The 21st COE Program, Nagoya University

Micro- and Nano-Mechatronics for Information-Based Society

Micro-Nano COE, Nagoya University

"Micro- and Nano-Mechatronics for Information-Based Society"

● Message from the Program Leader ●

Yasunaga MITSUYA
Professor,
Graduate School of Engineering

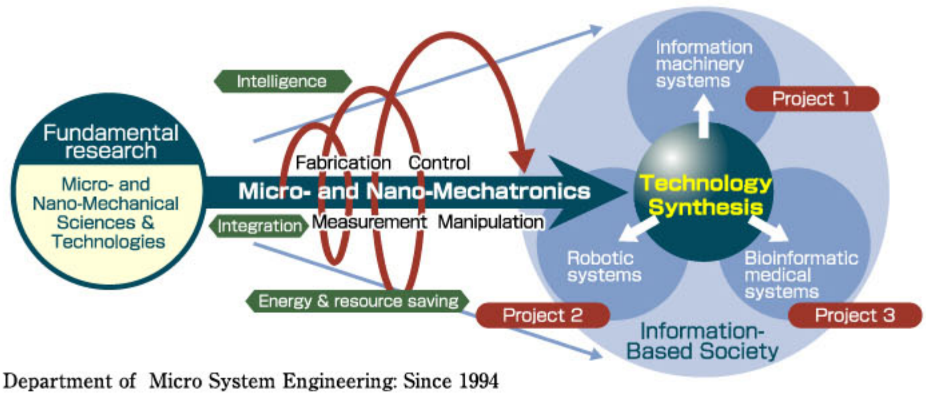
In academic year 2002, the Ministry of Education, Culture, Sports, Science, and Technology launched the 21st Century Center of Excellence (COE) Program, aiming to provide prioritized support to Japanese universities to create world-leading research and educational centers. Among many proposals submitted, the "Micro- and Nano-Mechatronics (the Micro-Nano COE)" program at Nagoya University was selected as a COE project in 2003. In this project, we use mechanical engineering approaches to further develop nano technology. This project is carried out under the leadership of the Department of Micro-Nano Systems Engineering (the former Department of Micro Systems Engineering prior to the Heisei 16 reorganization). Three Departments studying on mechanical engineering relating fields collaborate in this project. In 1994, Nagoya University became the first university in the world to install a Graduate School of Micro Systems Engineering, which has taken the initiative in research and education in mechanical technology of micro-nano sciences.

This COE project covers a wide variety of fields: nano-mechanical sciences (basic science), mechatronics (fundamental technology), and systems technology (applied technology). We have chosen three systems (information machinery systems, robotic systems, and bioinformatic medical systems) as our main research targets, and we believe that our research can be most effectively applied in these areas. In particular, we are a pioneer in systems technology and carry a wealth of expertise and experience based on the cooperation between scientists and engineers from industry and academia.

Our COE project received a special fund to acquire major equipment for research needs as well as a fund to aid young researchers and create an ideal research and educational environment. As a natural consequence, we acknowledge our responsibility to utilize these resources most effectively.

Our goal is to become an active center of the Micro-Nano COE project. By introducing our program to the public, we will seek opinions and evaluations from a wide variety of people, including the public, academics, and industry, and utilize their ideas to bring the current Micro-Nano Science and Technology center to the highest level and contribute to society. In this way, we would like to fulfill the expectations of our COE program.

Our objectives



Department of Micro System Engineering: Since 1994

We aim to deepen the understanding of the nano-mechanical sciences (nano sciences in mechanical engineering) and, by combining micro-nano-mechatronics technologies, we will develop systems technology that will become the next generation infrastructure of an advanced information-based society. We will provide seamless support to further research and education in order to establish novel technologies that will apply nano technology to actual devices and systems, especially using mechanical engineering approaches.

The people in charge

● Program leader

Yasunaga MITSUYA
(Overall research activities, Information machinery systems)
Professor, Department of Micro-Nano Systems Engineering, Graduate School of Engineering

● Sub-leaders

Toshio FUKUDA (Robotic systems)
Professor, Department of Micro-Nano Systems Engineering, Graduate School of Engineering

Koji IKUTA (Bioinformatic medical systems)
Professor, Department of Micro-Nano Systems Engineering, Graduate School of Engineering

Kazuo SATO (Fundamental technology)
Professor, Department of Micro-Nano Systems Engineering, Graduate School of Engineering

Keisuke TANAKA (Basic mechanical science)
Professor, Department of Mechanical Science and Engineering, Graduate School of Engineering

Tomohide NIIMI (Creative education)
Professor, Department of Micro-Nano Systems Engineering, Graduate School of Engineering

Eiji SHAMOTO (Public relations & liaison)
Professor, Department of Mechanical Science and Engineering, Graduate School of Engineering

● The people in charge

Fumihito ARAI
Associate Professor, Department of Micro-Nano Systems Engineering, Graduate School of Engineering

Nobutada OHNO
Professor, Department of Computational Science and Engineering, Graduate School of Engineering

Yoshiaki AKINIWA
Associate Professor, Department of Mechanical Science and Engineering, Graduate School of Engineering

Akira UMEMURA
Professor, Department of Aerospace Engineering, Graduate School of Engineering

Mitsuhiro SHIKIDA
Associate Professor, Eco Topia Science Institute

Eiichi TANAKA
Professor, Department of Mechanical Science and Engineering, Graduate School of Engineering

Kenji FUKUZAWA
Associate Professor, Department of Micro-Nano Systems Engineering, Graduate School of Engineering

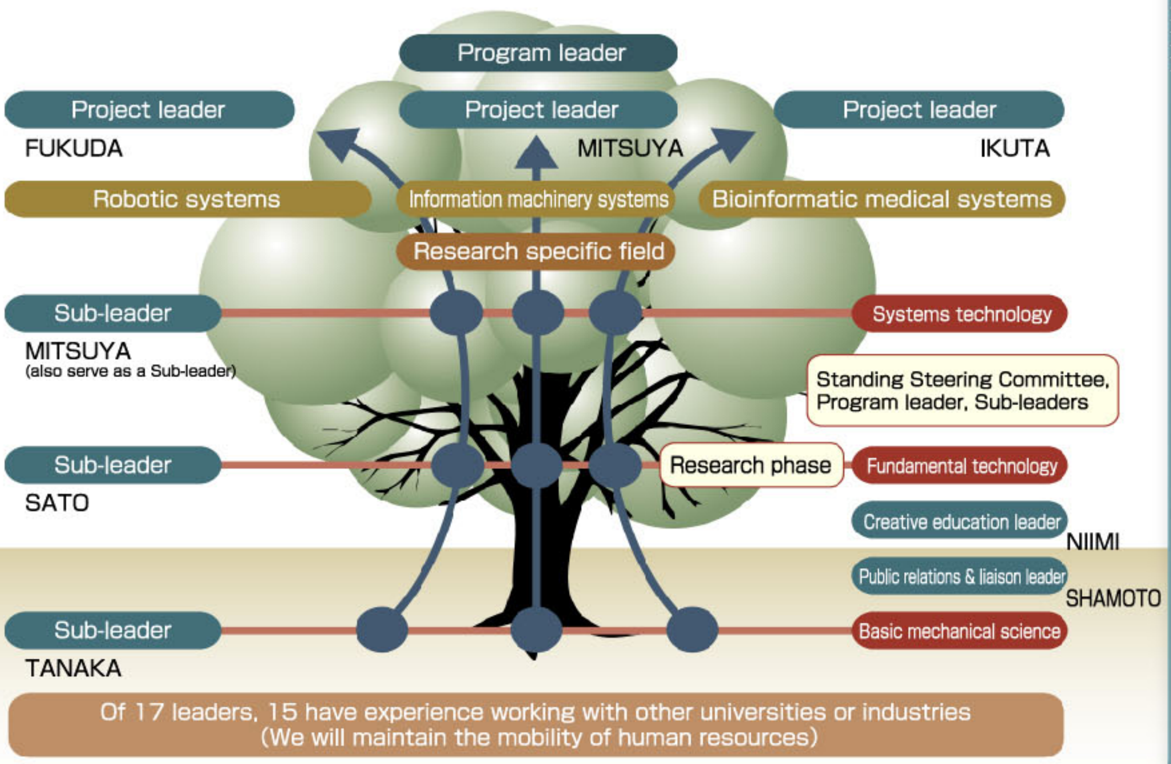
Shigeyuki HOSOE
Professor, Department of Mechanical Science and Engineering, Graduate School of Engineering

Goro OBINATA
Professor, Center for Cooperative Research in Advanced Science & Technology

Noritsugu UMEHARA
Professor, Department of Mechanical Science and Engineering, Graduate School of Engineering

The hierarchical structure and leaders/members

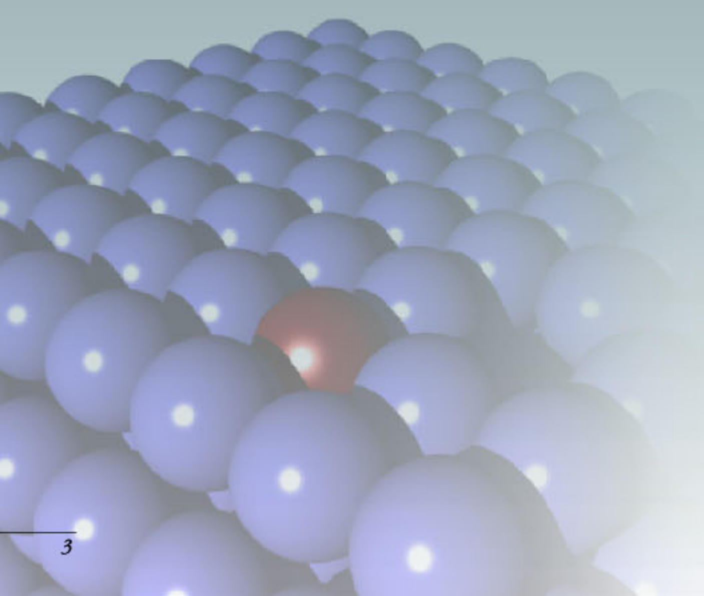
Matrix structure (Research phases x Systems)



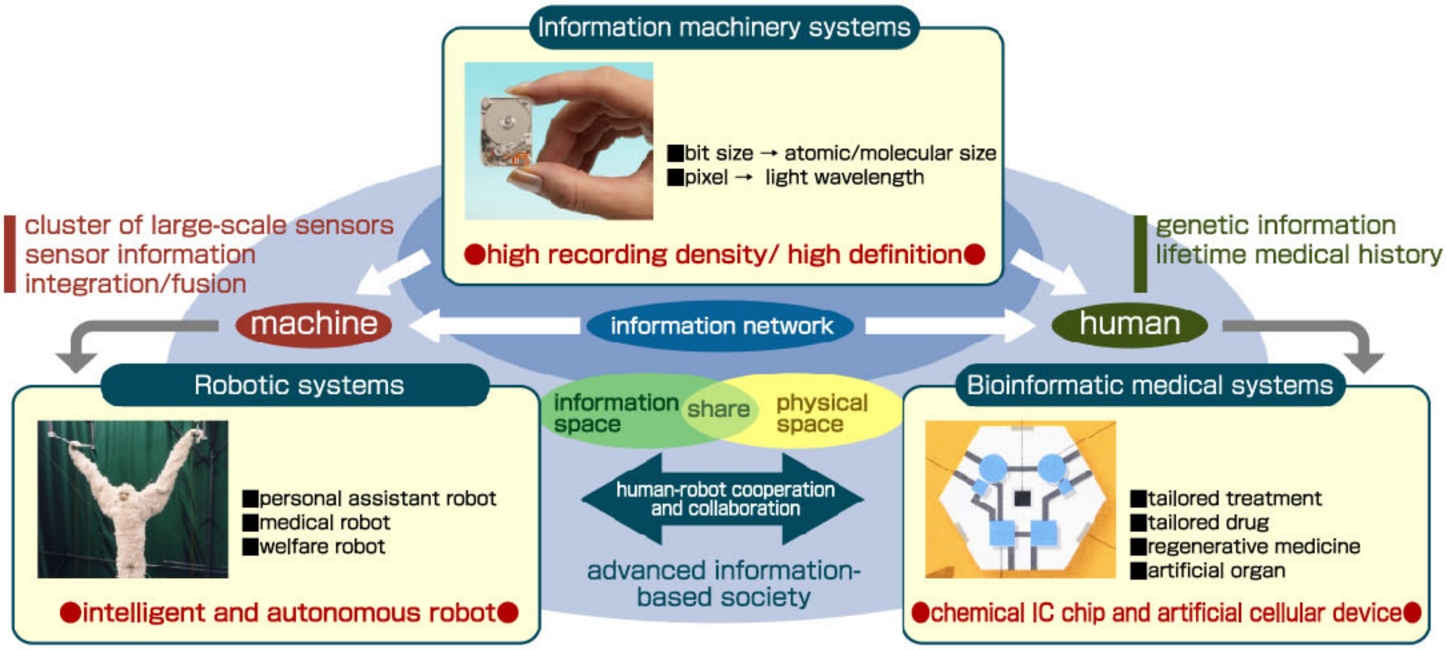
Our Organization

The distinctive feature of our COE is its matrix structure. The members of the center are organized in a matrix comprising three research levels (basic science, fundamental technology, and systems technology) and three projects (information machinery systems, robotic systems, and bioinformatic medical systems).

In addition, sub-leaders are assigned to each research level and systems. In particular, for the mission to support young researchers and to cultivate highly creative minds, we have nominated a dedicated sub-leader for creative education. A standing steering committee has been organized by these leaders. The center aims to operate an organization that is able to provide research and education in a wide range of basic sciences related to systems technology, and to emphasize objectives and responsibility to society.



Our Research Targets

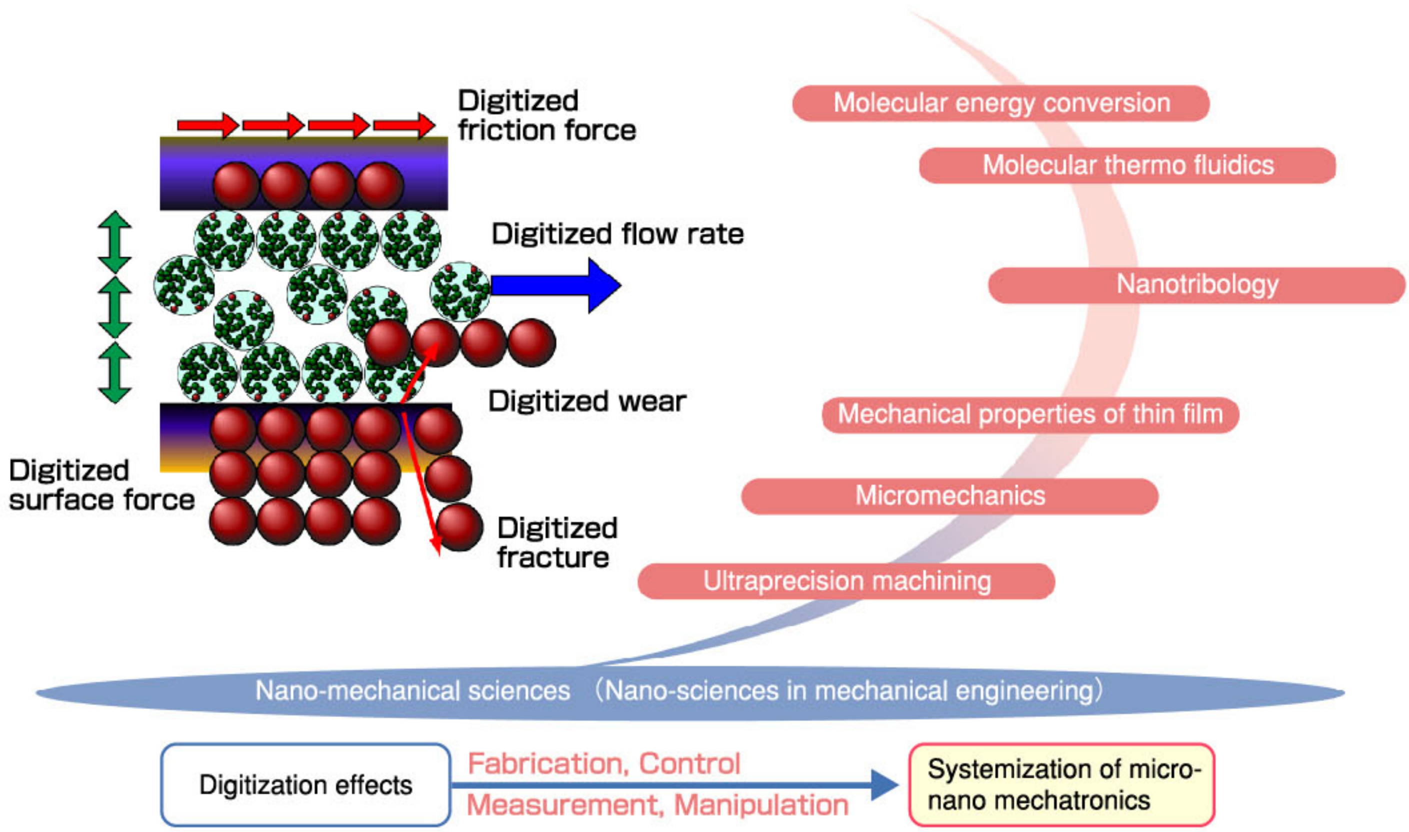


Our Research

Nano technology is a current focus of attention in the field of materials and electronics technologies; in addition, it will be an extremely important technology in the field of mechanical technology. The mechanical systems always accompany a relative movement, which involves an interface between a solid and liquid/gas. Relative movement in the micro-nano field involves effects on atomic and molecular conformations or behaviors, resulting in surface tension, friction, abrasion, fracture, and flow. In the field of nano mechanical sciences, we target such atomic/molecular conformations and behaviors.

In our center, we have achieved significant results in mechatronics, and now aim to synthesize technologies involving fabrication, control, measurement, and manipulation with the nano mechanical sciences, systemizing the resulting field as a fundamental technology for micro-nano mechatronics. Furthermore, we are engaged in research and development in the fields of information machinery systems, robotic systems, and bioinformatic medical systems, all of which are systems technologies necessary for an information-based society.

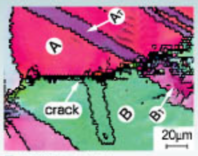
Nano-Mechanical Sciences



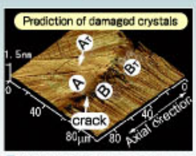
●Micro-nano evolution of the mechanical properties of thin film materials

TANAKA AKINIWA

Micro-nano detection of fatigue damage

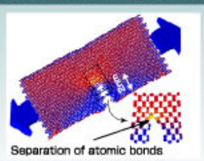


EBSD analysis of crystalline orientation

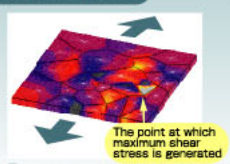


AFM detection of fatigue slip

Prediction of film fracture using micro-nano mechanics

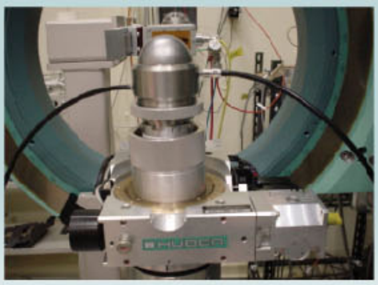


Molecular dynamic analysis of fractures from nano-scale defects



FEM and BEM analyses of thin film properties

Internal stress analysis of thin films



In situ measurement using synchrotron radiation (Cu thin film, heat cycle)

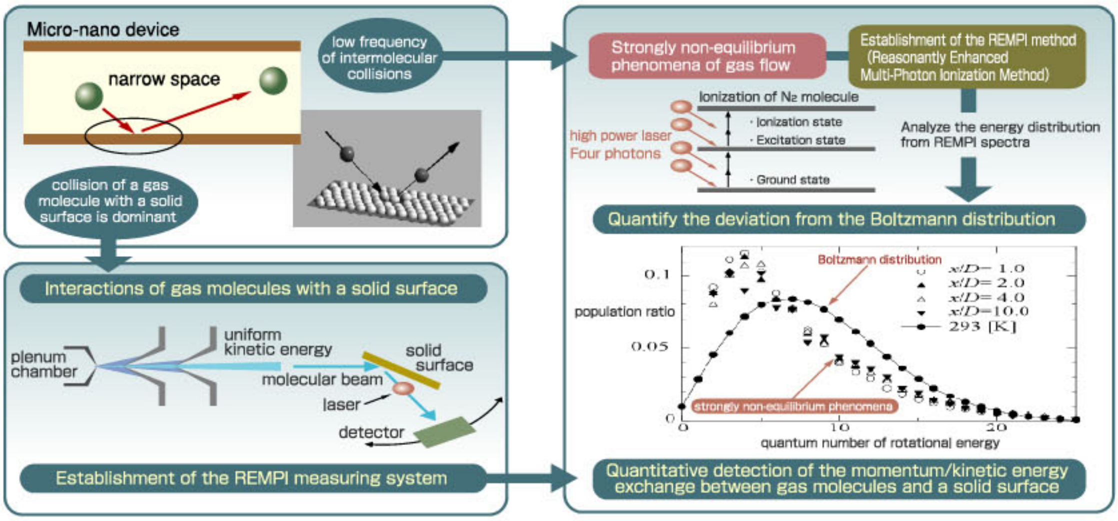
High-precision measurement using the newly developed method

Optimum Design and Integrity Assessment

Using X-ray diffraction, we have developed a novel high-precision, non-destructive method to detect the internal stress distribution in thin films, which are components of microstructures. Combining electron back scattering diffraction (EBSD) and atomic force microscopy (AFM), we have also established a method to quantify fatigue damage in thin film materials caused by long-term use. Combining these two methods, we have constructed a micro-nano mechanical model, and, by simulating a fracture within a thin film, we aim to develop technology for optimum design and integrity assessment of microstructures.

●Quantification of the interactions of gas molecules with a solid surface

NIIMI



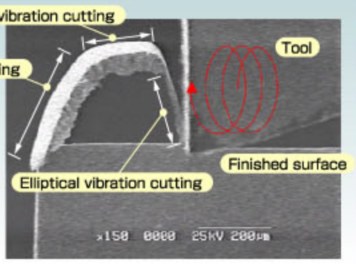
In the flow fields around micro-nano devices, non-equilibrium phenomena arise due to the small number of intermolecular collisions. In such cases, the interactions of gas molecules with a solid surface become important. We have established the Resonantly Enhanced Multi-Photon Ionization (REMPI) method, and shown a deviation of the rotational energy distribution in a supersonic free molecular flow of nitrogen from the Boltzmann distribution. Integrating the REMPI method into a molecular beam facility, for example, we can quantify the momentum and energy exchange between gas molecules and a solid surface.

●Ultra-precision micro-machining of hard materials by applying elliptical vibration cutting

SHAMOTO

Micro - machining technology

Development of an ultrasonic elliptical vibration cutting device and technology

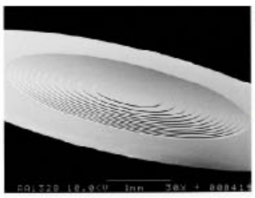


【Elliptical vibration cutting method】

An innovative machining technique by applying elliptical vibration to tools

Ultra-precision micro-machining (nm order of roughness) of hard materials (hardened steel, glass, tungsten carbide, tungsten alloy, etc.) is realized.

●Mold for fresnel lenses



Ultra-precision machining of mold material (W alloy) for glass devices is achieved for the first time.

●Spherical machining of hardened die steel

Mirror surface machining of dies and molds for various plastic parts is realized without polishing!

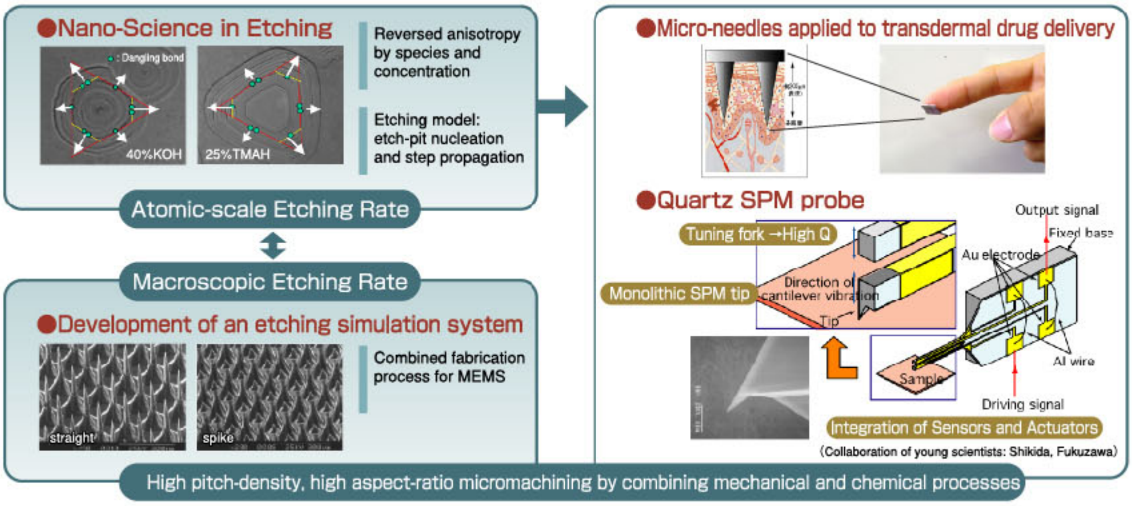
●Mold for small glass lenses

Ultra-precision micro-machining of hard refractory W alloy (roughness: 40 nm Rz)

We have developed a novel ultra-precision micro-machining (elliptical vibration cutting) method that enables cutting of hard materials while applying micro elliptical vibration at the tool tip. We are currently applying this technology to the ultra-precision micro-machining of various hard materials, which cannot be achieved using conventional technologies. For example, a big challenge in electron optics has been the development of a mass production method for glass devices with ultra-precision microstructures, such as optical waveguides and holographic optical elements. The use of the elliptical vibration cutting method enabled us to achieve ultra-precision micro-machining of a tungsten alloy mold for glass devices.

●Micro-nano process for fabricating silicon MEMS

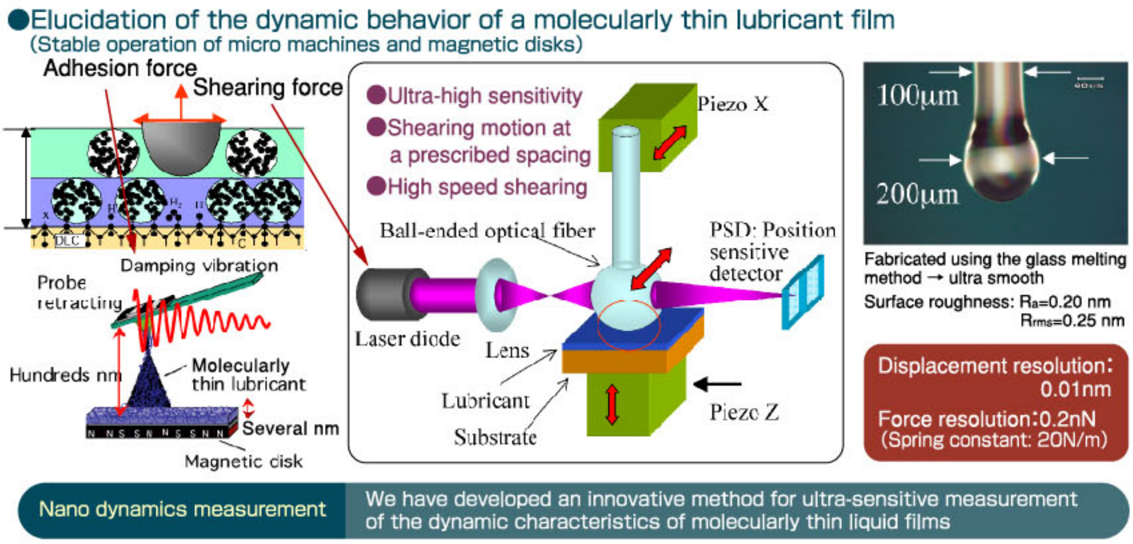
SATO SHIKIDA



We have discovered that etching anisotropy can be reversed by the species and concentration of etching solutions. We have successfully demonstrated a correlation between etching rates and atom removal modes on a crystal surface, and have also developed a high precision etching simulation system. Furthermore, we have established a high pitch-density, high aspect-ratio silicon micro-machining process by combining mechanical and wet-chemical processes. We are applying these technologies to fabricate micro-needle arrays for drug delivery and quartz probe tips for scanning probe microscopy systems.

●Ultra high sensitivity measurement of the dynamic characteristics of molecularly thin liquid films

MITSUYA FUKUZAWA



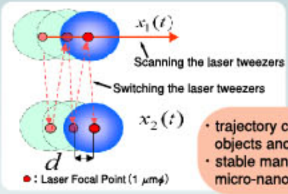
In the field of micro machines and magnetic disks, it is extremely important to elucidate the dynamic characteristics of thin films in order to obtain sufficient reliability and durability of these films. We have developed a novel apparatus to measure the dynamic characteristics of molecularly thin lubricant films: a ball-ended optical fiber is vibrated on the film, and the transmission function is used to determine the dynamic characteristics of the film. In order to detect displacement, we used a glass ball at the end of an optical fiber as a lens, and were able to resolve displacement to 0.01 nm, a phenomenally high resolution equal to one-tenth the diameter of a hydrogen molecule.

●Micro-nano manipulation technology and its application to bio-systems

FUKUDA
ARAI

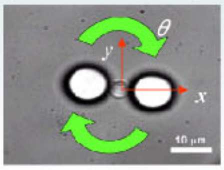
1. Micro-nano manipulation in solution (closed space)

Trajectory control using laser manipulation and indirect laser manipulation



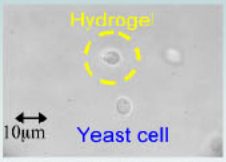
・trajectory control of multiple objects and stability analysis
・stable manipulation of micro-nano particles

Synchronized Laser Micromanipulation

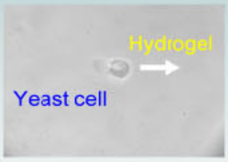


orientation control by indirect manipulation

2. Preparation and utility of a functional microtool



in situ formation of a thermal gel microtool by laser irradiation



indirect manipulation using a thermal gel microtool

Improved advantage, safety, and operativity

3. Creating a local limited space and on-chip analysis of cellular reactions

- *in situ* formation of a vertical permeation membrane
- single cell manipulation and separation
- micro reactor
- on-chip cell culture
- other applications (including gene analyses, etc.)

We have developed a novel technique for *in situ* creation of a micro reaction chamber for cell manipulation

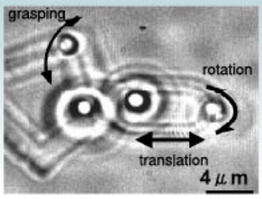
We aim to develop novel technologies for the manipulation of micro-nano objects. Further, we aim to extend the use of these technologies to manipulation of biological systems, including proteins and cells.To manipulate micro-nano objects, we have developed a laser manipulation technique. With this technique, multiple nano-beads can be concurrently manipulated by scanning and/or switching a laser beam in order to control the movement and/or rotation of cells.

To establish a technique which enables the manipulation of cells without causing damage, the following novel methods have been developed: a method that applies sol-gel transition for manipulation of cells under a microscopic field. We also established *in-situ* fabrication of a micro reaction chamber using photocrosslinkable resin.

●Optically driven nano robots and biochemical IC chips

IKUTA

An optically driven nano manipulator



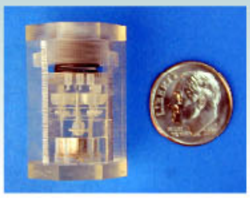
Verification of in-liquid operativity and cell manipulation.

Length: 10 μm,
degree of freedom: 3

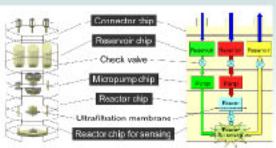
Micro Finger for microsurgery in deep and/or narrow space in human body

Bimanual remote microsurgery through the working channels in an endoscope

Biochemical chip for cell-free protein synthesis



Total synthesis system that integrates micro pumps reactor and sensors, etc..
Successful synthesis of many proteins directly from their genes



New micro fabrication process for biodegradable microdevices

A micro bend pipe made from poly-lactic acid: verification that this new device exhibits no cellular toxcity

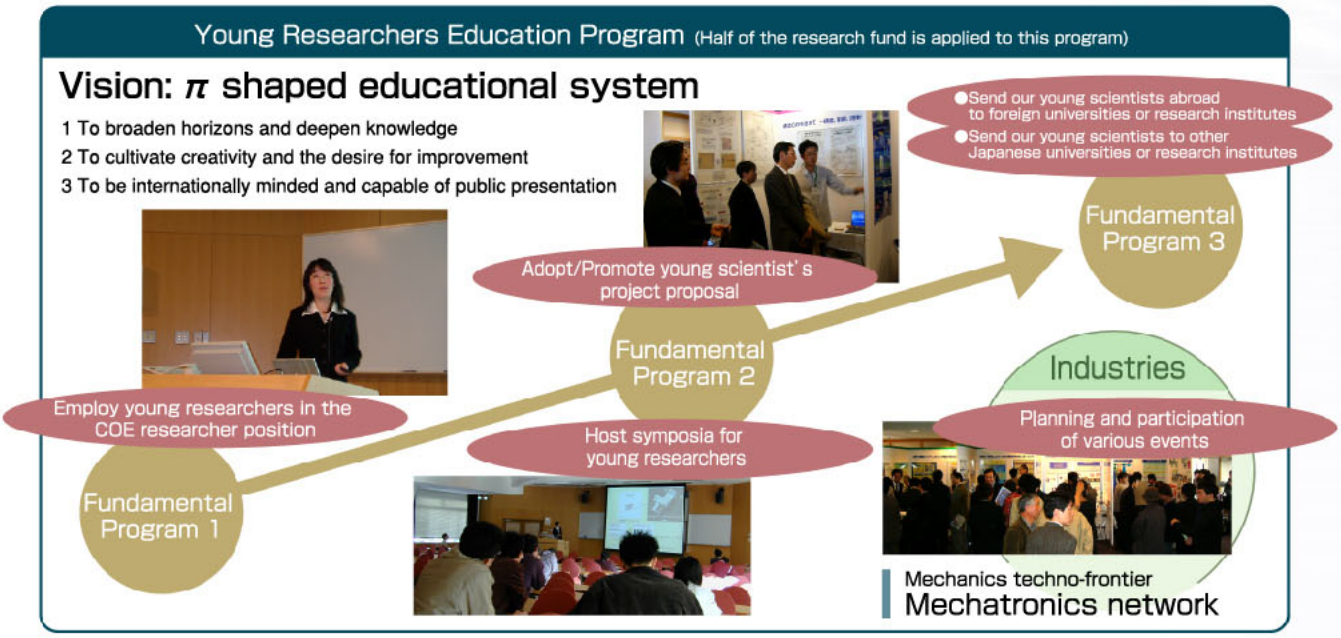
We have successfully developed a unique prototype "nano robot" that is remote-driven and controlled by laser beam. This nano robot is fabricated by our orignal nanostereolithography. The remote control performance of this machine in water has been verified microscopically. With this new technology, cell and intracellular operations become feasible. In addition, we have developed unique remote control robot, "Micro Finger," that enables microsurgery in deep and/or narrow spaces. The Micro Finger can easily pass through an endoscope; therefore, this new technology opens a new field of minimally invasive therapy.

To date, we have developed more than 20 Biochemical IC chips, which concept has been proposed by professor Ikuta in 1996. We have already succeeded the cell-free protein synthesis by using several chips.

● Young Researchers Education Program ●

Our educational approach

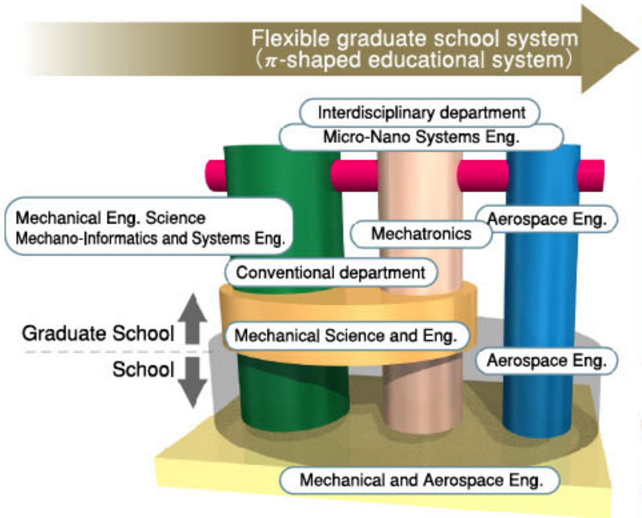
We emphasize education to develop young researchers. In this project, half of the research fund is used to educate young researchers. Based upon our vision of a unique π shaped educational system that has been adopted in the Graduate School of five mechanical field relating engineerings, we carry out three fundamental programs: 1) to broaden horizons and deepen knowledge, 2) to cultivate creativity and the desire for improvement, and 3) to be internationally minded and capable of public presentation. To meet each goal, we 1) provide employment for young researchers as COE researchers, 2) promote young researcher's projects, and 3) dispatch young researchers to foreign or other Japanese universities. The number of students who participate in these projects has increased, indicating that our educational program has been effective. In particular, the number of applications to young researcher's projects has doubled, and the number of students pursuing the Ph.D. degree has increased.



Prospects for developing young researchers

Nagoya University is adopting a flexible graduate school system to support a double major policy. The π shaped educational system derives from the shape of the symbol π. Its features include, in addition to the double major, interdisciplinary studies, needs-oriented studies, and securing flexibility and mobility. The core major area of study at this COE is Micro-Nano systems engineering, and we are pursuing the implementation of this educational system. Moreover, we are promoting an overseas training program to expose young researchers to the global environment. Our educational efforts as a central presence to shoulder the next generation is now beginning to show its effects in activities such as venture businesses founded by students and our alumni performing at high levels in various workplaces.

Prospects for developing young researchers



4/1/04 Reinforced the COE system by an organizational upgrade

《Features》
- Double major
- Interdisciplinary studies
- Needs oriented
- Securing flexibility and mobility

Impact of the COE
- Growing enrollment in doctoral candidates
- Growing number of employers for Research Associates
- Growing enrollment of high performing students in post graduate studies
- Growing enrollment in doctoral candidates who have studied abroad

Introduction of the overseas training system

Venture businesses founded by students (5/1/05)
Future contributions made by alumni in various workplaces

Educational effects of our central presence to shoulder the next generation

Scholastic significance and contribution of actual applications

Scholastic significance

Systematization of Micro-Nano mechatronics fundamental technology

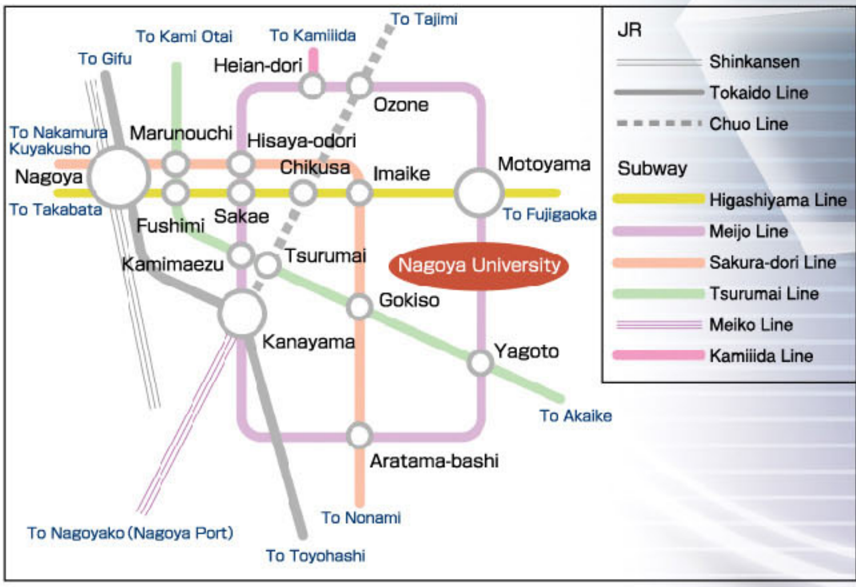
- Pursuit of Micro-Nano science and engineering
- Fusion of Mechatronics as a fundamental technology Fabrication/control/ measurement/manipulation in the Micro-Nano domain
- Develop systematization technology as infrastructure of an Information Society

Contribution of the application of this technology

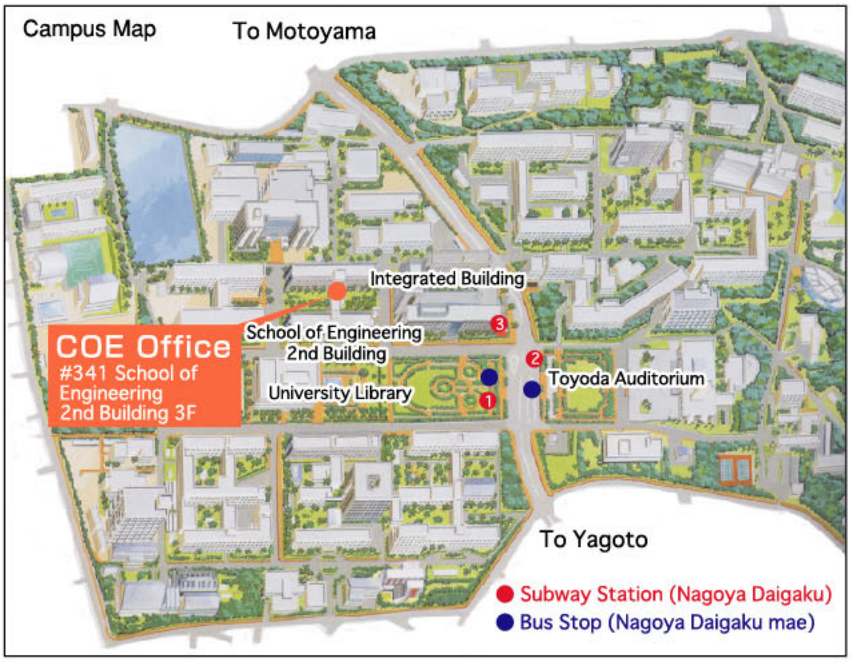
Shouldering the progress of an Advanced Information Society

- **Information machinery systems**
  (develop high speed-large capacity information storage/high speed-high resolution imaging devices)
- **Robotic systems**
  (develop personal assistant robot/medical robot/ welfare robot)
- **Bioinformatic medical systems**
  (develop tailored treatments/tailored drugs/ regenerative medicine/artificial organs)

Sharing physical and information spaces via network; contributing to the realization of a Ubiquitous Society



《Access to Nagoya University》
From Nagoya Railway Station: 20 min.
by subway Higashiyama Line to Motoyama Station,
then transfer to Meijo Line to Nagoya Daigaku Station.



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