TECHNOLOGY TRANSFER

OIST

OKINAWA INSTITUTE
OF SCIENCE AND TECHNOLOGY
GRADUATE UNIVERSITY

RESEARCH

EDUCATION

Welcome to OIST

a university for the future

沖縄科学技術大学院大学

Welcome to the Future of Research and Education

No boundaries

OIST is pioneering change in the global practice of education and research. The absence of academic departments, a policy of broad access to all research equipment, and shared common space for faculty-led research units from widely differing disciplines remove traditional barriers to collaboration and promote cross-disciplinary research opportunities. While students receive strong training in their discipline of choice, their studies also include courses that fall outside of their area of specialization. Students are required to do at least one of their three rotations in a laboratory conducting research outside of their core discipline.

Message from the President

Over the next 30 years, we will encounter some of the greatest transitions that any generation has had to face. We are at the brink of the fourth industrial revolution, whereupon artificial intelligence, robotics and automation will greatly change all aspects of our society—from the employment landscape, to education, to healthcare, and even what it means to be "human." We are facing many grand challenges on a worldwide scale, such as energy provision, aging societies, healthcare, urbanization and food supply. As new technologies rapidly change our societal needs, collaborations between government, industry and academia become crucial to providing innovative solutions to these global problems.

Industrial research is often constrained to low-risk applied research that offers calculable, but limited gains. Academic research provides the foundation through which breakthrough innovations are made. Well-supported academic research institutes can give scientists the creative and intellectual freedoms to pursue high-risk, high-reward projects that have the potential to revolutionize their field. Partnerships between industry and academia are necessary for continuous innovation; many top technology companies have recognized this importance and are investing heavily in top universities.

The Okinawa Institute of Science and Technology Graduate University (OIST) is poised to become one of these leading research universities. In 2017, Japanese Prime Minister Shinzo Abe recognized the potential of OIST, noting our "prominent faculty whose work has Nobel prize potential and top-class students". As the university grows, we hope to strengthen partnerships with government, industry and other academic institutions to achieve our mission of conducting internationally outstanding education and research in science and technology, while also contributing to the sustainable development of Okinawa.

This brochure provides merely a glimpse of some of our innovative education and research performed at OIST. For a more comprehensive view, please see our website, or better yet, schedule a tour of our beautiful campus. We happily welcome you to Okinawa.

Peter Gruss
OIST President

OIST President Peter Gruss with students

OIST for Innovation

Breakthrough innovation is the key to the future and OIST is revolutionizing the way it is cultivated. Internationalism and quality are our greatest strengths. We recruit the best researchers from around the world to perform the highest quality research in a wide variety of scientific fields. Theoretical physics, marine research, neuroscience, and microfluidics are just a sampling of the different research topics at OIST. The University features a department-less structure to allow for greater interdisciplinary collaborations by encouraging researchers from different fields to interact. Our success is based on an open, competitive, international, and interdisciplinary approach to research and education.

Power grid managers seeking to incorporate more wind energy need to balance peaks and lows in generation. Conventional wisdom suggests that connecting wind farms spaced far apart could help average out those fluctuations. As it turns out, it is not so simple.

Professor Mahesh Bandi analyzed data from wind farms in Texas and Ireland. He found that turbines very far apart from one another peaked and lulled at almost the same times. Specific wind patterns can be spread over large distances, so the same amount of turbulence could be experienced at multiple sites.

“Correlation distance is on the orders of hundreds of kilometers, which means you cannot average as easily as one might have imagined,” said Bandi, who heads the Collective Interactions Unit.

This research showed there is a limit to how well fluctuations can be managed. Even in the theoretical case of linking together all the wind farms on the planet, it would not be possible to avoid fluctuations completely.

“Knowing the structure of these fluctuations can help design a better grid,” Bandi said.

A physicist and engineer, Bandi looks for fluctuations all around him, and this leads him to study a wide array of topics: from fish fins and bird songs, to human feet and Japanese fusuma screens. The freedom to work across many fields is the thing he appreciates most about OIST.

“I would not be able to easily pursue interests as diverse as renewable energy fluctuations, foot biomechanics and the science of art at a university with a conventional department structure,” Bandi said.

Fluctuations Abound

Describing the world through fluctuations, and designing better energy grids in the process.

By exploiting the correspondence between turbines and propellers, Professor Mahesh Bandi plans to study fluctuations in flight, of which inflight turbulence is an extreme example.

Messy Turbulence

Making sense of turbulent flows provides insights into a variety of phenomena, from typhoons to oil and gas transport.

Researchers in the Fluid Mechanics Unit study flow in three dimensions.

Turbulence is a difficult problem that has confounded mathematicians, physicists and engineers for hundreds of years. Some have even written it off as hopeless and unsolvable.

Professor Pinaki Chakraborty and his team in the Fluid Mechanics Unit embrace the challenge. By combining approaches from both physics and engineering, they are starting to make sense of the mess.

Specifically, they are interested in liquid or gas flows when they are transitioning from a smooth state, like a gently flowing stream, to a high-velocity, jumbled state, like a rushing river. While calm flows are well understood, this "transition to turbulence" is extraordinarily difficult to tackle mathematically.

"This transitional state has very, very strange features," Chakraborty said. "By doing experiments, we are starting to tease out many features of these transitional flows that people have missed for over a hundred years."

The team also wants to clarify what happens once flows become turbulent. Turbulence highly influences friction, but how explicitly is part of the puzzle. To understand this relationship, Chakraborty's unit works closely with the Continuum Physics Unit on various experiments. They custom built a 20-meter-long glass tube to analyze flows in three dimensions. They also study them in two dimensions using a thin waterfall of soap film.

Their findings could have wide-ranging implications, such as improving typhoon forecasts. Friction between a typhoon and the surface of the ocean has dual effects: slowing the speed of the storm, while simultaneously generating heat that can increase intensity.

"Our ability to predict the intensity of a typhoon is very much tied to our ability to predict friction between the typhoon and the surface of the ocean," Chakraborty said.

Friction also causes oil or gas to slow down as it moves through a pipeline and requires a pump to keep it moving. Reducing friction even a little could add up to substantial savings because less energy is needed to run pumps.

"We are starting to understand where friction is coming from," Chakraborty said. "It gives us hope that perhaps we can come up with ways to manipulate and control friction."

It seems this problem is not so hopeless after all.

Chemistry Inspired by Nature

Designing new metal-based molecules for non-toxic catalysts with nature as a guide.

Researcher Olga Gladkovskaya holds glowing mechanophores, the cheap, non-toxic catalysts that the Coordination Chemistry and Catalysis Unit is developing.

Professor Julia Khusnutdinova and her collaborators are seeking to design catalysts that are non-toxic and cheaper than catalysts widely used by the chemical industry today.

"To make optimal systems, we look at how nature does it and try to make something similar," said Khusnutdinova, who runs the Coordination Chemistry and Catalysis Unit.

Catalysts are enablers; they help make chemical reactions happen. Khusnutdinova is particularly interested in metal catalysts that can facilitate many reactions, from making fuels to pharmaceuticals.

The chemical industry often relies on catalysts that contain expensive, precious metals that are toxic, such as iridium, rhodium or ruthenium. Also, the essential "ligand" frames around the metal molecules often contain phosphorus, which make them unstable in air.

"Nature does not use precious metals," Khusnutdinova said. "It uses cheap metals and simple, stable ligands."

She and her team designed a catalyst based on manganese, which is the third most abundant element in Earth' s crust. Besides being cheap, it is not toxic. They also synthesized a simple, stable ligand structure around the manganese that they modeled after an enzyme called iron hydrogenase.

The manganese catalyst and ligand design was very efficient: one catalyst was able to convert 6,000 molecules of carbon dioxide into formate salt, which could then be turned into a variety of useful fuels or materials. Their catalyst did this under relatively mild conditions, only 65℃. Usually, higher temperatures are required.

Converting carbon dioxide into usable fuels is an intriguing area of research because it could turn a harmful greenhouse gas into a renewable energy source.

"Carbon dioxide is a readily available, common waste product of the chemical industry," Khusnutdinova said. "That waste could be turned into renewable energy and help provide an alternative to fossil fuels."

In addition to catalysts, the unit is also synthesizing molecules called "mechanophores," which can help engineers test the strength of new construction materials. These molecules light up in response to pushing, stretching or other mechanical force. Historically, they can only be used once, or take hours to return to their original state before the next test can commence. The team designed a new mechanophore that can be reused and is extremely fast, returning to its original state in milliseconds.

"It is difficult to know how much stress a material can experience until it breaks," Khusnutdinova said. "These mechanophore sensors can help visualize the stress in new building materials."

Experiments in Quantum Physics

An ultra-cold electrons-on-helium system is an ideal experimental set up to study quantum physics.

The Quantum Dynamics Unit uses liquid helium to study electrons and how to use them as units of information.

Quantum phenomena happen on such small and fast scales, minor defects in an experimental set up can cloud results. That is why Professor Denis Konstantinov uses liquid helium for his experiments with electrons. Condensed helium gas remains a liquid even at extremely low temperatures that would freeze any other substance. For this reason, it is an extremely pure substance free of any contamination. It is also free of any defects due to the inherently smooth internal structure of the quantum liquid.

Konstantinov and his collaborators in the Quantum Dynamics Unit use liquid helium as a substrate and observe actions of electrons pinned to the surface. A refrigeration system drops experimental temperatures to near absolute zero.

"This system is very clean, free of defects or impurities," Konstantinov said. "So if we see some interesting effects, we can actually explain what is happening because we are free from uncertainties."

In contrast, defects always exist in solid materials, so it is hard to tell how they affect experimental results. By using such a simple system, Konstantinov and his team are able to conduct experiments, develop theories and provide explanations that can then be adapted by others to understand oddities in electron systems in solid materials.

The researchers are also investigating aspects of quantum computing with electrons-on-helium, including how to use electrons as units of information called qubits. Konstantinov wants to see if it is possible to make a qubit based on spin and orbital interactions.

The electron and helium system is excellent for experiments, but not for creating new technologies because it requires such cold temperatures. While OIST seeks collaborations with industry, the university also provides plenty of support for fundamental research.

"Everyone understands this is a very nice system, but that you cannot get industrial results," Konstantinov said. "So you have to be really crazy about understanding science and not care about other things like opening a start-up. We enjoy this stage of trying to understand what is happening."

Shapeshifting Structures

Molecular self-assembly that varies shape and function on cue shows promise for future medical therapies.

Professor Ye Zhang and the Bioinspired Soft Matter Unit seek to design self-assembling molecules with medical applications.

Some groups of molecules can "self-assemble," spontaneously forming structures such as tubes and spheres when they physically interact with one another. Professor Ye Zhang and her colleagues in the Bioinspired Soft Matter Unit seek to design molecules that self-assemble in response to various stimuli. This allows them to not only spatial-temporally control the assembly, but also the resulting morphology and function of the self-assembly in a living system.

"In material science, the function is always related to the structure," Zhang said. "If you can control the morphology at nano or microscale, you can potentially manipulate the function and even discover new applications."

For example, the group designed molecules with specific bonds that broke apart when hit with UV light. This allowed the fragments to reassemble into novel nanostructures with different functions. This shapeshifting ability holds great potential for biological applications.

"For example, you introduce the molecules into a living organism and they adopt a certain assembled structure," Zhang said. "Then using light, you break the balance of this self-assembly and the molecules switch to another morphology with a new active function."

In pharmaceutical design, such a concept would allow a drug to reach its target in a living organism – an organ or a tumor – in an inactive state, thus limiting potential side effects. Once broken down in this targeted location, the drug would reshape itself into a different structure with therapeutic activity.

In another example, Zhang designed molecules that, upon contact with cervical cancer biomarkers, self-assemble into nanofibrils that tie up the cancer cell's skeleton and inhibit metastasis.

"Controlling molecular self-assembly at the nano- and micro-scales is a central challenge for molecular engineering," Zhang said. "But if you can do it, you have a powerful tool with infinite possibilities."

Professor Jun Tani and his Cognitive Neurorobotics Research Unit study consciousness through a blend of robotics, cognitive neuroscience, and philosophy.

Exploring the Robotic Mind

Training robots reveals how experience influences human brain development and raises intriguing questions about consciousness.

Professor Jun Tani has tutored humanoid robots to perform various tasks for the past 20 years. Sometimes, the robots surprise him. For example, when one robot kept dropping a block, Tani tried to push the robots' hands closer together to show it how to successfully grasp the object.

"He resisted," Tani said. "It's the first time I felt the robot has his own intention."

Robot-based experiments enable Tani to see how brains develop through interaction, the "nurture" part of development rather than genetically encoded "nature." Specifically, he is interested in how the brain develops compositionality, which is the ability to take many small things and rearrange them in different ways, such as combining words into sentences. By programming a robot with a set number of neurons, but no wiring between them, he can see how the robot establishes connections as it learns.

"If we just make a model, we cannot predict as well what kind of self-organization comes out, what kind of compositionality is developed," Tani said. "Those things are not predefined, they just emerge through interaction."

When learning, the robots are autonomously anticipating what comes next without consciousness. When something unexpected happens, the robot becomes consciously aware of it as an error. The robot seeks to resolve that error as quickly as possible by shifting its prediction to match the new situation. Humans do something similar, but autistic individuals have difficulty resolving errors, as well as establishing compositionality. Tani and his Cognitive Neurorobotics Research Unit hope to gain insight into autism and other disorders by studying how robots learn and resolve problems.

Tani often blends robotics with cognitive neuroscience and philosophy. He relates his experimental results to existing theories about consciousness. When robots resist or show their own will, it raises some intriguing questions about how robots can be safely integrated with human society while allowing for their autonomy.

"Once a robot has consciousness," Tani said, "we cannot pull the plug. It starts to have free will."

Movement and the Brain

Tools from video games will help explore how the brain controls movement in real life.

The Neuronal Rhythms in Movement Unit uses real-time motion capture technology to study movement.

While many neuroscientists are fascinated by the decision-making parts of the brain, Professor Marylka Yoe Uusisaari is far more interested in the fundamental structures that control movement, including the brain stem and cerebellum.

“For me, movement is the foundation of everything,” Uusisaari said. “Movement is the only reason we have brains. Animals that don’t move don’t have brains.”

Uusisaari wants to understand how basic movements, such as walking, wiggling toes or reaching for a coffee cup, are coordinated from thought to execution. While seemingly simple, these actions requires massive coordination between many muscles.

“If we can really understand how simple, natural movements happen, we can understand fundamental things about how brains work in general,” she said.

Uusisaari, who runs the Neuronal Rhythms in Movement Unit, is using her background in computer science, video games and neuronal circuit electrophysiology to build innovative neuroscience experiments. She and her collaborators are using the same real-time motion capture technology used to create realistic animations in video games and movies.

The circle of cameras will fully capture the movement of mice outfitted with tiny sensors. The system will be combined with real-time fluorescence brain imaging as well as precise single-cell electrical measurements to show which individual neurons are working when.

“The system will allow for very natural behaviors, so we can see how movements are related to each other,” Uusisaari said.

It is harder than it sounds. The neurons they want to examine and control are buried deep down in the brain, so are difficult to access. They are also combining multiple technologies, which individually can be challenging to work with. While a risk, Uusisaari is excited at the potential discoveries that could one day have medical applications, such as improved prosthetics or spinal cord injury treatments.

Ocean Power

A particle physicist "will not sleep peacefully" until the world is powered by the sun, wind, and, especially, waves.

Professor Tsumoru Shintake and the Quantum Wave Microscopy Unit reach for a clean future with energy powered by ocean waves.

Ocean waves contain 100 times more power in a square meter than wind or solar, so it is no wonder many countries are attempting to tap this potentially huge source of renewable energy.

But so far, most other prototypes break, sink or are too expensive. The main issue is that they are all too big, explained Professor Tsumoru Shintake. His approach: start small.

"Today we can fly in a Boeing 787, but of course the Wright Brothers did not do this," Shintake said.

Shintake and his collaborators in the Quantum Wave Microscopy Unit are developing a small "Wave Energy Converter" to operate just off shore. Waves constantly breaking over reefs and beaches will turn mini turbines to generate electricity. Being near the beach shortens expensive cables needed to transport the electricity to consumers.

The converters range from 35 to 70 centimeters in diameter. They are reminiscent of wind turbines, but are adapted to the dynamic ocean environment. For example, the five blades and support stem are flexible so they do not break under the constant battering of waves or even extreme storms.

The group will test the first demonstration system in the Maldives, a nation of more than 1,000 islands in the Indian Ocean. On many remote islands, diesel generators power lights and air conditioner. At severe risk of disappearing under rising seas due to climate change, the country has pledged to become carbon neutral by 2020. Shintake hopes wave energy will help the Maldives and many other nations stop using fossil fuels.

While the first installation is modest, Shintake and his team have ambitious plans to scale up this and other turbine designs, building wave farms capable of generating as much electricity as a nuclear reactor.

"This flagship project will be the start of sustainable life on our planet," Shintake said. "But this is starting from a small island."

Robots and Rodents

Combining diverse experimental and computational approaches to understand the human brain and improve artificial intelligence.

The Neural Computation Unit has enabled smartphones on wheels to bounce-up and balance by learning a model of how their bodies respond to the wheel movement and finding appropriate control via simulation.

Humans can learn from a small number of examples or experiences. Robots, not so much. Computers typically require millions of data points before being able to differentiate between a dog and a cat, or win complex board games.

Professor Kenji Doya is fascinated with how humans learn, and how those processes can be transferred to robots, improving their ability to learn and adapt. Such adaptive processes will be required if self-driving cars and other autonomous machines are to become reality.

One thing in particular that humans excel at is simulation of various scenarios — considering different options and potential outcomes before making a decision. Doya is investigating how robots can similarly utilize simulation to learn faster.

For example, he and his collaborators in the Neural Computation Unit programmed a standard smartphone on wheels to learn how to balance. Learning an internal model of its body and simulating movements, the equivalent of human mental simulation, drastically reduced the number of trial and error cycles before the robot succeeded.

In addition to robots, Doya also works with humans and mice using various imaging techniques, including functional MRI and two-photon microscopes, to see what brain areas are active and how neurons update their codes during mental simulation. The team's current studies seek to explain how local circuits formed by groups of neurons carry out mental simulations. The next challenge is determining how those circuits work together.

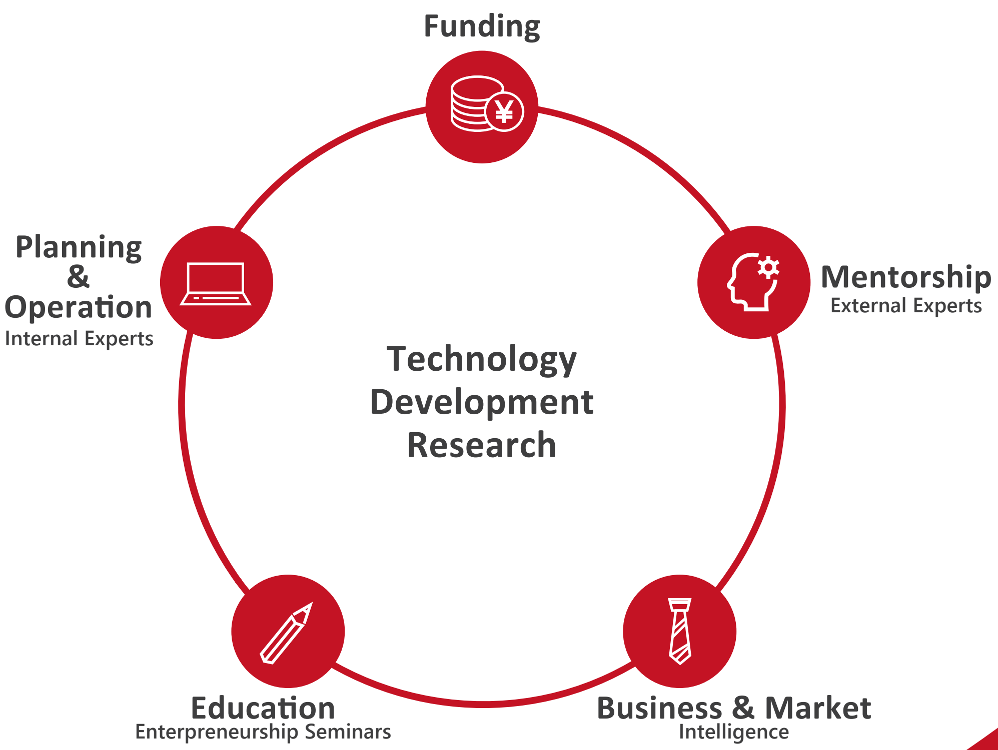
"How are local circuits appropriately selected and combined to adapt to the given situation? That is a fundamental question that hasn't been addressed," Doya said. "People do not even know what are the right theoretical or experimental paradigms to address such a question."

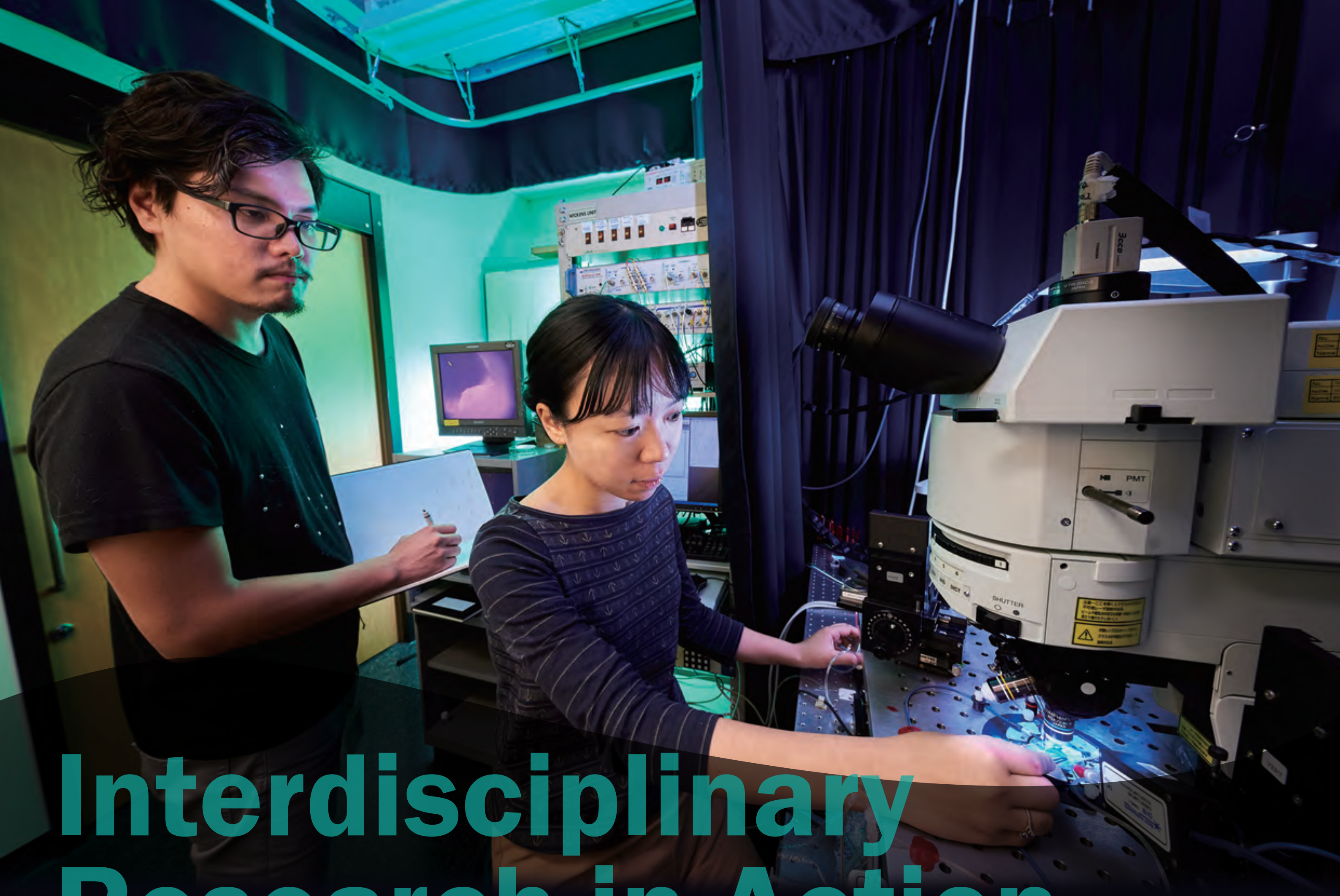
Doya is participating in several major research collaborations taking on these challenges. The Brain/MINDS project aims to map the entire marmoset brain. He and collaborators are also developing programs to run on the "post K" supercomputer, slated to come online in 2020, for analyses and whole-brain simulations using such large-scale data. Doya is leading the Kakenhi project "Correspondence and Fusion of Artificial Intelligence and Brain Science," which brings together researchers from neuroscience and A.I. Doya is confident that the two fields can help each other to improve understanding of brain networks and computer learning algorithms.

"The current success in A.I. is based on deep learning, which mimicked what the brain does," Doya said. "But there should be even more that can be learned from the brain through collaborations between neuroscientists and A.I. researchers."

Proof-of-Concept Research at OIST

Innovation derived from basic science is the key to tackling global challenges, from clean energy to healthcare to the environment – and OIST scientists are meeting these challenges head on. Our Technology Development and Innovation Center (TDIC) supports proof-of-concept research to bridge the technology gap between discoveries made in the labs and their commercial applications. OIST also promotes entrepreneurship and startups based on university technologies. Efforts like these enhance the impact of OIST research on society and contribute to the self-sustaining development of Okinawa.





Interdisciplinary Research in Action

Neuroscientists team up with physicists to test potential dopamine treatments for Parkinson's disease and other neurological disorders.

Researchers from the Neurobiology Research Unit use 2-photon microscopy to study learning and adaptive behavior in the brain.

Interdisciplinary research is a founding principle of OIST. No departments, common equipment, and even the long, sweeping hallways are designed to encourage interaction and collaboration across disciplines.

Philosophy is now reality. Joint research between the Neurobiology Research Unit and the Femtosecond Spectroscopy Unit grew out of a lunch conversation between physicists and neuroscientists.

"The architecture, the space, the organization of OIST really promotes that kind of interaction," said Professor Jeff Wickens, who runs the Neurobiology Research Unit. "In most universities, the physics department is in a different building from the biology department, so you are unlikely to chat over lunch."

Wickens is interested in how neurotransmitters such as dopamine and acetylcholine work on the molecular level in the basal ganglia, a brain structure involved with learning and adaptation. The timing of dopamine release appears to be critical for learning and reinforcing behaviors, including basic tasks like movement. Patients with Parkinson's disease lack sufficient dopamine, and drug treatments could possibly be more effective if delivered in timed pulses.

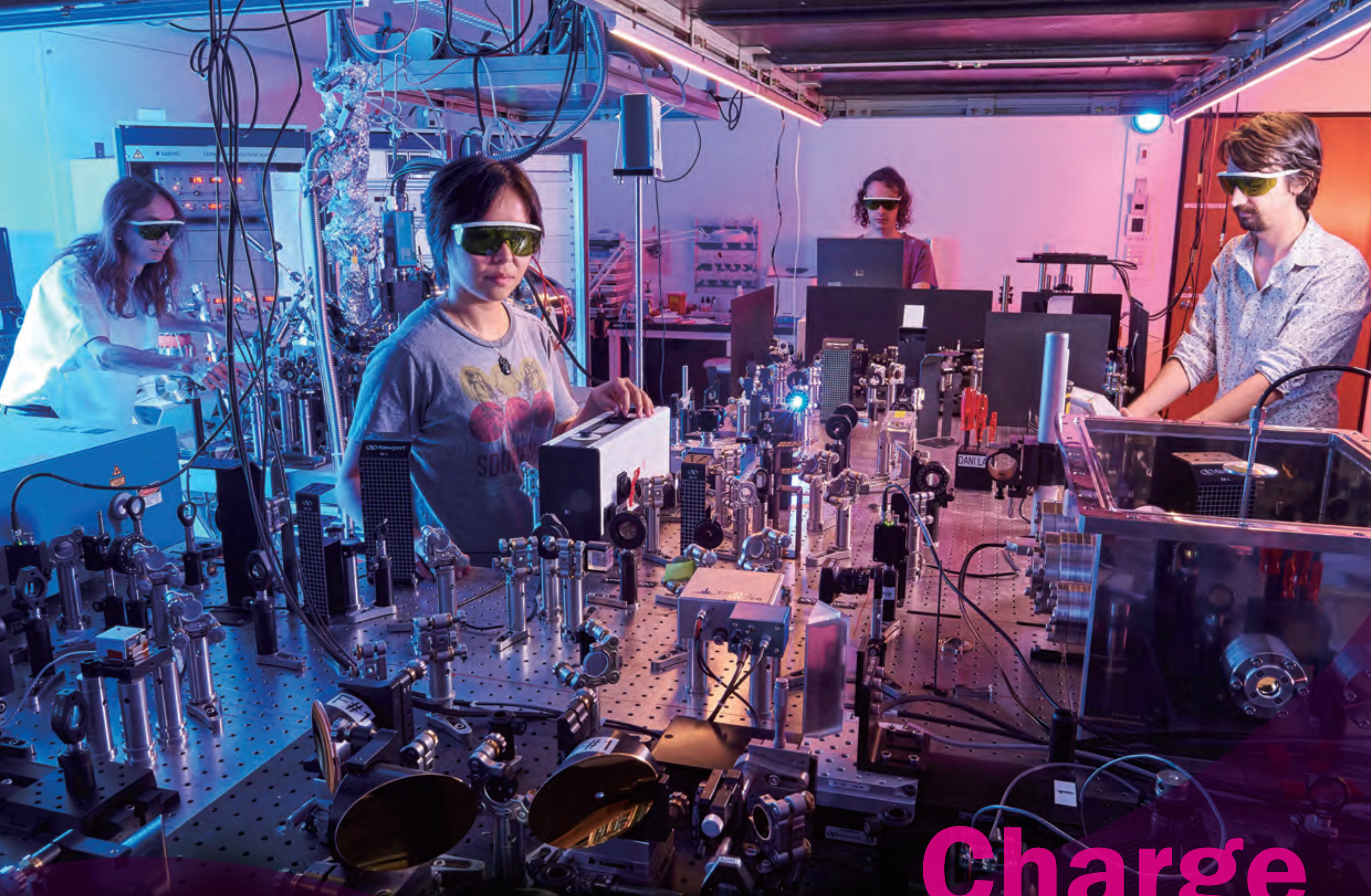
Wickens and his team worked with Professor Keshav Dani and his physics unit to develop a new way to release spurts of dopamine. They filled small fat blobs, called liposomes, with dopamine, and attached antennae made of nanoparticles to the liposomes. Dani's femtosecond laser fires extremely intense pulses of light, which stimulates the nanoparticles and prompts the liposomes to release just a little dopamine. This process can be repeated precisely and quickly, like real pulses, because the effect is so fast.

"It is very experimental at the moment," Wickens stressed. "It wouldn't work as a treatment at present because existing lasers are too bulky to implant, but in the future they may be miniaturized."

The group needs to determine if the artificial delivery system works in the brain, and if it produces the same physical reaction that occurs naturally. If so, then they could begin to investigate how to adapt it for real treatment. In addition to Parkinson's, the research could shed light on other disorders, such as Attention Deficit Hyperactivity Disorder (ADHD), schizophrenia and drug addictions.

As Dean of the Graduate School, Wickens is also very excited about educating the next generation of scientists in a new way, one that encourages highly interdisciplinary work like this. He anticipates that this training will enable OIST graduates to communicate well across fields and pursue innovative research.

"The future is not going to come from anything I am doing now," Wickens said. "The future is going to come from my students."



Charge Cinematography

Seeing electrons in motion requires merging divergent technologies – fast lasers with powerful electron microscopes.

The Femtosecond Spectroscopy Unit uses its microscope and laser system to capture the motion of electrons.

While most people can envision the nanoscale — a billionth of a meter — it is more challenging to grasp the brevity of a femtosecond — a millionth of a billionth of a second. A femtosecond is to a second, what one second is to millions of years.

“As devices get smaller and smaller, and we want them to work faster and faster, those operations all depend on what happens on the nanoscale in femtoseconds,” said Professor Keshav Dani, who runs the Femtosecond Spectroscopy Unit.

Directly imaging what happens on such fast and small scales is difficult. Conventional tools often have the right spatial or temporal resolution, but not both. To overcome this hurdle, Dani and his team combined two tools — a femtosecond laser and an electron microscope — into a powerful system that captures both the time and spatial scale of the motion of electrons.

The system took five years to design and build. It starts with a femtosecond laser, which fires extremely rapid pulses of light that excite and probe electrons in a sample material. The sample is located inside an electron microscope, which can image electrons on the nanoscale. With a maze of mirrors, crystals and lenses to guide, split, mix and strengthen both the laser light and the electrons, Dani and his team are able to make movies of electrons in motion in various materials.

For example, the team made a movie of electrons in a solar cell as they reorganized within a fraction of a nanosecond after absorbing light to give the solar cell its power.

“Going forward, with the tools we have developed, we hope to directly visualize the behavior of electrons at the nano-length scale and femto-time scale in devices and quantum materials,” Dani said. “Measuring on the femto-nano scale might allow us to capture quantum effects that may be happening on the shortest of timescales and in the smallest regions of space.”

Mathematics + 3-D Printing = Innovation

Using new mathematical tools to solve intriguing problems leads to anything from new medical devices to toys.

Dr. Johannes Schoenke holding a kaleidocycle, with more than the usual six hinges, developed and 3-d printed in the Mathematics, Mechanics, and Materials Unit.

Professor Eliot Fried and his colleagues test fundamental physical theories by building mathematical models, performing simulations and running experiments. Then they use their findings to develop new technologies.

“OIST has given me the opportunity to expand into those directions and develop an integrated approach,” said Fried, who heads the Mathematics, Mechanics, and Materials Unit.

The Unit is highly interdisciplinary; experts in engineering, material science, physics, chemistry, biology, and math work together on complex projects. The group identifies a process or phenomena to study, and then selects the most suitable tools to tackle the problem.

For example, the researchers are developing a microscopic fluid pump driven by magnets. They determined how exactly three magnets should sit in a triangle, so that when one rotates, it causes the other two to move, or vice versa. They plan to 3-D print the extremely small pump as part of an OIST Proof of Concept project.

Ultimately, they want to use this pump inside microfluidic equipment, including medical diagnostic tools called “lab-on-a-chip.” The pump will precisely control the flow of fluid, such as blood or urine, through a channel. Two external magnets will rotate a tiny magnetized propeller inside the device’s fluid chamber. This will eliminate the need for electrical components inside the device, making it far more robust.

On the other end of the spectrum, the unit has also used 3-D printing to create a toy. A kaleidocycle usually contains six tetrahedra that turn in one fixed manner on six hinges. Fried and his collaborators worked out mathematically how to make a kaleidocycle with seven or more hinges. The asymmetrical shape could have a range of applications, from next-generation kitchen mixers to kinetic art.

“A lot of fundamental mathematics and geometry goes into these kaleidocycles,” Fried said. “It could be a great educational toy, especially if they have to assemble it. Who knows, maybe it could even become the next Rubik’s Cube.”

Chowing Down, Cleaning Up

Hungry microbes remove pollutants from wastewater, reducing environmental pollution and human health risks.

The Biological Systems Unit uses microbial fuel cells to treat wastewater produced by the Mizuho Awamori Distillery in Okinawa.

What does a whisky distillery in Scotland, a winery in the United States, a pineapple factory in Thailand and an awamori distillery in Okinawa, Japan have in common? They all use microbes to clean their wastewater.

Professor Igor Goryanin and his collaborators developed "microbial fuel cells" to remove organic pollutants from wastewater produced by these facilities. If the nutrient-rich wastewater was left untreated and released into rivers, lakes or oceans, it could cause algal blooms that consume most of the available oxygen, devastating the surrounding ecosystem.

Bacteria are the key to the microbial fuel cell cleaning systems. Hungry microbes chow down on organic matter, converting it to energy. The energy produced then helps power the treatment system, including pumps and data processing.

"We use different microbes in each country, but they are all doing the same job," said Goryanin, who heads the Biological Systems Unit.

In Okinawa, the unit helps the Mizuho Awamori Distillery to treat its wastewater, which contains organic byproducts from the distillation of rice into Okinawa's signature alcohol. The microbes have reduced the distillery's waste management significantly because far less wastewater must be trucked off site. The scientists are also partnering with a local tofu factory, pig farms and environmental agencies for oil remediation.

The researchers are working to improve the system's efficiency, bring down material costs and expand applications. In particular, they are conducting extensive genetic studies to identify the best microbes for different functions. Microbes exist in complex communities, so the team sequences genomes of hundreds of bacteria species and investigates which ones proliferate under different conditions.

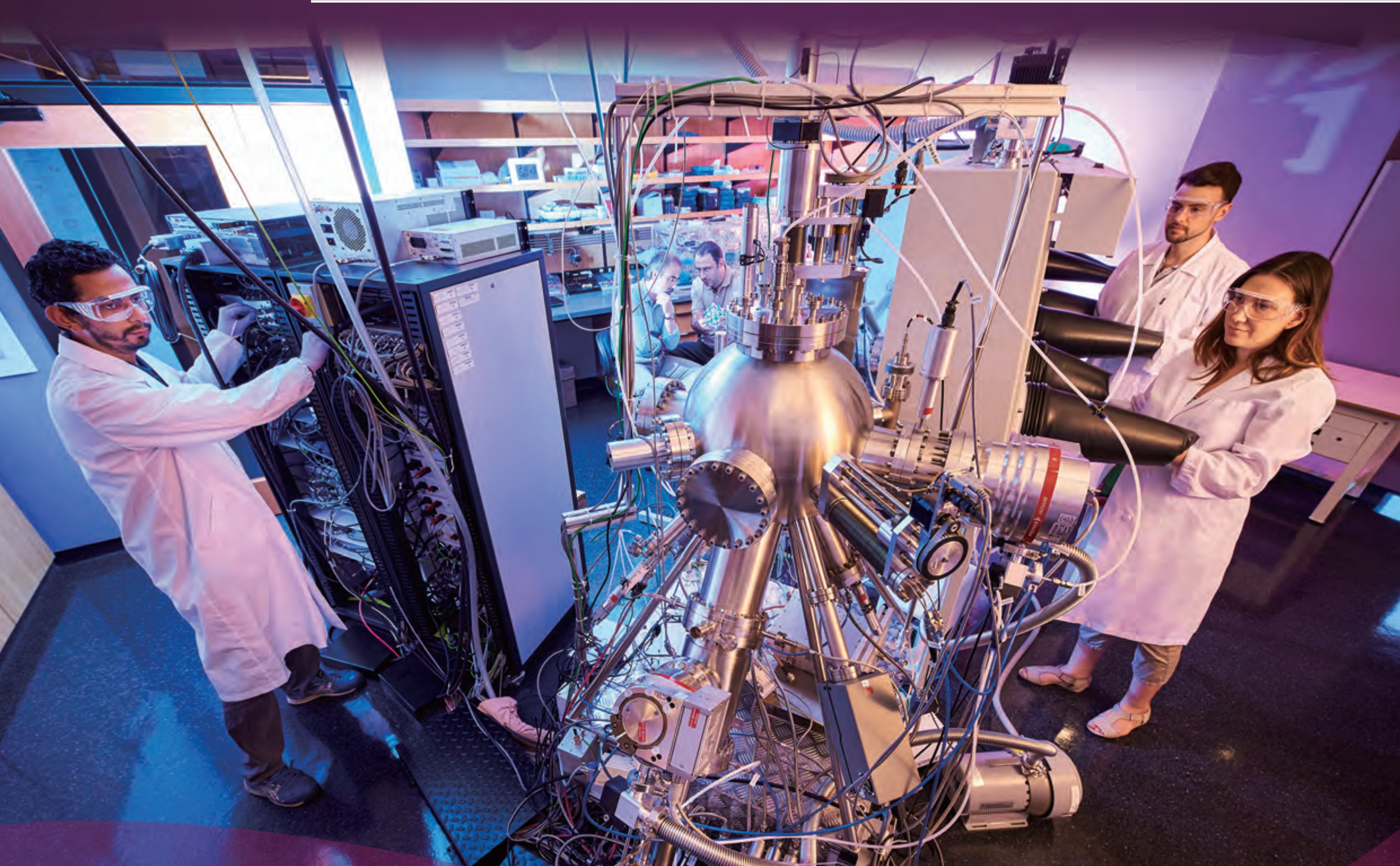
With microbial fuel cells already installed in several nations, the team hopes to expand to developing countries that struggle with clean water. The system will not only help protect the environment, but also may potentially reduce the spread of infectious diseases.

"It's cheaper to prevent disease than to treat it," Goryanin said. "Cleaning wastewater before it makes us sick is far more effective than developing new drugs."

Nanosensors for Everyone

Nanoparticles help create small, low-cost sensors for air quality and disease detection.

Researchers from the Nanoparticles by Design Unit operating the Cluster Beam Deposition machine.



Imagine a small chip that plugs into a smartphone, then measures various gas levels in the air within a building or outside. The data would appear on the smartphone, indicating if the levels of oxygen, carbon monoxide and other gases are safe or not.

This is one of the many dreams of Professor Mukhles Sowwan, who runs the Nanoparticles by Design Unit. Yet it is not too far from becoming reality. As part of a Proof of Concept project, the unit is building a miniaturized air quality sensor based on a unique configuration of nanoparticles. The challenge is finding cost-efficient production methods.

The unit is also working on "label-free biosensors," nanoparticles that latch onto proteins to identify specific diseases. Unlike current biosensors, the nanoparticles do not require a large fluorescent marker that lights up when binding to a target. The more nimble sensors could potentially catch diseases earlier.

To develop both sensors, Sowwan' s group uses a physical "sputtering" method to deposit material on a target. This approach provides much greater precision to study and design nanoparticles than other chemical-based processes.

"We design from the beginning," Sowwan said. "Our physical methods give us the flexibility to change many experimental parameters, and this allows us to control the size, shape and microstructure of the nanoparticles."

This research combines physics, chemistry, biology and materials science. Nanoparticles by Design Unit members are not only from these diverse scientific backgrounds, but come from all around the world, including Algeria, India, China, South Korea, Japan, Australia, United States, Peru, Ireland, United Kingdom, Spain, France, Austria and Greece. The exchange of cultures, ideas and approaches is enriching and challenging, ultimately leading to better scientific questions.

"My unit is a reflection of OIST," Sowwan said. "Everyone is from different countries, different backgrounds. We work together in harmony on science and technology projects. This is just amazing."

The biotechnology industry is very interested in developing compact "lab-on-a-chip" devices that can quickly perform medical diagnostic tests. Such a device aims to rapidly test a single drop of blood, urine or saliva, avoiding the need to send samples away to a laboratory. Getting ultra-fast results offers many benefits, such as early detection of common diseases caused by bacteria and viruses.

Understanding fundamental micro-nano-fluidic phenomena is necessary to develop these biotechnology platforms. Professor Amy Shen and her team in the Micro/Bio/Nanofluidics Unit conduct fundamental research and use that insight to develop a wide range of biosensors and other devices.

"We are lucky we are able to do both applied research and fundamental science," Shen said.

For example, Shen and her unit members are patenting a new assembly method that better protects bioreceptors preloaded into a "lab-on-a-chip" device. Bioreceptors are the molecules that detect the presence of target proteins. The team also designed a novel sensor capable of simultaneously measuring mass and charge of molecules, which determines whether bioreceptors are successfully loaded and operational in subsequent detection steps.

In partnership with industry, the researchers are developing methods to separate plasma from blood without electric power, an essential step before immunoassays. They are also investigating innovative biophotonic materials that can be used in sensing devices as transducers, which convert physical measurements into optoelectronic signals. The processes they use to develop the materials are cost-effective, user-friendly and can be easily adopted in industrial settings.

They are working to incorporate those new biophotonic materials into a portable testing instrument as part of a Proof of Concept project. The instrument aims to empower a patient to run their own diagnostic tests at home and read the results on a smartphone, which could also be sent to their doctor in real time.

Working with industry encourages the scientists to consider cost and performance at early stages of research. While they could make a 20-nanometer-tall device with higher sensitivity, a 500-nanometer-tall device is much cheaper to mass produce.

"You have to consider all those factors when you design a real product," Shen said. "That is a very good learning experience for my lab members. It prepares them for the next stage of their careers, whether in academia or industry."

Microfluidics for the Real World

Using fundamental fluid mechanics and engineering physics to design medical and biotechnology devices.

PhD student Ainash Garifullina belongs to the Micro/Bio/Nanofluidics Unit, which studies the processes behind "lab-on-a-chip" devices.

Perovskite's Promise

Fundamental surface science research supports development of advanced solar cells and other applications.

Development of perovskite-based solar cells has rapidly advanced — energy conversion rates by these materials have jumped from 3.8 percent to over 22 percent in under a decade, bringing them close to silicon-based solar cells that top out around 26 percent in the lab.

Perovskites are a class of crystals that can contain different compounds, but maintain a specific structure. Perovskite-based solar cells can be more cost-efficient than traditional silicon solar cells because they can be made from cheaper raw materials and do not require expensive equipment to produce.

But perovskite solar cells still face a major roadblock — lifespan. While lifespan has increased from a few hours to thousands of hours, cell stability still needs to improve to be commercially viable.

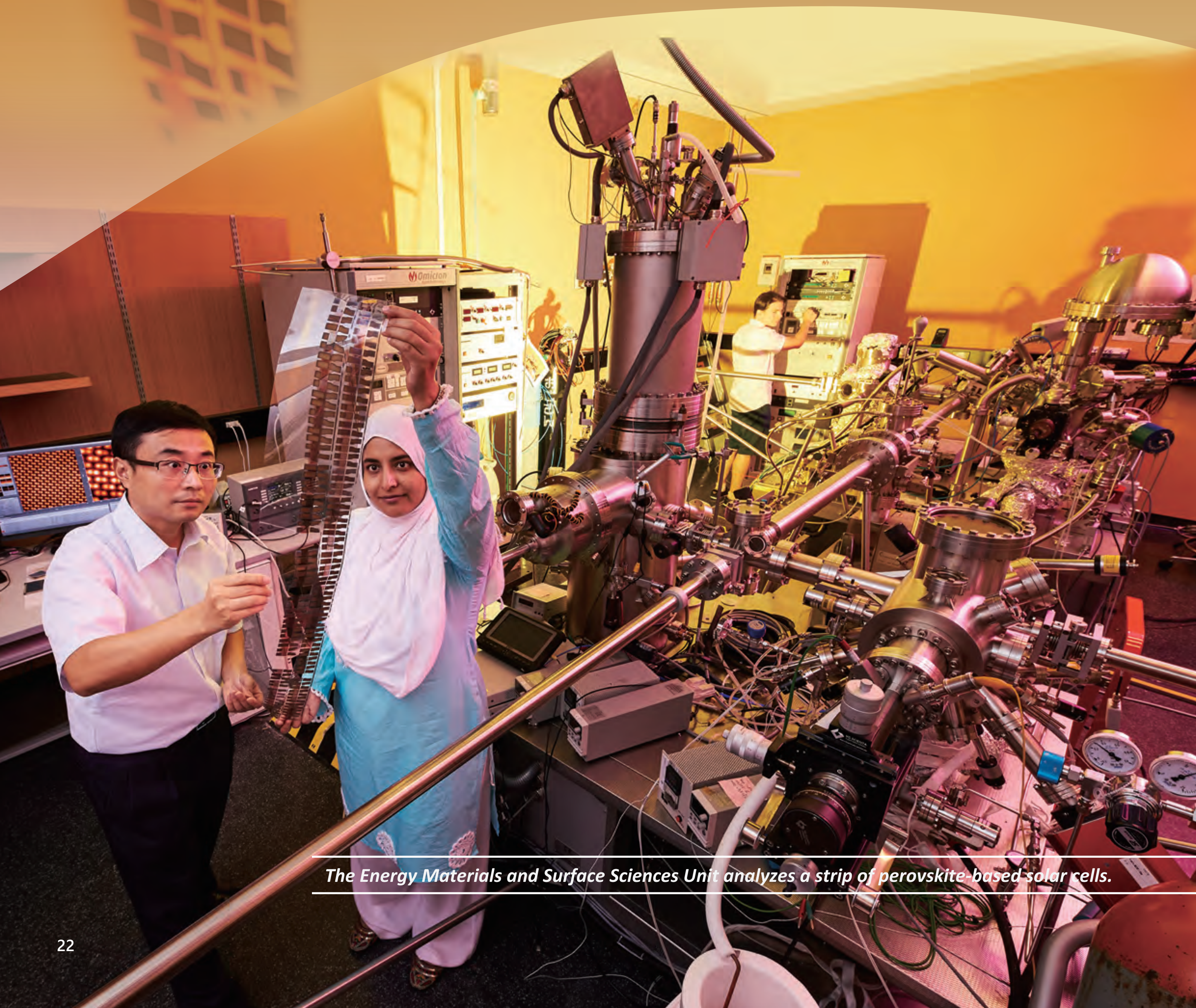
Professor Yabing Qi and his team in the Energy Materials and Surface Sciences Unit are working to improve the lifespan, performance and production of perovskite solar cells. Their painstaking fundamental research has revealed dozens of insights.

For example, they found that degradation of iodide-containing perovskite was not only caused by the outside environment, but also one of the elements in the perovskite itself. The iodide element in perovskite turned into a gas, making it easy to move around and break down the structure.

"If we can understand what causes degradation, then we can try to eliminate, or at least minimize, those factors, and enhance the stability of perovskite solar cells," Qi said.

The group has also found ways to streamline production methods, one of which they are patenting as part of a Proof of Concept project. Instead of using a powder material early in the process, they use a gas, which makes fabrication cheaper and easier.

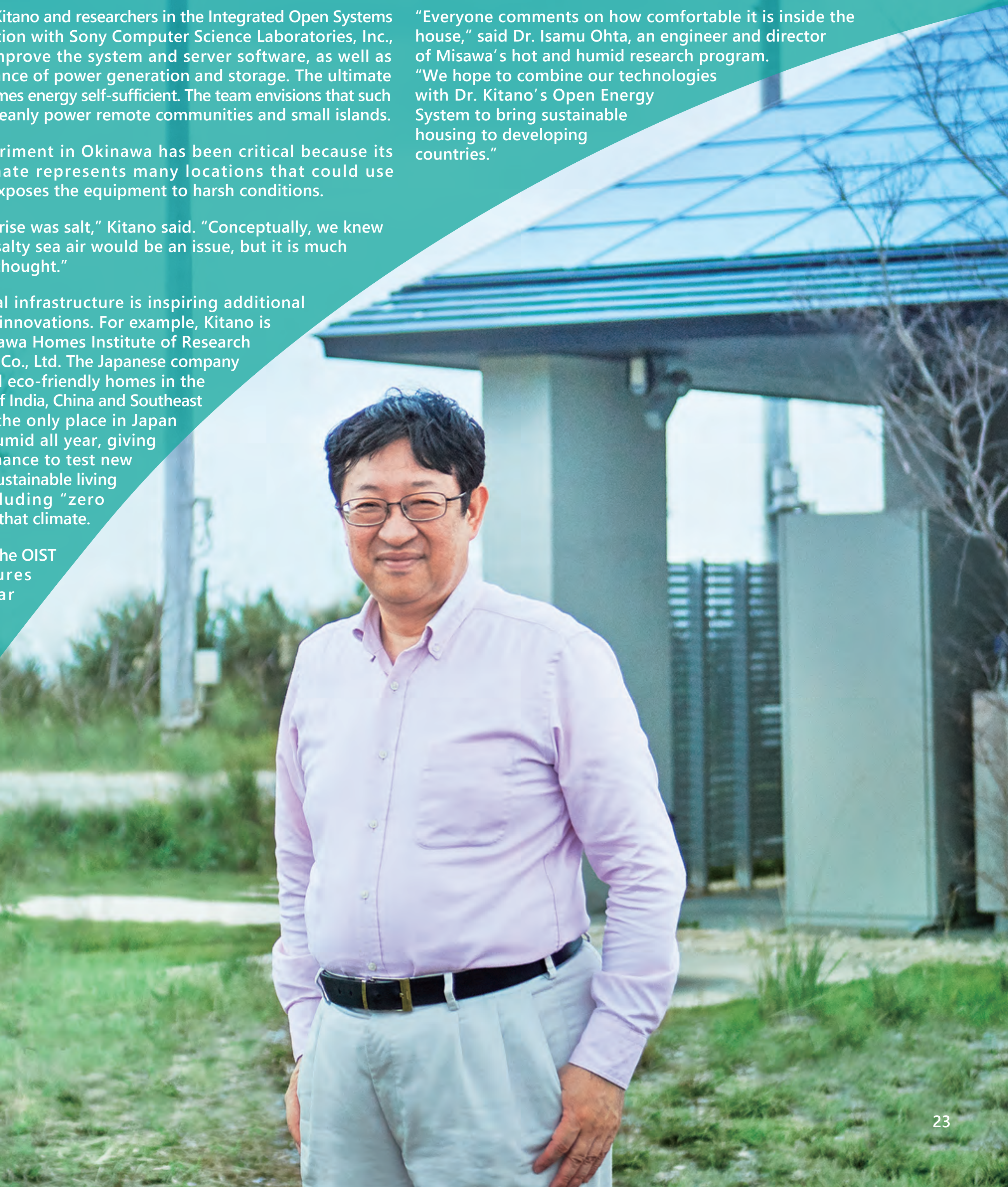
While much excitement revolves around solar cells, the unit's perovskite research has a range of applications, including LED lights and photodetectors. Qi's team is also interested in energy storage devices, potentially addressing two major aspects of renewable energy — production and storage — with one integrated system.



The Energy Materials and Surface Sciences Unit analyzes a strip of perovskite-based solar cells.

Sustainable Living Architecture

Okinawa provides the perfect test bed for sustainable energy systems in hot and humid environments.



Professor Hiroaki Kitano stands outside of a test building in the OIST R&D Zone —the goal is to develop "zero energy homes" for sustainable housing.

Solar panels atop 19 OIST faculty houses produce power that is then shared amongst the residents. An "energy server" remotely manages the system, sending electricity from one house to another as needed. The "Open Energy System" has been operating since 2013, providing a real world experiment in sustainable micro-grids.

Professor Hiroaki Kitano and researchers in the Integrated Open Systems Unit, in collaboration with Sony Computer Science Laboratories, Inc., are working to improve the system and server software, as well as find the right balance of power generation and storage. The ultimate goal is to make homes energy self-sufficient. The team envisions that such micro-grids can cleanly power remote communities and small islands.

Having the experiment in Okinawa has been critical because its subtropical climate represents many locations that could use the system, and exposes the equipment to harsh conditions.

"The biggest surprise was salt," Kitano said. "Conceptually, we knew that the island's salty sea air would be an issue, but it is much tougher than we thought."

Okinawa's natural infrastructure is inspiring additional partnerships and innovations. For example, Kitano is working with Misawa Homes Institute of Research and Development Co., Ltd. The Japanese company is looking to build eco-friendly homes in the growing markets of India, China and Southeast Asia. Okinawa is the only place in Japan that is hot and humid all year, giving the company a chance to test new technologies for sustainable living architecture including "zero energy homes" in that climate.

A test building in the OIST R&D Zone features a "Cascade Solar System" that not only generates electricity, but also collects the heat trapped under the solar panels. That heat is converted to energy that powers a novel dehumidifier system. Rooms are kept cool by running cold water through the walls and ceiling, avoiding the need for energy-hungry air conditioners.

"Everyone comments on how comfortable it is inside the house," said Dr. Isamu Ohta, an engineer and director of Misawa's hot and humid research program. "We hope to combine our technologies with Dr. Kitano's Open Energy System to bring sustainable housing to developing countries."

OIST
Graduate University

OIST's founders recognize that great discoveries lie at the intersections of major sciences, when researchers make novel connections between disparate disciplines. Accordingly, OIST has built a five-year graduate program for students to grow highly competent in their core discipline while also learning to communicate scientifically with people in completely different fields. Over half of the faculty and students are recruited from outside Japan, and all education and research is conducted entirely in English.

Recruit the best students in the world

OIST searches the globe for outstanding students who will become tomorrow's leaders in scientific research.

Treat every student as a unique individual

OIST works with each student to design an individualized program of studies. The aim is for students to achieve first-class research outcomes, and to reach their full potential as independent scientists playing lead roles in research.

Provide excellent conditions for thesis research

A low student-to-staff ratio assures high quality advising during thesis research and OIST faculty members lead cutting-edge research groups. In addition, working alongside top researchers in well-funded laboratories with state-of-the art facilities and equipment helps students to excel in research.

Give good support for living

At OIST, students are able to concentrate on research and studies without worrying about living costs, health care, and housing. OIST takes care of the practical needs for living in Okinawa.

Encourage creative thinking and interactions

The campus abounds in physically pleasant spaces designed for contemplation and discussion.

Facilitate global networking

OIST is at the hub of a global network. Its program is constantly enriched by visits from leading researchers from around the world. OIST connects its students internationally to increase their visibility as emerging researchers and launch stellar careers in science.

What makes OIST exceptional is its student-centered approach. This University provides the resources, guidance, and support students need for each step they take toward achieving their goals in research and scholarship.

The research organization and culture at OIST has allowed PhD students in various fields of science to manage their own projects and publish scientific articles as the leading author, allowing them to develop a sense of leadership and independence.

Zafer Hawash

Zafer Hawash joined OIST in 2012 to undertake his PhD and study Material Engineering in the Energy Materials and Surface Sciences Unit. Four years later, he published, as a first author, three research articles and a review about his work on the next generation of solar cells.

"My field of research is material sciences and material engineering, for which technical equipment and its availability is most crucial. In my previous work in research, access to equipment was limited, but the nature of OIST makes it easy to provide what I need to progress in my projects. I also had a lot of support from my faculty professor and the group leaders in my research group. The research unit itself is highly multidisciplinary—we have people coming from engineering, from pure physics, or even chemistry. Working on material science requires all these skills, which is perfectly adapted to the multidisciplinary approach of OIST."

"Professor Amy Shen is very positive about new ideas, and with the resources and equipment at our disposal at OIST we get to explore new concepts and follow our own hypothesis. You do not have to shadow a post-doc if you don't want to. You also mix every day with researchers from very different backgrounds, sometimes leading to collaborations on new projects stemming from conversations!"

Hsieh-Fu Tsai and Shivani Sathish

Shivani Sathish and Hsieh-Fu Tsai began their PhDs in the Micro/Bio/Nanofluidics Unit in 2014 and have now both published their respective first-author papers on their research. Shivani has a background in genetic engineering but now develops microfluidics chips to improve the efficiency of disease detection. Hsieh-Fu, who holds a master's degree in biophotonics, works on the behavior of cells exposed to an electric field.

"My current research is very different from my undergraduate degree, but because OIST allows you to widen your field, I went on to do something completely new. Professor Amy Shen is very supportive of her students, and creativity is very much encouraged. What was just an idea became my own project, leading to my first leading author publication. I also got to present my research at a campus-wide seminar and I received great feedback and ideas to keep my research improving!"

"What helped me tremendously in publishing these papers was the support of my mentor, Professor Noriyuki Satoh. Under his guidance, I developed my research and writing skills as well as learned how to work independently. The way Professor Satoh has structured his laboratory at OIST, within which each unit member has his clearly defined solo project, also makes it very easy to help each other as there is no competition. Finally, having access to the OIST sequencing center, with little gatekeeping and great technical support, was critical in achieving great research outcomes."

Ken Baughman

Ken Baughman was a PhD student in the Marine Genomics Unit from 2012 to 2017, and was the lead author on high-profile papers about sequencing the genome of important actors on the marine ecosystem.

Photo: Yuna Zayasu

The environment

Preserving the environment is a top priority at OIST. The site is steep and densely wooded, carved into a series of narrow ridges and deep ravines by the heavy rainfall of the subtropical climate. The environmental impact assessment showed that the valleys and small streams support a valuable ecosystem with rare flora and fauna. Construction could therefore only take place on the ridges, with a skywalk spanning buildings high above the stream. Environmental considerations like the Skywalks, a series of pools for fish to seek refuge, and highly efficient water use earned Laboratory 2 a Leadership in Energy & Environmental Design (LEED) Silver Certification.

World-class Research Environment

Research activities

The OIST research program aims to be at the leading edge of science and technology, encompassing the life sciences, the physical sciences, the environmental sciences, and mathematics. OIST' s mandate of collaborative, boundary-free research is built into every element of the campus design and layout. Flexible workspaces and shared equipment keep disciplines from clustering, while grouping major research instruments helps maintain equal access.

Research Support

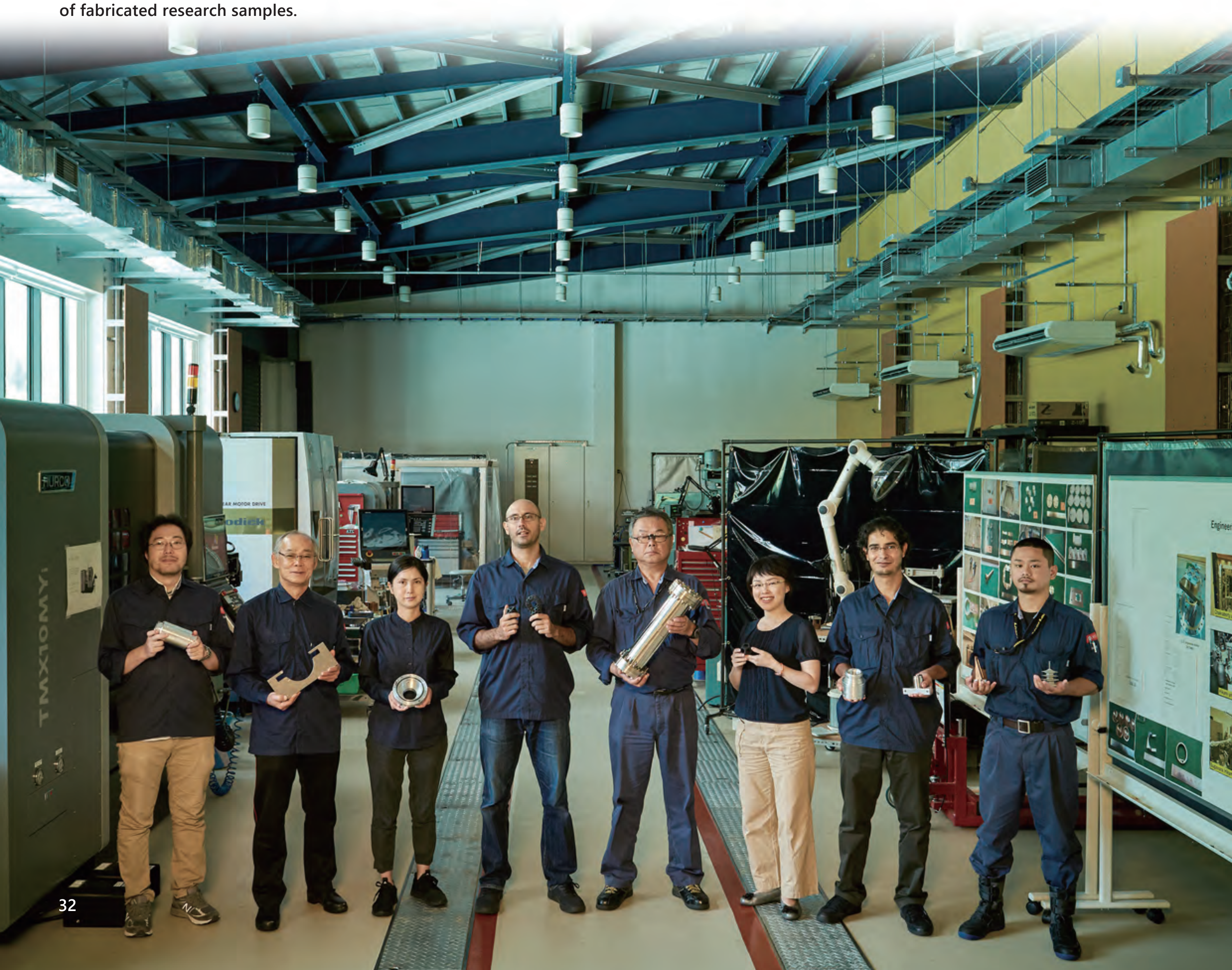
The Research Support Division (RSD) contributes to the research and education goals of OIST by providing excellent common research facilities and research support services for researchers and students at OIST. The technical sections of RSD provide maintenance of common equipment and facilities, operation training, fair access, consultation on experimental design and choice of methods/instruments, and technical support on data acquisition and analysis. Administrative sections of RSD provide support on grant applications, collaborations, health and safety and other support to research activities.

Animal Resources Section

The Animal Resources Section oversees the husbandry and care of live animals at OIST. These animals include mice, rats, finches, zebrafish and frogs. The facilities are accredited through AAALAC International and feature an individual ventilated caging system and cage exchanging system. Round-the-clock veterinary care is also available. An Animal Care and Use Committee comprised of internal and external reviewers examines experimental protocols, while focusing on animal welfare, inspects facilities and reviews the animal care program semi-annually.

Mechanical Engineering and Microfabrication Support Section

The Mechanical Engineering Group, Microfabrication Group and Material Analysis Group comprise the Mechanical Engineering and Microfabrication Support Section. The section provides support services on the following technologies: manufacturing research equipment using sophisticated mechanical design, machining and assembling, application of cryogenics and vacuum technology, development of research equipment using micro/nano-fabrication technologies, and material analysis of fabricated research samples.



Okinawa Marine Science Support Section

The Okinawa Marine Science Support Section provides a variety of services to support OIST marine researchers and their collaborators including field work support, maintenance and management of common equipment for marine science research. The OIST Marine Science Station, located a few kilometers away from the OIST main campus, is an onshore marine facility at Seragaki port that serves both OIST and non-OIST scientists. This facility features both indoor and outdoor tanks, a seawater pump facility, a workshop, offices, and a pool for testing equipment.

DNA Sequencing Section

The DNA Sequencing Section provides high throughput sequencing services to the OIST researchers. These services include: de novo genome sequencing, re-sequencing, RNA sequencing, and ChIP-sequencing, as well as consultation on experimental plan and library preparation. Conventional DNA sequencers, a digital PCR machine and real-time PCR machines are also maintained and supported by the DNA Sequencing section.

Imaging Section

The Imaging Section manages the common light microscopes (LM) and electron microscopes (EM). The LMs include confocal laser scanning microscopes, multi-photon excitation microscopes, super resolution microscopes (SIM, STORM/PALM, STED), a light sheet excitation microscope, etc. The EMs include analytical TEM (transmission electron microscope), cryo-TEM, environmental TEM, SEM (scanning electron microscope), SBF-SEM, and FIB/SEM. The section also has experts to provide technical support on those equipment.

Scientific Computing and Data Analysis

The Scientific Computing and Data Analysis Section provides advanced high-performance computing and research storage resources to OIST scientists. This includes end-to-end consultations and infrastructure of long and short term research projects, the management, monitoring and maintenance of computing and storage resources, and acquisition and management of scientific software on the computing system. Sango is a main computing cluster which contains over 10,472 computing cores over 436 nodes while Tombo is an independent test cluster contains 1,588 computing cores over 99 nodes.

Occupational Health and Safety Section

To promote a culture of safety, health and environmental protection, the Occupational Health and Safety Section reviews research protocols, provides support to Institutional Review Boards, provides safety consultation, inspection and training, and acts as a liaison between OIST and outside health and safety authorities. OHS's target areas include biosafety, chemical safety, radiation safety, laser safety, hazard in field, laboratory waste, controlled equipment, security export control, safety training, occupational health and safety, research ethics and research integrity. The available facilities include a BSL2/3 facility, a radioisotope facility, and computer systems related to safety.

Grants and Research Collaborations Section

The Grants and Research Collaborations Section provides administrative support to researchers by providing information on external grant opportunities, supporting the pre-award process for grant applications and post-award process for grant management, supports research collaborations with academic partners, and cooperates with the Technology Licensing & Business Development Section and General Counsel Office in creating collaboration agreements.

Instrumental Analysis Section

The Instrumental Analysis Section manages the common equipment and facilities for mass spectrometry, NMR spectroscopy, lab automation, flow cytometry and centrifuges. The section also provides technical support such as equipment use training, sample preparation, data acquisition and data analysis.

Okinawa

Okinawa is a beautiful subtropical island located in the center of Asia, a region of rapid economic growth. This idyllic location offers a rich research environment for a world-class graduate university and the potential for future development.

With its highly imaginative academic minds and sophisticated research infrastructure, OIST will make scientific discoveries that will drive technological development in Okinawa.

OKEON Project

The Okinawa Environmental Observation Network (OKEON) is an initiative led by researchers at OIST with the goal to establish an observation network to measure, monitor, and understand the terrestrial environment of Okinawa. Thus far, 24 monitoring sites have been established across the island, each with devices collecting long-term data on Okinawa's ecosystems. OKEON related-projects include modeling the impacts of sediment and pollution runoff on coral reefs, documenting and monitoring Okinawa's rich and unique biodiversity, and using acoustic recorders to investigate human impacts on Okinawan soundscapes. This network is a collaboration between OIST scientists and the people of Okinawa, with over 100 partners on the island.

Inside the Biodiversity & Biocomplexity Unit at OIST. This lab leads the OKEON arthropod sampling project.

Sorting arthropod samples for OKEON—arthropods are known as indicators and drivers of many aspects of ecosystem functioning.

Contributions Beyond Research for Okinawa

In addition to pursuing excellence in science and innovation, OIST strives to give back to the Okinawan community, whether by bringing the magic and joy of science to local students, or helping to protect the island from invasive species.

Every year OIST holds a Summer School of Science program for local children, where children from preschool to junior high explore different scientific subjects. OIST also provides tours and short learning events, such as "Eigo de oshigoto" or Work in English, for children from all over Okinawa.

ACCEPTING
ROBIAL LIFE
TEDxOIST

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