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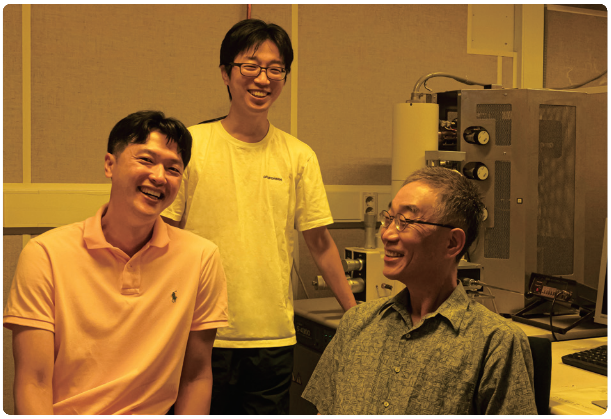
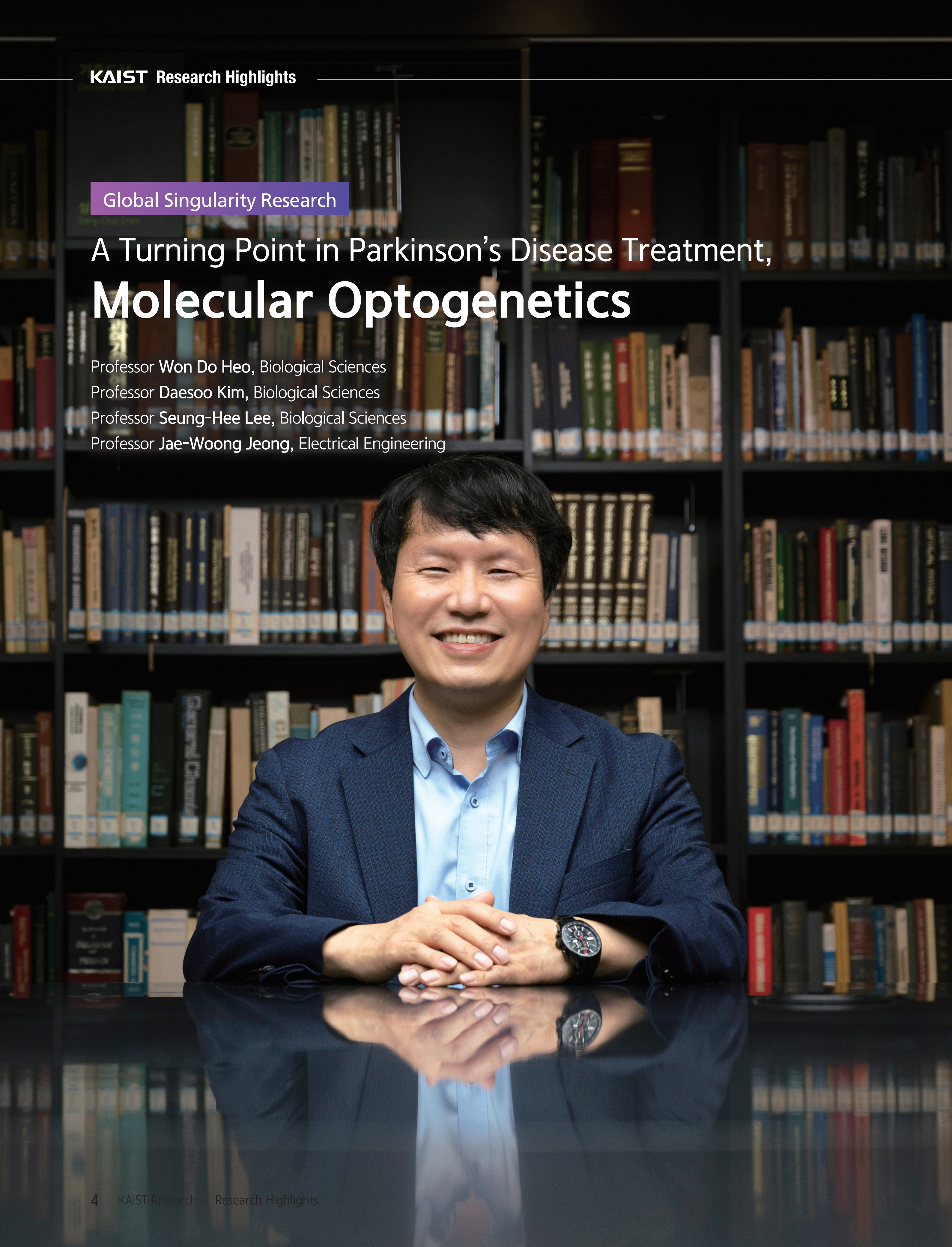




Global Singularity Research

A Turning Point in Parkinson's Disease Treatment, **Molecular Optogenetics**

Professor **Won Do Heo,** Biological Sciences
Professor **Daesoo Kim,** Biological Sciences
Professor **Seung-Hee Lee,** Biological Sciences
Professor **Jae-Woong Jeong,** Electrical Engineering

I am writing something similar to a diary entry,
but my hand is shaking too much. Would you write it for me instead?

The above request was made by Na Hye-sok to a student volunteer in 1947. Considering that Na was described in her final years as an 'old woman shivering with her mouth open,' we can speculate that she had been suffering from Parkinson's disease during her later years.

The advancement of science and technology has brought with it a multitude of breakthroughs in treatment methods, allowing humans to enjoy longer lifespans. However, a new type of disease has risen up to challenge humanity's progress: degenerative brain diseases. How can we help those who are suffering to this day from a disease without a definite means of treatment?

Setting our sights on the treatment of degenerative brain diseases

Parkinson's disease is a long-term degenerative disease that mainly affects the motor system, causing tremor, rigidity. A progressive neurological disorder that mainly causes motor dysfunctions such as resting tremor, muscle rigidity, slowness of movement and balance impairment, which are similar to the symptoms experienced by Na Hye-sok (1896~1948). Additionally, Parkinson's disease patients often experience depression or even dementia. Although the etiology of the disease still remains elusive, it has been reported to be related to a problem in dopamine production due to damaged neurons in the substantia nigra.

Currently, treatments for degenerative brain diseases like Parkinson's disease are mostly limited to symptomatic treatments. Hence, numerous studies and discussions are underway to explore semi-permanent and fundamental solutions. Such goals can be achieved by understanding the functions of neurons at the molecular and cellular levels (Professor Won Do Heo), the mechanisms of neural networks (Professor Seung-Hee Lee), and the behavior of animals in addition to humans (Professor Daesoo Kim). Furthermore, it is imperative to include optogenetic technology when implanting devices in the brain (Professor Jae-Woong Jeong) to establish systems capable of identifying brain functions. Such technologies would go a long way in helping us better understand and treat brain diseases.

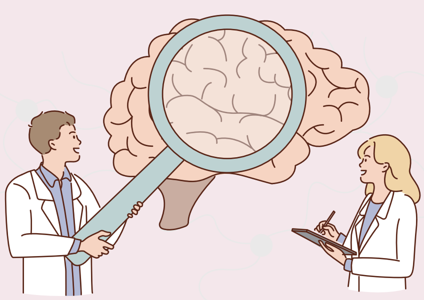
Optogenetics, a remote control for the brain

The double helix structure of DNA was first discovered in 1953, published in Nature by James Dewey Watson (1928~), Maurice Hugh Frederick Wilkins (1916~2004), and Francis Crick (1916~2004). Among these scientists, Francis Crick, who is well-known as 'the father of brain science', claimed that 'the singularity of brain science research can only be overcome with regulation techniques faster than neural signals, which means we need to utilize light.' In 2005, a Stanford University research team led by Professor Karl Deisseroth (1971~) supported Crick's claim as developing a new technology, termed optogenetics[1], rendering researchers to rapidly turn neurons on and off with light, supporting Crick's claims.

Early developments in the field of optogenetics[1] involved channelrhodopsin found in green algae, which acts as a

1) **Optogenetics** _ a combination of the words 'opto' (light) and 'genetics' describing biological technology that controls living tissue cells with light. A prime example involves genetically altering nerve cells to express ion channels that respond to light.

> The first approach involves Professor Won Do Heo's research on monitoring various proteins and controlling cellular proteins and functions in real time with light.



channel that allows the passage of cations like sodium and potassium ions when exposed to blue light with a wavelength of 460 nm. In other words, shining light onto neurons that express channelrhodopsin will cause the neurons to become activated.

More recent optogenetics research involves the insertion of specific genes into viruses to induce the brains of mice to express proteins in response to corresponding signals. For example, researchers implanted optical fibers in the brains of mice and observed responses to stimuli. The utilization of genetic engineering technology enables control at a cellular level, allowing for the rapid application or removal of stimuli. This type of technology has the advantage of being able to vary the wavelength of light to operate various types of circuits. In contrast to past research methods involving imprecise observations of stimuli-responses, the discovery of channelrhodopsin made revolutionary advancements in the field by enabling millisecond-level precision when analyzing response rates.

KAIST's original technology: molecular optogenetics

Early optogenetic technologies involved complex processes to control genes at the cellular level. These were limited to activating or inhibiting neurons and could not control specific cellular molecules and processes such as the structures of the synapses.

In 2008, Professor Won Do Heo of KAIST made a game-changing breakthrough by introducing a new term: molecular optogenetic technology. Up until this point, optogenetics was fixated on the activation of neurons. In contrast, molecular optogenetics focuses on the individual molecules level, such as functioning proteins in the cells.

From the moment a cell receives various types of external signal molecules (for example, due to stress), the cell goes through about 5,000 signal transduction protein molecules, including those related to cell division and neural synapse formation. Furthermore, various mechanisms are involved in the on/off process. Therefore, a wider variety of cells and cellular functions can be controlled by regulating signals at the protein molecular level.

For example, it would be possible to remotely control cellular functions by using light to control the influx and residence times of calcium ions. This became a reality in 2015 when Professor Heo introduced his 'calcium ion activation technology (OptoSTIM1),' which was used to double the memory capabilities of mice by increasing calcium concentrations. Moreover, Professor Heo succeeded in recording memories in the brain. The technology is currently being used as a basic means of activating neurons.

From 'conjecture' to experimental research: aiming to achieve singularity in brain research

Among all disciplines of research, the field of brain research is considered as one of the most challenging. This is mainly due to the fact that researchers are limited to 'conjecture' based on observable phenomena given that it is not

possible to artificially control nerves and synapses. Despite the growing concern of brain diseases arising from longer lifespans and exposure to numerous sources of stress, treatment methods have yet to advance beyond the level of relieving symptoms. This is an alarming lack of progress considering how the world desperately needs methods of treating nerve damage and information processing abnormalities.

KAIST has adopted four main approaches to brain research. The first approach involves Professor Won Do Heo's research on monitoring various proteins and controlling cellular proteins and functions in real time with light.

Second, Professor Seung-Hee Lee's research investigates how the brain processes sensory information via cortical neural circuits at the synaptic level in vivo. She was one of the pioneers who applied optogenetics to study cortical circuits and cell types. She also applied cutting-edge technology to measure and image neural activity in vivo in the mouse brain. Currently, Professor Lee is focusing on research to understand how the brain processes external stimuli and stores them as meaningful memories. She is working to identify specific neural circuits that store particular sensory information and transform them into motor decisions.

On the other hand, Professor Daesoo Kim is aiming to apply optogenetic technology to the treatment of Parkinson's disease and various degenerative brain diseases. By developing brain-computer interface technologies and artificial intelligence systems that can analyze animal behavior, it is now possible to verify the potential of molecular optogenetic technology for the study of entity behaviors.

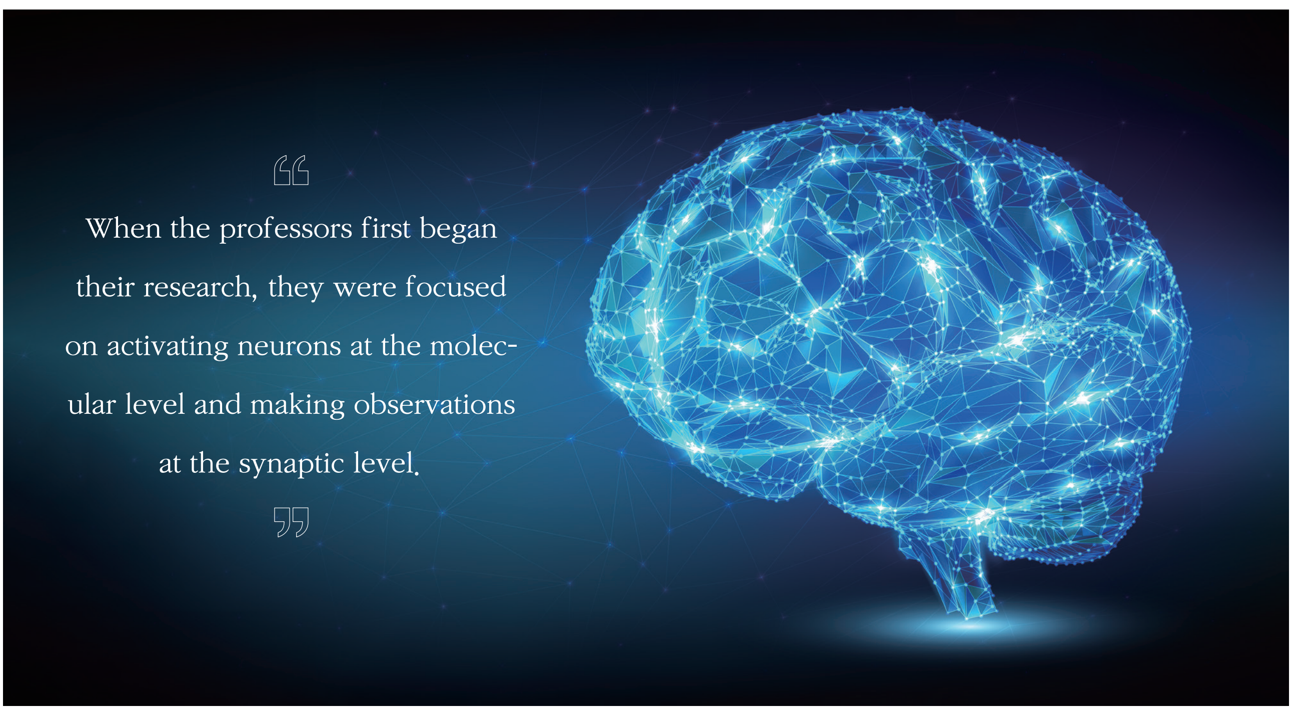
In the field of molecular optogenetics, the development of neural devices is as important as protein expression and imaging research. Professor Jae-Woong Jeong's work involves developing implantable wireless devices that can enable optogenetic and neuropharmacological control of neurons in animal brains. Multi-functional neural interface tools and implantable wireless devices are becoming increasingly important for brain function research and brain disease treatments worldwide. However, most available technologies have yet to progress beyond conceptual demonstrations.

Professor Jeong is investigating miniaturized wireless neural implants that can enable sophisticated multi-functional neural interfaces for molecular optogenetics. If standardized, the technology would open many new opportunities for basic neuroscience studies as well as clinical applications. His research team is aiming to develop devices that can be chronically implanted in the brain to wirelessly monitor neural acitivities and provide target-specific neuromodulation for the treatment of various neurodegenerative diseases.

Stepping closer to a treatment for Parkinson's disease

When the professors first began their research, they were focused on activating neurons at the molecular level and making observations at the synaptic level. This was because they believed it would be possible to visualize the location at which sensory and cognitive memories are recorded in real time. In addition, the team hoped to better understand the processes through which these memories were stored. So far, no one has managed to produce real-time visual representations of synaptic changes or newly formed synapses within a single entity. If such images could be produced in real time with synaptic sensors, researchers would be able to better grasp the mechanisms behind brain functions like learning and memory. Moreover, such developments would help us make significant strides in our understanding of brain diseases.

The research team developed real-time synaptic sensors to visualize the formation synapses in behaving mice. The team is also producing various types of viruses able to express molecular optogenetic proteins and sensors for monitoring molecular activity in



> Regardless of how the world views a person's life, is there a life more valuable than one that is lived to its fullest? From this perspective, the brain disease research taking place at KAIST could potentially become a major turning point.

specific cells in the brain. By measuring the changes in calcium signals at the cellular level, it is possible to monitor neural activity patterns in real time. Furthermore, this would also allow for the detection of signal variations at the cellular level.

Parkinson's disease is a disease caused when dopaminergic neurons in the substantia nigra fail to function properly. Therefore, it could be said that this research is making progress towards to the treatment of Parkinson's disease. The ultimate goal is implant devices in the brain for the treatment of brain diseases. To achieve this goal, the research team is working to develop multi-scale neural interface devices that enable both optogenetic control and fluid drug control.

A new paradigm for the treatment of intractable brain diseases

The research team divided the singularity research into two stages. The first stage, which is scheduled until 2022, focuses on using molecular optogenetic technology to analyze changes in animal memory, cognition, and behavior and analyze how behavior is affected by the expression and activity of molecules that cause brain diseases. Through this process, the team is planning to use the world's first synaptic optoprotein sensor to be the first to discover the principles of neural networks in a mouse brain. Additionally, the team will use molecular optogenetic technology to explore the working principles behind natural intelligence at the molecular level to propose a new paradigm for improving brain functions.

For the second stage, which will last until 2028, the team is planning to develop brain disease treatment technologies by combining molecular optogenetic technology (with the highest level of sensitivity in the world) with wirelessly controlled optogenetic systems to activate neurons and neural circuits. The research team believes that they could open a new paradigm for memory research and the treatment of intractable brain diseases by utilizing molecular, cellular, and neural circuit targets and applying systems neuroscience, molecular sensor technology, and molecular optogenetics.

For the betterment of humanity

Na Hye-sok died at the early age of 53 in 1948. Although she lived and died as an artist until her dying breath, her artistic journey was brought to an end not by the denouncements of her contemporaries, but rather a disease she suffered.

Regardless of how the world views a person's life, is there a life more valuable than one that is lived to its fullest? From this perspective, the brain disease research taking place at KAIST could potentially become a major turning point. The quest to improve the lives of others - helping them live their lives to the fullest - starts with a philanthropic mindset and a willingness to help humanity as a whole.

UP Research Program

Measuring a Deep and Mysterious World: **Optical Frequency Combs**

Professor **Young-Jin Kim,** Mechanical Engineering

If we continually split matter into smaller components, how far can we go? The search for the fundamental constituent of matter has been ongoing for several millennia since ancient times. A countless number of scholars have taken on the quest to seek the 'smallest particle that makes up all matter' throughout history, including Thales, Democritus, Dalton, and Bohr. Yet it was only in 1926 that an answer was finally found. Moreover, the continuous evolution of human technology has allowed us to dive deeper into the microscopic world, leading to the discovery of the atomic nuclei of neutrons and protons that make up atoms. But this raises the same question yet again: "what is the true constituent of all matter?" Given that humanity has arrived at the point where we can measure atoms as small as 0.1 nanometers, exactly how far have we come in terms of our measurement technology?

The dwarf of all dwarves, the picometer

A nanometer is an incredibly small length that is a billionth of a meter. It is no wonder the term 'nano' was born out of 'nanus', the latin word for 'dwarf.' Consider the human body, which is comprised of 60 trillion cells: a single cell is several tens of micrometers in size; the nucleus within the cell is 1~5 micrometers; a chromosome is about 1 micrometer; and the width of DNA is 2 nanometers. This is evidence of the truly small nature of a nanometer. But is there a realm even smaller, and can we measure it?

It would be an understatement to say that Professor Young-Jin Kim from the Department of Mechanical Engineering and his research team are interested in 'the measurement of length.' More specifically, rather than the visible macroscopic world, they are more fascinated with the ultra-microscopic realm of picometer scale, the existence of which in itself is debatable. Take note that a picometer is a trillionth of a meter or a thousandth of a nanometer.

Professor Kim's deep interest in such small realms arises from the question of "what is the smallest scale at which we can measure and control dynamic behaviors at a fast rate?" Humanity could make significant strides of progress by finding a solution to this ultimate question; perhaps this is why we have progressed to the point where we can make measurements and control phenomena at the nanometer scale. Nevertheless, Professor Kim is entering a realm that is even smaller than atoms at the picometer scale.

Approaching the smallest of small worlds

Such acute levels of precision requires technology with the resolution to discern extreme measurements at ultra-fast time scales. Several conditions need to be satisfied, such as a vacuum state, and only a narrow selection of samples can be even be measured under such conditions. Such considerations gave birth to the idea of the 'femtosecond optical comb.'

Optical frequency combs are named as such as they are basically 'light with multiple frequencies like a comb' achieved using pulse lasers. This type of laser emits light not in the form of a continuum, but by rapidly and repeatedly shifting

> Optical frequency combs are named as such as they are basically 'light with multiple frequencies like a comb' achieved using pulse lasers. This type of laser emits light not in the form of a continuum, but by rapidly and repeatedly shifting between two discrete states: on and off.

between two discrete states: on and off. Among such lasers, femtosecond lasers have incredibly short pulse durations of 10-18 seconds. As a result, Fourier transform[1)] will result in the intervals even in the optical frequency domain. Furthermore, in the frequency domain, multiple modes exist over a wide wavelength range, forming hundreds of thousands of wavelength modes. Each wavelength is significantly narrower than that of a typical laser and can be easily stabilized with a time-frequency standard. This is a key technology that will enable humanity to overcome existing limitations and make significant breakthroughs.

Making leaps for upgrades: plasmonic EOT phenomenon

For their Leap Research, Professor Kim's research team set their sights on the plasmonic EOT phenomenon. An abbreviation for 'extraordinary optical transmission,' EOT refers to a phenomenon in which light of a certain wavelength is able to pass through a hole on a metal plate that is smaller than its wavelength with greater ease compared to light of other wavelengths. This phenomenon cannot be explained by classical optics, which states that light cannot pass through a hole smaller than its wavelength. In reality, however, transmittance continues to take place even as the size of the hole decreases, albeit with decreasing degrees of transmittance. If the metal plate has several holes, the transmittance for a specific wavelength can increase up to 20,000-fold. This phenomenon is referred to as 'plasmonic resonance.' Using optical frequency combs, it is possible to analyze optical frequency and phase information in addition to transmission information with great detail. Therefore, optical frequency combs are highly useful when sensitive measurements are required.

What are the properties and advantages of optical frequency combs?

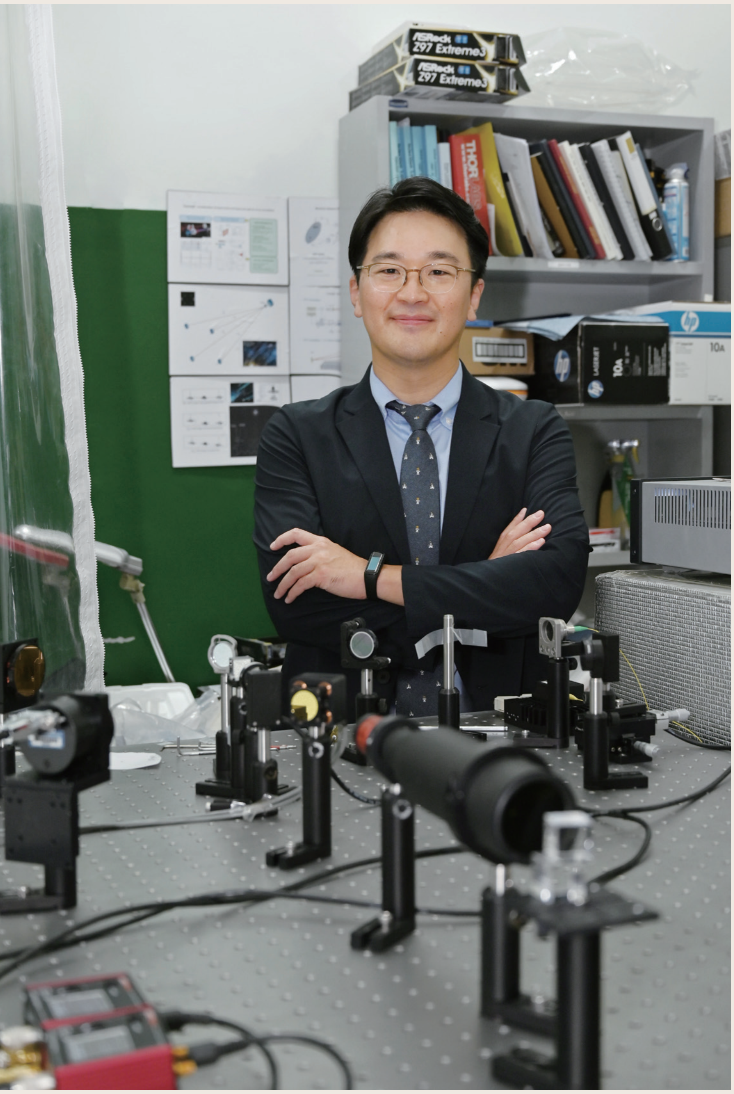
We must then consider the advantages of optical frequency combs when it comes to dealing with even smaller domains. Light exhibits stronger interactions when gathered at the thin interface between metal and organic matter, and these interactions take place between light and matter even when considering subatomic-scale displacements, enabling the measurement of the finest of changes. When an optical frequency comb is applied to such plasmonic phenomena, it has an advantage in obtaining optical frequency and optical phase information as it is substantially narrower and more stable compared to existing light sources.

The next question to ask is whether optical frequency combs have the same excellent properties post-transmission as it does during input. Photons are converted into surface plasmons at the input side, and the surface plasmons are then reverted to photons at the output side. Thus, it is crucial to check if any properties are altered following the two conversion processes.

Lasers that we generally see in our everyday lives have a single wavelength, which is why we perceive them to remain unchanged after passing through glass. However, this is not the case for femtosecond lasers with narrow pulse widths. The high output resulting from the gathering of energy within a narrow space results in variations between the input light and output light in terms of not only wavelength, but also in other various properties. However, it was determined through research that the original properties are successfully maintained.

Additionally, a study is underway to understand the physical changes that take place when the temperature of the surface plasmons is varied. A change in temperature can result

1) **Fourier transform** _ the decomposition of a function dependent on time into component functions dependent on frequency. As a wavelength or signal is the collective sum of multiple specific wavelengths, it can be analyzed with time and frequency information.



in either thermal expansion or contraction, which can affect the spacing between the holes. A change in hole spacing causes the plasmon resonance peak to be shifted, at which a high-resolution phase measurements can be accomplished with a resolution of 2 picometers.

Future technology emanating from the picometer

Why is it so important to explore such small realms? Professor Kim expects this technology to become a core technology for the production and measurement of next-generation EUV semiconductor equipment. GIven the demand for finer laser line widths, the measurement and controlling ranges of key semiconductor equipment need to also become significantly sharper. Hence, optical comb-based plasmonic phase measurement technology is expected to become an important core technology to enable such ultra-fine levels of measurement and control.

Moreover, this technology could potentially replace PCR-based molecular genetic testing methods for the detection of respiratory viruses like the coronavirus. Harmful elements could be quickly detected by performing optical frequency comb phase spectroscopy with body fluids from respiratory patients.

There is also the potential for application in advanced satellite development. Time synchronization (controlling multiple devices/transmitting data in sync with a click signal) is a key consideration for satellites, which is why satellites are equipped with atomic clocks based on atomic frequency. Optical frequency comb technology has the potential to improve the precision of atomic clocks and enable miniaturization through plasmon resonance.

Humanity's quest to discover the fundamental constituent of matter

In 400 B.C.E, Thales claimed that the fundamental constituent of matter was water. More than 2,300 years later, humanity came to believe the fundamental constituent of matter lies in the nanomater-scale atomic realm. Over the next 100 years after this discovery, we began exploring an even smaller world. Humanity has discovered a great unknown abyss in the picometer. What kind of world does the picometer hold? How will it affect our future? This is the discovery of a completely new realm, and we have only begun to scratch the surface.

"Why is it so important to explore such small realms? What kind of world does the picometer hold? How will it affect our future?"

I KC30 I KAIST Challenge 30 - ❶

Searching for Qin Shi Huang's Dream: The Source of Immortality

Professor Kwang-Hyun Cho, Bio and Brain Engineering

1953 was the year Watson and Crick announced their discovery of the DNA helix structure. Their relatively short paper of only 128 lines played a major role in the rapid growth of the biology field. Their publication led to the discovery of molecular components within cells, which could be compared to 'parts' of a car. Moreover, these discoveries instigated the emergence of 'systems biology,' a transdisciplinary field of research that views cellular mechanisms of action as a single system.

A new development in the 21st century: systems biology

Although significant effort has been dedicated to the study of biological phenomena, most research tend to isolate individual phenomena in a vacuum. In reality, life as we know it is the result of interactions between various dynamic and ever-changing components. Research regarding the fundamental principles of various biological phenomena began to garner interest, fostering greater transdisciplinary integration with many other fields, including computer science, mathematics, physics, and control engineering. This gave birth to systems biology, an amalgamation of biology and engineering that focuses on studying various biological phenomena by considering an organism as a single system.

Compared to the long history of molecular biology, which spans over 70 years, the term 'systems biology' was first introduced to the world in 1968. It is worth noting that there were prior instances where scientists proposed similar concepts. However, systems biology truly gained traction with advancements in measurement technology, which made it possible to gather data on biological phenomena through quantitative and precise measurements. Additionally, while biology and engineering were gener-


Protein-Protein Interaction
SIGNALS and SYSTEMS
Linear Systems
Hybrid Systems II
Pattern Discovery in Biomolecular Data
퍼지이론 및 응용
NEW BIOLOGY
STATISTICS FOR ENGINEERS

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ally viewed as separate disciplines in the past, current trends see researchers from various fields like mathematics and engineering take an interest in solving the mysteries of biological phenomena.

Professor Kwang-Hyun Cho first began his career in systems biology with the question of “can biological phenomena be mathematically modeled?” With mathematically quantified models, it is possible to analyze the principles of biological phenomena and even develop methods of controlling organisms. In fact, personalized precision medicine is steadily becoming a reality with more advanced methods of controlling biological phenomena at the molecular level. Other notable applications include the development of new drugs as well as drug repurposing, which aims to determine if existing drugs can have effects on new diseases. In this context, the restoration of cancer cells or aged cells into young and healthy cells could also be viewed as research aiming to control biological phenomena.

Changing the way we think: shifting the paradigm of cancer treatment

Professor Cho’s research focuses on cancer and aging. The system of regulatory mechanisms that control the molecules within our cells is highly complex and dynamic. Each molecule has its own role, but at the same time, each molecule interacts with other molecules to result in complex regulatory actions. In other words, if a molecule is altered due to any one of multiple causes, (e.g., external stimuli), all molecules connected to this molecule in this vast and complex system also experience changes, causing a chain reaction of sorts. This ultimately results in what we identify as a response to the external stimuli.

Gene mutations can take place in normal cells due to various factors. If such mutations accumulate beyond a critical point, normal cells will turn into cancer cells. In the same vein, young cells gradually turn into aged cells due to the accumulation of gene damage.

Cancer cells and aged cells do not naturally return to their normal state. As both processes are irreversible, the conventional belief is that cancer cells cannot be reverted back into normal cells.

“Even if a cell is damaged by gene mutation, it still possesses functional redundancies that may render it possible to replace damaged functions via a different route, potentially restoring the cell’s normal functions.”

As a result, the focus of cancer treatment has been to kill cancer cells.

However, this approach to cancer treatment has a critical flaw in that normal cells are also inevitably killed in the process along with cancer cells, which is a major side-effect of cancer treatment. Even if we try to develop treatments that specifically target only cancer cells, the extra care in the approach can often result in some cancer cells remaining in the body and developing a resistance to the drug, potentially leading to cancer recurrence.

Making cells young again

Professor Cho believes that, instead of outright killing cancer cells, it is possible to develop a new approach to cancer treatment by finding ways to revert cancer cells back to normal cells or by altering the properties of cancer cells to more closely resemble a normal state. The same can be said for aging. Statistics estimate that the life expectancy of children born in 2018 is 82.7 years. However, their healthy life expectancy, which excludes years of illness, is only 64.4 years. In other words, most people will spend their final 18 years of their life suffering from illness.

This problem is related to the aging process of our cells. Aged cells secrete a proinflammatory substance known as cytokine, which can cause geriatric diseases or even cancer. Instead of trying to deal with each individual disease, we could face the problem from a different angle by developing methods of reverting aged cells that cause diseases back into young cells. This would be a breakthrough that would essentially make life expectancy equal to healthy life expectancy.

Even if a cell is damaged by gene mutation, it still possesses functional redundancies that may render it possible to replace damaged functions via a different route, potentially restoring the cell’s normal functions. In January 2020, Professor Cho presented his findings on how colorectal cancer cells could be reprogrammed into normal colon cells in Molecular Cancer Research, a journal published by the American Association for Cancer Research (AACR). Later in November of the same year, Professor Cho announced his research on the reversed aging of cells back into young cells by regulating molecules in aged human

Furthermore, from the perspective of evolution, Professor Cho's ultimate question asks whether humanity could evolve to be able to naturally revert cancer cells and aged cells back into young, healthy cells.

dermal fibroblast cells (<Proceedings of the National Academy of Science of the United States of America(PNAS)>). Currently, Professor Cho's team is conducting research on reverting breast and lung cancer cells back into normal cells.

The 'common principle' of biological phenomena

Cancer cells are categorized according to the tissue in which the cancer occurs. Aging also has various mechanisms that differ between individual cells. Therefore, Professor Cho always asks the question of 'how' when carrying out research on reverting cancer cells and aged cells into normal cells. If Professor Cho's hypothesis is correct and there is in fact a molecular switch common to all cancer cells that can return them to normal, then it may be possible to reprogram cancer cells back into normal cells by simply learning how to control this switch. Furthermore, from the perspective of evolution, Professor Cho's ultimate question asks whether humanity could evolve to be able to naturally revert cancer cells and aged cells back into young, healthy cells.

Professor Cho's research began by shifting his thought process. His journey into this field of research began with a fundamental question about the principles of cancer treatment methods that kill cancer cells. This evolved into the idea of 'treatments able to revert cancer cells back into normal cells, which would substantially reduce the various side-effects of chemotherapy.' It was with this idea for a new paradigm in cancer treatment technology that Professor Cho began his unique research on reversing cellular aging and cancer.

The value of courage for the 'voyage' of research

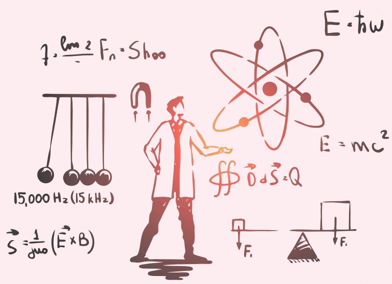
Professor Cho compared research to a 'voyage' into an unknown world. However, such voyages and adventures are almost always challenging and can often lead to failure. Nevertheless, the scientific questions we ask during the process will broaden our knowledge. Based on this belief, Professor Cho urges his students and all young scientists to have the courage to dive into the unknown.

SYSTEMS BIOLOGY

| KC30 | KAIST Challenge 30 - ❷

The 5th Force Shaping the Universe: Friction

Professor Yong-Hyun Kim, Physics / Graduate School of Nanoscience and Technology



In physics, there are four fundamental forces of the universe (also referred to as the ‘four fundamental interactions’): gravitational force, weak (nuclear) force, strong force, and electromagnetic force. Although not included in this group, an equally important force is friction, which occurs when an object is in direct contact with another object. However, friction was originally understood as a type of electromagnetic force, and thus was not considered with greater significance.

Professor Yong-Hyun Kim of the Department of Physics and the Graduate School of Nanoscience and Technology at KAIST states that ‘friction is a core part of physics, yet few truly understand its importance.’ Then we must ask, what is friction exactly? Let us find an answer to this question by exploring Professor Kim’s research.

Friction, becoming a fundamental force

How are we able to walk? This may seem like a silly question, but upon closer inspection, the answer lies in the friction forces between our feet and the floor, specifically friction that arises from electromagnetic forces. Despite it clearly being an integral part of our daily lives, friction does not receive the recognition of the four fundamental forces of physics.

Professor Kim blames this on our misunderstanding of friction that stems from it being accepted as a type of electromagnetic force. Professor Kim points out that friction can occur with gravitational and nuclear forces and suggests that it should be as a common factor of all four fundamental forces, not solely electromagnetic force. He proposes giving friction the title of ‘the 5th element’ and presents a new paradigm through which to view this type of force.

Friction, a quantum mechanics approach

Professor Kim's main field of expertise is quantum materials theory. Quantum mechanics is the most fundamental theory of modern physics, and its theories are used to explain the microscopic world of matter (of atoms and molecules). Prior to quantum mechanics, physicists used classical physics to explain the macroscopic world of matter that is closer to our daily lives. In contrast, quantum mechanics helps us understand phenomena that occur in the microscopic realm, many of which cannot be explained by classical theories.

One could say that quantum mechanics is a tool that helps us understand the universe. Since its introduction in 1920, quantum mechanics has continuously evolved over the past century. In recent years, physicists are utilizing computers and approximation methods (analysis methods that produce results that, despite not being mathematically

or theoretically 100% accurate, are practically meaningful) to solve problems that cannot be explained with conventional physics. As quantum mechanics deals with the total energy of a system, it is a useful approach for problems involving climate change or energy efficiency.

Advancements in our understanding of quantum mechanics has made it possible to explain the inherent physical properties of matter. This is especially true at the nanoscale of atoms, where quantum properties are more pronounced, and thus a quantum mechanics approach is vital to fully grasp physical properties at the nanoscale. Professor Kim's field of research - quantum materials theory - is focused on examining physical properties that are involved in the microscopic realm.

Friction in the microscopic realm, revealed by graphene

Graphene, which is often touted as a 'dream nanomaterial,' is a planar polymeric allotrope of carbon consisting of carbon atoms connected in a honeycomb structure. This material was first discovered in 2004 by Andre Konstantinovich Geim (1958~) and Konstantin Novoselov (1974~) from the University of Manchester in the United Kingdom. The two scientists used Scotch tape to extract a single 0.2 nm layer of graphene from graphite, which is commonly used in pencils.

Professor Kim's research on friction also brought his attention to graphene. Similar to experiments in the macro world, it can be challenging to analyze and understand the results of experiments in the microscopic world if the experiments are too complex or if there are too many variables. With a two-dimensional planar structure and a smooth surface, graphene is an ideal material for friction analysis. When friction is applied to the surface of graphene, energy is lost due to the graphene bending vertically.

“Professor Kim has expanded his research beyond graphene to also investigate the properties of metal chalcogen. By elucidating the relationship between friction and the thermoelectric effect, Professor Kim and his team hopes to uncover new insights into the fundamentals of frictional electricity or triboelectricity.”

Using a metal probe capable of measuring temperature differences, Professor Kim also discovered that the thermoelectric effect (the flow of current through a circuit due to temperature differences) takes place on the surface of graphene. This proves that the thermoelectric effect can also occur at the nano or atomic level. This is a significant discovery as it may allow us to estimate physical properties, the shapes of electron clouds, or images of atoms by analyzing voltage differences at the nano or atomic level.

Professor Kim has expanded his research beyond graphene to also investigate the properties of metal chalcogen. By elucidating the relationship between friction and the thermoelectric effect, Professor Kim and his team hopes to uncover new insights into the fundamentals of frictional electricity or triboelectricity.

Hope for a society that encourages ‘working towards the long run’

Whatever we do, we cannot expect to be satisfied by only taking a single step. While some tasks can be completed in a short time, others require long periods of trial and error, overcoming one failure after another with persistence. KAIST’s ‘KC30 Project’ may be the most extensive experiment the institute has ever conducted to establish new foundations for basic science.

Professor Kim hopes that the KC30 Project is continuously supported long into the future. In order for KAIST and Korea as a whole to progress forward, Professor Kim emphasizes how we need to focus on steady developments with long-term goals rather than focusing solely on solving immediate issues. In a culture that has a preference for immediate results, researchers are forced to avoid taking on long-term projects. Therefore, Professor Kim hopes that new support programs can be organized to promote researchers to look far into the future towards long-term goals.

Science and Technology New Deal Project - COVID-19 Rapid Diagnosis Technology

COVID-19 Diagnosis, a Solution for the Fight Against Time
Nanoplasmonic Chips

Professor Ki-Hun Jeong, Bio and Brain Engineering

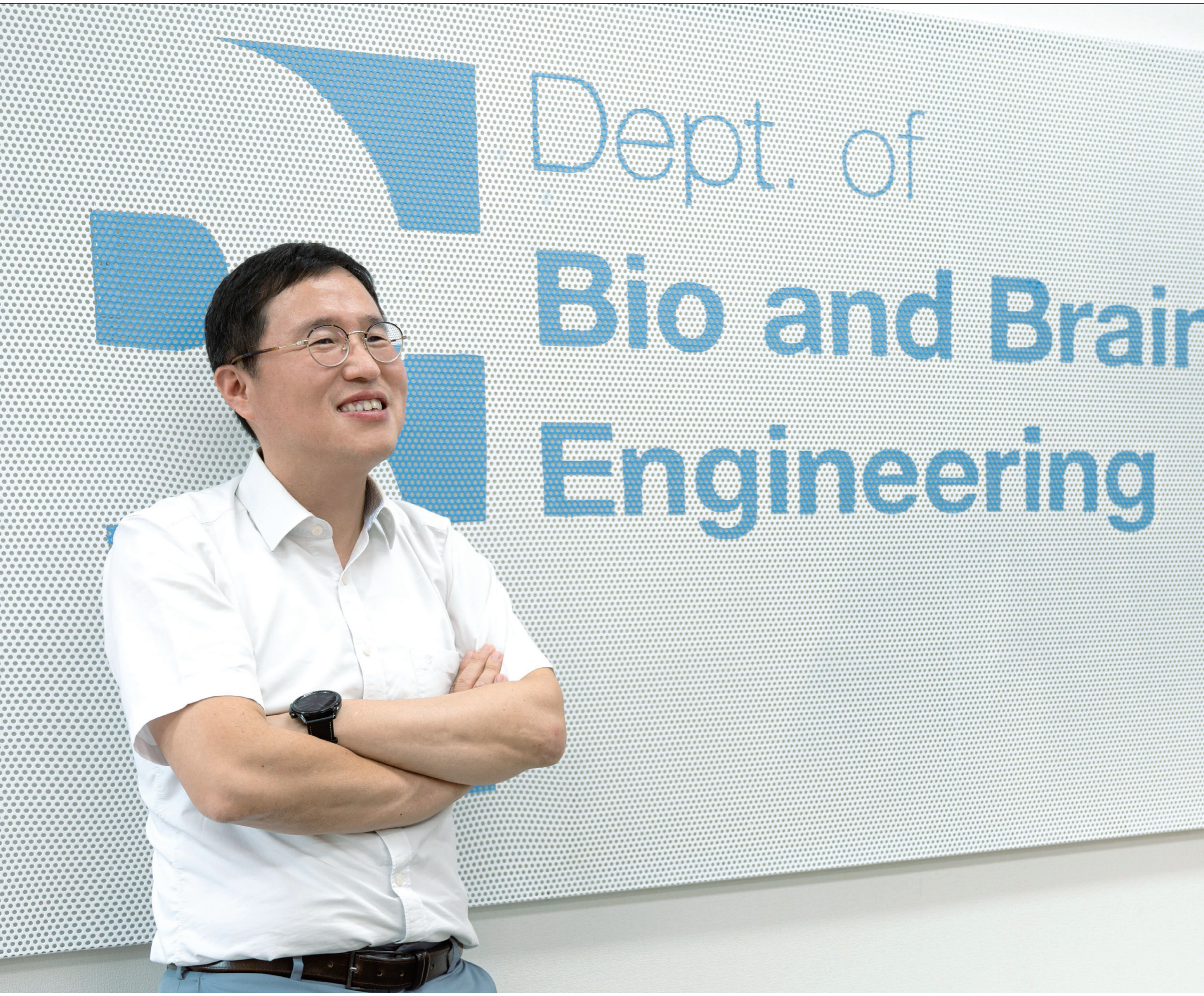
In December 2020, Korea initiated a plan to fight the rapid spread of COVID-19. This involved operating temporary screening locations where anyone could be tested for COVID-19 for free, even if they had not been in contact with a confirmed case. As people could be tested anonymously, there was a dramatic increase in the number of tests being conducted, which in turn greatly magnified the need for fast and accurate virus screening technology. In fact, this type of rapid screening technology is at the core of the nation's various efforts to find and identify confirmed cases, the number of which has been rapidly growing by the day.

The 'Big 3' of COVID-19 diagnosis tests

The three main types of COVID-19 diagnosis tests are RT-PCR tests, antigen tests, and antibody tests. The RT-PCR (reverse transcription polymerase chain reaction) test is a diagnosis method involving the amplification of genes from cells taken from saliva or the nasopharynx (the space inside the nose through which air flows when breathing). On the other hand, antigen tests check for proteins unique to the SARS-CoV-2 virus, whereas antibody tests detect the virus in blood samples via antigen/antibody reactions.

The most commonly employed diagnosis method is the RT-PCR test. As the SARS-CoV-2 virus is an RNA-based virus, RNA is converted into DNA before performing the RT-PCR test. Given the amount of DNA doubles after each cycle, this results in abundant samples for testing. Therefore, the RT-PCR test produces accurate results.

Although the RT-PCR test is the most widely used diagnosis method, it takes a long time to complete as the test samples must be sent to centers with large diagnostic equipment. Additionally, the process of increasing the amount of DNA requires the temperature to be increased and decreased, rendering it difficult to produce results in real time.



Nanoplasmonic chips were applied to PCR tests to accelerate the diagnosis process from one hour to five minutes.

> This technology enables us to produce smaller temperature control devices with the noteworthy benefit of significantly lower manufacturing costs.

In recent months, COVID-19 self-testing kits based on the antigen method were made available for purchase at convenience stores. Despite the advantage of being able to quickly produce diagnosis results, these kits are limited by their lower sensitivity (a property indicating how effectively a method can identify infected patients) compared to other methods.

Nanoplasmonic PCR: works anytime, anywhere!

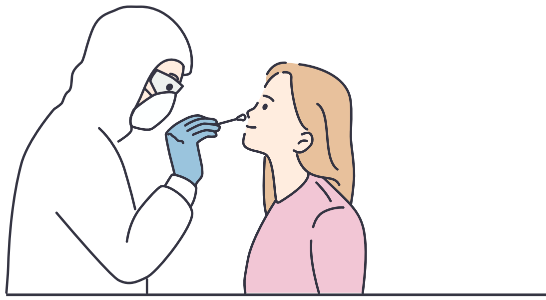
Upon closer inspection of the PCR process, it is clear that temperature control is an important factor of the DNA amplification process. For this reason, Professor Ki-Hun Jeong turned his focus towards nanoplasmonics (nano-structures for plasmonics). Nanoplasmonics involves the absorption of light and generation of heat at the boundary between a metal surface and a dielectric when light hits the metal surface and reacts with electrons.

A nanoplasmonic array consists of a thick lattice of glass pillars embedded with gold. A plasmonic nanopillar array is formed by embedding gold on top of the glass pillars, each of which are only 100nm in diameter (a thousand times smaller in diameter than a human hair). This forms large nanoislands on the top surface and small nanoislands on the sides of the nanopillars.

When light is irradiated onto a metal thin film, electrons at the interface between the metal thin film and the dielectric vibrate simultaneously. This phenomenon is called surface plasmon resonance (SPR). In addition to metal thin films, it is possible to excite free electrons on the surface of nanoparticles by exposing the outer surface of the nanostructure to light of a specific wavelength.

Vacuum-packed chips for nanoplasmonic PCR

> It will not be long until COVID-19 diagnostic technologies are soon integrated into the world of lab-on-a-chip technology, which has been described as 'a laboratory in the palm of your hand.'



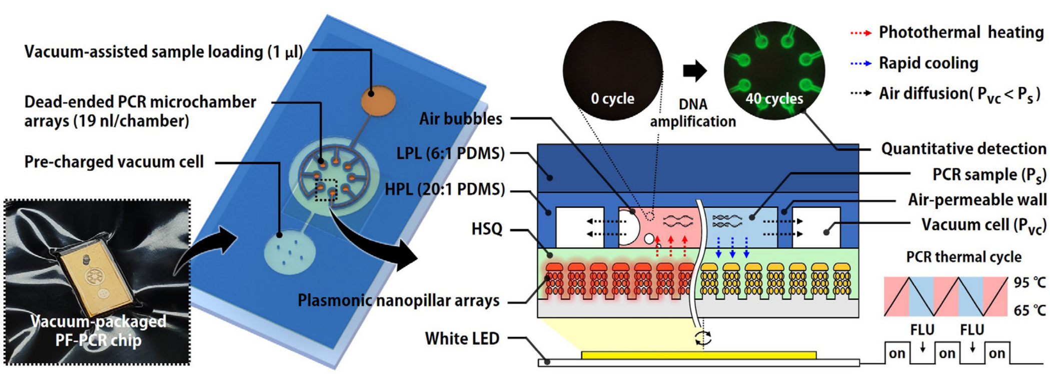
In addition to causing vibrations, electric dipole characteristics can be observed. The excited electrons collide with metal atoms to absorb light of a specific frequency band, converting light energy into thermal energy (photothermal effect).

The gold nanoislands of the nanoplasmonic pillar array used by Professor Jeong for his research are smaller than the wavelength of light. Generally, the wavelengths in the visible light region that are absorbed by the gold nanoislands vary greatly depending on the size and spacing of the nanoislands. The developed nanostructure possesses high light absorption properties throughout the entire visible light spectrum and rapidly radiates heat when receiving light. Furthermore, given that the structure has thousands of nanopillars, the high surface area enables rapid cooling as heat is easily able to escape. Therefore, nanoplasmonic technology could be applied to PCR testing to produce results 10 times faster than with a conventional thermal cycler.

Increasing cost-effectiveness as well as speed

Nanoplasmonic chips were applied to PCR tests to accelerate the diagnosis process from one hour to five minutes. This technology enables us to produce smaller temperature control devices with the noteworthy benefit of significantly lower manufacturing costs.

KAIST is currently working with relevant industries and the National NanoFab Center to develop a prototype and prepare for approval processes of the Ministry of Food and Drug Safety. It will not be long until COVID-19 diagnostic technologies are soon integrated into the world of lab-on-a-chip technology, which has been described as 'a laboratory in the palm of your hand.'



A New Breakthrough in COVID-19 Diagnosis: Converging Chest X-rays with Artificial Intelligence

Professor Jong Chul Ye, Bio and Brain Engineering

COVID-19 has been the most prominent social and scientific issue for the past two years. The COVID-19 pandemic, which has swept across the entire world, has forced humanity to devote significant resources to the development of treatments and vaccines. Fortunately, the emergence of multiple vaccines is bringing the world closer to a 'with COVID' society.

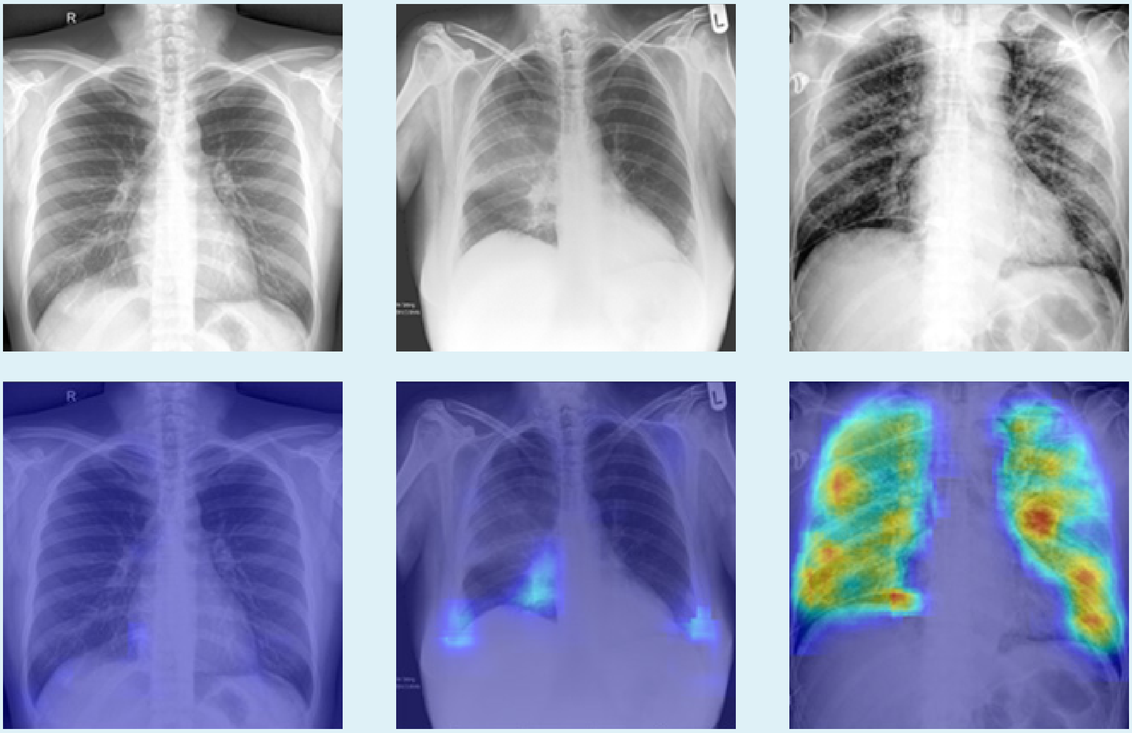
However, Professor Jong Chul Ye emphasizes how diagnostic technology, which can help us mitigate the spread of the virus, is just as important as new treatments. Specifically, he points out the value of bioimaging and chest X-ray technology. Bioimaging can be summarized as a technique of displaying phenomena that take place in cells. In addition to bioimaging, Professor Ye is conducting research on chest X-rays due to the high prevalence of lung lesions found in patients infected by the coronavirus. He states that he sees the possibility of being able to diagnose COVID-19 with chest X-rays similar to how diseases like pneumonia are diagnosed.

Q. Professor Ye, why did you take an interest in COVID-19 diagnosis technology?

A. Currently, most of the world uses a technology known as the reverse transcription polymerase chain reaction (abbreviated as RT-PCR) to diagnose COVID-19. Due to the nature of viruses, only a small amount of a virus penetrates into the body. For this reason, we must convert the genetic information of the virus - which is RNA - into DNA. After this conversion, we must perform amplification with a polymerase. The RT-PCR test is able to accurately diagnose whether a patient has been infected by the SARS-CoV-2 virus, but current processes can take several hours to complete.
This may not be a major concern for countries with PCR machines, but there is a surprisingly large number of countries without access to such equipment, making it significantly more challenging to diagnose the disease. This is why I began to think about X-rays. X-ray equipment can be found in almost all hospitals, and so if we can use these to perform chest X-ray radiography (CXR, chest X-rays), we may be able to find an effective solution that can quickly and easily diagnose coronavirus infections.

Q. How does AI chest X-ray diagnosis differ from conventional COVID-19 diagnosis methods?

A. The most notable difference is that chest X-ray diagnostic technology uses bioimaging data. I noticed that a significant percentage of COVID-19 patients develop lung lesions. Younger generations may not be aware of this, but we used to diagnose lung patients by examining X-rays. This means that we can train artificial intelligence to identify lung lesions in COVID-19 patients to quickly provide a diagnosis. I originally thought to apply bioimaging technology to computed tomography (CT) due to its high diagnostic accuracy. However, CT scans take significantly longer to complete



Normal

Bacterial pneumonia

COVID-19

than chest X-rays, and there is the risk of the equipment being contaminated with the virus. In contrast, chest X-rays, while somewhat less accurate, are a low-cost method that can quickly diagnose infected patients. This speed is especially important when we consider the rapidly growing number of cases around the world.

> Currently, our AI chest X-ray diagnostic technology has an accuracy of 93%.

Q. How accurately can chest X-rays diagnose patients?

A. Currently, our AI chest X-ray diagnostic technology has an accuracy of 93%. Considering that some COVID-19 patients do not have any type of lung lesions, this is a fairly high level of accuracy. However, we are planning to increase the accuracy of this method by creating sub-categories of 'severity' that describe the degree of viral infection. For this purpose, we are gathering data on the locations of lung damage. For example, we can divide the lungs into left/right and top/middle/bottom to determine the severity of damage according to a system of six stages based on the location and area of inflamed sections.

> When we first began developing the AI chest X-ray technology, we intended to develop a solution for countries that lacked equipment like RT-PCR to carry out COVID-19 diagnosis.

Q. I can imagine that accuracy is the most important factor to consider. What challenges did you face when trying to improve the accuracy of the technology?

A. In the beginning, the accuracy of the technology was not as high as it is currently. We used the CNN (convolution neural network) technique to train the AI. However, some patients were being diagnosed as infected even when they were not, and the AI tended to give biased diagnoses when analyzing chest X-ray images that were not used for training.

To solve this problem, we decided that we needed to dive deeper into AI learning technologies. This is when we learned about the 'transformer' model, which is mainly used for natural language processing in AI chatbot services. A chatbot is a computer program that communicates through text or voice. Now, it may seem surprising that we used natural language processing technology, but there are many similarities between natural language processing and the diagnostic methods of radiologist. For example, when a doctor makes a judgement on whether a patient is infected with the coronavirus based on inflammation in the bottom part of both lungs, they are essentially treating the characteristics of each area of the lung as words and identifying the relationships between these characteristics. The introduction of chatbot technology actually helped us reach an accuracy of 93% for COVID-19 diagnosis through chest X-rays.

Q. It must be important to collaborate with hospitals.

A. During the initial months of the pandemic, there were very few chest X-ray images of infected patients as there were few patients to begin with. Given that a large pool of data is a prerequisite for such research, we were facing an uphill battle from the start.

We employed three main approaches to solve this problem. First of all, we began to collect data by signing research collaboration agreements with the Asan Medical Center, Chungnam National University Hospital, Kyungpook National University Hospital, and Yeungnam University Medical Center. Through these agreements, we were able to collect chest X-ray data of COVID-19 patients by age group and infection progress.

We then investigated the different types of X-ray equipment and radiographic patient positions used at various hospitals. We employed a generalization method for AI training to collect chest X-ray data while excluding environmental factors. You could say that this was somewhat like a 'statistical' process of 'averaging.' This required us to use preprocessing techniques, which we developed

> Professor Ye integrated AI and natural language processing technologies into chest X-ray imaging to provide a faster means of diagnosing COVID-19. What we can learn from his accomplishment is that unexpected collaborations can often lead to new possibilities.

ourselves.

Lastly, we needed to be able to distinguish COVID-19 patients from other patients. Therefore, in addition to chest X-ray data of patients infected with the SARS-CoV-2 virus, we added chest X-ray data of patients with pneumonia or other lung disorders to the AI training process. With several decades' worth of data, the AI was able to identify characteristics of COVID-19 that appeared in each section of the lung, which greatly increased the diagnostic accuracy.

Q. What are your plans moving forward?

A. When we first began developing the AI chest X-ray technology, we intended to develop a solution for countries that lacked equipment like RT-PCR to carry out COVID-19 diagnosis. For example, countries like Indonesia and India still have lacking medical infrastructure. However, as most countries do possess X-ray equipment, we thought that the best approach was to use equipment that was available.

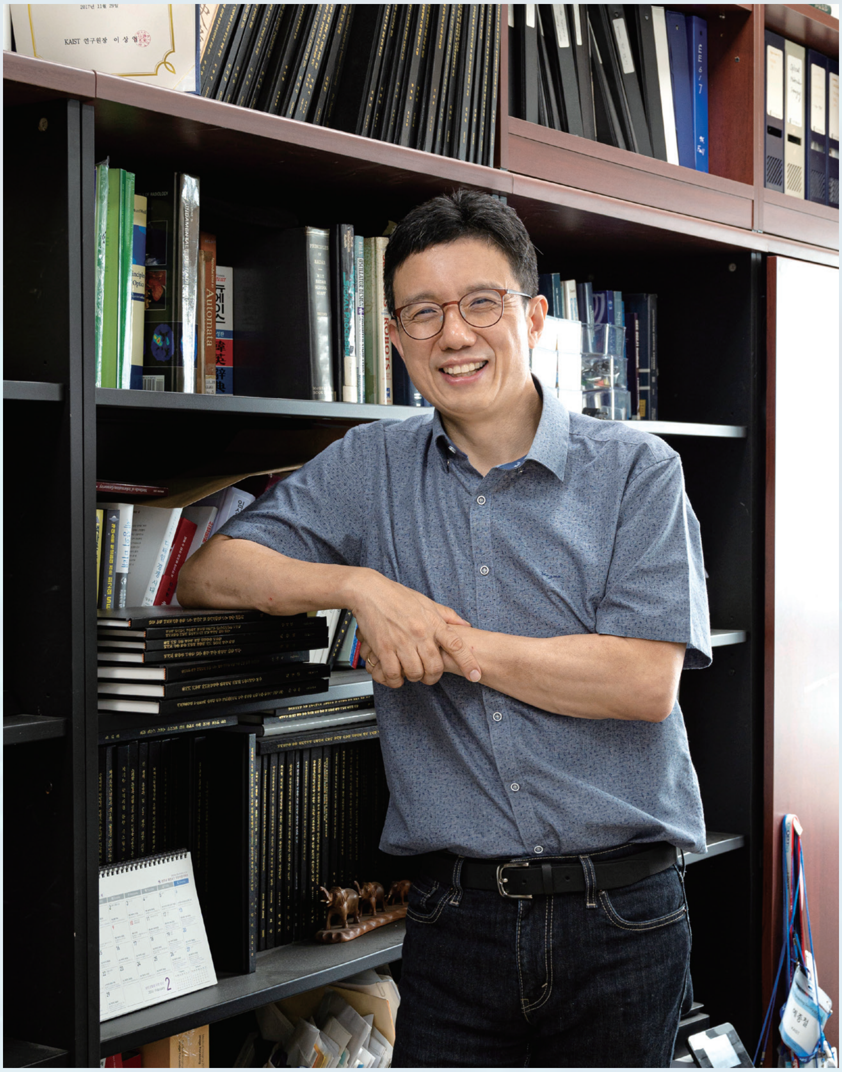
Moreover, this technology can be used to diagnose tuberculosis patients. Deaths due to tuberculosis are still prominent in countries like Indonesia. Our AI chest X-ray technology can quickly diagnose tuberculosis patients with a single X-ray image. We hope that our technology can help prevent the disease from worsening or spreading even in remote locations without access to doctors.

With further developments, I believe chest X-ray diagnostic techniques could be applied to the diagnosis of various lung-related diseases. AI based on natural language processing technology can learn the characteristics of each section of the lung and identify links to diseases. By analyzing these links, the characteristics of each disease can be determined. I believe that we can eventually develop technology capable of identifying multiple lung diseases.

A 'blue chip' in healthcare: artificial intelligence

AI technology has been a major breakthrough in the electronics and services industries, as evident by the rapid development of self-driving cars and even AlphaGo. Now, Professor Jong Chul Ye has expanded AI technology to the field of healthcare. He is seeking to commercialize the COVID-19 diagnosis method (which is currently undergoing clinical trials at Asan Medical Center) through a startup company called 'Prometheus.' Furthermore, the professor is working with Seoul National University and DRTech to develop a next-generation X-ray system capable of AI imaging diagnosis.

Professor Ye envisions that, in the future, we will be



able to extract necessary information for diagnosis from a patient's biometric data and create AI treatment devices. Furthermore, he predicts that humanity will realize technologies capable of processing and extracting vast amounts of genomic information as well as technology for bone age diagnosis. His predictions go as far as to say that it will not be long until AI technology is able to diagnose mental diseases based on the symptoms of patients.

Limitless potential is within our grasp only if we widen our perspective. Professor Ye integrated AI and natural language processing technologies into chest X-ray imaging to provide a faster means of diagnosing COVID-19. What we can learn from his accomplishment is that unexpected collaborations can often lead to new possibilities.

The Value of Collaboration -
A Story of Three Researchers in the Nanophotonics Field

Emeritus Professor **Yong Hee Lee,** Physics
Professor **Min-Kyo Seo,** Physics
Professor **Hansuek Lee,** Physics

Since 2018, KAIST has operated several 'Cross-generation Collaborative Labs' to promote research innovations that carry on from one generation to the next. These labs are designed to ensure the academic legacies and know-how of older and more experienced professors are maintained and further developed by being passed on to younger and upcoming faculty members.

Teaming up to advance nanophotonics education and research

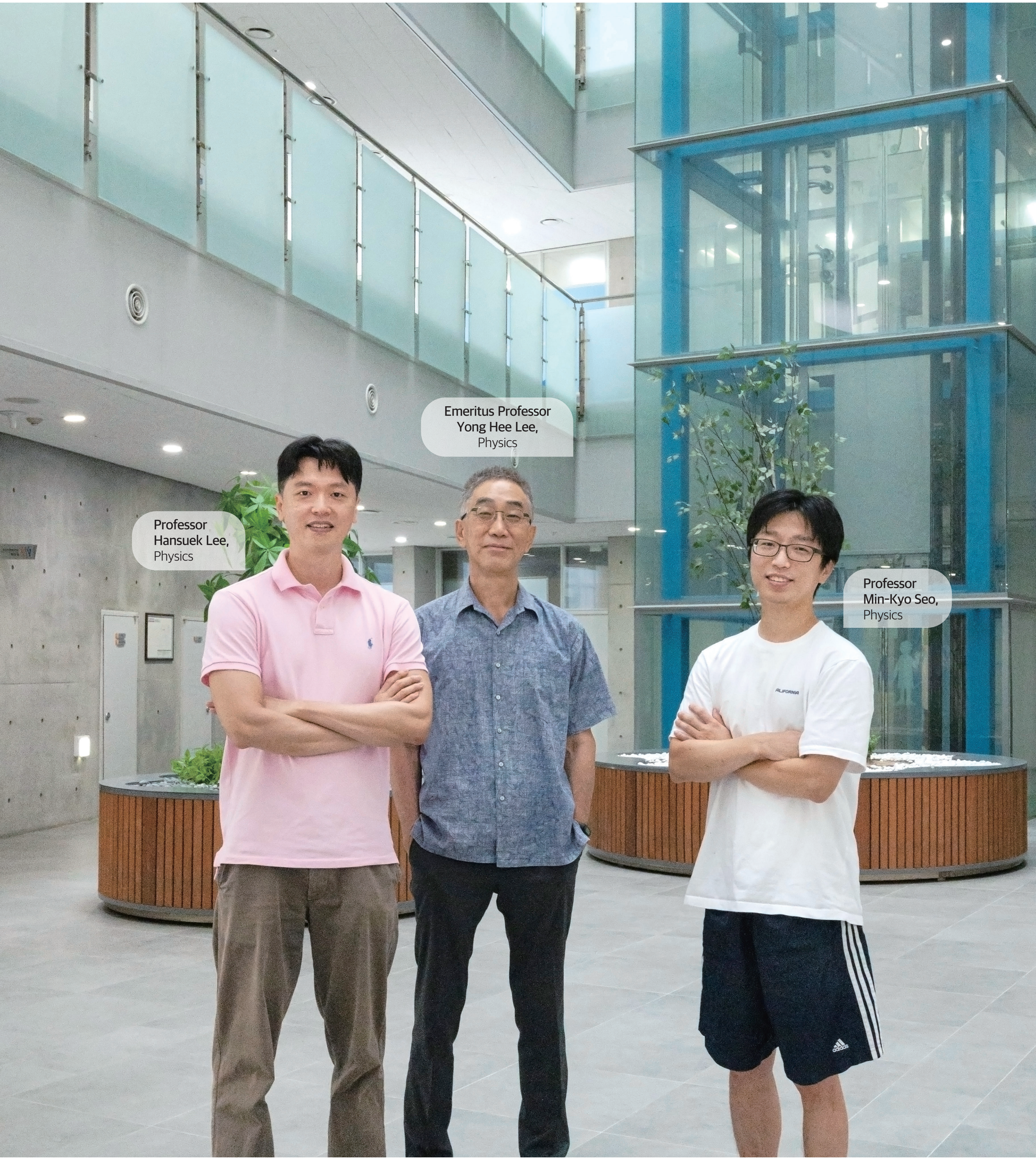
The 'Nanophotonics Cross-generation Collaborative Lab' is led by Emeritus Professor Yong Hee Lee, who is an authority in the field of photonic crystal lasers. He is joined by two younger faculty members: Professors Hansuek Lee and Min-Kyo Seo.

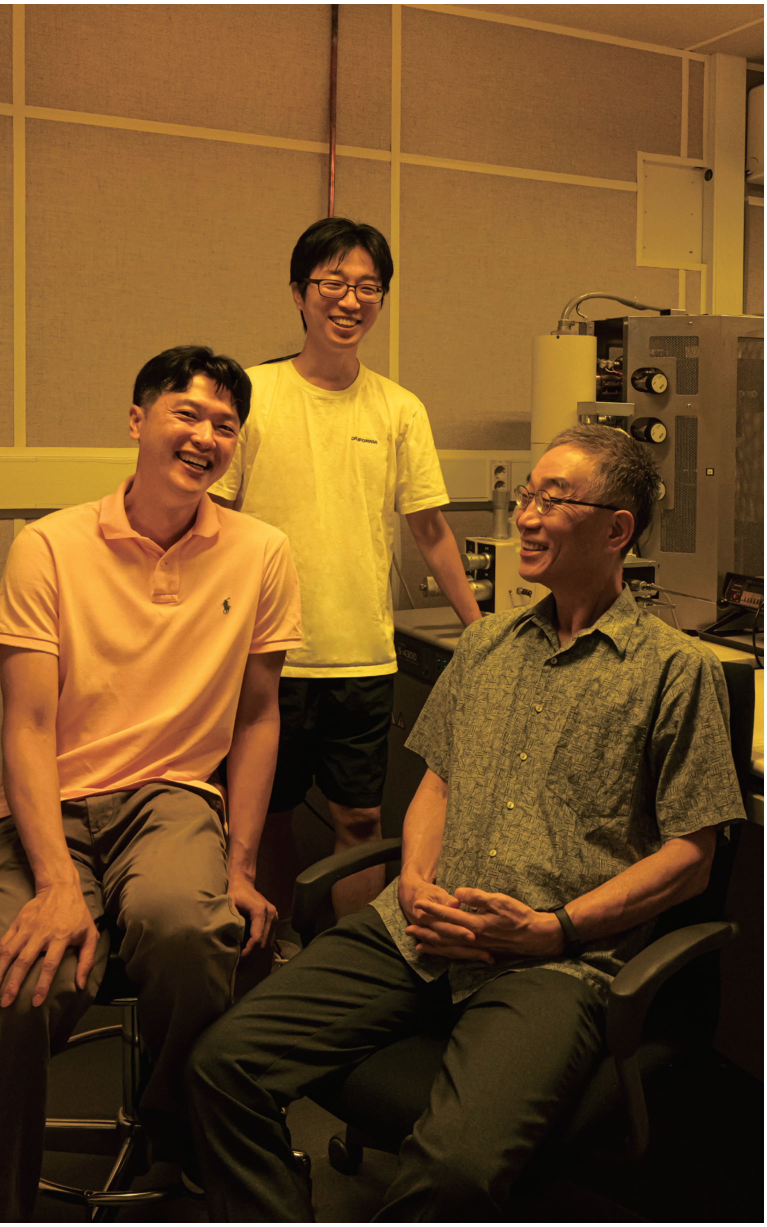
Although all three professors fall under the common banner of physics, the research fields of each professor slightly differ from one another. The nanophotonics research of Emeritus Professor Yong Hee Lee serves as the foundation on which the lab is built, and Professors Min-Kyo Seo and Hansuek Lee are taking this field further with their research on light-matter interactions and optical phenomena in optical resonators, respectively.

By working together, the three professors were able increase their research efficiency by establishing a co-operative relationship with both horizontal and vertical elements. The head professor first set out a vision and long-term research direction, and the younger professors then proposed their ideas to add 'value' to the head professor's accomplishments. The Nanophotonics Cross-generation Collaborative Lab has set their sights on 'developing future nonlinear opto-electronic devices and quantum optical devices' by combining the unique traits and specialties of each faculty member. Using optical micro- and nano-resonators, the professors are conducting research to trap light in extremely small spaces to observe how it interacts with matter. Their research topics range from developing new methods of effectively controlling light to exploring theories and limitations of light-matter interactions. The technologies being developed are expected to become key platforms in a wide variety of fields, ranging from quantum information to biophysics.

What is nanophotonics?

Nanophotonics is a new field that combines nanotechnology with optical science. As a core technology of optical integrated circuits (which exchange signals with light instead of electric signal), nanophotonics technology is expected to be applied to quantum communication and information processing technologies, where the core technologies are strongly correlated with the ability to confine light in small spaces for as long as possible. As the intensity of light increases the longer it is


Emeritus Professor Yong Hee Lee, Physics
Professor Hansuek Lee, Physics
Professor Min-Kyo Seo, Physics



contained, this can lead to stronger interactions with matter. Furthermore, nanophotonics can be used to realize and increase nonlinear and quantum optical phenomena.

On the other hand, a resonator is a device that stores energy or waves. An optical resonator holds light similar to how a tuning fork holds sound. Again, the important factor is how well and how long light is trapped. Numerically, this can be represented with volume (V) and quality factor (Q, a dimensionless parameter indicating the degree of damping of a vibrator or resonator) through the value of Q/V. A greater Q/V value indicates that the resonator is able to contain light more effectively, leading to strong interactions with matter. Hence, the lab is aiming to increase the Q/V value through their research.

Putting together pieces of a puzzle to create a bigger picture

Professor Yong-Hee Lee's career has been dedicated to the development of resonators as small as the wavelength of light by focusing on confining photons in the smallest possible space. His accomplishments include an ultra-compact optical resonator with a regular arrangement of photonic structures made of a dielectric material in a period of abount half the wavelength of light, which is called photonic crystals .

Photonic crystals confine light of a specific frequency band (referred to as a photonic band gap) inside them. A photonic band can be viewed as an energy band that represents all states in which light can exist within a certain structure. Another way to look at energy bands is as a solution of states in which particles or waves can exist within a specific structure when it is formed. A photonic band gap is an interval in which such a solution does not exist. In other words, when a certain space is surrounded by a photonic crystal, light of a frequency corresponding to the optical band gap is trapped without being able to escape.

Professor Min-Kyo Seo's research utilizes various optical resonators to study interactions between light and matter. Furthermore, he is working to apply his findings to quantum optical devices. His research

> Nanophotonics is a new field that combines nanotechnology with optical science.

involves a vast array of resonators, from optical resonators made with nonlinear mediums, plasmonic resonators based on metal nanostructures instead of dielectrics, and meta-material-based resonators. In contrast to photonic crystal mediums, which are arranged with a period of about half the wavelength of light, meta-material mediums are arranged with a significantly smaller period of about a 1/10 of the wavelength of light. With meta-materials, it is possible to achieve optical properties that are difficult to realize with only a single natural medium due to increasing complexity light propagation and refraction.

On the other hand, Professor Hansuek Lee conducts research on a resonator known as an 'ultra-high-Q resonator.' Generally, the quality factor (Q) of an optical resonator increases with its volume (V). In contrast to the previous two professors, who aim to decrease V, Professor Hansuek Lee is focused on increasing Q. This involves increasing the time that light is contained by smoothing the surface of the device (to minimize scattering) as well as preventing light from being absorbed by materials (by removing impurities).

Through this process, Professor Hansuek Lee was able to create a resonator with a Q/V value similar to resonators developed through the minimizing V approach.

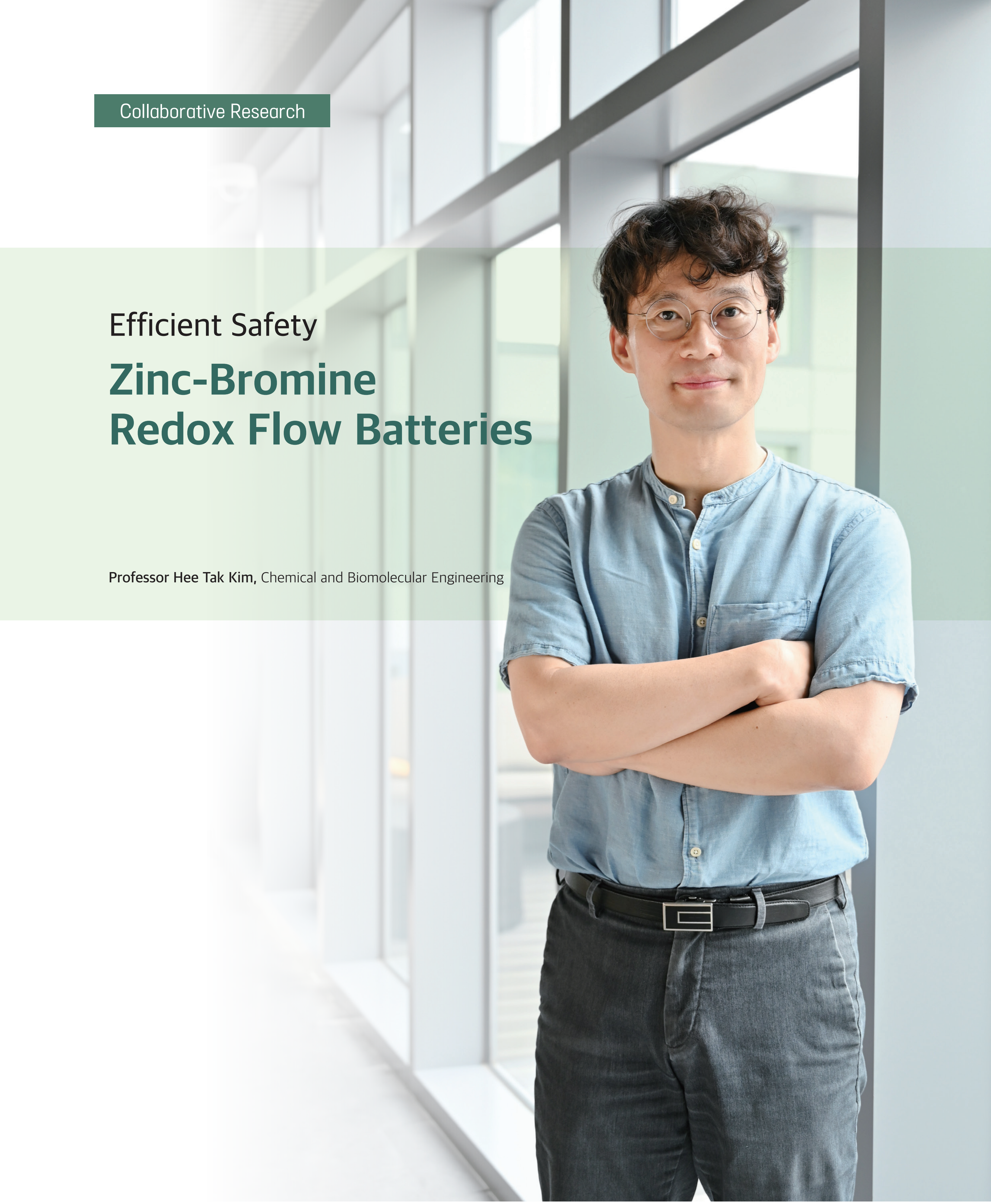
Empirically, the limit of Q/V is approximately $10^6 X(\frac{\lambda}{n})^3$ (lambda is the wavelength of the light and n is the refractive index of the material). However, this is an experimental/empirical limit that is not based on theoretical limitation. Therefore, research efforts are ongoing with the goal of overcoming this limit.

KAIST to become a hub of optical research

The first steps of the Nanophotonics Cross-generation Collaborative Lab involved the sharing of ideas. Instead of slowing down, the lab is building up momentum by supporting education for undergraduate and graduate students and by collaborating with overseas researchers. Although the COVID-19 pandemic has made it difficult to meet in person with students and researchers, the professors are using online seminars and workshops as a new means of communication.

While the subject of 'light' connects the three scientists of the Nanophotonics Cross-generation Collaborative Lab, all three believe that the field of optics will expand outward to become a core part of numerous disciplines beyond just physics. The lab created a website (https://www.qntc.kaist.ac.kr/) to make it easier for young scientists and researchers from various fields to explore the lab's research. Additionally, the website hosts seminars and events to share ideas and engage with other researchers, and users can use the online reservation system to gain access to experimental equipment. The three professors may be exploring how they can contain light, but it is clear that they have an 'open mindset' to share their academic knowledge to the rest of the world.

1) **Nonlinear opto-electronic device** _ A nonlinear phenomenon occurs when a strong light, (e.g., high-power lasers or light focused by a resonator) causes nonlinear polarization in a medium, which causes light to undergo a more than twofold increase in wavelength or a change in phase. A nonlinear opto-electronic device is an ultra-compact optical device that uses this phenomenon to effectively generate and control light. Presently, this technology has been partially commercialized in the field of optical communication transmission lines. Optical logic switches and optical memory have various applications in the communications field for optical modulation devices used to convert or amplify wavelengths. In addition to coherent communication technology capable of sending large amounts of data at high speeds, this technology could allow us to realize the highly sought-after technology of optical computers.



Collaborative Research

Efficient Safety

Zinc-Bromine Redox Flow Batteries

Professor Hee Tak Kim, Chemical and Biomolecular Engineering

What comes to mind when you think about clean and unlimited energy sources? Most people would jump to renewable energy, such as solar and wind. However, these energy sources only work during daylight hours or with sufficient wind; without these conditions being met, these sources cannot provide us with energy. In other words, efficient energy production can only be truly realized with the development of energy storage systems capable of storing energy for later use.

ESS, a catalyst for the renewable energy industry

Renewable energy is characterized by the fact that the generated energy must be used immediately; otherwise, it ends up being lost. To ensure continuous energy access even during the night or during days without wind, it is crucial to develop means of storing generated energy for use during these periods.

The solution to this problem is energy storage systems (ESS). In addition to the storage and timely supply of energy, ESS technology is used for applications related to energy output, frequency adjustments, output stabilization, peak power reduction, and surplus power sales. Given the diverse applications of ESS technology, its demand has skyrocketed with the continuous growth of the renewable energy industry.

Many countries around the world view ESS as an emerging industry, especially with the introduction of carbon point systems. The Korean government has been actively enacting new support policies since 2017 to foster the rapid growth of the domestic ESS market. This resulted in Korean companies accounting for a third of the global ESS market.

However, this process has had its fair share of growing pains. Since August 2017, there have been multiple accidents involving ESSs based on lithium-ion batteries catching fire. Due to the growing safety concerns, many have called for additional measures to strengthen safety. To make matters worse, while the global ESS market continuously grew from 11.6GWh in 2018 to 16GWh, Korea's market backtracked from 5.6GWh to 3.7GWh.

The high cost of ESS technology is also a major issue. The commercial feasibility of ESS technology is rather low at $700 per kWh. With the prospects of Korea's energy industry looking uncertain due to the growing safety concerns of large-capacity batteries and the high cost of ESS technology, Professor Hee Tak Kim decided to focus his research on finding a solution for this topic.

The increased stability of redox flow batteries containing 'water'

Lithium-ion batteries have a higher energy density and faster charge/discharge speed compared to secondary cells (general rechargeable batteries) and are thus more commonly found in everyday applications, including electric cars and electronic devices. However, lithium-ion batteries are inherently flammable as they use flammable organic compound-based electrolytes.

Conversely, redox flow batteries use aqueous electrolytes. As the electrolyte is mainly composed of water, redox flow batteries have a significantly lower risk of fire compared to organic electrolytes, resulting in higher stability. Furthermore, as the active material [2] of a redox flow battery[1] is dissolved in a liquid with low flammability, energy can be stored in a stable manner.

Zinc-Bromine redox flow batteries, a cost-effective and safe solution

Currently available redox flow batteries include vanadium redox flow batteries (VRFB), lithium-ion batteries (LIB), sodium sulfide (NaS) batteries, lead acid batteries, and zinc-bromine redox flow batteries.

So why did Professor Kim choose zinc-bromine redox batteries from the wide range of redox battery types? He explains that his choice is based on 'chemical cost,' which refers to the cost of an active material required to store 1kWh of energy. Zinc and bromine have the lowest chemical costs among all battery active materials behind only sodium and sulfur. Compared to lithium-ion batteries, which cost \$50~100, zinc and bromine as raw materials cost less than \$10. Furthermore, the excellent stability of the electrolyte enables a wide range of operating temperatures. Moreover, the electrolyte is able to contain high concentrations of zinc and bromine, resulting in a high energy generation density that enables systems to be designed with less volume.

Conventional redox batteries require an external electrolyte storage tank and a pumping system that circulates the electrolyte throughout the battery system. Such additional components not only increase the cost but also the complexity of the overall operation process. Professor Kim was able to eliminate the need for a storage tank and a pumping system by researching means of placing the active material inside the battery. This resulted in a less expensive battery with greater efficiency due to the improved energy density.

Finding solutions to technical limitations by looking at the bigger picture

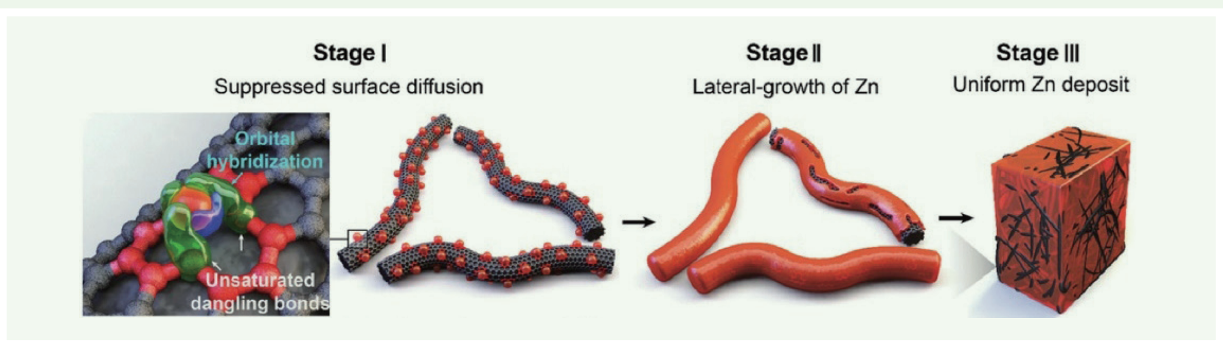
What kind of challenges did Professor Kim encounter while conducting his research? Professor Kim describes three obstacles he has to overcome. The first issue involves self-discharging due to a phenomenon known as crossover, where the active material that is dissolved in the electrolyte moves toward the opposite pole. The second problem involves whether the technology can ensure the reversibility of electrostripping (which occurs due to reverse reactions) and electroplating (through which zinc ions are precipitated as zinc metal), which take place during the repeated process of charging and discharging. The final matter is finding a means of stopping the oxygen and hydrogen gas evolution due to water electrolysis.

In order to solve these issues, Professor Kim plans to find solutions by considering the battery structure design in addition to the material. For example, if it proves difficult to fundamentally prevent gas generation, then the battery structure could be modified to remove the gas from the battery and automatically refill the electrolyte. Additionally, the professor is continuously investigating various means of improving the electrode and membrane capabilities.

Diversifying the battery industry to respond to contemporary needs

The zinc-bromine battery being developed by Professor Kim has a lower energy density than lithium-ion batteries. This means that the technology is less competitive in industries that require high energy density, such as the electronics and electric car industries. Instead, the zinc-bromine battery may be more suitable for applications with a greater focus on stability and price without strict volume or weight requirements. According to Professor Kim, the battery industry needs to diversify itself according to various use environments and requirements.

However, Professor Kim believes that the battery industry as a whole will move towards products with



simple structures, long lifespans, and greater efficiency. Therefore, he plans to increase the performance of his battery technology from the prototype level of 100W to 1kW. Furthermore, the professor plans to develop batteries according to needs of various future industries: lithium metal electrode batteries with high energy density per volume for electric vehicles and electronics, lithium sulfur batteries with high energy density per weight for unmanned aerial vehicles, and aqueous batteries for ESSs (which prioritize safety).

Upgrading technology through joint research

Professor Kim emphasizes that his accomplishments are a result of working together with others. Specifically, this research was part of a joint project involving KAIST, GIST, UNIST, and DGIST. When asked about how he felt about taking part in the joint research, Professor Kim states, “the other professors and I had a lot in common, which may be because we all work at science and technology institutes.”

Even though the professors had to communicate through online channels, they held several online meetings to discuss and solve problems together, inspiring and motivating each other. Professor Kim added that the research group is exploring ways to reduce trial-and-error when implementing the developed technology, as there are only a few researchers with experience in designing and manufacturing large-capacity batteries.

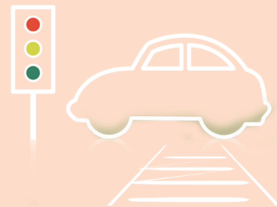
Additionally, Professor Kim hopes that the students participating in the joint project between the science and technology institutes can learn and understand the importance of collaborative research by engaging with their peers, sharing experiences, and broadening the perspectives. Lastly, Professor Kim concluded the interview by expressing his wish to meet other researchers in person to learn about new technologies together once the COVID-19 pandemic comes to an end.

1) **Redox Flow Battery_** a combination of ‘reduction,’ ‘oxidation,’ and ‘flow.’ Through redox reactions at the electrodes, electrical energy is stored in the electrolyte for an extended period of time. The ‘flow’ part refers to a system that pumps the electrolyte into stacks where electrochemical reactions take place (the overall output of the system is dependent on the size and number of stacks).

2) **Active material_** a material that participates in reactions inside a capacitor. Active materials convert electrical energy into chemical energy for storage and reverses the process to release electrical energy.

Venture Research Program for Graduate Students 1

Artificial Intelligence Traffic Police: A Self-thinking Traffic Control System



According to statistics released by the Korea Expressway Corporation, two-thirds of all traffic accident deaths in Korea that took place over a 5-year period from 2015 were caused by drowsy driving or negligence by the driver to maintain vision of the road ahead. Various methods and policies are being discussed and reviewed to reduce the number of fatal road accidents, including the amendment of laws to prevent secondary traffic accidents as well as measures to strengthen road monitoring. While institutional efforts are in full swing to solve this problem, we must also explore the various technological measures available to us that could contribute to a better solution.

Traffic congestion: a major problem in modern cities that needs to be resolved

According to the Korea Transport Institute, the social cost of traffic congestion has steadily increased since 1994 (the year the survey was first commenced). This value had reached up to 59.6 trillion KRW by 2017, which is equivalent to approximately 3.4% of Korea's national GDP. To make matters worse, the United Nations predicts that the number of megacities in the world with over 10 million inhabitants will increase from 33 in 2018 to 43 by 2030, which is also expected to worsen traffic congestion worldwide.

Various solutions to traffic congestion have been proposed, including the construction of additional roads and the implementation of toll systems. To find a solution through a different approach to existing methods, Dr. Jinwon Yoon and Ph.D. candidate Hwapyeong Yu from the Department of Civil and Environmental Engineering teamed up with Ph.D. candidate Kyuree Ahn from the Department of Industrial and Systems Engineering to develop a cost-effective technique by 'optimizing traffic signal control.' Through their research, the team proposed a 'smart traffic signal' system that integrates artificial intelligence.

A smart AI traffic police

The traffic signal control method currently used worldwide is the adaptive traffic signal control (ATSC) method, which was developed during the 1990s. Here, traffic-related statistical data are gathered by detectors and sensors embedded in the road. Although this method does provide a reliable means of traffic signal control, it has the disadvantage of being less effective upon encountering changes to traffic patterns or when the volume of traffic suddenly increases.

For this reason, many cities around the world are gathering big data on traffic. Cameras are installed at intersections to collect traffic image data, which are then analyzed through deep learning[1] to produce high-quality traffic big data. However, several challenges remain when it comes to developing signal control models.

Big data meets deep learning

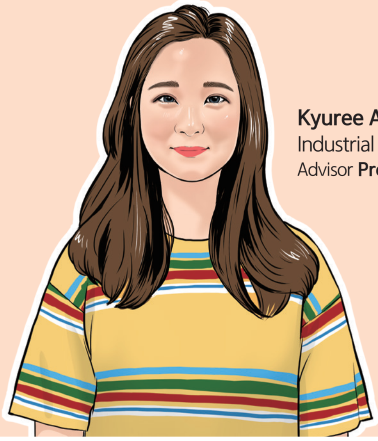
To tackle this problem, the research team proposed the development of a multi-intersection signal control device based on a single trained model capable of responding to various traffic conditions (e.g., day and night, weekdays and weekends, etc.). They got their idea after witnessing traffic police officers manually control traffic signals on site. Essentially, traffic police officers alter the system to give a green light to maximize the number of passing vehicles during each signal cycle for each intersection. As each intersection is connected to its neighboring intersections, this allows for the sharing of data regarding the number of vehicles currently passing a signal. Furthermore, strategies are shared between intersections through this interconnected network.

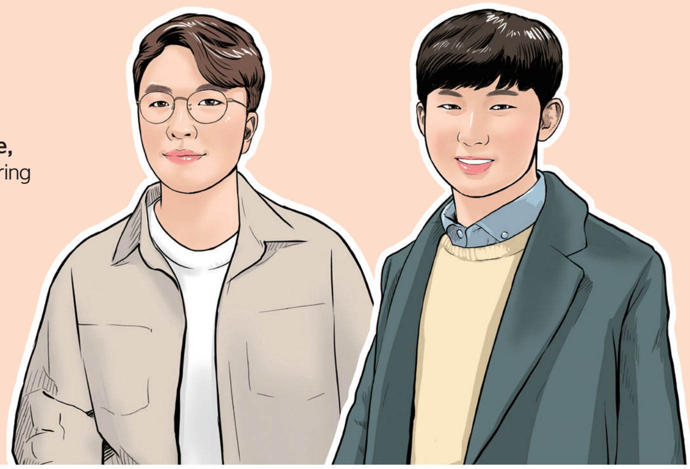
First, the research team set the variables for reinforcement learning as data obtained in actual traffic intersections (via cameras, loop detectors, etc.). The number of vehicles waiting ahead of each traffic signal, the average speed, and the number of inflowing/outflowing vehicles were used to describe

Hwapyeong Yu, Ph.D. Candidate,
Civil and Environmental Engineering
Advisor **Professor Hwasoo Yeo**

Dr. Jinwon Yoon,
Civil and Environmental Engineering
Advisor **Professor Hwasoo Yeo**

Kyuree Ahn, Ph.D. Candidate,
Industrial and Systems Engineering
Advisor **Professor Jinkyoo Park**





the traffic conditions. Furthermore, the number of passing vehicles during a single signal cycle was used as a reward variable for reinforcement learning. The green time at each intersection was set as a control variable to train the policy of ensuring each road is designated an appropriate green time.

To solve interconnection issues between multiple interactions, the traffic network was expressed as a graph consisting of nodes and edges in consideration of the relationship between traffic condition properties and signal control. This was followed by data processing with a message passing graph neural network (MPGNN). Using the processed data, an appropriate green time was designated for each interaction. Finally, by sharing data between all signals, the model learned the interconnecting policy of finding a mutually cooperative signaling solution, which resembles how actual traffic police relay information to one another.

How effective is the proposed signal control system? The research team conducted an evaluation to determine how quickly and effectively the proposed algorithm is able to resolve vehicle congestion, and the results were overall positive. The algorithm was even able to resolve unexpected stagnations in the patterns.

All in all, the team successfully developed a multi-intersection cooperative signal system by utilizing MPGNN. The developed model, which uses graphical representations to express traffic conditions in the network in a more generalized space, is a highly applicable model that is capable of responding to traffic conditions with which the model has no prior experience.

The secret to success in joint research: abundant communication

The joint research project involved two research teams that were versed in different disciplines and terminology. Therefore, the entire process began by developing a deeper understanding between the researchers. None of their success would have been realized had it not been for the abundant communication and conversation between the members to share their ideas and experiences. Following graduation, Dr. Jinwon Yoon has entered the industry to realize the AI traffic signal control system developed through this research project. The remaining members of the team are continuing their academic research to create a more stable and extensive system. Overall, while this research project provided an opportunity to develop a model applicable to traffic signals, the knowledge gained through the process has the potential to be applied to a broad range of fields and applications.

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1) **Deep learning** _ a machine learning technique that allows computers to distinguish objects by mimicking the means through which the human brain processes information to identify patterns in large amounts of data. With deep learning, a computer can recognize, reason, and make judgements even without the input of all criteria for distinguishing objects. This technique is widely used for voice, image, and photographic analysis.

Venture Research Program for Graduate Students ❷

Can Machine Learning be Applied to Quantum Mechanics Theory?

Quantum mechanics and machine learning··· At first glance, this may seem like an odd pairing, which is not surprising considering that quantum mechanics is generally viewed as 'a fundamental theory of modern physics that explains the microscopic material world of atoms and molecules,' while machine learning is a branch of the artificial intelligence field.
However, 'eureka!' moments are sometimes found in the most unexpected of places. Ph.D. candidates Ryong-Gyu Lee and Minjong Noh from the School of Electrical Engineering teamed up with Ph.D. candidates Taejin Kwon and Seoyoung Lee from the Department of Nuclear and Quantum Engineering to form an unconventional research team to explore new, untested ideas. Their goal: 'to apply machine learning algorithms for quantum mechanical first-principles calculations.'

Taking machine learning into the microscopic realm

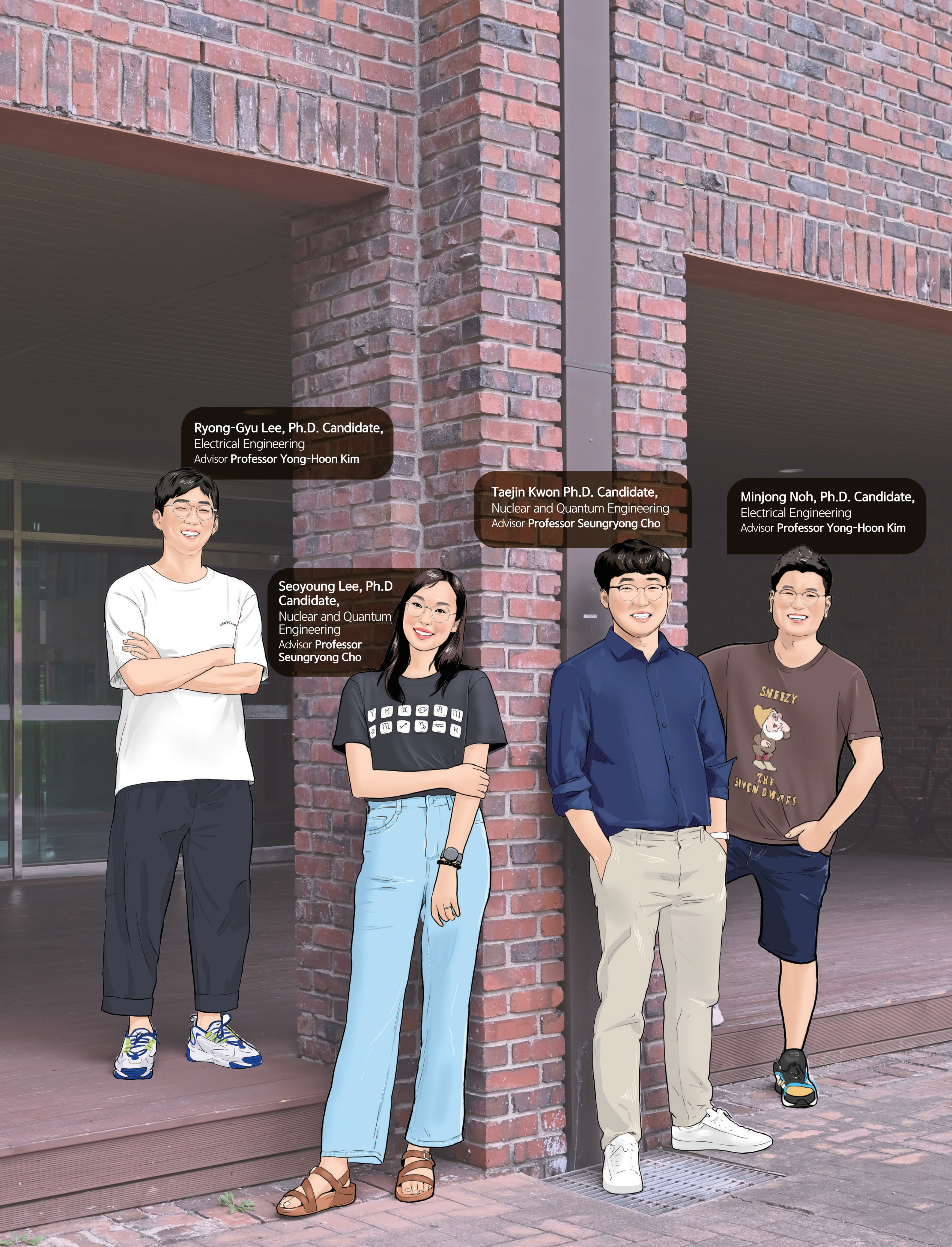
Professor Yong-Hoon Kim's research team studies 'optical and energy nano-devices,' whereas Profess Seungryong Cho's research team studies medical and industrial imaging. As Professor Cho's team investigates various forms of imaging, they also conduct research using machine learning (techniques that allow computers to learn like humans and derive new knowledge by learning given data).

The efficacy of machine learning is largely dependent on the quantity of available data. Currently, the National Supercomputing Center (under KISTI) is using the density functional theory for first-principles calculations. If machine learning could be implemented to predict the initial conditions of calculations and reduce the loops of the self-consistent method, this would effectively decrease the computation power and economic resource requirements of such calculations. Looking further, this type of breakthrough could be expected to greatly contribute to national competitiveness.

Quantum materials simulations, first-principles calculation methods

Let us first learn about first-principles calculation methods. These methods are used to determine the physical and chemical properties of matter using only basic information regarding the laws of physics, constants, and particles. In simpler terms, these methods are used to determine all properties of matter - which we have never seen before - without using data obtained from visible experiments. From a theoretical standpoint, one can fully understand what happens in the microscopic realm if they know the number and locations of all protons, neutrons, and electrons. Of course, this involves using the Schrödinger equation.

In reality, there are countless electrons and atoms that interact with one another, and changes in potential energy also need to be considered. In other words, it is basically impossible to reach a mathematical solution considering all these components and factors. For this reason, calculations are carried out by restricting certain motions or by assuming


Ryong-Gyu Lee, Ph.D. Candidate,
Electrical Engineering
Advisor Professor Yong-Hoon Kim
Seoyoung Lee, Ph.D Candidate,
Nuclear and Quantum Engineering
Advisor Professor Seungryong Cho
Taejin Kwon Ph.D. Candidate,
Nuclear and Quantum Engineering
Advisor Professor Seungryong Cho
Minjong Noh, Ph.D. Candidate,
Electrical Engineering
Advisor Professor Yong-Hoon Kim

> Machine learning allowed us to explore unchartered theories that have not yet been studied in the first-principles calculation field.
> Conversely, the first-principles calculation methods can endlessly generate physically meaningful and unbiased training data that are based on established theories.
> The journey began as a risky adventure, but the transdisciplinary research involving the two different fields ultimately led to major leaps in research.

that some particles remain stationary.

Notable first-principles calculation methods include the density functional theory and the Hartree-Fock (HF) theory. Among these methods, the density functional theory calculates the ground state total energy, electronic band structure, and the electron energy level of an atom. Furthermore, this data can be used to calculate various secondary physical quantities. For example, as force can be calculated from the total energy of an atom according to its position, molecular dynamics simulations are possible. Therefore, first-principles calculations enable a wide variety of predictions and simulations. The fact that all results are obtained directly from first principles without parameters has led to a paradigm shift in physical property research, enabling more detailed interpretations and a better understanding of experiments while also greatly affecting predictions and designs.

Saving time and effort through machine learning

Today, the significant impacts of AI and machine learning can be felt in not just science and technology, but society as a whole. Instead of having to directly test every possible case, data are obtained through the process of 'abstraction,' which closely resembles the learning process of humans.

The research team chose the density functional theory in an attempt to reduce burdensome calculations. In density functional theory calculations, the initial condition consists of a density matrix, which assumes that all atoms constituting matter exist independently without affecting each other. However, in reality, electronic transitions can take place between atoms due to electronegativity differences. If we could use machine learning to calculate the initial conditions as accurate to reality as possible, we could reduce the number of iterative calculations that are needed.

There have been several past attempts that implemented machine learning. Most cases involved informatics approaches where the focus was the discovery of new material compositions, structures, and properties based on physical and chemical property data. However, as these endeavors depended on databases, they had the fatal flaw of resulting in underestimated property predictions for elemental combinations or structures not included in the databases. In the study carried out by the research team, machine learning was applied for first-principles calculation methods and quantum mechanics calculations.

Efforts to apply machine learning to DFT

As previously mentioned, the implementation of machine learning requires a significant amount of data. Moreover, variables can be effectively extracted using a calculation formula with a standardized form. Therefore, the research team created a calculation platform called 'NanoCore,' which can utlize various types of atomic structures and apply calculation formulas with identical conditions to each structure.

Additionally, the data required for machine learning was saved as standardized formats (e.g., JSON files) to implement a program for database management.

The research team encountered another challenge during the research process. Generally, past studies used the convolutional neural network (CNN) model to predict the density matrix. The team expected the density matrix training results to be successful with the training error decreasing with further optimizations. However, when the predicted density matrix was applied as the initial condition for density functional theory calculations, the calculation process did not become significantly faster.

After much discussion, the two labs concluded that the structure of the density matrix was ill-suited for machine learning to increase computation speed. Instead, they set a new training goal in electron density. Using their past research experience, Professor Cho's team devised a 'U-Net'-based machine learning model that was optimized for electron density training. As a result, the implementation of the new 'U-Net' model produced meaningful electron density training results. Furthermore, when the predicted electron density was applied as an initial condition for density functional theory calculations, the team achieved a 33% reduction in loops of iterative calculations. Moreover, the total energy calculated using the predicted electron density had a relative error of 0.026% compared to the final energy value.

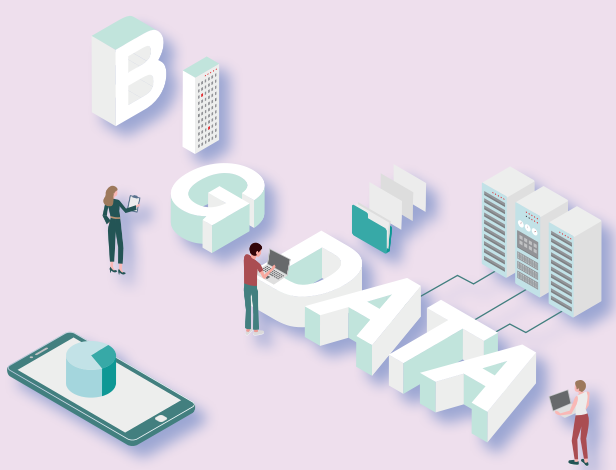
Similar yet different

Nanodevices and imaging... It cannot be argued that the two labs study vastly different fields. Professor Kim's research team ran into issues from the start when it came to understanding the new terminology: "we had little experience using such large quantities of data at once, so it was incredibly challenging to gather and process that much computational data."

Professor Cho's research team also recalls the many difficulties they encountered during this research: "there were things we struggled to comprehend with our knowledge in the field of quantum mechanics. It was no easy task trying to develop a machine learning method suitable for quantum mechanics."

Although machine learning and first-principles calculation methods share similarities in that they are methods toward optimization, the two fields have different philosophies when it comes to approaching problems. Whereas first-principles calculation methods produce results solely based on theoretical laws of physics, machine learning derives optimal models based on empirical data.

Nevertheless, the two research teams shared a belief in that their respective fields could complement each other. "Machine learning allowed us to explore unchartered theories that have not yet been studied in the first-principles calculation field. Conversely, the first-principles calculation methods can endlessly generate physically meaningful and unbiased training data that are based on established theories." The journey began as a risky adventure, but the transdisciplinary research involving the two different fields ultimately led to major leaps in research.

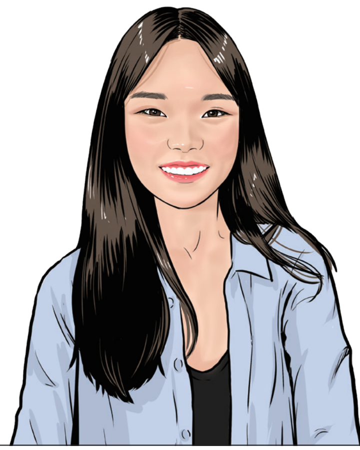


Introducing the Excellence Award Winners of the 2021 Winter/Spring Semester URP Program

The URP (Undergraduate Research Participation) Program supports undergraduate students to conduct creative and flexible research.

Developing Technologies that Benefit Everyone.

Research to predict the model performance in various environments for ubiquitous mobile sensing deployments.



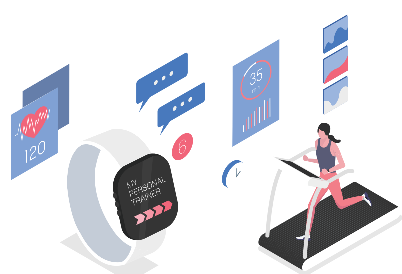
Yewon Kim, Electrical Engineering
Advisor **Professor Sung-Ju Lee,** Electrical Engineering

The modern world is more convenient than ever with recent advancements in mobile devices and AI technology. Most notably, mobile sensing technology (which uses sensors in smartphones and smartwatches) allows users to enjoy various healthcare-related services with only their mobile devices. For example, a person can check their daily activity and even take measures to prevent heart disease. However, mobile sensing technology has not yet reached the point where it can be ubiquitously deployed. This is mainly because the technology is unable to account for sensor reading variations arising from inherent differences between individual users or mobile devices. This results in sensing models performing poorly for new users. For this reason, I focused my research on predicting the effectiveness of sensing models according to the user environment. My work could enable the system to update models to maximize the performance of mobile sensing technologies in real life situations.

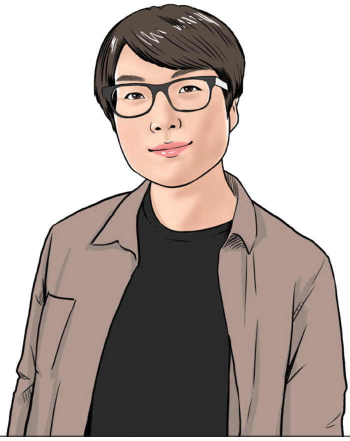
As it is my dream to become a researcher, I thought it would be necessary to develop a better understanding of what research is before entering graduate school. The URP program was the perfect opportunity for me as I was looking to gain firsthand research experience. With amazing support from my professor and TA, I was able to learn valuable lessons and try my hand in various experiments that I had always wanted to try. I analyzed the results I obtained to identify causes, then by modifying my research method accordingly, I could achieve better results when I experimented again. Through this process, I was able to become a better researcher. I was thrilled when I found out that my efforts were rewarded with the Grand Prix for the 2021 Winter/Spring Semester URP Program.

My goal as a researcher is to develop healthcare services on smart devices that work well for all users. Wearable devices like smartwatches are capable of detecting a diverse range of biosignals. Biometric data can be used to detect health issues in the early stages or provide personalized services that make life more convenient: the possibilities are endless. It is my vision to realize personalization through mobile sensing to create a society in which all users, including the elderly and those with physical disabilities, can enjoy effective mobile services.

I would like to express my appreciation for the URP program through which I was given the opportunity to experience what is like to perform research. Also, the help and support of Professor Sung-Ju Lee and TA, cannot be understated, so I thank them all for their encouragement. I believe that I have successfully taken my first step as a researcher through this program. Based on what I learned through this experience, I will continue on this path to become a researcher that can make a difference in the world. I wholeheartedly recommend the URP program to any undergraduate student with research interests.



Becoming a Great Researcher, One Step at a Time



For my URP research, I developed an algorithm for pressure gauges that measure the pressure of sections in nuclear fusion reactors that directly exchange heat with the external environment.

Hoiyun Jeong, Physics
Advisor **Professor Yong-chul Ghim,** Nuclear and Quantum Engineering

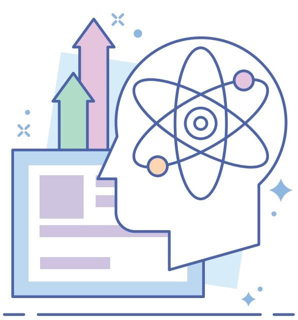
For my URP research, I developed an algorithm for pressure gauges that measure the pressure of sections in nuclear fusion reactors that directly exchange heat with the external environment. This study is highly important as the pressures of these sections are key factors that impact plasma control.

When I found out that I would be assigned with this research as part of my URP program, I thought to myself, "can an undergraduate student really handle such an important topic?" I still ask myself the same question from time to time, but nevertheless, the responsibility that came with such a topic provided me with the motivation to focus on my research.

During my research, there were several moments when I encountered challenges that I did not expect. For example, there were multiple instances where I was delayed by ordered parts not arriving in time or the necessary programs not being installed. Nevertheless, I came to understand that these experiences during my URP project are also a part of the research process. In fact, I saw them as opportunities to develop my ability of finding solutions to various hurdles (both large and small) in research.

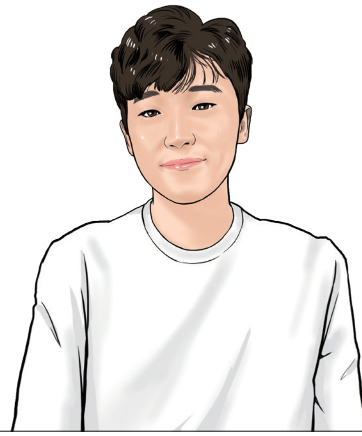
In addition to these minor issues, I constantly pondered and explored ways to be more proficient with my research. As my research involved a device that outputs a value, I relentlessly questioned whether the output value was reliable and sought ways to increase this reliability. During this process, I asked many questions to my advisor. Perhaps thanks to my fixation on this matter when processing data, I was able to achieve good research results. Furthermore, I learned to be more critical when it comes to interpreting data. I believe that all the little things I focused on amalgamated to successful research results in the URP program.

With the conclusion of the URP program, the greatest lesson I took away from my experience was the realization that I still have a long way to go to become a competent researcher. The research topic I worked on is still ongoing with many challenges to overcome. Even if this particular research is concluded, it is but the tip of the iceberg when we look at the greater picture. Nevertheless, I am taking one step at a time to grow further by using what I learned from the URP program. I will continue to endeavor onwards to achieve at the highest level and one day become a great researcher.



Contributing to the Development of Quantum Computers through My URP Research

I conducted a study to efficiently solve the maximum independent set problem for all graphs of neutral Rydberg atom arrays, a platform for quantum computing.



Jaeyong Hwang, Physics
Advisor **Professor Jaewook Ahn,** Physics

For my URP project, I conducted a study to efficiently solve the maximum independent set problem for all graphs of neutral Rydberg atom arrays, a platform for quantum computing. Due to the nature of Rydberg atoms, it is difficult to achieve quantum computing for arbitrary non-planar graphs. However, my research solved this issue using a newly developed atom array called the 'Rydberg quantum tree-wire.'

As someone who has always been interested in the development of quantum computers, I had hoped to join a lab that conducts research in the field. However, I remember not being able to find a lab that specialized in quantum computing for my Individual Study course. I also remember panicking when I joined the Quantum Computing Lab (which I joined to learn more about 'Rydberg qubit' systems) as I could not understand a word being spoken by the professor and graduate students at the first lab meeting. There is clearly a big gap between the theory one learns in class and the knowledge one can gain through experience in a lab.

With no experience and knowledge in the field, I worked and thought hard to produce some research results. After learning the jargon used in the lab (which took an entire semester), I applied for the URP program and began my research on a new research topic. I worked tirelessly on my URP research and even managed to receive high marks for my final presentation. This was all possible thanks to the deep discussions I had with the graduate students in my lab as well as the guidance of Professor Jaewook Ahn, to whom I asked countless questions regarding the subject. I am immensely grateful for all of their support. Also, I would like to thank KAIST for providing undergraduate students with the opportunity to dive into research through Individual Study courses and the URP program.

In a couple of decades, we will reach a point where computer hardware cannot keep up with the pace of software development due to the physical limitations of computers (e.g., size and heat). In order to solve computing problems that require tremendous amounts of computational power, I believe that we will need a paradigm shift with new approaches like quantum computing. Based on my URP research, I hope to develop quantum computers based on Rydberg atom systems and other physical systems in the future, contributing to a better future with advancements in science and technology.

> "In order to solve computing problems that require tremendous amounts of computational power, I believe that we will need a paradigm shift with new approaches like quantum computing."

Research Partner

From ‘**Sharing**’ to ‘**Symbiosis**’

A partner for scientists: KAIST Analysis Center for Research Advancement

Analytical Challenges Collaboration Project Team

The new concept of 'shared kitchens' is steadily gaining traction as a startup in today's society. Although the restaurant market is continuously growing by the day, recent years have seen almost 90% of all new restaurants end up closing. Given such statistics, the shared kitchen market is a new and attractive alternative that requires less initial capital to get started. The idea involves a single kitchen that is shared by multiple businesses specializing in food delivery. Here, each business is able to use the kitchen during specific time slots. Through this method, businesses can get started with a tenth of the initial capital usually required to open an independent restaurant. Participants of shared kitchens can use kitchen facilities and cooking equipment at low cost and can gain access to downtown areas that normally have expensive rent.

In what ways has the social concept of 'sharing' been implemented in the science and technology sector? Research instruments tend to be incredibly expensive, which can often discourage researchers from purchasing them, especially if they are utilized sparingly. Moreover, scientists would love to have a group of specialists analyze experimental data for them, providing a platform where researchers can share ideas. Let us find out more about this 'partner of scientists' that all researchers hope to have in their vicinity.

Q. What is KARA? Please tell us more about the history and role of the center.

A. KARA stands for the 'KAIST Analysis Center for Research Advancement.' Essentially, the center is a shared hub of state-of-the-art and expensive equipment required by researchers. The center provides researchers with opportunities to use advanced instruments, access necessary research environments, and achieve research accomplishments in an efficient manner.

Launched as the Academic Research Support Group in 1991, the name 'KARA' was adopted in 2013 with the construction of the center. KARA's main roles are acquiring key infrastructure and equipment for joint research and providing advanced research support and systematic training through our analysis experts.

Instruments used in the science and technology field are very expensive and definitely not for one-time use. This prompted us to consider the concept of 'sharing.' Another issue to consider is the difficulty of fully utilizing advanced instruments; without proper knowledge and training, the full potential of such equipment is wasted. Considering that it takes a lot of time and effort to learn these skills, it would be prudent to have specialists for each equipment. Furthermore, upon obtaining data from the instruments, researchers need the help of experts who can analyze the data. For this reason, we are organizing customized training courses through the KARA Academy, including basic and advanced courses as well as applied courses. To put things simply, we are striving to become a center that has everything a researcher needs.

Q. I am sure other institutions have also implemented the idea of 'sharing' in research. In what ways does KARA stand out from the crowd?

A. If I had to pick one notable difference, it would be our 'analysis orientation.' KARA strives to identify the needs of researchers and present solutions accordingly. When a researcher comes to our center in search of certain equipment or technology, we sometimes notice that there are more efficient methods than what the researcher has in mind. In these situations, we suggest our ideas to the researcher and devise a better strategy together.

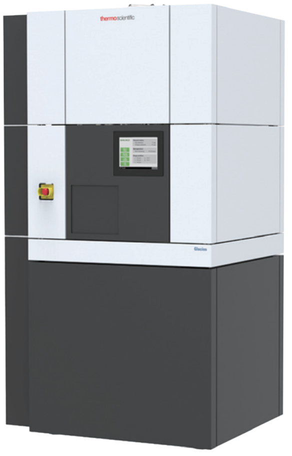
Therefore, KARA has set four core values when it comes to acquiring equipment: 'leading edge,' 'total solution,' 'open access,' and 'integrated support.' Additionally, the team in charge of analysis consists of professional specialists with broad expertise in their respective fields. We also cannot forget our world-class analysis environments, which are designed to minimize environmental factors that could potentially affect the analysis results, including (but not limited to) interference between equipment, vibrations, magnetic fields, and noise. In addition to our leading efficiency, our center is recognized for its economic feasibility, and thus we are a benchmark for many universities and research institutes around the world.

Q. Please describe some of the more notable instruments in the center.

A. KARA has two types of transmission electron microscopes: a double-Cs-corrected TEM and a cryo FE-TEM. In the case of the double-Cs-corrected TEM, it has a resolution high enough to enable researchers to directly observe atoms at the sub-nm scale. This allows for the direct observation of atom arrangements when analyzing the structures of materials, and a researcher can also use the technology to conduct qualitative and quantitative analyses of atoms. Furthermore, the double-Cs-corrected TEM can produce high-resolution images of single-atom catalysts, which is a hot topic of research. On the other hand, the cryo FE-TEM is an electron microscope that produces high-resolution images after freezing bio samples (e.g., proteins) to cryogenic temperatures. In the past, cryo FE-TEMs were used to reveal the structure of aldehyde-alcohol dehydrogenase.

Our cryo-FIB was also an exciting acquisition to our instrument portfolio. This instrument freezes cells to cryogenic temperatures and produces samples of desired sections. It has the added benefit of being able to be used in conjunction with our cryo FE-TEM. The cryo-FIB is a key pre-treatment instrument that helps researchers an-

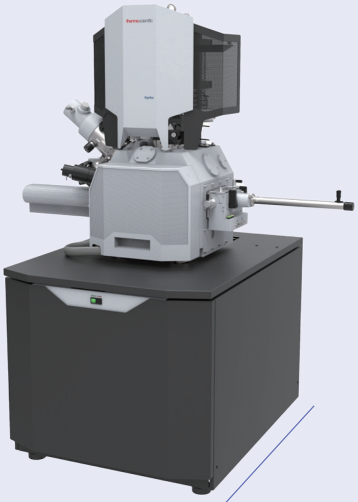
Double Cs corrected TEM



Cryo Field Emission TEM

KARA has two types of transmission electron microscopes (TEM): a double-Cs-corrected TEM and a cryo FE-TEM. The double-Cs-corrected TEM has a resolution high enough to enable researchers to directly observe atoms at the sub-nm scale, and the cryo FE-TEM produces high-resolution images and enables electron diffraction analysis by freezing bio samples to cryogenic temperatures.

KARA is open to all KAIST members, universities, research centers, and companies in pursuit of becoming an open space with an open mindset. 'Science' and 'technology' are fields that the general public views as distant except when they are using technology products that have been released to the masses. Nevertheless, you will find KARA at the center of this network of connections.



Cryo-Focused Ion Beam System (Cryo-FIB)

alyze the microstructures of organisms and materials near natural states with high resolution. It is indispensable for structural biology, drug development, and research on infectious diseases.

Q. What is the Analytical Challenges Collaboration Project?

A. You could say that it is a program that fosters collaboration to overcome hurdles in analysis. Through this program, we provide close support for research with measurement analysis struggles, and we also establish collaborative systems between labs and KARA. Additionally, we aim to share our analytical technology know-how with labs and industries to not only contribute to research in KAIST but also help advance national industrial technology research.

Through this program, which was inaugurated this year, we hope to develop analysis methods and standardize analytical technologies required in the industrial sector. With additional communication channels, we can also diversify our analytical support methods. All in all, we look forward to learning new techniques and finding ways to overcome difficult challenges in analytical research.

By acquiring more state-of-the-art analytical instruments and building up analytical know-how, KARA can become a world-class analysis center that is recognized globally for its competitiveness. The cooperative and collaborative systems that we establish to solve analytical challenges are primarily for the purpose of helping researchers, but we also expect our center's competitiveness in the analytical field to grow through these initiatives.

KARA is open to all KAIST members, universities, research centers, and companies in pursuit of becoming an open space with an open mindset. The world is becoming increasingly interconnected through the internet. However, despite being in an era where anyone can access desired information at will, many places in the world still remain unconnected to this network of information.

'Science' and 'technology' are fields that the general public views as distant except when they are using technology products that have been released to the masses. As a result, it is no surprise that the sharing of information and technology remain limited. Nevertheless, you will find KARA at the center of this network of connections.

Having dedicated our past 50 years for Korea, We will devote our next 50 years for all humanity.

With a focus on developing core DNA (Data/Network/AI) technologies that will pioneer the 4th Industrial Revolution and by producing research achievements and creating value through innovations in the biomedical field, KAIST will ensure the success of the Science and Technology New Deal Project and contribute to national economic growth in the post-COVID-19 era for it is our ultimate goal to bring joy and prosperity to all humanity.

50TH INNOVERSARY
1971-2021

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