same time, technical challenges toward decommissioning have also becoming clearer. Based on these achievements and challenges, IRID will keep working on technology development necessary to decide the method for fuel debris retrieval in 2018, and contributing to completion of decommissioning at the earliest time.

発表者：木下博文　国際廃炉研究開発機構（IRID）

タイトル：福島第一原発の廃炉に向けたロボットの研究開発

要旨：
国際廃炉研究開発機構（IRID）は、福島第一原子力発電所の廃炉に向けた研究開発を行う 18 法人により設立された団体であり、福島第一原発のニーズを識別するため、東京電力（株）福島第一廃炉推進カンパニーと提携し、さまざまな廃炉技術の開発について統合管理を行っている。

本セッションでは、廃炉の中核事業である燃料デブリの取り出し準備のための研究開発例を紹介する。2012 年と 2013 年の調査で 1～3 号機の原子炉建屋内は高線量下にあることから、3 種類（高圧水ジェット、ドライアイスブラスト、吸引・ブラスト）の除染装置を開発した。最近の例としては、原子炉格納容器（PCV）内部調査のための形状変化型ロボットの開発、また、燃料デブリ位置把握のための宇宙線ミュオンを用いたリモートセンシングの技術開発を行った。これらの開発成果と共に技術的な課題も明確になってきており、成果と課題を踏まえて IRID が廃炉に向けた取り組みの状況を発表する。

（仮訳）

Radiation Tolerance of Components On The Shelf

Shinji Kawatsuma
Director, Demonstration Test Department
Naraha Remote Technology Development Center
Japan Atomic Energy Agency (JAEA), Naraha 979-0513, Japan
Email: kawatsuma.shinji@jaea.go.jp
Keyword(s):Component On The Shelf(COTS), Radiation Tolerance

Even before Fukushima Daiichi NPPs Accidents, Many kind of Nuclear Robots like as Bilateral Servo Manipulator (BSM) had been developed and deployed [1]. In the case of BSM developed from 1980's to 1990's, Digital Semiconductor devices like as processors had been moved from manipulator arm itself to lower radiation area. As for Analog Semiconductor Devices for detector, irradiation test had been conducted and the changes by irradiation had been obtained and circuits to compensate the changes had been developed for radiation hardening. Irradiation Test Results on organic materials and semiconductor device had been stored in Database [2].

After Fukushima daiichi NPP accidents, Unmanned heavy conduction Machines like as PakBOT or Quince had been considered to deploy, which had not been considered for radiation hardening, then the radiation tolerance estimation had become to be needed.

Rough Estimation was done based on the irradiation tests results data stored in the database (see Table).

Table Rough Estimation of Radiation Tolerance of Parts for Robots and Remote Devices

Cable	1M-100M Gy
Oil	-10KGy
Bipolar Transistor	10k Gy
Bipolar Op Amp	100k Gy
CPU	20-100 Gy
CCD	10-100 Gy

Tolerance of Semiconductors devices were critically lower than the one of organic materials like as cable or oil. The tolerance of Semiconductor like as processors were around several tens Gy and 20Gy at minimum. Unmanned Heavy Construction machines was estimated as much as same. Reconnaissance robots was considered to deployed in higher radiation, and smaller enough worker kick out, and then the management level of the reconnaissance robot was determined 30Gy. Quince robot was expected to be deployed under much higher radiation. The bulk of the semiconductors in the DB was Si, but the recent bulk of semiconductor was GaAs and the radiation tolerance was also expected higher, then the semiconductor devices were tested and estimated 150 Gy at minimum [3].

References

[1] "Comprehensive report on Bilateral servo manipulator", JNC, March, 1999,J NC-TN8440 2000-001

[2] Fukushima, Kawatsuma, et al, "Build and data storage for database on radiation Tolerance of components and materials", 1993/5, PNC TN8410 93-192

[3] https://roboticstaskforce.files.wordpress.com/2011/05/20110427-rcpt-radiation.pdf

市販半導体素子(COTS)の耐放射線性

川妻　伸二

モックアップ試験施設部　部長

楢葉遠隔技術開発センター

日本原子力研究開発機構

Email: kawatsuma.shinji@jaea.go.jp

キーワード:市販半導体、耐放射線性

福島第一原子力発電所事故の以前にもバイラテラルサーボマニピュレータ（BSM）[1]等多くのロボットが開発され、供されていた。1980 年代から 1990 年代に開発された BSM では、プロセッサー等の半導体はマニピュレータ本体から離して低放射線下に配置するとともに、検出器などに用いられるアナログ半導体は、照射試験で特性変化を把握し、その変化分を補償する回路を付加することで、耐放射線性の向上を図った。この際に行った有機物や半導体の照射試験結果をデータベースに格納していた[2]。

東京電力福島第一原子力発電所事故後、耐放射線性を考慮していない無人建設重機、PakBOT、Quince 等が投入されることになり、これらロボットの耐放射線性を評価する必要が生じた。

原子力機構が 1980-90 年代にデータベースとして纏めていた照射試験結果から､大まかな耐放射線性を評価した（Table 参照）。

Table Rough Estimation of Radiation Tolerance of Parts for Robots and Remote Devices

Cable	1M-100M Gy
Oil	-10KGy
Bipolar Transistor	10k Gy
Bipolar Op Amp	100k Gy
CPU	20-100 Gy
CCD	10-100 Gy

ケーブルやオイルなどの有機材の耐放射線性に比べて、半導体のそれは極めて低い。

CPU 等ロボット制御に必要な半導体は凡そ数十 Gy,最低値は 20Gy 程度であった。無人建設重機や偵察ロボットの耐放射線性も数十 Gy と判断されたが、無人建設重機の使用限界管理目標値は最低値である 20Gy が妥当と判断された。偵察ロボットのような小型のロボットについては、無人建設重機より高い放射線下で使用されること、万が一の場合は作業員が通路わきに蹴り寄せることも可能と考えられたことから、30Gy とした。QUINCE についてはより高線量下での使用が検討された。最近の半導体は 1980-90 年代の Si ではなく GaAs などを母材としており、これらの母材は Si よりも耐放射線性が高いことから､その耐放射線性は照射試験をして確認することとした。その結果 150Gy と判断し、使用限界管理目標値も 150Gy として、提案した[3]。

参考文献

[1] 核燃料サイクル開発機構東海事業所「両腕型サーボマニプレータの開発総括報告書(制御関連他)」，1999 年 3 月，JNC-TN8440 2000-001

[2] 福嶋，川妻等「耐放射線性機器・材料データベースの構築・整備」1993/5，PNC TN8410 93-192

[3] https://roboticstaskforce.files.wordpress.com/2011/05/20110427-rcpt-radiation.pdf

"Decommissioning Experiences at the USDOE Savannah River National Laboratory"

Kevin M. Kostelnik, Ph.D.
Savannah River National Laboratory
Director, Environmental Restoration Technology

The US Department of Energy (DOE), Office of Environmental Management (EM) mission is to complete the safe cleanup of the environmental legacy which resulted from five decades of government-sponsored nuclear energy research and nuclear weapons development. Significant progress has been made through its mission completion philosophy based on reducing risk and reducing environmental liability.

Savannah River National Laboratory (SRNL) is the applied research and development laboratory for the DOE Office of Environmental Management. Continued progress at all EM sites requires innovation and advanced technologies to achieve success and to accelerate cleanup. SRNL continues to execute its missions with an emphasis on deployable solutions – applying its capabilities to serve a variety of customers across the DOE Complex, as well as other US Federal agencies, international clients and collaborators and within the private sector.

SRNL, as the lead laboratory for research, development and technology demonstration within the DOE-EM program, has extensive experience in the nuclear facility deactivation and decommissioning (D&D) field, radioactive waste processing and disposition, nuclear material management, and contaminated soil and groundwater remediation.

This presentation will highlight SRNL experience with regard to the design, development, and implementation of strategies and technologies for the deactivation and decommissioning (D&D) of nuclear facilities. With an emphasis on matching effective and efficient solutions to site-specific conditions and stakeholder considerations, appropriate decommissioning end-states of nuclear facilities (i.e., demolition, partial demolition/partial grouting, in-situ decommissioning,) can be obtained through modeling, performance assessment for regulatory concurrence and comprehensive monitoring strategies.

Additionally, innovative techniques and on-going research and development efforts that will improve our understanding and prediction of the long-term structural, hydraulic, and chemical performance of materials and waste forms; as well as, various in-process characterization and remote sensing technology that improve worker safety and operational efficiency will also be discussed.

SRNL-MS-2016-00055

R2SRT 2016
International Workshop on:
Radiation Resistant Sensors and Related Technologies for Nuclear Power Plant Decommissioning

April 19-20, 2016.
Iwaki, Japan
****

Research, Development and Innovation in Instrumentation and Measurement for improved Core Safety, Performance and Control

Prof. Dr. Abdallah Lyoussi
CEA/DEN/CAD/DER
CEA Cadarache Research Center, France

Summary

Instrumentation and measurement methods in nuclear environments are key aspects that contribute to the quality of scientific and technological programs in the fields of physics, energy, nuclear fuel cycle, safeguards and radioactive waste management. Furthermore, measurements relying on nuclear physics now play an important role in various fields of application such as biology, medicine and environment [1].

For nuclear physics and technology side, nuclear power and/or experimental/research reactors are widely used around the world for various purposes, such as energy production, irradiation of material or fuel samples for present and future power reactors, safety studies, assessment of neutronic parameters (such as neutron absorption cross sections or reaction rates), production of artificial radio-elements, etc.

A sustainable nuclear energy requires research on fuel and material behaviour under irradiation with a high level of performances in order to meet following needs for the benefit of industry and public bodies:

- A constant improvement of the performances and safety of present and coming water cooled reactor technologies. Taking into account the lifetime extension and the progressive launch of generation III, nuclear power plants using water coolant will be in operation through the entire century. They will require a continuous R&D support following a long-term trend driven by the plant life management, safety demonstration, flexibility and economics improvement. Experimental irradiations of structure materials are necessary to anticipate these material behaviours and will contribute to the operation optimisation.
- Fuel technology in present and future nuclear power plants is continuously upgraded to achieve better performances and to optimise the fuel cycle, still keeping the best level of safety. Fuel evolution for generation II and III is and will stay a key stake requiring developments, qualification tests and safety experiments to ensure the competitiveness and safety: experimental tests exploring the full range of fuel behaviour determine fuel stability limits and safety margins, as a major input for the fuel reliability analysis.
- To meet nuclear energy sustainable development objectives in the resources and waste management, generation IV reactors are mandatory and require innovative materials and fuels which resist to high temperatures and/or fast neutron flux in different environments.

These environments will be needed for demonstrating the technical, economical and safety performances of these technologies.

To perform such accurate and innovative progress and developments, specific and ad-hoc instrumentation, irradiation devices, measurement methods are necessary to be set up inside or beside the Material Testing Reactor –MTR- reactor core. These experiments require beforehand in situ and on line sophisticated measurements to accurately determine parameters such as thermal and fast neutron fluxes and nuclear heating in order to precisely monitor and control the conducted assays [2] [3], [4].

The lecture will focus on radiation detection and measurement dealing with both power and experimental nuclear reactors (MTR). It will start by presenting the basics, physical principles, performances and limitations of the main nuclear radiation detectors used in the frame of nuclear reactor(s) measurement and monitoring [5], [6], [7] such as:

- gaseous detectors (fission chambers, proportional counters),
- scintillators and semi-conductors with neutron convertor materials/layers
- Self-Powered Neutron Detectors (SPND)
- Activation detectors/Dosimeters

These detectors are used for both direct and non-direct in-core and/or ex-core measurement.

After specific examples of using such detectors and instrumentation for reactor control and monitoring needs will be presented and discussed.

The EPRs neutron monitoring by specific measurement techniques will be treated and explained. As it will be seen, the EPRs core neutron instrumentation concept combines two complementary systems which perform different tasks; the Aero-ball Measuring System (AMS) and a monitoring system using a fixed in-core Self Powered Neutron Detectors (SPND) [8], [9]. The two systems are functionally linked by the process of calibration. The monitoring signals can be calibrated at regular intervals under reference conditions using the AMS results.

The new Material Testing Reactor JHR (Jules Horowitz Reactor) currently under construction at CEA Cadarache research centre in the south of France will represent a major Research Infrastructure for scientific studies regarding material and fuel behavior under irradiation. It will also be devoted to medical isotopes production. JHR will offer a real opportunity to perform R&D programs regarding needs above and hence will crucially contribute to the selection, optimization and qualification of these innovative materials and fuels.

To meet such aims accurate and innovative experiments, irradiation devices that contain material and fuel samples are necessary to be set up inside or beside the reactor core. These experiments require beforehand in situ and on line sophisticated measurements to accurately reach specific and determining conditions such as thermal and fast neutron fluxes and nuclear heating to precisely monitor and control the conducted assays.

Main JHRs experimental measurement devices, their aims and characteristics, associated innovative sensors will be presented. Furthermore a multipurpose measurement device and advanced analysis methodology based on combination of neutron detection (fast and thermal) and photon characterization by using innovative detectors associated to nuclear heating measurement carried out thanks to suitable and innovative calorimetric sensors (differential calorimeter, gamma thermometer).

Finally, radiation measurement in harsh media such in the nuclear reactor core needs to be:

- **Reliable**: (impossible or difficult maintenance on irradiated objects)

- **Accurate**: (to meet scientific requirements; e.g. µm dimensional measurements)
- **Miniature**: (narrow location: few mm available)
- **High temperature resistant**: (> 300°C, up to 1600°C)
- **Corrosion resistant**: (operation in pressurized water, high temperature gas, liquid metals…)
- **Neutron / γ "resistant"** (dose > 1GGy/d and > 10dpa/y in Material Testing Reactors)

To meet such requirements specific innovative detection systems have been developed and/or are under research and development. For selective neutron detection under high radiation (neutron and gamma) innovative works and developments have been carried out among which those linked to silicon carbide (SiC) neutron detector [10], [11]. Silicon carbide (SiC) semiconductor due to its high-temperature operation, high critical breakdown voltage, high thermal conductivity and its radiation resistance/hardening can be used to fabricate devices capable to operate under extreme and harsh conditions. Progress works, new developments and specific challenges will be also presented and discussed.

Conclusions and some identified perspectives will end the lecture.

References:

[1] "Advancements in Nuclear Instrumentation Measurement Methods and their Applications: ANIMMA" international scientific conference www.animma.com. 1st–4th edition proceedings: http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=6717173

[2] "JHR Project: a future Material Testing Reactor working as an International user Facility: The key-role of instrumentation in support to the development of modern experimental capacity" G. Bignan, C. Gonnier, A. Lyoussi, J-F. Villard, C. Destouches, JP Chauvin, B. Maugard. ANIMMA2015 international conference. Lisbon, April 20-24 2015.

[3] A. Lyoussi et al., Advanced methodology and instrumentation for accurate on line measurements of neutron, photon and nuclear heating parameters inside Jules Horowitz MTR Reactor, RRFM_IGORR 2012, Prague, Czech Republic, ISBN 978-92-95064-13-3, 2012.

[4] D. Fourmentel et al., Comparison of Thermal Neutron Flux Measured by Uranium 235 Fission Chamber and Rhodium Self-Powered Neutron Detector in MTR, IEEE, Transactions on Nuclear Science, Vol.61, Issue: 4, Part: 2, pp. 2285-2290, 2014.

[5] S.N. Ahmed "Physics & Engineering of Radiation Detection" Academic Press in an imprint of Elsevier, UK 2007.

[6] G.F. Knoll: Radiation Detection and Measurement", 4th Edition, John Willey and Sons 2010, ISBN 978-0-470-13148-0.

[7] A. Lyoussi "Détection de rayonnements et instrumentation nucléaire », EDP Sciences, ISBN : 978-2-7598-0018-6.

[8] Carsten Düweke, Nicloas Thillosen, Jörg Ziethe « Neutron Flux Incore Instrumentation of AREVA's EPR™ », 978-1-4244-5208-8/09, 2009 IEEE.

[9] A. Grün, W-H. Dio, "Core Instrumentation of SIEMENS/KWU Pressurized Water Reactor Nuclear Power Plants", Siemens Report, July 1998.

[10] F. Issa, V. Vervisch, L. Ottaviani, D. Szalkai, L. Vermeeren, A. Lyoussi, A. Kuznetsov, M. Lazar, A. Klix, O. Palais, and A. Hallen, IEEE Trans. Nucl. Sci. 61, 2105 (2014).

[11] V. Vervisch, F. Issa, S. Biondo, L. Ottaviani, W. Vervisch, D. Szalkai, L. Vermeeren, A. Klix, A. Hallen, A. Kuznetsov, M. Lazar, and A. Lyoussi, "Thermal neutron detection enhancement by ^{10}B implantation in silicon carbide sensor," *MRS Proc.*, vol. 1693, pp. mrss14–1693–dd03–09, Jul. 2014.

発表者：Prof. Dr. Abdallah Lyoussi（CEA/DEN/CAD/DER）

タイトル：改良炉心の安全性、パフォーマンス、および制御のための計装および測定における研究開発と改良

要旨：

原子力および実験/研究用原子炉は、核物理学と技術面で、様々な目的、例えばエネルギー生産、現在および将来の発電用原子炉用材料や燃料サンプル照射、安全性試験、中性子評価（中性子吸収断面積または反応速度）等、世界中で広く利用されている。

CEA カダラッシュ研究センターで現在建設中の新しい材料試験炉 JHR（ジュールホロビッツ炉）で試験されている新材料は、照射中の材料および燃料挙動に関する科学的研究のための主要研究基盤を示す。それは医療用同位体生産専用となる。JHR は、革新的な材料や燃料の選択、最適化、および技術取得に大きく貢献していく。

発表では、動力炉および実験炉（MTR）の両方に対応する放射線検出および測定に焦点を当てる。それは原子炉の測定および監視のフレームに使用される主な放射線検出器の基本的、物理的原理、性能および制限を提示する。

- ガス状の検出器（核分裂電離箱、比例計数器）
- 中性子コンバータ材料/層を有するシンチレータと半導体
- セルフパワー中性子検出器（SPEND）
- アクティベーション検出器/線量計

これらの検出器は、炉心及び炉心外の測定に、直接かつ間接の両方で使用される。

このような検出器や原子炉の制御と監視のニーズのための計装の具体的な使用例を提示し議論される。

炉心内のような過酷なメディアにおける放射線測定は、以下の要件を満たす必要がある。

･信頼性：(照射対象物の不可能または困難なメンテナンス)

･正確性：(科学的な条件を満たす、例えばμm 次元の寸法測定)

･小型：(狭所：数 mm で利用可能)

･耐温度性：(>300℃、最大 1600℃)

･耐腐食性：(加圧水、高温ガス、液体金属中での操作)

･中性子/γ 線 "耐性"（材料試験炉での使用　>1GGy/d および>10dpa/y）

このような条件を満たすための特定の革新的な検出システムは研究開発中である。高放射線（中性子とγ線）下での選択的な中性子検出のための革新的な製品開発は、シリコンカーバイド（SiC）中性子検出器に連結したものが実施されている。その高温動作、高臨界絶縁破壊電圧、高熱伝導性と耐放射線性/硬性のシリコンカーバイド（SiC）半導体は、極端な過酷条件下での動作が可能なデバイス製造に使用することが可能である。

（仮訳）

OECD NEA Activity in the Area of the Use of Robotic and Remote Systems in Radioactive Waste Management and Decommissioning

Vladimir Lebedev
Division of Radiological Protection and Radioactive Waste Management
OECD NEA, 46, quai Alphonso Galo, 92100 Boulogne-Billancourt, France
Email: Vladimir.lebedev@oecd.org
Keyword(s): Radiation resistant sensors, robotic systems, decommissioning, radioactive waste management, tasks and radiation levels

The use of remote semi- and fully-automated systems and semi-autonomous and autonomous robotic systems is considered a very important approach to improve the safety and health protection of personnel during active stages of the dismantling and decommissioning, and for the management of radioactive waste.

Operations that could be performed using the above mentioned systems can be conditionally divided into three categories: planned dismantling operations under normal conditions; post-accident dismantling of facilities under very-high radiation conditions; and remote handling and control during the stages of radioactive waste management.

The OECD NEA recognises the benefits of such systems, particularly in terms of worker safety. However, these systems take time to deploy, often require manual set-up, and often do not have the required flexibility for the performance of specific tasks. Review of implemented remote handling techniques in decommissioning, and identification of relevant lessons learned have been documented in the framework of the NEA Co-operative Programme on Decommissioning (CPD) [1]. Research and development needs in terms of robotic systems application were studied and presented in the NEA publication "R&D and Innovation Needs for Decommissioning Nuclear Facilities" [2].

The development of robotic systems was identified as a cross-cutting issue of relevance for each stage of decommissioning, as well as for radioactive waste management, especially management of HLW.

Research and development of approaches to increase the resistance of sensors and on-board robotic or remote control systems to high-level radioactivity is quite an important issue from the point of view of reliability, credibility and acceptable operational life for the sensors and for the entire system.

The NEA assists its member countries to most safely and effectively implement normal and post-accident decommissioning, and HLW management. The use of remote control and robotic tools is essential in all of these areas. The presentation will present the NEA's recent activity in the area of robotic systems implementation, and of potential future relevant activities.

References

1 "R&D and innovation needs for decommissioning nuclear facilities", OECD 2014, NEA No. 7191
2 "Remote handling techniques in decommissioning" a report of the NEA Co-operative Programme on decommissioning (CPD), NEA/RWM/R(2011)2, 2011

発表者：Vladimir Lebedev（OECD NEA）

タイトル：放射性廃棄物管理及びデコミへのロボット並びに遠隔システムの利用分野における OECD　NEA の活動

要旨：

半自動及び全自動遠隔操作システム並びに半自動並びに全自動ロボットシステムは解体とデコミ段階、また放射性廃棄物の管理段階における個人の安全と健康保護の改善のために非常に重要であると考えられている。
OECD NEA はそのようなシステムの利点を特に労働者の安全の観点から認識している。然しながら、このようなシステムは配置に時間がかかり、しばしばマニュアルによるセットアップを必要とし、特定の作業に対する性能に対し必要とされる柔軟性を持たない。デコミの分野でこれまで実施されてきた遠隔ハンドリング技術のレビュー、並びに NEA のデコミに対する共同プログラム（CPD）の枠の中で報告されてきた関連の知見を明確にする。ロボットシステムの開発がデコミ並びに放射性廃棄物の管理、特に HLW の管理において、各ステージに関連する横断的な課題として明らかにされる。センサーの耐久性を増すこと並びに高レベル放射能へのオンボードロボット技術或いは遠隔制御システムは、センサーと全体システムへの信頼性、信用性並びに許容できる操作寿命の観点で重要である。NEA はそのメンバー国に対し、通常並びに事故後のデコミ並びに HLW 管理に対して、最も安全で効果的な手段を与える。この報告ではロボットシステム領域における手段並びに関連する将来の活動における NEA の最近の活動が報告される。

（仮訳）

Silicon Carbide-based Thermal and Fast Neutron Detectors for Nuclear Reactor Monitoring

L. Ottaviani[*1], F. Issa[2], V. Vervisch[1], A. Klix[3], L. Vermeeren[4] and A. Lyoussi[5]
[1]IM2NP – UMR CNRS 7334, Aix-Marseille University, France
[2]European Spallation Source (ESS), Lund, Sweden
[3]KIT Institute of Neutron Physics and Reactor Technology, Germany
[4] SCK•CEN, Belgium
[3]INSTN, CEA Cadarache, France
*Email: laurent.ottaviani@im2np.fr
Keyword(s): Radiation resistant neutron sensors, Silicon Carbide, high temperature

Silicon carbide (SiC) is a wide band gap semiconductor which becomes an attractive material for the conception of nuclear detectors. Indeed, compared with classical semiconductors, SiC detectors appear to be very resistant to the radiation-induced damage.

In the framework of the European project "I-SMART" (Innovative Sensor for Material Ageing and Radiation Testing), we developed three types of thermal and fast neutron detectors, all based on ion implantation of ^{10}B as Neutron Converter Layer. The choice of Boron isotope 10 is explained by the relatively high thermal neutron cross section (3900 barns).

Mechanisms for detecting neutrons are based on indirect methods where neutrons interact with ^{10}B nucleus to produce charged particles (^{4}He and ^{7}Li nuclei). These charged particles lose energy in the detector and create a generation current of electron-hole pairs. In order to collect the electron-hole pair a p-n junction has been realized.

To validate devices, current-voltage measurements have been performed before and after irradiation.

The detectors have been tested under thermal neutron irradiations at room temperature in SCK•CEN facilities, and under fast neutron irradiations at high temperature in KIT facilities (see Fig. 1).

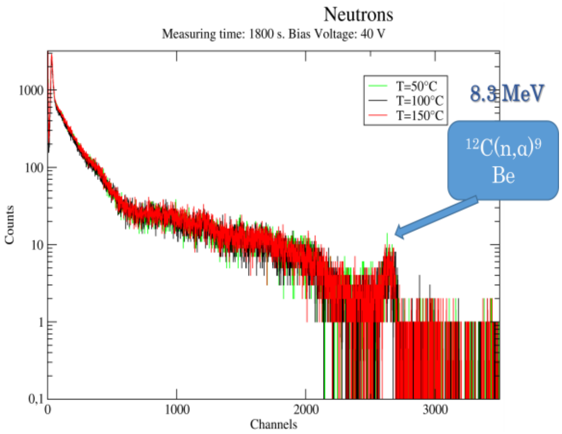


Fig.1 Fast neutron detection pulse height spectrum measured up to 150°C

Analyses reveal that SiC detectors, under irradiation and at elevated temperature, respond to neutrons showing consistent counting rates as function of external reverse bias voltages and radiation intensity. The counting-rate of the thermal neutron-induced peak increases with the area of the detector, and appears to be clearly linear with respect to the power of the nuclear reactor. The detection of fast neutrons is stable and reproducible up to 500°C.

4H-SiC MOSFETs and Logic Inverters for Radiation-Hardened Electronics

Shin-Ichiro Kuroki*[1], Hirofumi Nagatsuma[1], Tatsuya Kurose[1],Milantha De Silva[1], Seiji Ishikawa[1,2], Tomonori Maeda[1,2], Hiroshi Sezaki[1,2], Takamaro Kikkawa[1], Takahiro Makino[3], Takashi Ohshima[3], Mikael Östling[4], and Carl-Mikael Zetterling[4]

[1]Research Institute for Nanodevice and Bio Systems, Hiroshima University

[2]Phenitec Semiconductor Co.,Ltd, Japan

[3]National Institutes for Quantum and Radiological Science and Technology (QST), Japan

[4]KTH Royal Institute of Technology, Sweden

*Email: skuroki@hiroshima-u.ac.jp

Keyword(s): Radiation-Hardened Integrated Circuits, Silicon Carbide (SiC), MOSFETs

Introduction

Radiation-hardened and high-temperature electronics has been required for nuclear power plants. 4H-SiC with wide-bandgap energy is one of the candidate for base semiconductor for the harsh environment electronics. In this work, 4H-SiC nMOSFETs with As-doped S/D and NbNi silicide contacts were demonstrated in harsh environments of high gamma-ray radiation up to over 100 Mrad and high-temperature up to 450°C. For an integrated logic circuits, pseudo-CMOS and nMOS inverters were also demonstrated.

Experimental

A 4H-SiC epitaxial layer was deposited on a 4H-SiC n-type (0001) 4° substrate. A SiO2 hard-mask was fabricated on the epitaxial layer for dummy gate. After the hard mask formation, As ions were implanted into the sample at a temperature of 500°C. After the ion-implantation, a carbon-cap was deposited, and the sample was annealed at a temperature of 1800°C for activation of the S/D impurity. After the activation, gate oxide was formed at 1150°C. The oxide thicknesses were 10 and 20 nm. NbNi silicide was formed on the S/D region for ohmic contacts. After the silicidation, an Al gate metal was formed, and after deposition of SiO_2 layer, Al metal pads or wires were formed. Gamma-ray radiation on the simple nMOSFETs up to 113 Mrad was carried out in Co-60 Irradiation Facilities of QST.

Results and discussion

After the gamma-ray radiation of 113 Mrad on the nMOSFETs, the change of field effect mobility at the device with oxide thickness of 10 nm was within 8%, and that of oxide thickness 20 nm was 26%. The change of threshold voltage was 6%. This nMOSFETs was also demonstrated in a high temperature of 450°C. Figure 1 show the circuits diagram, microphotograph and Vin-Vout characteristic of 4H-SiC pseudo-CMOS inverters. By using the pseudo-CMOS, high swing voltage was achieved.

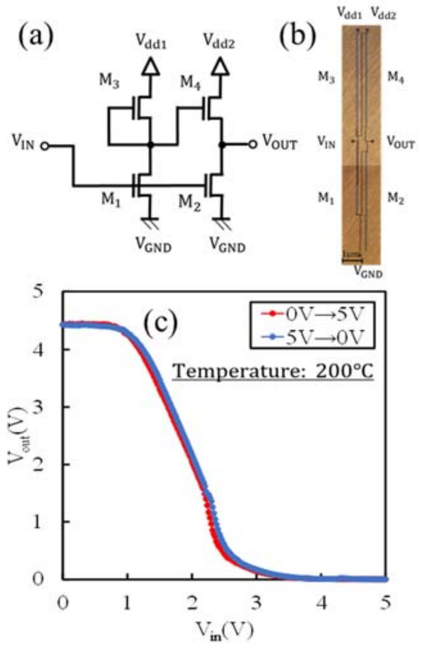


Fig. 1 4H-SiC pseudo-CMOS inverter: (a) circuit diagram, (b) micro-photograph, and (c) Vin-Vout curves.

References

[1] S. Kuroki *et al.*, ICSCRM2015, We-P-60 (2015).

[2] H. Nagatsuma *et al.*, Proceedings of RASEDA, Nov. 2015, Kiryu(Japan) p.117.

発表者：Shin-ichirou Kuroki（広島大学）

タイトル：耐放射線電子機器用 4H-SiC MOSFET 並びに論理変換器

要旨：
耐放射線並びに高温電子機器は原子力発電施設で必要とされる。広帯域エネルギーを持つ 4H-SiC は、厳しい環境用電子機器として、基本となる半導体のひとつである。この報告では、As-doped S/D 並びに NbNi 珪化物を圧着した 4H-SiC nMOSFETs が、100Mrad を超える高ガンマ線並びに 450℃を超える高温の厳しい環境での使用が検証された。集積論理回路としては、擬-CMOS 並びに nMOS インバータも検証された。

（仮訳）

Possibility for an image capturing of nuclear debris matters

Masafumi Kumano, Masayoshi Esashi and Shuji Tanaka

Tohoku University, Japan

*Email: kumano@mems.mech.tohoku.ac.jp

Keyword(s): Image capture, MEMS

Image capturing of debris matter in nuclear decommission process is important but difficult problem because of an extremely strong radiation condition of nuclear debris. Though the vacuum tube imager like “Chalnicon” can be used under relatively strong gamma ray irradiation condition, but compact solid state device is desired for on-the-site work. Conventional imaging device based on crystal Si, like CMOS or CCD cannot suffer from gamma ray radiation level of 10kGy/h, or 10MGy tolerance. Inherently radiation damage of the device is introduced by collision process between high energy gamma ray flux and bounded electrons around atoms of the material. Candidate of the imager materials and device is reviewed and possibility of imaging system under such high irradiation condition is discussed. Combination of the technologies like, ALD (atomic layer deposition), amorphous thin film semiconductor film , MEMS and Silicon carbide LSI will be effective .

At present, vacuum tube imager “Chalnicon” has been used in relatively strong radiation circumstances . The heart of the tube is thin layered amorphous chalcogenide compounds , CdSe ,$CdSeO_3$ and As_2S_3 , and read out method using scanning electron beam [1). During gamma ray penetration, multiple electrons is thought to be transmitted along with gamma ray path. The inserted wide band gap insulator film, CdSeO3, serves as a blocking layer for both of the read out electron beam, and the electron flux induced by gamma ray. In Chalnicon tube, read out scanning electron beam lies in vacuum and no radiation damage problem occurs with gamma ray which lead to long operation lifetime. Besides chalcogenides, amorphous silicon with variable bandgap component will be the other candidate of photo receptor material to be tested[3). On the way, extreme thin wideband gap blocking layer should be installed. For this purpose, new multi element ALD process can be applied [4).

Read out electronics will be realized by 4HSiC CMOS technology, which now ready to use for mixed signal LSI operated under the temperature range over 300℃[5) and shows potential use in high dose gamma ray condition[6). Because of the band mismatch between SiC and visible wavelength photon energy, 2d photo diode array chip should be separately connected on SiC CMOS chip. Interconnection and packaging technology for heterogeneous device integration has been developed in MEMS program at Tohoku University, where LTCC(Low temperature co-fired ceramics) process [7) will contribute to interconnection and rewiring problem of the imager.

References

[1] K.Shimizu *et al.*, IEEE Trans. ED-18,**11**(1971) p.1058
[2] F.Nava *et al.*, Nuclear Instruments and Methods in Physics Research A 505(2003) p.645
[3] K.Haga *et al.*, JJAP 25 (1986) p.L39
[4] M. Kumano *et al.*, Power MEMS (2010) p.230
[5] D.T.Clark *et al.*, Materials Science Forum Vols. 679 (2011) p.726
[6] T.Yokoseki *et al.*, Materials Science Forum Vols. 821(2015) p.705
[7] S.Tanaka *et al.*, IEEE MEMS 2012,Paris, France, p.369

*ALD and heterogeneous integration work in MEMS was supported by “Creation of Innovation Centers for Advanced Interdisciplinary Research Areas Program”

発表者：Masafumi Kumano(東北大学）

タイトル：燃料デブリ物質の撮像の可能性

要旨：
廃炉プロセスの過程で、デブリ物質のイメージ確認は重要であるが、燃料デブリの高放射線条件のために困難な課題である。”Chalnicon”のような真空管撮像は、比較的高いガンマ線照射条件で使うことができるが、オンサイト作業ではコンパクトな固体素子が望ましい。 CMOS や CCD のような Si の結晶は、10kGy/h の放射線場で 10Mgy までの耐久性に制約される。素子の損傷は、強いガンマ線と物質の原子核の周りの電子との衝突によって引き起こされる。撮像材料と素子の候補が検討され、そのような高放射線場における撮像システムが議論される。ALD(atomic layer deposition)、アモルファスな薄膜半導体フィルム、MEMS 並びに炭化ケイ素系 LST の組み合わせが有効であろう。

（仮訳）

Development of Super Radiation Resistant Metal-Oxide-Semiconductor Transistor Based on Silicon Carbide

T. Ohshima1*[1], T. Yokoseki[1,2], K. Murata[1,2], T. Matsuda[1,2], S. Mitomo[1,2], T. Makino[1], S. Onoda[1], Y. Hijikata[2], Y. Tanaka[3], M. Kandori[3], S. Okubo[3], and T. Yoshie[3]

[1]National Institutes for Quantum and Radiological Science and Technology (QST), Japan

[2]Saitama University, Japan

[3]Sanken Electric Co., Ltd., Japan

*Email: ohshima.takeshi@qst.go.jp

Keyword(s): Silicon carbide, Metal-Oxide-Semiconductor transistor, Gamma-ray irradiation

Introduction

For decommissioning of TEPCO Fukushima Dai-ichi nuclear reactors, it is necessary to develop electronic devices with super radiation resistance. Silicon carbide (SiC) is regarded as a promising candidate for not only power electronics with outstanding excellent characteristics but also high radiation tolerant electronics. Tanaka *et al.* reported that 4H-SiC Buried Gate Static Induction Transistors (BGSITs) could be operated up to 10 MGy [1]. Onoda *et al.* demonstrated 4H-SiC Metal-Semiconductor Field Effect Transistors (MESFETs) with radiation hardness of 10 MGy [2]. However, although high radiation resistance of SiC Metal-Oxide-Semiconductor Field Effect Transistors (MOSFETs) was demonstrated up to MGy order, radiation resistance of SiC MOSFETs up to 10 MGy has not yet been realized. In this paper, we study gamma-ray radiation response SiC power MOSFETs in high dose regions.

Experimental

Vertical structure power 4H-SiC MOSFETs were used in this study. The gate oxide was formed using dry oxidation and subsequent annealing in N_2O atmosphere. The MOSFETs were irradiated with gamma-rays from ^{60}Co in N_2 at room temperature (RT) or 150°C. The current-voltage (*I*–*V*) characteristics of the MOSFETs were measured in air at room temperature (RT).

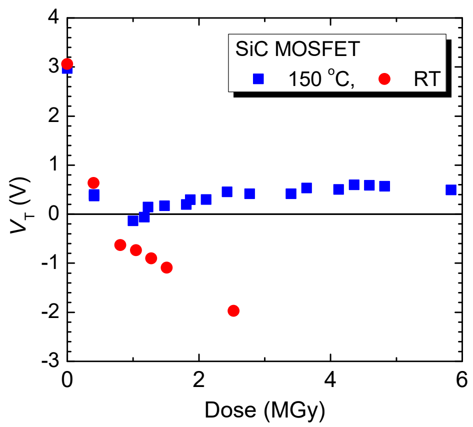


Fig. 1 V_T for SiC MOSFETs as a function of absorbed dose. Squares and circles indicate results obtained from MOSFETs irradiated at 150 °C and RT, respectively.

Results and discussion

The values of threshold voltage (V_T) as a function of gamma-ray absorbed dose are plotted in Fig. 1. The squares and circles indicate results obtained from SiC MOSFETs irradiated at 150°C and RT, respectively. The V_T for all MOSFETs decreases with increasing absorbed dose. However, the decrease in V_T for MOSFETs irradiated at 150°C saturates or slightly recover at doses above 1 MGy. On the other hand, V_T for MOSFETs irradiated at RT decreases with increasing absorbed dose.

References

[1] Y. Tanaka, S. Onoda, A. Takatsuka, T. Ohshima, T. Yatsuo, Mater. Sci. Forum **645-648** (2010) p.941.

[2] S. Onoda, N. Iwamoto, S. Ono, S. Katakami, M. Arai, K. Kawano, T. Ohshima, IEEE Trans Nucl. Sci. **56** (2009) p.3218.

炭化ケイ素を基板とした超耐放射線性金属－酸化膜－半導体トランジスタの開発

Development of Super Radiation Resistant Metal-Oxide-Semiconductor Transistor Based on Silicon Carbide

大島　武 [*1], 横関貴史 [1,2], 村田航一 [1,2], 松田拓磨 [1,2], 三友　啓 [1,2], 牧野高紘 [1], 小野田忍 [1], 土方泰斗 [2], 田中雄季 [3], 神取幹郎 [3], 大久保秀一 [3], 吉江　徹 [3]

[1]量子科学技術研究開発機構 (QST), 日本

[2]埼玉大学, 日本

[3]サンケン電気, 日本

*Email: ohshima.takeshi@qst.go.jp

キーワード: 炭化ケイ素, 金属－酸化膜－半導体トランジスタ, ガンマ線照射

はじめに

東京電力福島第一原発の廃止措置には、超耐放射線性の電子デバイスの開発が必要である。炭化ケイ素（SiC）半導体は非常に優れた特性を持つパワーエレクトロニクスの候補材料であるだけでなく優れた耐放射線性を有することが知られている。田中らは 4H-SiC Buried Gate Static Induction Transistors (BGSITs) が 10MGy までの照射を行っても動作することを報告している[1]。小野田らは 4H-SiC 金属－半導体電界効果トランジスタ (MESFETs)の 10MGy 耐性を実証している[2]。 しかし、SiC 金属－酸化膜－半導体電界効果トランジスタの MGy 級の耐放射線性は実証されているものの、10MGy 耐性はまだ実現していない。この研究では、SiC パワーMOSFET の高線領域までのガンマ線照射を調べた。

実験

本研究では縦型の 4H-SiC パワーMOSFET を用いた。ゲート酸化膜は乾燥酸素による酸化後に N_2O 雰囲気中での熱処理を行うことで形成した。MOSFET に窒素雰囲気中、室温または 150°C で ^{60}Co からのガンマ線照射を行った。電流－電圧特性は室温、大気中で行った。

結果及び考察

図 1 にしきい値電圧（V_T）のガンマ線照射量依存性を示す。■及び●印は、それぞれ、150°C 及び室温にてガンマ線照射を行った結果である。ガンマ線照射量の増加と共に V_Tの値が減少していることが分かる。しかし、150°C で照射したものの方は 1MGy 以上では低下しない又は若干回復している。一方、室温照射の場合は、ガンマ線量の増加と共に V_Tが低下している。

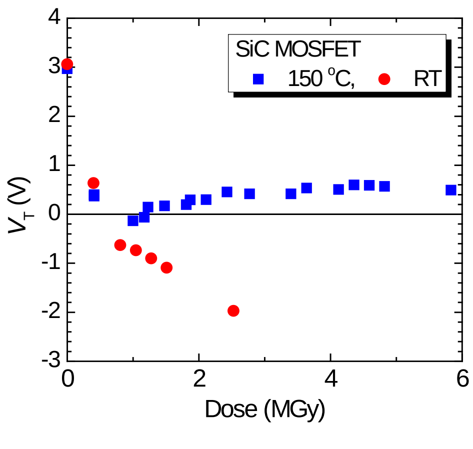


図 1 V_T のガンマ線量依存性
■及び●印は、それぞれ、150°C 及び室温にてガンマ線照射を行った結果。

参考文献

[1] Y. Tanaka, S. Onoda, A. Takatsuka, T. Ohshima, T. Yatsuo, Mater. Sci. Forum **645-648** (2010) p.941.

[2] S. Onoda, N. Iwamoto, S. Ono, S. Katakami, M. Arai, K. Kawano, T. Ohshima, IEEE Trans Nucl. Sci. **56** (2009) p.3218.

Application of Spintronics to Nuclear Technology

Sadamichi Maekawa
Advanced Science Research Center (ASRC)
Japan Atomic Energy Agency (JAEA), Tokai 319-1195, Japan
Email: maekawa.sadamichi@jaea.go.jp

Keyword(s): Spintronics, Thermoelectronics, Radiation resistant sensors

Spintronics [1], i.e., spin based electronics is a radiation-resistant electronics. Instead of the usual semiconductor-based electronics, spintronics utilizes magnets as basic materials. It has already been installed in aircrafts, which is free from cosmic rays.

It is also expected to work in areas with strong radiation.

Spintronics has a potential application for the energy harvesting technology from waste heat. Here, instead of the usual thermo-electrics based on semiconductors which is called Seebeck effect, spin current [2], i.e., flow of spin, is used for heat transport. This is called spin Seebeck effect [3]. We develop the spin Seebeck devices and its application to the nuclear waste together with Tohoku University and NEC, supported by Japan Agency of Science and Technology (JST).

I will present the recent progress in the spin Seebeck effect.

References

[1] S. Maekawa ed., "Spin Electronics"
(Oxford University Press, 2006).
[2] S. Maekawa, H. Adachi, K. Uchida, J. Ieda, and E. Saitoh,
J. Phys. Soc. Jpn. 82, 102002(1-23) (2013).
[3] S. Maekawa et al., eds. "Spin Current"
(Oxford University Press, 2012).

発表者：前川　禎通

タイトル：スピントロにクスの原子力への応用

要旨：

電子スピンに基礎を置くスピントロにクスは、放射線に強いエレクトロニクスとして知られている。従来の半導体を基礎としたエレクトロニクスとは違い、スピントロニクスでは基本材料は磁石である。すでに、耐宇宙線用のデバイスとして航空機や人工衛星等に搭載されており、さらに強い放射線の存在する場所での使用も期待されている。
スピントロにクスはその応用として、廃熱からの発電への可能性も持ってる。スピンの流れ（スピン流）を熱輸送に用いた発電（スピンゼーベック効果）は、従来の半導体を用いた熱電発電（ゼーベック効果）とは違い、スピントロにクスの発展版である。我々は、科学技術振興機構 (JST)の援助を受けて、東北大学及び NEC とともに、スピンゼーベック効果を用いて核廃棄物から発電を行う技術の開発を進めている。
スピンゼーベック効果とその応用に関する最近の進展を示す。

Advanced CMOS Image Sensors Development for High Sensitivity, High Speed and Wide Spectral Response

Rihito Kuroda and Shigetoshi Sugawa
Graduate School of Engineering, Tohoku University
6-6-11 Aza Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan
Email: rihito.kuroda.e3@tohoku.ac.jp
Keyword(s): CMOS image sensor, Photon countable sensitivity, Ultra-high speed, UV-Visible-NIR spectral response

Among various kinds of sensors that capture physical quantities in nature to convert them to electrical signals, image sensors are to be the key device in sensor network systems due to the vast amount of information obtained from imaging. Image sensors are utilized not only in the field of photography using digital cameras and smartphone cameras but also in various application fields such as measuring instrument, automotive, life science and medical analyses, disaster and crime preventions, remote sensing and control, agriculture, material science and so on. Demands for image sensors with sensing capability greater than human eyes are increasing more and more, that includes extremely low light level imaging, ultra-high speed imaging and multi spectral imaging.

In this presentation, brief overview CMOS image sensors that have become to be widely employed in both consumer and scientific applications, and the progress of performances are described. And the research and developments of advanced CMOS image sensors at Tohoku University are introduced, which include technologies to achieve photon-countable sensitivity with wide dynamic range of 100 dB in single exposure [1], ultra-high speed imaging over 10 million frames per second [2-3], and wide spectral response image sensor technology covering ultraviolet (UV)-visible-near infrared (NIR) light waveband with high stability to UV irradiation [4-5].

References

[1] S. Wakashima, F. Kusuhara, R. Kuroda and S. Sugawa, “A Linear Response Single Exposure CMOS Image Sensor with 0.5e- Readout Noise and 76ke- Full Well Capacity”, 2015 Symp. VLSI Circ., Tech. Dig., C88-89 (2015).
[2] Y. Tochigi, K. Hanzawa, Y. Kato, R. Kuroda, H. Mutoh, R. Hirose, H. Tominaga, K. Takubo, Y. Kondo and S. Sugawa “A Global-Shutter CMOS Image Sensor with Readout Speed of 1-Tpixel/s Burst and 780-Mpixel/s Continuous”, IEEE J. Solid-State Circuits, 48, 329-338 (2013).
[3] R. Kuroda, Y. Tochigi, K. Miyauchi, T. Takeda, H. Sugo, F. Shao and S. Sugawa, “A 20Mfps Global Shutter CMOS Image Sensor with Improved Light Sensitivity and Power Consumption Performances”, ITE Transactions on Media Technology and Applications, 4, 149-154 (2016).
[4] R. Kuroda and S. Sugawa, “Si image sensors with wide spectral response and high robustness to ultraviolet light exposure”, IEICE Electronics Express, 11, 20142004-1-16 (2014).
[5] S. Nasuno, S. Wakashima, F. Kusuhara, R. Kuroda, S. Sugawa, “A CMOS Image Sensor with 240 $\mu V/e^-$ Conversion Gain, 200 ke^- Full Well Capacity, 190-1000 nm Spectral Response and High Robustness to UV light”, ITE Transactions on Media Technology and Applications, 4, 116-122 (2016).

発表者：黒田理人、須川成利　東北大学大学院　工学研究科

タイトル：高感度化・高速化・広光波長帯域化の高機能 CMOS イメージセンサ開発

要旨：
各種センサの中で、イメージセンサは、映像から膨大な量の情報を得られることから、センサネットワークシステムのキーデバイスとなっている。イメージセンサは、デジタルカメラやスマートフォンなど写真の分野だけでなく、計測器、自動車、生命科学や医療分析、災害や防犯、リモートセンシングやリモートコントロール、農業、物質科学など、さまざまな応用分野で利用されており、高機能イメージセンサへの需要はますます増加している。

本発表では、一般消費者と科学用の両方のアプリケーションに広く採用されている CMOS イメージセンサの概要と機能の進捗について説明する。また、東北大学で研究開発が行われている高機能 CMOS イメージセンサについて、高感度化・高速化・広光波長帯域化に向けた技術の取り組みを紹介する。

（仮訳）

High Radiation Resistant Visualization Technologies using Silica Based Glass Imagefiber

Tomoaki Toriya*, Yutaka Endo, Katsuaki Izoe, and Manabu Kudo
Fujikura Ltd., Japan
*Email: tomoaki.toriya@jp.fujikura.com

Keyword(s): Radiation resistant imagefiber, High-OH silica, Fluorine-doped silica, Hydrogen loading

Introduction

Fujikura has been developing and providing radiation resistant fiber scope based on silica glass fiber technology. High-OH content silica glass core fiber is well known to perform a good optical transmission against radiation. However, durability of image observation is limited due to radiation-induced absorption. This paper describes our recent results of improvement in radiation durability of silica glass imagefiber by adopting fluorine-doped core and hydrogen loading technique. The sample fiber has been evaluated in image quality and transmission efficiency. The experimental results show that hydrogen behaves to inhibit optical absorption and works effectively for several months.

Experimental

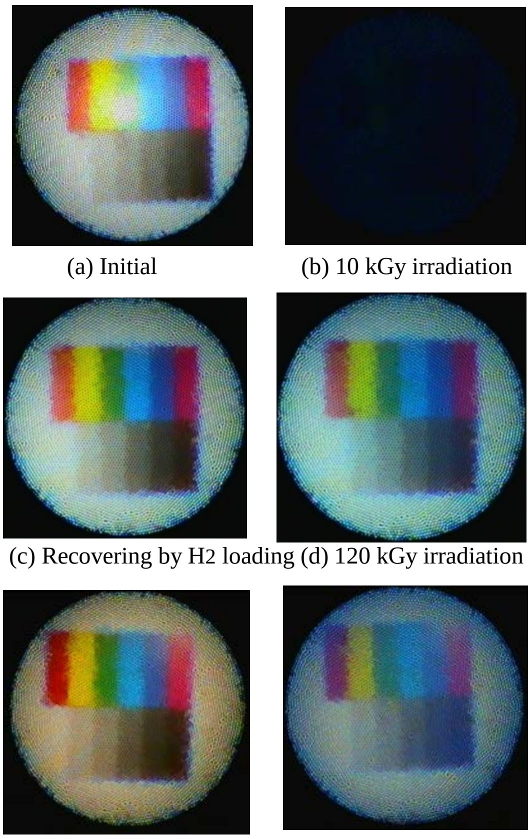
The sample imagefiber was made of fluorine-doped silica glass core with 6,000 pixel. This material has better radiation resistance than high-OH silica core. The fiber length was 100 m long. Middle 20 m of 100 m was irradiated to Co-60 gamma-ray. The test was conducted in three steps. Firstly, the sample was irradiated to 2 MGy in 10 kGy/hr. After the test, it was loaded hydrogen and irradiated again to 120 kGy in 5 kGy/hr in order to assess the recovery effect of absorption loss. Finally, the sample was irradiated to additional 180 kGy in 10 kGy/hr after 6 months for evaluating the persistence of the hydrogen effect.

Results and discussion

At the first test of high dose rate 10 kGy/hr, absorption in visible range increased immediately and image was darkened in a few minutes.(Fig.1(a),(b)) It indicates that fluorine doping has limited effect against high-dose rate.

In the next test, the effect of recovery by hydrogen was confirmed against re-irradiation.(Fig1.(c),(d))

Finally, at the persistence test, it was proven that hydrogen loading effect persisted for 6 months. (Fig1.(e),(f)) It indicates that fluorine-doped silica core with hydrogen loading has a remarkable potential to provide high radiation resistant visualization tool.



(a) Initial (b) 10 kGy irradiation
(c) Recovering by H_2 loading (d) 120 kGy irradiation
(e) After 6months (f) 180 kGy irradiation

Fig. 1 Transmission image of F-doped silica core imagefiber

発表者：Tomoaki Toriya（フジクラ）

タイトル：石英基材ガラスイメージファイバーを用いた高耐放射線可視化技術

要旨：

フジクラでは石英ガラスファイバー技術に基づく耐放性のファイバースコープの開発を行ってきた。高-OH 含有石英ガラス芯ファイバーは、放射線に対して良好な光学的透過性を持つ。然しながら、イメージ観測の耐久性は放射線-誘起吸収により制約されてくる。この論文では、フッ化物注入芯と水素装荷技術の適用による、石英ガラスイメージファイバーの耐放性改良技術の最近の結果が報告される。サンプルのファイバーは、イメージの品質と透過効率で評価された。試験結果から、水素は光学的吸収を抑制し、数ケ月に亘り効果があることが示された。

（仮訳）

Photonics Approaches for Plant Decommissioning

Yoshihiro Takiguchi[*1, 2], Akira Kobayashi[1], Kazuhisa Fujita[2, 3] Sin-ichiro Okihara[2,],
Kazuaki Toyosawa[3], Nobumitsu Maebashi[3], Kazuhiro Takahara[3], Tetsuaki Akiyoshi[3]
Takahiro Makino[4], Takeshi Ohshima[4] and Hiroshi Abe[4]
[1]Hamamatsu Photonics K.K., Japan
[2]The Graduate School for the Creation of New Photonics Industries, Japan
[3]Toyokoh, Japan
[4]National Institutes for Quantum and Radiation Science and Technology, Japan
*Email: taki@crl.hpk.co.jp
Keyword(s): CdSe Imaging device, Laser Cleaning, Si PD sensors

Introduction

For a nuclear power plant decommissioning process, there are so many photonics related systems to be adopted to make the process faster and easier. The Photonics technologies include optical imaging devices working under a high radiation dose condition, laser cleaning system, laser cutting systems and other radiation monitoring systems. The imaging or monitoring devices are required to operate under 10kGy/h of radiation doses and 2MGy of total accumulated doses for Fukushima plant decommissioning process. In this talk, we will present current situations for these device and systems.

Experimental

There are two experimental approaches for imaging device and other sensor elements carried out at Takasaki Quantum Application Laboratory. Fist one is for imaging device using CdSe photoconductive layer in vacuum tube. We have conducted an imaging experiment with various radiation dose conditions to find out its potential of applicability to Fukushima 1st reactor decommissioning. We found the device could stand for imaging higher than 2kGy/h of radiation field. Second one is for Si photodiode experiment. We have irradiated Si PD, LEDs, electronics parts and optical glass plates under 2k to 10kGy/h radiation conditions at Co-60 Gamma-ray Irradiation Facilities of Department of Advanced Radiation Technology at Takasaki. We found that Si PDs were operated for more than 2 months under 2kGy/h of radiation. Finally, we will present a new laser cleaning system to treat surface of plants for removing radioactive layers. It has efficient collection function of the removed powder-like materials from the surface for safe decommissioning process.

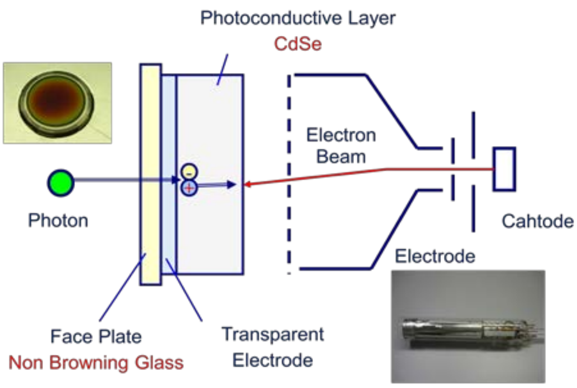


Fig. 1 Imaging Tube under radiation irradiation

Results and discussion

We are still working toward realistic system design for Fukushima plant decommissioning with various photonics technologies. It is not easy to operate those photonic systems under such hard irradiation conditions. However, it is our task to realize those systems by the time we starts the decommissioning in few years. If you have any queries, please contact taki@crl.hpk.co.jp.

Development of onsite/in-situ, rapid and radio-resistance remote analysis by optical fiber based laser induced breakdown spectroscopy

Ikuo Wakaida*1, Hironori Ohba1, Katsuaki Akaoka1, Masabumi Miyabe1, Morihisa Saeki1, Masaki Oba1, Chikara Ito1, Masaaki Kato1

1Japan Atomic Energy Agency (JAEA), Japan
*Email: wakaida.ikuo@jaea.go.jp

Keywords: Radiation resistant optical fiber, Laser induced breakdown spectroscopy (LIBS), Remote elemental analysis, Onsite/in-situ analysis

Introduction

For the decommissioning of “Fukushima Daiich Nuclear Power Station” which contained damaged or melt downed core, development of rapid, easy, onsite and in-situ remote diagnostic/analysis techniques under the severe environments such as extremely high radioactive condition, will be strongly required. In order to accomplish these requirements, the concept of probing by light and diagnostic by light with radiation resistant optical fiber will be one of the simple, powerful and applicable choices without sensor hardening technique (Fig.1).

Optical Fiber based LIBS probe is constructed, and we have successfully observed some specific spectra from the simulated sample of molten debris made by sintered oxide of Zr and U under water condition, and also observed the spectrum from simulated metal sample under radioactive condition of 10kGy/h and after total dose of 2MGy..

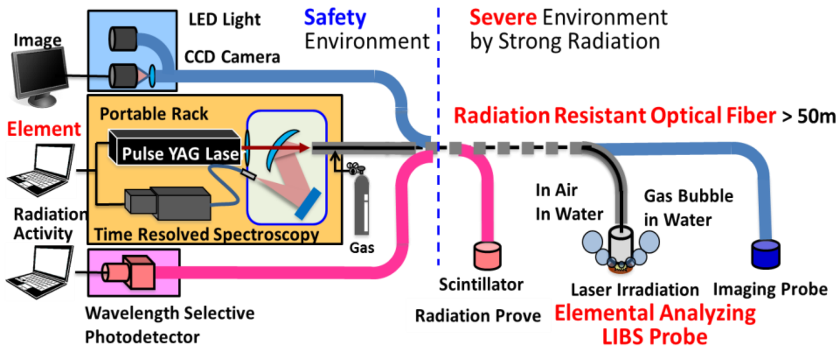


Fig.1 Concept of radiation resistant optical fiber based remote analysis

Experimental and Results

To simplify the portable LIBS system[1], the laser beam (Commercial Nd:YAG fundamental 1064 nm) is delivered with the optical fiber and focused onto the sample, and the plasma emission is collected by the same focus lens and delivered through the same optical fiber. Echelle type wide range and high resolution spectrometer is used for time resolved spectroscopy.

Gamma ray irradiation test was performed in ^{60}Co irradiation facility under high radiative condition of 10kGy/h and total dose of over 2MGy. In this experiment, the portable LIBS system was set in the safety area, and optical fiber was set under the strong Gamma ray field. The spectrum was compared before and after irradiation as shown in Fig.2. The result suggests no damage with laser delivery and no signal attenuation in the near infrared region.

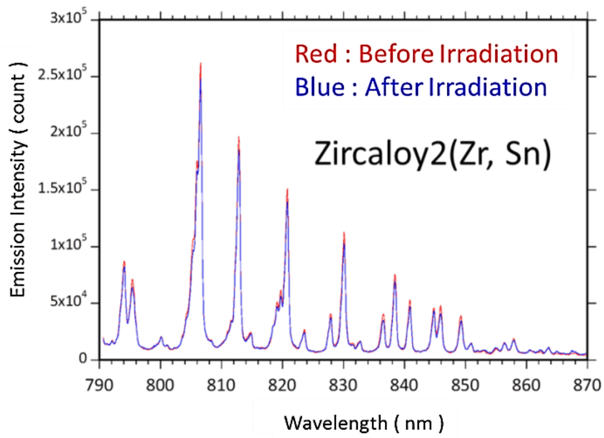


Fig.2 Spectrum before and after irradiation

References

[1] M. Saeki, *et al.*, J Nucl Sci Tech, **51** (2014) 930-938

光ファイバを用いたレーザー誘起発光分光法による その場、迅速、耐放射線性遠隔分析手法の開発

若井田育夫[*1], 大場弘則[1], 赤岡克明[1], 宮部昌文[1],
佐伯盛久[1], 大場正規[1], 伊藤主税[1], 加藤政明[1]

[1] 日本原子力研究開発機構 (JAEA), 日本
*Email: wakaida.ikuo@jaea.go.jp

キーワード：耐放射線性光ファイバ、レーザー誘起発光分光法 (LIBS),
遠隔組成分析、その場分析

はじめに

炉心溶融を起こした福島第一原子力発電所の廃止措置においては、極めて高い放射線場における溶融物等の迅速簡便なその場遠隔組成分析手法の開発が求められている。耐放射線性光ファイバを活用し、光を使って光で診断する手法は、センサーの耐放射線技術を使うことなく実現可能な有力な候補の一つと考えられる（図１）。

耐放射線性光ファイバを用いたLIBSプローブを試作し、ウラン、ジルコニウム酸化物を焼結した模擬デブリの水中分析試験に適用した結果、各元素特有のスペクトル観測に成功した。また、10kGy/h の線量率環境で累積量2MGy の環境においても、金属模擬試料のスペクトル計測が可能であることも確認した。

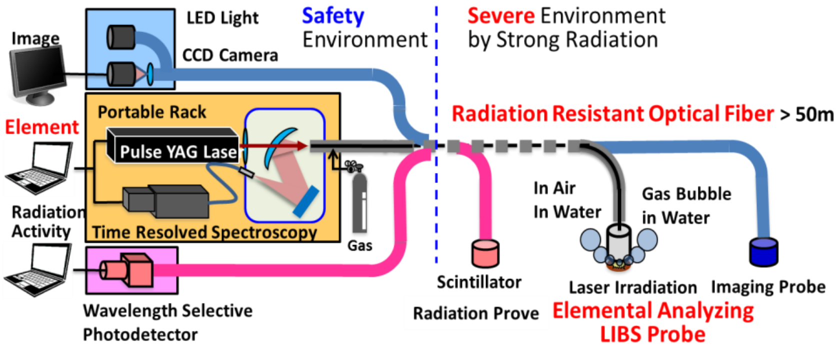


図１　耐放射線性光ファイバを活用した遠隔診断プローブの概念

実験装置と結果

可搬型 LIBS 装置を簡略化するため、レーザー光（市販 Nd:YAG レーザー基本波 1064 nm)を光ファイバで伝送し、レンズで集光照射することで試料をプラズマ化するとともに、生成されたプラズマ発光も、同一の光ファイバを用いて搬送した。搬送されたプラズマ発光を、エシェル型の広帯域高分解能分光器により時間分解分光することで元素スペクトルを取得し、試料の組成を評価した。

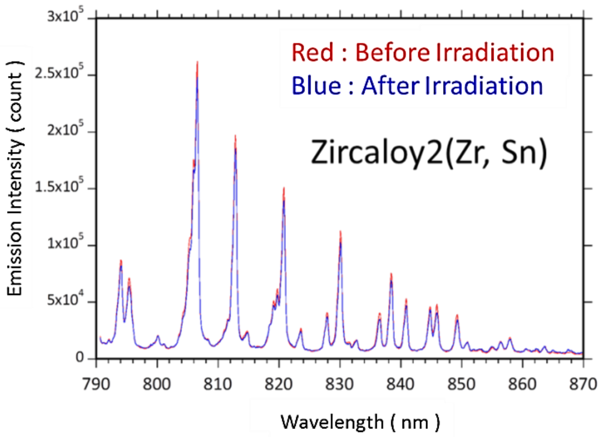


図２　ガンマ線照射前後のスペクトル比較

ガンマ線照射試験は、^{60}Co 照射施設で実施し、線量率 10kGy/h、累積線量 2MGy 以上とした。この試験では、可搬型 LIBS 装置や試料はガンマ線の影響の無い安全な領域に設置し、光ファイバ部分のみをガンマ線の強い領域に設置した。ガンマ線照射前と照射後のスペクトル取得状況を比較した結果を図２に示す。ガンマ線照射環境においてもレーザー光を光ファイバで搬送可能なこと、近赤外波長領域では、スペクトル計測でガンマ線の影響が見られないことが確認できた。

参考文献

[1] M. Saeki, *et al.*, J Nucl Sci Tech, **51** (2014) 930-938