Research of Materials Science in Tohoku University

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1. <Chronology of Tohoku University focused on Research of Materials Science>

Following Tokyo University (1877) and Kyoto University (1897), Tohoku University was founded in 1907 as the third Imperial. Today the University is one of the largest and oldest national universities in Japan with five campuses in Sendai. Since its inception, the university has embraced its "research first" and "open-door" policies and puts strong emphasis on education led by prestigious scholars and researchers. In addition, Tohoku University was the first university to admit female students in Japan, and it also accepted transfer students from professional schools and colleges ahead of its time

. <Chronology of Tohoku University focused on Research of Materials Science>

- >June1907 Tohoku Imperial University founded
- >Jan.1911 College of Science established.
- >July 1915 College of Medicine established.
- >Apr. 1919 College of Science reorganized as the Faculty of Science.
- >May 1919 Iron and Steel Research Institute established.
- > Faculty of Engineering established.
- >Aug.1923 Department of Metallurgy established.
- >Sept.1935 Research Institute of Electrical Communication established.
- >Mar.1941 Research Institute of Mineral Dressing and Metallurgy established.
- >Jan. 1943 Research Institute for Scientific Measurements established.
- >Oct. 1943 Institute of High Speed Mechanics established.
- > Chemical Research Institute of Non-Aqueous Solutions established.
- >Oct.1947 Name of the university changed from Tohoku Imperial University to Tohoku University in accordance with educational reforms.
- >May1987 Institute for Materials Research reorganized as a national collaborative research institute.

(Continue)

>May1989 Institute of High Speed Mechanics reorganized as Institute of Fluid Science.

>Apr.2001 Institute of Multi-disciplinary Research for Advanced Materials established by merger and reorganization of Research Institute for Advanced Materials Processing, Research Institute for Scientific Measurements, and Institute for Chemical Reaction Science.

2. Schools and Research Institutes Involved Mainly in Materials Science

1) Research Institutes

/Institute for Materials Research

/Institute of Fluid Science

/Research Institute of Electrical Communication

/Institute of Multi-Disciplinary Research for Advanced Materials

2) Graduate Schools

/Graduate School of Science(Physics, Chemistry).

/Graduate School of Engineering (Mechanics, Electrics-Electron-Communication, Applied Physics,Chemistry, Materials Science).

/Graduate School of Environmental Studies

3) Inter-Departmental Centers

- New Industry Creation Hatchery Center
- Center for Inter-Disciplinary Research
- High-Voltage Electron Microscope Laboratory

3. Current research topics:Genre

(1)Physics and Chemistry of Materials(Basic studies)

Giant Magneto-Resistance

Tunnel Magneto-Resistance

(2)Preparation, Synthesis, Purification, Smelting of Materials

(3)Fabrication, Processing toward Devices

Mechanical control, Development of monitors and sensors

<Another view points>

(a) Nanotechnology related Science,
Technology

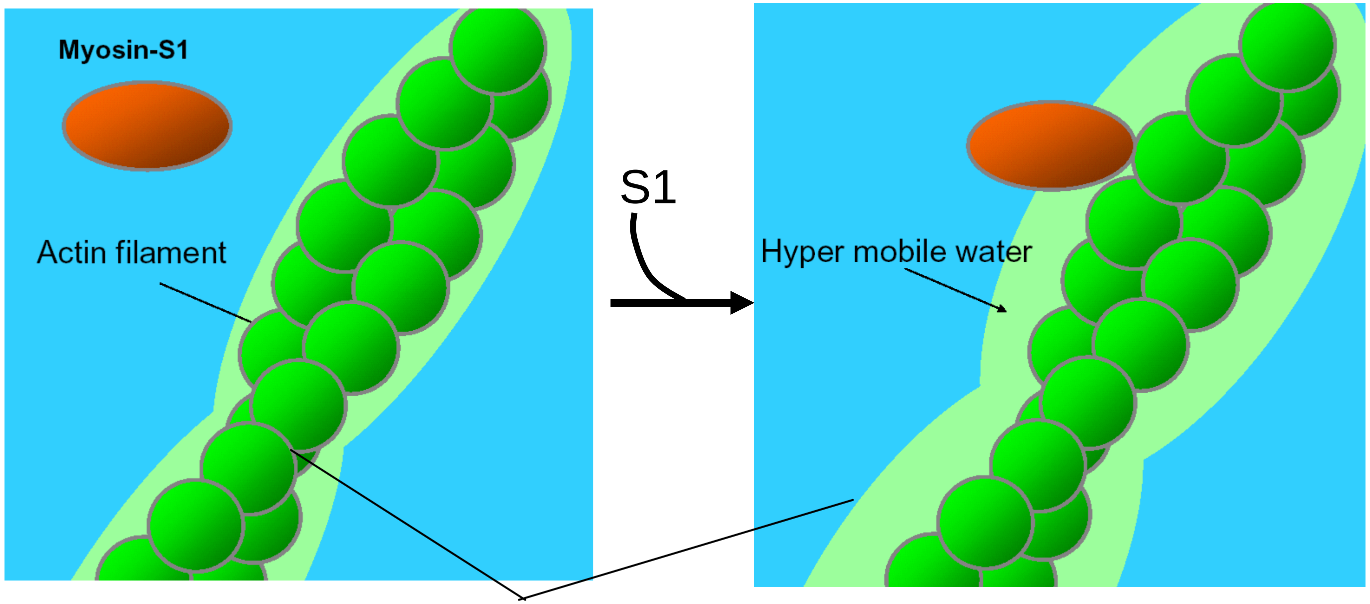
(b) Advanced Base Metals
/Purification
/Crystal Grain Boundary Control

- Protein materials for nanomachines –
Graduate school of Engineering, Prof. Makoto SUZUKI

TOHOKU UNIVERSITY

A finding of hyper-mobile water (BJ 2003)

Volume increase of hyper-mobile water by S1-binding (+70%) (BBRC 2004)



Hyper-mobile water

Objects: Elucidation of force generation mechanism of muscle motor proteins, and construction of nano-actuator mechanism

(2) Methods: Microwave dielectric spectroscopy with ultra-high resolution & application of synthetic polymer gels

(3) Outputs:

- **Discovery of Hyper-mobile water around actin filaments**
- **Dynamic change of water mobility around motor proteins accompanying chemical reactions**
- **Nano-actuation mechanism**

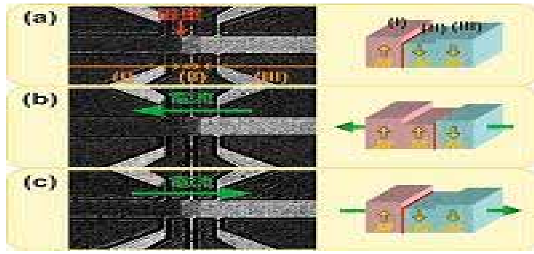
Preparation, characterization, and application of new classes of compound semiconductors and their quantum structures for new functional high-speed devices

Research institute of Electrical Communication, Prof. Hideo OHNO

Research activities:

Our research activities cover the areas of preparation, characterization, and application of new classes of compound semiconductors and their quantum structures for new functional high-speed devices, which can be realized by controlling the electronic and spin states in semiconductors. More specifically, our research is focused on (1) Semiconductor Spintronics, where non-volatile spin memory and new functionality based on the spin degree of freedom using III-V based ferromagnetic/non-magnetic semiconductor heterostructures are being explored, (2) THz-far infrared lasers based on the intersubband optical transition in broken-gap semiconductor heterostructures (InAs/GaSb), (3) the quantum transport phenomena in two-dimensional electron gases, and (4) non-volatile spin memories based on magnetic metal devices. Materials of interest include such nonmagnetic semiconductor heterostructures as GaAs/AlAs and InAs/GaSb, and III-V based ferromagnetic semiconductors such as (Ga, Mn)As and (In,Mn)As. All these materials are prepared by Molecular Beam Epitaxy.

Molecular beam epitaxy (MBE)- sputtering equipment for the growth of III-V based ferromagnetic/nonmagnetic semiconductor heterostructures and magnetic metal devices.



Current induced domain wall switching in a ferromagnetic semiconductor structure: The Magneto-optical-polar Kerr Effect images of (a) the initial state, (b) after application of a current pulse from right to left , showing that the domain wall is now at the right edge of region II. (c) A current pulse in the opposite direction switches the domain wall back to its original position.

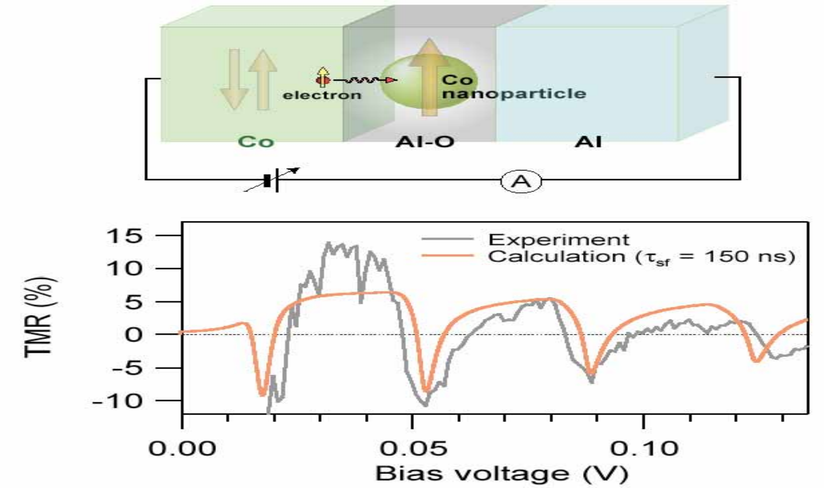
Research topics:

1. Semiconductor Spintronics
   a. Properties and Application of III-V Based Ferromagnetic Semiconductors and their Quantum Structures
   b. Spin Memory
   c. Spin Coherence in Semiconductor Nanostructures and Its Application to Quantum Information Technology
2. Quantum Cascade Structures and Their Application to THz Optical Devices
3. Quantum Transport Properties in Semiconductor Quantum Nano-Structures
4. Growth and Characterization of Semiconductor Quantum Nano-Structures
5. Magnetic Metal Devices and their Application to Nonvolatile Spin Memories

Physics and Materials for Spin Electronics

Institute for Materials Research, Prof. K. Takanashi

We work on the development of novel magnetic materials by artificial nanostructure control and the observation of new physical phenomena for spin electronics.



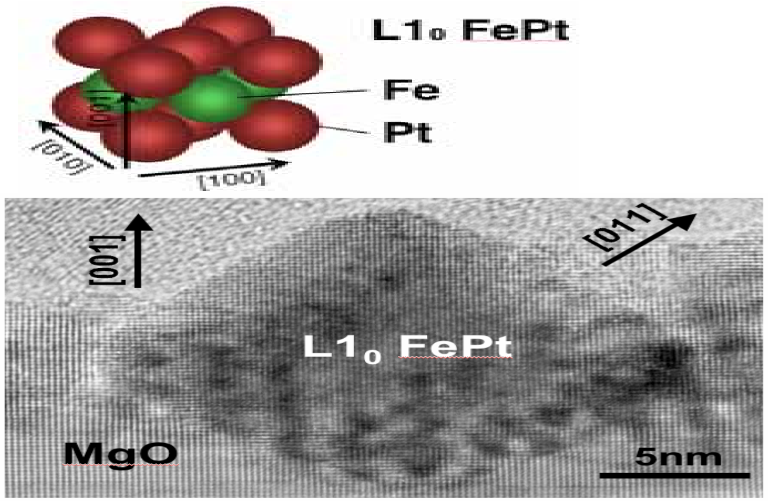
1.Enhanced spin life time in nanoparticles

Spin dependent single electron tunneling through a cobalt nano-particle was observed. The result shows extremely long spin life time is realized in nanoparticles which will be useful for quantum interference devices and quantum computing.

2. Nanostructure control and huge coercivity in $L1_0$ ordered FePt alloy

Highly coercive $L1_0$ ordered FePt nanoparticles with octahedral structure were successfully fabricated via a unique thin film deposition process.

$L1_0$ FePt nanostructures will be used for high-density information storages and scanning probe



Quantum Phenomena in Novel Materials and Nanostructures

Institute for Materials Research, Prof. S. Maekawa

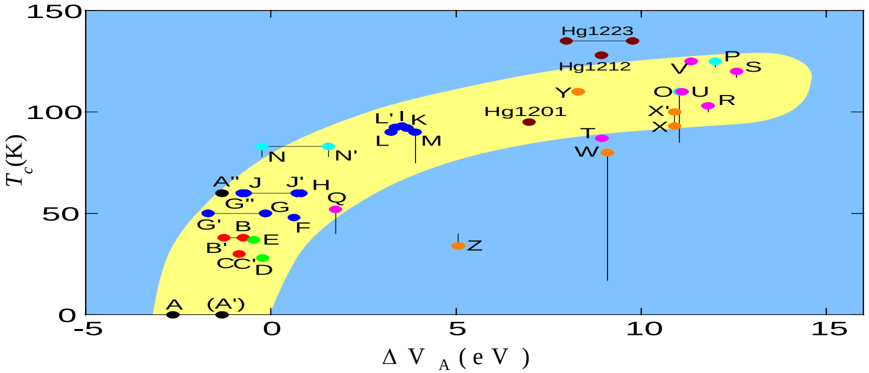


Fig. 1. Correlation between T_c and the electrostatic potential, ΔV_A, acting on a positive hole on oxygen: Each mark shows a high-temperature superconducting cuprate. A definite correlation exists between the T_c and ΔV_A. The relationship can be utilized in material design.

The microscopic world such as atoms and molecules is governed by quantum mechanics which is a different law from that in the macroscopic world. This law sometimes appears in front of us when materials are selected and/or microfabrication technique is utilized to them. Superconductivity which appears in cuprates, metals and alloys is a typical example. Anomalous change of the electrical resistance caused by the magnetism in tunnel junctions and transition metal oxides is another one. The aim of this laboratory is to study theoretically quantum phenomena in materials and nanostructures. The current research interests are: the mechanism of superconductivity in cuprates and new superconducting materials with unique properties (Fig. 1), and the study of the quantum phenomena and the construction of the basic concepts in quantum computing devices in superconductor/ferromagnet nano-hybrid structure (Fig. 2).

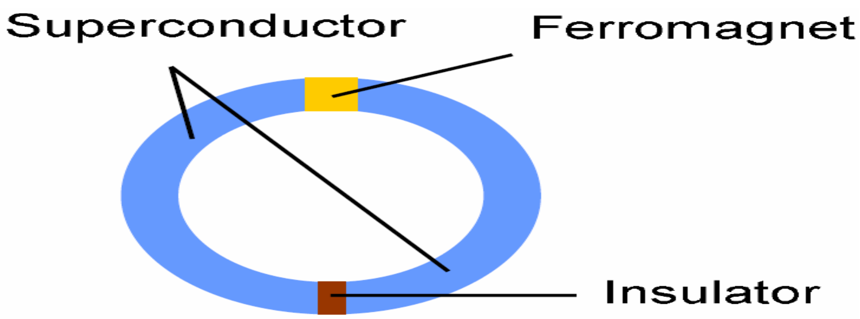


Fig. 2. Quantum computing device in superconductor/ferromagnet nano-hybrid structure.

Development of Liquid Alloys and Their Applications

Institute for Materials Research, Prof. Akihisa INOUE

This laboratory is engaged in the study of advanced nonequilibrium metallic materials with amorphous, quasicrystalline or nanocrystalline phase exhibiting useful physical and chemical properties. These nonequilibrium materials have been produced by utilizing highly supercooled liquid obtained by rapid solidification etc. Emphasis has been paid to formation mechanism, preparation processing, thermal stability, crystallization, physical and chemical properties, and deformation behavior of bulk or porous glassy single phase alloys (Fig. 1) and bulk glassy mixed phase alloys containing nanoscale quasicrystalline and crystalline particles. Presently , various advanced materials, i.e., soft and hard magnetic materials in iron- and neodymium-based alloys, high fracture toughness materials in zirconium- and copper-based alloys and high specific strength materials in aluminum- and magnesium-based alloys have been developed in bulk glassy, nano-quasicrystalline and nano-crystalline states and have attracted much attention as new engineering materials.

In the research field of materials science and engineering, significant achievements have been accomplished by this group in the following research topics: (1) fabrications of novel amorphous/glassy, quasicrystalline and nanocrystalline alloys, (2) clarifications of their formation mechanisms, (3) nanometer-scale analyses of their metallographic morphology, structure and composition, (4) findings of their useful properties, and (5) applications (Fig. 2). In particular, worldwide scientific attention centering on is the first success in fabricating the bulk metallic glasses in a number of alloy systems by conventional solidification techniques of which the cooling rate is approximately several degrees per second. As a result of these findings, it is clarified that the bulk metallic glasses with a size in centimeter range are fabricated from supercooled liquid by its stabilization mechanism. It is also of concern that empirical rules for the description of the stabilization phenomenon of the supercooled liquid are proposed, and are utilized for further finding of new bulk metallic glasses. For instance, ferromagnetic bulk metallic glasses have recently been fabricated in the framework of alloy designing due to the empirical rules.

Fig. 1 Shape and outer surface appearance of some bulk glassy alloys in massive, cylindrical rod and tube forms produced by water quenching and copper mold casting.

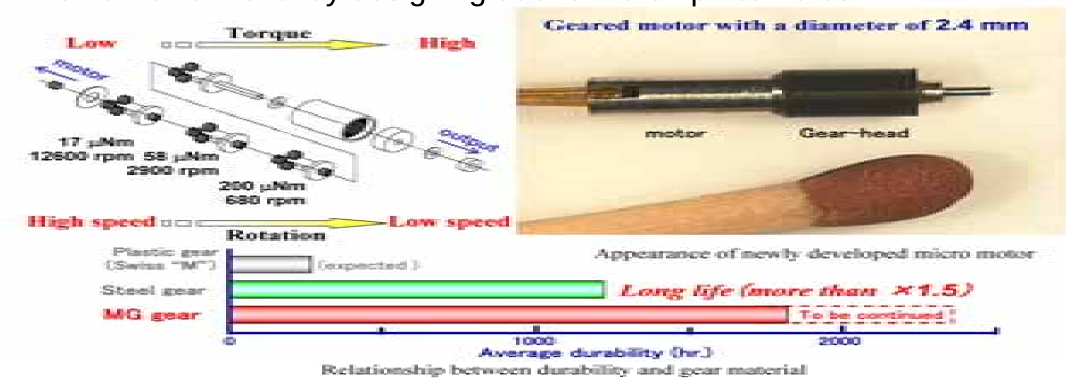
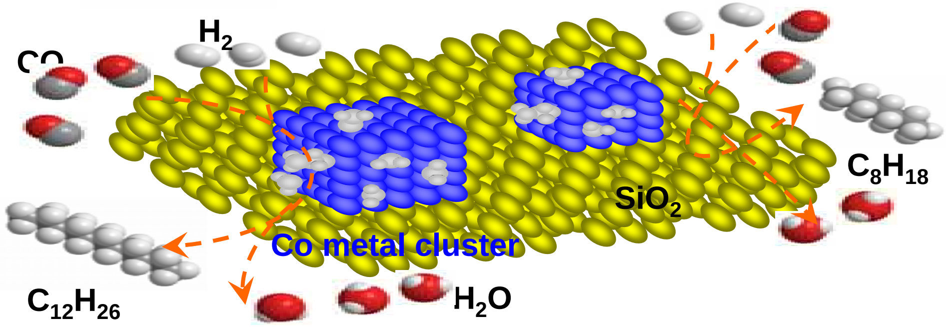


Fig. 2 Outlook and durability of a micro-geared motor of 1.5 mm in diameter constructed by using two super precision sun-carrier gears made of Ni-based glassy alloy.

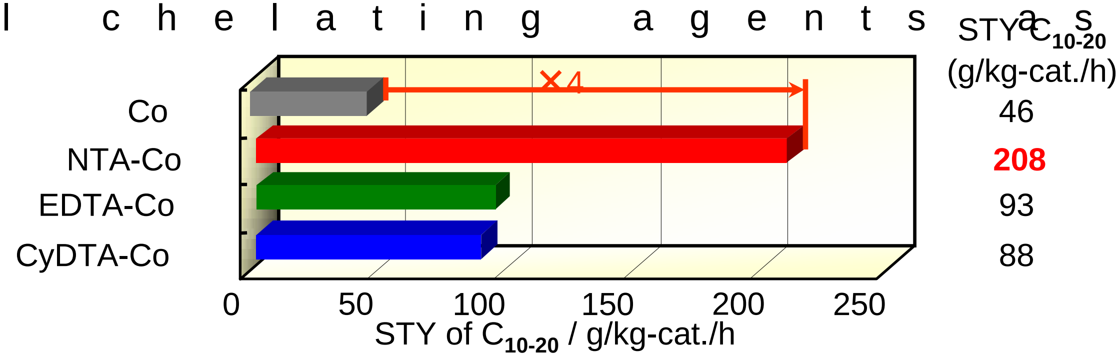
Novel preparation method of highly active Co nanocluster catalysts with chelating agents for the synthesis of ultra clean transportation fuels

TOHOKU UNIVERSITY

Graduate School of Engineering, Prof. M. Yamada



Fischer-Tropsch synthesis (FTS) reaction has been paid much attentions as very promising method to produce ultra-clean and high quality diesel fuels because this reaction provides pure aliphatic hydrocarbons (FT oil). While FTS processes have been commercialized only in South Africa and Malaysia based on large-scale gas fields, it is a quite important issue to develop a novel process that can utilize natural gas from a large number of small-scale remote gas fields. For this purpose, a simplified and on-site FTS process is necessarily required, which could be realized by developing more active and selective FTS catalyst. It is well known that SiO_2 supported metallic Co catalysts show higher activities and higher selectivities for $C_{10\text{-}20}$ hydrocarbons (i.e. diesel fuels) at medium reaction temperatures and pressures. Several previous studies suggest that metallic Co nanocluster is formed on SiO_2 under the working state (see upper figure), which is active for FTS reaction. However, the activities and selectivities of the state-of-the-art catalysts are not enough for the simplified and on-site FTS process mentioned above. Therefore, it is very important to design and prepare more accurately the active structures of Co/SiO_2 catalysts on nano-size level. For this purpose, we have recently tried to prepare more active Co/SiO_2 catalysts by using several chelating agents as modifiers of Co-structures. It has been found that modification with chelating agents is quite effective for Co/SiO_2 catalyst. Especially, the space-time yield (STY) of $C_{10\text{-}20}$ hydrocarbons with NTA-modified catalyst is 4 times greater than that with unmodified catalyst (see right figure).



[P=1.0 MPa, T=503 K, CO conversion＝20±3%]

Preparation of Semiconductor Grade Ultra-Pure Iron

Institute of Multidisciplinary Research for Advanced Materials
Prof. M. Isshiki

TOHOKU UNIVERSITY

Laboratory scale purification process

Anion Exchange

Oxidation Refining

Hydrogen Plasma Arc Melting

99.9999% pure iron !

Purpose

β-$FeSi_2$ has been noted as one of the environmental friendly semiconductor materials. β-$FeSi_2$ is also attractive for new infrared opto-electronics devices to fabricate an optical interconnection of LSI, because of its direct gap of ~0.8eV corresponding to the wave length for light communication and a possibility of epitaxial growth on Si substrate.

For realizing it, semiconductor grade ultra high purity iron is required.

Purification process

We have developed a laboratory scale purification process consisting of anion exchange, oxidation refining and hydrogen plasma arc melting to prepare a high purity iron with a purity of 99.9999%. A pilot plant of this process has been constructed with some companies as one of the projects of Ministry of Economy, Trade and Industry.

Method for purity estimation

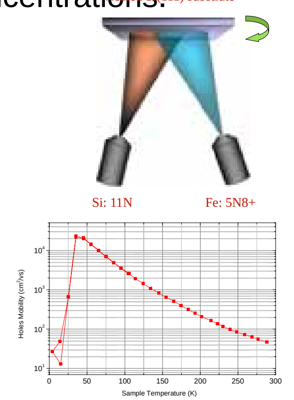
Glow Discharge Mass Spectrometer(GDMS) was used for analyzing impurity concentrations.

Results

Using a commercial grade pure iron with 99.9% as a starting material, 99.9998% pure iron could be obtained.

Evaluation of the produced pure iron as a source material for β-$FeSi_2$

Molecular beam epitaxy(MBE) of β-$FeSi_2$ has been carried out on hydrogen terminated Si sustrates. We succeeded MBE growth of β-$FeSi_2$ for the first time. We could obtain the highest hole mobility.



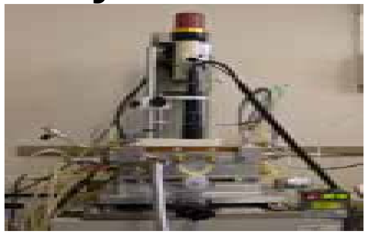
Crystals for solar cells with high conversion efficiency

Institute for Materials Research, Prof. Kazuo NAKAJIMA

We develop novel crystal growth techniques and new Si-based crystals for solar cells with high conversion efficiency on the basis of the crystal physics.

1. Development of an *in situ* observation system to directly observe the growing interface between the growth melt and the crystal

To develop high-quality Si multicrystals for solar cells with high-efficiency, we must understand the growth mechanism to control the grain orientation and the grain size using this system.



2. Extremely high-quality Si multicrystals for solar cells can be obtained by our dendritic casting method

100 mm

***A Si multicrystal ingot with controlled grain orientation, large grain size, and long lifetime can be grown was realized by using dendrite crystals grown along the bottom of the crucible.
Solar cells prepared by this ingot have very high efficiencies.***

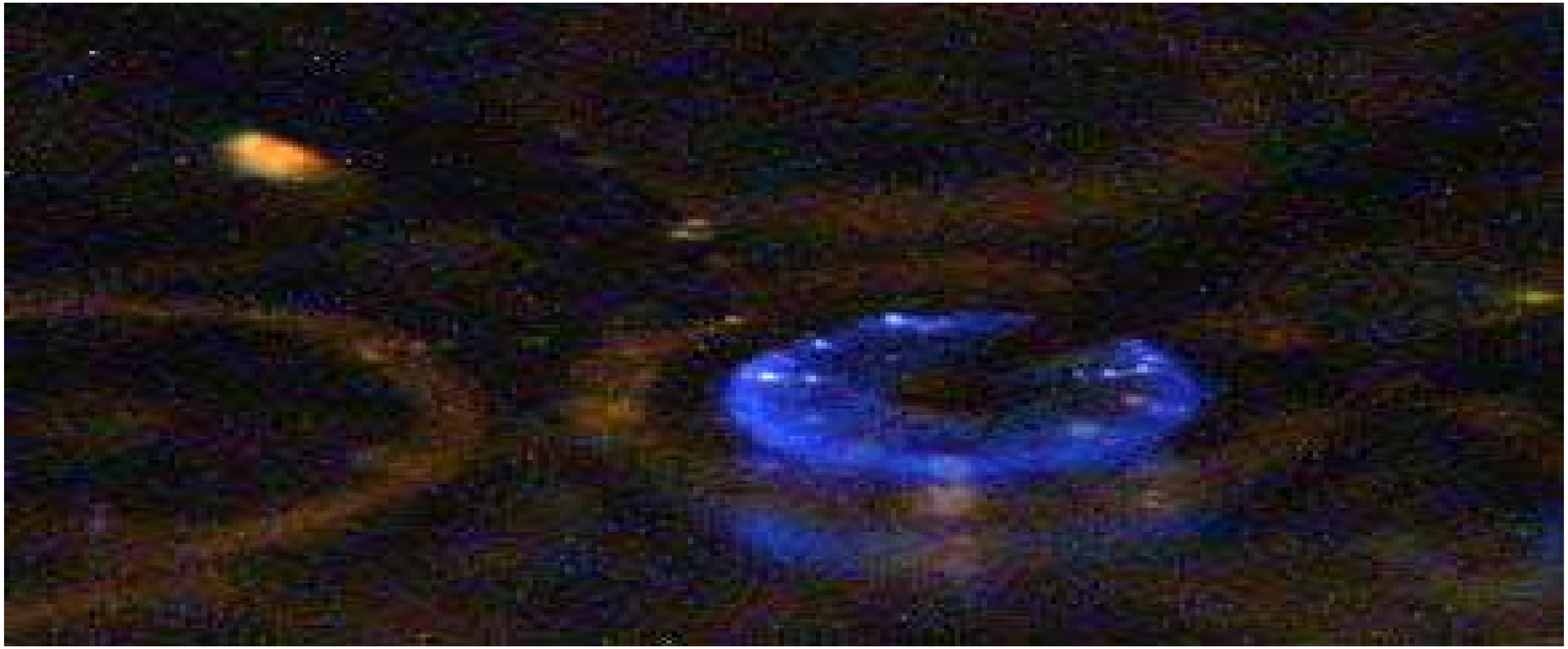
3. Si crystal lenses or mirrors by plastic deformation

We found that Si crystal wafers can easily deformed below the melting temperature of Si by plastic deformation. Such a Si Crystal lens can be applied for a new solar cell system and an X-ray monochromator. Application fields hold large potential.

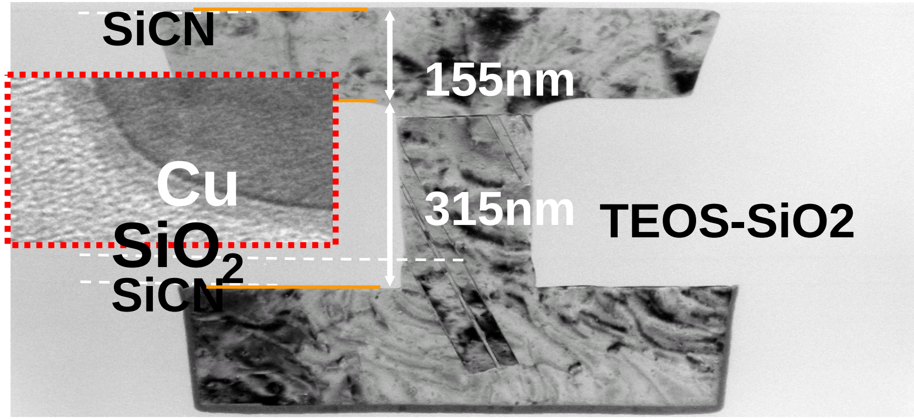
Si(111) crystal lens

First realization of p-type ZnO and light emitting pn diode
Institute for Material Research, Prof. Kawasaki group

ZnO has been known as one of the best semiconductors for highly efficient ultra-violet diode lasers due to its large exciton binding energy, since room temperature lasing was demonstrated by the same group 8 years ago. Intensive research has been carried out in the world since then but the key for p-type ZnO is turned out to be just making crystal thin film as defect-free as possible. However, cutting-edge technologies such as combinatorial, laser-heating, and laser-MBE have open up the way. The work has been done in collaboration with Tsukuba-U, RIKEN, Shizuoka-U, RIEC-Tohoku-U, Tokyo Tech., and NIMS, was published in Web site of Nature Materials on Dec. 19.



New Material and Process for Future Semiconductor Technology
Graduate School of Engineering, Prof. J. Koike



Two-layer Cu-Mn interconnect lines at a technology node of 90 nm, showing an excellent structural integlity and reliability.

Future semiconductors require low-resistance and high-reliability interconnect lines. The newly developed Cu-Mn alloy and its process can provide not only a solution for future problems but also cost effective means for the current process with high production yield.

The proposed technology has been under investigation by several device makers worldwide.

Funding for this project is approx. 0.4 million USD per year and another 0.5 M USD from industry.

TOHOKU UNIVERSITY

Next-Generation Information Storage (Hitachi.Ltd.)
Research Institute of Electrical Communication
Prof. Y. NAKAMURA

Research activities:

As the information technology advances, the information storage is gaining significance as a key device. The demand for storage for all sorts of information such as text, pictures, and audio-visual data is high. Accordingly the recording density of the hard disc drives has been increasing at a high pace of 60% annually. However, the bit volume is becoming so small that the conventional longitudinal magnetic recording is near its physical limit. The perpendicular magnetic recording scheme, which has been developed at RIEC, is supposed to be the way to be taken to go beyond this limit.

To achieve high recording density, we have to have a system of head and medium which is (1) easy to record, (2) stable against thermal decay, (3) with low noise and high resolution.

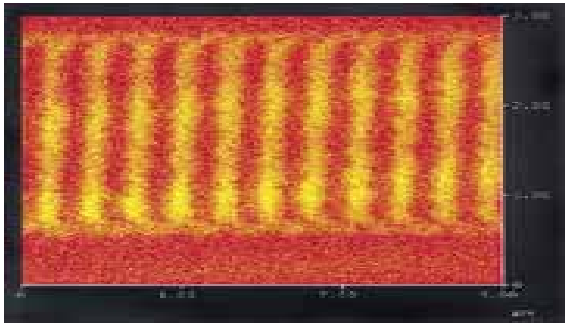


Fig.1 MFM image of bits written on perpendicular magnetic recording medium

The recording performance is a complex function of the parameters such as the head field and its profile, medium magnetic anisotropy, medium grain size and its distribution, the exchange coupling between grains and so on. The present theory is inconsistent with observations in some cases. In this research group we are to analyze the basic physical process of recording and determine which parameter affects the recording performance and how. And using such analysis design tools will be developed for super-terabit recording.

Research topics:

Understanding of the detailed recording mechanism by comparing the experimental data with the theoretical predictions. Analysis of recording performance by using micromagnetics simulation model and other advanced models, and development of a design scheme using the results.

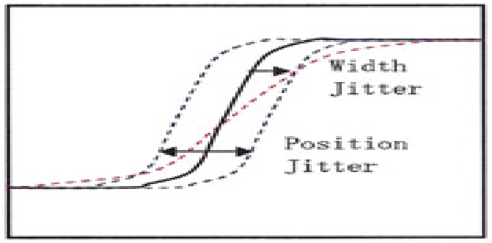


Fig.2 Magnetic transition and jitter modes.

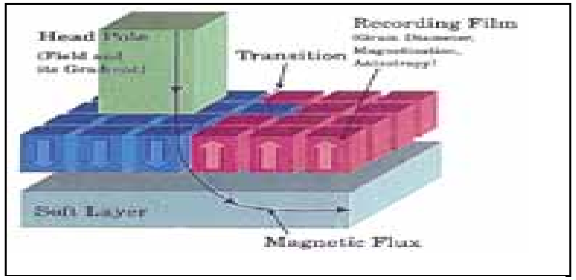
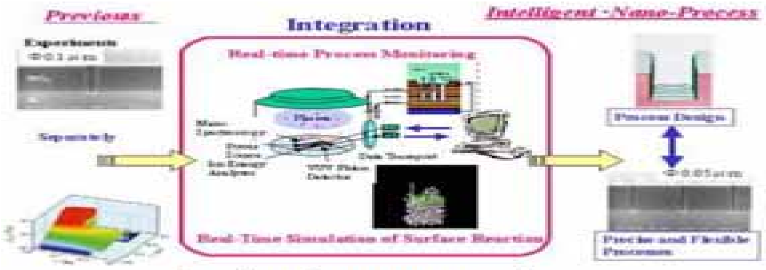


Fig.3 Micromagnetics model of recording head and perpendicular recording medium

Atomic Layer Processes for Future Nano-scale Devices
Institute of Fluid Science, Prof. Seiji SAMUKAWA

To fabricate next generation nano-scale devices, plasma, beam (ion and neutral beam), atom manipulation and bio-nano processes must be precisely controlled. This laboratory plans to study the interaction between reactive species (electrons, ions, atom, molecular, radical and photon) and material surfaces. Additionally, based on atom and molecular processes, future bio-nano processes have been also investigated. Our goal is “Intelligent Nano-Processes” by combination of digital processes (atomic layer processes) and simulations of surface chemical reactions.



Precise plasma processing

Environmentally harmonized plasma processes for future nano-devices

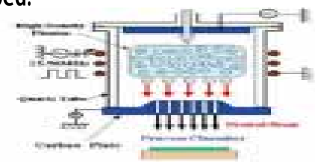
Environmentally harmonized new gas chemistry for high-performance SiO_2 etching is proposed. Our newly designed CF_3I/C_2F_4 gases have a very low global warming potential and achieve a high-performance etching through the selective radical generation in the plasma.

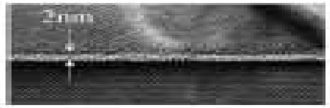
Silicon dioxide etching using environmentally harmonized new gas chemistry

Fabrication of 3-dimesional nano-structure using beam technology

To accomplish highly efficient and selective surface reactions in 3-D nano-structure processes (chemical vapor deposition, etching), a high-performance, multi-beam (positive ion, negative ion and neutral) generation system has been developed.

50nm Precise Etching Processes using Neutral Beam

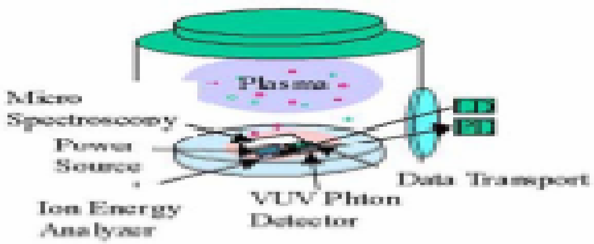




Ultrathin Oxynitride Film Formation

High-performance On-wafer-Monitoring System

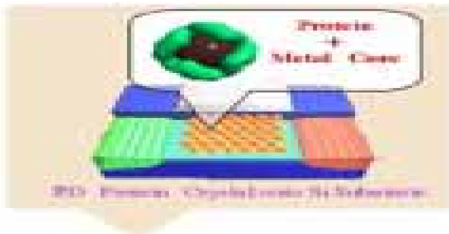
On-wafer monitoring and sensing systems are developed for precise control of plasma, beam and atom manipulation processes on the surfaces.



On-wafer monitoring system in plasma processing

Bio-Nano Processes

New advanced nm patterning techniques for future generation devices are developed using a protein and DNA.



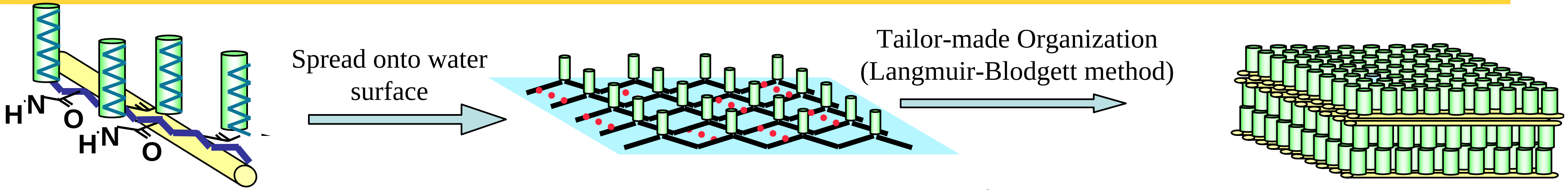
6nm metal electrode pattering using 2D protein (including metal core in protein) crystal

Fabrication of Soft Nano-Devices using Functional Polymer Nanosheets

Institute for Material research, Prof. Tokuji Miyashita

TOHOKU UNIVERSITY

We have developed polymer nano-sheets with one molecular thickness (1-2 nm) and fabricated a new type of flexible soft nano-devices by the tailor-made organization of various polymer nano-sheets (Bottom-up nanotechnology)



polymer molecule

Polymer nano-sheet (1-2 nm) on water surface with self-assembly

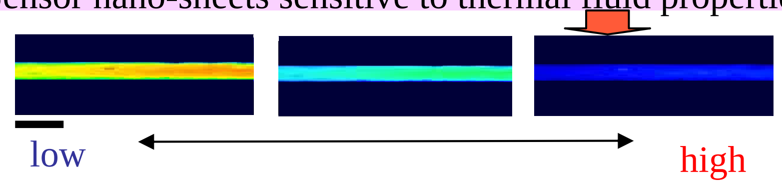
ordered 3D nano-devices

Tailor-made Assembly (Bottom-up Nanotechnology)

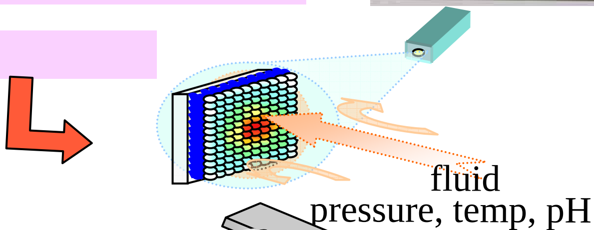
* Functional Polymer Nano-sheets Assemblies

1. Brilliant colour from pediorical nanostructure by polymer nano-sheets with various deposited layers on Si wafer

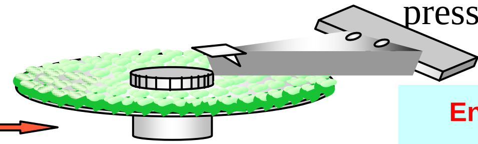
2. Sensor nano-sheets sensitive to thermal fluid properties



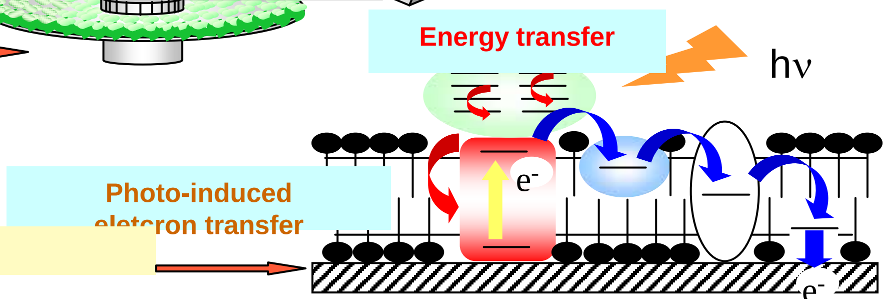
temperature visualization in nano confined area



3. Fluorinated polymer nano-sheets (excellent repelling properties, new lubricant)



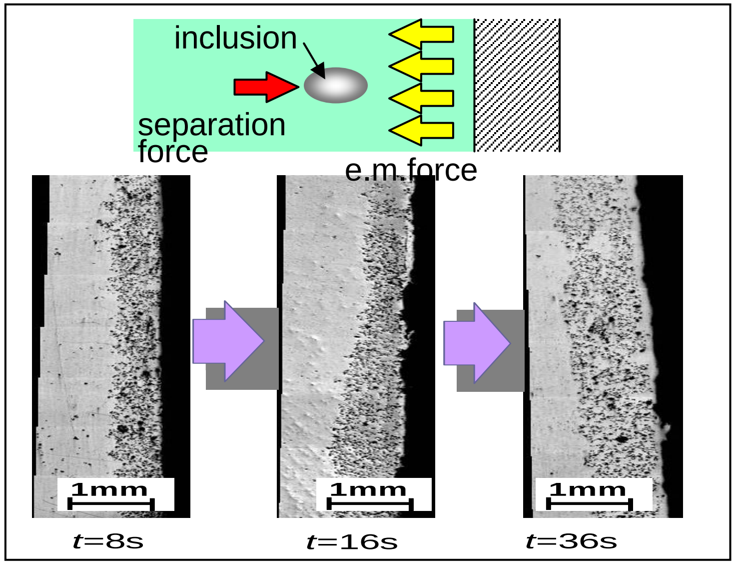
4. Photofunctional and Electric conductive Nano-sheets (Organic Transistor)



Photoenergy conversion soft-device

Material Process for Circulatory Society
Electromagnetic Processing of Materials, EPM
Graduate School of Environmental Studies
Prof. Shoji Taniguchi

Electromagnetic processing of materials (***EPM***) applies MHD phenomena that appears by the interaction between imposed magnetic or electric field and conducting materials. Electromagnetic (e.m.) stirring and e.m. braking are widely used in continuous casting of liquid steel. Various applications of EPM are being investigated in our laboratory.



Super-Clean Metal Production by E.M.Force

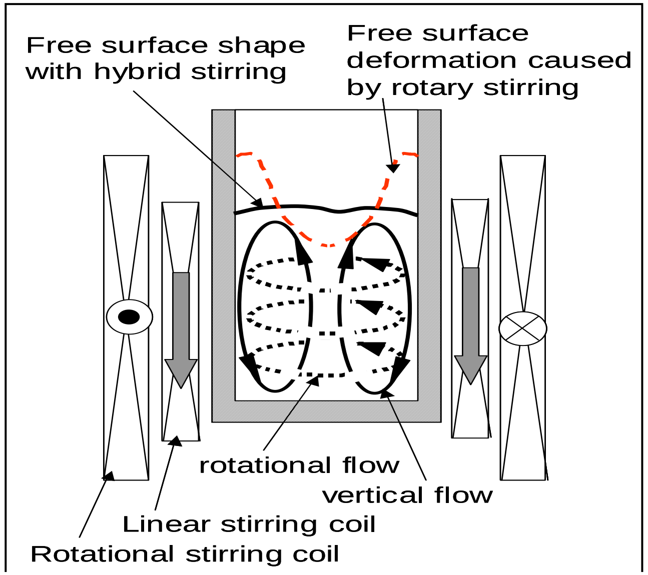
Clean materials are needed in various industries like electronics and automobiles. In order to achieve higher cleanliness, it is needed to eliminate non-metallic inclusions by highly efficient method than the ordinary methods based on gravity separation. One of the most promising method is the e.m. separation that enables high speed separation without contact to metal. We are now investigating the separation efficiency of 20μm-SiC particles from liquid Al.

Fabrication of Particle-Reinforced Al Composite

The above method to separate SiC particle is being applied to produce graded metal-matrix composites that are deformable and high wear resistance.

Double-Axis-Electromagnetic Stirrer (DAEMS)

In materials-engineering field, solidification under strong stirring is demanded to obtain a uniform composition and fine structure of metal products. Electromagnetic stirring fits this demand well, but the free-surface deformation and fluctuation should be prevented for imposing much stronger stirring force. DAEMS is a new stirrer composed of rotational and linear stirring by which the deformed surface can be corrected to be flat. This project is funded by the Japan Science and Technology Agency (JST).



EPM2006 in Sendai (October 23-27, 2006)

The 5th International Symposium on EPM will be held in Sendai next year. The 4th Symposium was held in Lyon. (http://www.isij.or.jp/epm2006)

Interface Science and Engineering of Joining Lab.

Friction Stir Processing & Grain Boundary Engineering

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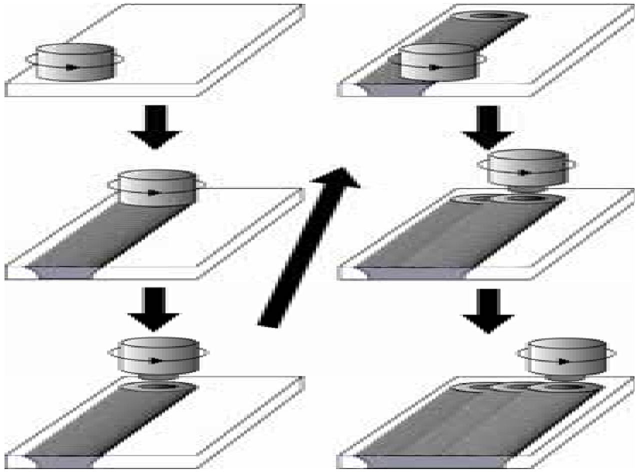

Fig.1 Schematic of multi-pass FSP.

1. Friction Stir Processing (FSP)

Friction Stir Welding (FSW) is a novel solid-state joining process using a non-consumable rotating tool plunged into the material and creates a stir-zone with very fine and homogeneous equiaxed recrystallized grains due to frictional heat and plastic flow generated by the rotating tool. FSW is used also for grain refinement as Friction Stir Processing (FSP). This group has applied the multi- pass FSP (***Fig.1***) for production of high performance bulk alloy plates with sub-microns in grain size. For example, the multi-pass FSP improved the formability of AZ91D diecast Mg alloy plate six times higher than the as-received one.

2. Grain Boundary Engineering (GBE)

Grain boundary engineering (GBE) is a technology to prevent intergranular deteriorations by increasing the frequency of coincidence-site-lattice (CSL) boundaries in materials. CSL boundaries with low energies are resistant to intergranular attacks and arrest the propagation of intergranular deteriorations, such as intergranular corrosion, SCC, etc. This group has established a GBE process to introduce ultra-high frequencies of CSL boundaries over 85% into austenitic stainless steels (***Fig.2***). The grain boundary engineered stainless steels indicated more than four times higher resistance to intergranular corrosion than the as-received ones (***Fig.3***).

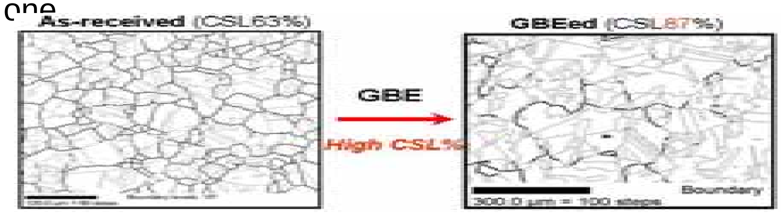

Fig.2 Increasing CSL% by GBE. (Black and gray lines indicate random and CSL boundaries, respectively.)

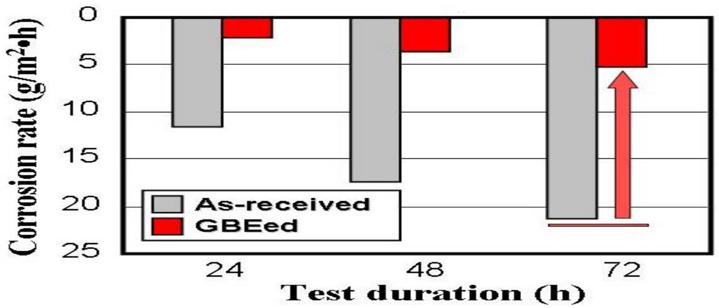

Fig.3 Suppression of intergranular corrosion of stainless steel by GBE.