



元素戦略

Element
Strategy Initiative:
To Form Core
Research Centers

元素戦略プロジェクト<研究拠点形成型>

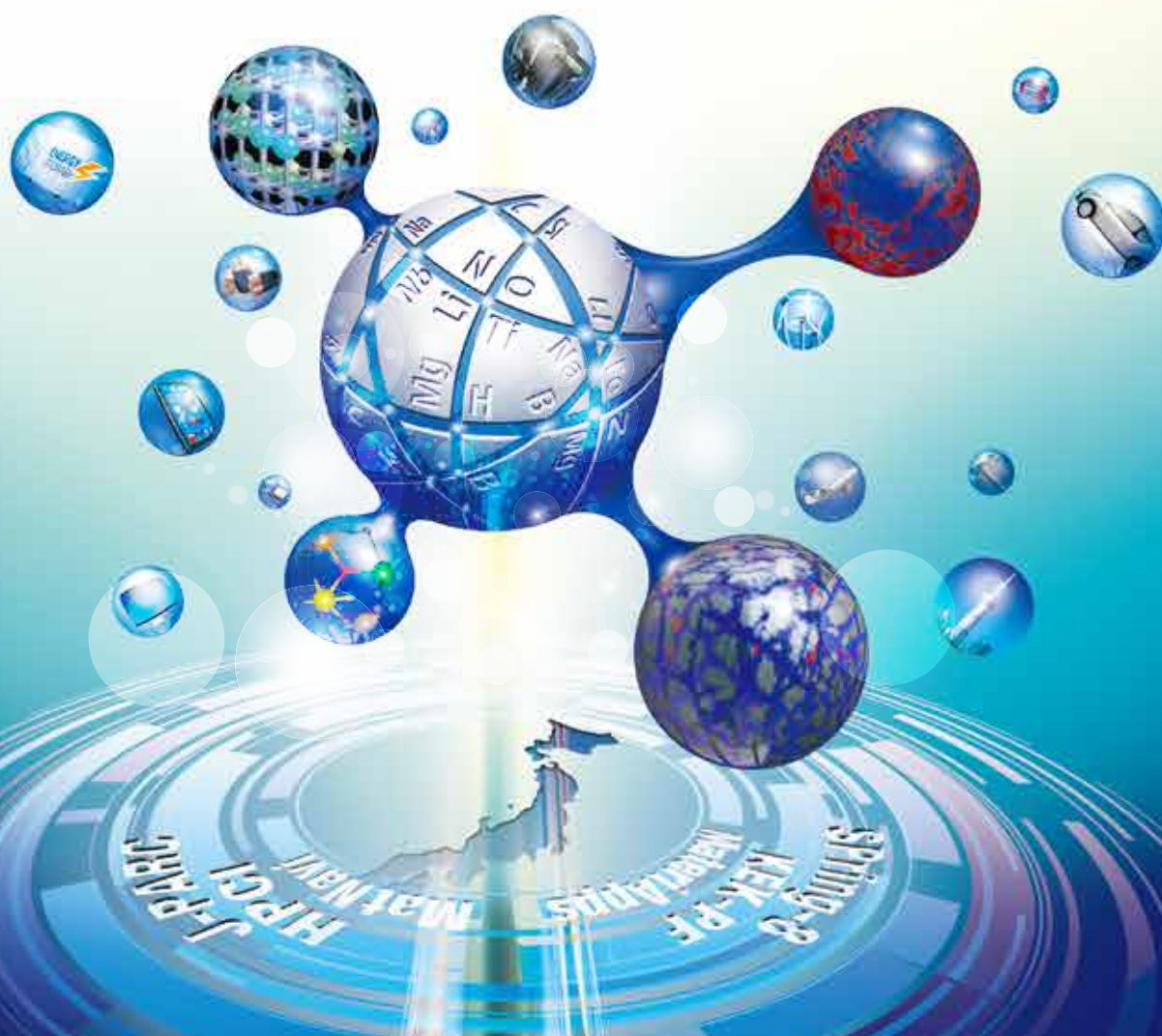
地球を

お も て な し
O Mo Te Na Si
8 42 52 11 14

地球は多様な元素の集まりです。私たちの暮らしは元素からつくった無数の材料で成り立っています。持続可能な未来社会を構築するには、地球上の有限な元素資源から優れた材料をつくりだしていく「元素戦略」が必要です。「元素戦略プロジェクト」は2012年に発足。材料の機能や特性を決めている元素のサイエンスを追究し、イノベーションの創出と産業応用を促進しています。

Omotenashi (O Mo Te Na Si): Being Hospitable Hosts to the Earth

The Earth is a collection of diverse elements. Our existence is made possible by countless materials produced from these elements. In order to build a sustainable future, we need an “element strategy” for developing superior materials from the limited element resources on Earth. The Element Strategy Initiative was launched in 2012 to pursue the science of elements that determine material functions and properties and for encouraging innovation and industrial applications.



基礎から応用に直結する研究開発を 4拠点で進めています。

Working to develop practical applications directly
from basic research at four research centers.

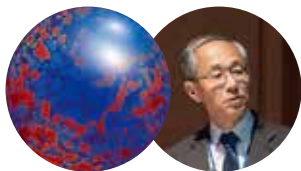


元素戦略プロジェクト<研究拠点形成型>
プログラム・ディレクター (PD)
玉尾 皓平

Kohei Tamao
Program Director, Element Strategy Initiative :
To Form Core Research Centers

磁性材料研究拠点

The Elements Strategy Initiative Center for Magnetic Materials (ESICMM)



設置機関：物質・材料研究機構 (NIMS) Core: National Institute for Materials Science (NIMS)

代表研究者：広沢 哲 Satoshi Hirose, Director General

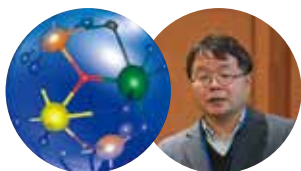
連携機関：東北大学、産業技術総合研究所、東京大学、東京大学物性研究所、京都大学、
高エネルギー加速器研究機構、高輝度光科学研究センター、名古屋大学、
北陸先端科学技術大学院大学、東京工業大学、九州大学、東北学院大学、兵庫県立大学
Collaborating institutes: Tohoku University, the National Institute of Advanced Industrial
Science and Technology, the University of Tokyo, the Institute for Solid State Physics at
the University of Tokyo, Kyoto University, the High Energy Accelerator Research
Organization (KEK), the Japan Synchrotron Radiation Research Institute, Nagoya
University, the Japan Advanced Institute of Science and Technology, the Tokyo Institute
of Technology, Kyushu University, Tohoku Gakuin University, and the University of Hyogo

開発対象：電気エネルギーと機械エネルギーの変換に適用されているバルク永久磁石材料

開発目標：希少元素フリーの新規高性能永久磁石材料の創製

電子材料研究拠点

Tokodai Institute for Element Strategy (TIES)



設置機関：東京工業大学 Core: Tokyo Institute of Technology

代表研究者：細野秀雄 Hideo Hosono, Representative

連携機関：物質・材料研究機構、高エネルギー加速器研究機構、東京大学
Collaborating institutes: National Institute for Materials Science, High Energy Accelerator
Research Organization (KEK), and the University of Tokyo

開発対象：半導体、透明電極をはじめとする電子材料全般

開発目標：多存元素を使って革新的な機能を実現

触媒・電池材料研究拠点

Elements Strategy Initiative for Catalysts and Batteries (ESICB)



設置機関：京都大学 Core: Department of Molecular Engineering, Kyoto University

代表研究者：田中庸裕 Tsunehiro Tanaka, Director

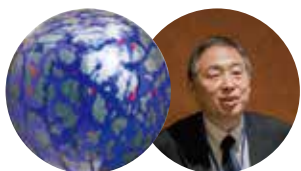
連携機関：東京大学、自然科学研究機構分子科学研究所、九州大学、熊本大学、東京理科大学
Collaborating institutes: The University of Tokyo, the Institute for Molecular Science of the
National Institutes of Natural Sciences, Kyushu University, Kumamoto University, and the
Tokyo University of Science

開発対象：固体触媒と二次電池材料

開発目標：希少元素フリーの新規高性能触媒と二次電池を実現

構造材料研究拠点

Elements Strategy Initiative for Structural Materials (ESISM)



設置機関：京都大学 Core: Department of Materials Science and Engineering, Kyoto University

代表研究者：田中 功 Isao Tanaka, Director

連携機関：東京大学、大阪大学、物質・材料研究機構、九州大学、経産省ISMA、内閣府SIP
Collaborating institutes: The University of Tokyo, Osaka University, the National Institute
for Materials Science, Kyushu University, the Innovative Structural Materials Association
(METI), and the Strategic Innovation Promotion Program (the Cabinet Office)

開発対象：実用材料として適用している金属材料、高靱性セラミックス材料、それらの複合材料

開発目標：強度と靱性が両立する究極材料の実現



Rare-metal-lean permanent magnet

The Elements Strategy Initiative Center for Magnetic Materials (ESICMM)



GL: Takashi Miyake,
CD-FMat, AIST



Background to the research

- Growing market for high-performance permanent magnets
- Anticipation for novel materials beyond neodymium magnet
- Anticipation for novel magnet materials that do not include critical elements

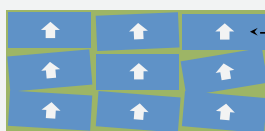
Points of the research

- Understanding high saturation magnetization and high magnetocrystalline anisotropy based on quantum theory
- Efficient materials discovery using a combination of computational, data-driven, and theoretical approaches
- High magnetic properties of Fe-rich rare-earth magnet compound NdFe_{12}N : prediction by first-principles calculations and visualization

Outline of the research
1

Requirements for high-performance magnet materials

Microstructure



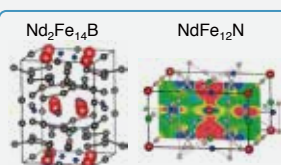
Sub phases

- Neodymium oxides
- Amorphous

Sub phases

- Optimized microstructures for high coercivity

Main phase



Main phase

- High saturation magnetization
- High magnetocrystalline anisotropy
- High Curie temperature

Figure 1 High-performance permanent magnet materials require a main phase having high saturation magnetization, high magnetocrystalline anisotropy, high Curie temperature, and a sub phase that blocks the magnetic coupling among main phases. Coercivity has strong positive correlation with the microstructure.

Outline of the research
2

Mechanism of magnetism in rare-earth magnet compounds

Transition metal

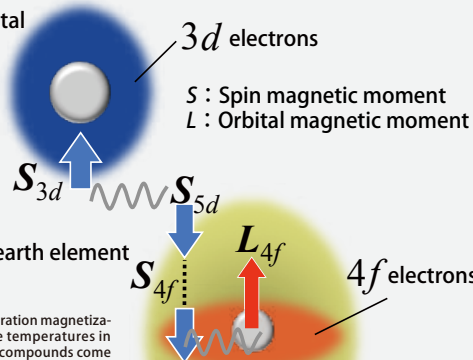


Figure 2 High saturation magnetization and high Curie temperatures in rare-earth magnet compounds come from the 3d electrons of transition metals, whereas the 4f electrons of rare-earth elements are the source of strong magnetocrystalline anisotropy. The direction of the orbital magnetic moment of the 4f electrons is affected by the crystal field produced by the surrounding charge distribution.

Outline of the research
3

Search for maximum performance of magnets through ab-initio data catalyst support

Procedure for materials design

Several hundreds of data points obtained by high-throughput ab-initio calculation are visualized.

Materials located around the peak position in performance are searched and targeted as candidate materials after their structural stabilities are examined.

Among candidates, those possibly synthesized are further investigated theoretically in detail.

Syntheses of thus predicted materials and their characterizations are tried out.

Ferromagnetism is unstable in the region to the left of the dashed line.

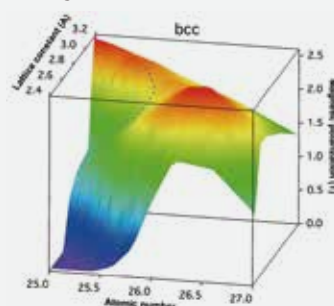


Figure 3 Saturation magnetic polarization J_S of the system plotted against the lattice constant a and atomic number of a fictitious atom Z . The ferromagnetic state is unstable in the region to the left of the dashed line. Here a bcc structure is assumed, and the electron number corresponds to the atomic number of fictitious atoms. A dome-like structure appears around $a \approx 2.65 \text{ \AA}$ and $Z \approx 26.4$, where J_S takes the maximum value of 2.66 T, which is much larger than that of $\text{Nd}_2\text{Fe}_{14}\text{B}$, is seen.

Outline of the research
4

Visualization in Mechanism of magnetism

- Visualization of electron spin-density that may affect the magnetic properties.
- Development of 3D-Printing technology that enables us to depict the crystal structure and electron density in the transparent resin.

This helps us to get better understanding and deep insights, supporting the creation of new ideas.

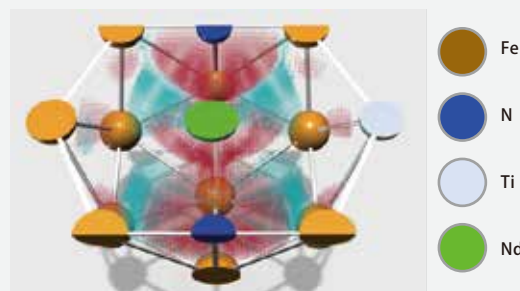


Figure 4 Difference in the electron spin-density is obtained by subtracting that of $\text{NdFe}_{12}\text{Ti}$ from that of NdFe_{12}N . The difference near the N atoms is conspicuous, is seen.

Roadmap

- Discovery of novel magnet compounds and optimization of chemical composition by machine learning / AI
- Mechanism elucidation of coercivity

Applications

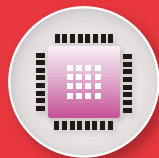
- Electric motors for xEVs (hybrid vehicles, electric vehicles etc.)
- Home electric appliances
- Industrial robot
- Wind turbines
- drone etc.

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The Elements Strategy Initiative Center for Magnetic Materials

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Creation of Novel-Function & High-Performance Electronic Materials based on Novel Concepts for Materials Design

Tokodai Institute for Element Strategy (TIES)



GL : Hideo Hosono,
Representative, TIES

Background to the research

- There have been numerous large-scale national projects on electronic materials to date.
- Materials design has become fixated on just a few concepts, such as diamond-structure semiconductors and perovskite dielectrics.
- There is a need for novel perspectives on abundant elements independent of obsolete approaches based on previous successes.

Points of the research

- Exploring novel material candidates making full use of condensed matter physics, electron theory, computational chemistry, materials informatics (M. I.), etc.
- Rapid syntheses of candidate materials utilizing such extreme experiments as super-high pressure and super-high vacuum.
- Rapid feedback of material property analyses using synchrotron radiation (KEK-PF and SPring-8), neutrons, and muons (J-PARC).

Outline of the research

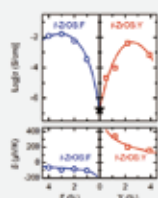
1

Novel Direct Band-Gap, Bipolar Semiconductors derived from New Concepts of M. I. and Molecular Orbitals



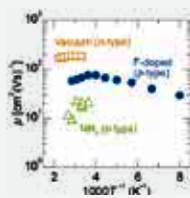
Red Luminescence as designed

Figure1 Novel nitride semiconductor, CaZn_2N_2 , discovered by M.I. and synthesized under high pressure



Bipolar Doping

Figure2 Oxysulfide semiconductor based on early-transition metals, ZrOS , designed under molecular orbital concepts



Hall Mobilities

Figure3 A new nitride semiconductor, Cu_3N , for solar-cell applications by p-type doping with interstitial fluorine

Outline of the research

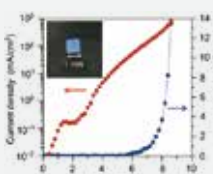
2

Novel Semiconductor Materials for Next-Generation Light-Emission-Type Flat-Panel Displays



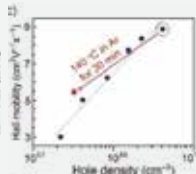
Green Electroluminescence with FWHM of 16 nm and Maximum Intensity of $180,000 \text{ cd m}^{-2}$

Figure 4 Low-voltage, high-brightness LED based on halide perovskite semiconductors with the novel oxide semiconductor Zn-Si-O as an electron-transport layer.



Electroluminescence by electron injection from Zn-Si-O

Figure 5 High efficiency blue-light emitting lead-free inorganic iodate semiconductor, Cs_3CuI_3 .



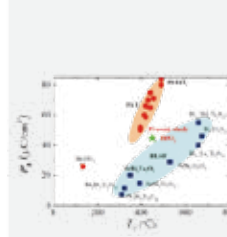
Hall Mobilities

Figure 6 Low-temperature, printable, high-mobility, p-type, transparent, amorphous semiconductor: Cs_2CuI_2 .

Outline of the research

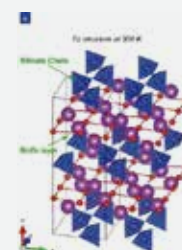
3

High-temperature stable, high dielectric constant, non-perovskite dielectrics for power-electronics applications



Higher T_C and Higher P_C than conventional materials

Figure7 Fluorite ferroelectrics with high T_C & P_C : $\text{HfO}_2\text{-Y}$.



Crystal Structure

Figure8 Silicate ferroelectrics satisfying requirements for vehicle applications: $(\text{Bi,La})_2\text{SiO}_5$



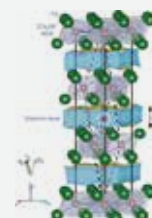
2-inch Single Crystal and Sensor Module

Figure9 High-temperature stable piezoelectrics for vehicle pressure sensors: $\text{CTAS} (\text{Ca}_3\text{TaAl}_3\text{Si}_2\text{O}_{14})$.

Outline of the research

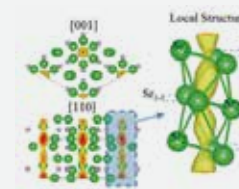
4

Inorganic and Solid-State Electride Materials soon to be commercialized as catalysts for ammonia synthesis at low temperature and pressure



Crystal Structure of Ca_2N

Figure10 Two-dimensional electrides under consideration for the base of commercial material systems



Crystal Structure and Electron Density Mapping

Figure11 A novel, intermetallic, one-dimensional electride explored using genetic algorithms: Sr_2P_3



Nodal Lines of a 2D electride, Y_2C

Figure12 A novel concept of "topological electrides" and their candidate materials.

Roadmap

- Stabilization of creation rates of novel materials and their design concepts
- Technical transfer to industries
- Concept proposal for post Elements Strategy

Applications

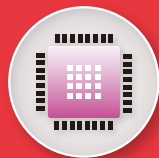
- High-efficiency & low-cost semiconductor materials for flat-panel displays
- High-temperature stable & high-dielectric constant dielectrics for vehicle power electronics
- Electride materials for catalysts

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Unraveling the Roles, Functionalities, and States of Hydrogen in Condensed Matter and Establishing Highly Sensitive Quantification Methods

Tokodai Institute for
Element Strategy (TIES)



GL : Hideo Hosono,
Representative, TIES

Background to the research

- The presence of hydrogen in oxides has often been ignored despite its high concentration ($\geq 10^{20} \text{cm}^{-3}$).
- Experimental and theoretical investigations have implied that the hydrogen strongly influences local and electronic structures of condensed matter.
- It is important to establish methods of quantification and state analysis for hydrogen and to unravel the roles and functionalities of hydrogen in order to utilize hydrogen as a key functional element.

Points of the research

- Development of thin films with extremely low hydrogen content and a method and apparatus to quantify the hydrogen concentration with high sensitivity.
- Combined use of density functional theory calculations and analyses using hydrogen-sensitive probes, such as NMR, infrared absorption, neutrons, and muons.
- Investigations of relationships between the concentrations and states of hydrogen in semiconductor thin films and the stability of their electron devices.

Outline of the research

1

Development of a High-Sensitivity Method & Apparatus to Quantify the Hydrogen Concentration in Thin Films

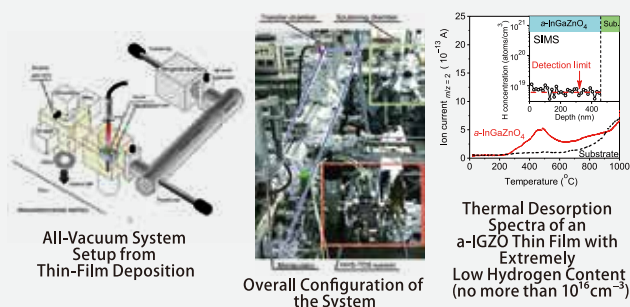


Figure1 High-Sensitivity method and apparatus for quantifying hydrogen concentration and their demonstration on a-IGZO thin films with extremely low hydrogen contents (under 10^{16}cm^{-3}).

- Implemented using an extremely low-out-gassing, ultra-high vacuum system with

all-vacuum transfer from the thin-film deposition chamber, and by performing calibration using high-accuracy ion implantation and the introduction of trace amounts of gas.

- Used for preparing reference samples with extremely low concentrations of hydrogen.

Outline of the research

2

Hydride Ions in Oxide Hosts Hidden by Hydroxide ions

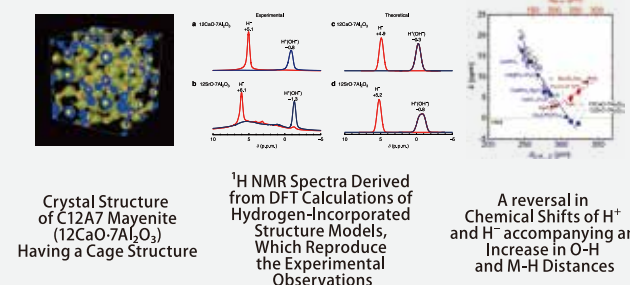


Figure 2 Demonstrating the presence of hydride in solid-state oxide crystals

- Splits of ^1H NMR spectra were observed in mayenite and apatite crystals

- A reversal in chemical shifts of H^+ and H^- is predicted by DFT calculations based on crystal structure models with hydrogen incorporated.

Outline of the research

3

Hydrides (hydrogen anions) in Amorphous Oxide Semiconductors and the Origin of Instabilities in their Electron Devices

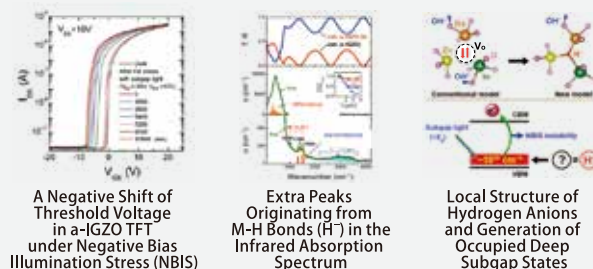


Figure3 Hydrides (hydrogen anions) in a-IGZO thin films and the origin of instabilities in their TFTs

- Amorphous oxide semiconductor TFTs such as a-IGZO exhibit large negative shifts in threshold voltage under illumination and negative bias stresses.
- Hydrides composed of metal cation-hydrogen anion bonds are observed in infrared

absorption spectra and identified by DFT calculations of hydrogen-incorporated models

- Hydrogen atoms incorporated into oxygen vacancies, V_O , bond to adjacent metal cations to form hydrides (hydrogen anions, H^-), which generate occupied deep subgap states above the valence-band maximum (VBM) and cause NBIS instabilities in a-IGZO TFTs.

Outline of the research

4

Electron Doping by Hydrogen Incorporation in Iron Oxyprictides to Produce Superconducting Phase

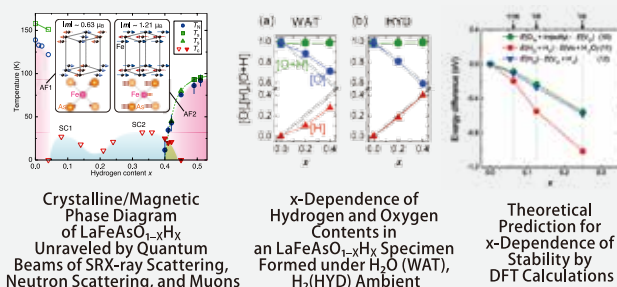


Figure4 Superconducting phase generated by hydrogen doping in Iron Oxyprictide $\text{LaFeAsO}_{1-x}\text{H}_x$ and states of the non-substituted hydrogens.

- Iron oxyprictide $\text{LaFeAsO}_{1-x}\text{H}_x$ shows, depending on x, two superconducting phases (SC1, SC2) originating from two antiferromagnetic mother phases (AF1, AF2).

Hydrogen and oxygen content were found experimentally to be complementary to each other.

- DFT calculations predict that stability is greatest when hydrogen anions H^- occupy the sites of oxygen vacancies V_O , which suggests the common image of V_O stabilization by H^- .

Roadmap

- Clarifying the relationships between material functionalities and device characteristics
- Extension to dielectric materials
- Exploration and creation of hydrogen-functionalized electronic materials

Applications

- Performance enhancement and stabilization of electronic materials and electron devices
- Novel hydrogen-functionalized materials including hydrides
- Analysis of low-hydrogen-content specimens

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Novel Automotive Catalysts Using Less Noble Metals

Elements Strategy Initiative for Catalysts and Batteries (ESICB)



GL: Tsunehiro Tanaka,
Graduate School of Engineering,
Kyoto University



Background to the research

- Reducing the use of platinum-group metals (PGM) in automotive catalysts is of practical importance.
- Thermal sintering of metal nanoparticles poses a significant problem to catalyst life.
- Catalytic active sites are thought to be the surface of noble metal particles.

Points of the research

- Plasma preparation for Rh nanofilm-coated metal honeycomb catalysts
- The catalytic activity of the Rh nanofilm is markedly superior to that of Rh nanoparticles.
- Improvement in catalytic performance using the function of a catalyst support.

Outline of the research

1

Paradigm shift in catalyst preparation and structure

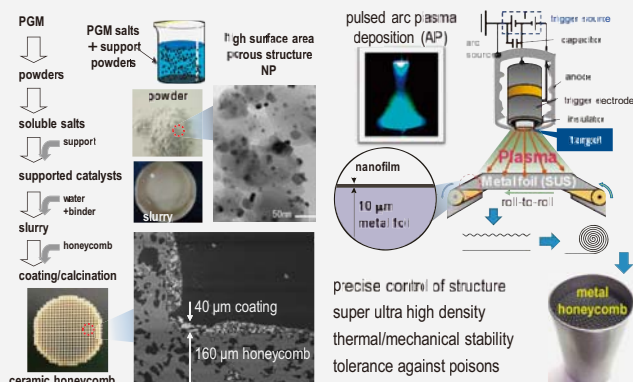


Figure 1 (Left) Conventional catalyst preparation via wet coating of powder containing metal nanoparticles. (Right) Novel catalyst preparation via pulsed arc plasma deposition of active metal nanofilms onto metal foil substrates.

Outline of the research

2

Catalytic performance of Rh nanofilm and Rh nanoparticle catalysts

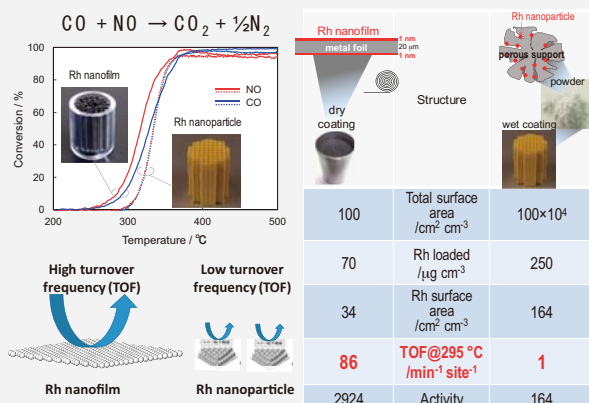


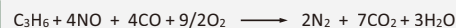
Figure 2 Catalytic performance of a Rh nanofilm-coated honeycomb catalyst compared with a conventional honeycomb prepared by wet coating. 0.1% NO, 0.1% CO, N₂ balance. GHSV = 1.2×10⁵ h⁻¹.

Outline of the research

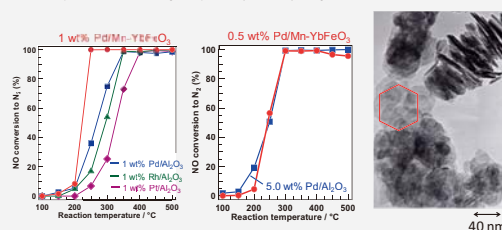
3

Reduction of Pd usage by improving a function of catalyst support

Model Reaction for purifying automotive exhaust gas



C₃H₈: residual component due to gasoline, CO: component formed by incomplete combustion of gasoline
NO: component formed under high temperature (> 1000 °C) in engine



The catalytic activity of 0.5 wt% Pd/Mn-YbFeO₃ is comparable to that of 5.0 wt% Pd/Al₂O₃.

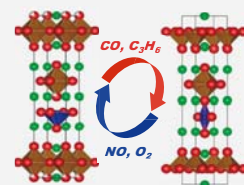
Figure 3 (Left) NO conversion to N₂ over Pd catalyst supported on Mn-modified hexagonal YbFeO₃ (Pd/Mn-YbFeO₃). (Right) TEM image of Pd/Mn-YbFeO₃ having hexagonal plate-like nanoparticles.

Outline of the research

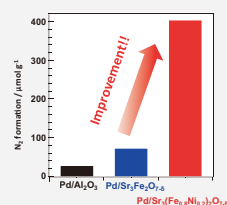
4

Development of novel catalyst support having oxygen storage capacity

Redox behavior of Sr₃(Fe_{0.8}Ni_{0.2})₂O_{7-δ}



Efficiency of NO reduction



Mechanism for NO reduction on Sr₃(Fe_{0.8}Ni_{0.2})₂O_{7-δ}

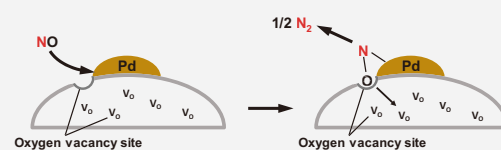


Figure 4 (Upper left) Structural change of Sr₃(Fe_{0.8}Ni_{0.2})₂O_{7-δ} during the purification of automotive exhaust gas (Upper right) Efficiency of NO reduction at oxygen vacancy site in Pd/Sr₃(Fe_{0.8}Ni_{0.2})₂O_{7-δ} (Below) Mechanism for NO reduction in Pd/Sr₃(Fe_{0.8}Ni_{0.2})₂O_{7-δ}.

Roadmap

- Elucidation of the reaction mechanisms for nanofilm catalysts
- Development of nanofilm catalysts for various chemical reactions
- Development of novel catalyst materials using the crystal structure of catalyst supports

Applications

- Automotive catalysts
- Microreactors and smart reactors

Contact us here

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Fire-Extinguishing Organic Electrolytes for Safe Batteries



Background to the research

- Fire incidents with explosions occurring in lithium-ion batteries have been problematic.
- The simple addition of flame-retardant solvents significantly degrades the battery cycle.
- How can we produce better batteries with a high level of safety?

Points of the research

- Highly concentrated fire-extinguishing TMP-based electrolyte can form a very robust passivation film on the anode surface.
- This enables an excellent battery life of more than 1,000 charge-discharge cycles with negligible degradation.
- Computational analysis using the K computer has revealed the formation mechanisms of stable passivation film.

Outline of the research

1

Toward ultimate safety while retaining repeated cycle stability

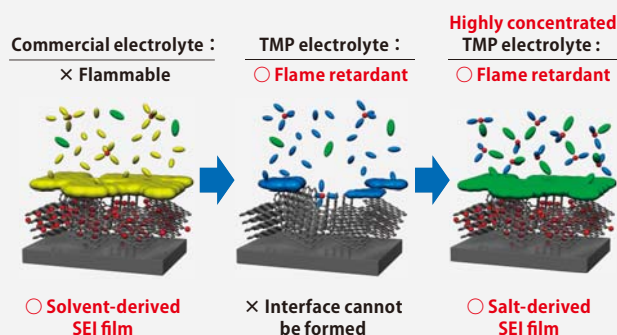


Figure 1 Electrolyte design concept for a safer battery. By ultimately simple strategy of increasing salt-concentration, interfacial character is dramatically modified to realize very stable operation, and many of the solvents are functionalized (fire-extinguishing TMP this time).

Outline of the research

2

Repeated cycle stability of hard carbon negative electrode for Na-ion batteries

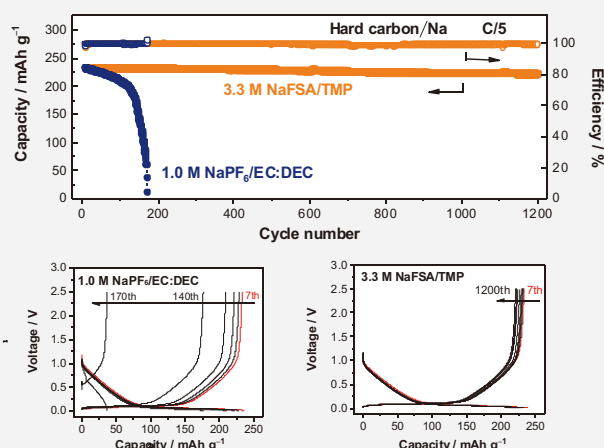


Figure 2 Capacity retention during repeated cycling of a hard-carbon anode for an Na-ion battery; the organic electrolyte developed in this study (3.3M NaFSA/TMP) achieved stable charging/discharging for more than 1,200 cycles (over a year and a half)

Outline of the research

3

Comparison of flammability

General electrolytes
1.0 M NaPF₆/EC:DEC (1:1)



New highly concentrated electrolytes
3.3 M NaFSA/TMP



Figure 3 Flame tests on conventional 1.0 M NaPF₆/EC:DEC (1:1 by vol) electrolyte (left) and laboratory-made 3.3 M NaFSA/TMP electrolyte (right)

Outline of the research

4

Electronic structures of highly concentrated electrolytes

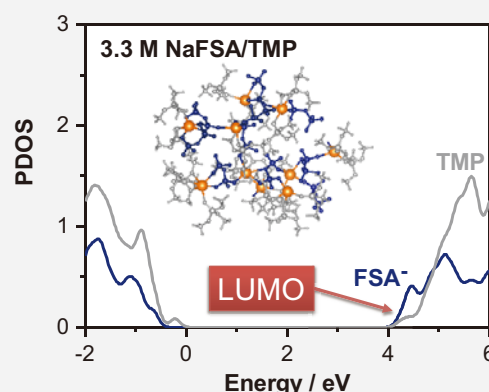


Figure 4 Electronic structures and coordination structures (insets) of 3.3 M NaFSA/TMP solutions obtained with DFT-MD simulations. Na⁺ cations, FSA⁻ anions and TMP solvents are shown in orange, blue and grey, respectively. The pDOS, projected density of states, shows that LUMO are located at FSA and that the FSA is attacked first upon reduction to form a passivation film.

Roadmap

- Paradigm shift of electrolyte concept
- Cost-cutting and industrial development
- Optimization for mass production

Applications

- Consumer batteries
- Batteries for vehicles
- Stationary batteries

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Concurrent enhancement of strength and ductility in bulk nanostructured hexagonal metals

Elements Strategy Initiative for Structural Materials (ESISM)



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Background to the research

- Concurrent enhancement of strength and ductility in structural materials is essential for guaranteeing a safe and secure society.
- Applications for strong, light-weight titanium and magnesium alloys have been limited by poor ductility owing to their hexagonal crystal structures.
- Creation of innovative hexagonal metals through bulk nanostructuring rather than the addition of critical alloying elements is targeted.

Points of the research

- Fully recrystallized titanium and magnesium alloys with various average grain sizes down to the sub-micrometer scale were successfully fabricated.
- Concurrent enhancement of strength and ductility was successfully achieved in bulk nanostructured titanium and magnesium alloys.
- Atomistic mechanisms of the superior mechanical properties in bulk nanostructured materials were clarified through state-of-the-art experiments, such as transmission electron microscopy and neutron diffraction, as well as theoretical calculations.

Outline of the research 1

Fully recrystallized magnesium alloys with various average grain sizes

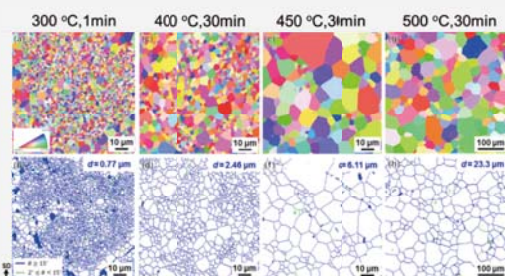


Figure 1 Magnesium-alloy samples having various average crystal grain sizes fabricated by high-pressure torsion (HPT) followed by recrystallization annealing treatments at the given temperatures and durations. (Top) Inverse pole figure (IPF) maps by electron backscatter diffraction (EBSD). Colors correspond to crystallographic orientations of grains. (Bottom) Grain boundary (GB) maps in which the blue and green lines correspond to high angle and low angle grain boundaries, respectively.

Outline of the research 2

Concurrent enhancement of strength and ductility in bulk nanostructured materials

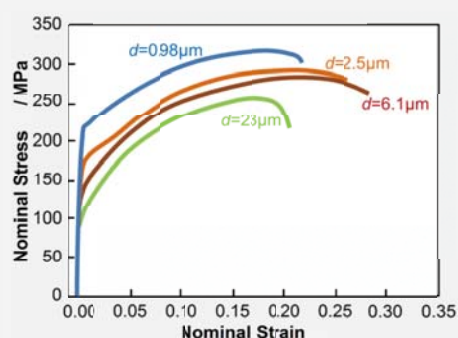


Figure 2 Comparison of stress-strain curves for Mg-alloy specimens having four different average grain sizes d .

Outline of the research 3

Mechanism of enhanced ductility in bulk nanostructured materials

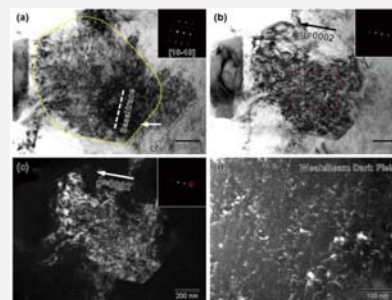


Figure 3 Transmission electron micrographs of ultrafine grained magnesium alloy sample with average grain sizes of $d = 0.98 \mu\text{m}$ after tensile deformation to a strain of 0.095. (a) Bright-field image observed along $[10-10]$ zone axis. (b) Bright-field and (c) corresponding dark-field images observed under two-beam condition with diffraction vector $g = (0002)$. (d) Weak-beam dark-field image of the rectangular area in (b) at a higher magnification. Highly dense, unusual dislocations with c -component can be observed. Such dislocations are presumed to be nucleated at grain boundaries when the stress level increases.

Outline of the research 4

Comprehensive understanding of ductility enhancement in bulk nanostructured metals under the new concept of *plaston*

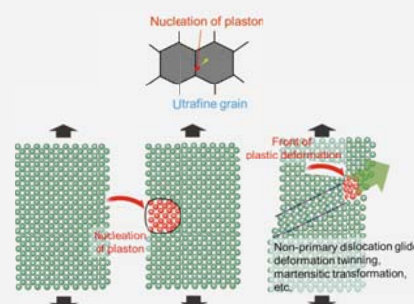


Figure 4 Unique plastic deformation mechanisms different from primary dislocation glide, such as non-primary dislocation glide, deformation twinning, and martensitic transformation, have been experimentally found to take place in bulk nanostructured materials. These mechanisms can be comprehensively explained under the new concept of *plaston*. When a large enough stress is applied, collective atomic motion occurs at lattice imperfections such as surfaces and grain boundaries, which eventually leads to the nucleation of plastic deformation. Similar phenomena are thought to take place at the front of the plastic deformation.

Roadmap

- Concurrent enhancement of strength and ductility in bulk nanostructured steels based on the new concept of *plaston*.
- Fundamental understanding of *plaston* in other materials having a variety of chemical bonds in order to overcome their brittleness.

Applications

- Vehicles and aircrafts
- Structures
- Biomaterials

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