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FEATURE STORY

Making buildings safer by preemptively visualizing earthquake damage

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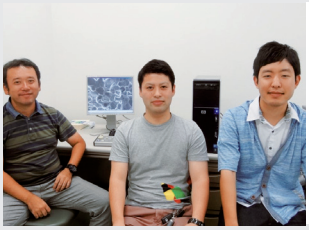
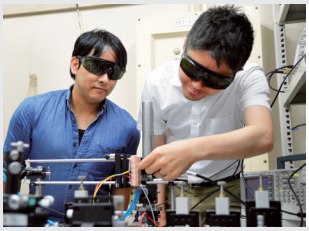
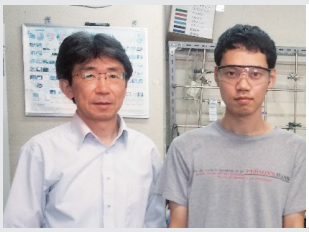
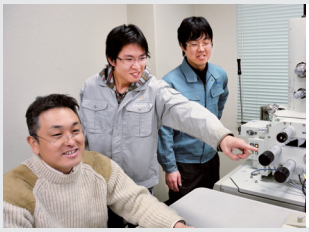
Research Highlights









Pick Up

Making buildings safer by preemptively visualizing earthquake damage

Taiki Saito

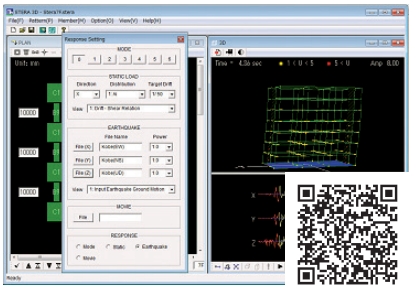
The series of earthquakes which hit the area in and around Kumamoto Prefecture in April 2016 are still fresh in our memory. Recorded twice at a seismic intensity of 7, the shocks killed or injured more than 2,000 people. These casualties, for the most part, were attributed to collapsed buildings, as was the case in the Great Hanshin-Awaji Earthquake in 1995. In spite of the scale of the destruction, effective countermeasures have still to be sufficiently implemented. To avoid such tragedies from happening again, Professor Taiki Saito has been conducting research to visualize how earthquakes shake and damage buildings and hopes to apply his research outcomes to disaster prevention.

Interview and report by Madoka Tainaka

Development of Software to Visualize Shaking and Damage of Buildings

According to the Cabinet Office's report of November 14, 2016, the earthquakes that hit Kumamoto Prefecture severely damaged over 180,000 houses, of which over 8,000 were completely destroyed. The Kumamoto eathquakes were far from being a rare occurrence. In the following year a series of destructive quakes struck around the world, such as in Italy and New Zealand, as well as closer to home, in the central part of Tottori Prefecture in October. In all of these examples earthquake-induced building collapse had a destructive impact on life and property. Given this critical situation, the critical importance of Professor Saito's efforts to make buildings safer by preemptively visualizing earthquake damage becomes clear.

One of the innovative accomplishments of his research is STructural Earthquake Response Analysis 3D: STERA_3D, a software tool which allows for a seismic analysis of buildings with various structures, including reinforced concrete. Professor Saito explained the aim of this software development as follows: "If you can understand in what way your house is likely to sway and collapse in the event of an earthquake, you will be better able to prepare for it beforehand. In reality, however, it is difficult to make such predictions unless you are a structural expert. That's why we have developed a software application that, by simply entering data such as column or beam size taken from the building's blueprints, allows you to see an animated simulation of earthquake tremors and structural vulnerability."



Development of earthquake response analysis program STERA3D

The Japanese and English versions of this software are available to download for free from Professor Saito's laboratory website. Another software tool called STructural Earthquake Response Analysis FEM: STERA_FEM, a software for visualizing the stress placed on a building's planar structural members such as walls, is also available from the same website. Professor Saito says these tools allow you to intuitively understand the risk factors of a building by showing damage-prone spots in red. They are already in use in a wide variety of environments, including research and education. (http://www.rc.ace.tut.ac.jp/saito/software-e.html)

Using Tools for Building Analysis of Post-Earthquake Disaster Management Facilities

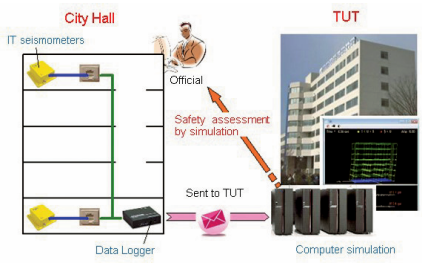
We cannot exactly tell when or where an earthquake will strike. Toyohashi City, the home of Toyohashi University of Technology, situated above the Nankai Trough, is estimated to have a 70% chance of experiencing an earthquake of magnitude 6 to 7 on the seismic intensity scale within the next 30 years. A sense of alarm about the impending earthquake has motivated Professor Saito to work on his research.

"One of the most crucial issues in times of disaster is securing the use of disaster management facilities such as city halls, hospitals and fire stations. However, various disaster management facilities, such as Uto City Hall, were themselves damaged by the earthquakes in Kumamoto Prefecture. This factor significantly

hindered the city's evacuation and recovery operations. The problem is that you cannot tell the risk of collapse just by looking at the building from the outside," says Professor Saito.

He further explains that a major vertical crack, for example, between two buildings of an apartment complex might appear to be hazardous to the untrained eye, but it is fairly safe as the two buildings are structurally separate. On the contrary, he adds, cross-shaped or horizontal cracks in a column are far greater hazards even when no major damage is apparent.

"To address this issue, we ran seismic simulations on the east and the west buildings of Toyohashi City Hall using my analysis tools with the data of the ground motion waveform prediction for the Nankai Trough earthquake provided by the Ministry of Land, Infrastructure, Transport and Tourism. As a result, we have found that the buildings have sufficient earthquake resistance. It turned out, however, that the west building is at risk of damage such as cracked walls and collapsed ceiling panels. Over in the east building, it was determined that in the case of a strong magnitude 7 quake, people would be unable to stay on their feet, and cabinets not secured to the floors or walls would fall over.



Vibration monitoring system

We don't know for certain what would really happen since the results are only simulations based on the drawings. We might be repeatedly hit by earthquakes of an unexpected scale, just as the people in Kumamoto have recently experienced. Currently we are in the initial stages of monitoring buildings to assess whether it is safe to continue using the buildings in the event of actual earthquakes," says Professor Saito.

More specifically, his concept involves the following. His research team installed three IT strong-motion seismometers in the city hall to continuously monitor vibrations. Every five minutes, the vibration data obtained by the seismometers are sent to the computers in Toyohashi University of Technology via the Internet for the analysis tools to run simulations in the cloud.

"If an earthquake strikes, we hope to be able to use the results of the simulations to assess whether it is safe to continue using the buildings. We are planning to implement more measures against earthquakes, such as having additional monitoring locations including fire stations and evacuation facilities, and installing a dedicated line for disaster prevention. Accumulating real-time data in the cloud can also improve the accuracy of the simulations."

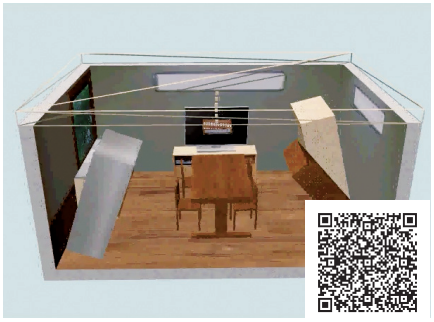
Sharing Research Outcomes to Raise Awareness of Disaster Prevention

Professor Saito has also developed software that shows an animated simulation of earthquake damage inside houses such as that caused by falling furniture. This software application works on smartphones and makes it easy to run simulations, with a flexibly adjustable furniture layout and an easily configurable restitution coefficient and friction coefficient . The existence of such a tool greatly contributes to raising awareness of disaster prevention not only among researchers and experts, but also the general public.

In addition to his work as a researcher, he also conducts analysis of buildings in Toyohashi City and writes informative books for the general public. Through such activities, he has once again realized the power of his analysis software.

"By seeing things in animation, people can identify them as immediate concerns, not just as abstract knowledge. It is not enough to know that an earthquake may strike, rather it is very important to imagine in detail what may actually happen beforehand. I should also mention this. A common mistake people make is to try to hold their furniture against the wall to prevent it from falling during an earthquake, but this only has a minimal effect and can be very dangerous. By widely sharing such insights which I have derived from my research, I hope to contribute to society by raising public awareness about disaster prevention."

Professor Saito's vision for the future is that he would like to work on more sophisticated analysis that incorporates topographic and geotechnical information.



An animated simulation of earthquake damage inside houses such as that caused by falling furniture.

"We are currently studying a collapsed apartment that stood at the edge of a cliff before the earthquakes in Kumamoto. All the surrounding buildings survived the quakes but only this apartment collapsed. The shaking of buildings greatly varies depending on the conditions of the ground and topography. It is no easy task to add geotechnical models to simulations, but we hope to provide more accurate analysis software by translating geotechnical characteristics into numerical data."

It is not easy to prepare for an earthquake when we do not know when it will strike, but we can at least save some lives by implementing seismic safety measures on buildings and furniture. I truly hope that Professor Saito's research will lead to the implementation of anti-earthquake measures on more buildings.

[Reporter's Note]

When he was a student of Tohoku University, Professor Saito worked on an analysis of the earthquake that struck off the coast of Miyagi Prefecture in 1978. The output of simulations in those days was in the form of numerical data only and it was difficult to intuitively understand the extent of the damage. The frustration he felt back then has driven him to achieve his current research accomplishments.

"I actually used my analysis software before I bought an apartment," says Professor Saito. Even if it complies with the Building Standards Act, you cannot tell the level of the actual aseismic performance just from its appearance. His wife really liked one apartment on the top floor with a wide balcony, but as a result of the analysis, the apartment turned out to be structurally vulnerable. Eventually, "My wife was convinced and we bought a different apartment," says Professor Saito with a laugh. It seems that the power of visualization was required to convince his wife.

地震による建物被害の「見える化」を防災対策支援へ役立てる

まだ記憶に新しいが、2016年4月に発生した熊本県地震では、震度7の地震を2度も観測し、2000名を超える死傷者を出した。その死傷の原因の多くは、建物の倒壊によるものである。建物倒壊は、1995年の阪神淡路大震災でも大きな被害をもたらしたが、対策はまだ十分に取られてないない。こうした悲劇を繰り返さないために、齊藤大樹教授が取り組むのは、地震による建物の揺れや被害を可視化し、防災支援に役立てる研究である。

建物の揺れや被害が見えるソフトウェアの開発

熊本地震では、住宅の全壊は8000棟以上に上り、半壊や一部破損を合わせると18万棟以上が被害を受けたとされる（2016年11月14日現在、内閣府資料より）。その後も10月の鳥取県中部地震に続き、イタリアやニュージランドでも地震による建物の倒壊による被害が相次いでおり、齊藤教授が手がける建物被害の可視化を防災支援に役立てる研究は、まさにいま、社会が必要とする最重要課題への取り組みと言える。

なかでも齊藤教授の研究の画期的な成果の一つが、鉄筋コンクリート造をはじめとする各種構造の建物の立体骨組みに対応した、解析ソフト「建物の立体地震応答プログラムSTERA_3D」の開発である。齊藤教授は、開発の目的を次のように説明する。

「自分が住んでいる家が地震のときにどう揺れ、どう壊れるのかがわかれば、事前に対策を立てることができます。しかし実際には、構造の専門家でもない限り、あらかじめ知るのは難しいですよね。そこで、設計図をもとに、梁や柱などの数値を入力するだけで簡単にシミュレーションができ、アニメーションで地震の揺れや建物の弱点を表すアプリケーションを開発しました」

このソフトは、フリーソフトとして日本語版と英語版が公開されており、齊藤教授の研究室のホームページから誰でも自由にダウンロードできる。同時に、建物の壁など平面部材にかかる力（応力）を可視化するソフト「有限要素解析ソフトウェアSTERA_FEM」も公開。破壊される可能性がある箇所を赤色で示すなど、直感的に建物の状況が理解できるツールとして、すでに研究や教育など、さまざまな場面で活用されているという。
（http://www.rc.ace.tut.ac.jp/saito/software-e.html）

地震後の防災拠点の建物診断にも活用

地震はいつどこで起こるかわからないが、豊橋技科大が立地する豊橋市は、30年以内に70%の確率で起こると予想される南海トラフ地震で、震度6強から7の激しい揺れが想定される地域である。その危機感が、齊藤教授を研究に駆り立てる原動力にもなっているという。

「なかでも被災時の大きな課題が、市役所や病院、消防署などの防災拠点の機能を確保する点にあります。実際に熊本地震では、宇土市役所をはじめとする複数の防災拠点が被害を受け、避難や復旧の大きな障壁となりました。問題となるのは、建物の倒壊の危険性は外側から見ただけではわからない点にあります」と、齊藤教授は言う。

例えば、マンションの棟と棟の間に生じた縦の大きな亀裂は、素人目にはいかにも危険に見えるが、実際にはそれぞれ構造的に切れているため問題ない。一方、一見、大きな損壊はないのに、柱にバツ状や横に亀裂が入っているほうがはるかに危ないという。

「その対策として、豊橋市役所の西棟、東棟について、国土交通省による南海トラフ地震の予測地震動波形を使い、それぞれ解析ツールでシミュレーションを行いました。その結果、耐震性は確保されていることがわかりました。ただし、西棟では壁のひび割れや天井パネルの落下の危険性が、東棟では震度7では激しい揺れで立っていられないこと、固定していないラックなどは転倒することがわかりました。

ただ、元となるのはあくまでも図面からの情報であって、実際の状況はわかりません。熊本地震のように、想定外の揺れに何度も見舞われないとも限りません。そこで、実際に地震が起きたとき、その建物を使い続けられるかどうかを判断するために、建物のモニタリングを始めたところです」と齊藤教授は言う。

具体的には、市役所にIT強震計を3台設置し、常時、振動をモニタリングする。IT強震計から得た振動情報は、インターネット経由で5分ごとに豊橋技科大のコンピュータに送られ、クラウド上で解析ツールを用いてシミュレーションを行うという構想だ。

「万一、地震が起こったら、シミュレーション結果をもとに、建物を使い続けられるかどうかの判断に役立てたいと考えています。さらに、モニタリングを消防署や避難所にも拡大して、防災のための専用回線を設けるなど、対策を強化していく予定です。さらに、リアルタイムデータをクラウド上に蓄積することで、シミュレーションの精度向上にも役立てたいと考えています」

研究の成果を広め、防災意識を高めたい

さらに齊藤教授は、地震による家具の転倒など、室内被害の様子をアニメーションで示すシミュレーションソフトの開発も手がける。こちらは、スマートフォンでも動くアプリで、家具のレイアウトを自在に変えられるほか、シミュレーションに必要な反発係数や摩擦係数なども簡単に設定できることから、研究者や専門家だけでなく、一般市民の防災意識向上にも寄与している。

そのほか研究者としての活動の傍ら、豊橋市内の建物の解析や、一般向けの啓蒙書の執筆なども手がける。そうした活動の中で、改めて自身の解析ソフトの威力を感じているという。

「アニメーションで見せることで、単なる耳学問ではなく、皆が我が身のこととして認識するようになるんですね。やはり事前に知識として知るだけでなく、想像力を養っておくことは非常に重要だと思います。ちなみに、地震のときに家具を倒れないように押さえる人がいますが、ほとんど力は伝わらないし大変危険なんですよ。このように私が研究を通じて得た知見をより多くの人に伝えることで、市民の防災意識を高め、社会に貢献していきたいですね」

今後はさらに地形や地盤を取り入れた、より高精度の解析にも取り組みたいと、齊藤教授は展望を語る。

「熊本地震で、周囲の建物は壊れていないのに、崖のヘリに建っているマンションだけが壊れたというので、調査をしています。地盤や地形によって、揺れ方は大きく違ってきます。地盤のモデルをシミュレーションに加えるのは容易ではありませんが、地盤の特性を数値化するなどして、より精度の高い解析ソフトを提供したいと思っています」

いつ来るかわからない地震に備えるのは容易ではないが、少なくとも建物や家具対策で救われる命が多数ある。齊藤教授の研究がより多くの建物の対策へとつながることを切に願う。

（取材・文＝田井中麻都佳）

取材後記

学生時代、在籍した東北大学で、1978年に起きた宮城沖地震の解析を手がけたという齊藤教授。当時のシミュレーションの出力は数値データのみで、被害状況を直感的に掴むのは難しかった。そのときのもどしかしい思いが、今の研究成果につながっているという。

「実は、私がマンションを購入する際にも、自分の解析ソフトを活用したんですよ」と、齊藤教授。建築基準法を遵守していても、耐震の程度は見た目では判断できない。奥様がとても気に入ったあるマンションのベランダの広い最上階の部屋は、解析の結果、構造上、弱いことが判明。結局、「妻も納得してくれて、別のマンションを購入しました」と齊藤教授は笑う。奥様を説得できたのも、見える化によるところが大きかったに違いない。

Researcher Profile

Dr. Taiki Saito received a PhD. degree in engineering from Tohoku University, Sendai, Japan, in 1990.
Since receiving his PhD, he has been engaged in earthquake disaster engineering research as a research associate in Tohoku University, a senior research engineer in the Department of Structural Engineering of the Ministry of Construction' s Building Research Institute, and a Chief Research Engineer in the International Institute of Seismology and Earthquake Engineering, Building Research Institute. Since 2012, he has been a member of the Faculty of Engineering, Toyohashi University of Technology. He is currently working as a professor in the Department of Architecture and Civil Engineering and a director in the Research Center for Collaborative Area Risk Management (CARM) in Toyohashi University of Technology.

Reporter Profile

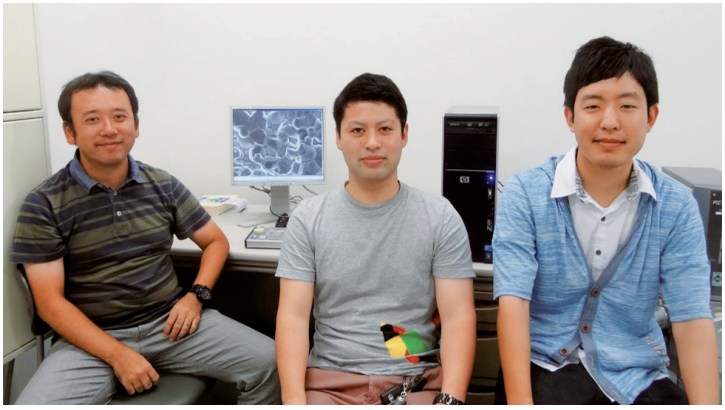
Madoka Tainaka is a freelance editor, writer and interpreter. She graduated in Law from Chuo University, Japan. She served as a chief editor of "Nature Interface" magazine, a committee for the promotion of Information and Science Technology at MEXT (Ministry of Education, Culture, Sports, Science and Technology)

Garnet-type fast ionic conductor for all-solid-state lithium battery

Development of garnet-type fast ionic conducting oxide for use in all-solid-state lithium batteries

By Ryoji Inada

Ryoji Inada and his colleagues have developed a garnet-type, fast ionic conducting oxide. The developed garnet-type oxide showed not only high ionic conductivity, around 1 mS/cm at room temperature, but also high electrochemical stability. Using this material as a solid electrolyte, an all-solid-state lithium battery was fabricated and its reversible charge and discharge reaction was demonstrated successfully. This finding contributes to the realization of highly safe, rechargeable batteries for large-scale power sources.



Associate Professor Ryoji Inada (left) with his students

Rechargeable all-solid-state lithium batteries are expected to be one of the next-generation energy storage devices because of their high energy density, safety, and excellent cycle stability. The materials used for the solid electrolyte must not only have a high lithium-ion conductivity (above 1 mS/cm at room temperature), but also possess chemical stability.

Oxide-based solid electrolyte materials have several advantages over sulfide-based ones, such as their chemical stability and ease of handling. On the other hand, there are certain challenges to overcome if one is aiming at a better electrochemical performance in solid-state batteries with an oxide-based SE, such as the formation of a solid-solid interface with low resistance between the solid electrolyte and the electrode.

In this study, Ryoji Inada and his colleagues at the Department of Electrical and Electronic Information Engineering, developed a garnet-type, fast ionic conducting oxide as the solid electrolyte for an all-solid-state battery. Using this material, a rechargeable all-solid-state battery was fabricated and tested.

The research team investigated the influence of alien cation (Ba2+ and Ta5+) substitution in Li7La3Zr2012 (LLZO, Fig. 1) on the crystal phase, microstructure, and ionic conducting property systematically. In order to stabilize the highly conductive cubic garnet phase, the Li concentration in the chemical formulae was fixed at 6.5 so that the formula of the compound may be expressed as Li6.5La3-xBaxZr1.5-xTa0.5+xO12 (LLBZTO).

As a result, the highest room temperature conductivity of 0.83 mS/cm was obtained in the LLBZTO garnet with Ba and Ta contents of 0.1 and 1.6, respectively (Fig. 1). The Activation energy of the LLBZT garnet tended to decrease monotonically with an increasing Ba substitution level; however, the excess Ba and Ta substitution degraded the conductivity.

In addition, they confirmed that the LLBZTO garnet has a wide potential for electrochemical applications, hence, various positive and negative electrode materials can potentially be utilized to construct an all-solid-state battery. We fabricated a TiNb2O7 (TNO) film electrode on LLBZTO using the aerosol deposition method and demonstrated its charge and discharge reaction using a TNO/LLBZTO /Li all-solid-state battery sample (Fig. 2).

These results indicate that the developed LLBZTO garnet can be used as a solid electrolyte in an all-solid-state battery and contribute to the realization of a very safe rechargeable battery for large-scale power sources,

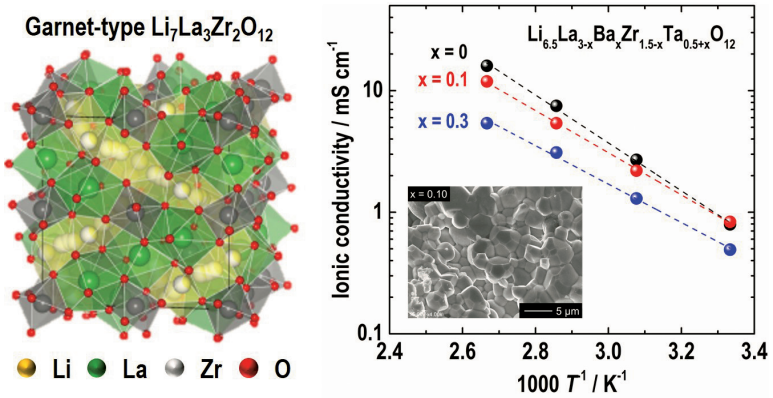


Fig1. Crystal structure of cubic garnet-type Li7La3Zr2012 (LLZO, left) and temperature dependence of ionic conductivity for Ba- and Ta-substituted LLZO with different compositions (right).

although additional investigation is required to enhance the performance of solid-state batteries. The researchers carried out further study to realize solid-state batteries with high energy density.

The above research results were reported in Frontiers in Energy Research on July 20, 2016.

This work was partly supported by Grants-in-Aid for Challenging Exploratory Research (Grant No. 26630111) and Scientific Research (C) (Grant No. 16K06218) from the Japan Society for the Promotion of Science (JSPS).

Reference

Ryoji Inada, Satoshi Yasuda, Masaru Tojo, Keiji Tsuritani, Tomohiro Tojo and Yoji Sakurai (2016). Development of lithium stuffed garnet-type oxide solid electrolytes with high ionic conductivity for application to all-solid-state batteries, Frontiers in Energy Research 4:28. DOI:10.3389/fenrg.2016.00028

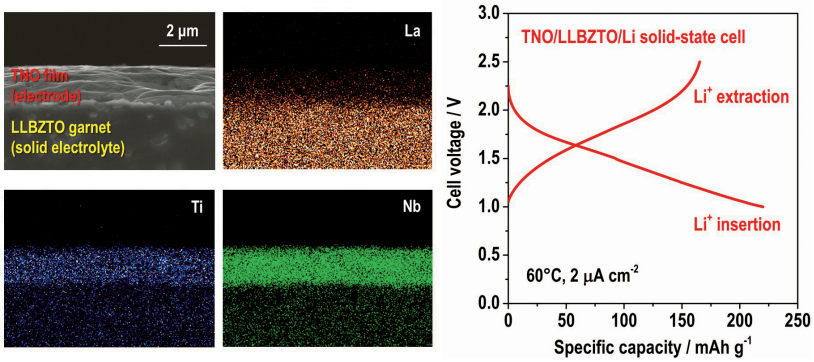


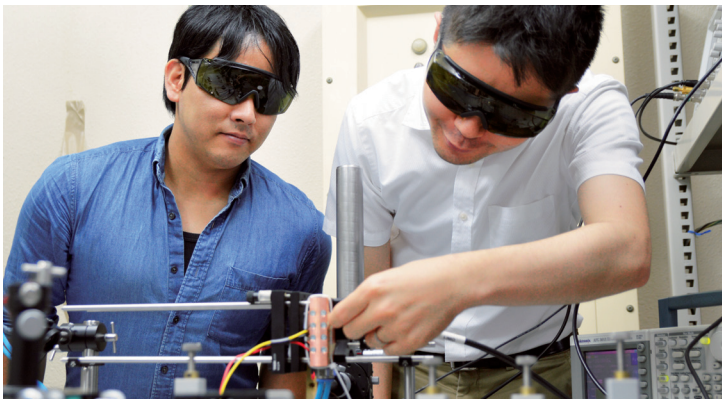
Fig2. Cross sectional SEM image and corresponding elementary distribution of Ti, Nb, and La for TNO film electrode formed on LLBZTO garnet (left). Charge and discharge curves for TNO/LLBZTO/Li all-solid-state battery tested at 60℃ (right).

World First Demo of Labyrinth Magnetic-Domain-Optical Q-switched Laser

A submillimeter-thick film with magnetic microdomains was used to control a Q-switched laser, increasing its pulse power 1,000 times

By Taichi Goto

Taichi Goto and his colleagues have fabricated the first magneto-optical (MO) Q-switched laser. Unlike electro-optic (EO) and acousto-optic (AO) effects, MO effects had not previously been used in Q-switched lasers, although the effects themselves are very well-known. The fabricated MO Q-switched laser contributes to the development of compact high-power lasers.



Assistant Professor Taichi Goto (right) with his student

The “Industry 4.0” concept, first introduced by the German government, has recently extended the scope of compact high-power laser applications to, for instance, laser manufacturing, vehicle engine development, or thruster systems for space exploration.However, integration of a controllable Q-switch into compact solid-state lasers has been challenging because of the mechanisms of EO and AO effects. In addition, previous Q-switches needed a large-sized power supply, which prevented down-scaling of the entire system.

Now, Taichi Goto, in cooperation with researchers at Iowa State University, and the Institute for Molecular Science have developed a magneto-optic (MO) Q-switched laser for the

first time, using a 190-micron-thick magnetic garnet film with labyrinth-shaped magnetic domains. They used custom-made coil and circuits to generate the pulsed magnetic field to be applied to the magnetic garnet, and successfully generated optical output with a pulse width in the tens of nanoseconds range. This was the first ever demonstration of a Q-switched laser driven by magnetic domain motions, and also the first evidence of the possibility of an integrated Q-switched laser. "The device was two orders of magnitude smaller than other reported controllable Q-switches," commented Associate Professor Taira.

"The most difficult part of realizing MO Q-switching was to combine three different techniques/fields: the preparation of a magnetic material, the fabrication of a high-speed magnetic field switch, and the construction of a laser cavity," explained PhD candidate Ryohei Morimoto.

According to Assistant Professor Taichi Goto, "there are no previous reports of MO Q-switches using thin garnets. This is not only the first demonstration, but it also represents an important first step in the development of an integrated high-power laser."

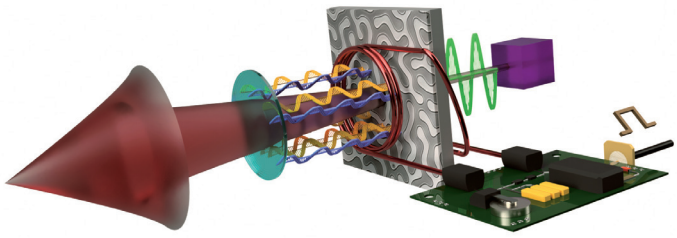
"We enjoy our collaboration and learn from each other," said Professor Mina Mani. "We further hope not only to advance research and create and pursue new challenges, but also to use science and technology to make a better world for us all." In addition, the researchers found a unique biasing technique that uses magnetism to decrease the electric power needed for Q-switching. When a ring-shaped permanent magnet was placed close to the magnetic garnet, they were able to generate the same optical pulse in the MO Q-switched laser using seven times less electric power. This result showed that this Q-switch does not need a large power supply for operation, meaning that drastic downscaling can be expected. The research team would like their future studies to be useful for laser users all around the world and to help in the establishment of new industries.

We acknowledge support from the following institutions:

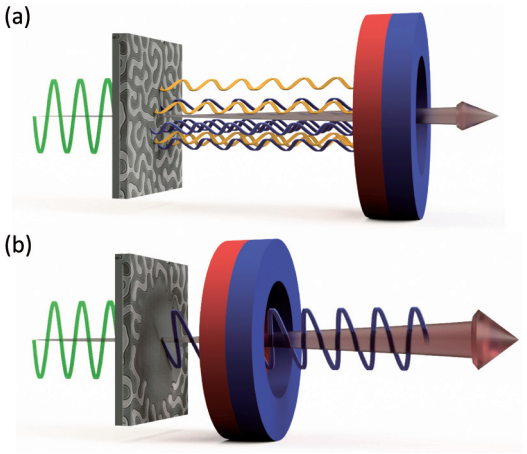
- Japan Society for the Promotion of Science (JSPS) KAKENHI Nos. 26706009, 26600043, 26220902, 25820124, and 15H02240.
- Japan Science and Technology Agency (JST) – Promoting individual research to nurture the seeds of future innovation and organizing unique, innovative network (PRESTO).

Reference

T. Goto, R. Morimoto, J. W. Pritchard, M. Mina, H. Takagi, Y. Nakamura, P. B. Lim, T. Taira, and M. Inoue, (2016)."Magneto-optical Q-switching using magnetic garnet film with micromagnetic domains," Opt. Express, 24, (16), 17635-17643. DOI: 10.1364/OE.24.017635.



A pulsed output with a power of dozens of watts and a pulse width of 40 ns was obtained through an MO Q-switched laser controlled by labyrinth-shaped magnetic domains.

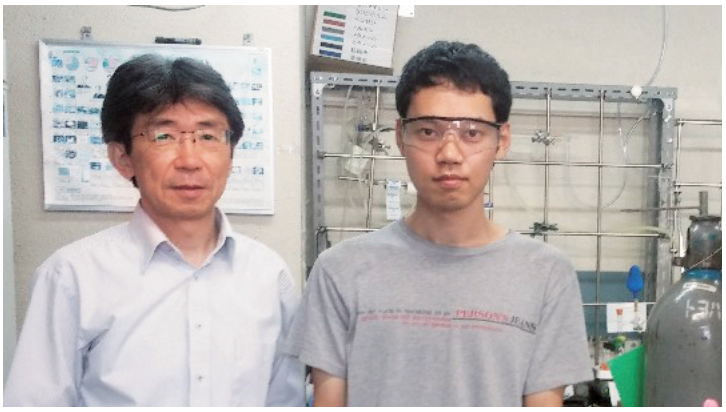


Labyrinth-shaped magnetic domains in the magnetic film can be erased by applying a magnetic field, drastically and quickly changing the peak power output of the laser.

Artificial enzyme for asymmetric synthesis using a synthetic chiral polymer

By Shinichi Itsuno

Cinchona alkaloid derivatives show catalytic activity in various kinds of asymmetric transformations in organic synthesis. These transformations are necessary steps in the production of pharmaceuticals. Shinichi Itsuno and his colleagues have successfully synthesized chiral polymers containing a cinchona alkaloid sulfonamide derivative as a repeating unit. This is the first example of a chiral polymer of cinchona sulfonamide, which shows high catalytic activity in the enantioselective desymmetrization of cyclic anhydrides.



Professor Shinichi Itsuno (left) with one of his students

Enzymes, high-molecular-weight chiral polymeric compounds, are complex biological catalysts. Capture of the substrate molecule, catalyzing the reaction, and release of the product are three important events performed by enzymes. In order to accomplish these events using a synthetic catalyst, the catalyst must necessarily have a large molecular weight so that it can act as a highly specific catalyst. To date no synthetic chiral polymers had been designed for this purpose, but now a research team from the Department of Environmental and Life Science at Toyohashi University of Technology has investigated a novel synthetic method for preparing chiral polymers containing repeating units of cinchona sulfonamide.

The lead author Shohei Takata said, "After testing many reaction conditions for the polymerization, we have synthesized chiral polymers containing cinchona sulfonamide repeating units. Chiral polymers are easily prepared according to the method we established."

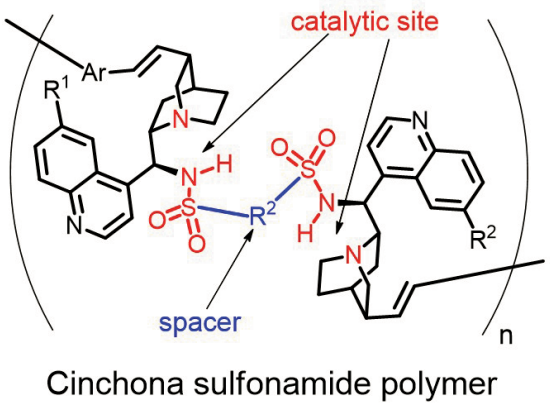
"We have found that Mizoroki-Heck coupling was successful in synthesizing cinchona sulfonamide polymers," explains the leader of the research team, Professor Shinichi Itsuno, "Moreover, our chiral polymers showed high catalytic activity in asymmetric reactions." Various kinds of such chiral polymers may be synthesized using this newly developed methodology to obtain various types of synthetic enzymes for specific reactions.

Furthermore, the chiral polymers developed in this study are insoluble in the usual organic solvents or water. The insoluble polymeric catalysts can be packed into a column, into which the substrate compounds can be introduced. The desired product can then be continuously obtained from the column. Without a usual reaction vessel, a continuous flow system may be possible using the polymeric catalyst. The flow system is a necessary technology for the automation of fine chemical syntheses.

Funding agency: This work was partly supported by a Grant-in-Aid for Scientific Research on Innovative Areas "New Polymeric Materials Based on Element-Blocks (No.2401) and Scientific Research (C) JSPS KAKENHI Grant Number JP15H00732, JP15K05517."

Reference

Shohei Takata, Yuta Endo, Mohammad Shahid Ullah, and Shinichi Itsuno (2016). Synthesis of cinchona alkaloid sulfonamide polymers as sustainable catalysts for the enantioselective desymmetrization of cyclic anhydrides, RSC Advances, 6 (76), 72300-72305. 10.1039/C6RA14535C



Cinchona sulfonamide polymer

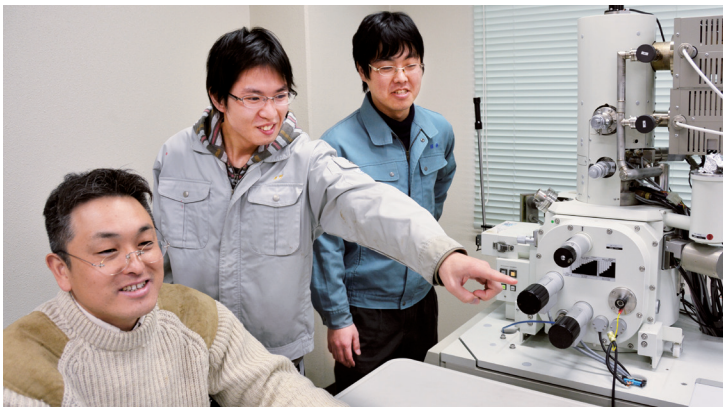
Structure of cinchona sulfonamide polymer

Development of a new thermoelectric material for a sustainable society

The first synthesis of bulk CaMgSi with thermoelectric properties

By Yoshikazu Todaka

Yoshikazu Todaka and his colleagues, in cooperation with researchers at the Nagoya Institute of Technology, have developed a new thermoelectric material, Calcium-Magnesium-Silicide (CaMgSi), which consists of non-toxic, cheap, and lightweight elements.
These findings could contribute to the development of green energy technology.



Professor Todaka(left) with his students

Thermoelectric materials, which can directly convert thermal energy into electrical energy (Seebeck effect), can be effectively used for the development of a clean and environmentally compatible power-generation technology.

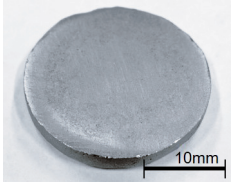
However, these materials are not commonly used for practical applications as they mostly include toxic and/or expensive elements.

Recently, Professor Yoshikazu Todaka and his research group from Toyohashi University of Technology's Materials Function Control Laboratory and the Nagoya Institute of Technology have successfully synthesized a new thermoelectric material, CaMgSi, which is an intermetallic compound. The key to this development was the synthesis procedure; bulk CaMgSi intermetallic compound was synthesized by combining mechanical ball-milling (MM) and pulse current sintering (PCS) processes.

"Significant thermoelectric properties in the intermetallic compound, CaMgSi, have been predicted by both theoretical and experimental studies", explain the researchers of this work, Nobufumi Miyazaki and Nozomu Adachi. " However, the biggest issue in front of us was the synthesis of thermoelectric CaMgSi of optimal size ", they continued. In general, alloys are produced by mixing the constituent elements in their molten forms. However, Mg vapors when the temperature is raised up to the melting temperature of Si; Ca, Mg, and Si can no longer exist in their liquid states.

Yoshikazu Todaka says "To overcome the aforementioned problem, we chose the mechanical ball milling process to mix the elements homogeneously, without melting, and then a chemical reaction between Ca, Mg, and Si was induced using the pulse current sintering process".

Consequently, it became possible to synthesize the intermetallic compound, CaMgSi, on a sufficient scale. The thermoelectric property of the synthesized CaMgSi exhibited a performance comparable to that of the previously developed Mg-based thermoelectric materials. It is expected that the slight change in the composition of CaMgSi and the addition of a fourth element to CaMgSi will further enhance its thermoelectric properties. Interestingly, they found that the novel thermoelectric material can exhibit both n- and p-type conductivity. Such a property is very significant for the application of such material in power-generation modules.



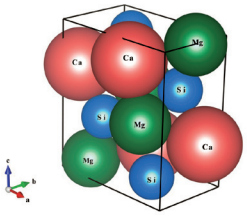
Picture of the synthesized bulk CaMgSi thermoelectric material through the procedure developed in this study.

The new thermoelectric material synthesized in this study is composed of lightweight elements, and has a low density of 2.2 g/cm3. Therefore, one of the possible applications of the material is in automobiles to utilize waste heat emitted from engines. These findings could contribute to the development of green energy technology.

This study was supported by Iketani Science and Technology Foundation (Grant No. 0271039-A). A part of this study was performed at the BL02B2 beamline of the SPring-8 synchrotron radiation facility with the approval of the Japan Synchrotron Radiation Research Institute (Proposal No. 2014B1237).

Reference

Nobufumi Miyazaki, Nozomu Adachi, Yoshikazu Todaka, Hidetoshi Miyazaki, and Yoichi Nishino (2017). Thermoelectric property of bulk CaMgSi intermetallic compounds, Journal of Alloys and Compounds, 691, 914-918. 10.1016/j.jallcom.2016.08.227



Schematic illustration of the atomic structure of the synthesized CaMgSi determined by X-ray diffraction.

全固体電池用ガーネット型酸化物イオン伝導体の開発

稲田　亮史

稲田亮史准教授らの研究グループは、優れた特性を有するガーネット型酸化物イオン伝導体を開発しました。開発した酸化物イオン伝導体は、室温下にて1mS/cm程度の高いイオン伝導率と優れた電気化学的安定性を備えています。また、本材料を固体電解質として試作した全固体電池にて、可逆的な充放電動作を確認することに成功しました。この結果は、大型電源への応用に適した安全性の高い蓄電池の実現に役立つものです。

充放電可能な全固体リチウム電池は、高いエネルギー密度と安定性・信頼性を同時達成可能な次世代型蓄電池として期待されています。全固体電池用固体電解質として使用される材料には、高いイオン伝導率に加えて優れた化学的安定性が求められます。

酸化物系固体電解質は硫化物系固体電解質と比較して、化学的安定性やハンドリングの容易さの観点で優位です。一方で、優れた電池特性を得るために必要不可欠な電極材料と酸化物固体電解質の接合界面の構築が実用に向けた大きな課題として残されています。

電気・電子情報工学系の稲田亮史准教授らの研究グループは、全固体リチウム電池への応用が期待できるガーネット型酸化物リチウムイオン伝導体を開発しました。さらに、開発材料を固体電解質とした全固体リチウム電池を試作し、その充放電特性を評価しました。

研究グループは、母材料であるLi7La3Zr2O12（リチウム・ランタン・ジルコニウム・酸素、LLZO、図1）に複数の異元素（バリウムBa、タンタルTa）を同時置換した際の結晶相、微細組織およびイオン伝導特性への影響を系統的に調査しました。高いイオン伝導特性を示す立方晶ガーネット構造を安定化するために、分子式中のリチウム量は6.5に固定しました。このため、材料組成は
$Li_{6.5}La_{3-x}Ba_xZr_{1.5-x}Ta_{0.5+x}O_{12}$
(LLBZTO) で表されます。

結果として、Ba，Ta置換量を各々0.1，1.6としたLLBZTOガーネットにおいて、最も高い室温イオン伝導率0.83mS/cmが得られました（図1）。イオン伝導率の活性化エネルギーはBa置換量の増加と共に単調減少する傾向が見られましたが、過剰なBa置換は伝導率の低下を引き起こすことを見出しました。

加えて、同研究グループは、開発したLLBZTOガーネットがリチウム電極基準で0－6Vと広い電位窓（※1）を有し、全固体電池を構成する際に、様々な正極・負極材料との組み合わせが可能であることを確認しました。チタン－ニオブ複酸化物TiNb2O7（TNO）薄膜電極をLLBZTOガーネット上に形成し、対極を金属リチウムとして試作したTNO/LLBZTO/Li全固体電池にて、可逆的な充放電反応を確認することに成功しました（図2）。

本研究の成果は、開発したLLBZTOガーネットが全固体電池用固体電解質として適用可能であることを示しており、大型電源への応用に適した安全性の高い蓄電池の実現に役立つものです。実用化に向けては更なる電池性能の向上が必要不可欠で、現在同研究グループは全固体電池のエネルギー密度向上に向けた様々な検討を進めています。

本研究成果は、平成28年7月20日（水）にFrontiers in Energy Research誌上に掲載されました。

本研究の一部は日本学術振興会（JSPS）科学研究費助成事業（課題番号26630111および16K06218）の支援の下で実施されたものです。

世界初の迷路磁区を使った磁気光学Qスイッチレーザー

新原理に基づいた国産Qスイッチレーザーの発想から実証まで

後藤　太一

豊橋術科学大学，アイオワ州立大学，分子科学研究所の研究者らは，共同で磁場と光の相互作用である磁気光学効果を発現する膜を用いた，集積化可能なQスイッチレーザーの開発を世界で初めて成功させました。本成果は小型高出力レーザーの発展に寄与するものです。

高出力、高繰り返し、高安定な小型レーザーは、日々の製造プロセスを、よりシンプルで、低コスト、スピーディーなものに変えうると期待されています。ドイツでは、製造現場のデジタル化（高度情報化）がもたらす製造業の変革をインダストリー4.0と名付けられ、全工程の制御自動化が一つのキーポイントとなってきており、レーザー加工はこれに大きく寄与し得ます。小型高出力レーザーの適用先は、これにとどまらず、自動車エンジンの点火プラグや、宇宙開発用スラスターシステムでの利用など多岐に渡ります。

しかし、これまで、レーザーが出るタイミングや、繰り返し回数などが、制御可能で集積化可能な固体レーザー向けのQスイッチ素子は無く、開発が切望されていました。制御可能なQスイッチ素子は、電気光学素子や音響光学素子が広く知られていましたが、光学素子の付属が必要であったり、分厚い結晶を用いる必要があったりと、原理的にmm以下の小型化が不可能でした。更にどちらも複雑かつ大型の制御電源が必須であり、小型レーザー本体のコンセプトにそぐわないものでした。

豊橋術科学大学電気・電子情報工学系の後藤太一助教、分子科学研究所、アイオワ州立大学の研究者らのグループは、迷路状の磁気ドメインをもつ厚さ190マイクロメートル（マイクロは１０万分の１）の透明磁性材料を用いて、初めて、膜のQスイッチの開発に成功しました。磁気ドメインとは、磁石のN極とS極が膜の面の中に、ランダムに点在することによって生じるもので、磁気のまだら模様と言い表すことができます。実験では、高速磁気パルスを、透明磁石材料に印加し、パルス幅45ナノ秒（ナノは1億分の1）、ピーク値約20ワットの、Qスイッチレーザーの取得に成功しました。これは、集積化可能な磁石材料を使った世界で初めてのQスイッチレーザーの結果報告となります。

さらに、磁性体の強みを活かし、小型永久磁石を、透明磁石材料の近くに設置することで、レーザーパルス発生に必要な電流を、7分の1にまで、低減できることを実験によって示し、チップに収まる程度の小型の制御回路で、同機能が実現できることも示しました。本成果は小型高出力レーザーの発展に大きく寄与することが期待されます。

本研究は以下の助成を受けて行われました。
・日本学術振興会　科研費　26706009，26600043，26220902，25820124，15H02240
・国立研究開発法人 科学技術振興機構 さきがけ

不斉合成のための合成酵素の開発

高度な不斉反応触媒活性を有するシンコナアルカロイドスルホンアミド型高分子

伊律野　真一

シンコナアルカロイド誘導体は、金属を使用しないキラル有機分子触媒として、様々な不斉反応の触媒として作用することが知られています。豊橋技術科学大学の研究グループは、スルホンアミド型シンコナアルカロイドを主鎖構造に組み込んだ合成高分子の新規合成法に成功しました。得られたキラルシンコナスルホンアミド高分子は高度な不斉触媒活性を示し、今後の合成酵素開発に大きく貢献する成果を得ました。

生体内で必要とされる様々な化学反応を行うために酵素が活躍しています。酵素は、タンパク質であり分子量の大きな巨大分子（高分子）化合物です。酵素は基質分子を間違いなく取り込み、反応を触媒し、生成物を放出する、という重要な働きを担っています。このような働きを実現するためには、触媒である酵素が巨大分子であることが極めて重要です。このような観点から、合成高分子であって高度な触媒活性を有する分子（合成酵素）の開発は、ファインケミカル合成分野で欠かせない技術であるはずですが、これまでにこのような合成高分子触媒の合成法そのものがほとんど研究されていませんでした。本研究では、一つの不斉反応に焦点をしぼり、その反応を効率よく触媒することのできるキラル高分子不斉触媒の開発に取り組みました。

シンコナアルカロイド誘導体が、多くの不斉反応の触媒として有効に働くことが知られているので、これを高分子の繰り返し単位として高分子主鎖構造中に組み込むことができれば、高分子不斉触媒のもっとも単純な形としてのキラル高分子を得ることができます。これまでにシンコナアルカロイド類の高分子化または高分子主鎖への組み込みついては報告例がありませんでした。本研究では、シンコナアルカロイドの持つ多彩な官能基を巧妙に利用して触媒活性部位を全く損なうことなく、高分子主鎖構造に組み込むことに成功しました。この高分子化のキーとなる反応は、溝呂木 - Heck反応です。溝呂木 - Heck重合法の開発により、初めてシンコナスルホンアミド型高分子を合成することができました。

得られたキラル高分子が触媒として働くかどうかが重要です。本研究では、実際に酸無水物の非対称化反応にこのキラル高分子を用いたところ、非常に高い触媒活性を示すことを明らかにしました。この高分子は通常の有機溶媒に溶けないため、反応後に回収することが極めて容易で、回収した高分子は触媒として何度でも使うことができます。将来的には、カラムに充填して原料化合物をその中に流すだけで、連続的に有用な生成物を連続的に取り出せるフローシステムへの応用が可能です。

本研究は、文部科学省・日本学術振興会科研費（JP15H00732，　JP15K05517）の補助を受けて行われました。

持続可能な社会に向けた新熱電材料の開発

新規熱電材料CaMgSiの初合成

戸高　義一

豊橋技術科学大学の戸高義一准教授と名古屋工業大学の研究チームは、無害・安価・軽量な元素のみで構成された新規熱電材料CaMgSiの開発に成功しました。この発見により、グリーンエネルギー技術の発展が加速されると予想されます。

「熱電材料」はゼーベック効果により熱エネルギーを電気エネルギーに直接変換可能なクリーンで環境適応性が高い発電材料です。しかし、ほとんどの熱電材料が有害元素や高価な元素を含むため、応用例は限られています。

そのような現状の中で、研究チームは「CaMgSi金属間化合物」という新規な熱電材料の開発に成功しました。この新規熱電材料CaMgSiの開発のキーとなる技術に、材料作製技術があります。本研究では、メカニカルボールミリング法とパルス電流焼結法を組み合わせた作製技術が採用されています。

CaMgSiに熱電特性があろうことは、理論・実験の両研究からも予想は出来ていましたが、この研究の一番の問題は如何に単体のCaMgSiを熱電材料に足る大きさで作製するかでした。金属間化合物のような合金の作製は、それぞれの元素を溶かして液体状態で混ぜ合わせる溶製法を用いるのが一般的です。しかしCaMgSiでは、温度をSiの融点がMgの沸点を超えており、3元素の液体状態を同時に得ることが出来ません。この問題を克服するために、メカニカルボールミリングにより各元素を溶解させること無く機械的に混合した後に、パルス電流焼結により化合物形成反応を促すことでCaMgSiを作製する方法を編み出しました。

その結果、充分な大きさのCaMgSi金属間化合物の作製に成功しました。作製したCaMgSiは過去に開発されたMg系熱電材料に匹敵する特性を示しました。今後の研究で、CaMgSiの組成を少し変更することや第4元素を添加したCaMgSiを作製することによって、より優れた熱電特性を発現する可能性があります。また、p型、n型の導電性を有するよう容易に制御できることが明らかになりました。この特性は、実際のモジュールへ応用する際に重要となります。CaMgSiは、軽量な元素のみで構成されていることから、その密度は2.2g/cm^{3}と小さいことも特徴です。従って、エンジン部等からの排熱を再利用する発電デバイスを自動車に搭載することが将来の応用先として考えられます。

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Pick Up

TUT symposium - “From the East Mikawa Area of Japan to the World”

Toyohashi University of Technology launched the “Research Institute for Science and Technology Innovation” in April 2016, accompanied by the commencement of16 cutting edge collaborative research projects with local companies, universities overseas, and national institutions. In this symposium, TUT reported the progress and results of these world leading research projects under the title of “From the East Mikawa Area of Japan to the World - Creation of new values by Industry-Academia-Government Collaborations”. A panel discussion with senior representatives of national and local governments, industries and academia was also held as a part of the symposium.

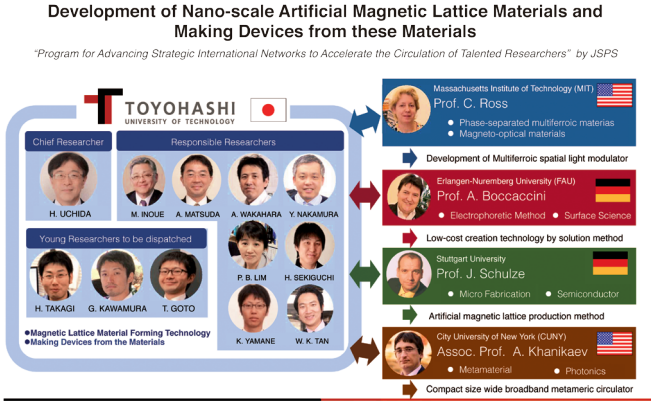
Schedule:

Date	14th February, 2017
Time	12:30 - 17:30
Place	Hotel Associa Toyohashi, Japan

TUT accelerates the circulation of young talented researchers across the globe

TUT started an international research project in collaboration with four universities in the United States and Europe; Massachusetts Institute of Technology (USA), City University of New York (USA), Erlangen- Nuremberg University (Germany) and Stuttgart University (Germany). The goal of this project is the development of novel functional materials for controlling light and electromagnetic waves and making devices from these materials. The project is supported by the Japan Society For the Promotion of Science (JSPS) – “Program for Advancing Strategic International Networks to Accelerate the Circulation of Talented Researchers”.

This JSPS program aims to develop high level young Japanese researchers who will form the nucleus of international networks. These networks will tap into top level talent worldwide, and be made up of promising Japanese research groups and members of top-ranked overseas research institutions. Their goal will be to jointly carry out international research projects.



Overview of the project

TUT Research
e-Newsletter from Toyohashi University of Technology
http://www.tut.ac.jp/english/newsletter/

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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