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FEATURE

An Interview with

Yoshihiko TAKANO

MANA Principal Investigator,
Group Leader of
Nano Frontier Superconducting Materials Group

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"If You Don't Shoot the Arrow, It Doesn't Hit the Target"

An Interview with Yoshihiko TAKANO

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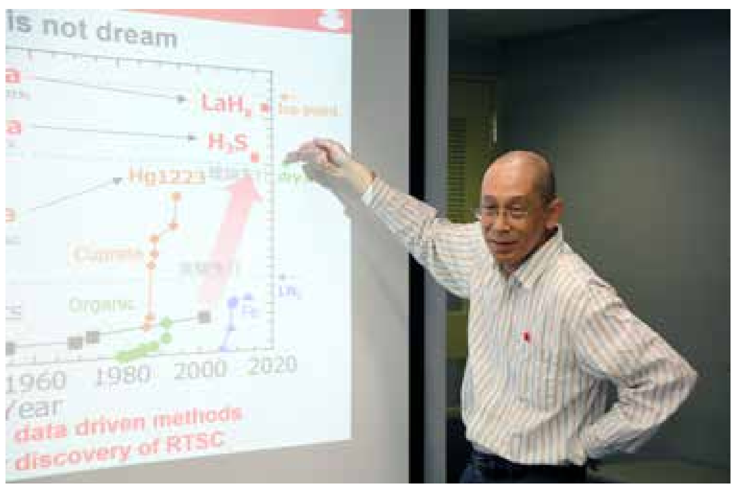
MANA Principal Investigator, Group Leader of Nano Frontier Superconducting Materials Group

With their ability to transport electricity without loss and at zero resistance, superconductors are a technology that could solve a host of environmental and energy problems. The Nano Frontier Superconducting Materials Group at MANA, led by Yoshihiko Takano, is focusing on the physical properties of high-temperature superconductors, as well as magnetic refrigeration materials and other functional materials. The group is also developing cables incorporating new superconducting materials. Recently, they have been searching for new substances by utilizing machine learning, and have discovered a series of new superconductors, as they work toward the ultimate goal: room temperature superconductivity. Currently, this research requires extremely low temperatures and extremely high pressures, so the team is also developing artificial intelligence for materials search, as well as high-pressure technologies.

Invitation to Superconductivity Research

– **What inspired you to enter the field of superconductivity?**

When I began my university studies in Japan, superconductivity was being talked about as a key technology to solve the world's energy problems, so I decided to enter the field. I initially worked on high-temperature superconducting cuprates.



Later I moved to the Institute of Solid-State Physics (ISSP) at the University of Tokyo, where I started a small project to investigate new materials, and discovered the niobium oxide superconductor $KCa_2Nb_3O_{10}$. I put this material into a n-butyllithium liquid and kept it there for a few days; the material integrated, and gradually became superconducting.

Superconductivity is of course a physical property, but the reaction between liquid and a solid is soft chemistry, so by using a combination of physics and soft chemistry, I was able to find this new material. Many people who read my paper called the material a tsukemono chodendo-tai, meaning "pickle superconductor."

– **You are famous for discovering a new superconductor using red wine. What made you think of that?**

Well, we could have used soft drinks or soy sauce or something. There are many possibilities. But if you use red wine, you can drink some too, and maybe you will feel good. Just like humans are attracted to each

other instinctively, people and materials may be naturally attracted to each other. You could say these are both a kind of chemical reaction.

We tested a material, $FeTe_{0.8}S_{0.2}$, in various alcoholic drinks and, to our surprise, it showed excellent superconducting properties after only one day. We tried beer, red and white wine, Japanese sake, shochu, and whisky, and with various concentrations of ethanol and water. The samples heated in alcoholic drinks all showed greater superconductivity, which was not dependent on the alcohol content. We found that red wine was the most effective.

After discovering this superconductor, I wasn't sure how the property arose, but I finally figured out the mechanism -- organic acids in the wine integrate the excess ions, inducing superconductivity.

Our results caused a lot of excitement. I was invited to many lectures to talk about it, and one of my friends even posted the paper on his office door.

This is a different approach from most research. Of course, there is a big difference between pure chemicals and red wine. The key difference is that there are 1,000 or more compounds in the wine, so we may not know which compound induces the superconductivity, but we know the answer is somewhere in the cup, and as we eliminate the possibilities, we approach the answer, like a detective.

From Nano-scale to Solving Global Problems

– **What are the main challenges for MANA?**

Room temperature superconductivity is one of MANA's grand challenges, and when we succeed, it will start a revolution -- with zero resistance at ambient conditions, we will be able to send electricity around the world with zero loss, from producing places such as solar farms in deserts, to wherever it is needed. This would solve a lot of the world's energy problems, as well as alleviate climate change.

It's very difficult right now, though. One of the most promising materials is metal hydrogen, but to make it, to achieve metalization, you need 400 gigapascals (GPa) of pressure, conditions you find at the center of the Earth. We can't create such high pressure -- maybe 200GPa is possible now -- but the metalization pressure would decrease if we combined hydrogen and some metal. For example, lanthanum and hydrogen can be metalized at 260GPa. The key point is to determine the correct target material, and that requires a lot of calculation, as well as machine learning.

Again, it requires a multi-disciplinary approach. We need extreme high-pressure techniques, which are being developed by geophysicists to replicate conditions deep underground. That's why I'm collaborating with the geophysics group at Geodynamics Research Center at Ehime University. We now have three core members in our group -- one working on high pressure, one on AI, and the other on materials.

– **Superconductivity is a so-called macroscopic quantum effect. Could you explain?**

These are quantum phenomena that occur at a macroscopic scale. When you scale down to nano size, at a certain point a material's properties suddenly change, and it exhibits quantum effects, such as superconductivity, photo emission, flame reaction, tunneling effect and so on.

Superconductivity arises when two electrons bind together at low temperatures to form a Cooper pair, whose quantum property is the origin of zero resistance. If enough Cooper pairs are involved, the phenomenon can be experienced at human scale, with the naked eye -- the macro scale. You have zero resistance no matter how long the cable is -- 1 meter, 1km and 1,000km superconducting cables all have zero resistance.

Nano-level phenomena are connected like beads to create one big phenomenon. For that reason, superconductivity research itself will lead to the elucidation of nano-systems. Superconductivity research has a wide range of implications and possibilities, from the nano-scale to solving global problems.

Serendipity is the Key to the Treasure Chest

– **What motivates you in your research?**

For me, it's the feeling of being a pioneer, of opening up a new field. MANA is focusing on the goal of high-temperature superconductivity, which is a huge undertaking. But there are many, many small and exciting discoveries to be made along the way, such as our finding that compounds in red wine can induce superconductivity.

I take many different approaches in my research. Each should be a unique path that combines different fields, such as electrochemistry and physics, or soft chemistry and physics. This approach keeps things interesting, and we almost always get a new result.

Also, I like to work with students. Their knowledge is limited, of course, because they lack research experience, but they have energy, and lots of ideas.

I have one more message for young scientists -- what I call the ABC of research. A is become addicted to research -- not just like it, love it. B is believe in your inspiration, and C is challenge yourself -- and never give up.

– **What's the secret to finding exciting discoveries?**

One of the things I value is serendipity, the unexpected good luck. Serendipity is the key to the treasure chest. It may seem like mere luck, just a fortunate happenstance or a pleasant surprise, but it only happens to people who are working, and are open to it -- people who are testing the boundaries, pushing the work forward.

I always tell my students: If you don't try, you'll never achieve anything. Work hard, and work fast. Your first idea may not be correct, but even mistakes can generate valuable experimental results. As the saying goes: "If you don't shoot the arrow, it doesn't hit the target."

Link to this article on the website

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https://www.nims.go.jp/mana/ebulletin/

MANA Planning and Outreach Team
International Center for Materials Nanoarchitectonics (WPI-MANA)
National Institute for Materials Science (NIMS)
1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan
TEL: +81-29-860-4710 FAX: +81-29-860-4706
EMAIL: mana-pr@nims.go.jp

RESEARCH HIGHLIGHTS

[Vol. 62]

Thermoelectric Device Combined with Wavelength-selective Thermal Emitter Generates Continuous Power, Day and Night

A team at MANA has created a thermoelectric device that can generate power continuously, 24 hours a day, without the problem of the voltage dropping to zero when night falls and temperatures drop.

Thermoelectric devices have been attracting attention for energy harvesting, especially those that require independent power supply, such as outdoor sensors and monitors. Such devices only require temperature difference between its top and bottom to generate power, which are more ubiquitous than photovoltaics. However, thermoelectric devices placed outside experience reversal of voltage when temperatures change -- they flip the sign of their voltage, and the electrical current changes its direction of flow, so the voltage drops to zero and power generation ceases.

To address this problem, the MANA team built their device with a wavelength-selective emitter that continually radiates heat, so that its surface temperature is always cooler than the bottom side of the thermoelectric module, which is placed below the selective emitter.

The device consists of a 100-nanometer-thick aluminum film on the bottom of a glass substrate. Because the top of the device is cooler than the bottom, the temperature difference creates constant voltage throughout the day and night. The team found that using a selective emitter eliminates the problem of the voltage dropping to zero during environmental changes in temperature.

As team leader Ishii noted, “Cooling can be used to create a temperature difference compared to the ambient temperature, and because radiative cooling takes place day and night, thermoelectric generation is always possible.”

The larger the temperature difference, the larger the voltage. Using the heat on the underside of the device increases the temperature difference between the bottom and top, so heat from the mounting surface helps boost power output as well.

This research was carried out by Satoshi Ishii (Principal Researcher, Photonics Nano-Engineering Group) and his collaborators.

Reference

"Radiative cooling for continuous thermoelectric power generation in day and night", Satoshi Ishii, Thang Duy Dao and Tadaaki Nagao
Applied Physics Letters, 117 [1] 013901 (July 7, 2020)
DOI : 10.1063/5.0010190

[Vol. 63]

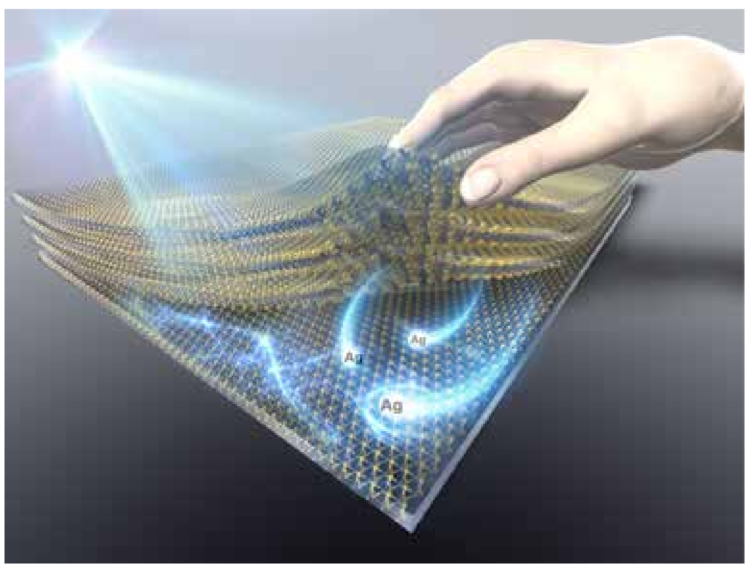
On/Off Boundary of Photocatalytic Activity between Single- and Bilayer MoS_2

A team at MANA has succeeded in spatially resolving the photocatalytic activity of molybdenum disulfide (MoS_2) as a model catalyst. The findings advance our understanding of the potential photocatalytic activity of 2D nanophotocatalysts.

Molecularly thin two-dimensional semiconductors are attracting interest as photocatalysts thanks to their layer-number-dependent quantum effects and high charge separation efficiency.

However, the correlation among the dimensionality, crystallinity and photocatalytic activity of such 2D nanomaterials remains unclear. The team used a silver (Ag) photoreduction technique coupled with microscopic analyses to spatially resolve the photocatalytic activity of MoS_2 as a model catalyst. They found that only monolayer (1L)-MoS_2 is active for Ag photoreduction reactions. The photocatalytic activity of 1L-MoS_2 is enhanced by a built-in electrical field originated from the MoS_2/SiO_2 interface, rather than by the specific surface structure and quantum electronic state of 1L-MoS_2.

The team discovered that photocatalytically active sites were geometrically distributed on triangular 1L-MoS_2 crystals, in which the Ag particles are preferentially deposited on the outermost zigzag edges and defective inner parts of the triangular grains. The degradation of photocatalytic activity and electron mobility with the formation of Mo(VI) species indicates that the species inhibit the in-plane diffusion of the photogenerated electrons to the reductive sites.



MoS_2 was chosen for the study because it is a useful sunlight-driven photocatalyst. There has been considerable effort recently toward the development of MoS_2-based photocatalysts for various reactions including water splitting, CO_2 reduction and bacteria inactivation.

The study provides insights into these critical aspects to guide a general design strategy to reveal the potential photocatalytic activity of 2D nanomaterials. The monolayer selectivity, activation and inactivation mechanisms in 1L-MoS_2 suggest future directions in designing 2D nanophotocatalysts.

This research was carried out by Takaaki Taniguchi (Senior Researcher, Functional Nanomaterials Group) and his collaborators.

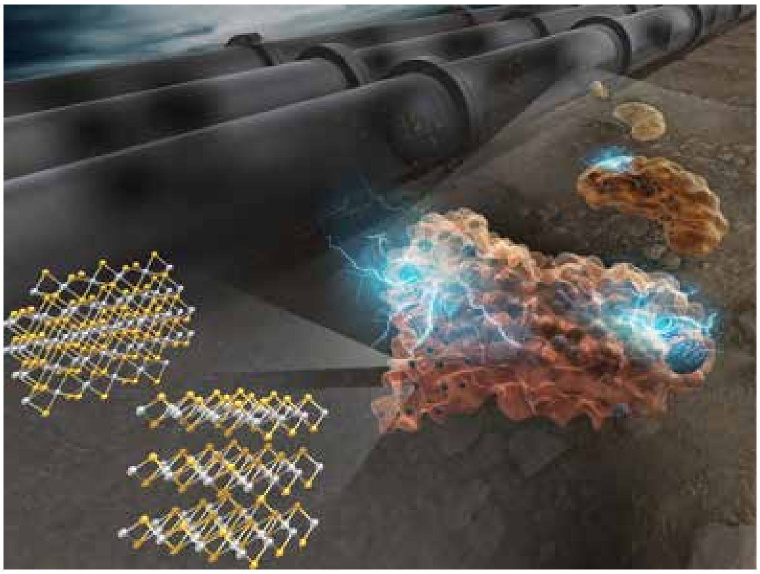
Reference

"On/Off Boundary of Photocatalytic Activity between Single- and Bilayer MoS_2", Takaaki Taniguchi et al.,
ACS Nano, 14, 6, 6663–6672 (May 12, 2020)
DOI : 10.1021/acsnano.9b09253

[Vol. 64]

Biogenic Iron Sulfide Nanoparticles Enable Electron Uptake in Bacteria

A MANA team has identified the mechanism underlying the synthesis of long, electrically conductive pathways via iron sulfide (FeS) nanoparticles (NPs) in bacteria. This has implications in the development of new ways to inhibit microbial iron corrosion, as well as understanding the pathways of organic matter preservation in marine systems.



Many bacterial species are capable of biosynthesizing NPs. These nanoparticles are ubiquitous in nature, and the formation of FeS minerals is driven by the reaction between ferrous compounds and the free sulfide predominantly produced by sulfate-reducing bacteria (SRB), which produce 97% of the sulfide on earth through their metabolic activity.

Biosynthesized NPs facilitate microbial energy production in various environments, including extreme conditions. However, until now little research has been done on the biological role of FeS NPs in such bacteria.

The MANA team identified FeS NPs with electrically conductive crystal phase associated with cellular membrane of the SRB D. vulgaris. They showed that the conductive NPs can function as an electron conduit, enabling bacteria to utilize solid-state electron donors via direct electron uptake.

This is the first report of SRB utilizing solid-state electron donors via direct extracellular electron uptake. This strategy does not require organic electron donors and would therefore be especially effective in sediments containing highly reductive minerals.

Since microbial sulfate reduction is the most important pathway for organic matter remineralization in marine sediments, the biogeochemical cycles of iron and sulfur facilitated by the metabolic activity of SRB are intimately linked to the carbon cycle.

This research provides new insights into the interplay and evolution of biogeochemical cycles including iron, sulfur and carbon. In addition, clarifying the mechanism behind the synthesis of long, electrically conductive pathways via FeS NPs could lead to effective strategies for inhibiting microbial iron corrosion.

This research was carried out by Akihiro Okamoto (Independent Scientist) and his collaborators.

Reference

"Biogenic Iron Sulfide Nanoparticles to Enable Extracellular Electron Uptake in Sulfate-Reducing Bacteria", Xiao Deng *et al.*
Angew. Chem. Int. Ed., 59 [15] 5995-5999 (December 25, 2019)
DOI: 10.1002/ange.201915196

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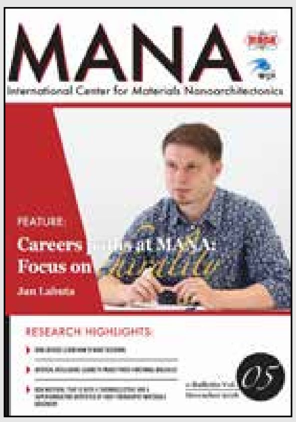
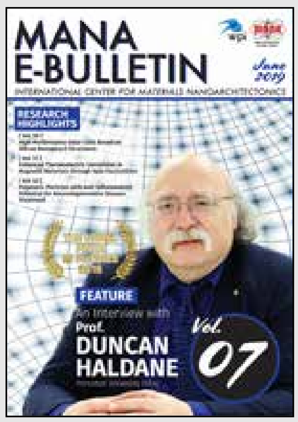
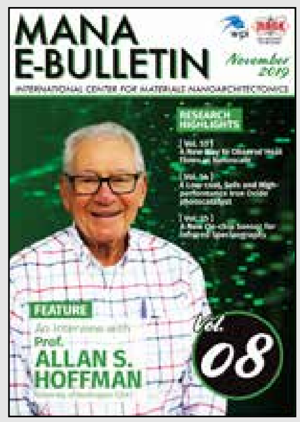
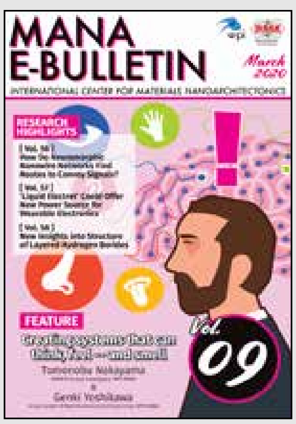
Nano Revolution for the Future









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