Overcoming a major obstacle to the practical application of regenerative medicine: Paving the way for the mass production of iPS Cells

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### Pick Up

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Overcoming a major obstacle to the practical application of regenerative medicine: Paving the way for the mass production of iPS Cells

Rika Numano

There are high hopes that the innovative approach of using iPS cells for regenerative medicine will be capable of radically transforming the treatment of diseases. However, there are many barriers to its practical application. One of the major problems is that mass production of iPS cells with homogeneous properties cannot be efficiently achieved. Associate Professor Dr. Rika Numano has developed a water-in-oil droplet electroporation as a novel method of overcoming this obstacle, and is now working to achieve the mass production of iPS cells. When voltage is applied to an aqueous droplet containing cells and Yamanaka factors (reprogramming genes), tiny pores are formed on the surface of the cells. The genes can then be introduced into the cells through these transient pores in the cell membranes. This new technique has several advantages over conventional transfection techniques, in that it can be performed relatively easily using fewer cells, and in that it has a lower chance of inducing cancer. As a result there is growing interest in the potential of this method to realize the development of mass-produced implantable iPS cells in the future.

Interview and report by Madoka Tainaka

Creating iPS cells conveniently without using viruses

Professor Shinya Yamanaka of Kyoto University was awarded the 2012 Nobel Prize in Physiology or Medicine for his famous discovery that mature somatic cells such as skin or blood cells can be reprogrammed to become pluripotent iPS cells by introducing four transcriptional factors. Regenerative medicine is an innovative field of medicine which utilizes iPS cells. It can potentially restore or replace damaged or lost physical functions as well as completely curing diseases or healing injuries.

A lot of clinical research has been conducted in the field of iPS cells, but there are some obstacles to its practical use, namely the difficulty in generating iPS cells that display consistent characteristics, and a very low production rate (about 1%).

Conventionally, the generation of iPS cells utilized viruses to introduce Yamanaka factors into cells, but these factors are also capable of inducing cancer in cells and creating tumors. Concerns have also been raised about the risk of parts of the viruses’ gene sequence remaining in cells. Currently, there are various methods being developed for generating iPS cells without using viruses, but all of these methods have demonstrated even poorer rates of production efficiency. In addition, the generation and culturing of iPS cells can only be done by trained experts, and these activities require specialized conditions in facilities in order to prevent contamination.

Dr. Numano explains, “We have developed a novel method of generating iPS cells by using water-in-oil droplet electroporation. Cell membranes are made of layers of oils. We have found that by momentarily applying several kilovolts to cells, with about the same voltage as static electricity, the cell membrane loosens and forms transient pores through which the Yamanaka factors can pass. This technique does not require the use of viruses.

However, commercially available electroporation equipment requires a costly pulse generator and sends out high-voltage pulses that kill more than half of the cells. Therefore, rather than implement a method using commercial electroporation equipment, we decided to develop a machine that uses direct-current electric fields to generate iPS cells in a more cell-friendly, convenient and efficient way.”

Aiming for chip-based mass production of iPS cells

The procedure for this novel technique is to take an aqueous droplet several microliters in volume containing cells and four Yamanaka factors, put this droplet inside insulating oil, and then apply a direct current from a metal electrode. When the aqueous droplet is exposed to an electric field between a pair of electrodes, the droplet moves back and forth in a rapid bouncing motion between the positive and negative electrodes several hundred times, and the transfection takes place efficiently.
times in a minute.

“This technique uses the basic physical property that oil does not mix with water. When the electric field is first applied, the droplet might move to the negative electrode, for example. However, the machine switches the polarity after the droplet contacts with this electrode, and so the droplet is repelled by the negative electrode and moves toward the positive electrode. This cycle is repeated many times, making the droplet move in a bouncing motion. This creates a minute electric current that loosens the cell membranes, allowing for the Yamanaka factors to be introduced into the cells.

Although this reactor is extremely small in size — a water droplet just a few microliters in volume — the droplet contains about ten thousand cells as well as the four types of genes known as ‘Yamanaka factors.’ This arrangement allows for these genes to be efficiently introduced into the cells. The droplet is insulated by the oil surrounding it, and so there is no risk of contamination in the reactor,” explains Dr. Numano.

One of the most striking points of this new method is that despite a high voltage being used to move the droplet, the electric current in the droplet is very small, and has little influence on the cells.

“We think that if we can conduct the same process in an even smaller reactor, such as picoliter-scale droplets in the micro-channels of a chip, we could further improve the diffusion efficiency of genes, allowing for better introduction of the genes into the cells.

Micro-channels are a completely closed system, with no danger of contamination. They also allow for Yamanaka factors to be introduced into the same cells, enabling a large number of iPS cells to be produced in a short period of time,” she says.

This water-in-oil droplet electroporation was developed in a joint research project with Professor Takayuki Shibata and Assistant Professor Hirofumi Kurita from Toyohashi University of Technology. Professor Takayuki Shibata is a bio-MEMS (Micro Electro-Mechanical System) researcher working on microneedle arrays for cells, and Assistant Professor Hirofumi Kurita is working on applications of electrostatic forces in life science. A patent has already been obtained for the device, and work is underway together with the electroporator manufacturer Nepa Gene Co., Ltd., in order to realize a practical implementation.

Dr. Numano adds, “Researchers at Juntendo University are conducting clinical research in regenerative medicine using iPS cells to treat Parkinson’s Disease. We have requested Professor Wado Akamatsu, from the Center for Genomic and Regenerative Medicine in Juntendo University, to investigate the characteristics of functional differentiation in the iPS cells that we have generated.

Apart from Juntendo University, many clinical studies are currently being conducted at Kyoto University, Osaka University, Keio University, and other institutions in order to seek treatments for neurodegenerative diseases that are considered difficult to cure. We also hope to accelerate our research on mass production methods for iPS cells in order to make the fruits of our research publicly available as soon as possible.”

Utilizing this technology to treat diseases by manipulating many cells at once

Before she switched to working with iPS cells, the main focus of Dr. Numano’s research was on circadian rhythms in mammals.

“All animals on the earth have a circadian rhythm, which is an internal clock that works in 24-hour cycles. The circadian rhythm is regulated by some 20 types of genes known as clock genes. These clock genes work together within the brains of mammals over 24-hour cycles. This is a very robust system, and is not easily disturbed by minor genetic mutations. If we want to control clock genes, we need to manipulate multiple genes at the same time,” Dr. Numano says.

For example, when flying from Japan to the US, our eyes are stimulated by light from the outside, which influences the clock genes in our brain in order to make adjustments to follow local time. However, it is difficult to shift the entire human biological clock by many hours in an instant. As a result, we become jet-lagged because it takes longer for the tissues outside of the nervous system to adjust to the local time.

“I have been working on analyzing the mechanism of the circadian rhythm. I have thought a lot about finding ways to adjust the circadian rhythm instantly. This would allow us to control physiological processes, such as to cure jet lag instantly, or to discover treatments for diseases that are related to the circadian rhythm.”

In her research, she came across the electroporation method, which can manipulate many genes at once. This method may allow genes to be introduced into CAR (Chimeric antigen receptor) T cells—a type of white blood cell that specifically attacks cancer cells—to improve their abilities, meaning that this method could also be employed for cancer treatment.

“In addition to iPS cells, this electroporation method can be applied to many other types of genetic manipulation. I would like to conduct further research to refine several aspects of the method, such as identifying how many more genes we can introduce in total, and the types of cells that can be regulated with the method,” said Dr. Numano about the future prospects of her research.

[Reporter’s Note]

Dr. Numano grew up in a family with many physicians: her father was a cardiologist and her mother was a pediatrician. She recalls her father’s disappointment when he came home from his university hospital if one of his patients had died that day.

She says, “I thought of becoming a physician as well. However, through witnessing my parents’ experiences, I decided to go into basic research where I could work on ways to fundamentally treat or prevent diseases.”

The Human Genome Project commenced when she was a student, and many other research efforts made progress in treating disease preventatively or at early stages. She obtained her doctorate degree while working in the laboratory of our previous Dean Yoshiyuki Sakaki, a prominent Japanese researcher who took a leading role in the Human Genome Project. After graduating, she came to Toyohashi University of Technology, and she has worked over a decade in collaboration with many researchers and companies in order to achieve her dream. Her bright, graceful smile offers the reassurance of an expert physician. We look forward to witnessing further successes in her career.
再生医療普及のカギを握る「iPS細胞の量産化」への挑戦

IPス細胞を用いた再生医療は、病気を根本から治療する革新的な医療として大きな期待が寄せられている。しかし、その実用化には多くの壁がある。その一つが、均質な細胞を数万個まで大量に量産することが難しいことである。研究者たちは、この壁を破る革新的な技術として、電気穿孔法（エレクトロポレーション）を応用した方法を検討している。

モデルとなるのは、京都大学の山中伸弥教授が、体細胞をiPS細胞に変換する際の電気パルスを用いる手法である。山中教授は、細胞を電圧パルスで処理することで、細胞膜の電気透過性が増し、山中因子を導入できると示唆した。この手法は、ウイルスを用いる場合よりも、均質な細胞を大量に効率よく量産することができる。

しかし、この手法には課題がある。山中因子を一つずつ導入した細胞を単独で培養する必要があるため、作製効率が下がる。さらに、ウイルスを用いる場合とは異なり、作製する際には特別な設備が必要となる。

そこで、山中因子を一つずつ導入する作業量を減らすため、山中因子を細胞に導入する際、電気パルスを用いる手法が検討されている。電気パルスを用いることで、細胞膜の電気透過性が高まり、山中因子の導入が容易になる。さらに、この手法はウイルスを用いる場合に比べて、作製効率が改善されると期待される。

現在、この手法を応用した臨床研究が進められている。再生医療として、世界中から大きな期待が寄せられている。しかし、その実用化には多くの壁がある。その一つが、均質な細胞を数万個まで大量に量産することが難しいことである。研究者たちは、この壁を破る革新的な技術として、電気穿孔法（エレクトロポレーション）を応用した方法を検討している。

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Wireless power transfer in fresh water using capacitive coupling

Using underwater inspection robots to detect the early-stage deterioration of structures
By Masaya Tamura

A research team led by Associate Professor Masaya Tamura of the Department of Electrical and Electronic Information Engineering at Toyohashi University of Technology successfully achieved wireless power transfer in fresh water using capacitive coupling. In the field of wireless power transfer, it had been considered difficult to realize wireless power transfer in fresh water using capacitive coupling because fresh water behaves as a dielectric material with extremely high dielectric loss. In this research, the team elucidated the high-frequency properties of fresh water through experiments. The team also discovered the frequency band that enables power transfer with high efficiency using an electric field and an electrode structure that can realize this high efficiency.

Wireless power transfer has attracted attention within a wide range of fields, ranging from mobile terminals to automobiles. Previously, research was mainly done in dry-land environments, though expectations are high for studies in underwater environments as the next target of research. For example, with regard to structural health monitoring systems for pipes, cooling towers or dam walls, there is an urgent need to develop underwater inspection robots that can move freely and perform inspection, even in the event of a disaster. Because these robots are battery-powered, with conventional technology it is necessary to pull them out of the water, charge them, and have them dive back into the water repeatedly. The development of technology to transfer power and information wirelessly in water, therefore, (Figure 1) will be key in improving the efficiency of this work.

As a solution, the research team led by Associate Professor Masaya Tamura developed a capacitive coupler that can supply power wirelessly in fresh water with high efficiency.

The efficiency of wireless power transfer depends on the kQ product, which is the product of the coupling coefficient k of the coupler and the Q-factor of the coupler loss including the influence of the surrounding environment. The higher the kQ product, the better the transfer efficiency. Since the influence of water surrounding the coupler is dominant over the coupler itself in an underwater environment, the study focused on the high-frequency properties of fresh water. The team made its own cell for measurements and clarified the relationship between frequency and the Q-factor of fresh water.

Based on these results, the team used electromagnetic field analysis to find the frequency of power transfer and the structure of the coupler where the value of the kQ product in fresh water is at a maximum. The team achieved a power transfer efficiency of at least 90% at a transfer distance of 2cm and at least 80% at 5cm. The team also succeeded in activating a sensor module via wireless power transfer to conduct infrared data communication. Power transfer efficiency was maintained at 90% or higher over a distance of 2cm, even when transferring 400W of power. Considering that the robot will park on top of the power supply station, this technology is suitable for practical use.

The result of this study will allow for robots that inspect the pipes and cooling towers of power plants or dam walls to communicate information and charge their batteries within the areas of inspection. The research team believes the technology will contribute to drastic improvements in user safety as well as in the operational efficiency of the robots. The coupler newly developed by the team is simple and lightweight, and therefore the impact on the total weight of the underwater inspection robot is kept to a minimum. Use of this lightweight coupler can also eliminate the need for an extensive redesign of the buoyancy system. The team seek to soon achieve the communication of information with electric field coupling in fresh water, as well as highly efficient wireless power transfer in seawater. Their ultimate goal is to realize the wireless transfer of power and information transfer in both fresh water and sea water.

This research was supported by JRFEC: Research Foundation for the Electrotechnology of Chubu and Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (C)

Reference
A research group led by assistant Professor Taichi Goto at Toyohashi University of Technology have, for the first time in the world, demonstrated “stop bands” that prevent propagation of specific frequency components of “forward volume spin waves.” Forward volume spin waves are transmitted through magnetic insulators without the flow of current, and are expected to be applied to the next generation of integrated circuits (ICs). Furthermore, among the spin waves that have been confirmed, forward volume spin waves are the most suitable for information transmission in IC chips, and there are high expectations for their application. However, until now, noise in forward volume spin waves was large, and the stop bands, which are one of the basic physical phenomena, could not be observed. In this demonstration, a magnetic insulator was combined with metal to suppress the noise in forward volume spin waves, and the expression of stop bands was confirmed experimentally.

In recent years, electronic devices using semiconductor materials have had difficulty in responding to the demands of the rapidly growing information society. Due to increases in energy density due to increased integration, chip temperatures have become high, causing defects. Therefore, the development of spin wave IC chips which can process information not by moving electrons themselves but by transmitting spin only, greatly reducing the generation of heat, is attracting attention.

Specifically, spin waves traveling through magnetic insulators have the advantage of low energy loss and long-distance transmission. Furthermore, among the spin waves whose existence has been confirmed, forward volume spin waves that transmit in all directions are said to be most suited for ICs because they can be wired diagonally or in curved shapes. On the other hand, these forward volume spin waves are noisy, and several fundamental spin wave phenomena have not yet been demonstrated. Demonstration of these fundamental principles is indispensable for the development of IC chips and has become an important issue.

Now a research group led by Taichi Goto, of Toyohashi University of Technology, has successfully combined an Yttrium iron garnet (YIG) – an oxide single crystal well known as a magnetic insulator – with two metals (gold and copper) to suppress noise. Through this approach the research team was able to confirm the expression of stop bands in forward volume spin waves experimentally for the first time in the world. In this research, firstly, a system that could simulate the propagation of spin waves was prepared using a three-dimensional model (Figure 1) with the same scale as real spin waves. Using this system, a sample structure was determined where noise was small and the “stop bands,” which are one of the fundamental spin wave phenomena, was confirmed. A stop band is a phenomenon that does not allow spin wave components of a specific frequency to pass through, and stop bands are also expressed in other waves such as electromagnetic waves including light.

Next, samples were made to be as close as possible to the simulation. Figure 2 shows a sample prepared using materials from Shin-Etsu Chemical Co., Ltd. Both ends of the yttrium-iron garnet (which was processed into a wire shape) were covered with gold film to suppress noise generation, and by arranging a copper film in stripes like a pedestrian crossing, the research team tried to hinder the propagation of specific frequencies. Spin waves of various frequencies were passed through this sample and the transmission characteristics were measured.

As a result, the “stop bands” were confirmed as shown in Figure 3. By comparing these with the characteristics of samples without stripe-arranged copper, it can be seen that the expression of stop bands is due to the stripe-arranged copper. Also, the experimental results and the calculation results are in good agreement. From this, the results can be predicted by simulation before experiments leading to the potential for efficient spin wave IC development.

The promising results of this research can be used for applications such as spin wave filters in spin wave IC chips in the future. In addition, they can also be used to slow down the transmission speed of spin waves and to control the direction of travel, contributing to the development of smaller chips capable of more dense information processing.

This research was jointly conducted by Assistant Professor Taichi Goto, PhD studentKei Shimada, Associate Professor Yuichi Nakamura, Professor Hironaga Uchida, and Professor Mitsuteru Inoue of the Toyohashi University of Technology. Additionally, the samples used for the experiment were prepared under a joint research initiative with Shin-Etsu Chemical Co., Ltd.

This research was supported by JST PRESTO Number JP JPR 1524 and JSPS KAKENHI Nos. 17K19029, 16H04329, 26220902.

Reference
Structure of Electrolyte Controls Battery Performance
Toward implementation of calcium-ion batteries

By Yoshiaki Murata

A research team at the Department of Electrical and Electronic Information Engineering, Toyohashi University of Technology has revealed that adding water into electrolyte improves the function of vanadium oxide, which is one of positive electrode materials used in calcium-ion batteries. Although water in electrolytes is known to produce many negative effects, it has now been found to bring about a phenomenon that speeds up the conventionally slow reaction of calcium-ion batteries. The results of the present study indicate that this phenomenon is caused by changes in the electrolyte structure. It is believed that this discovery will greatly benefit the development of electrolytes for implementing calcium-ion batteries in the future.

Secondary batteries are valuable resources that support various industries. Nowadays, secondary batteries are required to be even more powerful to cope with increased use of reusable energy and electric vehicles. Lithium-ion secondary batteries are already widely used as powerful secondary batteries. However, in recent years, the safety of secondary batteries has been brought into question with countless reports citing combustion. Going forward, the need for batteries in our current society is expected to increase exponentially along with the rise in electric vehicles. This means a higher demand for lithium, which in turn is expected to cause problems such as higher prices and potential resource depletion.

Fig.1 Changes in charge/discharge characteristics due to water addition.

Calcium-ion batteries are a type of next-generation secondary battery that do not use lithium and can achieve a battery voltage that rivals that of lithium-ion batteries. Compared to lithium-ion batteries, calcium-ion batteries are safer, cheaper to produce and their resources are much more plentiful. While calcium-ion batteries are currently attracting attention for these reasons, they are still subject to a number of issues. One such issue is that they operate at a speed much lower than that of lithium-ion batteries. In this study, Toyohashi University reported that the slow operating speed of calcium-ion batteries could be improved by adding water into the electrolyte. The graphs of the test results show that overvoltage that occurs during charge/discharge greatly decreases as the amount of added water increases and that reaction proceeds without any problems. As a result of various tests, it was proved that this phenomenon is caused by the fact that the structure of the electrolyte is greatly changed by the addition of water.

Yoshiaki Murata, PhD student and first author of the study explains that, “The electrolyte is made up of positive ions (calcium ions), negative ions and solvent molecules, and the state around the calcium ion greatly changes when water is added. What that means is that, in order to improve the performance of a calcium-ion battery, preferably no negative ion is attached to the calcium ion in the electrolyte and a solvent molecule that easily separates is attached to the calcium ion. While we still need to discover an electrolyte with these characteristics that does not include water in order to achieve calcium-ion batteries, the discovery of this phenomenon will surely help with future electrolyte development.”

The result of the present study was actually a secondary result obtained while studying new electrolytes. Electrolytes need to be sufficiently dehydrated when they are developed, but this dehydration process is difficult. The present study arose when it was noticed that the characteristics of a battery which had an insufficiently-dehydrated electrolyte actually improved during tests. Although there have been reports of a phenomenon in which the performance of magnesium-ion batteries for example had improved after the addition of water, the mechanism behind this was not clearly understood. It was surprising that the same phenomenon could be seen in calcium-ion batteries, and we believe that elucidating the mechanism behind this behavior will prove useful for the future development of electrolytes.

Our research team is looking to develop and assess new electrolytes based on this newly discovered electrolyte structure that improves the performance of calcium-ion batteries. Further, we have not been the only ones to study this; there has been rapid increase in the number of studies of calcium-ion batteries in recent years. Ultimately, we would like to develop a calcium-ion battery that has the capability to rival or overtake lithium-ion batteries.

This work was partly supported by JSPS KAKENHI Grant Numbers JP24360109, JP18H01427 from the Japan Society for the Promotion of Science (JSPS).

Reference
Chirality of vitamin-D derivative affects the protonation states of its receptor protein

Ab initio molecular orbital calculations with K Computer for development of novel and potent drugs.

By Noriyuki Kurita

Vitamin-D is understood to play many important roles in the onset of immunological diseases, as well as the regulation of calcium level in the blood. These physiological actions caused by active vitamin-D are triggered by the specific interaction of active vitamin-D with the vitamin-D receptor (VDR); many types of vitamin-D derivatives have been developed as potent ligands against VDR. The binding affinity between human VDR and vitamin-D derivatives has been reported to depend significantly on the chirality of the derivative.

However, the reason for the dependence has not been clarified, which makes it a bottleneck in the development of novel and potent drugs against immunological diseases, whose onset is related to the activation of VDR.

Now, researchers at the Department of Computer Science and Engineering at Toyohashi University of Technology and at Teijin Pharma Ltd. and Teikyo University, have highlighted the possibility that chirality of vitamin-D derivatives can affect the protonation states of histidine residues in the vitamin-D receptor protein via ab initio molecular simulations and biomedical analyses. This finding emphasizes that protonation states should be considered more precisely in molecular simulations, when investigating specific interactions between candidate drugs and target proteins related to disease pathogenesis.

Therefore, the researchers considered the other possible protonation states of these histidine residues and determined the most stable states using the ab initio FMO calculations. The results illustrated, for the first time, the possibility that the difference in the chiralities of vitamin-D derivatives can induce changes in protonation states of the histidine residues in the VDR that exists near the derivative. Due to this change in the protonation state, the VDR can bind more strongly to the VDR and can thus produce more stable complexes with it.

This finding provides an important and essential warning for the molecular simulations to consider protonation states of histidine residues in proteins more precisely while investigating the specific interactions between proteins and ligands.

"We have used sophisticated molecular simulations and the K computer to find that the protonation states of the histidine residues in the VDR change significantly with alterations in the chirality of ligand”, explains Associate Professor Noriyuki Kurita. “Since histidine residues exist in many proteins involved in the pathogenesis of diseases, we should consider their protonation states more precisely via in silico drug design based on molecular simulations."

The first author, graduate student Yuta Terauchi, said, “Our final goal is to develop novel and potent drugs capable of activating VDR based on our ab initio molecular simulations, as well as on the basis of biomedical studies performed by our collaborators.”

The authors are participating in an in silico drug design consortium – the fragment molecular orbital drug design (FMODD) consortium – in which various researchers from universities, drug companies, and national institutes are investigating the specific interactions between disease-related proteins and many types of candidate drugs using ab initio molecular simulations based on the FMO method and the K computer. Similar molecular simulations are underway now for a huge number of vitamin-D derivatives in order to propose novel ligands for VDR, which can act as candidates for potent new drugs against immunological diseases, such as cancer.

A part of this research was undertaken during activities of the FMODD consortium. A part of the results was obtained using the K computer (project ID: hp170183 and hp180147).

Reference
無線電力伝送はモバイル端末から自動車まで幅広い分野で注目を浴びています。これまで陸上環境での研究が主でしたが、次の一連のターゲットとして水中環境が期待されています。例えば、配管や冷却塔、ダムの堤体壁面など構造ヘルスモニタリングシステムにおいては、自由に移動でき、災害時でも調査が可能な水中点検ロボットの開発が急務となっています。このロボットはバッテリ駆動のため、充電のためには何度も引き上げ、再び潜航させるという作業を繰り返す必要があります。このような作業による運用効率の低下を改善するには、給電ステーションを介した水中での無線電力情報伝送（図1）の技術開発が鍵となります。

そこで、田村昌也准教授らの研究チームは淡水中でも高効率に無線で給電できる電界結合器を開発しました。無線電力伝送における電力伝送効率は伝送用結合器のもつ結合係数$k$と周辺環境の影響を表す$Q$値の積である$kQ$積に依存します。$kQ$積が高いほど伝送効率も向上します。水中では結合器よりも結合器を取り巻く水の影響が支配的であることから本研究では淡水の高周波特性に注目し、自作の測定セルを用いて測定を行い、周波数と淡水の$Q$値の関係を明らかにしました。その結果を用いて電磁界解析から淡水中で$kQ$積が最大値を示す電力伝送周波数と結合器構造を明らかにしました。これにより送電距離2cmで90%以上、5cmで80%以上の電力伝送効率を実現しました。実際に淡水を介した無線電力伝送でセンサモジュールを駆動し、赤外線によるデータ通信にも成功しました。また、400Wの電力を送電距離2cmで送電しても電力伝送効率90%以上を維持できている。給電ステーションに着底することを考えると、実用に耐える効率と考えられます。

研究チームは、本研究成果により発電所の配管や冷却塔、ダムの堤体壁面などの水中点検ロボットに対し、点検区域内での通信・充電が可能となり、使用者の安全性やロボットの運用効率の飛躍的向上に貢献できると考えています。開発した結合器は非常にシンプルかつ、軽量であるため、水中点検ロボットの総重量に与える影響を最小限に抑え、浮力システムの大掛かりな再設計も不要になることが期待されます。また、電界結合による淡水中での情報通信や海水中での無線電力伝送効率も高効率化が見えてき、最終的には、淡水・海水のどちらでも無線電力情報伝送を実現したいと考えています。

前進体積スピン波のストップバンドの発現を実証

前進体積スピン波のストップバンドの発現を実証に成功した

豊橋技術科学大学の後藤太一助教らは、「前進体積スピン波」の特定の周波数成分の伝播を妨げる「ストップバンド」を実証しました。前進体積スピン波は、電流を流さずに磁性絶縁体中を伝わることから、次世代の集積回路への応用が期待されています。また、確認されているスピン波の中でも、情報伝達に最も適しており、応用が強く期待されているものです。しかし、これまで、前進体積スピン波のノイズは大きく、基本的な物理現象の一つであるストップバンドが観測できていませんでした。今回の実証では、磁性絶縁体と金属を組み合わせ、前進体積スピン波のノイズを抑制し、ストップバンドの発現を実験で確認しました。

近年の半導体材料を利用した電子デバイスは、高集積化によるエネルギー密度の増加に伴い、チップの温度が高くなり、不具合を生じるなどの急成長する情報化社会からの要求に答えることが難しくなってきています。そこで、電子自体は移動せずスピンだけを伝えることで情報処理を行い、熱の発生が大幅に低減可能なスピン波集積回路チップの開発が注目を集めています。この中でも、磁性絶縁体中を伝わるスピン波は、エネルギーの損失が小さく、長距離伝播が可能な利点を持っている。さらに、存在が確認されているスピン波の中でも、ある方向に伝わる前進体積スピン波は、直流状の配列だけでなく、斜めや曲線の配列の可能性があるため、最集積回路への適用が見えてきています。そこで、この電子自体が移動せずスピンだけを伝えることで情報処理を行い、熱の発生が大幅に低減可能なスピン波集積回路チップの開発が集積を集めています。

この中でも、磁性絶縁体中を伝わるスピン波は、エネルギーの損失が小さく、長距離伝播が可能な利点を持っている。さらに、存在が確認されているスピン波の中でも、ある方向に伝わる前進体積スピン波は、直流状の配列だけでなく、斜めや曲線の配列の可能性があるため、最集積回路への適用が見えてきています。図1は、電子自体が移動せずスピンだけを伝えることで情報処理を行い、熱の発生が大幅に低減可能なスピン波集積回路チップの開発が集積を集めています。

今後の研究課題としては、これらの基礎研究成果を応用し、さらに高性能なスピン波集積回路チップの開発が期待されています。
二次電池は、再生可能エネルギーの利用普及や、電気自動車の普及を支える重要な技術として、更なる性能の向上が必要です。性能の良い二次電池として、リチウムイオン電池が既に広く普及しています。一方で、近年発火事故の報告は絶えず、二次電池の安全性は社会問題化しています。また、これからの社会では電池の需要は電気自動車の普及と共に増える見込みで、これによって生じるリチウムの需要増加は、資源枯渇リスクや価格高騰の観点で考慮すべき問題です。

カルシウムイオン電池は、リチウムを用いない次世代二次電池の一つです。カルシウムは次世代二次電池の中でも特に、リチウムイオン電池に匹敵する電池電圧を実現可能であり、リチウムイオン電池と比較して安全性が高い、資源量も豊富で、コストがあらゆる材料で構成されており、水を添加した際には、カルシウムイオン電池の特性が大きく変化します。具体的には、カルシウムイオン電池の性能は向上するためには、電解液の中でカルシウムイオン電極にマイナスイオンが付いており、さらには剥がれやすい溶媒分子が付いていることが好ましいです。カルシウムイオン電池を実現するためには、水を含まずにこれらの特徴を有する電解液を発見することが必要です。カルシウムイオン電池の実現は、電解液開発の一つであり、我々の研究では、リチウムイオン電池に匹敵あるいはリチウムイオン電池を上回る性能を持ったカルシウムイオン電池の開発を行っていきたいと考えています。

カルシウムイオン電池でも同様の現象が起こった、という驚きと共に、今後の研究に役立つと考えました。研究チームは、今回発見できたカルシウムイオン電池の性能を向上させる電解液の構造をもとに新たな電解液を開発・評価したいと考えています。また、我々の研究だけではなく、ここ数年でカルシウムイオン電池の研究例は急速に増加しつつあります。最終的には、リチウムイオン電池に匹敵あるいはリチウムイオン電池を上回る性能を持ったカルシウムイオン電池の開発を行いつつ考えています。

今回の成果は、新しい電解液の検討中に副次的に得られた成果です。電解液の開発の際には、電解液を十分に脱水する必要があります。我々の研究では、電解液に水を添加することで、この遅い動きを改善することを報告しました。実験結果の図から、放電・充電時に発生する過電圧が、水添加によって大きく減少し、反応がスムーズに進行していることが分かります。様々な検討の結果、この現象が電解液の性能を支配する電解液の構造が、水の添加によって大きく変化していることが明らかとなった。

電解液の構造が電池の性能を支配する

カルシウムイオン電池の実現に向けて

村田 芳明

豊橋技術科学大学電気・電子情報工学系の研究チームは、カルシウムイオン電池正極材料の一つである酸化バナジウムの性能が、電解液に水を添加することで向上することを明らかにしました。電解液に含まれる水は、様々な悪影響を及ぼすことが知られています。従来非常に低速だったカルシウムイオン電池の反応が高速化される現象が見出されました。今回の研究結果から、この現象は、電解液の構造の変化によって引き起こされていることが明らかとなりました。今後、カルシウムイオン電池実現のための電解液開発に向けて、重要な指標を与えると考えられます。
TEDx is a program of local, self-organized events that bring people together in the spirit of hearing ideas worth spreading, in other words to share a TED-like experience.

TEDx ToyohashiUT (Toyohashi University of Technology) executive committee was voluntarily established in early 2018 by an enthusiastic group of TUT students who had been impressed by TED Talks.

The goal of hosting TEDx ToyohashiUT is to stimulate fresh thinking at TUT which, allied with our technological knowhow will help us to develop novel and unique ideas. We will share these ideas with the world, while always retaining our curiosity to learn more.

“SURF THE FUTURE” - Ride the wave of the times, and spread your ideas as wide as the ocean

Under this theme, the first TEDxToyohashiUT was held on March 17th 2019, and several guest speakers were invited to talk. 120 audience participated (includes partners, staff and other speakers)
Toyohashi University of Technology

The Toyohashi University of Technology (TUT) is one of Japan’s most innovative and dynamic science and technology based academic institutes. TUT Research is published to update readers on research at the university.

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