National Chiao Tung University and Tohoku University International Joint Laboratory Activities Report (August 2018 - July 2021)

Term 1

“Striving to build a strategic international platform for research and education”

――Making Japan a “Semiconductor Nation” Again――

June 14, 2021

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Preface

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Taiwan is today the world's foremost semiconductor nation and in research and development, it is the world's leader in cutting-edge technologies. The global hub of this semiconductor-device research and development is Hsinchu Science Park centered about National Chiao Tung University. Based on an ideal industry-government-academia collaborative system established in Hsinchu Science Park as a business ecosystem, National Chiao Tung University is an institution having world-class expertise in the research and development of semiconductor devices, circuits, and systems. Now, with the IoT and AI era in sight, it is becoming a platform for AI chips (Taiwan Moon Shot Project has been already started.) as a foundation for those technologies, and in parallel with this development, it is expanding its education in semiconductor devices and systems. In addition to attracting top-notch students from Asia and around the world, National Chiao Tung University is developing high-quality semiconductor researchers and engineers for the AI society across a wide range of educational programs in electronics.

We are convinced that, with regard to the global dissemination of Tohoku University original "materials process", "nano-device" and "sensor technologies" for Hydrogen Energy, Nano-device system and Bio-medical sensor network developed up to now and their application, it is more effective to pursue these activities at National Chiao Tung University via the industry-government-academia collaborative system. We are greatly interested in collaborating with National Chiao Tung University that, among all universities in Taiwan, is the most specialized in industry-government-academia collaboration in meeting the challenges of AI technologies. By cultivating a strong partnership (best friendship) between NCTU and Tohoku University in this way, we would like to build up the world's most advanced and practical industry-government-academia research and development hub (including educations) in both universities. Through these activities, we would also like to contribute to the vitalization of Japan's and Taiwan's electronics industry based on international collaboration.

Activities Report for the National Chiao Tung University and Tohoku University International Joint Laboratory (August 2018 - July 2021)

Term 1 "Striving to build a strategic international platform for research and education"

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1. Background of the Establishment of the International Joint Laboratory

By 2017, Tohoku University had carried out academic exchanges over an extended period with National Chiao Tung University (Taiwan). Much collaborative research was performed, and human exchanges of instructors and students were made centered around the New Industry Creation Hatchery Center, the Institute of Fluid Science, the Graduate School of Engineering, the Graduate School of Science, and the Advanced Institute for Atomic and Molecular Materials Research (now the Advanced Institute for Materials Research) (**Figure 1**).

Figure 1. History of National Chiao Tung University and Tohoku University Exchanges

An agreement was concluded between the universities in 2015, with the New Industry Creation Hatchery Center as the responsible department and the Graduate School of Engineering as a related department, to promote research and educational exchanges in the field of semiconductor devices. Following this, a joint workshop on nanotechnology and nanodevices was held by the Institute of Fluid Science together with National Chiao Tung University in 2010, and the broad cooperative relationship in the fields of semiconductors and nanodevices was strengthened. Based on these results, the Institute of Fluid Science and the Graduate School of Science became related departments in 2010, in addition to the New Industry Creation Hatchery Center and the Graduate School of Engineering which were already related departments, and the cooperative agreement between the universities was renewed. Furthermore, between 2010 and 2014, the Institute of Fluid Science, the Advanced Institute for Atomic and Molecular Materials Research, and National Chiao Tung University made brisk progress in collaborative research on quantum nanodevices. In 2014 the Advanced Institute for Atomic and Molecular Materials Research and Taiwan's National Chiao Tung University held a joint workshop on materials science, math, and nanodevices. In 2016 the agreement between the universities was renewed for a second time for the purpose of strong cooperation for an even broader range of subjects. In 2017 the Research Institute of Electrical Communication and National Chiao Tung University started the JST-supported "Infrastructure Development for Promoting International S&T Cooperation (Japan-Taiwan)" program and also began collaborative project research. 2018 saw the establishment of the Network Joint Research Center for Materials and Devices, where the Institute of Multidisciplinary Research for Advanced Materials works in cooperation with Hokkaido University, the Tokyo Institute of Technology, Osaka University, and Kyushu University, as well as the establishment of the National Chiao Tung University's collaborative research and education center at National Chiao Tung University's College of Science. The first symposium was also held in 2018. Having achieved this sort of active, university-wide accumulation of exchanges, a liaison office was established between the universities in 2017, aiming to realize a program of student exchanges and establish an international joint laboratory.

In Taiwan, the Ministry of Education and the Ministry of Science and Technology have been promoting the establishment of joint laboratories in collaboration with well-known overseas universities for the purpose of driving cutting-edge research and education as well as the internationalization of the universities. National Chiao Tung University has produced research results and papers that are top-class internationally for the field of microelectronics, and it is no exaggeration to say that it has supported the development of the electronics industry in Taiwan, which is now the global leader in semiconductors, on both the research and human resources development fronts. The university has also put an exceptional amount of effort into exchanges of students and research with overseas institutions. It has agreed to establish separate liaison offices and joint research centers with UC Berkeley; the University of Illinois, Urbana-Champaign; Carnegie Mellon University; Chalmers University of Technology; the University of Paris; and more. And it has aimed for cooperation in research and education that makes use of the special characteristics of each institution. Amidst this background, Tohoku University and National Chiao Tung University agreed to establish a joint laboratory to realize collaboration in academic research for the fields of materials science, where

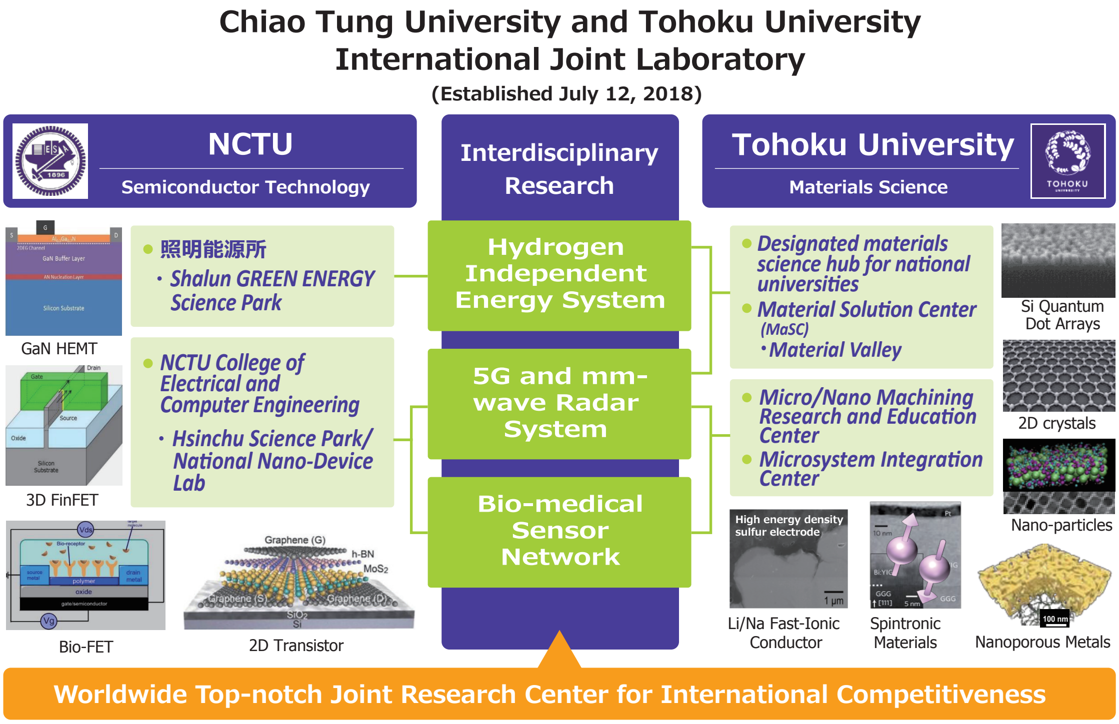


Figure 2. Concept for the National Chiao Tung University and Tohoku University International Joint Laboratory

Tohoku University has its strengths and is top-class globally, and semiconductor technology, where National Chiao Tung University has its strengths and is top-class globally. Through this joint laboratory the universities seek to make rapid developments in research and education (**Figure 2**).

As for the areas of research for this joint laboratory, the lab would have as its objective the tackling of urgent tasks in three fields through cooperation and the building of an academic base for problem solving through the integration of the materials sciences and semiconductor technology. The three fields are 1) energy device systems, 2) nanodevice systems, and 3) biomedical sensor networks. As these research areas straddle multiple departments, it is absolutely necessary to tackle them with a university-wide system. For instance, energy device systems straddle the Institute for Materials Research, the Institute of Fluid Science, the Advanced Institute for Materials Research, the Institute of Multidisciplinary Research for Advanced Materials, the Graduate School of Environmental Sciences, and the Graduate School of Engineering; nanodevice systems straddle the Institute of Fluid Science, the Research Institute of Electrical Communication, the Institute for Materials Research, the New Industry Creation Hatchery Center, and the Graduate School of Engineering; and biomedical sensor networks straddle the Graduate School of Biomedical Engineering, the Graduate School of Engineering, and the Institute of Fluid Science. Tohoku University built the joint laboratory within its International Joint Lab Center, which is positioned within the Advanced Research Office, and through the promotion of international collaborative research, the university is building an academic base for “realizing a smart society that can be sustainably developed amidst population decline and super-ageing,” the importance of which is greater than ever for both Japan and Taiwan. There are expectations that the joint laboratory will serve as a hub for the accumulation and circulation of international knowledge in its role as a receptacle for researchers from throughout the university, for human exchanges with National Chiao Tung University and the Hsinchu Science Park, and for collaborative research related to MEMS, nanotechnology, and the materials sciences, Tohoku University's forte. In this way, the international joint laboratory established at Tohoku University serves as the parent body for the promotion of international collaborative research in cooperation with National Chiao Tung University as a hub of Tohoku University, and it is expected that this laboratory will allow for more opportunities for short and long-term stays for instructors, more regular workshops, more collaborative proposals for collaborative research, and an expansion in regular student exchanges.

2. Conditions at the Joint Laboratory Established at National Chiao Tung University

Taiwan is now the leader in the global semiconductor industry, having pulled ahead of the United States and South Korea. In other words, the country's electronics industry is at the forefront of advanced technological trends. Central to this dominance is the Taiwan Semiconductor Manufacturing Company (TSMC), which now even surpasses the American company Intel. TSMC is an extremely innovative company that led the world in establishing the foundry business model. Hsinchu Science Park's world-leading platform (centered on Chiao Tung University and TSRI) also provides significant support. This is the result of Taiwan having steadily accumulated basic technology at the Hsinchu Science Park over fifty years. This once again demonstrates the importance of accumulating basic technology, something that Japan has forgotten, and should be studied for the purpose of "making Japan a 'semiconductor nation' again."

Taiwan's National Chiao Tung University was established in 1896 and is located in the Hschinchu Science Park, Hsinchu City, Taiwan. The university has 13,058 students (7,762 graduate students, 5,296 undergraduate students) and 700 instructors/researchers. It is fully equipped with management buildings, buildings for experiments, student dorms, and guest houses. Furthermore, it neighbors the Taiwan Semiconductor Research Institute (TSRI), which is the platform for semiconductors in Taiwan, and the National Synchrotron Radiation Research Center. It is a global base of cooperation between industry, government, and academia for semiconductor device research.

The International Joint Laboratory with Tohoku University is set up on the first floor of National Chiao Tung University's Engineering Building No. 5 (**Figure 3**, **Figure 4**. Neighbors the international collaborative research center of the internationally top-class semiconductor manufacturer TSMC. The liaison office and the joint lab have been set up next to each other). Instructors and students from Tohoku University make short and long-term stays at the joint lab, and the lab promotes international collaborative research between industry, government, and academia. Faculty dispatched from Tohoku University stay at the liaison office, and researchers and students from Chiao Tung University (one postdoc, two doctoral students; Tohoku University Professor Samukawa acts as a co-advisor) and Tohoku University serve as members of/enroll at the international joint laboratory. At the same time, National Chiao Tung University's joint laboratory

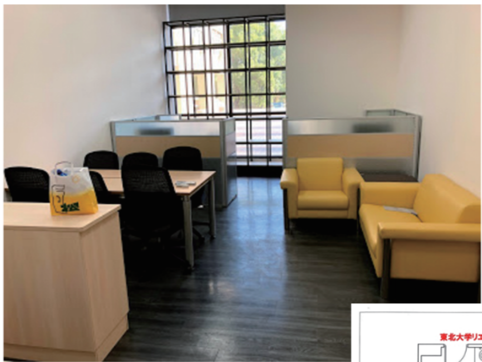
National Chiao Tung University and Tohoku University International Joint Laboratory

Chiao Tung University and Tohoku University International Joint Laboratory established on the Chiao Tung University campus
(adjacent to Chiao Tung University/TSMC's collaborative research center)

Figure 3. National Chiao Tung University and Tohoku University International Joint Laboratory (National Chiao Tung University Engineering Building No. 5)

Tohoku University Liaison Office and Joint Laboratory

(December 14, 2018)



Liaison Office

Joint Laboratory

Figure 4. National Chiao Tung University and Tohoku University International Joint Laboratory Office (Engineering Building No. 5)

has been set up on the fourth floor of the Material Solutions Center (MaSC) on the Katahira campus at Tohoku University where researchers from National Chiao Tung University are invited to promote international collaborative research. Furthermore, Taiwan's National Chiao Tung University applied to the Ministry of Education and the Ministry of Science and Technology for a five year international project and the establishment of a joint research center to deepen cooperation with international research hubs based on cooperation with Tohoku University so that there have been budgetary provisions in effect since April 2018 extending for five years (NT$1,500,000 for operating expenses, including travel expenses, lodging expenses, and staff employment expenses for Tohoku University researchers). At the same time, at Tohoku University instructors have obtained collaborative research funds with companies and competitive funds from the "Infrastructure Development for Promoting International S&T Cooperation" program (supported by JST and MOST), A-STEP (a JST program), Basic Research S, Basic Research A, and the Cross-Ministerial Strategic Innovation Promotion Program. Consequently, activities at National Chiao Tung University, which is at the core of the International Joint Laboratory, are substantive. Instructors and students from Tohoku University make short or long-term stays and promote international collaborative research between industry, the government, and academia while making use of already installed, state-of-the-art equipment for trials and xperiments.

3. Specific Research System (Names of Researchers, Research Details, Periods, Research Locations, etc.)

The management organization and research system (draft) for the joint laboratory is as indicated in **Figure 5** and **Table 1**. The university has established an executive committee composed of six individuals : (then) Director Hayasaka from Tohoku University, head of the Advanced Research Office, and National Chiao Tung University's Professor T.S. Lee, Vice-President for Research,

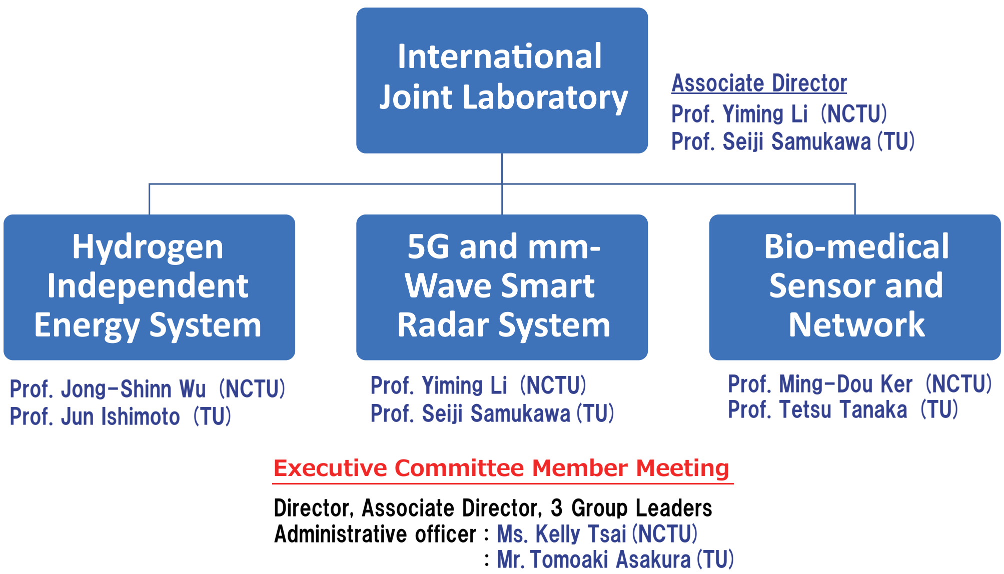


Figure 5. National Chiao Tung University and Tohoku University Management Organization

Table 1 (a). Research Areas, Area Chiefs, and Area Members (at Launch)

Research Areas	Persons Responsible at Tohoku University	Persons Responsible at Chiao Tung University	Tohoku University Core Members
1) Energy Device Systems	Professor Seiji Samukawa (IFS/ AIMR) Specially Appointed Professor Tatsuoji Kono (IMR)	Professor Der-Ray Huang	Professor Shinichi Orimo (AIMR/ IMR) Specially Appointed Professor Michiaki Yumoto (IMR) Professor Takashi Tokumasu (IFS) Associate Professor Masaki Mizuguchi (IMR) Professor Koji Amezawa (IMRAM) Professor Hitoshi Takamura (SE) Professor Toshimasa Wada (SES)
2) Nanodevice Systems	Professor Seiji Samukawa (IFS/ AIMR)	Professor Jenn-Hwan Tarng	Professor Akinobu Teramoto (Niche) Professor Takahito Ono (SE) Professor Qiangjiao Chen (SE) Professor Takashi Matsuoka (IMR) Professor Noriharu Suematsu (CIES)
3) Biomedical Sensor Networks	Professor Tetsu Tanaka (SBE)	Professor Ming-Dou Ker	Professor Takahito Ono (SE) Professor Makoto Ota (IFS) Professor Takehito Sato (IFS)

Table 1 (b). Research Areas, Area Chiefs, and Area Members (Current)

Research Areas	Persons Responsible at Tohoku University	Persons Responsible at Chiao Tung University	Tohoku University Core Members
1) Energy Device Systems	Professor Jun Ishimoto (IFS)	Professor Jong-Shinn Wu	Professor Takashi Tokumasu (IFS) Associate Professor Masaki Mizuguchi (IMR) Professor Koji Amezawa (IMRAM) Professor Hitoshi Takamura (SE) Professor Toshimasa Wada (SES)
2) Nanodevice Systems	Professor Seiji Samukawa (IFS/ AIMR)	Professor Jenn-Hwan Tarng	Professor Akinobu Teramoto (Niche) Professor Takahito Ono (SE) Professor Qiangjiao Chen (SE) Professor Takashi Matsuoka (IMR) Professor Noriharu Suematsu (CIES) Professor Junichi Murota (Micro System Integration Center)
3) Biomedical Sensor Networks	Professor Tetsu Tanaka (SBE)	Professor Ming-Dou Ker	Professor Takahito Ono (SE) Professor Makoto Ota (IFS) Professor Takehito Sato (IFS)

Institute of Materials Research: IMR, Institute of Fluid Science: IFS, Advanced Institute for Materials Research: AIMR, Center for Innovative Integrated Electronic Systems: CIES, Graduate School of Engineering: SE, Graduate School of Science: SS, Graduate School of Environmental Sciences: SES, Graduate School of Biomedical Engineering: SBE, New Industry Creation Hatchery Center: Niche

serve as lab leaders, Professor Samukawa from Tohoku University and Professor Li from National Chiao Tung University serve as subleaders of the lab, and there is also an individual in charge of clerical work, an individual in charge of financial affairs, and a research areas chief. The committee undertakes the management of the joint laboratory.

Table 1 (a) shows a list of the members at the time of launch in 2018. From Tohoku University's side, the launch was done with a university-wide framework, with instructors participating from the Institute for Materials Research, the Institute of Fluid Science, the Advanced Institute for Materials Research, the Research Institute of Electrical Communication, the Graduate School of Engineering, the Graduate School of Science, the Graduate School of Environmental Sciences, the Graduate School of Biomedical Engineering, and the New Industry Creation Hatchery Center. Although there was an addition of some members in the 2018-2021 period for the nanodevice systems group and the biomedical sensor networks group, collaborative research has continued to move forward with hardly any change to the members. At the same time, in the energy device systems group, Samukawa, who was initially serving as the head of the Unexplored Energy Research Center at the Institute of Fluid Science, took up the additional post of group leader while Professor Der-Ray Huang, an authority on hydrogen energy in Taiwan, also began work. "Renewable energy derived from hydrogen-based autonomous energy systems" was raised as a collaborative research theme, Specially Appointed Professor Kono Tatsuoki, a specialist at the Institute for Materials Research, was asked to be a group leader for the start of the drafting of a research plan, and a plan was drafted. However, Professor Der-Ray Huang of National Chiao Tung University passed away from illness in spring of 2019, the baton was hurriedly passed to Professor Jong-Shinn Wu, famous as a rocket researcher, and the drafting of a plan was carried out once more. Furthermore, on the Tohoku University side as well, Specially Appointed Professor Kono Tatsuoki began to focus solely on his original work beginning in 2019 due to the circumstances of his work, and Professor Samukawa was asked by Professor Ishimoto Jun, who had succeeded him as center chief, to serve as the group leader when Professor Samukawa resigned from his post as head of the Unexplored Energy Research Center.

4. Overview of the Results of Collaborative Research

1) Nanodevice Systems Group

Figure 6 shows the current roadmap for cutting-edge semiconductor technology. As of 2020, TSMC was building the most cutting-edge devices in the world, and 7/5 nm generation devices made with three-dimensional FinFETs were the main type of devices being mass produced. 5/3 nm generation devices will be introduced to the market beginning in 2022 and 3/2 nm generation devices will be introduced beginning in 2025.

At the time of launch for the National Chiao Tung University and Tohoku University International Joint Laboratory in 2018, Tohoku University, Chiao Tung University, and TSRI had already achieved the first sub-7-nm GE FinFET in the world using neutral beam technology in collaborative research as shown in **Figure 7** (High Performance Complementary Ge Peaking FinFETs by Room Temperature Neutral Beam Oxidation for Sub-7 nm Technology Node Applications., IEEE International Electron Devices Meeting , 33.5 (San Francisco, 12/07/2016)). The nanodevice systems group at the National Chiao Tung University and Tohoku University International Joint Laboratory then set a goal of developing cutting-edge 5/3 nm and 3/2 nm generation semiconductor devices.

First, in 2018 the group worked to develop the GAA and nanosheet structures that will be

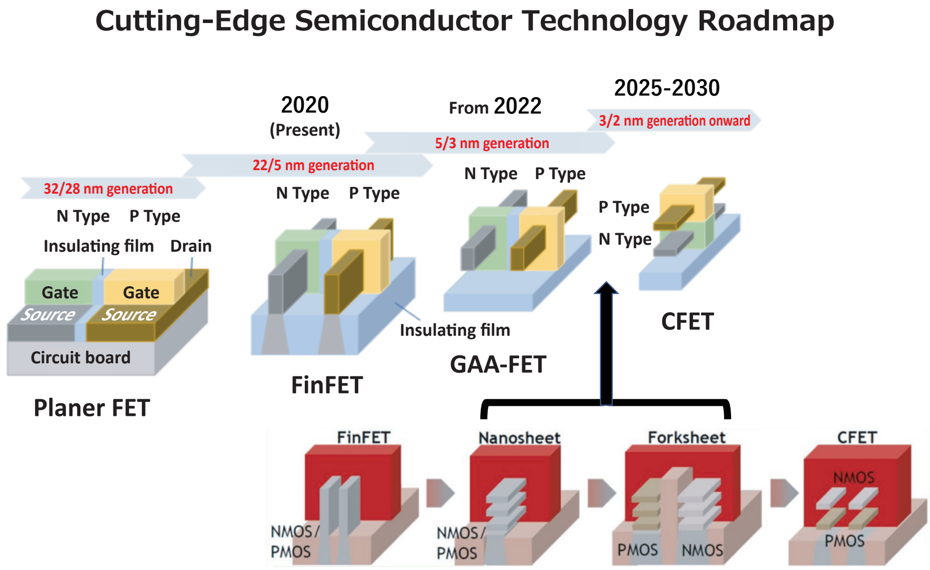


Figure 6. Cutting-Edge Semiconductor Technology Roadmap

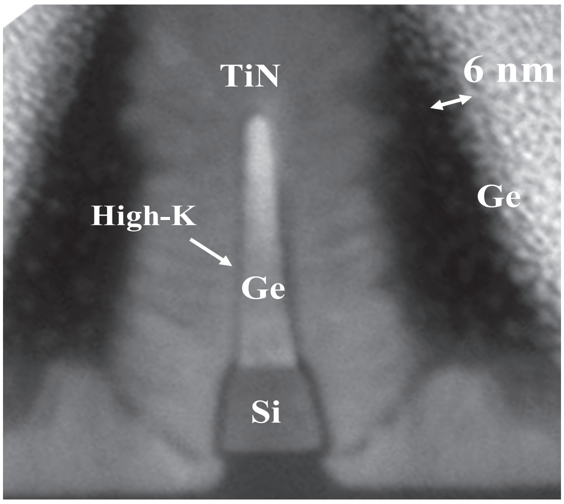


Figure 7. Sub-7-nm Ge FinFETs Using Neutral Particle Beams

predominate in the 5/3 nm generations. As a result, the group achieved the first nanosheet structure in the world at the 2018 IEEE IEDM (Voltage Transfer Characteristics Matching by Different Nanosheet Layer Numbers of Vertically Stacked Junctionless CMOS Inverter for SoP/3D-ICs applications, IEEE 2018 International Electron Device Meeting, 21.4 (San Francisco/USA, 2018/12/04)) and the first GAA structure in the world at the 2019 IEEE IEDM (First Demonstration of CMOS Inverter and 6T-SRAM Based on GAA CFETs Structure for 3D-IC Applications", IEEE 2019 International Electron Device Meeting, 11.7 (SanFrancisco/USA, 2019/12/10)).

Based on these results, in 2020 this research was adopted for the "three-dimensional heterogenous function hCFETs for AI chips" nanoelectronics technology (supported by JST and MOST) that contributes to the AI system structures for the "Infrastructure Development for Promoting International S&T Cooperation (Japan-Taiwan Research Exchange)" program, and National

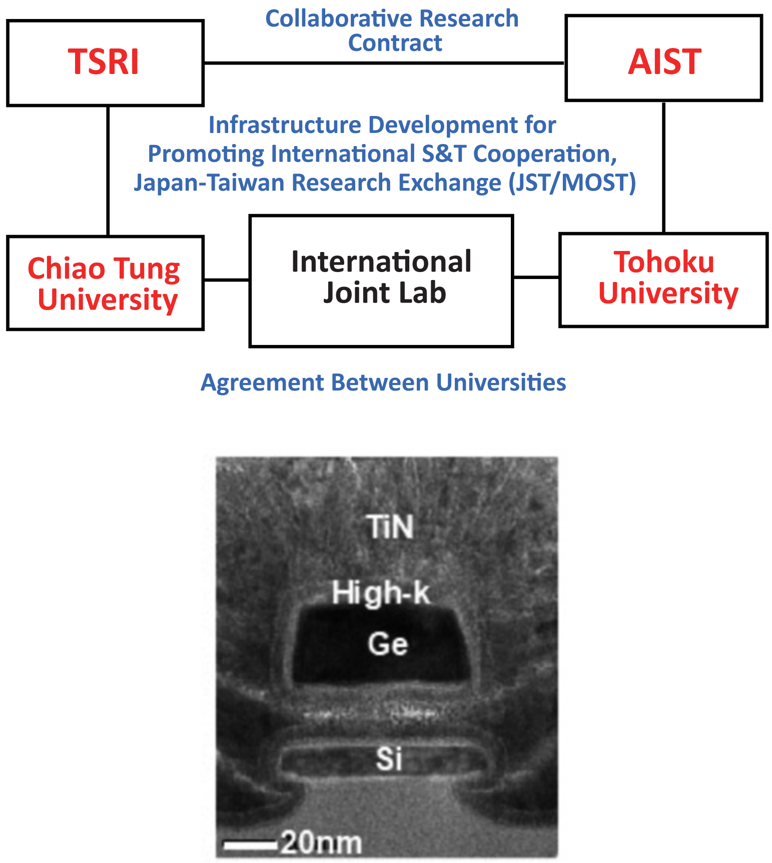


Figure 8. Cooperative System of the International Joint Laboratory and the World's First 3/2 nm Generation Si/Ge Heterogeneous Channel CFET

Chiao Tung University and Tohoku University International Joint Laboratory, together with the National Institute of Advanced Industrial Science and Technology and TSRI, achieved the world's first 3/2 nm heterogenous complimentary field effect transistors (hCFETs) with integrated three-dimensional heterogenous functions and materials that will be the technological basis for AI chips (**Figure 8**). The results were published at the 2020 IEEE IEDM (First Demonstration of heterogenous Complementary FETs utilizing Low-Temperature (200°C) Hetero-Layers Bonding Technique (LT-HBT), IEEE 2020 International Electron Device Meeting,15.5 (2020/12/04)) and subsequently attracted attention. Because this research successfully built an Si/Ge heterogeneous channel integration platform for the 2 nm generation, it provides a platform that is necessary and indispensable for the development of AI chips, an area where there will be a transition to systems on chips for devices of heterogenous materials (Si/Ge, Sic, GaN, etc.). Such devices which will be a necessity by 2030.

Based on the above results, the International Joint Laboratory proposed international joint research with TSMC, Innolux, and Macronix in collaboration with National Chiao Tung University in 2021 despite the COVID-19 crisis (see "Supplementary Materials (1)"), and there are plans to start the first substantial international industry-academia joint research for the lab (an agreement has already been reached with Innolux and negotiations are ongoing for TSMC and Macronix).

2) Biomedical Sensor Networks Group

As indicated in **Figure 9**, this group has succeeded in building a biomedical technology platform for biomedical sensors through the integration of semiconductor technology, which is the strength of National Chiao Tung University, and MEMS/NEMS sensor technology, which is the strength of Tohoku University. The group's final aim is to integrate LSI, energy harvesters, and prototypes of three-dimensional stacked retinal prosthesis chips for fully implantable retinal prostheses.

With the progressive aging of society, there has been an increase in the number of patients losing their eyesight due to eye diseases that occur with aging, such as with age-related macular denegation, and there is a particularly significant trend in this direction in Japan. Additionally, there are said to be approximately three million people worldwide with retinitis pigmentosa. With age-related macular degeneration and retinitis pigmentosa some of the photoreceptor cells in the retina that function to change light signals to electrical signals degenerate and die off, causing blindness. An effective medical treatment method for those with such diseases has not yet been established, and there is a high rate of blindness once these diseases arise. Currently, it is said that there are 45 million blind individuals worldwide, but it is believed that the percentage of individuals blinded by these diseases will rise further in the future. At the same time, from existing research it is understood that retinal sells that are not photoreceptor cells have a high survival rate for age-related macular degeneration and retinitis pigmentosa. Currently, there is research being conducted on treatment methods for restoring an individual's photoreceptor cells from iPS cells, but in the engineering field as well there have also been widespread developments on retinal prostheses that aim to reconstruct lost vision through the electrical stimulation of the remaining retinal cells. This group's research involves the development of retinal prostheses that are fully implanted in the eye and that use three-dimensional stacked retinal prothesis chips. These retinal prostheses consist of three-dimensional stacked retinal prosthesis chips; flexible cables that have stimulating electrode arrays; rectification, smoothing, and

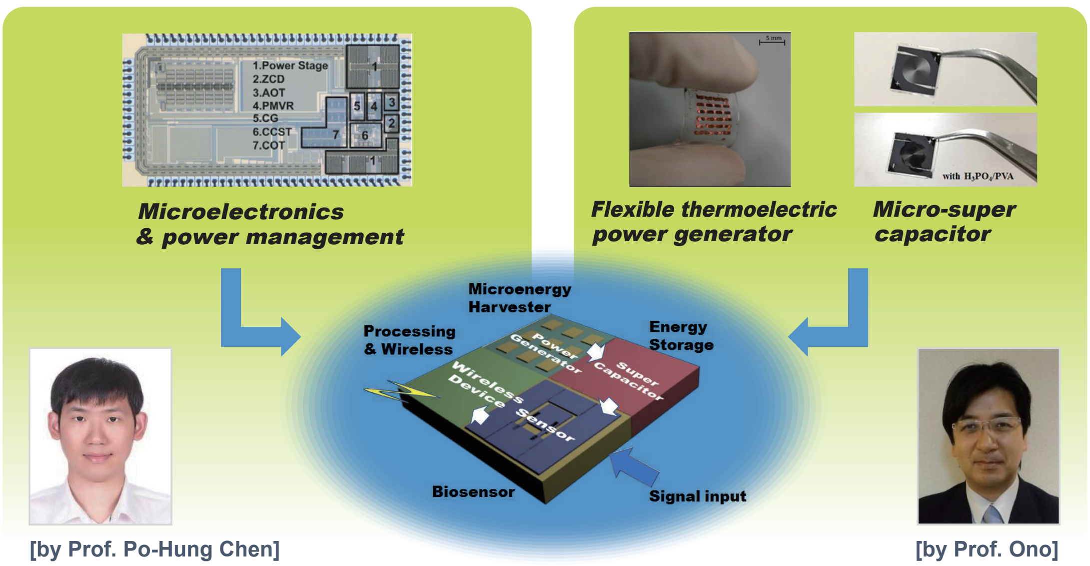


Figure 9. Construction of a Biomedical Technology Platform

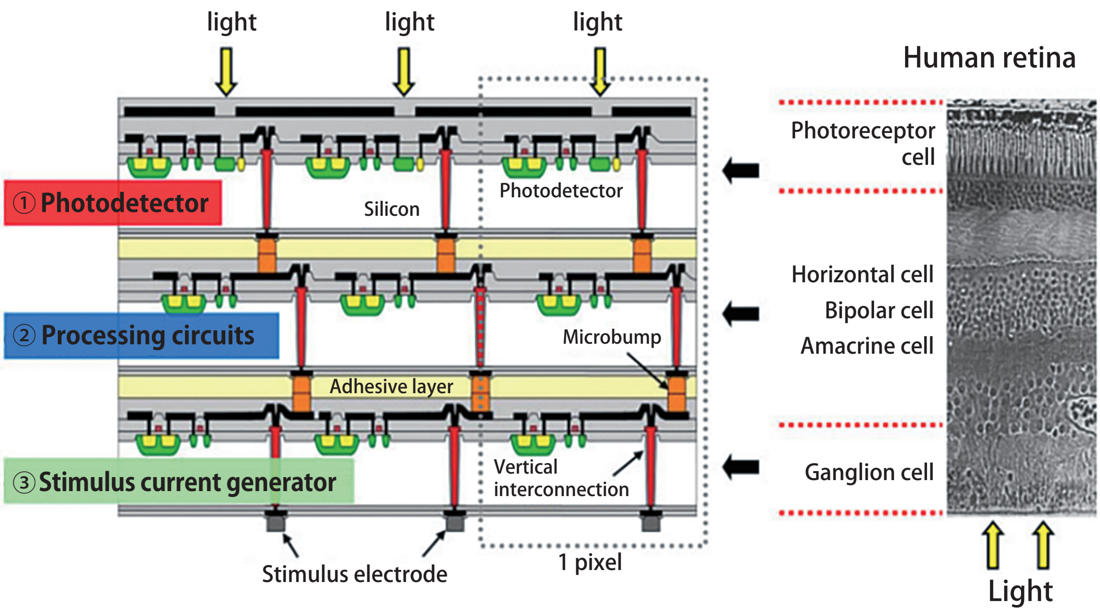


Figure 10. Three-Dimensional Stacked Retinal Prosthesis Chip

voltage-controlled circuits; and coils that receive electrical power. These parts are unified into a single module and implanted in the eye. Three-dimensional stacked retinal prothesis chips are made by using three-dimensional integrated technology to vertically stack light-receiving element chips, which are made up of photo diode arrays, and LSI chips, which process higher dimensional visual information like edge enhancement and create stimulating currents. The light-receiving element chips and LSI chips are connected electrically by through-silicon via (TSV) that passes between the chips and by metal microbumps. On the outermost surface of these three-dimensional stacked retinal protheses there is only the light-receiving element, and it is possible to achieve a high aperture ratio, a high resolution, a small scale, a light weight, and higher dimensional visual information processing. Through collaboration with National Chiao Tung University, by 2020 the group had succeeded in producing a three-dimensional stacked retinal prosthesis chip (**Figure 10**) with 1,369 pixels that possess edge detection functions and functions to output biphasic current pulses that stimulate the retina in response to external light. This chip achieved a 99% pixel activity rate. Additionally, the group also succeeded in implanting a retinal prosthesis chip and inducing light perception.

Additionally, the group is developing new large-area flexible thermoelectric elements with the aim of integrating energy harvesters and LSI. In order to use the plating process to produce thermoelectric elements, the group has developed a method for depositing Te thermoelectric materials rapidly over a large area. Furthermore, in order to improve the thermoelectric performance, the lab has performed exploratory experiments on the doping effect of nanoparticles and on impurities in Te thermoelectric materials. The lab has actually created a flexible energy harvester prototype and confirmed its effectiveness (**Figure 11**).

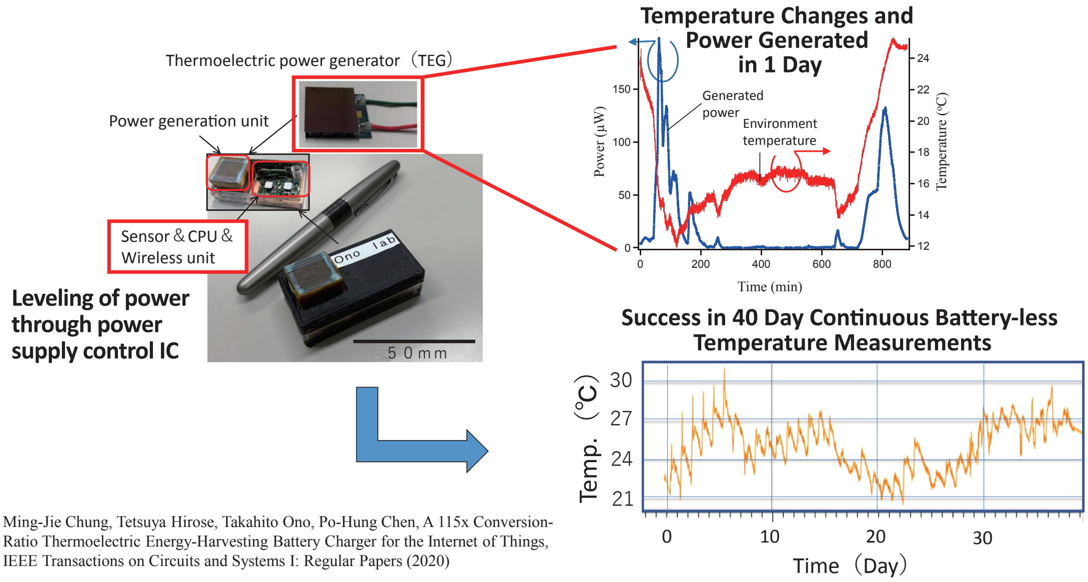


Figure 11. Development of a Highly Temperature-Fluctuation-Resistant IoT Sensor System for Thermal Storage and Power Generation

3) Energy Device Systems Group

This group's research combines the hydrogen energy materials and energy flow technology that are Tohoku University's strength with the system integration that is Chiao Tung University's strength with the goal of realizing a renewables derived hydrogen-based autonomous energy system (**Figure 12**). Taiwan is among the most developed countries for hydrogen energy and has launched the Shalun Smart Green Energy Science City (**Figure 13**) in Tainan where it has invested several hundreds of billions. National Chiao Tung University's Taiwan campus is at the heart of this science park and is actively cooperating with industry on photovoltaic cells, wind power, and hydrogen energy systems. This project also uses National Chiao Tung University's Taiwan campus as a hub for introducing hydrogen-based autonomous energy systems in collaboration with Taiyo Nippon Sanso; performing comprehensive examinations on hydrogen refinement, transport, storage, and risk management for hydrogen as an energy carrier; and building next generation renewable hydrogen energy systems. In particular, the project examines optimization and mutual compensation for proper hydrogen supplies as well as optimized usage as an energy carrier and aims to realize a smart green hydrogen city from natural energy based on the SDGs.

There is a need to shed the concentrated management style based on the enormous power sources of electric companies and to establish a basic P2P (peer-to-peer) concept (**Figure 14**) that necessitates the building of dispersed supply and use systems in order to effectively use hydrogen as an energy medium. Consequently, the group is not only developing small scale, dispersed hydrogen production technology and immediate use frameworks and storage methods, they are also developing the most effective hydrogen supply method that uses the latest network theory and overlay network resources for alternative compensation for energy surpluses. The group has already succeeded in

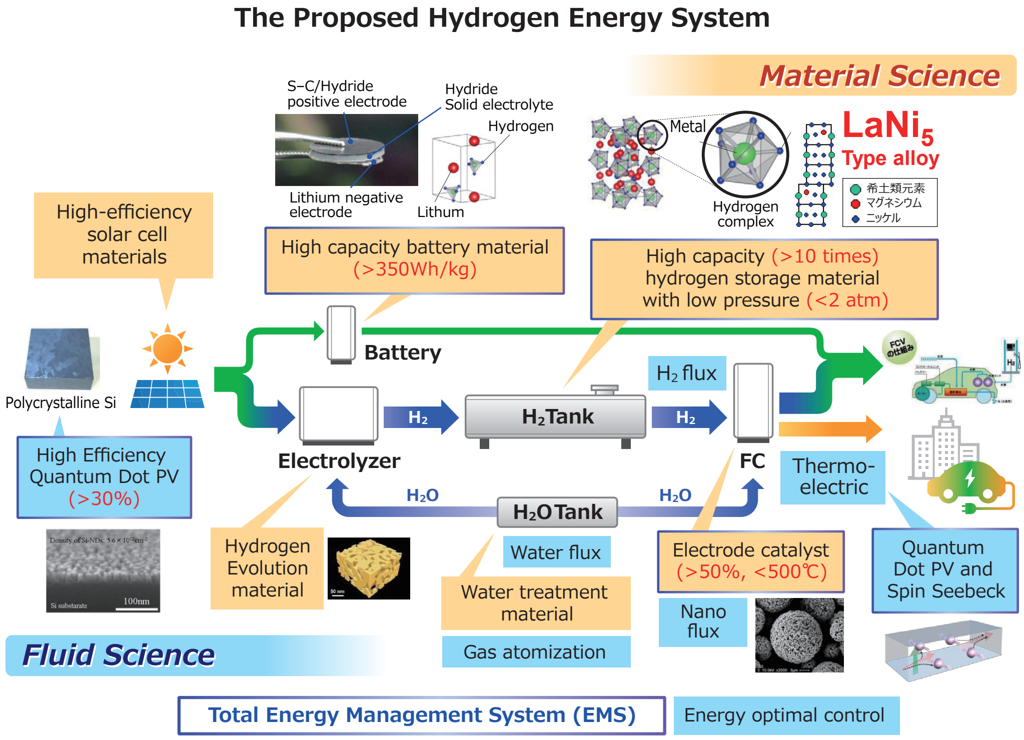


Figure 12. Renewables Derived Hydrogen-Based Autonomous Energy System

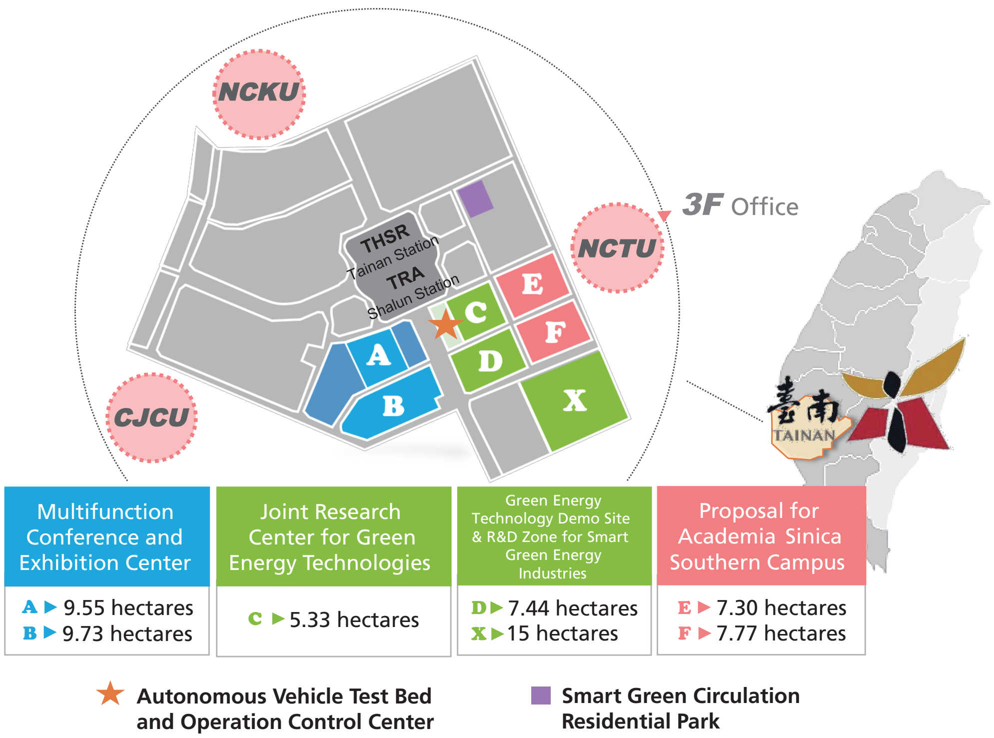


Figure 13. Shalun Smart Green Energy Science City, Neighbored by National Chiao Tung University's Tainan Campus

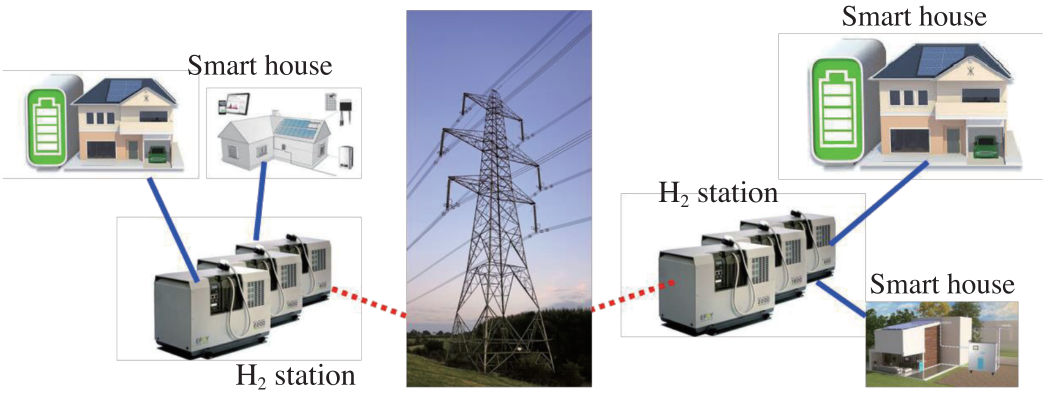


Figure 14. Diagram of P2P Polyphasic Hydrogen Energy Supply Chain

developing a method for simulating mutual compensation-based hydrogen energy supply chains using graph theory. For hydrogen demand and supply, the group has succeeded in developing an algorithm that enables the optimal distribution of H2 using graph theory and probability density functions. Additionally, the group has designed hydrogen stations that give thorough consideration to safety and the threshold concentration for hydrogen ignition. And the group has implemented coupled multiphase flow-structure supercomputing for hydrogen leak events that accompany the propagation of cracks, computations necessary for the design of high-pressure hydrogen tanks that give consideration to the effects of material degradation based on hydrogen embrittlement and repeated stress. As a result, the group analyzed the propagation of cracks through materials through peridynamic models, a type of particle method and the basis for linear fracture mechanics and continuum mechanics, which are necessary for the analysis of crack propagation events in high-pressure hydrogen tanks. Additionally, the group has developed a system for the coupled analysis of three-minute rapid charging and made it possible to predict concentrations of leaked hydrogen through coupled fluid-material computing for 70 MPa high-pressure rapid hydrogen leak events.

4) Future Outlook

In the three years since the launch of the National Chiao Tung University and Tohoku University International Joint Laboratory in August 2018, Tohoku University has striven as a Japanese university to build a strategic international research and education platform that gathers together remarkable basic technologies for the purpose of realizing world leading semiconductor devices, biomedical sensor networks, and hydrogen energy systems through the integration of Tohoku University's materials and process technology and energy flow technology with National Chiao Tung University's semiconductor device and systems integration technology (**Figure 15**). As a result, for semiconductor devices, the university has succeeded in building the world's first 3/2 nm generation three-dimensional heterogenous materials integration platform with the cooperation of the National Institute of Advanced Industrial Science and Technology (AIST) and the Taiwan Semiconductor Research Institute (TSRI). These are groundbreaking results that have captured the world's attention. Furthermore, the university has also realized a biomedical IoT platform for biomedical sensors that

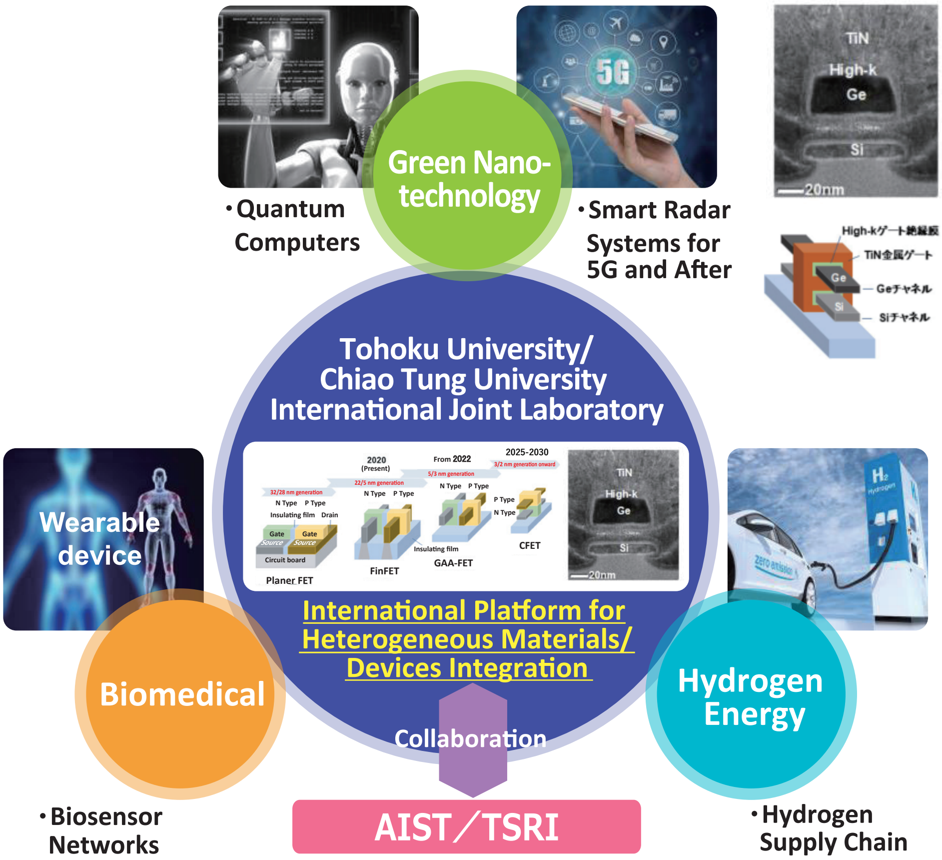


Figure 15. Future Outlook for the National Chiao Tung University and Tohoku University International Joint Laboratory

allows for the development of mature silicon technologies based on this heterogeneous materials integration platform. This is an extremely significant result for the new endeavor of building a strategic international research and education platform as an international joint laboratory. Going forward, the lab will implement experiments for function verification and animal implants for three-dimensional stacked retinal prosthesis chips for retinal prostheses that are fully implanted in the eye, will further develop quantum computing devices, and will realize AI chips and next-generation millimeter-wave systems on chips (SoC) that integrate ultra-high frequency GaN HEMTs and ultra-low power consumption Ge FinFets. Additionally, the lab will develop sensor systems using energy harvesters and LSI and will verify the systems as biomedical IoT sensors. Going forward, we expect major developments for medical ICT as an international joint laboratory partnered with National Yang Ming Chiao Tung University, which has promoted linkages with biomedical engineering through a merger with Yang-Ming University, a medical university.

At the same time, for hydrogen energy systems, the joint lab will evaluate the introduction of hydrogen-based autonomous energy systems on the Taiwan campus and will build hydrogen energy technology platforms, since a framework for international cooperation has been created with Taiwanese hydrogen companies and with Taiyo Nippon Sanso. The joint lab aims to build a hydrogen energy supply chain based on this platform. In traditional systems, supplies are unidirectional, only coming from the power source. However, hydrogen will have lost its mission as an energy carrier if a problem arises with these electrical supplies due to climate change or natural disasters. Therefore, this project aims to build a decarbonization P2P multigrid polyphasic hydrogen supply chain that enables mutual compensation. Furthermore, comprehensive scientific verification based on multiple scientific principles, not simply on fluid engineering knowledge, will be implemented for polyphasic, high-concentration hydrogen supplies as an energy carrier.

5. Joint Papers and Analysis

Figure 16 shows the number of joint papers around the time of the establishment of the National Chiao Tung University and Tohoku University International Joint Laboratory in 2018 and the liaison office in 2017. Following the launch of the International Joint Laboratory, around 20 joint papers have been published per year. It is astounding that even in 2020, with the COVID-19 pandemic, over 20 joint papers were published. It is believed that in the future we will be able to stably accelerate the promotion of the double degree program, coordinated courses, and collaborative research by having pushed the building of an international research and education platform.

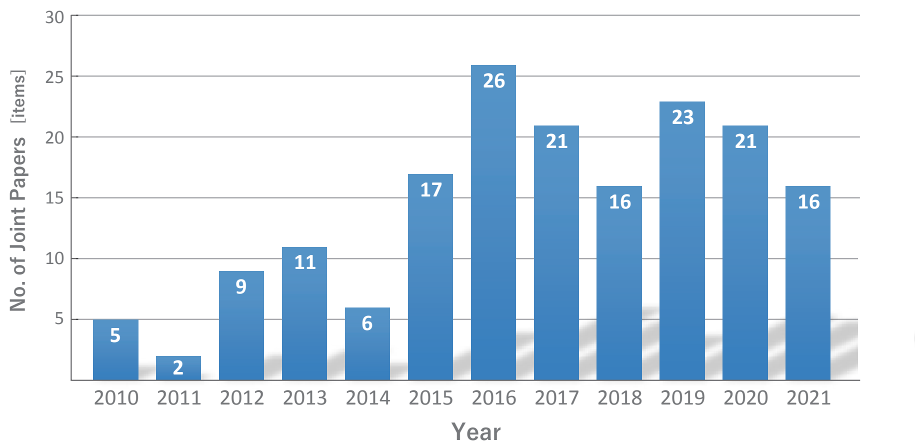


Figure 16. Trend of Joint Papers at Tohoku University and National Yang-Ming Chiao Tung University (From Scopus, May 2015)

Figure 17 shows the trend for related departments for joint papers with National Chiao Tung University (which became National Yang Ming Chiao Tung University in 2021) around the launch of the International Joint Laboratory. A broad expansion can be seen compared to the initial numbers for the related departments, not only for the engineering departments but also for the medical, dental, and pharmacological departments. 2021 in particular deserves special mention as there was an increase of nine articles for the medical, dental, and pharmacological departments due to the merger between the medical Yang-Ming University and Chiao Tung University to form Yang Ming Chiao Tung University. Due to the expansion of the cooperative framework for research and education to the medical, dental, and pharmacological departments as a strategy of the International

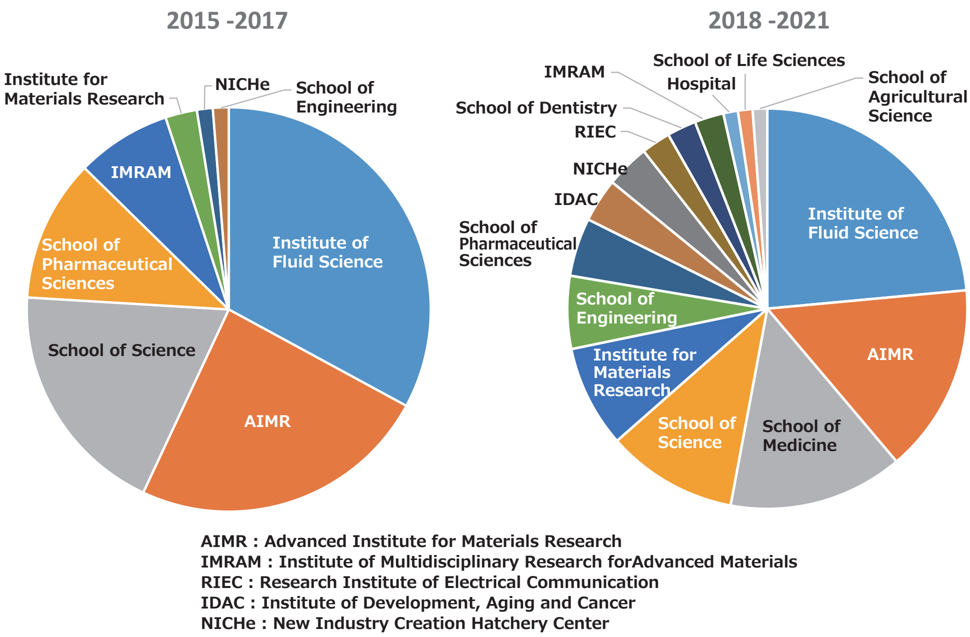


Figure 17. Percentage of Papers by Tohoku University Department for Joint Papers Around the Launch of the International Joint Laboratory.

Joint Laboratory, we can expect significant medical ICT developments based on the semiconductor materials and sensors platforms.

6. Overview of Exchange Achievements

1) Numbers from the Receiving and Sending of Faculty and Students

Table 3 shows the numbers for exchanges of faculty and students. Since 2018 when the International Joint Laboratory was launched, there has been a significant increase in the number of faculty sent and received, and it is clear that the establishment of the joint laboratory has had a major effect. Recently, two visiting professors from National Chiao Tung University have been appointed to Tohoku University (Profess Li and Professor Wu) and three visiting professors from Tohoku University have been appointed to National Chiao Tung University (Professor Samukawa, Professor Ono, and Specially Appointed Professor Kono) where they are serving as co-advisors to students. Additionally, at the second executive committee meeting held on November 5, 2019, it was decided between President Ono of Tohoku University and President Chen of National Chiao Tung University

Table 3. Numbers for Faculty and Student Exchanges

2. Exchange Achievements

Exchange Details		Exchange Achievements for the Past 5 Years					
		2015	2016	2017	2018	2019	Total
Exchange of Faculty/ Researchers	Received	31	17	47	26	43	164
	Sent	16	21	27	38	20	122
Study Abroad Exchanges (Exchange Framework with Universities That Have Agreements)	Received	1	2	2	0	4	9
	Sent	0	0	0	0	0	0

to establish a system of cross-appointments. Going forward, we expect there to be a further increase in exchanges through the use of the cross-appointments system. Furthermore, the increase in study abroad exchanges from AY 2019 due to the effects of the double degree program that was agreed upon in 2018 is also deserving of attention. We would like to accelerate student exchanges going forward together with the current acceleration of research exchanges for the nanodevice systems group, the biomedical sensor networks group, and hydrogen-based autonomous energy systems.

2) Holding of Executive Committee Meetings and Workshops (3 Executive Meetings, 10 Workshops)

Three research projects exist under the joint laboratory: 1) hydrogen-based autonomy energy systems (energy device systems group), 2) post-5G smart radar systems (nanodevice systems group), and 3) biomedical sensor networks (biomedical sensor networks group). Leaders for each group are assigned both from members of Tohoku University and from members of Chiao Tung University. The drafting and promotion of research plans is carried out under the responsibility of these group leaders. An executive committee meeting composed of the laboratory leader, the laboratory subleader, the joint group leaders, and the office management group (the Institute of Fluid Science at Tohoku University, the College of Electrical and Computer Engineering at Chiao Tung University) is held once every academic year and joint workshops are held at the same time for the presentation of research results. The executive committee meetings and the joint workshops hosted by the universities have been held once a year for three years: on December 14, 2018; November 5, 2019; and October 29, 2020. Deliberations were made on all operations (personnel, research details, research funds) and research presentations were made. Besides these events, technical workshops for each group were also held for the active exchange of technology. The energy device systems group has held one workshop in three years, the nanodevice systems group has held four, and the biomedical sensor networks group has held two.

December 14, 2018

1st Joint Workshop, 1st Executive Committee Meeting

(Host: Chiao Tung University)

National Chiao Tung University and Tohoku University Joint Research Center Establishment Ceremony (December 14, 2018)

Technical Workshop for
International Joint Research
between NCTU and Tohoku University

14:40-14:43 Remark by Senior Vice President Edward Yi Chang
14:43-14:46 Remark by Executive Vice-president Tadahiro HAYASAKA
14:46-14:50 Introducing TU staff by Mr. Hiroshi OIKAWA, Chief, International Affairs Center
14:50-14:55 Group Photo
15:00-15:20--- **Speaker 1** – Prof. Dr. Tatsuoki KONO, IMR, Hydrogen Energy System
15:20-15:40--- **Speaker 2 and NCTU Moderator** - Prof. Dr. Jong-Shinn Wu (吳宗信) / Distinguished Professor Dept. of Mechanical Engineering
15:40-16:00--- **Speaker 3 and TU Moderator** – Prof. Dr. Seiji SAMUKAWA, mm-Wave Smart Rader and Hydrogen Energy System
16:00-16:20--- **Speaker 4** – Prof. Dr. Yiming Li (李義明) / Professor, Dep. of Electrical and Computer Engineering
16:20-16:40--- **Speaker 5** – Prof. Dr. Tetsu TANAKA(徹 田中), GSBME, Bio-Medical Sensor project
16:40-17:00--- **Speaker 6** - Prof. Dr. Ming-Dou Ker (柯明道) / Professor, Dept. of Electronics Engineering

November 5, 2019

2nd Joint Workshop, 2nd Executive Committee Meeting

(Host: Tohoku University)

Tohoku University-National Chiao Tung University
5th Technical Workshop 2019

November 5, 2019
Katahira North Gate Hall, Tohoku University

Moderator: Seiji Samukawa (Tohoku University)
Yiming Li (NCTU)

By commemorating the establishment of the Joint Research Center between Tohoku University and National Chiao Tung University, a joint technical workshop will be held in Katahira North Gate Hall, Katahira Campus of Tohoku University, Sendai on November 5, 2019. Professor Takashi Matsuoka (Niche Tohoku University) and Prof. Jenn-Hwan Tarng (ECE, NCTU) are invited as keynote speakers. 3 Group Leaders from 3 joint projects such as mm-Wave Rader System, Hydrogen Energy System, and Bio-medical Sensor Network from both universities will also have invited talks in this joint workshop.

13:00-13:25 **Joint Symposium Opening Ceremony**
President Hideo Ohno (Tohoku University)
President Sin-Horng Chen (NCTU)
13:30-13:45 Joint Workshop Opening Remarks
Vice-president for RD, Prof. Tadahiro Hayasaka (Tohoku University)
Vice-president for RD, Prof. Ta-Sung Lee (NCTU)
Prof. Shigeru Obayashi (Tohoku University, Japan)
Prof. Jenn-Hwan Tarng (NCTU, Taiwan)

(Technical Workshop)
1)13:45 **From the Dawn, through the Present, to the Future of Nitride Semiconductors**
Takashi Matsuoka (Tohoku University, Japan)
2)14:30 **mm-Wave Phased Array for 5G & Radar Applications**
Jenn-Hwan Tarng (NCTU, Taiwan)
15:15 Break (15 min)
3)15:30 **Current and Future Hydrogen Energy Applications in Taiwan**
Jong-Shinn Wu (NCTU, Taiwan)
4)15:50 **Development of multi-phase hydrogen energy supply chain by Peer to Peer** method
Jun Ishimoto (Tohoku University, Japan)
5)16:10 **2019 Joint Research Activities on Nano-Devices**
Yiming Li (NCTU, Taiwan)
6)16:30 **Atomic Layer Defect-free Etching for GaN-BASED HEMTs**
Seiji Samukawa (Tohoku University, Japan)
7)16:50 **SoC Technology for Biomedical Applications -- Neuromodulation Therapy**
Ming-Dou Ker (NCTU, Taiwan)
8)17:10 **Research Progress of Next-Generation Biomedical Sensor and Network Project**
Tetsu Tanaka (Tohoku University, Japan)

Joint Symposium

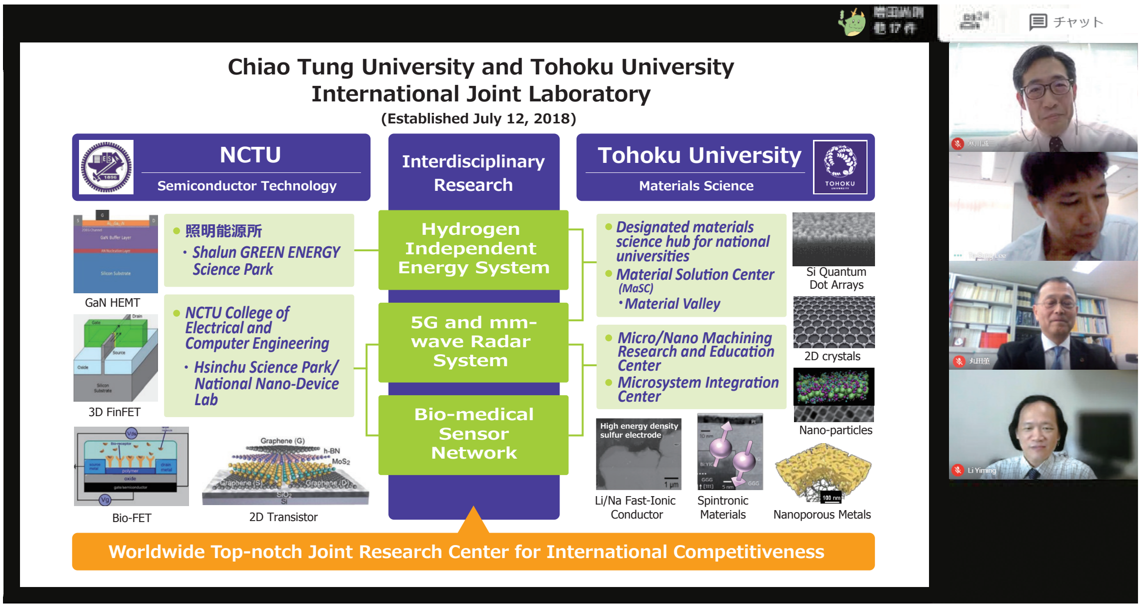
November 4-6 National Chiao Tung University and Tohoku University Joint Lab/Network Hub/Academic Energy Hub Joint Symposium (Draft)

As of August 30

	Nov. 4		Nov. 5			Nov. 6	
AM	9:00 – 12:00	Collaborative Research Hub Chiao Tung University Symposium on Material Device Networks	9:00		President Chen of National Chiao Tung University, other observations inside the university		Energy value studies, Creativity and Research Hub (International Center, 200-300 people) Co-hosted with JST Science Agora (planned) Nov. 6: Energy policies and cooperation with regional communities
			11:00 ~ 12:00	Tohoku University/NCTU joint lab executive committee (Serishiru, Director Hayasaka, Vice-President Li, 20 people)			
Lunch (Hagi Restaurant)							
PM	13:00		13:00	All-inclusive meeting (Esupasu, President Ono, Director Hayasaka, 70 people)			Energy value studies, Creativity and Research Hub
	15:00 ~ 16:00	Poster Session	13:30	Tohoku University/Chiao Tung University joint lab ceremony, joint workshop (Esupasu, 35 people)	Energy value studies, Creativity and Research Hub. Symposium (Sakura Hall, 35 people) Co-hosted with JST Science Agora (planned) Nov. 5: Technology oriented (directed by Tohoku University)		
	16:00						
	18:00	Tohoku University/National Chiao Tung University joint banquette. Presidents, Director Hayasaka in attendance (Westen) (42-45 people)	18:00				

October 29, 2020

3rd Joint Workshop, 3rd Executive Committee Meeting (Online)



Agenda

<u>Opening Addresses (14:00-14:30)</u> Chair: Prof. Yiming Li (NCTU)
Professor Ta-Sung Lee (R&D Vice-president, NCTU, Taiwan)
Professor Kaoru Maruta (Director of IFS, Tohoku University, Japan)
Professor Jenn-Hwan Tarng (Dean of ECE, NCTU, Taiwan)

<u>Technical Workshop</u>

Keynote Session Chair: Prof. Seiji Samukawa (Tohoku Univ.)

1) 14:30 *(Keynote)* **Semiconductor Device Technology for Quantum Computers**
Dr. Kazuhiko Endo (AIST/Tohoku University, Japan)

2) 15:00 *(Keynote)* **Tunable Diameter and Interspace of Ge Quantum Dots for Qubits and Readout Devices Using Highly-Controllable Spacers and Selective Oxidation of SiGe**
Professor Pei-Wen Li (NCTU, Taiwan)

General Session Chair: Prof. Seiji Samukawa and Prof. Yiming Li

3) 15:30 **Nano-Devices Technologies Gr (1)**
Professor Seiji Samukawa (Tohoku University/AIST, Japan)

4) 15:40 *(Invited)* **High Resolution sub-10μ m Micro-LED Technology**
Dr. Xuelun Wang (AIST, Japan)

5) 16:00 **Nano-Devices Technologies Gr (2)**
Professor Yiming Li (NCTU, Taiwan)

6) 16:10 *(Invited)* **Full Color Microled by Quantum Dots Technology**
Professor Hao-Chung Kuo (NCTU, Taiwan)

7) 16:30 *(Invited)* **Introduction of HYDROGENIUS Activities: Investigation of Material Compatibility to High-Pressure Hydrogen-Gas Environment**
Professor Osamu Takakuwa (Kyushu University, Japan)

8) 16:50 *(Invited)* **Oxidative Steam Reforming of Ethanol for Hydrogen Production over Metal Oxide/$La_2ZR_2O_7$ Catalysts**
Professor Chi-Shen Lee (NCTU, Taiwan)

9) 17:10 **Bio-Medical Sensor Network Gr (1)**
Professor Tetsu Tanaka (Tohoku University, Japan)

10) 17:20 *(Invited)* **Nanoengineered Energy Harvesting System for Health Care Devices**
Professor Takahito Ono (Tohoku University, Japan)

11) 17:40 **Bio-Medical Sensor Network Gr (2)**
Professor Ming-Dou Ker (NCTU, Taiwan)

12) 17:50 *(Invited)* **A Micromachined Multimodal Probe for Ischemia Muscle Monitoring**
Professor Yu-Ting Cheng (NCTU, Taiwan)

Closing Remarks

東北大学 TOHOKU UNIVERSITY　　國立交通大學 National Chiao Tung University

Tohoku University-National Chiao Tung University
The 6th Joint Technical Workshop(online) 2020

14:00-18:10 (JST), October 29/2020

in conjunction with
The 17th International Conference on Flow Dynamics (ICFD2020)

Moderator: Professor Seiji Samukawa, Tohoku University/AIST, Japan
Professor Yiming Li, NCTU, Taiwan

Online Address <Open from 13:30 (JST) on Oct. 29>
https://meet.google.com/xqv -ixvo-fqw

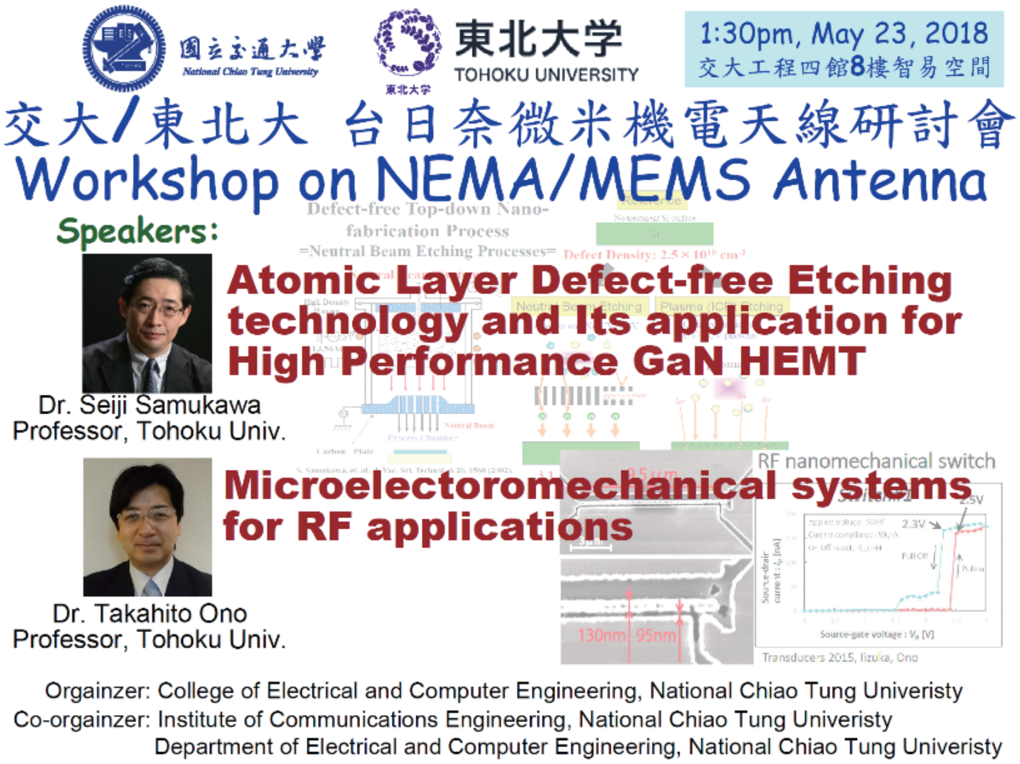
By commemorating the establishment of the Joint Research Center between Tohoku University, Sendai, Japan and National Chiao Tung University (NCTU), Hsinchu, Taiwan, a joint technical workshop will be held in conjunction with the 17th International Conference on Flow Dynamics (ICFD2020) at Sendai, Japan, on October 29, 2020. Dr. Kazuhiko Endo (AIST/Tohoku University) and Professor Pei-Wen Li (NCTU) are invited as keynote speakers. 3 Group Leaders and Invited Topics Speakers from 3 joint projects such as Nano-Devices, Hydrogen Energy System, and Bio-Medical Sensor Network from both universities will also have talks in this joint technical workshop.

Individual Workshops

May 23, 2018

Workshop on NEMS/MEMS Antennas

(Host: Nanodevice Systems Group)



August 7, 2018

Hydrogen Energy Workshop

(Host: Hydrogen-Based Autonomous Energy Systems Group)

Conclusion of Collaborative Research MOU for Hydrogen-Based Autonomous Energy Systems with Taiwan's Chiao Tung University

Taiwan, August 7, 2018

Taiwan is among the most developed countries for hydrogen usage (hydrogen scooters)

台灣氫能產業發展聯盟成立大會暨臺灣氫能策略論壇		
時間	分	議程
9: 30~10: 00		報到
10: 00~10: 15	15	貴賓致詞
10: 15~10: 30	15	會員大會
10: 30~10: 45	15	氫能機車啟動儀式
10: 45~10: 50	5	國立交通大學/日本東北大學mou簽訂(洽談中)
10: 50~11: 00	10	茶敘
11: 00~11: 30	30	台灣氫能產業概況/黃得瑞主任 沙崙智慧綠能科學城
11: 30~12: 30	60	再生能源產氫系統介紹/日本東北大學(邀請中)
12: 30~13: 30	60	午餐/
13: 30~13: 50	20	氫能發電/中興電工(邀請中)
13: 50~14: 10	20	儲氫設備/晉陞太空(邀請中)
14: 10~14: 30	20	氫氣的來源/光宇材料(邀請中)
14: 30~14: 50	20	燃料電池/美菲德(邀請中)
14: 50~15: 10	20	氫能載具/亞太燃料
15: 10~15: 30	20	茶敘
15: 30~16: 30	60	臺灣氫能策略論壇
16: 30		賦歸
以上議程及演講主辦單位保留修改的權利		

November 30, 2018

Biomedical Sensors and Networks Workshop

(Host: Biomedical Sensor Networks Group)

Technical Workshop of Biomedical Sensor and Network Project in
International Joint Research Laboratory
between NCTU and Tohoku Univ

Date: November 30 (Friday), 2018

Venue: WPI-AIMR Main Building (B01), Katahira campus, Tohoku Univ.

(www.tohoku.ac.jp/en/about/map_directions.html)

10:00-10:05 Opening remarks

10:05-10:15 Introduction of International Joint Research Laboratory
[Prof. Seiji SAMUKAWA]

10:15-10:35 Overview on the Research Projects in Biomedical Electronics Translational Research Center (BETRC) of NCTU
[Prof. Morris (Ming-Dou) KER]

10:35-11:05 Integrated Biomedical Micro/Nano Devices with 3D -IC Technology
[Prof. Tetsu TANAKA]

11:05-11:35 AI-Enabled Mobile Health -Care Applications
[Prof. Chen-Yi LEE]

11:35-12:05 Micro/Nano Sensors for Health Care Applications
[Prof. Takahito ONO]

12:05-13:20 Lunch

13:20-14:20 Lab tour (T. Sato laboratory and M. Ohta laboratory)

14:30-15:00 Atmospheric Pressure Plasma Flow for Bio -medical Applications
[Prof. Takehiko SATO]

15:00-15:30 Power Management for Implantable Medical Devices
[Prof. Po-Hung CHEN]

15:30-15:45 Break

15:45-16:15 Model of Tissue with Mechanical Properties for Edu-Tech
[Prof. Makoto OHTA]

16:15-16:45 A Fully Integrated Closed-Loop Neuromodulation SoC with Wireless Power and Bi-Directional Data Telemetry for Real -Time Human Epileptic Seizure Control
[Dr. Cheng-Hsiang CHENG]

16:45-17:00 Discussion of joint research project

17:00-17:05 Closing remarks
[Prof. Morris (Ming-Dou) KER]

17:05- Dinner

January 21, 2019

Workshop on 5G and Millimeter-Wave Smart Radar Systems

(Host: Nanodevice Systems Group)

2nd Joint Workshop

on 5G and mm-Wave Smart Radar System

Jan. 21, 2019,
Fluctuation Free Facility, New Industry Creation Hatchery Center
Tohoku University

Moderator
Prof. Seiji Samukawa (*IFS/AIMR, Tohoku University)*
Prof. Yiming Li *(ECE, UNCU)*

Program

1) 10:00-10:05 Opening Remarks, Prof. S. Samukawa and Prof. Y. Li
2) 10:05-10:40 **Prof. Tetsuya Suemitsu** (CIES, Tohoku University)
"Advanced GaN HEMT for 5G and mm-Wave Mobile Communications"
3) 10:40-11:15 **Prof. Jenn-Hwan Tarng** (NCTU)
"Overview 2 Flagship Research Projects 3DNET Smart Campus & Center for mm Wave Smart Radar Systems and Technologies"
4) 11:15-11:50 **Prof. Noriharu Suematsu** (RIEC, Tohoku University)
"Direct Digital RF Transceiver for 5G & mm-wave Applications"
Lunch Break (100 min)
5) 13:30-14:00 **Prof. Akinobu Teramoto** (Niche, Tohoku University)
"High Quality Dielectric Film Formation on GaN Devices."
6) 14:00-14:30 **Prof. Yiming Li** (NCTU)
"GaN HEMTs for future RF applications."
7) 14:30-15:00 **Prof. Seiji Samukawa** (IFS/AIMR, Tohoku University)
"Atomic Layer Defect-free Etching Process for Advanced GaN HEMT"
8) 15:00-15:30 **Prof. Zuo-Min Tsai** (NCTU)
"Millimeter-wave CMOS phased array front end design and the Discussion of MEMs device applying on Millimeter-wave phased array radar systems"
9) 15:30-16:00 **Prof. Takahito Ono** (SE, Tohoku University)
"Microsensors and Micropower Devices for IoT Sensor Network"
10) 16:00-16:05 Closing Remarks, Prof. Jenn-Hwan Tarng (NCTU)
11) 16:05-17:30 **Laboratory Tour in Niche.**

August 23, 2019

Biomedical Sensors and Networks Workshop

(Host: Biomedical Sensor Networks Group)

2nd Joint Workshop on Bio-medical Sensor Network between NCTU and Tohoku Univ.
Date: August 23 (Friday), 2019
Venue: Aoba-kinen-kaikan, Aobayama campus, Tohoku Univ.

(https://www.eng.tohoku.ac.jp/english/map/?menu=campus&area=c&build=03)

13:20-13:50 Photovoltaic-Powered Sub-retinal Prosthetic System: Design and Animal Tests
Prof. Chung-Yu Wu, Institute of Electronics Eng., National Chiao Tung University (NCTU)
13:50-14:20 Development of Integrated Biomedical Micro/Nano Devices
Prof. Tetsu Tanaka, Graduate School of Medical Eng., Tohoku University,
14:20-14:50 Implantable Neuro-Stimulator Design for Biomedical Applications with CMOS Technology Break
Prof. Morris Ker, Institute of Electronics, NCTU,
15:00-15:30 Energy Harvesting Power Converter for Internet of Things
Prof. Po-Hung Chen, Institute of Electronics Engineering, NCTU,
15:30-16:00 Propagation mechanism and formation process of fine bubbles by underwater plasma streamer
Prof. Takehiko Sato, Institute of Fluid Science, Tohoku University,
16:00-16:30 Micro sensors for body area network
Prof. Takahito Ono, Graduate School of Eng., Tohoku University,
16:30-16:35 Closing remarks Prof. Tetsu Tanaka
18:00- Dinner
Hana near Sendai station (和食 波奈 仙台店)

https://r.gnavi.co.jp/t060002/map/

November 28, 2019

Neutral Beam Workshop

(Nanodevice Systems Group)

The 3rd Joint Workshop on Neutral-Beam fabrication for More Moore and More than Moore

Venue: ED816, National Chiao Tung University (NCTU), Hsinchu 300, Taiwan
Time: 13:00-16:15, November 28, 2019

Organizers: College of Electrical and Computer Engineering, NCTU
Joint Research Center of NCTU and Tohoku University

Moderator: Professor Yiming Li, NCTU

Scientific Program of the Workshop

13:00	Registration		
13:10	Opening Address by Vice President for R&D Professor Ta-Sung Lee, NCTU		
13:20	Opening Remarks by Dean Professor Jenn-Hwan Tarng of ECE, NCTU		
13:20-14:00		Professor Seiji Samukawa, Tohoku University	Principal of neutral beam generation and atomic layer defect-free processes for future sub-10 nm Devices.
14:00-14:30		Dr. Yao-Jen Lee, Taiwan Semiconductor Research Institute	Research platforms for more Moore application in TSRI
14:30-14:45	Coffee break		
14:45-15:15		Dr. Niraj Man Shrestha, National Chiao Tung University	Importance of defect-free recess process in GaN-based HEMT
15:15-15:45		Dr. Daisuke Ohori, Tohoku University	2D array of nano-pillar structure by fusion of bio-template and neutral beam etching
15:45-16:15		Mr. Takuya Ozaki, Tohoku University	Neutral beam etching system (in Japanese)
16:15	Closing		

December 16, 2019

Workshop on High-Voltage Technologies

(Host: Nanodevice Systems Group)

2019 NCTU/TU Joint Workshop on High-Voltage Technologies

Monday, 2019/12/16, ED-816, NCTU, Hsinchu, Taiwan
Moderator: Professor Yiming Li

2019/12/05 ver3

松岡 隆志 教授
Professor Takashi Matsuoka

寒川誠二 教授
Professor Seiji Samukawa

09:00-10:00	Visiting President Sin-Horng Chen Visiting RD VP Ta-Sung Lee Visiting ECE Dean Jenn-Hwan Tarng	President Office
10:00-12:00	Lab Tour at NFC and TSRI	
12:00-14:00	Lunch Break	
14:00-14:10	Opening address, RD VP Professor Ta-Sung Lee	
14:10-14:20	Opening remarks, Dean of ECE College Professor Jenn-Hwan Tarng	
14:20-15:20	**Professor Takashi Matsuoka: Potential of N-Polarity in Applications for GaN-Based Devices**	**Plenary Talk**
15:20-15:30	Coffee Break	
15:30-16:00	**Professor Seiji Samukawa: Atomic Layer Defect-free Etching for GaN-Based HEMTS**	**Invited Talk**
16:00-16:30	Q&A	
16:30-16:40	Closing	
18:00-20:00	Dinner Meeting	

3) Joint Classes

National Chiao Tung University and Tohoku University's International Joint Laboratory has established a joint class called "Energy Materials and Devices" which has been held twice, in the fall semester of 2018 and the spring semester of 2019, and lectures were held for graduate students of National Chiao Tung University and Tohoku University.

The class was divided in a complimentary manner into semiconductor technology, which is National Chiao Tung University's strength, and energy materials, which is Tohoku University's strength, and we are proud to have achieved lectures that could only exist at an international joint laboratory (classes led by Professor Li and Professor Wu of Chiao Tung University and by Professor Samukawa, Professor Ono, and Specially Appointed Professor Kono of Tohoku University). Students from National Chiao Tung University formed the core of the class, but over 20 students participated, and it was very well received.

NCTU/Tohoku Univ. Joint Class 2018: Energy Materials and Devices - Schedule (Each Wed. EFG; from 13:20)

	Date	Lecturers	Contents	Remarks
1	9/12	Prof. Yiming Li	Introduction	
2	9/19	Prof. Seiji Samukawa	Nano-fabrication and QD devices (1/2)	
	9/21	Prof. Seiji Samukawa	Nano-fabrication and QD devices (2/2)	Fri. IJK; from 18:00
3	~~9/26~~		The class on 9/26 (Wed.) will be moved to 9/21 (Fri.)	
4	~~10/3~~		The class on 10/3 (Wed.) will be moved to 10/12 (Fri.)	
5	~~10/10~~		Holiday - No Class	
	10/12	Prof. Takahito Ono	MEMS/ NEMS Sensor and Thermoelectric Devices (1/2)	Fri. IJK; from 18:00
6	10/17	Prof. Tatsuoki Kono	Second Battery and Hydrogen Storage Materials, Hydrogen Energy system (1/2)	
7	10/24	Prof. Jong-Shinn Wu	Hybrid/ Liquid Rocket Propulsion (1/2)	
8	10/31	Prof. Jong-Shinn Wu	Hybrid/ Liquid Rocket Propulsion (2/2)	
9	11/7	Prof. Yiming Li	Midterm Report	
10	~~11/14~~		The class on 11/14 (Wed.) will be moved to 11/16 (Fri.)	
	11/16	Prof. Takahito Ono	MEMS/ NEMS Sensor and Thermoelectric Devices (2/2)	Fri. IJK; from 18:00
11	11/21	Prof. Tatsuoki Kono	Second Battery and Hydrogen Storage Materials, Hydrogen Energy system (2/2)	
12	11/28	Prof. Jong-Shinn Wu	Hydrogen Peroxide / Catalyst / Syngas	
13	12/5		NCTU Sports Day - No Class	
14	12/12	Prof. Yiming Li	Modeling and Simulation of QD Energy Devices (1/2)	
15	12/19	Prof. Yiming Li	Modeling and Simulation of QD Energy Devices (2/2)	
16	12/26	Prof. Yiming Li	Computational Nanoelectronics and Nanostructures	
17	1/2	Prof. Yiming Li	Final Report	
18	1/9	Prof. Yiming Li	Take home writing report Due on 2019/1/9	

Energy Materials and Devices
Joint Class 2019 between NCTU/Tohoku Univ.

2019/01/02

	Date	Lecturers	Contents	Remarks
1	2/22	Prof. Yiming Li	Introduction	
2	3/1		Holiday - No Class	
3	3/8	Prof. Seiji Samukawa	Nano-Fabrication and QD Devices (1/2)	
	3/9	Prof. Seiji Samukawa	Nano-Fabrication and QD Devices (2/2)	9:00~12:00 Sat.
4	~~3/15~~		The class on 3/15 (Fri) will be moved to 3/9 (Sat.)	
5	3/22	Prof. Yiming Li	Modeling and Simulation of QD Energy Devices (1/2)	
6	3/29	Prof. Yiming Li	Modeling and Simulation of QD Energy Devices (2/2)	
7	4/5		Holiday - No Class	
8	4/12	Prof. Tatsuoki Kono	Second Battery and Hydrogen Storage Materials, Hydrogen Energy system (1/2)	
	4/13	Prof. Tatsuoki Kono	Second Battery and Hydrogen Storage Materials, Hydrogen Energy system (2/2)	9:00~12:00 Sat.
9	4/19	Prof. Takahito Ono	MEMS/NEMS Sensor and Thermoelectric Devices (1/2)	
	4/20	Prof. Takahito Ono	MEMS/NEMS Sensor and Thermoelectric Devices (2/2)	9:00~12:00 Sat.
10	~~4/26~~		The class on 4/26 (Fri) will be moved to 4/13 (Sat.)	
11	~~5/3~~		The class on 5/3 (Fri) will be moved to 4/20 (Sat.)	
12	5/10		**Midterm Report**	
13	5/17	Prof. Jong-Shinn Wu	Hybrid / Liquid Rocket Propulsion (1/2)	
14	5/24	Prof. Jong-Shinn Wu	Hybrid / Liquid Rocket Propulsion (2/2)	
15	5/31	Prof. Jong-Shinn Wu	Hydrogen Peroxide /Catalyst /Syngas	
16	6/7		Holiday - No Class	
17	6/14	Prof. Yiming Li	Computational Nanoelectronics and Nanostructures	
18	6/21		**Final Report**	

7. List of Accomplishments

(Joint Papers by Members of the Joint Laboratory for August 2018 - June 2021: 37)

Nanodevice Systems Group

1. Tai-Chen Kuo,Tzu-Lang Shih,Yin-Hsien Su,Wen-Hsi Lee, Michael Ira Current, and Seiji Samukawa, Neutral beam and ICP etching of HKMG MOS capacitors: Observations and a plasma-induced damage model, Journal of Applied Physics, Vol. 123 (2018) pp. 161517 (6pp).
2. Daisuke Ohori, Takuya Fujii, Shuichi Noda, Wataru Mizubayashi, Kazuhiko Endo, En-Tzu Lee, Yiming Li, Yao-Jen Lee, Takuya Ozaki, and Seiji Samukawa, Atomic layer germanium etching for 3D Fin-FET using chlorine neutral beam, Journal of Vacuum Science & Technology A,Vol.37(2019) pp.021003(5pp).
3. Yi-Chia Tsai, Blanka Magyari-Köpe, Yiming Li, Seiji Samukawa, Yoshio Nishi,and Simon M. Sze, Contact Engineering of Trilayer Black Phosphorus with Scandium and Gold, IEEE Journal of the Electron Devices Society,Vol.7 (2019)pp322(7pp).
4. Niraj Man Shrestha, Yiming Li, Tetsuya Suemitsu, and Seiji Samukawa, Electrical Characteristic of AlGaN/GaN High-Electron-Mobility Transistors With Recess Gate Structure, IEEE Transactions on Electron Devices, Volume: 66, Issue: 4 , (2019) pp.1694(5pp).
5. Takuya Fujii, Daisuke Ohori, Shuichi Noda, Yosuke Tanimoto, Daisuke Sato, Hideyuki Kurihara, Wataru Mizubayashi, Kazuhiko Endo, Yiming Li, Yao-Jen Lee, Takuya Ozaki, and Seiji Samukawa, Atomic layer defect-free etching for germanium using HBr neutral beam, Journal of Vacuum Science and Technology A, Vol. 37, No. 5, (2019) pp. 051001 (7 pp).
6. Niraj Man Shrestha, Prerna Chauhan, Yuen Yee Wong, Yiming Li, Seiji Samukawa, Edward Yi Chang, Low resistive InGaN film grown by metalorganic chemical vapor deposition, Vacuum, Volume 171, (2020) pp. 108974 (6 pp).
7. Hua-Hsuan Chen, Susumu Toko, Daisuke Ohori, Takuya Ozaki, Mitsuya Utsuno, Tomohiro Kubota, Toshihisa Nozawa and Seiji Samukawa, Growing low-temperature, high-quality silicon-dioxide films by neutral-beam enhanced atomic-layer deposition, Journal of Physics D, Appl. Phys. Vol.53 (2021) pp.015204 (8pp).
8. Tao Xu, Heqing Li, Jing Song, Guilian Wang, Seiji Samukawa, Xijiang Chang, Jingxia Yang, Enhanced Corrosion Resistance of Silicone-Modified Epoxy Coatings by Surface-Wave Plasma Treatment, Int. J. Electrochem. Sci., vol.14(2019) pp.5051(12pp).
9. D. Ohori, S. Takeuchi, M. Sota, T. lshida, Y. Li, J.-H. Tarng, K. Endo and S. Samukawa, Highly Water-Repellent Nanostructure on Quartz Surface based on Cassie-Baxter Model with Filling Factor, IEEE Open Journal of Nanotechnology, vol.1(2020) pp.1(5pp).
10. Daisuke Ohori, Takahiro Sawada, Kenta Sugawara, Masaya Okada, Ken Nakata, Kazutaka Inoue, Daisuke Sato, Hideyuki Kurihara and Seiji Samukawa, Atomic-layer etching of GaN by using an HBr neutral beam, Journal of Vacuum Science & Technology, A 38, 032603(2020) pp.032603(6pp).
11. Tomoki Harada, Tsubasa Aki, Daisuke Ohori, Seiji Samukawa, Tetsuo Ikari and Atsuhiko Fukuyama, Decreasing of the thermal conductivity of Si nanopillar/SiGe composite films investigated by using a piezoelectric photothermal spectroscopy, Japanese Journal of Applied Physics, Vol.59, (2020) SKKA08(5pp).
12. Firman Mangasa Simanjuntak, Takeo Ohno, Sridhar Chandrasekaran, Tseung-Yuen Tseng and Seiji Samukawa, Neutral oxygen irradiation enhanced forming-less ZnO-based transparent analog memristor devices for neuromorphic computing applications, Nanotechnology, Vol.31(2020) pp. 26LT01 (8pp).
13. M. Lee, Y. Li, M. Chuang, D. Ohori and S. Samukawa, Numerical Simulation of Thermal Conductivity of SiNW–SiGe0.3 Composite for Thermoelectric Applications, IEEE Transactions on Electron Devices, vol. 67, No.5, (2020) pp. 2088(5pp).
14. Narasimhulu Thoti, Yiming Li, Sekhar Reddy Kola, and Seiji Samukawa, Optimal Inter-Gate Separation and Overlapped Source of Multi-Channel Line Tunnel FETs, IEEE Open Journal of Nanotechnology, vol.1(2020) pp.38(8pp).
15. Min-Hui Chuang, Daisuke Ohori, Yiming Li, Kuan-Ru Chou, and S. Samukawa, "Fabrication and simulation of neutral-beam-etched silicon nanopillars" Vacuume, vol.181(2020)109577(5pp).
16. Niraj Man Shrestha, Yiming Li, Chao-Hsuan Chen, Indraneel Sanyal, Enn-Hawn Tarng, Jen-Inn Chyi, and S. Samukawa, "Design and Simulation of High Performance Lattice Matched Double Barrier Normally Off AlInGaN/GaN HEMTs" IEEE Journal of the Electron Devices Society, vol.8(2020), pp873(5pp).
17. Min-Hui Chuang, Yiming Li and Seiji Samukawa, On the energy band of neutral-beam etched Si/Si0.7Ge0.3 nanopillars, Japanese Journal of Applied Physics, 60, (2021) pp. SBBI03 (9pp).
18. D. Ohori, T. Fujii, S. Noda, W. Mizubayashi, K. Endo, Y. J. Lee, H. H. Tarng, Y. Li and S. Samukawa, High Electron Mobility Germanium FinFET fabricated by Atomic Layer Defect-free and Roughness-free Etching, IEEE Open Journal of Nanotechnology, vol.2 (2021) pp.26 (5pp)
19. Sou Takeuchi, Daisuke Ohori, Masahiro Sota, Teruhisa Ishida, Yiming Li, Jenn-Hwan Tarng, Kazuhiko Endo, and S. Samukawa, Surface wettability of silicon nanopillar array structures fabricated by biotemplate ultimate top-down processes, Journal of Vacuum Science & Technology, A 39(2021) pp. 023202 (9pp).

20. AN-CHEN LIU, KONTHOUJAM JAMES SINGH, YU-MING HUANG, TANVEER AHMED, FANG-JYUN LIOU, YU-HAU LIOU, CHAO-CHENG TING, CHIEN-CHUNG LIN, YIMING LI, SEIJI SAMUKAWA, AND HAO-CHUNG KUO, Increase in the Efficiency of III-Nitride Micro-LEDs: Atomic-layer deposition and etching, IEEE NANOTECHNOLOGY MAGAZINE, JUNE (2021), pp.02-18 (17pp).

Biomedical Sensor Networks Group

21. Hisashi Kino, Takafumi Fukushima and Tetsu Tanaka, Investigation of TSV Liner Interface with Multiwell Structured TSV to Suppress Noise Propagation in Mixed-Signal 3D-IC, IEEE Journal of the Electron Devices Society, 7 (2019) pp. 1225. AvailableXXXX Non-applicable
22. Sungho Lee, Rui Liang, Yuki Miwa, Hisashi Kino, Takafumi Fukushima and Tetsu Tanaka, Multichip thinning technology with temporary bonding for multichip-to-wafer 3D integration, Japanese Journal of Applied Physics, 59 (2019) pp. SBBA04-1.
23. Miao Xiong, Zhiming Chen, Yingtao Ding, Hisashi Kino, Takafumi Fukushima, and Tetsu Tanaka, Development of Eccentric Spin Coating of Polymer Liner for Low-Temperature TSV Technology With Ultra-Fine Diameter, IEEE TRANSACTIONS DEVICE LETTERS, 40 (2019) pp.95.
24. Hideto Hashiguchi, Takafumi Fukushima, Mariappan Murugesan, Hisashi Kino, Tetsu Tanaka, and Mitsumasa Koyanagi, High-Thermoresistant Temporary Bonding Technology for Multichip-to-Wafer 3-D Integration With Via-Last TSVs, IEEE TRANSACTIONS ON COMPONENTS, PACKAGING AND MANUFACTURING TECHNOLOGY, 9 (2019) pp.181.
25. Takanobu Yagi, Fujimaro Ishida, Masaaki Shojima, Hitomi Anzai, Souichiro Fujimura, Takanori Sano, Shun Shinozaki, Yuuma Yamanaka, Yuuto Yamamoto, Yoshihiro Okamoto, Makoto Ohta, Masanori Nakamura, on behalf of the CFD-BIO study group, Systematic review of hemodynamic discriminators for ruptured intracranial aneurysms, Journal of Biorheology, 33(2019) pp.53.
26. Nguyen Van Toan, Truong Thi Kim Tuoi, Takahito Ono, Thermoelectric generators for heat harvesting: From material synthesis to device fabrication, Energy Conversion and Management, 255 (2020) pp.113442.
27. Truong Thi Kim Tuoi, Nguyen Van Toan, Takahito Ono, Theoretical and experimental investigation of a thermoelectric generator (TEG) integrated with a phase change material (PCM) for harvesting energy from ambient temperature changes, Energy Reports, 6(2020) pp.2020.
28. Ming-Jie Chung, Tetsuya Hirose, Takahito Ono, Po-Hung Chen, A 115x Conversion-Ratio Thermoelectric Energy-Harvesting Battery Charger for the Internet of Things, IEEE Transactions on Circuits and Systems I: Regular Papers, 67 (2020) pp.4110.
29. YIJIE LI, Nguyen Van Toan, Zhuqing Wang, KHAIRUL FADZLI SAMAT, Takahito Ono, Thermoelectrical properties of silicon substrates with nanopores synthesized by metal-assisted chemical etching, Nanotechnology, 31 (2020) pp.455705.
30. Mu-Chien Wu, Satoshi Uehara, Jong-Shinn Wu, YunChen Xiao, Tomoki Nakajima and Takehiko Sato, Dissolution enhancement of reactive chemical species by plasma-activated microbubbles jet in water, Journal of Physics D: Applied Physics, Vol. 53, No. 48 (2020) pp.485201.
31. Mingzi Zhang, Simon Tupin, Hitomi Anzai, Yutaro Kohata, Masaaki Shojima, Kosuke Suzuki, Yoshihiro Okamoto, Katsuhiro Tanaka, Takanobu Yagi, Soichiro Fujimura, Makoto Ohta, on behalf of the CFD-BIO study group, Implementation of computer simulation to assess flow- diversion treatment outcomes: systematic review and meta- analysis, Journal of Neuro Interventional Surgery, (2020) pp.016724.
32. Takafumi Fukushima, Yuki Susumago, Zhengyang Qian, Chidai Shima, Bang Du, Noriyuki Takahashi, Shuta Nagata, Tomo Odashima, Hisashi Kino, Tetsu Tanaka, Significant Die-Shift Reduction and μLED Integration Based on Die-First Fan-Out Wafer-Level Packaging for Flexible Hybrid Electronics, IEEE TRANSACTIONS ON COMPONENTS, PACKAGING AND MANUFACTURING TECHNOLOGY, 10 (2020) pp.1419.

Hydrogen-Based Autonomous Energy Systems Group

33. Eitaro Koya and Masahiko Nakagawa and Shinya Kitagawa and Jun Ishimoto and Yoshikatsu Nakano and Naoya Ochiai, Atomization in High-Pressure Die Casting - Step 2 Simulation of Atomized Flow of Molten Aluminum by LES-VOF Method, SAE Technical Paper, (2018) pp. 10.4271.
34. Przemysław Smakulski, Jun Ishimoto, and Sławomir Pietrowicz, Numerical research of solidification dynamics with anisotropy and thermal fluctuations, International Journal of Numerical Methods for Heat & Fluid Flow, 30 (2020) pp.3005.
35. Naoya Ochiai and Jun Ishimoto, Numerical analysis of the effect of bubble distribution on multiple-bubble behavior, Ultrasonics Sonochemistry, 61 (2020) pp.104818.
36. Eitaro Koya, Masahiko Nakagawa, Shinya Kitagawa, Jun Ishimoto, Yoshikatsu Nakano, Naoya Ochiai, CFD Analysis of Mechanisms Underlying the Porosity-reducing Effect of Atomized Flows in High-pressure Die Cast Products, MATEC Web Conf., 326 (2020) pp.06006.
37. Yusuke Naito, Romain Montini, Hirochika Tanigawa, Jun Ishimoto., Masami Nakano and Katsuya Hirata, Experiment and Numerical Analysis of a Rotating Hollow Cylinder in Free Flight, Advances in Hydroinformatics, (2020) pp.923.

(International Academic Conference Joint Presentations by Laboratory Members for August 2018 - June 2021: 65, Invited Lectures/Keynote Speeches: 20)

Nanodevice Systems Group

1. **(Invited Lecture)** Seiji Samukawa, Neutral Beam Technology for Damage-free Etching Process, Digest of 2018 International Conference on Compound Semiconductor Manufacturing Technology, (Austin, 2018/05/07).
2. **(Invited Lecture)** Seiji Samukawa, Low-Temperature atomic layer defect-free etching, modification and deposition process, Collaborative Conference on Materials Research (CCMR) 2018, (Incheon, 2018/06/25).
3. **(Invited Lecture)** Seiji Samukawa, Atomic Layer Defect-free Top-down Processes for Future Nano-devices, The 7th International Conference on Microelectronics and Plasma Technology (ICMAP), (Incheon, 2018/07/27).
4. **(Invited Lecture)** Seiji Samukawa, Atomic Layer Defect-free Top-down Process for Future Nano-devices, 14th IEEE International Conference on Solid-State and IntegratedCircuit Technology, S05-3 (Qingdao/China, 2018/11/01).
5. **(Invited Lecture)** T. Okada, G. Kalita, M. Tanemura, I. Yamashita, M. Meyyappan, and Seiji Samukawa, Electricity generation by water flow on nitrogen-doped graphene, 15th International Conference of Flow Dynamics, (Sendai, 2018/11/07).
6. **(Invited Lecture)** Seiji Samukawa, Atomic Layer Defect-free Etching and Deposition Processes for future sub-10-nm devices, 71st Annual Gaseous Electronics Conference, TF2.00003 (Portland/USA, 2018/11/09).
7. **(Invited Lecture)** Seiji Samukawa, Atomic Layer Defect-free Top-down Process for Future Nano-devices, 2nd Asia-Pacific Conference on Plasma Physics, International Workshop on Plasma and Bio-nano Devices, 2 (Kanazawa, 2018/11/14).
8. P. J. Sung, C. Y. Chang, L. Y. Chen, K. H. Kao, C. J. Su, T. H. Liao, C. C. Fang, C. J. Wang, T. C. Hong, C. Y. Jao, H. S. Hsu, S. X. Luo, Y. S. Wang, H. F. Huang, J. H. Li, Y. C. Huang, F. K. Hsueh, C. T. Wu, Y. M. Huang, F. J. Fou, G. L. Luo, Y. C. Huang, Y. L. Shen, W. C. Y. Ma, K. P. Huang, K. L. Lin, S. Samukawa, Y. Li, G. W. Huang, Y. J. Lee, J. Y. Li, W. F. Wu, J. M. Shieh, T. S. Chao, W. K. Yeh, Y. H. Wang, Voltage Transfer Characteristics Matching by Different Nanosheet Layer Numbers of Vertically Stacked Junctionless CMOS Inverter for SoP/3D-ICs applications, IEEE 2018 International Electron Device Meeting, 21.4 (San Francisco/USA, 2018/12/04).
9. **(Invited Lecture)** Seiji Samukawa, Atomic layer defect-free etching and deposition processes for future sub-10-nm devices., 7th International Conference on Advanced Plasma Technologies (ICAPT-7) (Hue, Vietnam, 2019/2/27).
10. **(Invited Lecture)** Seiji Samukawa, "Creating Green Nanostructure and Nanomaterials for Advanced Nano-energy devices", IEEE Distinguished Lecturer in IEEE EDS Tainan Chapter (Tainan ,2019/05/10).
11. **(Invited Lecture)** Seiji Samukawa, "High Efficiency Nano-energy Devices Fabricated by Atomic Layer Processes", 4th International Conference on nano-energy and Nano-system (Beijing ,2019/06/16).
12. **(Invited Lecture)** Seiji Samukawa, "Creating Green Nanostructures and Nanomaterials for Advanced Energy Nanodevices",46th European Physical Society Conference on Plasma Physics, I3.302 (Milan,2019/7/10).
13. **(Invited Lecture)** Seiji Samukawa, "Atomic Layer Defect-free Etching Processes for future sub-10-nm devices", Satellite Workshop of XXXIV ICPIG and ICRP-10 (New trends of plasma processes for thin films and related materials), (Sapporo, 2019/7/20).
14. T. Fujii, Daisuke Ohori, S. Noda, Y. Tanimoto, D. Sato, H. Kurihara, W. Mizubayashi, K. Endo, Y. Li,Y.-J. Lee, T. Ozaki, S. Samukawa, "Atomic Layer Etching for Germanium using Halogen Neutral Beam=Comparison between Br and Cl Chemistry=", AVS 19th International Conference (ALD/ALE2019), ALE2-TuM12, (Bellevue, USA, 2019/7/23).
15. Hua-Hsuan Chen, D. Ohori, T. Ozaki, M. Utsuno, T. Kubota, T. Nozawa, S. Samukawa, "Low Temperature High Quality Silicon Dioxide by Neutral Beam Enhanced Atomic Layer Deposition", AVS 19th International Conference (ALD/ALE2019), AF-TuA1, (Bellevue, USA, 2019/7/23).
16. **(Keynote Speech)** Seiji Samukawa, "Creating Green Nanostructures and Nanomaterials for Advanced Energy Nanodevices", IEEE International Microwave, Electron Devices & Solid-State Circuit Symposium (IMESS) 2019, (Penang, 2019/10/9).
17. **(Invited Lecture)** Seiji Samukawa, "Creating Green Nanostructures and Nanomaterials for Advanced Energy Nanodevices", IEEE Distinguished Lecturer Program (Universiti Malaysia Perlis, 2019/10/10).
18. **(Invited Lecture)** Seiji Samukawa, "Atomic Layer Defect-free Etching for Future sub-10nm Nano-devices", 2019 International Electron, Devices and Materials Symposium (IEDMS 2019), B3-1 (New Taipei City, 2019/10/25).
19. M.-H. Chuang, Y. Li, M.-Y. Lee, D. Ohori, and Seiji Samukawa, Invited Impact of Elastic Properties on Phonon Energy Dispersion of Highly Ordered Silicon Nanowires, 16th International Conference of Flow Dynamics, OS1/3-4 (Sendai, 2019/11/06).

20. M.-Y. Lee, Y. Li, M.-H. Chuang, D. Ohori, and Seiji Samukawa, Simulation of Thermoelectric Properties for SiNW-SiGe0.3 Composite Using Landauer Approach, The 19th International Symposium on Advanced Fluid Information (AFI-2019), CRF-35 (Sendai, 2019/11/07).
21. **(Invited Lecture)** Seiji Samukawa, Kazuhiko Endo, "Atomic Layer Etching, Deposition and Modification Processes for Novel Nano-materials and Nano-devices", 3rd Asia-Pacific Conference on Plasma Physics, PL-26 (Hefei, China,2019/11/07).
22. S.-W. Chang, P.-J. Sung, T-Y. Chu, D. D.Lu, C. -J. Wang, N.-C. Lin, C.-J. Su, S.-H. Lo, H.-F. Huang, J.H. Li, M.-K.Huang, Y.-C. Huang, S.-T. Huang, H.-C. Wang, Y.-J. Huang, J.-Y. Wang, L.-WYu, Y.-F. Huang, F.-K. Hsueh, C.-T. Wu, W. C.-Y. Ma, K.-H. Kao, Y.-J. Lee,C.-L. Lin, R.W. Chuang, K.-P. Huang, S. Samukawa, Y. Li, W.-H. Lee, T.-S.Chao, G.-W. Huang, W.-F. Wu, J.-Y. Li, J.-M. Shieh, W. -K. Yeh, Y.-H. Wang、"First Demonstration of CMOS Inverter and 6T-SRAM Based on GAA CFETsStructure for 3D-IC Applications", IEEE 2019 International Electron Device Meeting, 11.7 (SanFrancisco/USA, 2019/12/10).
23. **(Invited Lecture)** Seiji Samukawa, "Atomic Layer Defect-Free Top-Down Process for Future Nano-Devices",2020 IEEE Electron Devices Technology and Manufacturing Conference (EDTM),1B-4 (Penang, Malaysia, 4/6/2020).
24. **(Keynote Speech)** Seiji Samukawa, "Atomic Layer Defect-Free Top-Down Process for Future Nano-Devices", The 20th IEEE International Conference on Nanotechnology (IEEE NANO 2020), WeKNO1.1 (Virtual Meeting, 7/29/2020).
25. Narasimhulu Thoti, Yiming Li, Sekhar Reddy Kola, Seiji Samukawa, New Proficient Ferroelectric Nanosheet Line Tunneling FETs with Strained SiGe through Scaled N-Epitaxial Layer, The 20th IEEE International Conference on Nanotechnology (IEEE NANO 2020), FrOAO1.5(Virtual Meeting, 7/31/2020).
26. **(Invited Lecture)** Seiji Samukawa, Atomic Layer Etching, Deposition & Modification Processes for Future Nanoscale-devices, IEEE NTC Distinguished Lecture in Joint Technical Seminar Program (Oregon IEEE Nano & Joint EPS/CAS Chapters), (Virtual Meeting, 10/16/2020).
27. T.-Z. Hong, W.-H. Chang, A. Agarwal, Y.-T. Huang, C.-Y. Yang, T.-Y.Chu, H.-Y. Chao, Y. Chuang, S.-T. Chung,J.-H. Lin, S.-M. Luo, C.-J. Tsai, M.-J. Li, X.-R. Yu, N.-C. Lin, T.-C. Cho,P.-J. Sung, C.-J. Su1, G.-L. Luo,F.-K. Hsueh, K.-L. Lin, H. Ishii, T. Irisawa, T. Maeda, C.-T. Wu, W. C.-Y.Ma, D.-D. Lu, K.-H. Kao, Y.-J. Lee,H. J.-H. Chen, C.-L. Lin, R. W. Chuang, K.-P. Huang, S. Samukawa, Y.-M. Li,J.-H. Tarng, T.-S. Chao, M. Miura,G.-W. Huang, W.-F. Wu, J.-Y. Li, J.-M. Shieh, Y.-H. Wang, W.-K. Yeh, First Demonstration of heterogenous Complementary FETs utilizing Low-Temperature (200 °C) Hetero-Layers Bonding Technique (LT-HBT), IEEE 2020 International Electron Device Meeting,15.5 (Virtual Meeting,2020/12/04).
28. Narasimhulu Thoti, Yiming Li, Sekhar Reddy Kola, S. Samukawa, High-performance metal-ferroeletric-semiconductor nanosheet line tunneling field effect transistors with strained sige, 2020 International Conference on Simulation of Semiconductor Processes and Devices (SISPAD), pp. 375-378, 9241591, 2020-September (Virtual Meeting,2020/9/23).
29. Daisuke Ohori, Niraj Man Shrestha, Yiming Li, Jenn-Hwan Tarng, S. Samukawa, High Performance GaN HEMT and Ge Fin FET Device Realizing by Atomic-layer Defect-free Etching with Chlorine Neutral Beam, International Symposium on VLSI Technology, Systems and Applications (VLSI-TSA), pp. 108-109, 9203657 (Hsinchu, Taiwan, 2020/10/13)

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30. S. Lee, Y. Sugawara, M. Ito, H. Kino, T. Fukushima, T. Tanaka TSV Liner Dielectric Technology with Spin-on Low-k Polymer, 2018 International Conference on Electronics Packaging and iMAPS All Asia Conference, 20180420, Mie Prefecture.
31. H. Kino, S. Lee, Y. Sugawara, T. Fukushima, T. Tanaka, Charge-Trap-Free Polymer-Liner Through-Silicon Vias for Reliability Improvement of 3D ICs, 21st IEEE International Interconnect Technology Conference, 2018060, USA.
32. Yuki Susumago, Achille Jacquemond, Noriyuki Takahashi, Hisashi Kino, Tetsu Tanaka, Takafumi Fukushima Mechanical Characterization of FOWLP Based Flexible Hybrid Electronics (FHE) for Biomedical Sensor Application, 2019 International Conference on Electronics Packaging ICEP 2019, 20190419, Niigata Prefecture.
33. Michael Proffitt, Tetsu Tanaka, Takafumi Fukushima, Hisashi Kino, Hiroshi Tomita Study of Transparent Electrodes for 3D-Stacked Retinal Prosthesis, 2019 MRS Spring Meeting, 20190423, USA.
34. Sungho Lee, Rui Liang, Yuki Miwa, Hisashi Kino, Takafumi Fukushima and Tetsu Tanaka, Multichip thinning technology with temporary bonding for multichip-to-wafer 3D integration, 2019 6th International Workshop on Low Temperature Bonding for 3D Integration, 20190522, Ishikawa Prefecture.
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Hydrogen-Based Autonomous Energy Systems Group

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(Supplementary Explanations on Accomplishments)

There was a total of 97 joint papers (12.13 papers per year) for Tohoku University and National Chiao Tung University in the eight years between 2010 and 2017 before the launch of the International Joint Laboratory. However, after the launch of the International Joint Laboratory there was a doubling in the number of joint papers, with a total of 76 joint papers (25.33 papers per year) in the three years between 2018 and 2021. Additionally, following the launch of the International Joint Laboratory there were also 39 joint papers outside of the joint laboratory compared to the the 37 joint papers by joint laboratory members, indicating how cooperation between the two universities has been promoted through events with National Chiao Tung University. Furthermore, **Table 4** shows the number of citations for the joint papers and the field-weighted citation impact (FWCI). Attention should be given to the fact that the number of citations per joint paper is higher than the number of citations per paper for either Tohoku University or Chiao Tung University, and the FWCI is also quite high. Additionally, **Figure 18** shows the number of papers in the top 10%. The percentage of papers in the top 10% out of all of the joint papers since 2018 was 12.5% (=2/16),

Table 4. Information on Published Papers for Tohoku University and Chiao Tung University and on Published Joint Papers

(Scopus 2017-2021)

	Tohoku University Total	National Chiao Tung University and Tohoku University Joint Papers	Chiao Tung University Total
No. of Published Papers	28,730	97	20,510
No. of Authors	15,634	-	13,635
No. of Citations	192,741	786	135,402
No. of Citations Per Paper	6.7	8.1	6.6
Field-Weighted Citation Impact (FWCI)	1.1	2.76	1.19

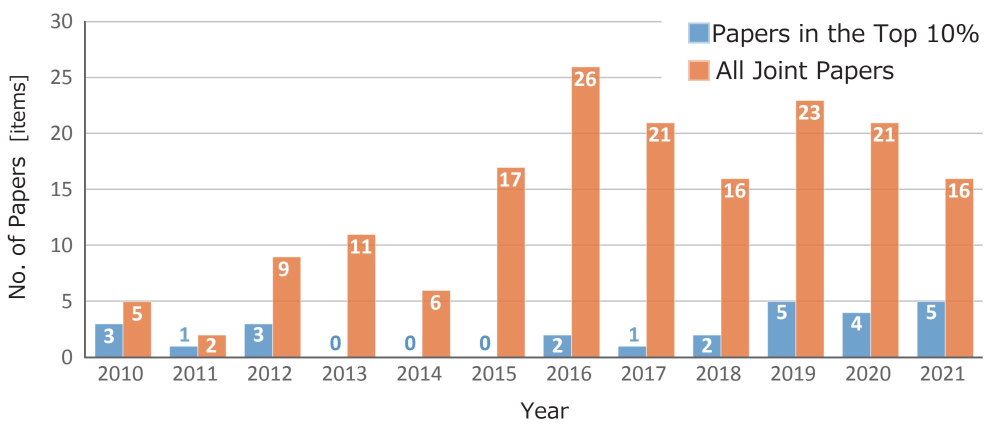


Figure 18. No. of Tohoku University/Chiao Tung University Joint Papers and No. of Papers in the Top 10%

21.7% (=5/23), 19% (=4/21), and 31.3% (5=16), greatly exceeding the percentage of papers in the top 10% for all of Tohoku University (an average of approximately 10%). From this it is clear that international joint papers have a major effect on improving the impact of papers.

8. Press Releases

1) Nanodevice Systems Group

In collaboration with the Taiwan Semiconductor Research Institute (TSRI) and the National Institute of Advanced Industrial Science and Technology (AIST), Tohoku University and Chiao Tung University's International Joint Laboratory has made groundbreaking results that are a global first for building a heterogenous materials integration platform for the 2 nm generation. Based on these results, the group will realize the world's first AI chips that integrate various devices and circuits, as well as furthering the move to systems on chips (SoC) that integrate GaN HEMTs and Ge FinFETs, which will be indispensable for millimeter-wave radar systems in 5G and after. Additionally, the group has made another significant achievement in being selected for the "Infrastructure Development for Promoting International S&T Cooperation" program (supported by JST and MOST), A-STEP (a JST program), and Basic Research S to further this research. Furthermore, going forward the group will be promoting international cooperation between industry and academia centered around cooperation with Taiwanese and Japanese companies with this platform as a base.

2) Biomedical Sensor Networks Group

This group has developed a new process for producing large-area, flexible, thermoelectric elements. Additionally, in order to use the plating process to produce thermoelectric elements, the group has developed a method for depositing Te thermoelectric materials rapidly over a large area. In order to improve the thermoelectric performance, the group has performed exploratory experiments on the doping effect of nanoparticles and on impurities in Te thermoelectric materials. The group has actually created a flexible energy harvester prototype and confirmed this new process' effectiveness.

9. Obtaining Competitive Funds

Chiao Tung University has undertaken to operate the International Joint Laboratory after having prepared a sufficient research fund through the support of Taiwan's Ministry of Education and Ministry of Science and Technology. However, Tohoku University has actively obtained external funds since the lab is a bottom-up international joint laboratory composed of several departments coming together for strategic research for semiconductor device systems. As a result, the university has succeeded in obtaining external funds through 2025 for research themes related to this joint laboratory (**Table 5**).

Table 5. Obtaining Competitive Funds

Name of Fund System/Research Funds	Research Task Name	Research Period (X - X)	Money Received for AY 2020 (Thousands of JPY)
Grants-in-Aid for Scientific Research/ Basic Research S	High mobility semiconductor elements using phonon field suppression through defect-free nano-sized periodic structures	October 2020 - March 2025	17,000
Nanoelectronics Technology Contributing to AI System Structures of the "Infrastructure Development for Promoting International S&T Cooperation (Japan-Taiwan Research Exchange)" Program	Three-dimensional heterogenous function integrated hCFETs for AI chip technology	April 2020 - March 2023	3,000
Research Results Development Project A-STEP (Adaptable and Seamless Technology Transfer Program through Target-driven R&D)	Development of GaN full-color directional micro-LEDs for VR/AR displays	December 2020 - March 2023	3,000
Cross-Ministerial Strategic Innovation Promotion Program	Research and development of IoT environmental sensors for room temperature generators	2018-2022	47,000
Grants-in-Aid for Scientific Research/ Basic Research A	Development of fully implantable, minimally invasive flexible retina prostheses for the regeneration of wide-field vision	April 2018 - March 2021	33,800
Grants-in-Aid for Scientific Research/ Basic Research A	Development of minimally invasive, dispersed pixel, fully implantable retina prostheses with information processing functions and the same viewing angles as for people	April 2021 - March 2024	32,100
Grants-in-Aid for Scientific Research/ Basic Research A	Creation of a base for dielet integrated in-mold electronics and the development of subcutaneous information visualization sheets	April 2021 - March 2025	32,300

10. General Summary

Taiwan is now the leader in the global semiconductor industry, possessing the semiconductor company TSMC and having pulled ahead of the United States and South Korea. In other words, the country's electronics industry is at the forefront of advanced technological trends. Central to this dominance is the Hschinchu Science Park's semiconductor device platform (Chiao Tung University and TSRI). Connecting the cutting-edge materials device production technology of the National Institute of Advanced Industrial Science and Technology and of Tohoku University with this cutting-edge platform and realizing a heterogenous materials/devices hybrid process before anyone else in the world is a result deserving of attention. These results will be extremely significant for being able to lead the world in the development of biomedical sensors and networks and of the extremely cutting-edge semiconductor devices that will be indispensable in the AI and IoT era going forward. Tohoku University promotes international cooperation between industry, academia, and government, such as in cooperation with Japanese and Taiwanese companies, using this international platform and thereby contributes to “making Japan a ‘semiconductor nation’ again.” Additionally, there are plans to develop a hydrogen-based autonomous energy system for the platform at the Shalun Green Energy Science Park on the Taiwan campus of Chiao Tung University.

Taiwan, where COVID-19 infections have been completely contained, has been able to function without stopping daily activities at all, including university education, research and development, and economic activities (3% increase in GDP for 2020). As a result, companies from around the world, including Apple and Microsoft, have entered the market one after the other. Research and and development at Chiao Tung University, TSRI, and the Hsinchu Science Park has also grown more and more vigorous. The integration and linking of this platform and the basic technology of Tohoku University and AIST is an extremely significant harvest for Japan and Tohoku University which must promote cutting-edge semiconductor research, the pillar of industry. Additionally, National Chiao Tung University merged with National Ying-Ming University, a medical university, on February 2, 2021, to form the National Ying Ming Chiao Tung University. This is a strategy of Taiwan’s Ministry of Science and Technology, which will emphasize cooperation with biomedical engineering going forward. Through the renewal of the contract for the International Joint Laboratory which expires in August 2021, it is expected that National Ying Ming Chiao Tung University and Tohoku University’s International Joint Laboratory will make significant developments in medical ICT as well based on the strategic international research and education platform for ultra-cutting-edge semiconductor device systems and sensor networks constructed in the first term.

By realizing this strategic international research and education platform, rare among Japanese universities, we can expect significant results as a hub of international cooperation between academia, government, and global companies, and we hope to contribute in as significant a way as possible to “a university that ranks globally.”

Supplementary Materials 1
"Collaborative Research Proposal for Taiwanese Companies"

Project Proposal between Japan and Taiwan

Platform of 3/2-nm-generation Heterogeneous-material-integration and Development of Ultra-high-performance 3D Device (Dream System-on-Chip: D-SoC)

Prof. Seiji Samukawa

Tohoku University

1. Overview of proposal

With the aim of making Japan a "semiconductor nation" again, the proposed project aims to develop and commercialize Japan's original basic manufacturing technology that plays a fundamental role in the development and commercialization of semiconductor devices. The goals of the proposal are threefold: (1) producing and commercializing manufacturing equipment for manufacturing cutting-edge devices; (2) creating an international platform for manufacturing equipment for developing cutting-edge devices through international collaboration between Japan and Taiwan; and (3) developing 3/2-nm-generation ultra-efficient heterogeneous-material integrated 3D devices, namely, "system on chips" (SoCs). Ranging from the development of equipment to the final development of cutting-edge devices and cutting-edge SoCs, this research project is unprecedentedly ambitious in terms of enabling integrated research and development and practical application of original manufacturing technology. This project—established by a consortium composed of manufacturing equipment companies possessing Japan's original basic fabrication technology for semiconductor manufacturing—has three main aims to achieve by 2030 while greatly strengthening each basic technology: (1) Japanese semiconductor manufacturing equipment companies to take the lead in the world in the semiconductor manufacturing equipment industry; (2) Taiwanese device manufacturing companies of 3/2-nm-generation heterogeneous-material-integration semiconductor devices to lead the world in the development and practical application of integrated 3D devices; and (3) contribute to the achievement of carbon neutrality by realizing energy-saving power semiconductors, post-5G high-frequency devices, and ultra-low power consumption CMOS devices (such as Nanosheet, Forksheet and 3D Complementary FET (CFET)) (**Fig. 1**: Development roadmap).

2. Background

The semiconductor industry in Japan, which was the world's number one semiconductor nation in the 1980s, lost momentum from 1990 onwards and has now almost completely collapsed. One of the major causes of this collapse is the fact that the industry came to rely solely on external outsourcing of semiconductor-manufacturing technology and its equipment.

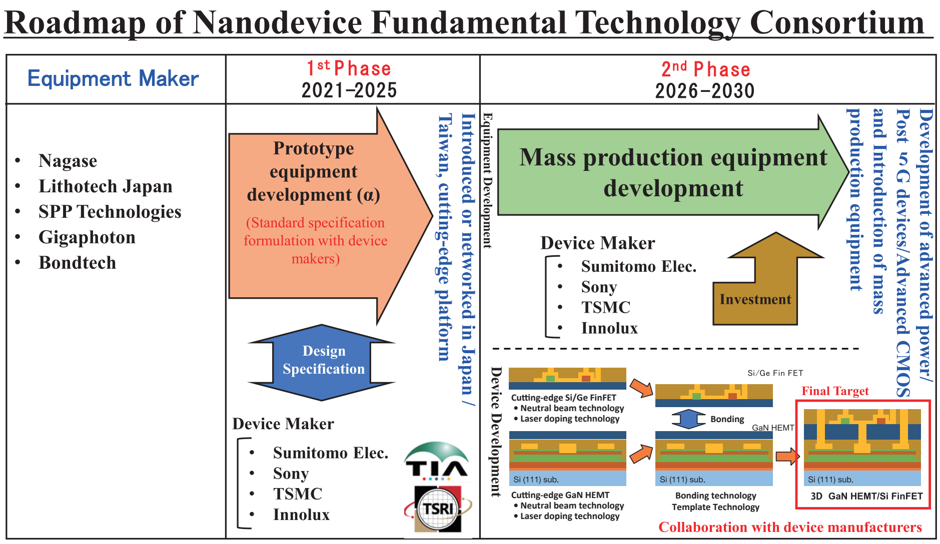


Fig. 1. Roadmap of Nanodevice Fundamental Technology Consortium.

As a result, Japan's original manufacturing technologies accumulated up to that point were not followed up on, and Japan lagged behind in the development of advanced semiconductor devices. State-of-the-art manufacturing technology is now indispensable not only for state-of-the-art memory and logic circuits but also for power semiconductors and high-frequency devices for post-5G communication. And in 2030, a completely new and innovative manufacturing technology will be introduced into the mass-production line. However, despite the fact that the Japanese semiconductor equipment industry has proposed several breakthrough manufacturing technologies that will be necessary in the next generation, it has not been able to accelerate the development of these technologies into practical equipment as well as develop its own proprietary technologies and actual cutting-edge devices. In this project, focusing on basic fabrication technology for manufacturing advanced semiconductor devices, we will develop equipment, build a platform for manufacturing equipment, and demonstrate and mass produce devices with that equipment.

3. Details

In this project, as a consortium, we will consolidate and strengthen our own basic fabrication technologies that are indispensable for practical development of 3/2-nm-generation heterogeneous-material-integrated 3D devices. Those technologies include (1) nano-template technology, (2) ultra-low-damage atomic layer etching, deposition, and surface-modification technologies, (3) low-temperature, shallow and high dose doping technology, and (4) low-temperature wafer-chip bonding technology. The goal of the consortium is to strengthen these manufacturing technologies and to develop the equipment for the device-mass-production. In addition to development of individual manufacturing equipment, we will introduce these fabrication equipment to international leading-edge platforms in Japan (TIA, mainly AIST) and Taiwan (TSRI) and form a network for collaborating with these platforms. In this way, we will create an original platform for integrating fundamental technologies that can be applied in development of advanced devices. Using this platform enables (i) joint research between these manufacturing equipment companies and leading-edge device companies, (ii) demonstration experiments concerning development of leading-edge devices targeted for introduction in 2030, and (iii) clarification of guidelines for mass producing devices in that development process through joint development with device manufacturing companies.

Although it has targeted specific devices, the Japanese semiconductor industry has accumulated its own compound-semiconductor manufacturing technology and still leads the world to some extent. Focusing on (1) ultra-high-efficiency power semiconductor devices using SiC- or GaN-based materials, (2) ultra-energy-saving post-5G high-frequency devices using GaN-based materials, and (3) advanced CMOS devices using Si or Ge, it has created a device (called "system-on-chip") that integrates dissimilar materials such as silicon, germanium, and compound materials (Power/Post-5G devices: **Fig. 2**, Advanced CMOS devices: **Fig. 3**).

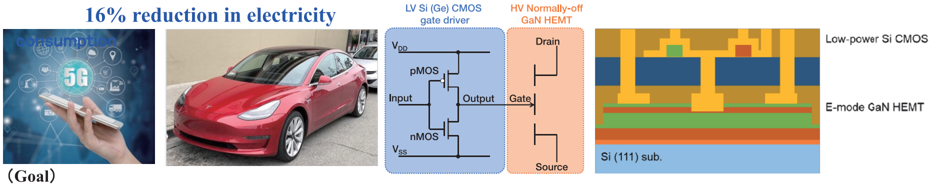
We expect to collaborate with Taiwan Semiconductor Manufacturing Company, Ltd (TSMC) on the development of these devices. In this joint research, we will develop a SoC that integrates the most-advanced GaN HEMT and a Si/Ge Fin FET, which is targeted for launch in 2030, by extending the basic manufacturing technology developed in this project to TSMC's existing technology. This is a fundamental technology that can be applied to memory, logic devices, and micro-LEDs, and its ripple effect will be significant. As for these advanced devices, we expect to collaborate with Taiwanese device companies (Memory: Macronix, Micro-LED: Innolux) in developing the Taiwan platform.

The unique feature of this project is that it aims to not only develop devices with device manufacturing company but also develop a platform for the first step (the first half of the next five years) toward mass-producing cutting-edge devices (power devices, post-5G high-frequency devices

Challenge to develop ultra-high efficiency 3D device (SoC)

The world's first "normally off GaN HEMT/Ultra-low power consumption Si (Ge) Fin MOSFET 3D hybrid device (ultra-high efficiency power semiconductor, post 5G ultra-high frequency device)"

16% reduction in electricity



(Goal)

1. **System-on-chip by ultra-low damage atomic layer process, low temperature shallow bonding technology, and 3D low temperature bonding technology.**
2. **High efficiency and high power GaN HEMT without heat generation (ultra high withstand voltage> 3.3kV, power loss <1/10, energy saving effect 9%) using a low power consumption MOSFET driver.**
3. **Low power consumption post 5G high frequency device (frequency> 100GHz, power efficiency> 20%, power density> 6W /mm).**

Fig. 2. Challenge develop ultra-high efficiency 3D GaN HEMT/Si (Ge) Fin FET hybrid devices

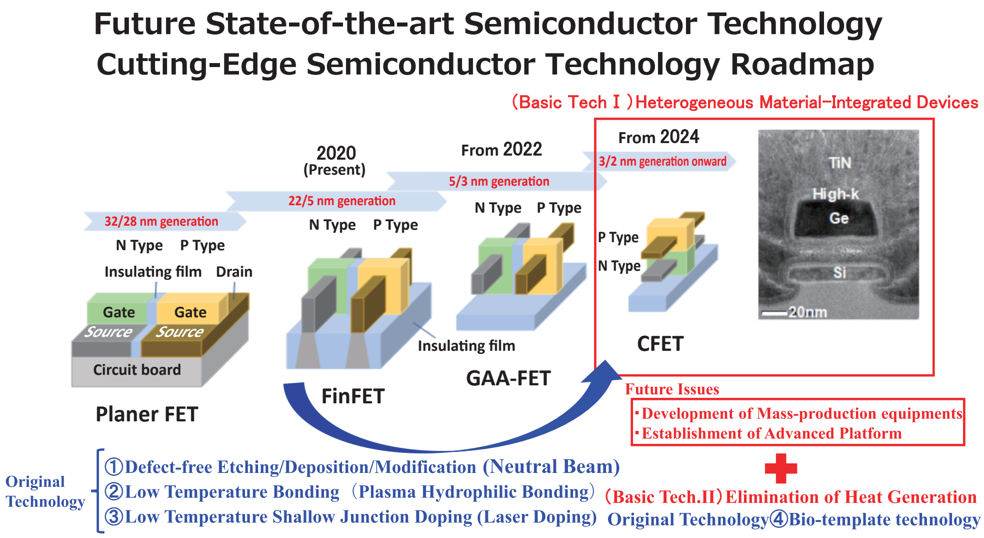


Fig. 3. Challenge develop advanced CMOS Devices (Nanosheet, Forksheet and 3D Complementary FET (CFET))

and advanced CMOS devices) that are necessary for green innovation in 2030. The first step is to build a platform by developing and combining the basic manufacturing technologies required for that generation of devices. In the second step (i.e., the latter half of the five-year period), the manufacturing equipment and target devices will be practically applied in parallel in the form of joint research with actual device manufacturing companies. This two-step research and development will not merely end with device development; in other words, it will be an effective project for developing actual mass-production equipment and processes that integrate silicon and compound technologies and for enabling mass production of targeted devices.

4. Member companies (manufacturing-equipment manufacturers) (Companies participating in the consortium)

1) Nagase & Co., Ltd. and Litho Tech Japan Co., Ltd.

Nagase & Co., Ltd. and Litho Tech Japan Co., Ltd. have licensed the proprietary “bio-template technology” proposed by Professor Samukawa of Tohoku University, and are promoting its practical application, as a technology to overcome the limitations of cutting-edge lithography technologies such as EB and EUV. Since biological “supramolecules” (proteins) are synthesized on the basis of genetic information, variations in their structure and size are less than 0.1 nm, so they are termed “nano-sized” standard products. Biotemplate technology is a revolutionary means of highly precise and controlled placement of proteins by modifying the surface of these nano-sized proteins with peptides—which can be selectively adsorbed on semiconductor substrates—by applying biotechnology. The current technology uses ferritin, an iron oxide-containing protein, to arrange the nanostructure in a regular pattern on a semiconductor substrate. It then removes the protein from the surface by heat treatment and uses the remaining iron oxide as a mask to transfer the nanostructure onto the semiconductor substrate by neutral-beam etching. Having strengths in biotechnology, Nagase has been able to synthesize high-purity iron oxide-containing ferritin and modify the surface to control the arrangement of the nanostructure. In the meantime, Litho Tech Japan has devised a uniform coating technology for ferritin. The company also possess imprinting technology, which it will continue to integrate with the coating technology to achieve more precise placement of ferritin.

2) SPP Technologies

As a joint venture between Sumitomo Precision Products and SPT of the U.K, it dominates the market for deep-plasma-etching technology (deep RIE technology) for MEMS and possesses advanced technology for controlling generation of high-frequency plasma for 12-inch substrates. The pulse-modulated-plasma and neutral-beam technologies proposed by Professor Samukawa at Tohoku University have been licensed to SPP Technologies, which is working on their practical application. First proposed by Prof. Samukawa, a pulse-modulated plasma with pulses in the order of microseconds is unlike an ordinary plasma; that is, instead of consisting of electrons and positive ions, it consists of positive and negative ions. From the pulse-modulated plasma, negative ions are accelerated through a carbon aperture to produce a highly efficient neutral beam with controlled energy. It has already been shown that when this method is applied to the etching, deposition, and surface-modification processes used in the semiconductor-device manufacturing process, defects at the atomic-layer level can be reduced to less than 1/100th of the conventional level; accordingly, it is considered an indispensable process for manufacturing nano-sized semiconductor devices. While developing a large-diameter neutral particle-beam source, this joint venture will develop it to handle etching, deposition, and surface-modification processes for all materials.

3) Gigaphoton Co., Ltd.

In 2001, Gigaphoton became the first company in the world to commercialize a mass-produced ArF excimer laser capable of oscillating at a high frequency of 4 kHz. Since then, it has been supplying the market with a succession of the latest ArF excimer lasers that are compatible with high-performance lithography equipment; in that way, it has been contributing to the development of lithography technology for supporting the ultra-fine integrated circuits of the gigabit generation. Moreover, KrF excimer lasers have been highly evaluated in terms of their abundant product lineup, high performance, high quality, and economic efficiency, and they continue to support the technological competitiveness of the world’s lithography-equipment manufacturers. To expand this business, Gigaphoton signed an organization-based collaboration agreement with Kyushu University in 2011 and established a joint research unit, called the Department of Gigaphoton Next GLP, at Kyushu University to develop advanced laser-processing technology. In particular, as a low-temperature shallow-junction technology, laser doping is an advanced process that is essential for manufacturing advanced nanodevices. This process has been applied to not only silicon and germanium but also SiC and GaN, and its effectiveness has been demonstrated. From now onwards, it is planned to demonstrate the effectiveness of laser-doping technology in regard to device-manufacturing processes as the trend towards larger apertures continues.

4) Bondtech Co., Ltd.

Under the guidance of Professor Tadatomo Suga of the University of Tokyo, who is a leading expert in “room-temperature bonding using surface activation,” which is a key process in 3D stacking of semiconductors, Bondtech has been focusing on developing technology that enables bonding under low vacuum and atmospheric pressure, which will enable the transition to mass production. As for the mass-production process, room temperature was not necessarily set as a condition; that is, a combination of heating (to about 150°C) and pressurization was used to achieve bonding in air. And different surface activation methods are used according to the bonding material used. Moreover, by applying the conventional method using an atomic beam, the degree of vacuum is reduced from an ultrahigh vacuum by a unique process; as a result, bonding of dissimilar materials such as compound semiconductors is possible. What’s more, gold and copper can be bonded using argon etching via a low-vacuum plasma, while silicon and glass can be bonded in air by using plasma hydrophilization. By combining conventional anode bonding (via electrostatic force) with plasma surface activation, “voidless” low-temperature bonding has been achieved. From now onwards, aiming for higher precision bonding as well as larger-diameter substrates, Bondtech will collaborate with SPP Technologies in developing the neutral beam proposed by Professor Samukawa of Tohoku University as a method for surface treatment.

Supplementary Materials 2
"Comments from Professor Yiming Li (Subleader of the Joint Lab) of National Chiao Tung University"

National Chiao Tung University/Tohoku University Joint Research Center 2018-2021Achievement Report

Prof. Yiming Li

Associate Director, Joint Research Center between NCTU and Tohoku University

1. Achievements

The Joint Research Center, of which Tohoku University is a partner, played a central role in developing heterogeneous complimentary field effect transistors (hCFETs) and their platforms through collaboration with the National Institute of Advanced Industrial Science and Technology (AIST) and Taiwan Semiconductor Research Institute (TSRI). hCFETs are 3D heterogeneous function integrated devices and serve as the technological foundation for millimeter-wave radar systems and artificial intelligence (AI) chips in the 5G era and beyond. This effort is a part of the "Infrastructure Development for Promoting International S&T Cooperation (Japan-Taiwan Research Exchange): Nanoelectronics and System Integration for AI" project carried out with support from the Japan Science and Technology Agency (JST) and Taiwan's Ministry of Science and Technology (MOST). The program seeks to develop device manufacturing process platforms essential for hybridizing heterogeneous materials/devices to produce system-on-chips (SOCs). These materials and devices are a prerequisite for sub-5-nm devices. The Joint Research Center has succeeded in developing a 2-nm generation Si/Ge heterogeneous channel integration platform, a groundbreaking achievement. This accomplishment was selected for presentation at the 2020 IEEE International Electron Device Meeting (IEDM2020), the most prestigious international conference in the semiconductor device field.

In addition, the Joint Research Center conducted basic research to break down barriers in transistor scaling. Improving transistor performance through scaling alone becomes difficult when the gate length reaches sub-50 nm. Performance improvements have been achieved by using technology boosters such as (1) adding strain to the transistor to improve carrier mobility, (2) replacing the gate dielectric with a high-k material, and (3) using fin-type field effect transistors. However, performance improvements using these technology boosters have already reached their limits, and new technology boosters are needed. For the fourth technology booster, we have proposed a transistor channel structure with a composite structure of periodic and defect-free semiconductor nanopillars embedded with matrix materials. This Tohoku University-original proposal suppresses phonon scattering of carriers depending on the materials, nanopillar size, and spacing, and makes possible dramatic improvements in carrier mobility and a transistor channel layer with low heat generation. This proposal has been selected as a Grant-in-Aid for Scientific Research - Basic Research (S). It will be deployed for transistor development in collaboration with AIST, the University of Tokyo, University of Miyazaki, TSRI and National Chiao Tung University.

2. Significance

Taiwan is now the No. 1 leader in the global semiconductor industry, having pulled ahead of the United States and South Korea. In short, the country's electronics industry is at the forefront of advanced technological trends. Central to this dominance is the significant role played by Hsinchu Science Park's platform (a partnership of National Chiao Tung University and TSRI). Joining this advanced platform with Tohoku University and AIST's advanced materials production technologies has resulted in the world's first hybrid process for heterogeneous materials and devices, a revolutionary achievement. This achievement is extremely significant in giving the partnership of NCTU and Tohoku University/AIST the ability to lead the world in developing essential ultra-advanced devices in the AI era and beyond.

Supplementary Materials 3
"Comments from Professor Ming-Dou Ker (Group Leader) of National Chiao Tung University"

Biomedical Sensor and Network Project in Joint Research Center between NCTU and Tohoku Univ. 2018-2021Achievement Report

Prof. Min-Dou Ker

Group Leader, Joint Research Center between NCTU and Tohoku Univ.

We have developed a high-conversion-ratio (HCR), high-voltage-tolerant (HVT) energy harvesting battery charger using 0.18-µm standard CMOS for Internet of Things (IoT), as shown in **Fig. 1**. To reduce conversion ratio (CR) of inductive power converter and optimize overall power efficiency, the proposed charger cascades a boost converter and reconfigurable charge pump. Different from the high-voltage device, the standard CMOS process has lower parasitic capacitance and on-resistance; therefore, it can reduce switching and conduction loss. The proposed converter is able to manage limited power from a thermoelectric generator (TEG). We realized a zero-current detector (ZCD) using an analog comparator with digital offset compensator to control off-time (TOFF) quickly and accurately. The self-idle constant on-time (SI-COT) and idle mode both control the mechanism, helping to further reduce static power dissipation. As a result, the proposed converter can achieve peak efficiency of up to 76% at a 92× conversion ratio with output power ranging from 10 µW to 1.9 mW. The available input voltage ranges are 40 to 400 mV, and the dual output voltage ranges are 1 to 1.6 V and 2 to 4.6 V for VBOOST and VOUT, respectively. **Fig. 2** compares the performance with state-of-the-art energy-harvesting DC–DC converters. The proposed converter provides a 4.6-V high output voltage using 1.8V standard CMOS device without any voltage stress issue. The standard CMOS process has lower on-resistance and parasitic capacitance, thus the proposed converter

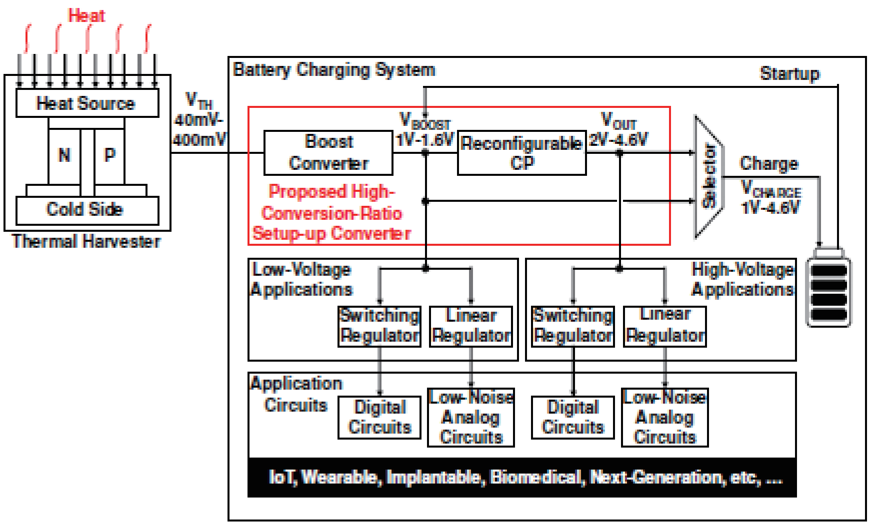


Fig. 1. The system architecture of the battery-charging system

	[12] JSSC 10	[11] JSSC 11	[13] JSSC 13	[15] TPE 13	[14] JSSC 15	[34] JSSC 16	This work
Converter Topology	Single boost	Boost and buck cascade	Boost and boost stepping-up	Single boost	Single boost	Charge pump and charge pump cascade	Boost and charge pump cascade
Output Number	Single	Dual	Dual	Single	Single	Dual	Dual
Control Loop	Single	Single	Single	Single	Single	Dual	Dual
Inductor	47μH	22μH	2μH, 100μH, 27μH	22μH	10μH	N	4.7μH
Input Voltage	20mV-250mV	25mV-100mV	30mV-200mV	70mV-600mV	10mV-300mV	0.35V-0.6V	40mV-400mV
Output Voltage	1V	1.8V	1.2V	3V-5.8V	1.1V	V_{OUT1} : 0.86V-1.8V V_{OUT2} : 2.5V-5.2V	V_{BOOST} : 1V-1.6V V_{OUT} : 2V-4.6V
Output Power	1μW-100μW	10μW-300μW	< 4.3mW	N/A	< 22mW	< 396μW	10μW-1.9mW
Maximum Conversion Ratio	50	72	40	82.86	110	14.86	115
Process	130nm CMOS	350nm CMOS	65nm CMOS	350nm BCDMOS	130nm CMOS	180nm CMOS	180nm CMOS (All in standard 1.8V devices)
Configuration of Power Stage	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Automatic Configuration
Peak Efficiency	75% @ V_{IN} = 100mV, CR=10	58% @ V_{IN} = 25mV, CR=72	73% @ V_{IN} = 200mV, CR=6	72.2% @ V_{IN} = 500mV, CR=11.24	83% @ V_{IN} = 300mV, CR=3.67	75.8% @ V_{IN} = 590mV, CR=2.39	78.4% @ V_{IN} = 100mV, CR=46
Worst Efficiency	35% @ V_{IN} = 40mV, CR=25	N/A	55% @ V_{IN} = 40mV, CR=30	N/A	60% @ V_{IN} = 40mV, CR=27.5	N/A	67.8% @ V_{IN} = 40mV, CR=115

Conversion Ratio (CR): V_{OUT}/V_{IN}

Fig. 2. Performance comparison with other state of the arts.

obtains 67.8% efficiency at 115× conversion ratio. Comparing to state-of the-art, the proposed DC–DC converter achieves the highest conversion ratio of 115× with high efficiency. The proposed topology is suitable for thermoelectric energy-harvesting battery charger for the Internet of Things. The relevant results have been published in IEEE Transaction on Circuits and Systems I (TCAS-I) 2020.

Publications

1. M.-J. Chung, T. Hirose, T. Ono, and P.-H. Chen, "A 115× Conversion-Ratio Thermoelectric Energy-Harvesting Battery
Charger for the Internet of Things", IEEE Transactions on Circuits and Systems I (TCAS-I), pp. 4110-4121, Aug. 2020.

National Chiao Tung University and Tohoku University International Joint Laboratory External Evaluation Report (August 2018 - July 2021)

June 21, 2021

National Institute of Advanced Industrial Science and Technology

Senior Executive Officer

Seigo Kanemaru

About the Outside Evaluator for the Project (Profile)

Kanemaru Seigo

Senior Executive Officer of the National Institute of Advanced Industrial Science and Technology

CV	Date of Appointment: April 21, 2021
March 1987	Completed his doctoral course at the Department of Electrical Systems, Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology. Doctor of Engineering.
April 1987	Joined the Electrotechnical Laboratory of the Agency of Industrial Science and Technology
April 2001	Group Leader for Functionally Integrated Systems, Electronics Research Division, Institute of Advanced Industrial Science and Technology
February 2004	General Planning Manager, Planning Headquarters
April 2006	Deputy Director, Electronics Research Division
April 2008	Director, Electronics Research Division
April 2011	Director, Nanoelectronics Research Division
May 2015	Research Director, Information Technology and Electronics; Research Director, Nanotechnology, Materials, and Manufacturing
April 2015	Director, Electronics & Manufacturing Area, National Institute of Advanced Industrial Science and Technology
April 2017	Assumed position of Director for the National Institute of Advanced Industrial Science and Technology
April 2020	Assumed position of Vice Director for the National Institute of Advanced Industrial Science and Technology
Other Currently Held Posts	Assumed position of Senior Executive Officer for the National Institute of Advanced Industrial Science and Technology
Concurrent Posts	Director of the Tsukuba Center, Director of the TIA Central Office, Chief Information Officer, Chief Information Security Officer

After completing his doctoral program at the graduate school of the Tokyo Institute of Technology in 1987, Mr. Kanemaru joined the Electrotechnical Laboratory of the Agency of Industrial Science and Technology, a hub for semiconductor device research. At the Institute of Advanced Industrial Science and Technology, Mr. Kanemaru experienced the center of electronics research, holding successive positions as director of the electronics and nanoelectronics research divisions, Director of the Electronics and Manufacturing Area, and Director and Vice Director of the Institute of Advanced Industrial Science and Technology. In April 2021 he assumed the positions of Senior Executive Officer, Director of the Tsukuba Center, and Director of the TIA Central Office. He has been at the core of semiconductor research from the 1980s, when the Japanese semiconductor industry was at its peak, to the present, and has experience not only in research but also in top management at a national research and development corporation. In addition, he is currently an officer for TIA at the National Institute of Advanced Industrial Science and Technology, the most advanced platform for semiconductor research in Japan. He has also served as Vice Chairman of the Japan Society of Applied Physics, as a member of the Research Project Evaluation Committee of the New Industry Creation Hatchery Center at Tohoku University, and as a member of the Broadcasting Technology Research Committee of the NHK Science & Technology Research Laboratories. From the above, it can be seen that Mr. Kanemaru is in a position to lead and coordinate Japan's activities in semiconductor research hubs and the semiconductor industry.

Evaluation of the Activities of the National Chiao Tung University and Tohoku University International Joint Laboratory

Evaluator	Name	Seigo Kanemaru
	Affiliation/Position	Senior Executive Officer of the National Institute of Advanced Industrial Science and Technology (Additional Posts) Director of the Tsukuba Center, Director of the TIA Central Office.
Date of Evaluation		June 21, 2021

Comprehensive Evaluation of All Activities (Please write a comprehensive evaluation of all activities in whatever form you like.)

Strategic research tasks have been selected that make use of the strengths of each school based on the organizational system of the international joint laboratory, which promotes a collaborative structure between the two universities and which began with an agreement between the universities in 2005. As the research results produced are all recognized as being superior research results and as there has been a broad improvement in the both the quality and quantity of research results compared to before the establishment of the laboratory, the organization can be judged to be substantive and agile in its operations. In particular, I believe that there is proof that the joint laboratory is going well in the fact that a new system was constructed for hydrogen energy systems through the cooperation of both universities in a situation where they were forced to change the promotional system due to the sudden death of one of the other party's professors. Additionally, there is proof in the new developments being made in the medical, dental, and pharmacological research fields.

Activities for the cultivation of human resources are also going smoothly, and exchange based on collaborate research is functioning as it should. I believe there is room for improvement in the fact that study abroad exchanges are taking place in one direction: from Tohoku University to Chiao Tung University.

Notable Results/Results with a Social Impact, etc. (From among the results of the activities please write about particularly notable results, results with a social impact, and reasons for these results in whatever form you like.)

Among the results of the nanodevice group, I would particularly like to praise the realization of the hCFET. In addition to producing the first research results in the world for a globally competitive area, the joint laboratory achieved these results through collaborative research with TSRI and AIST. I give high marks to the joint laboratory for working to promote cooperation not only between the two universities but also between Japan and Taiwan.

The development of retinal prosthesis chips by the biomedical sensor networks group is the result of the integration of the strengths of each university in the form of a device, and while the application of this technology is the next task to be dealt with, we can expect positive future developments from these results.

I expect the basic technologies created in the hydrogen-based autonomous systems research by the energy device systems group to clarify the task of social implementation and to develop these systems by utilizing the close proximity of Taiwan's science park.

Expectations, Recommendations, Etc. for Future Activities (Please write, in whatever form you like, about the significance of these activities for the country and expectations/recommendations for future activities at the university based on the global situation for the semiconductor industry.)

Currently, the importance and future prospects of the semiconductor industry are once more being evaluated highly, and in Japan as well, the industry is being positioned as part of the government's strategy. While we can see a limit to the miniaturizing of semiconductors, there is a need to redefine what qualifies as new and cutting-edge semiconductor technology. I hope that this joint laboratory will develop new research and development systems together with other organizations by integrating the fields of technical superiority for both countries.