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RNBS

RESEARCH INSTITUTE FOR NANODEVICE AND BIO SYSTEMS
HIROSHIMA UNIVERSITY

広島大学 ナノデバイス・バイオ融合科学研究所

Preface

The Research Institute for Nanodevice and Bio Systems (RNBS) was founded on May 1, 2008 with the faculty members of the Department of Semiconductor Electronics and Integration Science and the Department of Molecular Biotechnology at the Graduate School of Advanced Sciences of Matter as well as the Graduate School of Biomedical Sciences. RNBS consists of four research divisions; (1) Nanointegration Research Division, (2) Integrated Systems Research Division, (3) Molecular Bioinformation Research Division, and (4) Nanomedicine Research Division.

The forerunner of this institute was The Research Center for Integrated Systems (RCIS) which was founded in 1986 as a ministerial ordinance. The center was reorganized 10 years later and The Research Center for Nanodevices and Systems (RCNS) was established in May, 1996.

It has been 34 years since the first RCIS was established by the first Director Dr. Masataka Hirose, Emeritus Advisor of National Institute of Advanced Industrial Science and Technology, Professor Emeritus of Hiroshima University. We also would like to thank the first Associate Director, Prof. Mitsumasa Koyanagi, Tohoku University, and Dr. Yasuhiro Horiike, Fellow Emeritus, National Institute for Materials Science, specially appointed Professor of University of Tsukuba.

The research at RNBS has been focused on silicon integrated circuits, devices, processes and materials so that the significant research results have been achieved as one of the prominent research institute among the national universities. The RNBS plays important roles not only as a research laboratory but also as an education institute, where graduate students and under graduate students as well as postdoctoral researchers have been studying on the most advanced leading-edge technologies to become independent leading researchers who conduct their researches by themselves in future semiconductor industries. The reputations of the graduates from the RNBS have been extremely high in the semiconductor industries.

The RNBS has achieved numerous projects supported by Japanese and local governments such as Nanotechnology Platform, Ministry of Education, Culture, Sports, Science and Technology, Strategic Basic Research Programs (CREST), Development of Systems and Technology for Advanced Measurement and Analysis, Japan Agency for Medical Research and Development (AMED), Grant-in-Aid for Scientific Research (A) by the Japan Society for the Promotion of Science (JSPS). The RNBS has also been selected as one of the members of the National University Research Institute and Research Center Council.
In April 2016, the Research Center of Biomedical Engineering (RCBE) was established in collaboration with the Institute of Biomaterials and Bioengineering at Tokyo Medical and Dental University, the Laboratory for Future Interdisciplinary Research of Science and Technology at Tokyo Institute of Technology, the Research Center for Nanodevice and Bio Systems at Hiroshima University, and the Research Institute of Electronics at Shizuoka University, with the support of the Minister of Education, Culture, Sports, Science and Technology (MEXT), Japan, The RCBE aims at promoting innovative researches in the field of biomedical engineering with strong network of these four institutes.

This annual report offers comprehensive information about the recent research activities and achievements at the RNBS to those who are engaged in the fields of advanced technologies. We hope this report will contribute to the mutual exchange of ideas and future progress of the researches on advanced integration of nanodevice and bio systems.

December 1, 2020

Seiichiro Higashi
Director
Research Institute for Nanodevice and Bio Systems
Hiroshima University, Japan

巻頭言

広島大学ナノデバイス・バイオ融合科学研究所は2008年5月1日に大学院先端物質科学研究科半導体集積科学専攻の研究グループと分子生命機能科学専攻の研究グループおよび大学院医歯薬学総合研究科、歯学部の研究グループの協力を得て学内措置で設立されました。これまでの半導体研究の実績に加えて、医学・医療との融合をめざした基盤技術の研究を推進するため、研究領域はナノ集積科学、集積システム科学、分子生命情報科学、集積医科学の4つからなっています。

本研究所の前身は文部科学省の省令センターとして1986年に設立された集積化システム研究センターです。1996年5月にはナノデバイス・システム研究センターが新たな省令センターとして改組設立されました。 最初のセンター設立から22年目に本研究所を設立いたしました。

30年以上の実績を有するセンターは初代センター長の廣瀬全孝先生(現産業技術総合研究所研究顧問、広島大学名誉教授)をリーダーに、初代センター主任の小柳光正先生（元広島大学教授、現東北大学客員教授）、クリーンルーム立ち上げにご尽力いただいた堀池靖浩先生（元広島大学教授、現物質材料研究機構名誉フェロー、筑波大学数理物質系特命教授）をはじめとする諸先輩の努力の賜です。

広島大学ナノデバイス・バイオ融合科学研究所は我が国の大学の中でもユニークな存在です。30年間一貫して、シリコン集積回路、デバイス、プロセス、材料の研究を続けており、この分野では国内でも有数の研究機関としてその研究成果を着実にあげてきました。さらに、我が国の半導体産業の将来を担う、学部学生、大学院生、博士研究員らの人材育成にも力を入れてきました。最先端技術の研究を通して、世界に発信できる研究者を育成すべく、学生、研究員が自ら研究を企画し、自立して研究開発を進める能力を持つことができるよう教育指導しており、その実績は産業界から高く評価されております。

これまでの研究実績として、文部科学省ナノテクノロジープラットフォーム、戦略的創造研究推進事業(CREST)、日本医療研究開発機構(AMED)医療分野研究成果展開事業、科学研究費助成基盤研究費(A)などの大型プロジェクトに採択されて、研究を加速推進しております。
ナノデバイス・バイオ融合科学研究所は，2016 年 4 月に、文部科学大臣から全国共同利用・共同研究拠点「生体医歯工学共同研究拠点」の認定（2016-2021 年度）を受け、東京医科歯科大学生体材料工学研究所、東京工業大未来産業技術研究所、静岡大学電子工学研究所とともに共同研究ネットワークを構築して、本研究所の強み・特色であるナノバイオ・メディカル・エレクトロニクス分野における革新的医療技術創出の拠点を構築します。

アニュアルリサーチレポートはナノデバイス・バイオ融合科学研究所の最近1年間の研究活動と研究成果の一端をまとめて、先端技術の研究・教育に携わる方々に最新情報を共有していただくために発行しています。このレポートが今後ともこの分野での研究交流の一助になれば幸いです。

2020年12月1日

広島大学
ナノデバイス・バイオ融合科学研究所
所長　　　　　東　清一郎

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Executive Committee
運営委員会

Director
所長

Adviser
顧問

Nanointegration Research Division
ナノ集積科学研究部門

7 Professors, 1 Special Appointment Professor, 4 Visiting Professors,
2 Associate Professors,1 Special Appointment Associate Professor,
1 Visiting Associate Professor, 2 Assistant Professors,
2 Special Appointment Assistant Professors
教授 7名（専任: 2, 併任: 5）, 特任教授 1名, 客員教授 4名,
准教授 2名（専任: 1, 併任: 1）, 特任准教授 1名, 客員准教授 1名,
助教 2名（併任）, 特任助教 2名

Integrated Systems Research Division
集積システム科学研究部門

3 Professors, 2 Visiting Professors, 4 Associate Professors,
教授 3名（併任: 3）, 客員教授 2名, 准教授 4名（専任: 1, 併任: 3）

Molecular Bioinformation Research Division
分子生命情報科学研究部門

3 Professors, 4 Visiting Professors, 1 Assistant Professor
教授 3名（専任: 1, 併任: 2）, 客員教授 4名, 助教 1名（併任）

Nanomedicine Research Division
集積医科学研究部門

5 Professors, 1 Assistant Professor
教授 5名（併任）, 助教 1名（併任）

Nanotechnology Platform
ナノテクノロジー・プラットフォーム

1 professor, 1 Special Appointment Associate Professor
教授 1名（専任）, 特任准教授 1名

Cooperative Research Staff (Faculty Members)
研究員（学内）、関連学部・学科

Visiting Scientists (Universities, Industries)
客員研究員（他大学、企業）

2. Staff of Research Institute for Nanodevice and Bio Systems (RNBS)

ナノデバイス・バイオ融合科学研究所構成員（2019年12月1日時点）

Nanointegration Research Division

ナノ集積科学研究部門

Seiichiro Higashi 東　清一郎	Director of RNBS and Professor 研究所長，教授（併任）
Shin-Ichiro Kuroki 黒木　伸一郎	Associate Director and Professor 副研究所長，教授
Akinobu Teramoto 寺本　章伸	Professor 教授
Takamaro Kikkawa 吉川　公麿	Professor (Special Appointment) 特任教授
Yutaka Kadoya 角屋　豊	Professor 教授（併任）
Atsushi Ikeda 池田　篤志	Professor 教授（併任）
Yoshitake Takane 高根　美武	Professor 教授（併任）
Manabu Shimada 島田　学	Professor 教授（併任）
Anri Nakajima 中島　安理	Associate Professor 准教授
Shuhei Amakawa 天川　修平	Associate Professor 准教授（併任）
Tetsuo Tabei 田部井　哲夫	Associate Professor (Special Appointment) 特任准教授
Hiroaki Hanafusa 花房　宏明	Assistant Professor 助教（併任）
Yuri Mizukawa 水川　友里	Assistant Professor 助教（併任）

Tomomi Ishikawa 石川　智己	Assistant Professor (Special Appointment) 特任助教
Yoshiteru Amemiya 雨宮　嘉照	Assistant Professor (Special Appointment) 特任助教

Integrated Systems Research Division

集積システム科学研究部門

Minoru Fujishima 藤島　実	Professor 教授（併任）
Idaku Ishii 石井　抱	Professor 教授（併任）
Kazufumi Kaneda 金田　和文	Professor 教授（併任）
Tetsushi Koide 小出　哲士	Associate Professor 准教授
Tsuyoshi Yoshida 吉田　毅	Associate Professor 准教授（併任）
Toru Tamaki 玉木　徹	Associate Professor 准教授（併任）
Takeshi Takaki 高木　健	Associate Professor 准教授（併任）

Molecular Bio-information Research Division

分子生命情報科学研究部門

Masakazu Iwasaka 岩坂　正和	Professor 教授
Akio Kuroda 黒田　章夫	Professor 教授（併任）
Seiji Kawamoto 河本　正次	Professor 教授（併任）
Takeshi Ikeda 池田　丈	Assistant Professor 助教（併任）

Nanomedicine Research Division

集積医科学研究部門

Kazuaki Chayama 茶山　一彰	Professor 教授（併任）
Michihiro Hide 秀　道広	Professor 教授（併任）
Hiroki Nikawa 二川　浩樹	Associate Director and Professor 副研究所長，教授（併任）
Koichi Kato 加藤　功一	Professor 教授（併任）
Kazuhiro Tsuga 津賀　一弘	Professor 教授（併任）
Yuhki Yanase 柳瀬　雄輝	Assistant Professor 助教（併任）

Nanotechnology Platform

ナノテクノロジープラットフォーム

Shin-Ichiro Kuroki 黒木　伸一郎	Professor 教授
Tetsuo Tabei 田部井　哲夫	Associate Professor (Special Appointment) 特任准教授

Visiting Professor

客員教授

Shin Yokoyama 横山　新	Visiting Professor 客員教授
Yuji Miyahara 宮原　裕二	Visiting Professor 客員教授
Takashi Ito 伊藤　隆司	Visiting Professor 客員教授

Hiroshi Ohki 大木　博	Visiting Professor 客員教授
Seiichi Miyazaki 宮崎　誠一	Visiting Professor 客員教授
Ryo Miyake 三宅　亮	Visiting Professor 客員教授
Shigeto Yoshida 吉田　成人	Visiting Professor 客員教授
Koichi Ito 伊藤　公一	Visiting Professor 客員教授
Takeshi Tanaka 田中　武	Visiting Professor 客員教授
Katia Zheleva Vutora	Visiting Professor 客員教授
Hideki Murakami 村上　秀樹	Visiting Associate Professor 客員准教授

Researchers

研究員

Tadashi Sato 佐藤　旦	Researcher, Nanotechnology Platform ナノテクノロジープラットフォーム研究員
Tatsuya Meguro 目黒　達也	Researcher 研究員
Azhari Afreen アズハリ　アフリーン	Researcher 研究員
Guan Jungang 関　俊剛	Researcher 研究員
Lia Aprilia	Researcher 研究員
Shinji Yamada 山田　真司	Research Associate 教育研究補助職員
Kazushi Okada 岡田　和志	Research Associate 教育研究補助職員

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顧問

Masataka Hirose 廣瀬 全孝	Professor Emeritus, Hiroshima University 広島大学名誉教授

Visiting Staff

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Hirofumi Fukumoto 福本 博文	Visiting Scientist, Asahi Kasei Corporation 客員研究員，旭化成(株)
Tomonori Maeda 前田 知徳	Visiting Scientist, Phenitec Semiconductor Corporation 客員研究員，フェニテックセミコンダクター(株)
Seiji Ishikawa 石川 誠治	Visiting Scientist, Phenitec Semiconductor Corporation 客員研究員，フェニテックセミコンダクター(株)
Hiroshi Sezaki 瀬崎 洋	Visiting Scientist, Phenitec Semiconductor Corporation 客員研究員，フェニテックセミコンダクター(株)
Hirofumi Tanaka 田中 博文	Visiting Scientist, Mitsui Chemicals Incorporated 客員研究員，三井化学(株)
Jun Kamata 鎌田 潤	Visiting Scientist, Mitsui Chemicals Incorporated 客員研究員，三井化学(株)
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Kenji Sakamoto 坂本 憲児	Visiting Scientist, Center for Microelectronic System, Kyusyu Institute of Technology 客員研究員，九州工業大学マイクロ化総合技術センター
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Hiromasa Watanabe 渡邉 礼方	Visiting Scientist, Sharp Takaya Electronic Industry Corporation 客員研究員，シャープタカヤ電子工業(株)
Atsushi Iwata 岩田 穆	Visiting Scientist, Sharp Corporation 客員研究員, (株)エイアールテック

Yositaka Murasaka 村坂　佳隆	Visiting Scientist, Sharp Corporation 客員研究員, (株)エイアールテック
Takafumi Ohmoto 大本　貴文	Visiting Scientist, Sharp Corporation 客員研究員, (株)エイアールテック
Toshifumi Imamura 今村　俊文	Visiting Scientist, Sharp Corporation 客員研究員, (株)エイアールテック
Tomoaki Maeda 前田　智晃	Visiting Scientist, Sharp Corporation 客員研究員, (株)エイアールテック
Masahiro Ono 小野　将寛	Visiting Scientist, Sharp Corporation 客員研究員, (株)エイアールテック
Yoshihiro Masui 升井　義博	Visiting Scientist, Hiroshima Institute of Technology 客員研究員, 広島工業大学
Kazuyoshi Nishino 西野　和義	Visiting Scientist, Shimadzu Corporation 客員研究員, (株)島津製作所
Hang Song 宗　航	Visiting Scientist 客員研究員

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支援スタッフ

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Masahide Sasaki 佐々木　雅英	General Affairs 総務担当
Eiji Ueda 植田　栄治	Office Assistant 事務補佐員
Chiaki Ashihara 葦原　千秋	Office Assistant 事務補佐員
Naoko Nakatani 中谷　尚子	Office Assistant 事務補佐員
Junko Hinohara 樋原　純子	Office Assistant 事務補佐員
Izuko Kushida 串田　何子	Office Assistant 事務補佐員

3. Executive Committee Members of Research Institute for Nanodevice and Bio Systems (RNBS)

ナノデバイス・バイオ融合科学研究所運営委員会委員

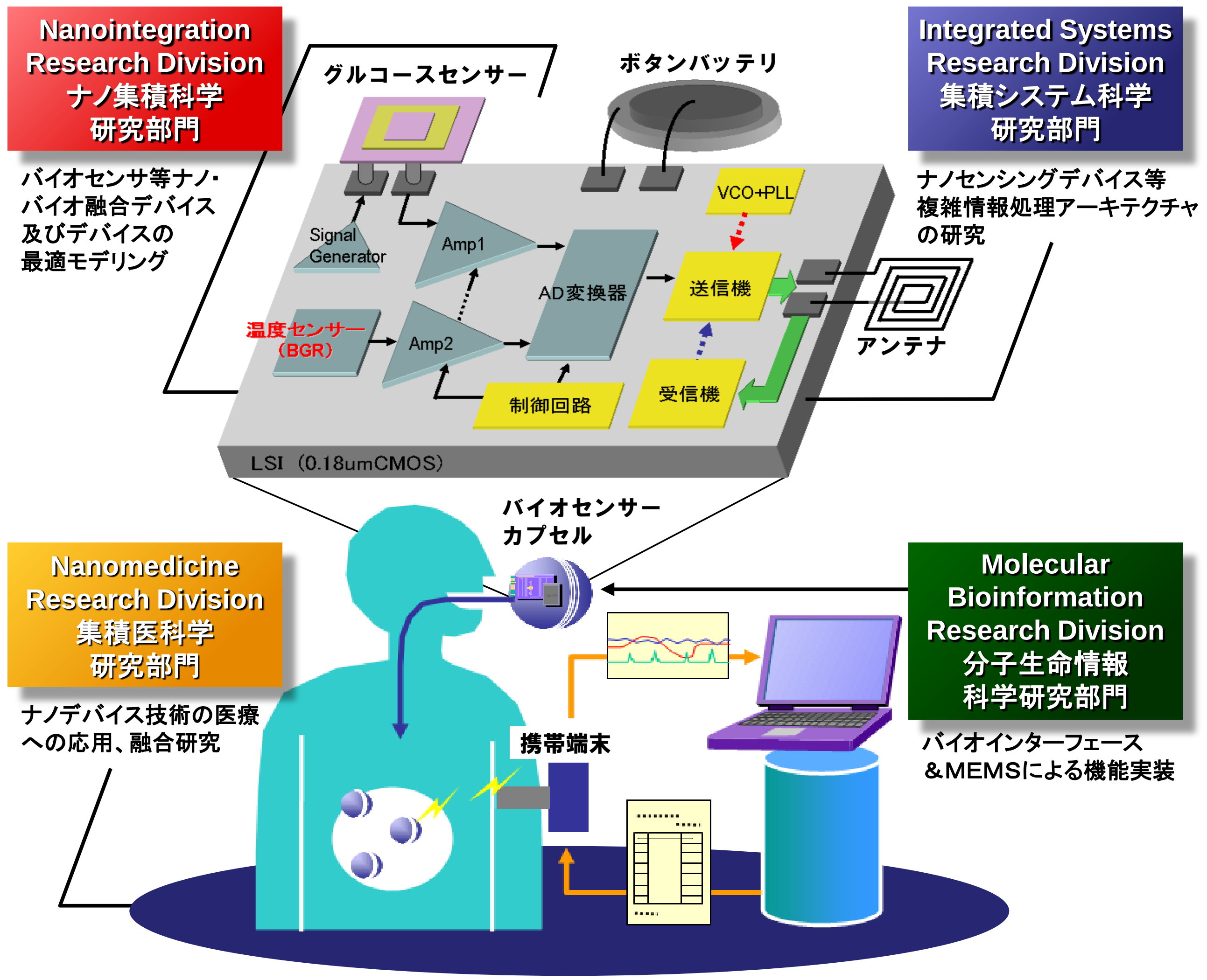
Seiichiro Higashi 東　清一郎	Director and Professor 研究所長・教授	Graduate School of Advanced Sciences of Matter 先端物質科学研究科
Shin-Ichiro Kuroki 黒木　伸一郎	Associate Director and Professor 副研究所長・教授	RNBS ナノデバイス・バイオ融合科学研究所
Hiroki Nikawa 二川　浩樹	Associate Director and Professor 副研究所長・教授	Graduate School of Biomedical Sciences 医歯薬保健学総合研究科（歯）
Masakazu Iwasaka 岩坂　正和	Professor 教授	RNBS ナノデバイス・バイオ融合科学研究所
Akinobu Teramoto 寺本　章伸	Professor 教授	RNBS ナノデバイス・バイオ融合科学研究所
Yutaka Kadoya 角屋　豊	Professor 教授	Graduate School of Advanced Sciences of Matter 先端物質科学研究科
Minoru Fujishima 藤島　実	Professor 教授	Graduate School of Advanced Sciences of Matter 先端物質科学研究科
Yositake Takane 高根　美武	Professor 教授	Graduate School of Advanced Sciences of Matter 先端物質科学研究科
Toshikazu Ekino 浴野　稔一	Professor 教授	Graduate School of Integrated Arts and Sciences 総合科学研究科
Yoshihiro Kuroiwa 黒岩　芳弘	Professor 教授	Graduate School of Science 理学研究科
Toshio Tsuji 辻　敏夫	Professor 教授	Institute of Engineering 工学研究院
Yoshihiro Sanbongi 三本木　至宏	Professor 教授	Graduate School of Biosphere Sciences 生物圏科学研究科
Michihiro Hide 秀　道広	Professor 教授	Graduate School of Biomedical Sciences 医歯薬保健学総合研究科（医）
Koichi Kato 加藤　功一	Professor 教授	Graduate School of Biomedical Sciences 医歯薬保健学総合研究科（歯）
Anri Nakajima 中島 安理	Associate Professor 准教授	RNBS ナノデバイス・バイオ融合科学研究所
Tetsushi Koide 小出 哲士	Associate Professor 准教授	RNBS ナノデバイス・バイオ融合科学研究所

4. Research Divisions of Research Institute for Nanodevice and Bio Systems (RNBS)

ナノデバイス・バイオ融合科学研究所の研究領域

The Research Institute for Nanodevice and Bio Systems was founded on May 1, 2008, aiming to develop the fundamental technologies necessary to achieve global excellence in electronic and bio integrated sciences for preventive medicine and ubiquitous diagnoses on early stages of illnesses in the future advanced medical-care society beyond the present information society. The research field includes Nanointegration, Integrated Systems, Molecular Bioinformation and Nanomedicine.

ナノデバイス・バイオ融合科学研究所は情報化社会の先にある高度医療保障社会に向けた、予防医学やユビキタス病気早期診断を実現するためのエレクトロニクスとバイオテクノロジーの集積科学基盤技術を開発するグローバルな教育研究拠点を構築することを目的として設立された。研究領域はナノ集積科学、集積システム科学、分子生命情報科学、集積医科学の4つからなる。



Research Divisions
研究領域

4.1 Nanointegration Research Division

ナノ集積科学研究部門

At the Nanointegration Research Division we focus the research on nanodevices, fabrication processes, nanointegration, nano-bio integration devices, photonic devices, nano-quantum devices, thin film devices, nanodevice modeling and functional materials. The outlines of researches at the Nanointegration Research Division are as follows.

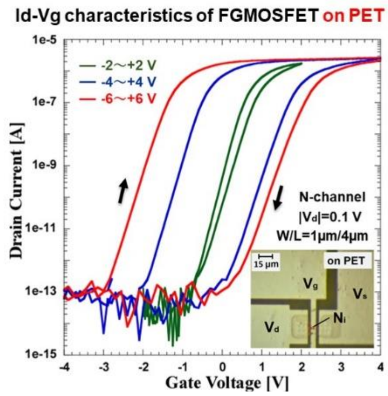
ナノ集積科学研究部門では、ナノデバイス、プロセス、ナノインテグレーション、ナノバイオ融合デバイス、フォトニックデバイス、ナノ量子デバイス、薄膜デバイス、ナノデバイスモデリング、機能性材料等に関する研究を行っている。ナノ集積科学研究部門における研究の主なものの概要を紹介する。

プラスチック上のフローティングゲートMOSFET メモリ動作
Memory Operation of Floating Gate MOSFETs on Plastic Substrate

教授　東　清一郎（併任）
Prof. Seiichiro Higashi

水のメニスカス力を利用して SOI ウエハ上の単結晶シリコン層をプラスチック（PET）基板に転写する技術において、PET 表面の洗浄法改善と濡れ性制御によって 99.97%の転写歩留まりを達成した。転写したシリコン層をチャネルとした MOSFET 構造中に Ni フローティングゲートを導入し、130℃の低温でデバイス作製プロセスを構築し、メモリ動作に成功した。

A high transfer yield of 99.97% has been achieved by meniscus force mediated layer transfer of SOI to plastic (PET) substrate based on improved surface cleaning and wettability control. By introducing Ni floating gate layer into gate dielectric of MOSFET, clear memory operation of the device fabricated at 130ºC on PET has been observed.



PET 基板上に 130℃プロセスで作製したフローティングゲート MOSFET の I_d-V_g 特性．ゲート電圧掃引による明瞭なメモリ動作を確認した

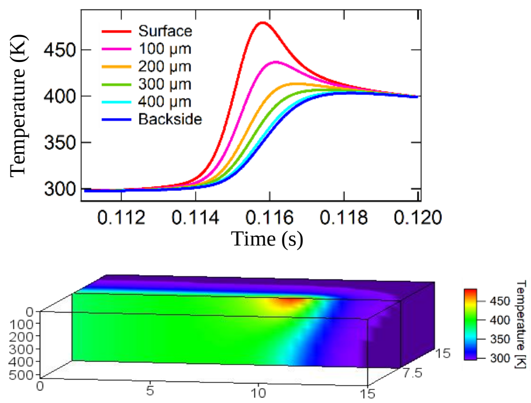
I_d-V_g characteristics of floating gate MOSFET fabricated at 130ºC on PET. Clear memory operation during the gate voltage sweep is observed.

プラズマプロセス中のシリコンウエハ温度の精密非接触測定
Precise Non-contact Measurement of Silicon Wafer Temperature during Plasma Processing

教授　東　清一郎（併任）
Prof. Seiichiro Higashi

大気圧熱プラズマジェット（TPJ）照射中のシリコンウエハ内温度分布を非接触で精密測定するために、熱光学係数（TOC）の精密測定および過渡熱伝導解析モデルの三次元化をおこなった。熱電対（TC）との比較から、ミリ秒時間分解で±2℃以下の精度で温度測定可能であることが明らかになった。

Temperature distribution inside silicon wafer during rapid plasma processing has been precisely observed by a Optical Interference Contactless Thermometer (OICT). Improvements in thermo-optic coefficient (TOC) and three-dimensional heat diffusion and optical simulation model achieved +/-2ºC accuracy on the basis of comparison with thermos couple (TC) measurements.



大気圧熱プラズマジェット（TPJ）照射急速熱処理中のシリコンウエハ内部温度の時間変化（上）と、ウエハ内部の三次元温度分布（下）

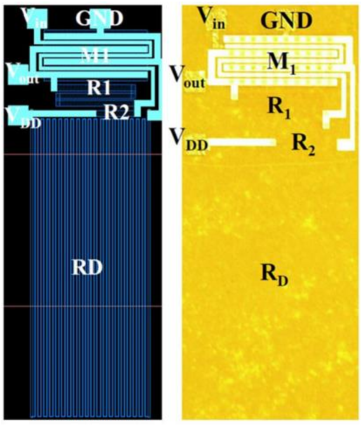
Transient temperature variation inside silicon wafer during atmospheric pressure thermal plasma jet (TPJ) irradiation and three-dimensional temperature distribution.

シリコンカーバイド極限環境エレクトロニクス
Silicon Carbide Harsh Environment Electronics

教授　黒木伸一郎
Prof. Shin-Ichiro Kuroki

シリコンカーバイド（SiC）半導体を用いた極限環境用集積回路の研究を進めている。耐放射線、耐高温化の研究を進め、また集積回路化の研究を進めている。本研究はスウェーデン王立工科大学、量研機構、産総研およびフェニテックセミコンダクター(株)との共同研究として進めている。本成果は Jpn. Jour. Appl. Phys.誌などに掲載された。

Research on SiC harsh environment electronics has been carried out. 4H-SiC Trench nMOSFETs with low parasitic capacitance were suggested and demonstrated. By this structure, short-channel effects are suppressed. This research is carried out under the collaboration with KTH Royal Institute of Technology, Sweden, QST, AIST and Phenitec Semiconductor Co. Ltd., Japan.



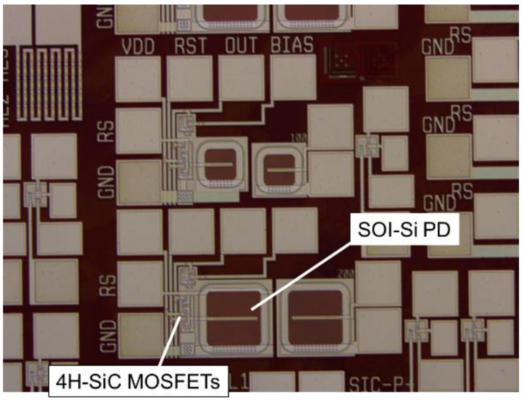
4H-SiC 1 段アンプ回路
4H-SiC Single-Stage Amplifier Circuits.

SiC 半導体と SOI 基板による耐放射線イメージセンサの研究
SiC Radiation-Hardened Image Sensors

教授　黒木伸一郎
Prof. Shin-Ichiro Kuroki

シリコンカーバイド（SiC）を用いた耐放射線イメージセンサの研究を進めた。3つの SiC MOSFETs と1つの Si フォトダイオードを1画素としている。出力信号を増加させるために、デバイス構造の検討を進めている。本研究は産総研、量研機構との共同研究として進めている。

SiC pixel devices with SOI wafer and 4H-SiC had been developed. For high output signal, we continue the designing and prototyping. This research has been carried out under the collaboration with AIST and QST, Japan.



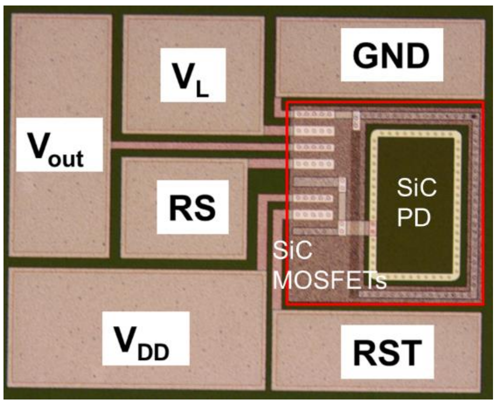
4H-SiC/ SOI-Si 耐放射線ハイブリッド画素デバイス
4H-SiC/ SOI-Si hybrid pixel device for Rad-Hardened image sensor.

フル SiC 耐放射線 UV イメージセンサの研究
Radiation-Hardened Full-SiC UV Pixel Devices

教授　黒木伸一郎
Prof. Shin-Ichiro Kuroki

今後のデブリ取り出しなどを見据え、フォトダイオードも SiC で作製したフル SiC UV（紫外光）イメージセンサを提案し、実証研究を進めている。3 MGy 以上のガンマ線照射後も駆動可能であることを示した。本研究は産総研、量研機構との共同研究として進めている。

Full SiC pixel devices for a radiation hardened UV image sensors had been demonstrated. These results were reported at ICSCRM2019. This research has been carried out under the collaboration with AIST and QST, Japan.



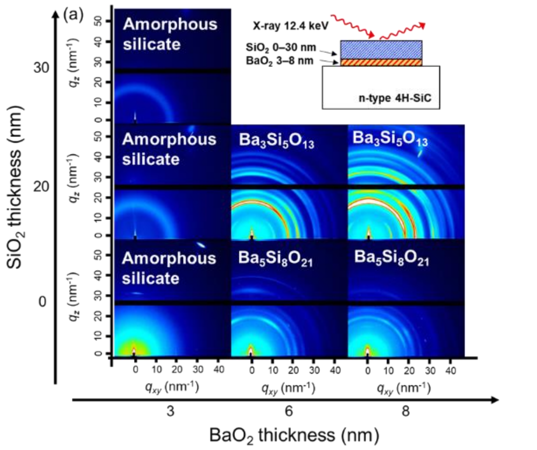
フル 4H-SiC UV ピクセルデバイス（1 画素デバイス）
Full 4H-SiC pixel device for Rad-Hardened UV image sensor.

4H-SiC MOSFETs へのガンマ線照射効果
Gamma-Ray Exposure Effects on 4H-SiC MOSFETs

教授　黒木伸一郎
Prof. Shin-Ichiro Kuroki

シリコンカーバイド（SiC）MOSFETs の反転層移動度向上技術として MOS 界面への BaO 導入の研究を進めた。MOS 界面での Ba シリケート構造を 2D X 線測定等により明らかにした。本成果は Materials Science in Semiconductor Processing 誌などに掲載された。この研究はフェニテックセミコンダクター社、SPring8 などとの共同研究である。

BaO thin films are introduced to 4H-SiC MOS interface for enhancing carrier mobility. The crystallinity of Ba silicate was discussed with the results of 2D XRD. This research has been carried out under the collaboration with Phenitec Semiconductor Co. Ltd., and SPring8, Japan.



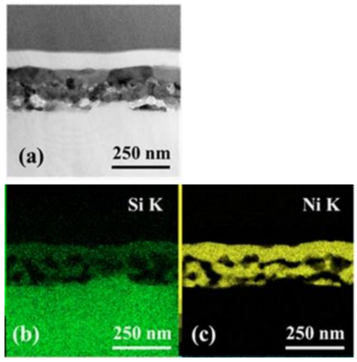
Ba 添加 4H-SiC MOS 構造での Ba シリケート結晶構造解析
Crystallinity of Ba silicate in 4H-SiC MOS structure.

4H-SiC 上のオーミック電極の高温信頼性評価
High-Temperature Reliability of Ni/Nb Ohmic Matals on 4H-SiC

教授　黒木伸一郎
Prof. Shin-Ichiro Kuroki

4H-SiC 上のオーミック電極の高温信頼性評価を進めています。特に CF_4:O_2 プラズマ処理による信頼性向上技術などを確立しました。これらの成果は Jpn. Jour. Appl. Phys. などで発表しました。本研究はフェニテックセミコンダクター社、SPring8、東北大学などとの共同研究である。

400℃ High temperature reliability of ohmic contacts on 4H-SiC at has been investigated. CF_4:O_2plasma treatment has been applied for enhancing the reliability. The results were reported at Jpn. Jour. Appl. Phys. This research has been carried out under the collaboration with Phenitec Semiconductor Co. Ltd., SPring8, and Tohoku University.



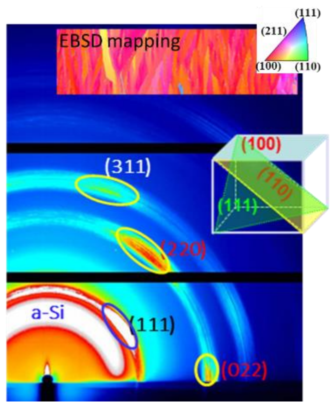
4H-SiC 上の NiNb シリサイド・オーミックコンタクトの EDX 像(元素分布性)
EDX images of NiNb silicide on 4H-SiC after 400°C, 100 hours aging.

レーザ結晶化による Si(100)薄膜形成
Si(100) Thin Film Formation Using Laser Crystallization

黒木伸一郎
Prof. Shin-Ichiro Kuroki

高性能シリコン薄膜トランジスタ実現のために、レーザ照射による Si(100)薄膜の形成の研究を進めている。Si(100)3 軸が揃ったレーザ照射条件を見出すことに成功した。これらの成果は Jpn. Jour. Appl. Phys.などで発表しました。本研究は Hanoi National University of Education (HNUE)との共同研究として進めている。

For high performance Si thin film transistors, Si(100) formation using laser crystallization has been investigated. Crystallinity condition map for (100), (211), and other crystal orientation, and the results were reported at Jpn. Jour. Appl. Phys. This research has been carried out under the collaboration with Hanoi National University of Education (HNUE).



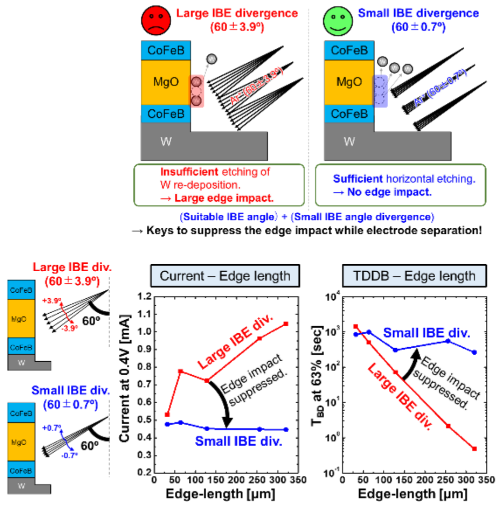
レーザ結晶化による Si(100)面制御：EBSD 像と 2D-XRD 像
Si(100) thin film formation using continuous wave laser crystallization : EBSD mapping and 2D-XRD.

MRAM における MgO 膜の信頼性
Reliability of MgO in MRAM

教授　寺本章伸
Prof. Akinobu Teramoto

Magnetoresistive Random Access Memory (MRAM)のトンネル絶縁膜である MgO の信頼性に関する研究を行っています。Magnetic Tunnel Junction(MTJ)を形成する為のエッチングの際、エッチングの精度を向上させることで信頼性低下を抑制できることを明らかにしました。

We evaluate the reliability of MgO tunnel insulator in Magnetoresistive Random Access Memory (MRAM). The reliability can increase by the precise control of the metal etching in magnetic tunnel junction (MTJ) formation.



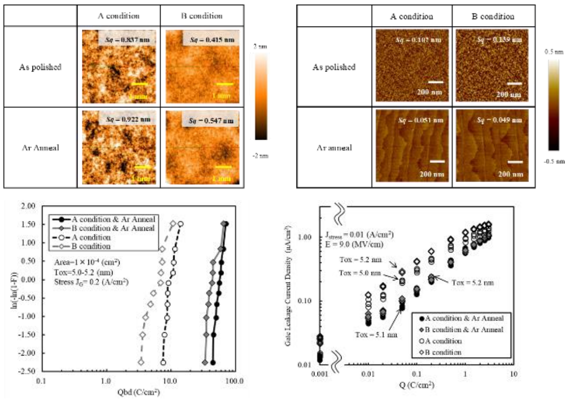
MTJ 形成時の IBE 時のダメージとその抑制効果
Process damage caused by IBE in MTJ formation.

Si 表面が絶縁膜の信頼性に与える影響
Influence of Si surfaces on SiO2 reliability

教授　寺本章伸
Prof. Akinobu Teramoto

研磨方法が異なる 2 種類のウェーハを用いて、MOS 構造を形成し、SiO_2 の信頼性を評価しました。研磨方法の違いにより、長周期、短周期のラフネスが異なるものができ、その上に形成した SiO_2 膜の信頼性(絶縁破壊電荷量、ストレス有機リーク電流)に差が現れました。

We evaluate the reliability of SiO_2 films formed on different Si wafers, which surfaces are different polishing method. The differences of the reliability (Charge to breakdown and Stress induced leakage current) and the surface roughness in different spatial wavelength region has been appeared for two kind of polishing methods.



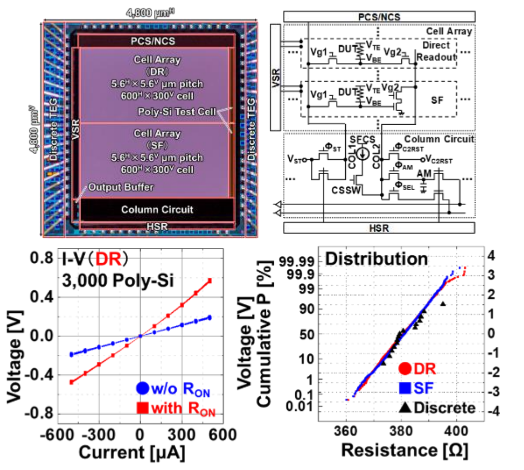
研磨方法を変えた Si ウェーハの表面像(左:White Light Interferometer、右:AFM)とそれぞれのウェーハ上に形成した SiO_2 膜の信頼性
Surface images of Si wafers (left: White Light Interferometer, right: AFM) and The reliability of SiO_2 films formed on these wafers.

統計的抵抗測定プラットフォームの開発
Platform for Statistical Evaluation of Resistance

教授　寺本章伸
Prof. Akinobu Teramoto

アレイ状のテストパターンを用いて抵抗の統計的評価を行っています。1-Poly、5-Metal の CMOS プロセスで回路を作った後、5 層金属上に抵抗を評価するための構造を形成することで、簡易なプロセスを用いて、統計的な評価が可能となりました。36 万個の素子について、1 秒以内に 1～10MΩの抵抗を測定できるようになりました。

We evaluate the statistical resistance evaluation by using the array test circuit. The plat for circuit is constructed with 1-Poy, 5-Metal structure and the evaluate structure is formed on top metal. As the result, the many (360000) cells can be measured in a short time (less than 1 sec) with large dynamic range (1~10 MΩ).



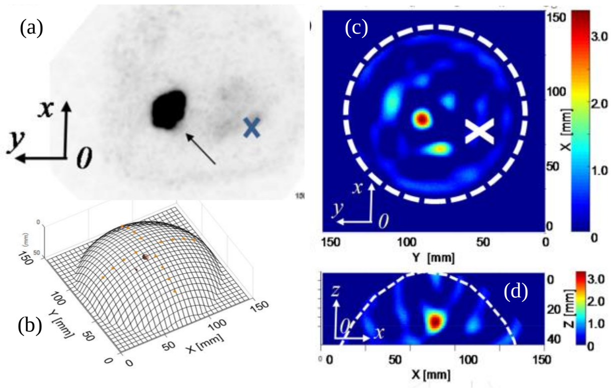
アレイ状の測定パターンと抵抗測定結果
Array test pattern and results of resistance measurement.

乳癌組織のマイクロ波3D イメージング
3 D Microwave Imaging of Breast Cancer

教授　吉川公麿（特任）
Prof. Takamaro Kikkawa

携帯型乳癌検出機をインパルス超広帯域マイクロ波レーダー技術で開発し、手術により全摘出された乳腺腫瘍組織の 3 次元イメージングと病理顕微鏡写真および陽電子放出断層撮影と比較することで検出性能を評価した。

Detectability of breast tumors in excised breast tissues of total mastectomy by IR-UWB-radar-based breast cancer detector was investigated by comparing with pathological images and images of dedicated breast positron emission tomography. (IEEE Transactions on Biomedical Engineering, 2019. IF: 4.424)



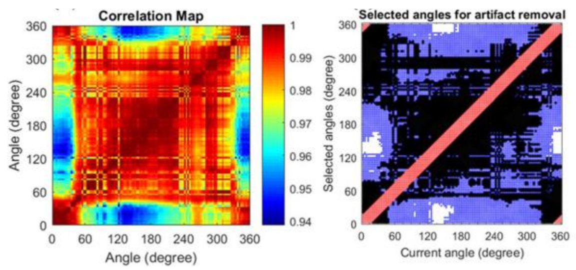
乳癌組織のイメージング (a)陽電子放出断層撮影(PET)イメージ (b) マイクロ波3D イメージ (c) 冠状面マイクロ波断層イメージ (d) 横断面マイクロ波断層イメージ
Microwave imaging of breast cancer tissues. (a) Positron Emission Tomography image. (b) Microwave 3D image. (c) Coronal plane microwave image. (d) Transverse plane microwave image.

マイクロ波イメージング表面散乱除去法
Surface Clutter Suppression Method for Microwave Breast Imaging

教授　吉川公麿（特任）
Prof. Takamaro Kikkawa

乳癌をマイクロ波を使ってイメージングする技術において、人体表面からの散乱波を除去するアルゴリズムを開発した。16 個のアンテナアレイを乳房表面で 360 度回転させ、受信波の相関が高い波形を選択し、L2 正則を導入した適応フィルターで 2 段階表面クラッター除去法を開発した。

A Two-Stage Rotational Surface Clutter Suppression Method for Microwave Breast Imaging with Multistatic Impulse-Radar Detector was developed.
(IEEE Transactions on Instrumentation and Measurement, 2020. IF: 3.658)



$$\min_{w}\left[\left\|b_{\tilde{k},i}-Hw\right\|^{2}+\lambda\left\|w-\overline{w}\right\|^{2}\right]$$

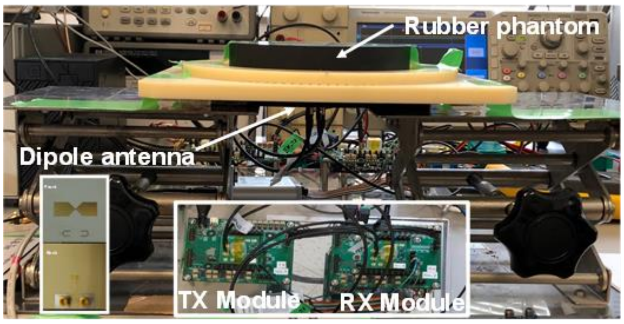
受信マイクロ波インパルス信号波形の相関係数の回転角度分依存性．高相関係数をもつ受信波形の選択（黒い点が選択された信号の角度）．L2 正則による最小二乗法
Correlation map of rotation angle dependence for received microwave impulse signals. Signal selection results where black dots are the angles from selected signals. A prior constraint is introduced to regularize the least square using L2 regularization.

CMOS インパルスレーダー集積回路
CMOS Gaussian Monocycle Pulse Transceiver for Radar Imaging

教授　吉川公麿（特任）
Prof. Takamaro Kikkawa

マイクロ波イメージンングのためにガウシアンモノサイクルパルスを用いたシングルチップレーダー送受信機 CMOS 半導体集積回路を開発した。CMOS-LSI を実装したレーダーモジュールで近傍界における間隔 10mm で配置された大きさ 10mm の 2 個のターゲットを分離描画できた。

A single chip Gaussian monocycle pulse transceiver CMOS-LSI for radar-based microwave imaging was developed. The GMP transceiver module can differentiate two phantom targets with the size of 10 mm and the spacing of 10 mm in the near field. (IEEE Transactions on Biomedical Circuits and Systems, 2020. IF: 4.042)



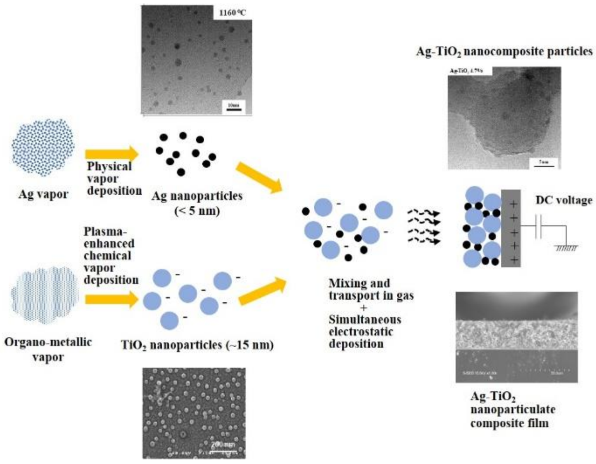
ガウシアンモノサイクルパルスを用いたシングルチップレーダー送受信機 CMOS 半導体集積回路を実装したレーダーモジュール．左下写真はダイポールアンテナ．中央下写真はレーダーモジュール．右下写真は CMOS-LSI
Photographs of radar-based microwave imaging module using single chip Gaussian monocycle pulse transceiver CMOS-LSI. Dipole antenna (left). Radar module (middle). CMOS-LSI (right).

ナノ物質の堆積による材料創製と表面汚染
Preparation of Materials and Surface Contamination by Deposition of Nanoobjects

教授　島田　学（併任）
Prof. Manabu Shimada

ナノサイズのクラスター・粒子状物質を合成し、ガス中に浮遊、堆積させて、有用な構造・組成をもつ薄膜、粒子、およびそれらの複合物を創製する研究を行っている。ナノサイズ物質が汚染物質として表面付着したときの影響も検討している。

Preparation of thin-films, particles, and their composites having useful structure and composition is being studied by synthesizing nano-sized clusters and particulate matter suspended in gases and depositing them in the gas phase. The effects of surface deposition of nanoobjects as contaminants are also being investigated.



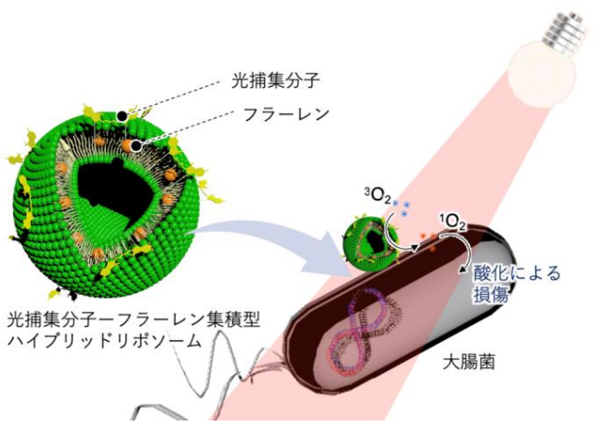
光触媒性能の向上を目指した銀-チタニア複合粒子・空隙薄膜のワンステップ気相作製手法
One-step gas-phase method for preparing Ag-TiO_2 composite porous thin film pursuing improved photocatalytic performance.

二元系含有リポソームの光抗菌活性
Photo-induced Antibacterial Activity of Liposome-Incorporated Dyad Systems

教授　池田篤志（併任）
Prof. Atsushi Ikeda

広い波長範囲で作用する光抗菌剤の開発のため、光捕集分子ーフラーレン誘導体二元系含有リポソームを調製した。我々は光線力学活性のさらなる向上を目指す。

To develop the photo-induced antibacterial agents which acted at a wide range of wavelength, we prepared liposome-incorporated dyad systems between light-harvesting antenna molecules and a fullerene derivative. We aim at the further enhancement of photodynamic activity.



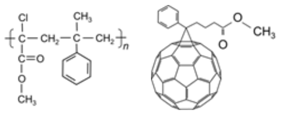
光捕集分子ーフラーレン誘導体含有リポソームとその光抗菌活性の模式図
Schematic image of liposome-incorporated light-harvesting antenna molecules and a fullerene derivative and photo-induced antibacterial activity.

有機ナノデバイスのための電気伝導性フラーレン混合有機レジスト
Fullerene-Containing Electrically Conducting Electron Beam Resist for Organic Nanodevices

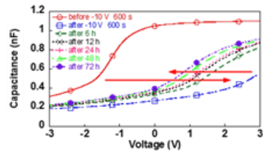
准教授　中島安理
Assoc. Prof. Anri Nakajima

簡便に高集積有機ナノサイズデバイスを作製するために、有機電子線レジストにフレーレンを混合した材料を開発している。電気伝導性の有機ナノドットや有機ナノワイヤ構造を電子線露光と現像のみのプロセスで作製できる。

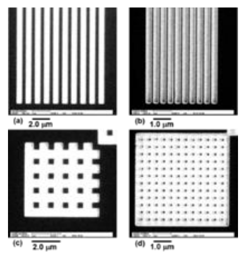
Fullerene-incorporated electron beam (EB) organic resists are developed to realize high integration of nanometer lateral-scale organic electronic devices. The structures of nanoscale dots and nanowires having electrical conductivity are able to be fabricated with a simple fabrication process of only EB exposure and development.



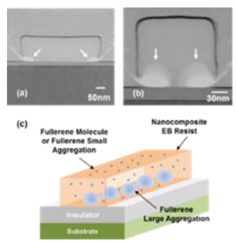
ZEP520a と PCBM
ZEP520a and PCBM.



C-V 特性
C-V characteristics.



ナノスケールドットとナノワイヤ構造の SEM 像
SEM micrographs of nanoscale dots and nanowires.



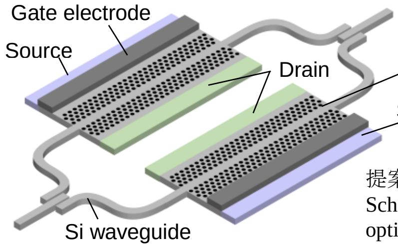
ナノワイヤ構造の透過電子顕微鏡像とフラーレンの分布
TEM of micrograph of nanowire and PCBM distribution.

トンネル電界効果トランジスタを用いた極低電圧シリコン光変調器の研究
Ultralow Drive Voltage Si Optical Modulator Using Tunnel Field-Effect Transistor

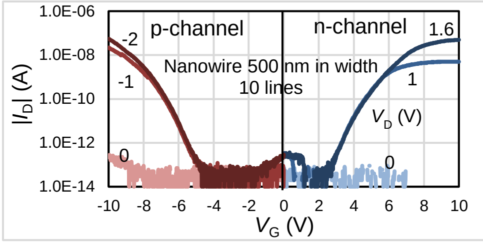
准教授　田部井哲夫(特任)
Assoc. Prof. Tetsuo Tabei

トンネル電界効果トランジスタ(TFET)を利用した、極低電圧駆動シリコン光変調器の研究を行っている。現在は変調素子として使用する n チャネル及び p チャネルシリコン TFET の試作を行い、その構造及び作製プロセスの最適化を進めている。

We study an ultralow drive voltage silicon optical modulator using a tunnel field effect transistor (TFET). Currently, we are proceeding with an optimization of the structure and fabrication process of n-channel and p-channel silicon TFETs used as optical modulators.



提案する光変調器の概略図
Schematic of the proposed optical modulator.



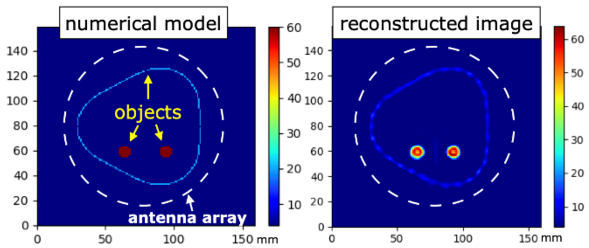
試作した n 及び p チャネル TFET のドレイン電流 (I_D)−ゲート電圧特性 (V_G)
Drain current (I_D) vs. gate voltage (V_G) characteristics of fabricated n-channel and p-channel TFET.

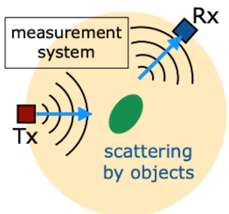
マイクロ波イメージングの研究
Microwave Imaging

助教　石川智己(特任)
Assist. Prof. Tomomi Ishikawa

マイクロ波映像法(MWI)に関するアルゴリズムの研究を行なっている。MWI では電磁波を照射、対象物体で散乱、そして受信アンテナで得られたデータから物体の形状、電気的性質を得る。特に乳がん検診への応用を目指し、必要となる計算アルゴリズムの開発や計算の高速化、並びに実用性の検証を行っている。

Microwave imaging and its computing algorithms are studied. Our research includes code development of the imaging using Computed Tomography and conventional confocal methods as well as testing its practicality for the purpose of the breast cancer inspection.





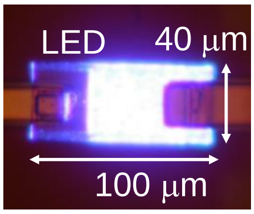
トモグラフィによる画像(非誘電率分布)再構成の数値シミュレーションの様子
A numerical simulation of the reconstruction (relative permittivity distribution) by computed tomography.

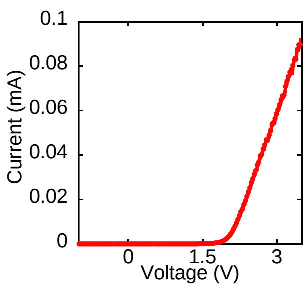
GaN-LED の異種基板上への集積化
Heterogeneous Integration of GaN-LED

助教　雨宮嘉照(特任)
Assist. Prof. Yoshiteru Amemiya

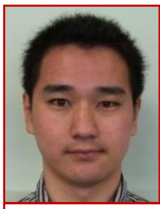
GaN-LED を常温大気圧下で異種基板上に接合する技術の研究を行っている。光回路上への集積化を目的として、石英基板や光導波路上に接合させた素子について、電流電圧特性や発光波長について評価した。

We are studying binding technology of GAN-LED under room temperature and atmospheric pressure. Devices were bounded on quartz substrates and optical waveguides for integrated optical circuits. Current-voltage characteristics and emission spectrum have been investigated.





LED 発光時の光学顕微鏡写真と電流電圧特性
Optical micrograph of light emission from GaN-LED and current-voltage characteristics.



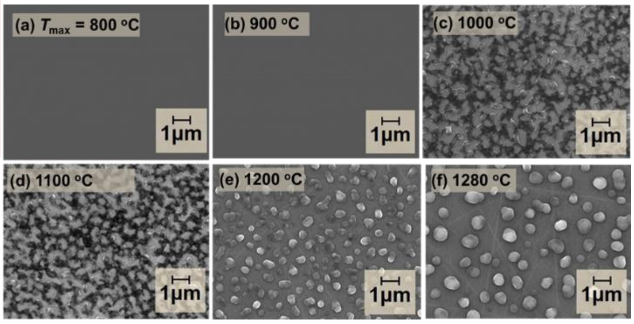
Si/SiC ヘテロ接合によるバンドアライメント制御の研究

Band-Alignment Control by Si/SiC Hetero-Structure

助教　花房宏明（併任）
Assist. Prof. Hiroaki Hanafusa

Si と SiC のヘテロ接合とアニール処理を組み合わせることで Si の融点を大きく下回る温度で Si 層がドット化する現象とそれにより電極金属のシリサイド化を行わずに低抵抗コンタクトが形成される現象について研究を進めている。

We are studying mechanism of Si dots formation that caused by annealing of Si/SiC hetero structure at below the Si melting point. We also investigating low-resistive contacts using the Si-dots/SiC structure without metal silicidation process.



アニール温度に依存した SiC 上 Si の泳動とドット化を示す電子顕微鏡像

Scanning electron microscope images of Si migration and dots formation in accordance with the annealing temperature.

4.2 Integrated Systems Research Division

集積システム科学研究部門

The Integrated Systems Research Division focuses on basic research for terabit-capacity highly-functional memories, super-parallel processing, bio-sensing, wireless interconnection and 3-dimensional integration. With the obtained results we aim at the realization of artificial-brain technology exceeding humans in intelligent-processing speed, storage capacity and adaptive learning. The outlines of researches at the Integrated Systems Research Division are as follows.

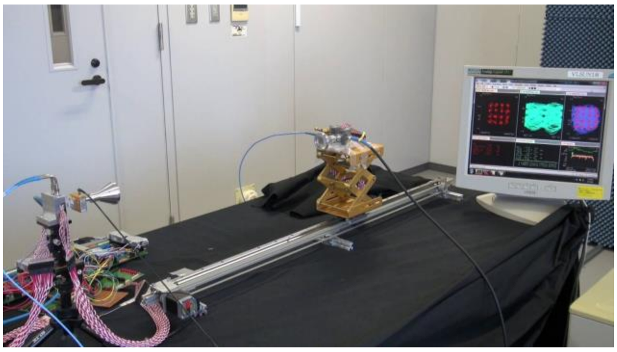
集積システム科学部門では、テラビット容量と高機能メモリ、超並列演算、バイオセンシング、無線インタフェース、3次元集積に関する基盤研究を推進している。そして、これらの基盤技術を用いて、人間の脳より速い認知処理、大規模な記憶容量、環境に適応する学習機能を有する集積ブレインの実現を目指す。集積システム科学部門における研究プロジェクトの主なものの概要を紹介する。

テラヘルツ波デバイス基盤技術の研究
Research on Fundamental Technology for Terahertz-Wave Devices

教授　藤島　実（併任）
Prof. Minoru Fujishima

ミリ波からテラヘルツ波までの超高周波 CMOS デバイスの研究を行っている。6G で 100Gbps を超える通信速度を実現する 300GHz 帯通信を CMOS 集積回路で実現することを目指している。

We are researching ultra-high frequency CMOS devices including millimeter wave to terahertz wave. We are working on the realization of 300GHz band communication, which will enable over 100Gbps communication speed for 6G, using CMOS integrated circuits.



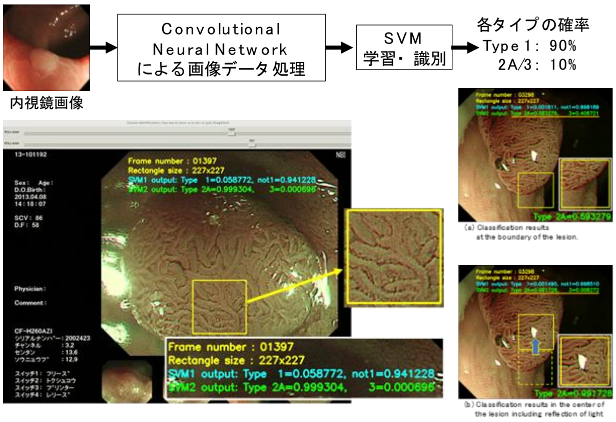
300GHz 帯 CMOS トランシーバを用いた伝送実験
Communication experiment with 300-GHz-band CMOS transmitter.

CNN 特徴を特徴抽出として利用した機械学習を用いた大腸がん診断支援システムの開発
Development of a Colorectal Cancer Diagnosis Support System Using Machine Learning with CNN Features as Feature Extraction

准教授　小出哲士　Assoc. Prof. Tetsushi Koide

提案手法は研究グループで提案している Bag-of-Features（BoF）に基づく診断支援の特徴量抽出処理を、学習済み CNN の結果を用いることで実現した。これにより、一般物体認識のために抽出された局所特徴量が、SVM による病理タイプ分類に有効な特徴量として利用できることが期待できる。提案手法の組込みシステム化を考慮して識別精度の検証を行い、その結果非腫瘍・腫瘍の識別において医療現場からの要求性能である 90% 以上の識別精度を確認した。

The proposed method realizes the feature extraction process for diagnosis support based on Bag-of-Features (BoF) proposed by our research group by using the results of trained CNNs. It is expected that the local features extracted for general object recognition can be used as effective features for pathology type classification by SVM. We verified the identification accuracy of the proposed method for embedded systems, and confirmed that the accuracy of the proposed method is over 90%, which is the required performance in the medical field for non-tumor and tumor identification.



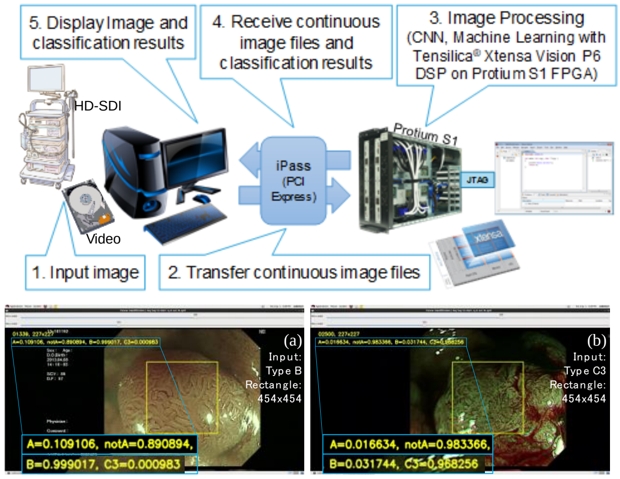
CNN 特徴を特徴抽出として利用した機械学習を用いた大腸がん診断支援システム
A Colorectal Cancer Diagnosis Support System Using Machine Learning with CNN Features as Feature Extraction.
https://ieeexplore.ieee.org/document/8702379

メディカルアプリケーションのためのソフト・ハード協調設計による画像処理システム IP コアの開発
Development of Image Processing System IP Cores with Software/Hardware Co-Design for Medical Applications

准教授　小出哲士　Assoc. Prof. Tetsushi Koide

CNN 特徴と SVM 分類を適用した診断支援システムをカスタマイザブルな Digital Signal Processing (DSP) コアである、Cadence 社の Cadence Tensilica Vision P6 DSP コアに実装し評価を行った。その結果、コアアーキテクチャに適したアルゴリズム改良を行うことで CNN や SVM の主要処理が効率的に実行でき、改良前と比較して処理サイクル数が 1/30 に削減されリアルタイム処理(30 fps@100 MHz) が実現可能であることを示した。

A diagnostic support system using CNN features and SVM classification was implemented on a Cadence Tensilica Vision P6 DSP core from Cadence, a customizable Digital Signal Processing (DSP) core, and evaluated. As a result, by performing algorithm improvement suitable for the core architecture, the main processing of CNN and SVM can be executed efficiently, the number of processing cycles is reduced to 1/30 compared to before the improvement, and real-time processing (30 fps @ 100 MHz) is feasible.



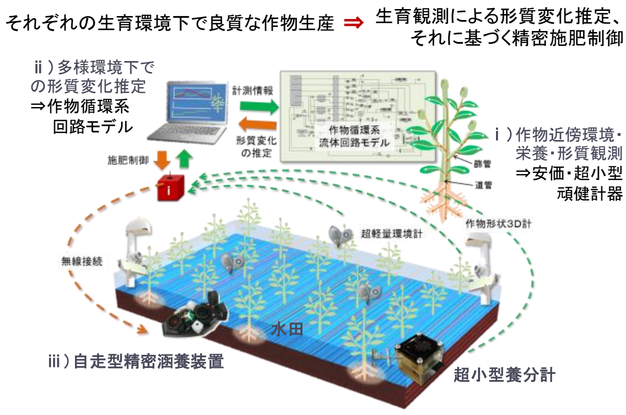
カスタマイザブル DSP コアへのプロトタイプシステムの実装
Implementation of a prototype system on a customizable DSP.
https://ieeexplore.ieee.org/document/8702379

フィールド向け頑健計器と作物循環系流体回路モデルによる形質変化推定技術の研究
Development of Plant Growth Estimation Technologies Combined with Robust Field Monitors and Micro-Fluidic Model Simulating Plant Vascular System

准教授　小出哲士　Assoc. Prof. Tetsushi Koide

長期間、作物の近傍に設置して、作物の栄養の吸収や作物周辺の環境(光、温湿度、CO_2等)を逐次観測することのできる小型の計器類と、それと連動して動く、作物体内の水分や養分などの循環の状態を予測する作物体内循環系流体回路モデルを作成し、肥料添加や作物周辺環境が、その成長にどのように影響していくかを推定する技術を開発している。(JST CREST Project)

We are going to develop an ultra-small nutrients analyzer, a compact 3D-monitor (shape, color, etc.), and an ultra-light environment sensor (light intensity, temperature, humidity, CO2, etc.), which can be installed near plants. Accordingly, plant growth estimation technologies based on micro-fluidic circuit model simulating plant vascular system are being developed. (JST CREST Project)



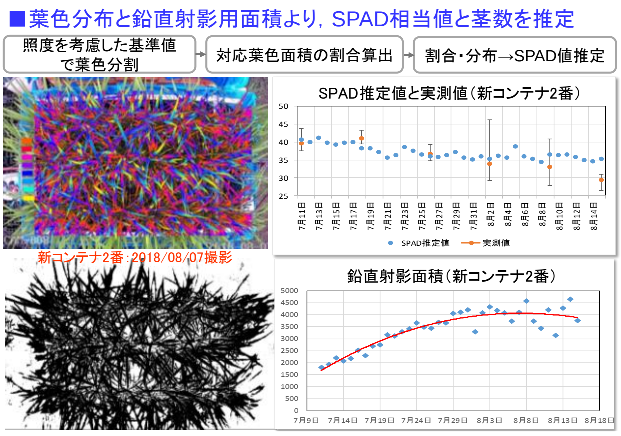
フィールド向け頑健計器と作物循環系流体回路モデルによる形質変化推定技術の概要
Overview of Development of plant growth estimation technologies combined with robust field monitors and micro-fluidic model simulating plant vascular system.
https://www.jst.go.jp/kisoken/crest/en/project/1111090/15666253.html

スマート農業のための水稲の成長を顕著に示す画像由来の形質パラメータの探索と評価
Search and Evaluation of Trait Parameters Derived from Images Showing Significant Changes in Rice Growth for Smart Agriculture

准教授　小出哲士　Assoc. Prof. Tetsushi Koide

作物周辺の環境や作物への施肥が、作物の形質変化にどのように影響するかを把握するために、作物画像の時系列情報を取得し、それらから形質変化に関係するパラメータを特徴抽出する技術と計器の開発を推進。水稲のより多次元の生育情報(葉面積や草丈、茎生長、葉温)を取得するために複数種のカメラを屋外実験圃場(準閉鎖系水稲生育実験圃場、ライシメータ)に構築して検証実験実施。これらの知見を盛り込んだ 3D 計プロト機を試作。(JST CREST Project)

In order to understand how the environment around the crop and fertilizer application to the crop affect the changes in crop traits, we are promoting the development of technology and instruments to acquire time-series information of crop images and extract characteristics of parameters related to trait changes from them. In order to obtain more multidimensional growth information (leaf area, grass height, stem growth, and leaf temperature) of paddy rice, verification experiments were conducted by constructing multiple types of cameras in outdoor experimental plots (semi-closed paddy rice growth experimental plots, lysimeters). A prototype of a 3D measurement system incorporating these findings was developed. (JST CREST Project)



屋外実験圃場（準閉鎖系水稲生育実験圃場）での検証結果
Verification results in an outdoor experimental field (quasi-closed system rice growth experimental field).
https://ieeexplore.ieee.org/document/8650285

4.3 Molecular Bioinformation Research Division
分子生命情報科学研究部門

Molecular Bioinformation Research Division is specialized in the research for MEMS (Micro Electro Mechanical Systems), immobilization of bio molecule, bio-sensing technology, and environmental monitoring. The outlines of researches at the Molecular Bio-information Research Division are as follows.

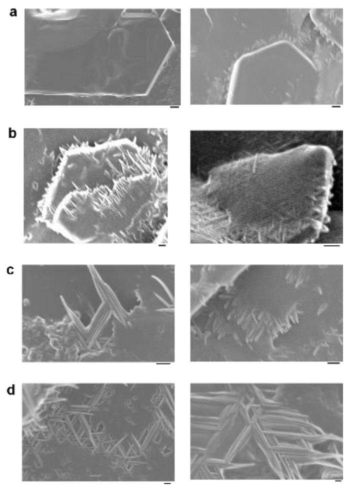
分子生命情報科学研究部門は、MEMS、バイオ分子固定、バイオセンシング、環境情報センシングに関する研究を行っている。分子生命情報科学研究部門における研究の主なものの概要を紹介する。

鰯のバイオリフレクターに関する研究
Bioreflectors of Aquatic Animals

教授　岩坂正和
Prof. Masakazu Iwasaka

鰯などの魚の皮膚で生成するバイオリフレクターの結晶板の内部構造において、幅 30nm のビームで構成されたナノ三角形格子が存在することを世界ではじめて発見した。AIP の Editor'Choice などで取り上げられた。

Internal triangular structure was found in guanine crystal platelet of several species of fishes.



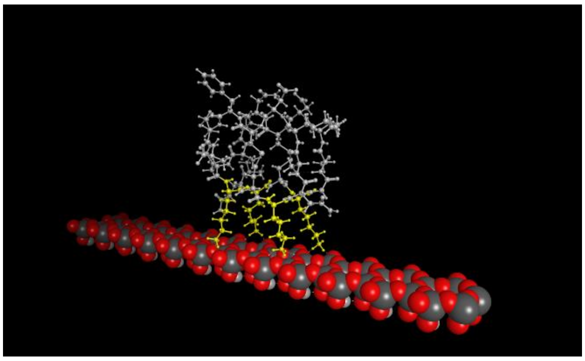
鰯などの魚の皮膚で生成するバイオリフレクターの結晶板の内部構造
Internal triangular structure in guanine crystal platelet.

シリコンとバイオの界面制御の研究
Interface Technology between Silicon and Biomolecules

教授　黒田章夫（併任）
Prof. Akio Kuroda

Si デバイスの表面に、活性を保ったままバイオ分子を固定化する技術は新しい半導体バイオセンサーの開発に必要である。平坦な表面構造を有するタンパク質分子を改変して、Si との親和性が高いアミノ酸を平面状に配置することで、新規の Si 結合タンパク質の開発を進めている。

The ability to target proteins to specific sites on a Si device while preserving their functions is necessary for the development of new biosensors. We are developing a novel Si-binding protein by engineering a protein to display amino acids with affinity for Si on the flat surface.



作製した Si 結合タンパク質の結合モデル図
平面状に配置したアミノ酸(黄色)が Si 表面と相互作用する
Molecular model of the Si-binding protein.

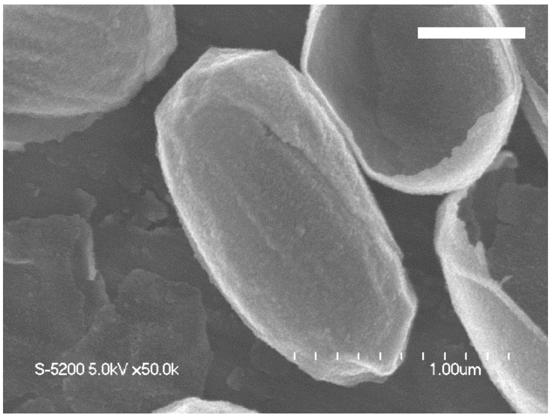
SiO_2 結合ペプチドの発見とタンパク質固定化への応用

Application of SiO_2-Binding Peptides for Protein Immobilization on Si-Based Materials

助教　池田　丈（併任）
Assist. Prof. Takeshi Ikeda

細胞内にてマイクロカプセル状の SiO_2 を形成するグラム陽性細菌 *Bacillus cereus* より、新規の SiO_2 結合ペプチドを取得した。本ペプチドを接着分子として利用することでSi 表面上に任意のタンパク質分子を固定化できるため、新たな半導体バイオ融合デバイスの開発が可能となると期待される。

We found novel SiO_2-binding peptides from a Gram-positive bacterium *Bacillus cereus*, which forms a microcapsule-like structure of SiO_2 in the cell. Because of its high affinity for SiO_2, this peptide should be a powerful tool for developing Si-based biodevices.



B. cereus が形成したマイクロカプセル状 SiO_2 構造体のSEM 像 スケールバー：500 nm

SEM image of microcapsule-like SiO_2 structures isolated from *B. cereus*. Scale bar: 500 nm.

4.4　Nanomedicine Research Division

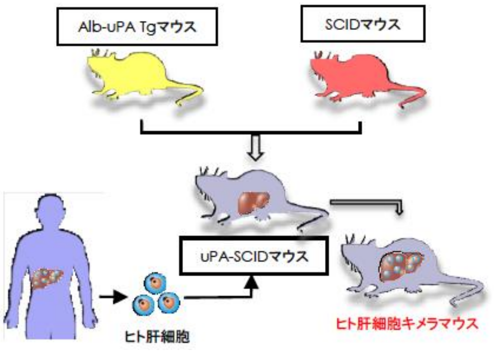
集積医科学研究部門

Nanomedicine Research Division is specialized in the research for integration between medicine and nanotechnology, nanomedicine, nanodentistry, nano-pharmacy. The outlines of researches at the Nanomedicine Research Division are as follows.

集積医科学研究部門では、ナノメディシン、ナノデンティストリー、ナノファーマシー等、医療とナノ技術の融合研究を行っている。現在行われている集積医科学研究部門における研究の主なものの概要を紹介する。

ウイルス性肝疾患に関する研究
Research on Hepatitis Viruses and Liver Disease

教授　茶山一彰（併任）
Prof. Kazuaki Chayama



ヒト肝細胞キメラマウス
Humna hepatocyte chimeric mouse.

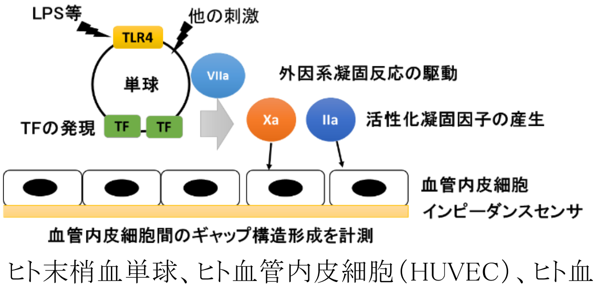
肝炎ウイルス感染モデルであるヒト肝細胞キメラマウスを用いて肝炎ウイルスの増殖機構とその制御に関する研究を行っている。本モデルを用いて、抗 HCV 薬であるピブレンタスビルは野生型 HCV には強力な抗ウイルス効果を有するが、NS5A-P32 欠失型 HCV など一部の変異型 HCV に対しては効果が低下すること（J General Virol 2019）、また海外との共同研究により HCV の持続感染により肝細内において epigenetic な遺伝子発現変化が生じ、その変化は抗ウイルス療法による HCV 排除後も長期的に維持され、肝発癌の誘因となっていること（Gastroenterology 2009）を見いだした。

We are currently investigating hepatitis virus virology and developing treatment against these viruses using human hepatocyte chimeric mouse. In this year, we showed that the effect of anti-hepatitis C virus (HCV) drugs are limited for a part of drug-resistant mutated HCV such as NS5A-P32deleted HCV (J General Virol 2019). We also found that epigenetic gene alterations in human hepatocytes induced by chronic HCV infection persists after HCV eradication by antiviral therapy and　associates with the risk of hepatocellular carcinoma development by collaborating with Strasbourg University (Gastroenterology 2019).

生体内環境を構築した in vitro 血管透過性亢進評価法の開発
Development of *in Vitro* Evaluation Technique of Vascular Hyperpermeability by Means of Impedance Sensor

教授　秀　道広（併任）
Prof. Michihiro Hide

助教　柳瀬雄輝（併任）
Assist. Prof. Yuhki Yanase



我々はこれまで、インピーダンスセンサ等のバイオセンサを利用した *in vitro* 血管透過性評価モデルの開発を進めてきた。その結果、インピーダンスセンサを利用して、実際の血管内環境に近い状態で、血管透過性の変化をリアルタイムに計測し得ることが示された。

ヒト末梢血単球、ヒト血管内皮細胞（HUVEC）、ヒト血漿共存下で、単球に発現する組織因子（TF）が血液凝固反応を駆動し、産生された活性化凝固因子（Xa, IIa）が血管透過性を亢進する過程をセンサチップ上で再現し、その変化をリアルタイムに検出することに成功した（Allergy. 2020;75:971-974）。

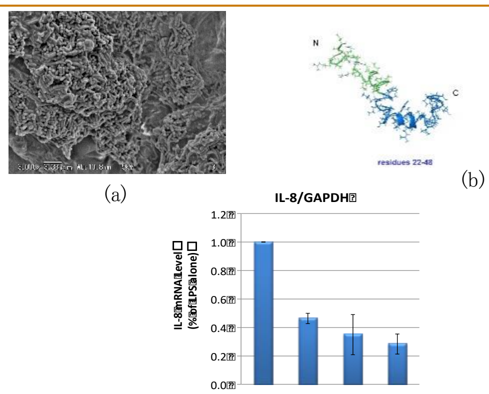
We successfully developed a technique for *in vitro* evaluation of vascular hyperpeameability in the presence of human endothelial cells, TF-expressing monocytes and plasma by means of impedance sensor.

L8020乳酸菌のバクテリオシン
Bacteriocin Derived from *L. Rhamunosus* L8020

教授　二川浩樹（併任）
Prof. Hiroki Nikawa

虫歯・歯周病を抑制する L8020 乳酸菌のバクテリオシン Kog1 には、抗菌作用だけでなく、歯周病菌の内毒素 LPS を不活性化させる作用がある。

Kog1, a bacteriocin produced by *L. rhamunosus* L8020 which suppress both cariogenic bacteria and periodontal burdens in oral cavity, inactivate the LPS produced by periodontal burdens.



(a) (b) (c)

L8020 乳酸菌(a)のバクテリオシン Kog1(b)は、歯周病菌の内毒素 LPS を不活性化させる作用がある(c)

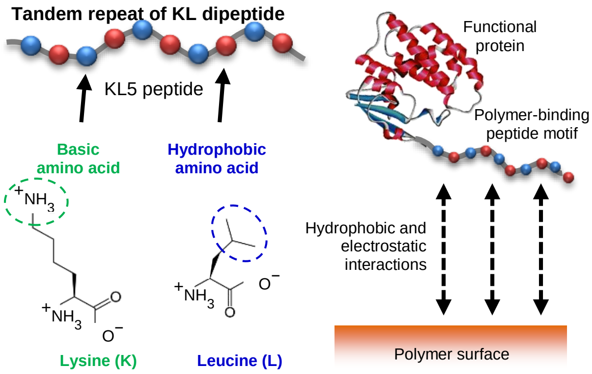
Kog1(b), a bacteriocin produced by *L. rhamunosus* L8020 (a) inactivate the LPS produced by periodontal burdens (c).

タンパク質固定用ペプチドモチーフ
Designing a Peptide Motif for Protein Tethering to Polymer Surfaces

教授　加藤功一（併任）
Prof. Koichi Kato

表面にタンパク質分子を固定化した高分子材料は様々な用途に応用することができる。我々は、生理的環境下で高分子材料表面に結合するペプチドモチーフを設計し、これを融合したタンパク質分子と高分子材料表面との相互作用について解析した。

Polymeric materials that tether protein molecules on the surface have a lot of potential applications. We designed a peptide motif that has an affinity for the surface of polymeric materials under physiological conditions and analyzed the interaction between proteins fused with the peptide motif and various polymer surfaces.

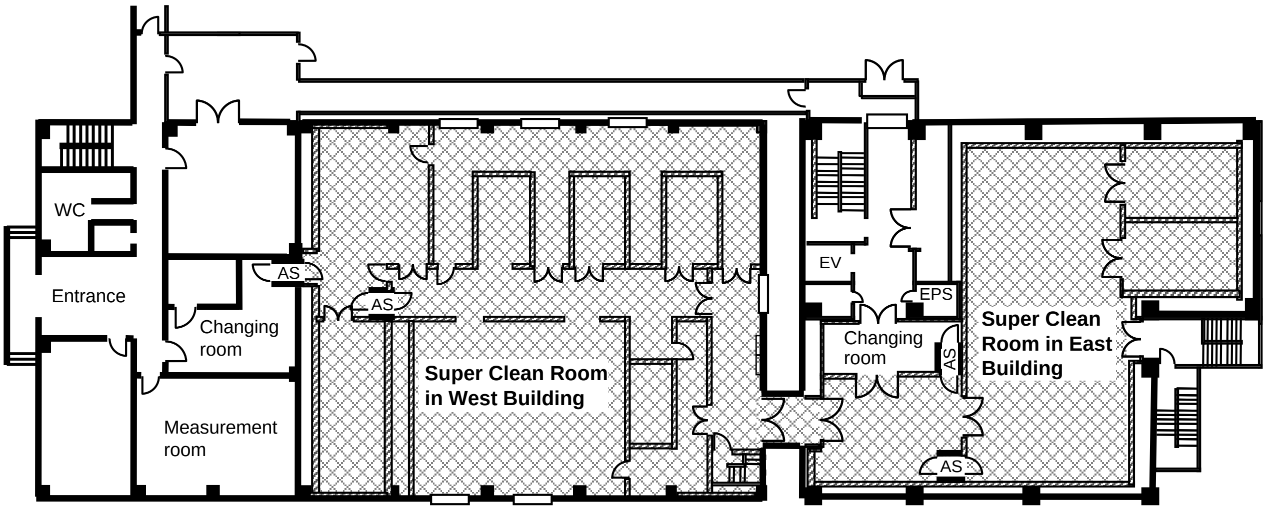


高分子表面に親和性をもつ KL5 ペプチドの設計
Designing KL5 peptide that has an affinity for polymer surfaces.

5. Research Facilities of RNBS
研究設備

5.1 Super clean rooms
スーパークリーンルーム

Super clean rooms, partly class 10 at 0.1-μm particles, are used for fabrication of advanced devices and LSI's.
先端デバイス及び LSI の製作はスーパークリーンルームで行われる。最も清浄度の高いセクションはクラス 10（1 立方フィート内に 0.1μm 以上の粒径の粒子が 10 個以下）である。



Plan view of clean rooms in west and east buildings. The total clean room area measures 830 m^2. Chemical filters are set in the east clean room to avoid hazardous gases.
西棟及び東棟クリーンルーム平面図。クリーンルーム総面積は 830m^2。東棟クリーンルームには危険ガス除去用のケミカルフィルターが設置されている。

Super clean room in west building.
西棟スーパークリーンルーム

Super clean room in east building.
東棟スーパークリーンルーム

5.2　Equipment for advanced devices and LSI fabrication

先端デバイス及びLSI作製のための設備

5.2.1　Lithography

リソグラフィー

◆ Variable rectangular-shaped electron beam lithography system (Hitachi HL700DII)

可変成形型電子ビーム描画装置
（日立　HL700DII）Resolution 50nm

◆ Point-beam type electron beam lithography system (JEOL JBX-5DII)　Resolution 50 nm

ポイントビーム型電子ビーム描画装置
（日本電子　JBX-5DII）Resolution 50nm

◆ Point-beam type electron beam lithography system (ELIONIX ELS-G100)

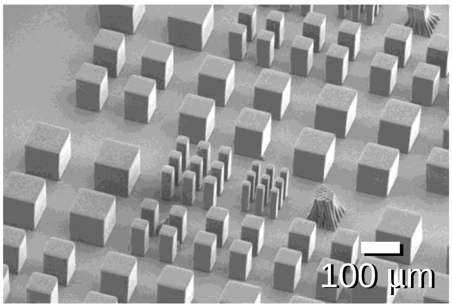
ポイントビーム型電子ビーム描画装置
（エリオニクス　ELS-G100）Resolution 6nm

◆ i-line optical stepper (Nikon NSR i8a)

i-線ステッパー
（ニコン　NSR i8a）Resolution 350nm

◆ Maskless photolithography system (Nanosystem Solutions D-light DL-1000)

マスクレス露光装置（ナノシステムソリューションズ　D-light DL-1000）　Resolution 1μm



Photoresist patterns by D-light DL-1000.
D-light DL-1000によるレジストパターン

5.2.2 Dry etching
ドライエッチング

- ICP (Inductively Coupled Plasma) etcher for Si (YOUTEC)

Si用ICP（誘導結合プラズマ）エッチング装置
（ユーテック） Cl_2, HBr, N_2, O_2 使用可能

- ECR (Electron Cyclotron Resonance) etchers for Si (KOBELCO)

Si用ECR（電子サイクロトロン共鳴）エッチング装置
（神戸製鋼） Cl_2, BCl_3, HBr, N_2, O_2 使用可能

- Si deep etching system (Sumitomo Precision Products)

Si用深堀りエッチング装置
（住友精密工業） C_4F_6, SF_6, Ar 使用可能

- ICP etcher for highly selective etching of SiO_2 (AYUMI INDUSTRY)

SiO_2用ICPエッチング装置
（アユミ工業） CF_4, H_2, O_2, Ar 使用可能

- ICP etcher for SiO_2 (SAMCO)

SiO_2用ICPエッチング装置
(サムコ) CF_4, H_2, O_2, Ar 使用可能

- RIE (Reactive Ion Etching) system for SiO_2 (KOBELCO)

SiO_2用RIE(反応性イオンエッチング)装置
（神戸製鋼） CF_4, H_2, O_2 使用可能

◆ ICP etcher for Al
(YOUTEC)

Al用ICPエッチング装置
（ユーテック）Cl_2, BCl_3, N_2 使用可能

◆ Magnetron RIE system for Al
(KOBELCO)

Al用マグネトロンRIE装置
（神戸製鋼）Cl_2, BCl_3, N_2 使用可能

◆ Chemical dry etching system for
Si_3N_4 and poly-Si (KOBELCO)

Si_3N_4及びSiO_2用ケミカルドライエッチング装置
（神戸製鋼）CF_4, N_2, O_2 使用可能

◆ Plasma asher for removing
photoresist (KOBELCO)

レジスト除去用プラズマアッシング装置
（神戸製鋼）N_2, O_2 使用可能

エッチング装置メンテナンス作業風景

During maintenance of dry etcher

酸化･拡散炉キャリア搬送風景

Wafer loading into furnace

5.2.3 Oxidation, annealing, and doping
酸化、アニール、不純物注入

◆ Oxidation and diffusion furnaces
(Tokyo Electron)

酸化・拡散炉
(東京エレクトロン) Max. Temp. 1150℃

◆ Ion implanter
(ULVAC)

イオン注入装置　Max 200 keV
(アルバック)　B, As, P 等注入可能

◆ RTA (Rapid Thermal Annealing) system
(Samco HT-1000)

高速熱処理装置
(サムコ　HT-1000) Max. Temp. raise rate 200℃/s

◆ Phosphorus diffusion furnaces
(SHINKO SEIKI)

リン拡散炉
(神港精機) Max. Temp.　900℃

◆ Annealing furnaces for general purpose
(Koyo Thermo System)

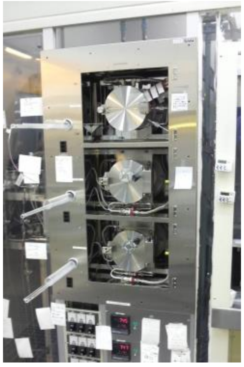
汎用熱処理装置 H_2, N_2, O_2, Low Pressure
(光洋サーモシステム) Max. Temp.　1000℃

酸化炉講習風景
Training of oxidation

5.2.4 Dielectric film deposition and epitaxial growth
絶縁膜堆積・エピタキシャル成長

◆ Low-pressure chemical vapor deposition (CVD) reactors for SiO_2, SiN, poly-Si (Tokyo Electron)

減圧CVD（化学気相成長）炉 （東京エレクトロン）
SiO_2, SiN, poly-Si堆積可能



◆ Atmospheric pressure CVD reactor for SiO_2
Doing of P and B possible (AMAYA)

SiO_2堆積用常圧CVD装置
(天谷製作所) PおよびBドープ可能

◆ Parallel plate type clean plasma CVD reactor for SiN, SiO_2, and amorphous Si (ULVAC)

平行平板型プラズマCVD装置 (アルバック)
SiN, SiO_2, アモルファスSi 堆積可能

◆ Molecular beam epitaxial growth system for GaAs and AlGaAs: Si, Be doping possible (EIKO)

分子線エピタキシャル成長装置
(エイコー) GaAs 等堆積可能

◆ Atomic layer CVD (ALCVD) reactor for SiN (Thermo Riko)

原子層CVD炉
(サーモ理工) SiN 堆積可能

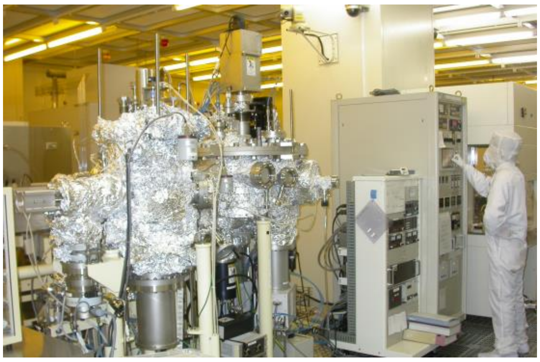
常圧CVDウェハセッティング風景

Wafer setting to atmospheric CVD reactor

5.2.5 Metal deposition
金属薄膜堆積

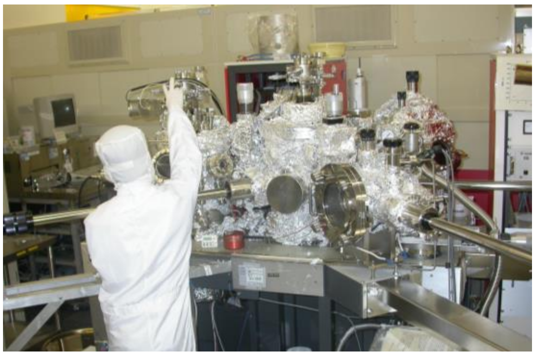
◆ Metal/dielectrics sputtering system for BiSrTiO compound etc. (ULVAC)

金属/絶縁膜スパッタリング装置 (アルバック)
BiSrTiO等堆積可能



◆ Sputtering machine for metal interconnects for Al, Ti, TiN (EIKO)

金属配線用スパッタリング装置 (エイコー)
Al, Ti, TiN 堆積可能



◆ Electron beam evaporation system for many kinds of metals (EIKO)

電子ビーム蒸着装置
(エイ コー) 多種材料堆積

◆ Sputtering system for general purpose for variety materials (EIKO)

汎用スパッタ装置
(エイコー) 広範な材料堆積

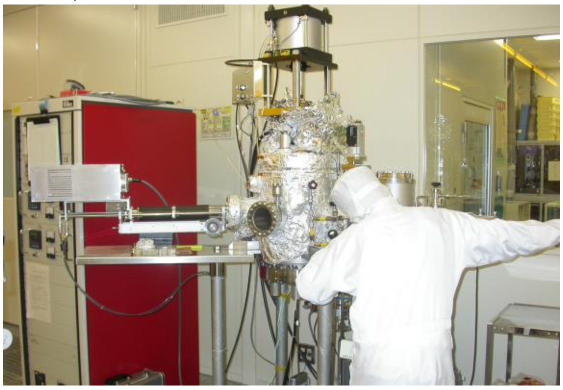
◆ Vacuum evaporation system for variety of metals (Donated: RICOH)

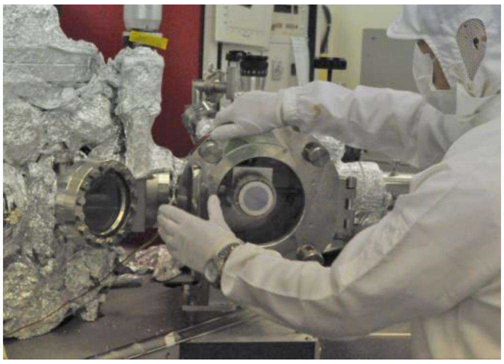
真空蒸着装置
(寄贈:リコー) Al 等堆積可能

5.2.6 Others
その他

◆ Surface-activated bonding system (EIKO)

表面活性化接合装置 (エイ コー)
Ar, H_2 Plasma treatment 可能





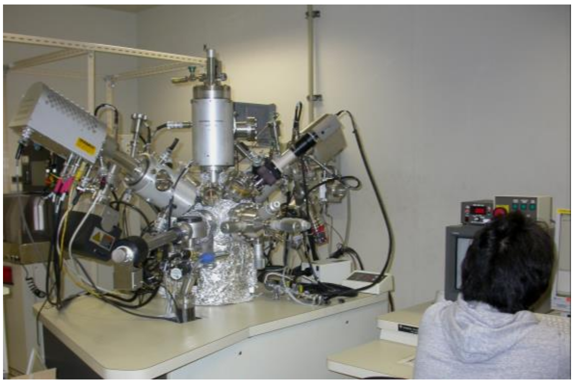
スパッタリング装置ウェハセッティング風景

Wafer setting to sputtering machine

5.3 Characterization and diagnostics equipment
評価・分析装置

◆ Secondary ion mass spectroscopy (SIMS) system with Cs and O ion gun (ULVAC-PHI PHI-6650)

2次イオン質量分析装置 (アルバック-ファイ PHI-6650) Cs, Oガン装備



◆ Total reflection of X-ray fluorescence spectrometer (Technos TREX-610)

全反射蛍光X線分析装置 (Technos TREX-610) 感度(Cr-Zn) 10^{10} atom/cm^2

◆ Fourier-transform infrared spectrometer (FTIR) (JEOL)

フーリエ変換赤外分光光度計（日本電子）Resolution 0.5cm^{-1}

◆ Atomic force microscope (AFM) (Seiko Instruments Inc. SPI3800)

原子間力顕微鏡（セイコーインスツルメンツ SPI3800）Resolution Z:0.01nm, X, Y:0.1nm

◆ High resolution X-ray diffractometer (Rigaku ATX-E)

高解像度X線回折装置 (リガク ATX-E) Angle resolution 0.0002°

◆ X-ray diffractometer (Rigaku RINT2100)

X線回折装置 (リガク RINT2100)

◆ Ellipsometer
(Rudolph Research Auto EL)

エリプソメーター（ルドルフリサーチ Auto EL）
Measurable thickness > 10nm

◆ Spectroscopic ellipsometer
(J.A.Woollam JAPAN M-2000D)

分光エリプソメーター（ジェー・エー・ウーラム・ジャパン M-2000D）Measurable thickness > 10nm

◆ Hall effect measurement system
(ACCENT HL5500PC)

ホール効果測定装置 (ACCENT HL5500PC)
Input impedance $10^{10}\,\Omega$

◆ High-resolution X-ray photoelectron spectroscopy
(XPS) system (KRATOS ESCA-3400)

X線光電子分光分析装置
(KRATOS ESCA-3400) X ray source：Mg, Ka

◆ High-resolution X-ray photoelectron spectroscopy (XPS) system (VG Scienta ESCA-300)

X線光電子分光分析装置 (VGシエンタ ESCA-300) Radius of analyzer：300mm, X-ray source：4kW

◆ Field emission scanning electron microscope (FE-SEM) (Hitachi S4700)

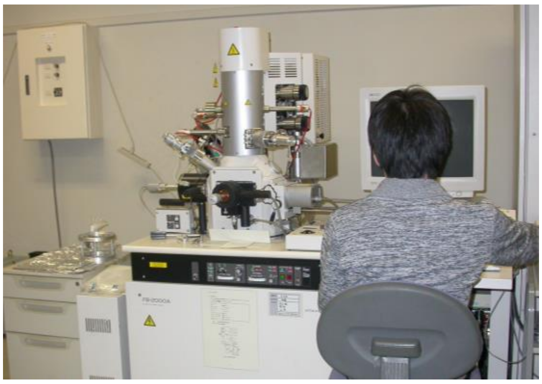
電界放出型走査電子顕微鏡

（日立　S4700）Resolution 1.5nm

◆ Focused ion (Ga) beam (FIB) system (Hitachi FB-2000)

集束イオン(Ga)ビーム加工装置

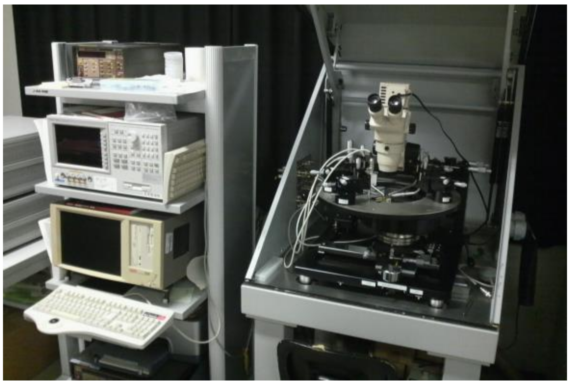
（日立　FB-2000）Min. beam diameter 10nm



◆ Manual wafer prober (Vector Semiconductor) and semiconductor parameter analyzer (Keithley)

マニュアルプローバー(ベクターセミコン)及び

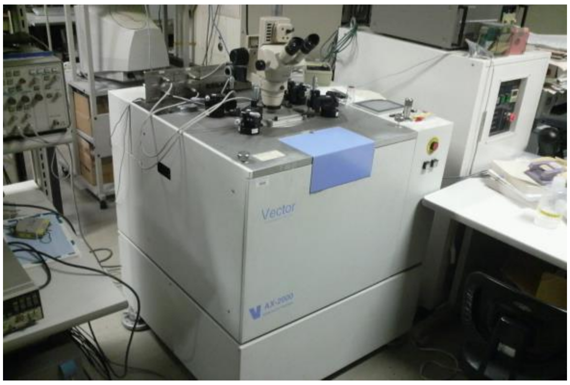
半導体パラメーターアナライザー(ケースレー)



◆ Semi-automatic wafer prober (Vector Semiconductor AX-2000)

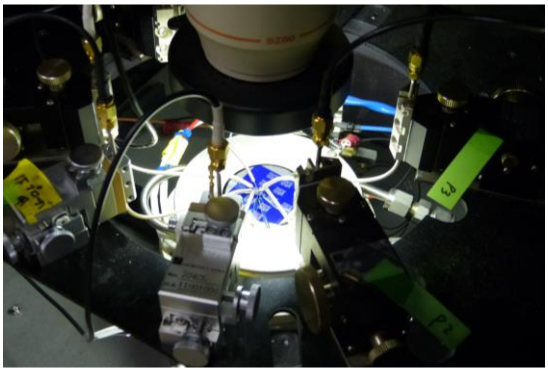
セミオートプローバー

(ベクターセミコンAX-2000)



SEMロードロック室へのウェハセッティング風景

Wafer setting to SEM load-lock chamber



マニュアルプローバーによる電気特性測定

Measuring electrical properties using manual prober

5.4 VLSI CAD environment

VLSI設計用CAD環境

5.4.1 Hardware

ハードウェア

Workstations

◆ SUN: 11 machines (SunFire X4600×1, SunFire V440×2, SunBlade2500×2, SunBlade2000×3, SunBlade1000×3)

◆ HP: 9 machines (ProLiant DL580G5×3, xw9300×1, xw8600×1, j6750×1, c8000×2, b2000×1)

Workstations for TCAD and LSI design
TCAD及びLSIデザイン用ワークステーション

5.4.2 Software

ソフトウェア

TCAD tools

◆ Process/Device Simulators: SYNOPSYS TSUPREM4/MEDICI, ISE TCAD, SYNOPSYS Sentaurus, Selete ENEXSS

Other simulators

◆ Electromagnetic Field Simulators: ANSOFT HFSS, CST Microwave Studio

◆ Optical Wave-guide Simulator: Apollo Photonics APSS

LSI design tools

◆ Layout Design: CADENCE Virtuoso*, JEDAT alpha-SX(ISMO), Silvaco Expert*

- ◆ Schematic Design: CADENCE Composer*, JEDAT alpha-SX(ASCA), Silvaco Gateway
- ◆ Functional Simulators: CADENCE SPW*, Mathworks MATLAB
- ◆ Circuit Simulators: CADENCE Artist*, Spectre*, Silvaco SmartSpice*, SYNOPSYS Star-HSPICE*, HSIM*, TimeMill/PowerMill*, NanoSim*
- ◆ Logic Simulators: CADENCE NC-Verilog*, VerilogXL*, MENTOR ModelSim*, SYNOPSYS VSS*
- ◆ Logic Synthesis: ALTERA QuartusII, CADENCE HDL Compiler*, SYNOPSYS Design Compiler*, FPGA Compiler*, XILINX ISE Foundation
- ◆ Automatic P&R: SYNOPSYS Milkyway*, Astro*, IC-Compiler*, CADENCE SoC-Encounter*
- ◆ Verification: CADENCE Diva*, Dracula*, Assura*, JEDAT Layver, MENTOR Calibre*, SYNOPSYS Hercules*

Notice that various kinds of popular CAD software (marked with “*”) which support Verilog HDL/VHDL simulation, synthesis, layout design and verification for digital/analog VLSIs are provided by VLSI Design and Education Center (VDEC), the University of Tokyo.

6. List of Publications

6.1 Advanced device, process, and material technologies for ULSI

6.1.1 Fabrication techniques for MOS devices and TFTs

[1] V. V. Cuong, S. Ishikawa, T. Maeda, H. Sezaki, Y. Satoshi, T. Koganezawa, T. Miyazaki, S.-I. Kuroki, “Influence of Ni and Nb thickness on low specific contact resistance and high-temperature reliability of ohmic contacts to 4H-SiC,” Jpn. J. Appl. Phys. **58**, 116501-1 - 116501-8, 2019.

[2] K. Muraoka, H. Sezaki, S. Ishikawa, T. Maeda, T. Makino, A. Takeyama, T. Ohshima and S.-I. Kuroki, “Gamma-ray irradiation-induced mobility enhancement of 4H-SiC NMOSFETs with a Ba-silicate interface layer,” Jpn. J. Appl. Phys. **58**, 081007-1- 081007-7, 2019.

[3] F. Hasebe, T. Meguro, T. Makino, T. Ohshima, Y. Tanaka, S.-I. Kuroki, “Direct Bonding of 4H-SiC and SOI Wafers for Radiation-Hardened Image Sensors,” Mat. Sci. Forum, 963, pp. 726-729, 2019.

[4] V. V. Cuong, S. Ishikawa, H. Sezaki, T. Maeda, S. Yasuno, T. Koganezawa, S.-I. Kuroki, “Optimization of Ni/Nb Ratio for High-Temperature-Reliable Ni/Nb Silicide Ohmic Contact on 4H-SiC,” Mat. Sci. Forum, 963, pp. 498-501, 2019.

[5] K. Muraoka, S. Ishikawa, H. Sezaki, T. Maeda, S.-I. Kuroki, “Characterization of Ba-Introduced Thin Gate Oxide on 4H-SiC,” Mat. Sci. Forum, 963, pp. 451-455, 2019.

[6] K. Muraoka, S. Ishikawa, H. Sezaki, T. Maeda, and S.-I. Kuroki, “Thickness Dependences on Interfacial Properties of SiO2/BaO2 layers on 4H-SiC (0001) ,” 8th International Symposium on Control of Semiconductor Interfaces (ISCSI-VIII), WP2-12, 2019.

[7] K. Nishigaito, T. Meguro, A. Takeyama, T. Ohshima, Y. Tanaka and S.-I. Kuroki, “4H-SiC Pixel Device with UV Photodiode and MOSFETs for Radiation-Hardened UV Image Sensors,” International Conference on Silicon Carbide and Related Materials 2019 (ICSCRM2019), TH.P.44, 2019.

[8] T. Okada, J. Inoue, F. Nishiyama, H. Sezaki, and S.-I. Kuroki, “Suppression of Ion Channeling Effects in 4H-SiC Substrate by Tilt Angle Control of Ion Implantation,” The International Conference on Silicon Carbide and Related Materials 2019 (ICSCRM2019), MO.P.33, 2019.

[9] V. V. Cuong, S. Ishikawa, T. Maeda, H. Sezaki, and S.-I. Kuroki, “Characterization of 4H-SiC MOS Capacitors with Different Metal Gates after 400°C High-Temperature Aging Tests,” The International Conference

on Silicon Carbide and Related Materials 2019 (ICSCRM2019), MO.P.33, 2019.

[10] V. V. Cuong, S. Ishikawa, T. Maeda, H. Sezaki, K. Muraoka, T. Meguro, and S.-I. Kuroki, “High Temperature Reliability of 4H-SiC Devices and Single Stage 4H-SiC MOSFET Amplifier at 400ºC,” The International Conference on Silicon Carbide and Related Materials 2019 (ICSCRM2019), We.P.55LN, 2019.

[11] T. Meguro, F. Hasebe, A. Takeyama, T. Ohshima, Y. Tanaka, and S.-I. Kuroki, “Pixel Array Integration with SOI-Si photodiode and 4H-SiC MOSFETs for Radiation-Hardened image sensors,” The International Conference on Silicon Carbide and Related Materials 2019 (ICSCRM2019), Th.P.30, 2019.

[12] A. Takeyama, K. Shimizu, T. Makino, Y. Yamazaki, S. Kuroki, Y. Tanaka, T. Ohshima, “Radiation hardness of 4H-SiC JFETs in MGy dose ranges,” The International Conference on Silicon Carbide and Related Materials 2019 (ICSCRM2019), Th.P.43, 2019.

[13] J. Inoue, S.-I. Kuroki, S. Ishikawa, T. Maeda, H. Sezaki, T. Makino, T. Ohshima, M. Östling, C.-M. Zetterling, “4H-SiC Trench pMOSFETs for High-Frequency CMOS Inverters,” Mat. Sci. Forum, 963, pp. 837-840, 2019.

[14] T. Ishii, S.-I. Kuroki, H. Sezaki, S. Ishikawa, T. Maeda, T. Makino, T. Ohshima, M. Östling, C.-M. Zetterling, “Suppression of Short-Channel Effects in 4H-SiC Trench MOSFETs,” Mat. Sci. Forum, 963, pp. 613-616, 2019.

[15] T. T. Nguyen and S.-I. Kuroki, “Dependence of thin film transistor characteristics on low-angle grain boundaries of (100)-oriented polycrystalline silicon thin film,” Jpn. J. Appl. Phys. 58 , SBBJ08-1- SBBJ08-6, 2019.

[16] A. Teramoto, J. Tsuchimoto, H. Park, M. Hayashi, K. Tsunekawa, T. Suwa, R. Kuroda, and S. Sugawa, “Dielectric breakdown of MgO in MRAM,” Special MRAM poster session IEDM, San Francisco, 2019.

[17] T. Maeda, Y. Omura, R. Kuroda, A. Teramoto, T. Suwa, and S. Sugawa, “A high-precision 1 Ω–10 MΩ range resistance measurement platform for statistical evaluation of emerging memory materials,” Japanese Journal of Applied Physics, **59**, SGGL03, 2020.

[18] H. Park, A. Teramoto, J. Tsuchimoto, K. Hashimoto, T. Suwa, M. Hayashi, R. Kuroda, K. Tsunekawa, and S. Sugawa, “High reliability CoFeB/MgO/CoFeB magnetic tunnel junction fabrication using low-damage ion beam etching,” Japanese Journal of Applied Physics, **59**, SGGB05, 2020.

[19] Y. Shiba, A. Teramoto, T. Suwa, K. Ishii, A. Shimizu, K. Umezawa, R. Kuroda, and S. Sugawa, “Low-Temperature Deposition of Silicon Nitride Films Using Ultraviolet-Irradiated Ammonia,” ECS Journal of Solid State Science and Technology, **8**(11), P715-P718, 2019.

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