MANA

International Center for Materials Nanoarchitectonics

FEATURE:

Advanced *nano-fabrication* technology catalyzing discovery and innovation at WPI-MANA

Toshihide Nabatame, Namiki Foundry Manager

RESEARCH HIGHLIGHTS:

e-Bulletin Vol. 06

March 2019

“Our role is to work with scient supporting their research on d

Facilities for lithography and nanofabrication were established at NIMS in 2004 under the leadership of Masakazu Aono, the Director the International Center for Materials Nanoarchitectonics (WPI-MANA) at NIMS from 2007 to 2017. The facilities became a part of WPI-MANA in 2009 and are now referred to as the Namiki Foundry.

“Researchers at NIMS and WPI-MANA are experts in materials science but few have experience of lithography and device fabrication,” says Toshihide Nabatame, Manager of the Namiki Foundry (Former MANA Foundry). “So our role is to work with scientists in supporting their research on device fabrication.”

The Namiki Foundry has eight cleanroom areas in its 235m^2 floor space. The areas are drawing and photo lithography; wet process; etching; film deposition; nano measurement; nano analysis; heat treatment and dicing and wiring (Fig.1).

The Namiki Foundry staff prepare samples suitable various type of characterization, for example, production of devices, using electron beam lithography to investigate properties of nanowires and nanosheets. Notably, they handle any kind of material including organic, inorganic, metals, insulators, magnetic, superconductors and composites.

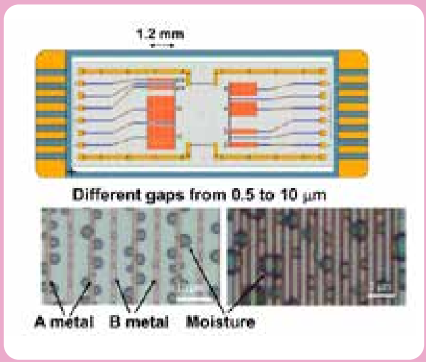
Effective communication in a bilingual environment

WPI-MANA is an international research organization with researchers from all over the world and the Namiki Foundry includes bilingual staff to work with researchers from overseas on their projects. “Our bilingual staff have TOIEC scores of more than 900 and provide consultation, training and all the necesarry operations in Namiki Foundry all in English,” explains Nabatame. “Also Namiki Foundry staff room is located adjacent to the clean rooms and are available all day until 19:30 to handle enquiries and conduct experiments.” (Fig.2) The annual fees for using the facilities are 50,000 JPY for NIMS/WPI-MANA researchers and 100,000 JPY for guests and trainees.

The Namiki Foundry has played a critical role in the wide ranging successful research conducted at WPI-MANA. “Our success is based on effective communication with the research staff at WPI-MANA,” says Nabatame. “We continue to welcome requests for consultation about research, tours of the facilities, and especially ‘nomikai (drink party)’!” ■

Examples of projects undertaken at the Namiki Foundry

● Moisture sensor with interdigital electrodes



JIN KAWAKITA, TOYOHIRO CHIKYOW. DETECTION OF MICRO/NANO DROPLET BY GALVANIC-COUPLED ARRAYS. ECS TRANSACTIONS. 75 (29) (2017) 51-59 10.1149/07529.0051ECST

Fig.1

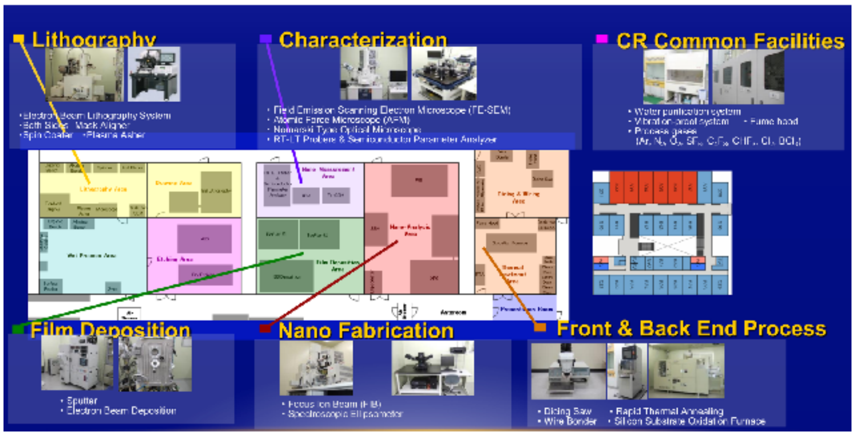


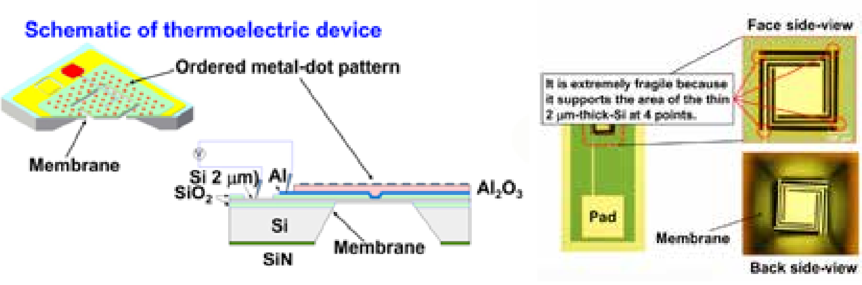
Fig.2

...tists in device fablication.”

Toshihide Nabatame
Namiki Foundry Manager

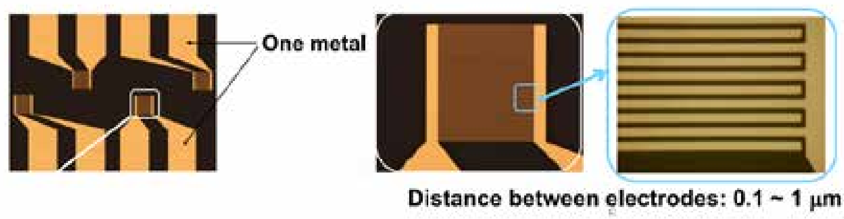
RESEARCH HIGHLIGHTS

● **Thermoelectric device with membrane structure for IR sensor**



TO BE PUBLISHED IN MICROMACHINES BY A. T. DOAN ET AL.

● **Interdigital electrodes fabrication process for membrane stress sensor (MSS)**



TOWARDS A DE FACTO STANDARD FOR OLFACTORY SENSING, GENKI YOSHIKAWA, MANA EBULLETIN VOL.2, FEATURE VIDEO
HTTP://WWW.NIMS.GO.JP/MANA/EBULLETIN/FEATURE_02.HTML

Please visit our e-Bulletin website for details!
More articles and Research Highlights are available.

WPI-MANA e-Bulletin Search

International Center for Materials Nanoarchitectonics (WPI-MANA)
1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan
☎ : +81-029-860-4709
✉ : mana@nims.go.jp

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

01 Photonic circuits hosting electromagnetic waves with pseudospin

Metamaterials are purposely built devices mimicking structural features of normal materials, but with unusual physical properties. Photonic crystals, for example, are periodic nanostructures consisting of material components with different refractive indices. They have lattice symmetries like solids, but the constituents of the unit cell of a photonic crystal are 'bits' of the different bulk materials. Similar to the structure–property relationships resulting from the behavior of electrons in solids (e.g. semiconduction), photonic crystals offer ways for manipulating the propagation of light. Now, Xiao Hu at WPI-MANA, NIMS, Tsukuba, Japan, and colleagues have succeeded in creating a photonic metamaterial that displays a special property known as a topological photonic state.

The researchers first considered theoretically a planar construction of microstrips organized in a honeycomb-like way. Strip segments inside hexagons are put narrower than those between hexagons in one half of the device, and vice versa in the other half, because a structure with alternatingly wide and narrow strips results in a so-called photonic band gap: a range of frequencies for which electromagnetic waves cannot naturally exist in the system. The nodes of the hexagonal network are connected to capacitors; the segments linking nodes act as inductors. (A capacitor, abbreviated 'C' in circuit theory, is an electric component capable of storing energy in an electric field. An inductor, abbreviated 'L', is a component that stores energy in a magnetic field when an electric current flows through it.)

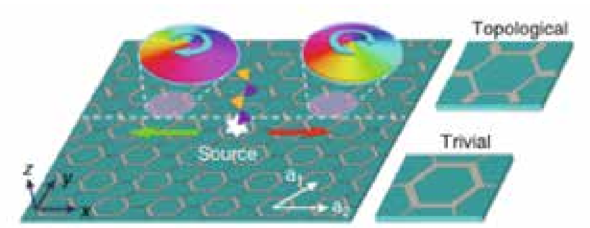


FIGURE:
MICROSTRIP SYSTEM CAPABLE OF HOSTING ELECTROMAGNETIC MODES WITH ORBITAL ANGULAR MOMENTUM.

The topological LC-circuit proposed by Hu and colleagues has a peculiar property. When excited by an electromagnetic wave with a frequency in the photonic band gap, at the intersection of the two halves, waves in opposite directions are created. What is remarkable is that these two waves can be assigned a quantity known as pseudospin, with values 'up' and 'down', respectively, and they are immune to backscatter even at sharp corners and robust to defects due to the topological protection.

To demonstrate their theoretical finding experimentally, the scientists fabricated the topological LC-circuit from microstrips—metallic strip lengths were about 1cm and both halves consisted of 14 × 8 hexagons — and, by using microwave near-field techniques, measured the electric-field component perpendicular to the sample. The measurements confirmed the existence of the special topological state.

Being able to generate and manipulate electromagnetic waves with pseudospin is promising for applications like communications and high-resolution imaging. The concept presented by Hu and colleagues is not restricted to the microwave range, but also applicable to infrared light. The planar geometry of the device makes it easy to include other circuit elements, such as resonators or superconducting Josephson junctions. One difficulty, though, is to channel the pseudospin modes out of the sample. As the scientists point out: "[To] figure out a way to emit efficiently electromagnetic modes [with pseudospin] … supported by the microstrip structure … into free space is one of the most intriguing future problems." ■

Reference

Y. Li et al., "Topological LC-circuits based on microstrips and observation of electromagnetic modes with orbital angular momentum", Nat. Comms. 9, 4598 (2018).
DOI: 10.1038/s41467-018-07084-2

02 Origins of macroscopic friction linked to energy landscape on the nanoscale

Everybody is familiar with friction—the phenomenon plays an important role in our daily lives. Yet, although phenomenological laws exist that describe friction on the macroscale, a detailed understanding of the processes involved on the microscale is lacking. Now, Hiroshi Sakuma and Shigeru Suehara (WPI-MANA, NIMS, Tsukuba, Japan) with their colleagues have studied friction forces in mica, both theoretically and experimentally, and have found the origin of molecular friction in this system.

Mica, a naturally laminated aluminosilicate material, should be one of the most common minerals at the earth's surface. It typically consists of AlO_6 'octahedral' sheets sandwiched between 'tetrahedral' sheets of SiO_4 and AlO_4. (Octahedral and tetrahedral refer to the arrangements of the aluminium, oxygen and silicon atoms within the layers.) In between layers are potassium atoms. They focused on difference between sliding paths (directions along which a force was exerted) parallel to the main crystallographic cleavage planes.

The scientists considered the energy change when applying a force to the top layer—in other words, when trying to pull away the layer—in each of different six directions as shown in Figure. Using a numerical technique called density functional theory, they calculated the increase (or decrease) in energy as a function of the displacement vector by which the plane was shifted. Combining the results for all six pulling paths resulted in a potential energy surface (PES); the height of the surface corresponds to the energy it takes to displace the top layer away from its origin to the new position.

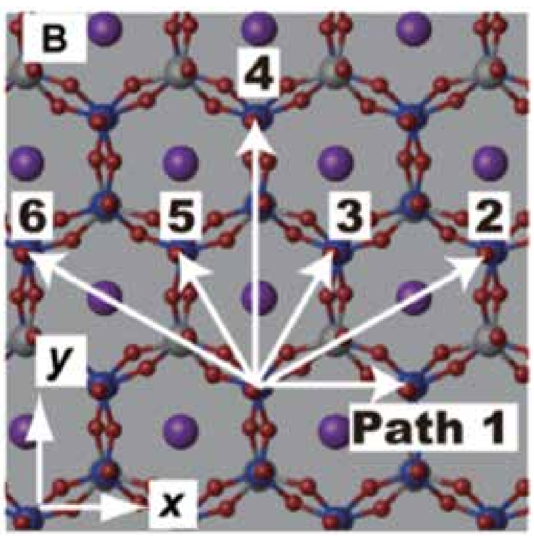


FIGURE:
STRUCTURE OF MUSCOVITE MICA AND CONSIDERED SLIDING DIRECTIONS.

The research team then performed experiments, to see whether the observed trends are indeed observed. They applied shear stresses in mica (parallel displacements within the material and sliding along path 4) up to forces corresponding to a pressure of 60 megapascal. Their main finding was that these stresses exhibited larger than those of predicted stresses by the numerical techniques. Ultimately, this means that molecular-scale friction does not simply scale up to the macroscopic level.

Careful observation of the recovered mica samples revealed that the presence of wear particles on the sliding plane. This wear particles would randomize the crystallographic sliding direction by their coincidental rotation. This means that the friction occurred along various crystallographic sliding directions. The shear stress predicted by in-plane averaging of the numerical techniques was quantitatively consistent with the experimental results.

The results of Sakuma, Suehara, and their colleagues help to better understand the nature of friction in layered materials, and to make comparisons between them. Quoting the scientists: "… the difference of PES among sheet-structure minerals can be a clue for understanding the difference of friction coefficients that are critical for the strength of natural faults." ■

Reference

H. SAKUMA ET AL., "WHAT IS THE ORIGIN OF MACROSCOPIC FRICTION?", SCIENCE ADVANCES 4, EAAV2268 (2018)
DOI: 10.1126/SCIADV.AAV2268

03 Porous structure of a layered silicate with selective adsorption properties revealed

It is not always easy to precisely determine the crystal structure of layered materials—but in order to fully understand and exploit their properties, detailed structural information is needed. Magadiite is such a layered material, used as an adsorbent and a catalyst. It is known that magadiite is a kind of layered silicates: tetrahedra, each with oxygen atoms at the vertices and a silicon atom in the center, grouped in planar arrangements. The precise structure, however, was not known—partly because the material typically occurs as small lamellas displaying poor crystallinity—until now. Satoshi Tominaka at WPI-MANA, NIMS, Tsukuba, Japan, and colleagues have succeeded in determining the crystal structure of magadiite. Based on their structural insights, Yusuke Ide (MANA, NIMS) and colleagues also managed to explain why the material has outstanding photocatalytic properties and proved its application in the synthesis of pure benzoic acid from toluene using a photocatalyst system.

The researchers looked at Na-magadiite (the natural, sodium-containing form) and H-magadiite (the 'protonated' form, obtained by removing sodium). By collecting X-ray diffraction data and using a method called pair-distribution-function analysis, they were able to come up with a structural model. Importantly, they found that in Na-magadiite, along the silicate layers, micropores filled with sodium atoms occur. Removing the Na content (by acid treatment) resulted in a structure with channels.

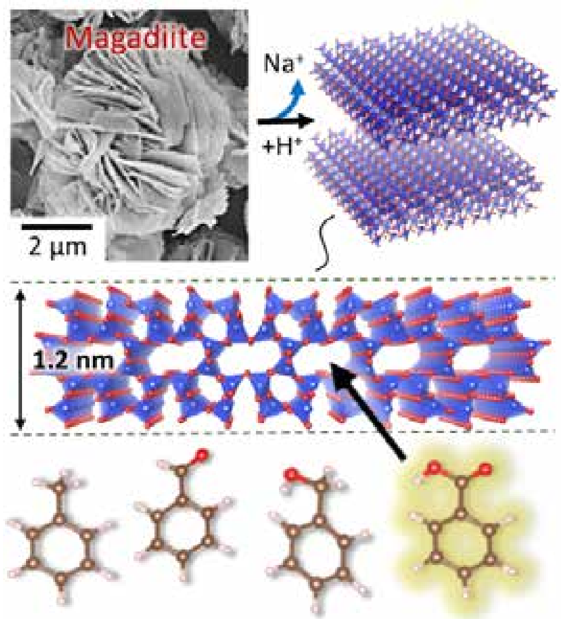


FIGURE:
STRUCTURE OF MUSCOVITE MICA AND CONSIDERED SLIDING DIRECTIONS.

The porosity of H-magadiite was confirmed by looking at nitrogen gas (N_2) adsorption. N_2 molecules can enter the pores; the size of the pores was estimated to be around half a nanometre.

The team also found that although the pores in H-magadiite are small, they can absorb benzoic acid (C_6H_5COOH). This property is of high importance in the photocatalytic synthesis of benzoic acid from toluene ($C_6H_5CH_3$), with titanium oxide (TiO_2) as a catalyst. By letting the synthesis take place in an environment with H-magadiite, the yield of benzoic acid was much higher than normal; the explanation is that the pores of H-magadiite temporarily store the C_6H_5COOH molecules.

Now that the full structure of magadiite has been established—including the geometry of the micropores along the thin silicate layers—further applications of the material can be investigated. Quoting the scientists: "These structural features of magadiite are expected to create advanced applications of magadiite as we demonstrated [for the case of benzoic acid production with magadiite as a selective adsorbent]." ■

Reference

Y. IDE, SATOSHI TOMINAKA ET AL., "ZEOLITIC INTRALAYER MICROCHANNELS OF MAGADIITE, A NATURAL LAYERED SILICATE, TO BOOST GREEN ORGANIC SYNTHESIS", CHEM. SCI.9, 8637 (2018). DOI: 10.1039/C8SC03712D