TUT Research
e-Newsletter from Toyohashi University of Technology

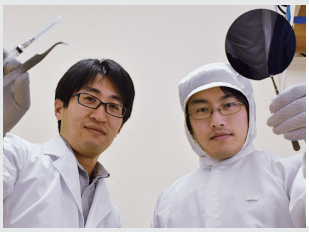
No.9 May 2017

FEATURE STORY

Professional in research and development of new materials through transmission electron microscopy (TEM)

Professor Hiromi Nakano has been observing and analyzing materials by transmission electron microscopy (TEM) for many years at companies and universities.

Research Highlights

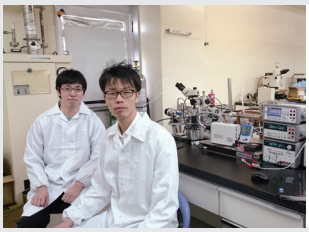


Can the brain feel it? The world´s smallest extracellular needle-electrodes 5

Single 5 μm diameter needle electrode block modules for unit recordings *in vivo*

Using an air conditioner in summer may affect sleep quality 6

The research suggests that sleep quality may be affected by subtle insensible airflow



Microhotplates for a smart gas sensor 7

Easy way of fabricating miniature hotplates

Nano-polycrystalline film leads to stronger magnetism compared to single-crystal films 8

Oxygen defects like nanopillars enhanced magnetic and magnetooptical response of STF films

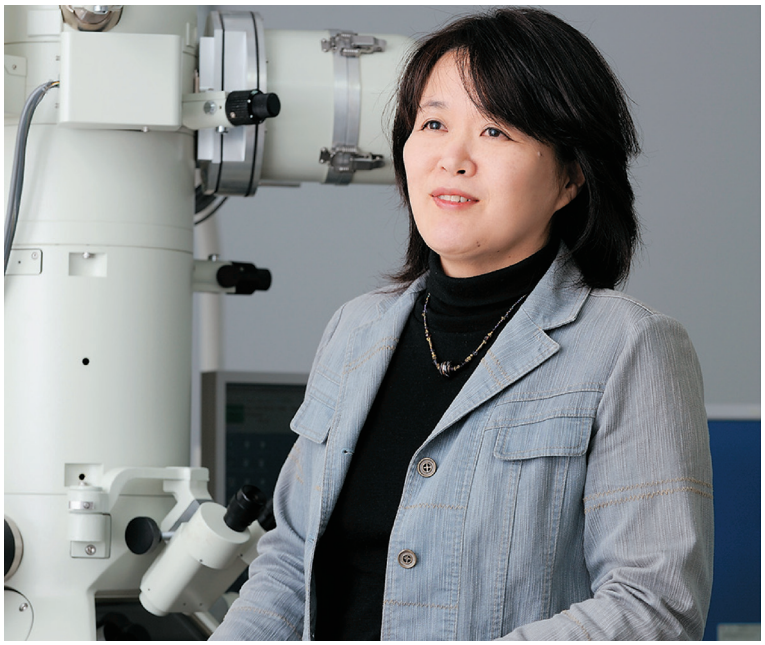
Pick Up

TUT symposium on “Changing Global Communication with AI - Ubiquitous Machine Translation” 12

One milestone toward TUT Multicultural Global Campus 12

Professional in research and development of new materials through transmission electron microscopy (TEM)

Hiromi Nakano



Professor Hiromi Nakano has been observing and analyzing materials by transmission electron microscopy (TEM) for many years at companies and universities. She is a TEM professional who is now attracting attention from domestic and foreign researchers and enterprises for her tenacious efforts in areas such as discovering unknown material properties and developing new materials with controlled crystal structure and texture at the atomic level. Recently, she succeeded in developing innovative new oxide phosphors used for white LEDs together with students in her lab. We talked with her about the contents of her research and the beliefs that guide it.

Interview and report by Madoka Tainaka

Tenacity is indispensable for TEM observations

"My specialty is to do material analysis using a transmission electron microscope (TEM)," Professor Hiromi Nakano says.

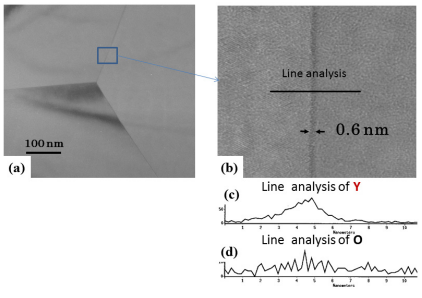
A TEM is an electron microscope that irradiates an observation specimen with an electron beam and searches the microstructure of the surface or interior of the observation object with the transmitted electron beam. With TEM, it is possible to analyze the texture and crystal structure of materials at the atomic level, and the technique is widely used for analyzing everything from inorganic materials such as ceramics and metals to organic materials and biomaterials. TEM is useful for material property control and new material design, and is an indispensable device for nanotechnology development. It is also used in various fields such as materials engineering, biology and medicine because researchers can observe samples while heating or cooling them, making it possible to capture images of shape change and behavior of nanoparticles due to temperature change.

"However, you must be very persistent to make observations with TEM. To be able to transmit the electron beam, the thickness of the sample must be 0.1 μm or less with a diameter within 3 mm. To achieve this one punctures the center of the sample with an argon ion beam, but if it is a thin laminated material, important parts may be peeled apart in the course of fabricating the thin film samples. If this happens one must start over again from the beginning. With difficult samples, it sometimes takes more than two months to make one thin film sample," says Nakano.

Nakano was once requested to observe aluminum nitride, which has the world's highest level of high thermal conductivity, by TEM. The material was produced by adding yttrium oxide to aluminum nitride as a sintering aid and applying heat treatment in a reducing atmosphere. Its high thermal conductivity was believed to be a result of the loss of the grain-boundary phase from that process. However, Professor Nakano was able to demonstrate with TEM photography that the grain-boundary phase remained even after heat treatment for 100 hours.

"When I presented a TEM image showing a thin layer containing 0.6 nm of yttrium including at the grain boundary at a conference, the place erupted. I was an unknown researcher at that time, and researchers didn't believe me even though I showed them the TEM picture as evidence. The researchers who were present exclaimed, 'We have taken images many times, but could not observe the grain-boundary phase, so why is it only you that found it?' I replied, 'It's perseverance.' After that, I became called 'The person with perseverance' for a while," says Nakano, laughing.

It was an accomplishment that was achieved as a result of Professor Nakano's observation technique that makes grain boundaries precisely vertical to the electron beam. To that extent, Nakano says that TEM research requires a certain amount of skill and tenacity, and, above all, beliefs which are firmly rooted in theory.



TEM image which is the origin for Prof. Nakano becoming called ´The person with perseverance´

Development of phosphor materials started from an educational viewpoint

However, Nakano also feels that it is difficult for students with a limited research period to be forced to only do TEM research. “Especially recently, there is a strong tendency to seek results as soon as possible,” says Nakano. Therefore, in recent years, she has been working in the laboratory on the development of oxide phosphor materials used in white LEDs.

For white LEDs used in applications such as lighting and LCD monitors, methods such as combining yellow phosphor on a blue LED chip or combining red, green and blue phosphors on a near ultraviolet LED chip are used. While the former has the merit that it can be realized at a low cost, there is the demerit that the combination of only blue and yellow has poor color rendering properties and only a cold white can be reproduced.

“For this reason, I started thinking about red oxide phosphor. It can be sintered at a lower temperature than nitride phosphor that is currently used at normal pressure, and because it is an oxide, it is highly stable, and is also easy to procure. It is also non-toxic, of course.” Specifically, red phosphor is prepared with a Li-Ta-Ti-O system solid solution as a matrix then adding a rare earth or the like as an activator.

“The students are more motivated because we can confirm light emission only by shining light on a sample with phosphor. Of course, it is difficult to find good synthesis conditions, and there may be repeated failures, but in fact, there is no such thing as a failure. Sometimes, unexpected results are born from failure. Our mission as researchers is to derive mechanisms from there. I hope that as many students as possible can experience this real pleasure.”

Student is showing: New phosphors synthesized in her laboratory that brightly emit with red and green colors.

In January 2016, Nakano Laboratory succeeded in developing a superior material with internal quantum efficiency (the rate at which absorbed energy is converted to light) of 98% in phosphors with trivalent europium ions as luminescent center ions. This new technology was announced in the Nikkan Kogyo Shimbun. However, since the external quantum efficiency is about 40%, there is room for improvement, and Nakano plans to develop phosphor materials other than red while working in cooperation with companies for practical applications.

Aiming for research with originality

On the other hand, Professor Nakano continues to conduct research based on TEM concurrently. Recently, she presented the results of over four and a half years of research at an international conference as an invited speaker and summarized them in a paper.

“When making a polycrystalline oxide, if a very strong magnetic field is applied, the particles become oriented in a certain direction, and a relatively large bulk material like a single crystal can be made. As a result, I was able to create a material with high anisotropy in the high electrical property called the Qf value. I went to Austria and discussed why this occurs with a famous Indian researcher who is the expert on that topic, but I still did not understand the answer, so I was convinced that this must be a mechanism unique to this material.”

Actually, this material, an oxide derived from titanium, is a unique material that forms a singular periodic structure called an M-phase in a certain composition area, in the same way as phosphor. It took time and perseverance to synthesize and analyze the material, but results were achieved thanks to the tenacity of Professor Nakano.

By the way, Professor Nakano recently learned that the “M” of M-Phase is named after the female researcher Maria who first discovered this phase. They happened to meet two years ago at an international conference, and Nakano says that she was able to solve a long-standing puzzle. International conferences are important opportunities to meet world famous researchers and speak directly to them.

Prof. Nakano (right) and Dr. Maria who discovered M-Phase.

Professor Nakano says, “It is only meaningful to do research with high originality that no one has ever done before.” Thanks to her indomitable perseverance, she is being heralded as a role model for female researchers everywhere.

[Reporter’s Note]

Professor Nakano was born and raised in Sabae City, Fukui Prefecture, known as the city of glasses, and comes from a family of glasses’ frame makers. She says that she was a born engineer from an early age who became familiar with machines and tools such as ultrasonic cleaners and drilling machines in the workshop.

“I thought that life with its ups and downs was compelling as I watched my father, who was a designer and manufacturer of glasses frames.” After graduating from graduate school, she started to work at Murata Manufacturing Co., Ltd. where she was the first female to pass the promotion exam for a management career. However she left at the age of 29 and joined Ryukoku University. At 33, she married and had a child, after which she devoted herself to research without rest, returning to her alma mater, Toyohashi University of Technology, at the age of 50. Nakano has lived a varied life as a researcher.

“I was writing papers while raising my child, and there were times when it was hard, but I have survived through perseverance,” she laughs. That smile was full of the pride and brightness peculiar to someone who has braved the stormy seas.

透過型電子顕微鏡（TEM）のプロとして、新材料の研究開発を究める

企業および大学において、長年にわたり、透過型電子顕微鏡（TEM）による材料の観察・解析を行ってきた中野裕美教授。粘り強い取り組みで、未知の材料特性を発見したり、原子レベルで構造・組織を制御した新材料を開発したりするなど、いまや国内外の研究者や企業から注目を集めるTEMのプロフェッショナルである。最近では、学生とともに白色LEDに用いられる酸化物蛍光体において、画期的な新材料の開発に成功した。その研究内容と研究者としての信念を聞く。

TEM による研究には粘り強さが不可欠

「私の専門は、透過型電子顕微鏡（TEM）を使って材料解析をすることです」と語る中野裕美教授。

TEM とは、観察対象に電子線を照射し、透過した電子線により、観察対象の表面や内部の微細構造を探る電子顕微鏡である。TEM では原子レベルでの組織・構造解析が可能で、セラミックスや金属といった無機材料から有機材料、生体材料までと幅広く利用され、材料の物性制御や新素材設計に役立てられるなど、ナノテクノロジーの進展に欠かせない装置だ。試料を加熱、あるいは冷却しながら観察し、温度変化によるナノ粒子の形状変化や挙動などを撮像することもできるため、材料工学をはじめ、生物学や医学など、さまざまな分野で活用されている。

「ただ、TEM による観察というのはとても根気がいるんです。電子線を透過させるために、試料の厚みは 0.1 μm 以下で、直径 3 mm 以内の薄片にする必要があります。そのため、中心部にアルゴンのイオンビームで穴を開けていくのですが、薄く積層している材料だと、薄片試料作製の過程で大事な箇所がぼろっと剥がれてしまうことがある。そうすると、またーからやり直しです。難しい試料の場合には、一つの薄片試料を作製するのに 2 カ月以上かかることもありました」と中野教授は語る。

かつて中野教授は、世界最高レベルの高熱伝導率を有する窒化アルミニウムの材料を、依頼されて TEM で観察したことがあった。その窒化アルミニウムは、緻密化と熱伝導率を向上させるため、焼結助剤として酸化イットリウムを添加した材料で、還元雰囲気下で熱処理をすることにより、粒界相は消失し、それによって熱伝導率が高まると考えられてきた。ところが、中野教授は、100 時間熱処理しても、粒界相は残存するという、証拠のTEM写真の撮像に成功したのだ。

「学会で、粒界に残る 0.6 nm のイットリウムを含む薄い層が写ったTEM写真を発表したら、その場が騒然としたんです。当時はまだ無名だったこともあり、証拠のデータを見せてもなかなか信じてもらえず、居合わせた研究者から、『僕たちは何度も撮影したが、粒界相は見えなかった。なぜ、あなたにだけ見えるんですか？』と詰め寄られたほど。思わず、『根性で観察したんですよ』と言い返したら、その後しばらく、“根性の人”と呼ばれる羽目になりました」と笑う。

それは、粒界を電子線に対して正確に垂直に立てる観察技術を持つ中野教授だからこそ成し遂げた快挙だった。それほどに、TEM を用いた研究には、確かなスキルと粘り強さ、そしてなによりも理論に基づく信念が必要なのだという。

教育的な観点から蛍光体材料の開発へ

しかし、研究期間が限られる学生に TEM の研究だけを強いるのは難しいとも感じている。「とくに最近は、結果を早く求める傾向が強い」と中野教授は言う。そこで研究室では、近年、白色 LED で使われる酸化物蛍光体の開発を手がけている。

照明や液晶モニターなどに採用される白色 LED には、青色の LED チップに黄色の蛍光体を組み合わせたり、近紫外の LED チップに赤・緑・青の蛍光体を組み合わせたりする方法などがあるが、前者は廉価に実現できるというメリットがある一方で、青と黄色の組み合わせだけでは演色性に乏しく、寒々しい白色しか再現できないというデメリットがある。

「そうしたことから目をつけたのが赤色の酸化物蛍光体です。現在、実用化されている窒化物蛍光体に比べて低い温度かつ常圧で焼成でき、酸化物なので安定性も高く、材料も手に入れやすいのが特長です。もちろん毒性もありません」具体的には、Li-Ta-Ti-O 系の固溶体を母体とし、これに希土類などを賦活材として添加して赤色蛍光体をつくる。

「蛍光体というのは、光を当てただけで発光を確認できるので、学生たちの目の色が変わるんですね。もちろん、なかなかいい合成条件が見出せず、失敗が続くこともありますが、本当は失敗なんて一つもない。ときには、失敗から思いがけない成果が生まれることもあります。そこからメカニズムを導き出すのが、我々、研究者の使命。その醍醐味を一人でも多くの学生にも経験してほしいですね」

2016 年 1 月、中野研究室では、3 価のユウロピウムイオンを発光中心イオンとする蛍光体において、内部量子効率（吸収したエネルギーが光に変わる率）98%という、すぐれた材料の開発に成功し、日刊工業新聞にその新技術が掲載された。ただ、外部量子効率は 40%程度と改良の余地があることから、今後は実用の用途に合わせ、企業と連携しながら、赤色以外の蛍光体材料開発にも取り組んでいく予定だ。

オリジナリティのある研究をめざして

一方で、中野教授は、TEM を基盤とした研究も並行して続けている。最近、4 年半越しの研究成果を国際会議の招待講演で発表し、論文にまとめている。

「多結晶の酸化物をつくる際に、非常に強い磁場をかけると、粒子が一定の方向に配向し、比較的大きい、まるで単結晶のようなバルク体が作製できます。その結果、Qf 値と呼ばれる電気特性の高い異方性を有する材料を創製することができたのです。なぜそうなるのか、オーストリアまで赴き、その道の専門家であるインド人の著名な研究者と議論したのですが、それでも答えがわからなかった。そのとき、これはこの材料特有のメカニズムに違いないと確信したのです」

実は、この材料も先の蛍光体と同じく、チタン由来の酸化物で、ある組成域でM - 相と呼ばれる、特異な周期構造を形成するユニークな材料である。その合成と解析には、時間と根気がかかったが、それを中野教授の持ち前の粘り強さで成し遂げたことで成果に導いた。

ちなみに、M- 相の “M” は、この相を最初に発見した女性研究者のマリアという人の名にちなむことを、中野教授は最近になって知った。一昨年、国際会議で偶然の出会いがあり、本人からそのことを告げられ長年の疑問が解けたという。国際会議は、世界の著名な研究者と出会い、直接話せる大事な機会の場でもあるのだ。

「まだ誰も手をつけたことがない、オリジナリティの高い研究を手がけることにこそ、意味がある」と語る中野教授。根気強く挑戦を続ける中野教授の姿はいま、女性研究者のロールモデルとしても注目を浴びている。

（取材・文＝田井中麻都佳）

取材後記

中野教授は、メガネの街として知られる福井県鯖江市で、メガネフレームの制作をする家に生まれ育った。幼い頃から、仕事場にある超音波洗浄機やボール盤などの機械や工具に慣れ親しんできた、生まれながらの「工学屋」だと自身を語る。

「メガネフレームのメーカーでもあり、デザインも手がけていた父親の背中を見ながら、浮き沈みのある人生も面白いなと思っていました」という言葉通り、大学院修了後は、村田製作所に務め、女性初の総合職として昇格試験にも合格したが、29 歳で退職し、龍谷大学へ。33 歳で結婚して一児を授かり、その後も休むことなく研究に専念し、50 歳のとき母校である豊橋技科大に赴任。変化に富む研究者人生を歩んできた。

「子育てをしながら論文を書き、大変なときもありましたけど、それこそ根性で乗り切ってきました」と笑う。その笑顔は、荒波を乗り越えてきた人特有の自負と明るさに溢れていた。

Researcher Profile

Dr. Hiromi Nakano received her B.S., M.S., and Dr. (Eng.) from Toyohashi University of Technology, Japan in 1981, 1983 and 2000, respectively. She joined Murata Manufacturing Co., Ltd. in 1983 then transferred to Ryukoku University in 1989. She joined the Cooperative Research Facility Center in Toyohashi University of Technology as an associate professor in 2009 and presently works as a professor and presidential advisor (Gender Equality). Her current interest is in the synthesis of new phosphors and characterization of ceramic materials using a transmission electron microscope to control of the material properties and the design of new materials.

Reporter Profile

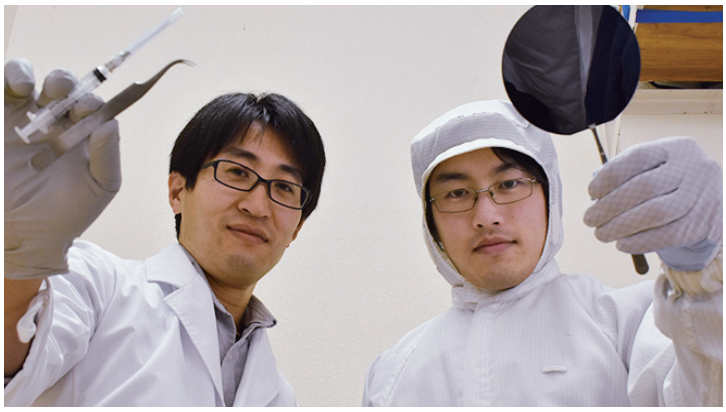
Madoka Tainaka is a freelance editor, writer and interpreter. She graduated in Law from Chuo University, Japan. She served as a chief editor of “Nature Interface” magazine, a committee for the promotion of Information and Science Technology at MEXT (Ministry of Education, Culture, Sports, Science and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

Can the brain feel it? The world´s smallest extracellular needle-electrodes

Single 5 μm diameter needle electrode block modules for unit recordings *in vivo*

By Hirohito Sawahata

Hirohito Sawahata and his colleagues have developed the world's smallest 5-μm-diameter low-invasive needle electrodes, which are assembled on 1 × 1 mm 2 blocks. Surprisingly, high quality neuronal signals from a mouse's cortex were stably recorded for a long period by this device. This new electrode device reduces the total invasiveness to brain tissue *in vivo* and realizes stable neural recordings, thus enhancing opportunities for needle-electrode device technology in neurophysiology.



Project Assistant Professor Hirohito Sawahata (left)

A research team in the Department of Electrical and Electronic Information Engineering and the Electronics-Inspired Interdisciplinary Research Institute (EIIRIS) at Toyohashi University of Technology developed 5-μm-diameter needle-electrodes on 1 mm × 1 mm block modules. This tiny needle may help solve the mysteries of the brain and facilitate the development of a brain–machine interface. The research results were reported in Scientific Reports on Oct 25, 2016.

The neuron networks in the human brain are extremely complex. Microfabricated silicon needle-electrode devices were expected to be an innovation that would be able to record and analyze the electrical activities of the microscale neuronal circuits in the brain.

However, smaller needle technologies (e.g., needle diameter < 10 μm) are necessary to reduce damage to brain tissue. In addition to the needle geometry, the device substrate should be minimized not only to reduce the total amount of damage to tissue but also to enhance the accessibility of the electrode in the brain. Thus, these electrode technologies will realize new experimental neurophysiological concepts.

The individual microneedles are fabricated on the block modules, which are small enough to use in the narrow spaces present in brain tissue; as demonstrated in the recording using mouse cerebrum cortices. In addition, the block module remarkably improves the design variability in the packaging, offering numerous *in vivo* recording applications.

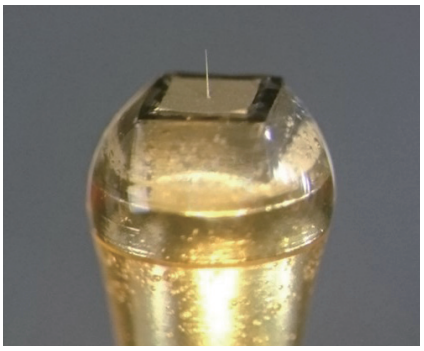


Fig.1 Extracellular needle-electrode with a diameter of 5 μm mounted on a connector

"We demonstrated the high design variability in the packaging of our electrode device, and *in vivo* neuronal recordings were performed by simply placing the device on a mouse's brain. We were very surprised that high quality signals of a single unit were stably recorded over a long period using the 5-μm-diameter needle," explained the first author, Assistant Professor Hirohito Sawahata, and co-author, researcher Shota Yamagiwa.

The leader of the research team, Associate Professor Takeshi Kawano said: "Our silicon needle technology offers low invasive neuronal recordings and provides novel methodologies for electrophysiology; therefore, it has the potential to enhance experimental neuroscience." He added, "We anticipate its contribution to the development of applications to solve the mysteries of the brain and the development of brain–machine interfaces."

This work was supported by Grants-in-Aid for Scientific Research (S) (No. 20226010), (A) (No. 25249047, No. 26242088), for Young Scientist (A) (No. 26709024), the PRESTO Program from JST, and Strategic Advancement of Multi-Purpose Ultra-Human Robot and Artificial Intelligence Technologies program from NEDO. Rika Numano was also supported by a Grant-in-Aid for Scientific Research (C) (No. 24590350), the Asahi Glass Foundation, and the Takeda Science Foundation.

Reference

Hirohito Sawahata, Shota Yamagiwa, Airi Moriya, Teo Dong Sheng, Hideo Oi, Yoriko Ando, Rika Numano, Makoto Ishida, Kowa Koida, and Takeshi Kawano (2016). Single 5 μm diameter needle electrode block modules for unit recordings *in vivo*. Scientific Reports. Article first published online: 25th of October 2016.
http://dx.doi.org/10.1038/SREP35806

Using an air conditioner in summer may affect sleep quality

The research suggests that sleep quality may be affected by subtle insensible airflow

By Kazuyo Tsuzuki

Professor Kazuyo Tsuzuki, in collaboration with the National Institute of Advanced Industrial Science and Technology and Asahi Kasei Homes, conducted research on the influence of the airflow from air conditioners on sleep. Using an air conditioner helps people to sleep better on sweltering nights. However, researchers found that when airflow is directed at a human body, even at an insensible velocity, it impacts on sleep conditions causing sleeping positions and affects the depth of sleep.

Professor Kazuyo Tsuzuk (3rd from right, front raw) with her laboratory members

A study by a joint research team including professor Kazuyo Tsuzuki of Toyohashi University of Technology, the Department of Architecture and Civil Engineering, the National Institute of Advanced Industrial Science and Technology and Asahi Kasei Homes, has revealed that airflow from an air conditioner (AC) stimulates the human body while sleeping and impacts on sleep conditions even if the mean airflow velocity is lower than an insensible level. It suggests some AC settings may have an unintentional negative impact on sleep quality despite the comfort the person feels.

Urban warming blocks the temperature from cooling at night. It causes sweltering nights which impact sleep quality. However, high-quality sleep can still be realized if the room temperature is controlled effectively with an AC. The general belief is that having the AC on all night is bad for health. Also, quite a few of us experience chills while sleeping and awakening due to cold temperatures.

Airflow velocity in the sleeping environment can be configured with the AC. However, no data on airflow velocity measurement or research on the influence of AC airflow has been available up to now.

The research team, led by professor Kazuyo Tsuzuki, had the subjects sleep in two bedrooms set to the same temperature using ACs set at different airflow velocities, then made a comparison of the depth of sleep and body temperature control using electroencephalogram (EEG) measurements as well as subjective reporting by the subjects.

We call the air velocity of 0.2m/s or lower “insensible airflow”, in a sense, the person remains unaware of such a low level of airflow. In this study, a comparison was made on the influence of two types of airflow, with mean velocities of 0.14 m/s (general AC) and 0.04 m/s (customized AC), both at a room temperature of 26 °C. Subjects felt cooler with the higher airflow velocity during wakefulness and sleep. However, no significant difference was observed in the feeling of comfort, length of sleep depth, skin temperature, rectal temperature or sense of warmth or coolness in each subject before sleeping. General AC lowers airflow when the room temperature reaches the desired setting and starts increasing the flow again when the temperature is higher. The study compared the correlation between the timing of the airflow starting to blow and body movement, heart rate and waking stage in sleep depth. The

Fig.1 Subject in experiment (before sleeping)

results found that the subjects have significantly greater body movements, an increased heart rate and a higher frequency of waking in the room that has the AC with a mean velocity of 0.14 m/s. This suggests the general AC may have some influence on sleep, as we discovered that subjects roll over or their sleep depth changes the moment cool air blows out.

This study was conducted using healthy adult male subjects. It implies that the cold airflow may have a greater impact on the overall sleep of female and elderly subjects with lower physical strength or a greater sensitivity to cold. The result of this study is

expected to be a useful clue as to how to configure the airflow velocity of an AC to create a comfortable sleeping environment.

This research is the result of the study conducted by Professor Kazuyo Tsuzuki at the National Institute of Advanced Industrial Science and Technology. The research results were reported online in the Energy and Buildings journal on December 23, 2016.

This research was conducted with the Grants-in-Aid for Scientific Research #21300271 and #25282016 by Ministry of Education, Culture, Sports, Science and Technology and Japan Society for the Promotion of Science.

Reference

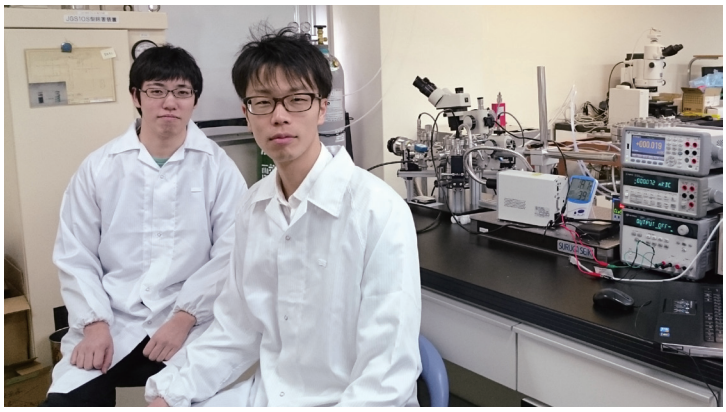
Morito, N., Tsuzuki, K., Mori, I., and Nishimiya, H. (2017). Effects of two kinds of air conditioner airflow on human sleep and thermoregulation. Energy and Buildings, 138,490-498.
http://dx.doi.org/10.1016/j.enbuild.2016.12.066

Microhotplates for a smart gas sensor

Easy way of fabricating miniature hotplates

By Tatsuya Iwata

Tatsuya Iwata and his colleagues have developed microhotplates (MHPs), in which an SU-8 photoresist was employed as a supporting material. The MHP can moderate the requirement for the layout design and the process condition of integrated smart gas sensors. Furthermore, the researchers confirmed that the MHP has a good thermal isolation property. It was demonstrated that the hotplate can be heated to 550 °C, and that it operates stably for 100 min.



Assistant Professor Tatsuya Iwata (right)

Gas sensors used for leakage alerts and air quality monitoring are essential in our daily lives. As we move towards a society where they are becoming ubiquitous, smart gas sensors, which perform signal processing and communication besides sensing, are increasingly gaining attention. In addition, integrating these functions into a single chip leads to low-cost and miniature smart gas-sensing systems.

Semiconductor gas sensors, which are the most widely used gas sensors, require a sensor material to be heated to several hundreds of degree Celsius. Therefore, in order to integrate these gas sensors with electronic circuits, a micro-hotplate (MHP), which is a MEMS-based heating structure, is required to thermally isolate the sensor and the circuits. The MHP is generally mechanically unstable, and there exists a tradeoff between the mechanical stability and thermal isolation property.

Recently, a research team led by Assistant Professor , Tatsuya Iwata has proposed the employment of SU-8 as a supporting material for the MHP, in order to improve the mechanical stability, while maintaining the thermal isolation. Furthermore, SU-8 is a polymer material that is widely used for microelectromechanical systems (MEMS) and has good mechanical stability and low thermal conductivity. The researchers fabricated the MHP and investigated its heating characteristics.

The first author Assistant Professor, Tatsuya Iwata, said that “By using a thick polymer film, it is possible to simultaneously realize the properties of mechanical stability and high thermal isolation. Furthermore, although we have yet to fully evaluate the mechanical stability, this device appears to be promising for use in smart gas sensors.”

“Mechanical stability is one of the major concerns for fabricating an MHP. Using a polymer material for such microhotplates seems to be an eccentric approach, but surprisingly, it went well. Moreover, this device will boost our study to develop multimodal sensors, which are multifunctional integrated sensors including gas sensors,” said Professor Kazuaki Sawada.

The fabricated MHP consists of a heating membrane with an area of

140 μm × 140 μm, and a 33-μm-thick SU-8 layer deposited on its bridges. The simulation confirmed that the MHP displayed good thermal isolation properties (Fig. 1). The MHP temperature was found to reach 550 °C at 5V. Moreover, the power consumption of the MHP approximately corresponded to 13.9 mW for heating to 300 °C, which is comparable with the power consumption reported in the previous studies. Furthermore, a stable operation under a constant voltage was observed for 100 min.

Owing to the thick SU-8 layer, the MHP does not need strict control of the stress that occurs inside the membrane during the fabrication process. This feature, together with the good thermal isolation property, facilitates the flexible layout design of the chip, and therefore, the MHP is beneficial to a miniature smart gas sensor chip. The researchers will advance their study to realize such smart gas sensors.

These research results were reported in the Journal of Micromechanics and Microengineering, on January 11, 2017.

Funding agency: Japan Society for Promotion of Science, Grant-in-Aid for Young Scientists (B), Grant Number 15K18049

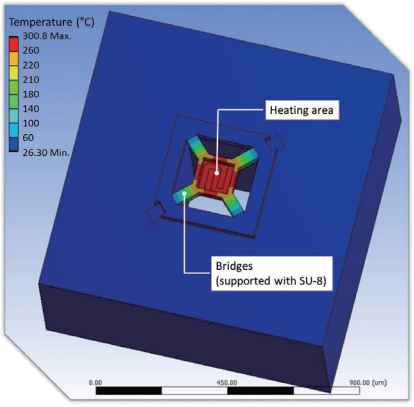


Fig.1 Simulation result of the temperature distribution in the proposed micro-hotplate.

Reference

T. Iwata, W. P. C. Soo, K. Matsuda, K. Takahashi, M. Ishida, and K. Sawada (2017), Design, fabrication, and characterization of bridge-type microhotplates with an SU-8 supporting layer for a smart gas sensing system, J. Micromechanics Microengineering, 27(2), 24003. https://doi.org/10.1088/1361-6439/aa556b

Nano-polycrystalline film leads to stronger magnetism compared to single-crystal films

Oxygen defects like nanopillars enhanced magnetic and magnetooptical response of STF films

By Taichi Goto

Taichi Goto and his colleagues have found that nanoscale pillar-shaped distribution of iron in strontium titanate changes its magnetic and magnetooptical response drastically. This research was achieved in cooperation with researchers at Myongji University, Harbin Institute of Technology, Massachusetts Institute of Technology, Universidad Técnica Federico Santa María, University of California, San Diego, and Trinity College Dublin. Surprisingly, the polycrystalline film on the silicon substrate showed stronger magnetism than a single crystalline film.

Assistant Professor Taichi Goto (right)

To realize the next generation of devices for information processing based on new phenomena such as spintronics, multiferroics, magnetooptics, and magnonics, their constituent materials need to be developed. Recent rapid progress in nanotechnology allows us to fabricate nanostructures that are impossible to obtain in nature.

However, complex magnetic oxides are one of the most complicated material systems in terms of development and analysis. In addition, the detailed mechanism, by which changes in atomic composition that do not affect overall structure lead to drastic changes in material characteristics even though the material structure is similar, is as yet unknown.

Now, researchers from Toyohashi University of Technology's Spin Electronics Group, as part of a research team (which includes Myongji University, Harbin Institute of Technology, Massachusetts Institute of Technology, Universidad Técnica Federico Santa

María, University of California San Diego, and Trinity College Dublin), have found that nanoscale pillar-shaped distribution of iron in strontium titanate (STF) changes its magnetic and magnetooptical response drastically. Surprisingly, the polycrystalline sample showed stronger magnetism than single crystalline film.

"In usual oxide systems, magnetic and magnetooptical effects are stronger in highly ordered structures. In other words, single crystalline material is better for obtaining better magnetic properties," explains Assistant Professor Taichi Goto, "However, iron-substituted strontium titanate deposited at certain oxygen pressure is different."

The STF films were prepared by pulsed laser deposition at various pressures directly on silicon substrate, and crystalline structure and magnetic properties were characterized systematically. A sample deposited at a certain pressure showed significantly stronger magnetism and larger Faraday rotation angle (magnetooptical effects) at room temperature. Several tests analyzing the oxygen stoichiometry and the corresponding Fe valence states, the structure and strain state, and the presence of small-volume fractions of iron revealed that the nanostructure and clustering of the elements enhanced magnetism.

These results show the broad possibility of polycrystalline films being used in silicon-based devices. In this paper, the integration of STF film with 0.1 mm scale optical resonator was demonstrated. Further, the integration of such novel oxides with conventional device concepts could pave a way for interesting systems in the future.

Funding agency:
T. G. acknowledges support from the JST PRESTO, JSPS Postdoctoral Fellowships for Research Abroad, Grant-in-Aid for Young Scientists (A) No. 26706009, and Challenging Exploratory Research No. 26600043.

C. R. acknowledges support from the NSF DMR1419807 and ECCS1607865 and from FAME, a SRC STARnet Center supported by DARPA and MARCO.

H. L. T. acknowledges support from the NSF DMR1419807. P. V. acknowledges support from the Center for Development of Nanoscience and Nanotechnology, CEDENNA, Chile.
J. M. F. acknowledges support from Fondecyt Iniciación 11130128 and DGIIP USM, Chile.

M.I. acknowledges support from the JSPS Grant-in-Aid for Scientific Research (S) No. 26220902.

This work utilized the shared experimental facilities of the Center for Materials Science and Engineering (CMSE), Award 024006-10 No. NSF DMR1419807.

Reference

Taichi Goto, Dong Hun Kim, Xueyin Sun, Mehmet C. Onbasli, Juan M. Florez, Shyue Ping Ong, Patricio Vargas, Karl Ackland, Plamen Stamenov, Nicolas M. Aimon, Mitsuteru Inoue, Harry L. Tuller, Gerald F. Dionne, J. Michael D. Coey and Caroline A. Ross, "Magnetism and Faraday rotation in oxygen-deficient polycrystalline and single-crystal iron-substituted strontium titanate", Phys. Rev. Applied, 7, 024006 (2017/02/08).
https://doi.org/10.1103/PhysRevApplied.7.024006

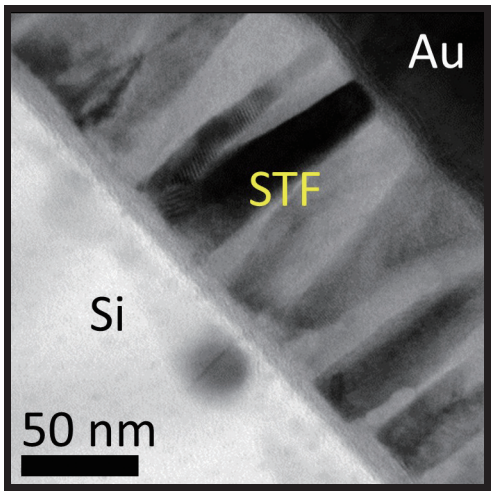


Fig.1 Image of nanopillar-like poly-crystalline STF film obtained by transmission electron microscopy.

夏のエアコン、快適と感じていても睡眠の質が悪化している？

人が感じない程度の速さの風であったとしても、睡眠は影響を受けている可能性を示唆

都築　和代

都築和代教授は、産業技術総合研究所、旭化成ホームズと共同で、エアコン冷房の気流が睡眠に与える影響について調べました。熱帯夜であってもエアコンを使って部屋の温度を快適にコントロールすることにより、よく眠ることができます。しかし、感じるか感じない程度の風速であっても、エアコンの風が寝ている人にあたると、体を動かしたり、睡眠深度が変わったりするなどの影響を受けることを明らかにしました。

豊橋技術科学大学建築・都市システム学系の都築和代教授と産業技術総合研究所、旭化成ホームズの共同研究チームは、エアコンの平均風速が不感気流以下であっても、寝ている時には身体への刺激となり、睡眠が影響を受けることを明らかにしました。これは、エアコンの設定によっては、人が快適だと感じていても、気づかないうちに睡眠の質を悪くしてしまっている可能性もあることを示唆するものです。

都市の温暖化は夜間の気温低下を妨害します。その結果、熱帯夜で睡眠の質が悪化することが多くなります。しかし、エアコンによって部屋の温度がうまく調節されれば、質の良い睡眠がとれます。とはいえ、一晩中エアコンを使うと体に悪いという風聞があり、また、寝冷えをしたり、寒さで途中に目が覚めたりした経験がある人は少なくありません。

就寝環境のエアコンの設定において、風の強弱を設定することはあるものの、実際の風速を測定したデータは提示されておらず、エアコンからの気流の影響について検討された研究はこれまでありませんでした。

都築和代教授らの研究チームは、風速が異なるエアコンを用いて、同じ温度に設定した2つの寝室で睡眠をとった時の、脳波計測による睡眠深度や体温調節、主観申告に及ぼす影響を比較しました。

0.2m/s 以下の速さの気流は、人が感じない気流という意味で不感気流と呼ばれます。本研究では、26℃の室温で、平均風速が 0.14m/s（一般的なエアコン）と 0.04m/s（特別仕様のエアコン）の 2 種類の気流の影響を比較しました。その結果、被験者は起床時や寝ている時には、気流が速い方を涼しく感じていましたが、一晩を通しての快適感、各睡眠深度の長さ、皮膚温や直腸温、寝る前の温冷感には有意な違いが認められませんでした。一般的なエアコンは、室温が設定温度になると気流が弱まり、室温が上がると再び気流が吹き出します。そのため、気流の吹き出すタイミングと体の動き、心拍数、睡眠深度の中での覚醒段階との関係について比較したところ、平均風速 0.14m/s のエアコンの方が、体動、心拍数の上昇、覚醒の頻度が有意に多くなりました。つまり、一般的なエアコンでは、冷風が吹き出す瞬間に、寝返りを打ったり睡眠深度が変わったりすることが判明し、睡眠に何らかの影響与えている可能性があることが示唆されました。

この研究は健康な青年男性を被験者として実施しました。体力が劣っていたり、寒さに敏感な女性や高齢者であれば、睡眠全体により大きな影響を与えた可能性が推察されます。また、本研究の成果は、快適な睡眠環境を作り出すためのエアコンの風速設定について、有用な手がかりになることが期待されます。

本研究は、都築和代教授が産業技術総合研究所において実施した研究成果です。 また、本研究の成果は 2016 年 12 月 23 日 Energy and Building 誌にオンライン版で掲載されました。

本研究は、文部科学省・日本学術振興会科学研究費 #21300271、#25282016、の補助を受けて遂行されました。

スマートガスセンサ向けマイクロホットプレート

岩田　達哉

岩田達哉助教たちは高分子材料である SU-8 を用いてマイクロホットプレート (MHP) を作製しました。この MHP を用いることでスマートガスセンサのレイアウト設計やプロセス条件に対する技術要求を緩和することができます。彼らはその MHP が優れた熱分離性能を有することをシミュレーションにより確かめ、また 550° C まで加熱が可能であることと、少なくとも 100 分間の安定動作を実証しました。

ガスセンサはガス漏れ検知や空気質モニタリング等に用いられ、我々の生活に不可欠なものです。一方、近年ユビキタス社会実現へ向け、センシングに加え、信号処理や情報通信の機能を有する、いわゆるスマートガスセンサが注目を集め、盛んに開発が行われています。さらに、これを IC チップ上に実現することで、スマートガスセンシングシステムの低コスト化や小型化が可能となります。

現在最も普及している半導体ガスセンサは、その材料を数 100° C に加熱する必要があります。そのため、これを電子回路と集積化するには、回路との熱分離のため、微小電子機械システム (MEMS) 技術を用いたマイクロホットプレート (MHP) が必要となります。しかしながら、この MHP はその支持部が機械的に脆弱であり、強度を向上させると熱分離性能が低下してしまうというトレードオフが存在します。

そこで、岩田助教率いる研究チームは、機械的強度と熱分離性能の両立をめざし、SU-8 を MHP 支持部の補強材料として用いることを提案しました。SU-8 は MEMS 構造体に広く用いられる高分子材料で、その特徴として、良好な機械的強度と低い熱伝導率が挙げられます。研究チームは提案の MHP を作製しその加熱性能を評価しました。

筆頭著者の岩田助教は「厚い高分子膜を用いることで、高い機械的強度と熱分離性能を両立できます。機械的強度に関しては今後評価する必要がありますが、これはスマートガスセンサに向けた有望なデバイスであると考えています。」と述べています。

「高い機械的強度を得ることは MHP 作製の上での大きな課題の一つです。(一般に熱に弱い) 高分子材料をこのような MHP に用いることは一見非常識な発想ですが、思いのほかうまくいきました。このデバイスによって、我々の目指すマルチ

モーダルセンサ (複数のセンサを 1 チップ上に集積化した高機能センサ) の開発も大きく前進するはずです。」と澤田教授は述べています。

作製された MHP は約 140 μ m 四方の加熱領域を有し、支持部であるブリッジ上に膜厚 33 μ m の SU-8 層が形成されています。シミュレーションにより、本構造は良好な熱分離性能を有することが確認され (図 1)、駆動電圧 5 V において 550˚ C まで加熱可能であることが実証されました。また、消費電力は 300˚ C 加熱時に約 13.9 mW と、これまでに報告されている MHP と同程度の低消費電力を達成し、少なくとも 100 分間の安定動作も示されました。

この MHP は、厚い SU-8 を形成しており、作製時に材料内部に発生する力 (残留応力) の精密な制御が不要となります。この特徴と良好な熱分離性能のおかげで、スマートガスセンサはより柔軟なレイアウト設計が可能となり、その小型化につながります。研究者らはこのようなスマートガスセンサ実現に向け、引き続き研究を進めていきます。

本研究成果は平成 29 年 1 月 11 日付で、Journal of Micromechanics and Microengineering のオンライン版に掲載されました。

本研究は、日本学術振興会 科研費 若手研究 (B)、15K18049 の助成を受けて行われました。

単結晶が高性能という常識を覆すSi上の多結晶磁性膜を発見

多結晶の鉄置換チタン酸ストロンチウムが示す磁性

後藤　太一

後藤太一助教らは、ミョンジ大学、ハルビン工業大学、MIT、フェデリコ・サンタ・マリア工科大学、カリフォルニア大学サンディエゴ校、およびトリニティ・カレッジダブリン大学と共同で、ナノサイズの鉄が柱状に集まった鉄置換チタン酸ストロンチウム膜が単結晶を超える大きな磁性および磁気光学特性を示すことを世界で初めて見出し、この膜を使ったシリコン光デバイスの作製に成功しました。

近年の半導体中を流れる電子を利用した電子デバイスの高集積化に伴い、発熱や高速化の鈍化が喫緊の課題です。そこで、現在の電子デバイスのデザインルールを根本から変えてしまう、異なった物理に基づいた次世代コンピュータの開発が求められています。そんな中、電子の移動以外を起源とする現象に注目が集まっています。スピントロニクス、マグノニクス、あるいは磁性を介するマルチフェロイクスは、スピンを起源とすることから、電子デバイスの抱える発熱やスピードの課題を解決できると期待されております。これに伴い、これらのスピンを使ったデバイスの基盤となる材料開発の重要性は、年々高まっています。最近では、人工的にナノスケールの構造を操作することで、自然界に存在し得ない超高性能な材料開発が進められています。

しかし、数ある材料のなかでも、複合磁性酸化物は、その構造が最も複雑な材料系の一つであり、似たような構造をもつ材料システムであっても元素の数が僅かに異なると特性が極端に変わるなど、分かっていない部分が多くあります。

今回、豊橋技術科学大学のスピン・エレクトロニクスグループはミョンジ大学、ハルビン工業大学、MIT、フェデリコ･サンタ･マリア工科大学、カリフォルニア大学サンディエゴ校、およびトリニティ・カレッジダブリン大学と共同で、ナノサイズの鉄が柱状に集まった鉄置換チタン酸ストロンチウム（STF）膜が、単結晶を超える大きな磁性および磁気光学特性を示すことを世界で初めて見出し、この膜を使ったシリコン光デバイスの作製に成功しました。

「ほとんどの磁性酸化物システムで、原子や分子が緻密に並んだ単結晶の方が、並び方がバラバラな多結晶に比べて、磁性および磁気光学効果は大きいとされてきました。言い換えれば、単結晶のほうが多結晶よりも性能がよいのが、ある意味普通でした。」と後藤助教は話す。「しかし、ある一定の圧力下で形成した STF では、多結晶の方が磁気光学効果が大きくなったのです。」幾つかの成膜圧力下で、シリコン基板上にバッファー層なしで直接 STF 膜を形成し、結晶構造や磁気特性をシステマティックに調べました。この中で、一定の圧力下で形成した試料だけ、室温環境下で、著しく大きな磁気および磁気光学効果を示すことが分かりました。磁性が増大された要因を調べたところ、クラスター上に鉄の成分が柱のように凝集したことにあると、明らかになりました。

これらの結果は、基板を問わない多結晶膜の磁気および磁気光学膜としての応用可能性を広げます。すでに筆者らは本論文の中で、開発した多結晶 STF 膜をシリコン導波路で作ったリング型の光干渉器と融合することで、0.1mm サイズの光アイソレータを形成し、動作をデモンストレーションしたことを報告しています。今後は、開発した STF と光集積デバイス以外との組合せや、異なる材料システムでの類似現象の発現などが期待されます。

ファンディングエージェンシー：
JST さきがけ
JSPS 科研費 No. 26706009、26600043、26220902

Pick Up

TUT symposium on “Changing Global Communication with AI - Ubiquitous Machine Translation”

On 24th April 2017, Toyohashi University of Technology, in cooperation with Microsoft Japan Co., Ltd., BroadBand Tower, Inc., and A.I. Squared, Inc., held a symposium in Tokyo entitled “Changing Global Communication with AI – Ubiquitous Machine Translation”.

The symposium provided a showcase for powerful developments in AI enabled machine translation technology, that can be utilized both in business and the broader community. Attendees of the symposium came from a wide spectrum of academia and the business community, such as translation and tourism. In an invited speech presented in English, simultaneous Japanese interpretation generated by a real-time machine translation system was demonstrated on each mobile device of the audience. The technological virtuosity and obvious practical use of the leading edge of translation system greatly impressed the audience.

Related article: TUT Research Vol.5 feature story - Machine Translation Opening Japan to the World by Hitoshi Isahara

One milestone toward TUT Multicultural Global Campus

As a Top Global University in Japan, TUT has been transforming the university open to the world by increasing compatibility of the university education system and mobility of students, researchers, university faculties and staffs with the global. As the start of 2017 academic year, several key projects have achieved the first milestone:

TUT Global House:


The TUT Global House is a newly built shared-house style of on-campus student accommodation, which enables international and Japanese students to live together. The first two accommodation building with 60 students capacity and one common service building were completed and started operation from April 2017. Both Japanese and International students are expected to nurture essential skills required in this globalized society through living and learning in this multicultural environment. It will complete the building in 2019 with total 180 student capacity.
http://www.sgu.tut.ac.jp/eng/student-life/boarding-house.

Global Commons at the University Library:


The first floor of the university library has been renovated to function as a hub of the Multicultural Global Campus. The renewed floor consists of a Global Lecture Area equipped with a large telepresence screen which allows for live communication with facilities around the world. Other facilities include the multipurpose collaboration space, study support area, coffee shop and deck-terrace.

TUT Research
e-Newsletter from Toyohashi University of Technology
https://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.

1-1 Hibarigaoka, Tempaku, Toyohashi, Aichi, 441-8580, JAPAN
Inquiries: Committee for Public Relations
E-mail: press@office.tut.ac.jp
Website: https://www.tut.ac.jp/english/