Development and standardization of Technology for on-site sensing and diagnosis

Measurement for Control

Akira Ono
Research Coordinator/Standard and Measurement

Measurement for control is technology for real-time knowledge and diagnosis of conditions in an actual environment.

Measurement and diagnostic technology fitting to a situation is in demand at both manufacturing sites and in everyday life. The development of information technology for understanding and coping with problems will gain more importance as a tool for a more efficient, more affluent and safer environment in industry and in society at large.

The National Institute of Advanced Industrial Science and Technology (AIST) is promoting research and development for the measurement and diagnosis of the real environment.

Kyushu accounts for about 10% of Japan' s industrial production, which is comparable to The Netherlands. All manufacturing sites for semiconductor, electronics, automobiles, food, environment/recycling and many other industries situated in this region face problems associated with measurement and diagnosis.

Innovation of On-site Sensing and Diagnostic Technology at Manufacturing Sites in Kyushu.

Fumikazu Ikazaki
Director of AIST Kyushu

In April 2005, AIST Kyushu has launched Academia-Industry-Government Collaborative Body " On-site Sensing and Diagnostic Systems Consortium "

The Consortium has two purposes: one is to provide basic solutions to technical needs of the regional industries, and the other is to provide basic solutions to nation's needs associated with on-site sensing and diagnostic technology. For this purpose AIST Kyushu intends to combine its R&D potential with the resources of universities, public laboratories, industries and administrative authorities in the activity of the Consortium. A person responsible for close communication with each member organization of the Consortium is assigned by AIST Kyushu.

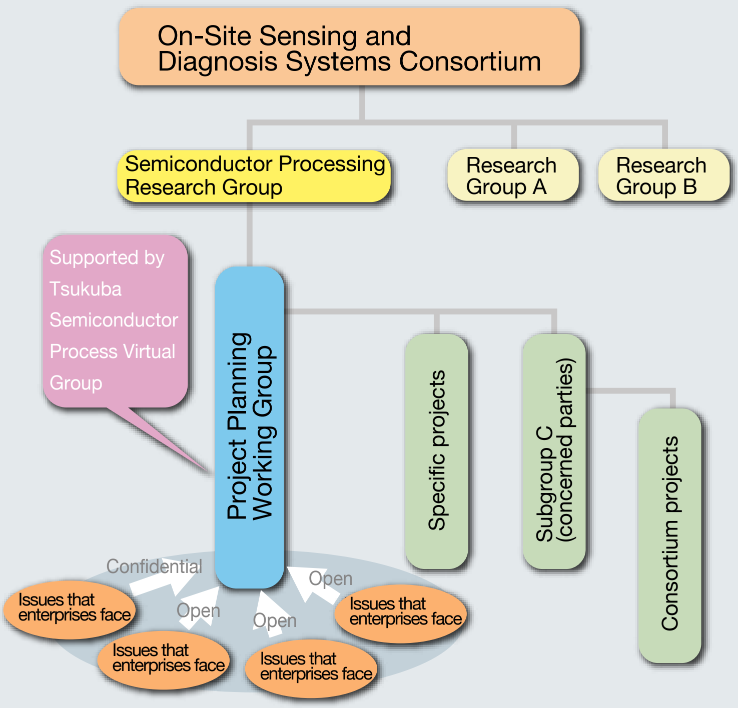
Activities of the Consortium include:

(1) meetings and seminars (general meeting in spring and seminar in autumn),

(2) monthly publication, and

(3) research groups for providing solutions to technical needs.

Semiconductor(SC) processing research group has been organized for providing solutions to the technical needs of SC factories in Kyushu, where SC factories are concentrated. A "virtual group" is also set up in AIST Tsukuba Center to support the research group(see chart to the right).



Development and standardization of Technology for on-site sensing and diagnosis

AIST Kyushu has shown high performance and further potential in practical measurement and diagnostic techniques. Its policy is to focus its activities in this field while taking the characteristics of regional industries into account for closer collaboration with them. One of the areas to be addressed in the future is microchemical measurement.

Academia-Industry-Government Collaborative Body, "On-site Sensing and Diagnostic Systems Consortium" as an innovation hub for providing solutions to technical needs of the regional industries in Kyushu

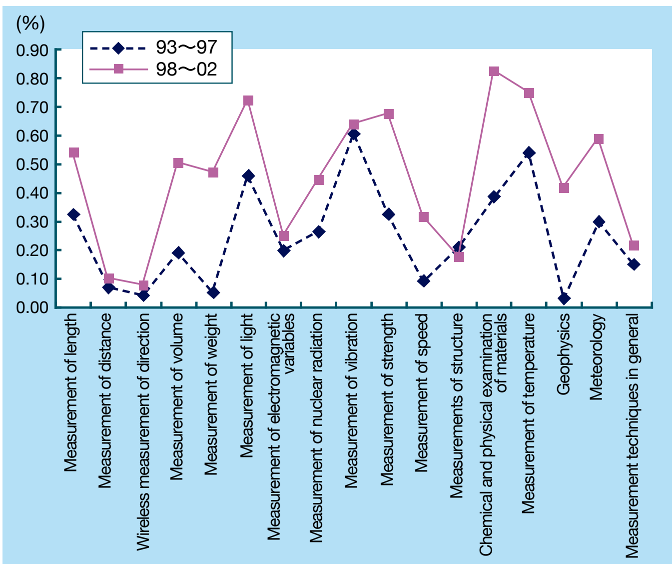
From the survey on on-site sensing and diagnosis conducted in 2004:

The survey showed that on-site measurement and diagnostic technology is in actual demand because of problems beyond the capabilities of individual enterprises; they need support by public institutions.

- Measurement and diagnostic technology is particularly needed in:
- Industries: Electronic devices, electrical machinery, chemistry
- Engineering fields: Robots, semiconductors/electronics, medical/pharmaceutical/welfare, environment
- Technology: Trace component detection, improvement in efficiency, in-line/on-site measurement

- Measurement/diagnostic problems in particular need of solutions
- Subjects: Materials, structures
- Level: Measurement/analysis at trace levels
- Methods: Simple, nondestructive

- Potential of intellectual property of AIST Kyushu:
- Originality: Emerging/growing fields (ensuring a leading position in the industry)
- Growth analysis: Techniques that match the needs of the time
- AIST's position: A leading organization in intellectual property in Japan



Increase in AIST's patent applications in the measurement/diagnostic field indicating an enhanced position in intellectual property

Understanding high temperature conditions:
Measurement of pressure and vibrations over 500°C

Hiroaki Noma
On-Site Sensing and Diagnosis Research Laboratory

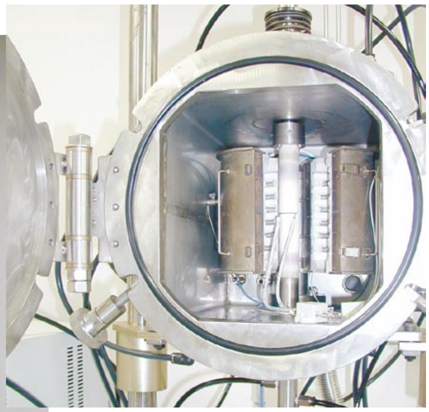


Photo : Experimental apparatus for evaluation of pressure sensors
(Left: the whole apparatus; above: inside of the furnace)

Why measure pressure and vibrations at high temperatures?

AIST intends to develop on-site measurement and diagnostic techniques needed for various situations by aligning its knowledge of sensor materials with measurement and control technology.

A particularly problematic case is high temperature environments. In spite of extensive studies, measurement of pressure and vibrations has not been possible over about 400°C due to the limit of heat resistance of the sensor materials. The high costs of high-temperature sensors have also hindered development of commercial products.

For example, combustion control in current automotive engines has not yet been conducted for individual cylinders. Knocking sensors employed in several models detect abnormal vibrations of the engine due to combustion problems based on an overall measurement taken outside the engine. In situ measurement of pressure in a cylinder would permit optimization of combustion in each cylinder, which would lead to fuel conservation and cleaner exhaust gases. Thus, development of an in-situ measurement technique of combustion pressure in reciprocal engines is an urgent task.

Another example is the need for high-temperature monitoring systems which has attracted much attention due to a series of recent accidents in power stations and chemical plants. A promising solution is diagnosis based on the detection of weak elastic wave (acoustic emission, AE) generated by abnormal vibrations in a plant or fracture within plant materials. Vibration/AE sensors usually employ piezoelectric material (a material that generates an electrical charge on its surface in response to stress applied to it) based on lead zirconate titanate (PZT). Since the commonly used sintered PZT bodies have low impact resistances and Curie points as low as about 300°C (a Curie point is the temperature above which the piezoelectricity disappears), applications in high temperature environments require accessories such as guiding bars or coolers, which tend to lower the precision of measurements. It is thus important to develop a technique for vibration/AE measurement at temperatures over 300°C.

AIST has been developing a sensor device highly resistant to heat and vibration based on a proprietary thin film technology, as well as a measurement/diagnostic technique using the device for high temperatures environments over 500°C.

Development of heat-resistant piezoelectric devices

Measurements at high temperatures need appropriate sensor materials. We chose as a candidate material aluminum nitride (AlN), a piezoelectric substance with a piezoelectric constant d33 of 5.6 pm/V and a melting point of 2790°C. It retains the piezoelectricity up to well over 1200°C. AlN is thus a promising material for high-temperature pressure and vibration sensors which can dispense with any cooling system. However, a polycrystalline sintered body of AlN is not piezoelectric since, unlike for other piezoelectric substances, the polarization of AlN cannot be controlled after sintering. This was a major hindrance to the commercialization of AlN piezoelectric devices. We obtained highly oriented AlN thin films using the high-frequency magnetron sputtering technique, which will soon be put to practical use. Improved semiconductor processing techniques will also reduce its production costs.

Measurement of pressure and vibrations at high temperatures

A step necessary after the development of AlN thin film devices is the evaluation of their performance at high temperatures in pressure and vibration sensing.

Studies at room temperature have revealed that the AlN thin film has frequency characteristics and linearity of pressure response comparable to those of quartz sensors. An experimental apparatus for evaluation of pressure sensors, shown in the Photo, is now employed in the evaluation of pressure characteristics of AlN devices at high temperatures. The electric furnace operates under a controlled atmosphere; the evaluation is conducted with nitrogen. Tests demonstrated that the device detects signals, i.e. it can measure temperatures over 500°C. Packaged pressure sensors are now under development.

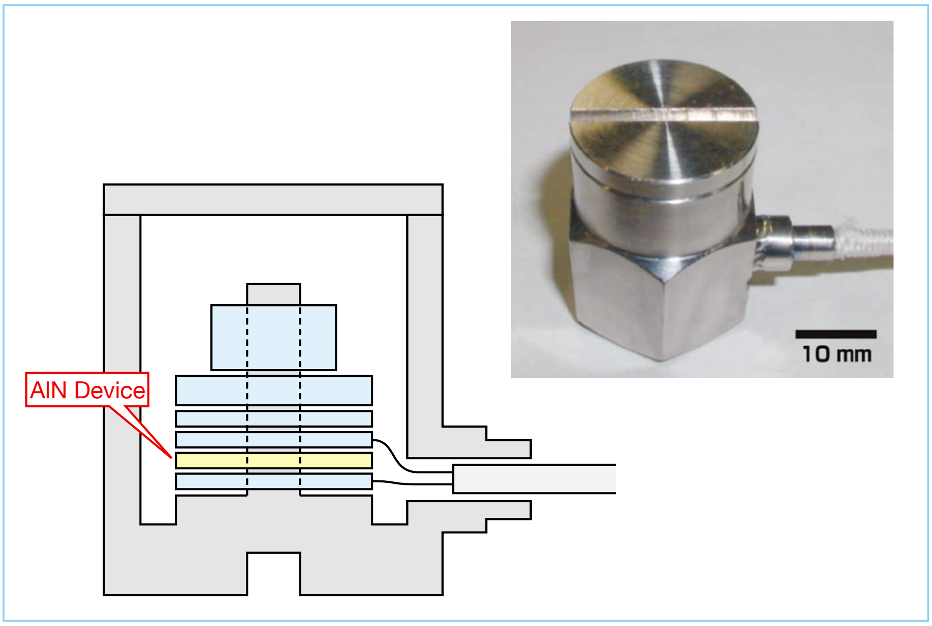


Fig. 1 : Heat-resistant AE sensor

The AlN thin film device, with a flat frequency response over 1 MHz, has been proved to be a promising vibration/AE sensor. Furthermore, a heat-resistant AE sensor shown in Fig. 1 was constructed and high-temperature characteristics were evaluated. Fig. 2 compares a 300-kHz sine wave input at 600°C with the response signal of the device. The device not only detected the signal at 600°C but retained the performance after cooling.

Possibility of measurement of pressure and vibrations over 500°C has thus been proven. Future development tasks include improvements in sensitivity, frequency characteristics and oxidation resistance. While pursuing them, we foresee development of control and diagnostic techniques involving the AlN devices, which will find applications in a measuring system of engine combustion pressure or measurement and diagnostic system for plant piping or gas turbines. Such systems will surely contribute to energy savings and improved the safety of our society.

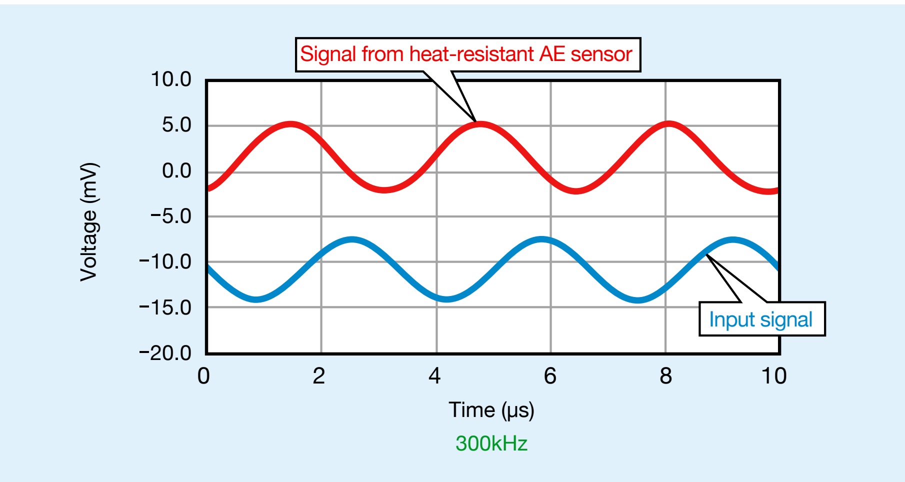


Fig. 2 : Signal from the experimental heat-resistant AE sensor (600°C)

Being Human-Friendly:
Health Monitoring Technology in Daily Life

Naohiro Ueno
On-site Sensing and Diagnosis Research Laboratory

On-site Sensing for health management

In the context of an aging population and declining birthrate, private health management and safety of each household are the keys for a long and healthy life of individuals. Based on the background, home healthcare (health management by individuals) and home medical care (obtaining medical data in daily life for sickness prevention and disease control) are rising in demand not only in Japan but also the United States and Europe as lifestyle-related diseases are serious problems. For example, a manufacturer of blood pressure gauges had a 10 percent growth in sales in 2003 compared to the previous year. At present, however, handy instruments for home use are limited to scales, body fat meters, blood pressure gauges and pulse meters, while long-term data acquisition depends upon the individuals' attention for continuous measurement. In addition, results presented only as numerical figures are difficult for laymen to interpret. AIST addresses these problems by developing human-friendly health monitoring technology for use in everyday circumstances: noninvasive and non-restrictive measurement methods of pulse wave and breath, and measurement methods involving visualization of information from inside the human body.

Piezoelectric film sensor

In home environment where many hard conditions (ex. high temperature) may exist, noninvasive measurement of human medical information, such as heartbeat and breath, requires special sensors with excellent flexibility, thin thickness, and high durability. AIST developed piezoelectric film sensors, which satisfy such requirements, based on depositing technology of heat resistant piezoelectric thin film on metal, glass and polymer film substrates. Constructed sensor that employs aluminum foil or polymer films as the substrate has provided better flexibility, higher durability and heat resistance than conventional film sensors, and thinnest thickness in the world. This technology enables acquisition of medical data in daily life without special attention. It has been verified that a sensor attached to a toilet seat can detect pulse signals of a user even through a fabric seat cover. Respiration signals of human beings during sleep have also been successfully obtained by using developed sensors without oppression to the body. The signals are useful for diagnosis of arteriosclerosis or sleep apnea syndrome which progress record in long term is required. We are also developing fiber type piezoelectric sensor that enables us to stitch the sensor into clothes. One of developing applications of the film sensor is measurement for swinging of standing body. Our target of the development is measuring devices that can be used by anyone anywhere.

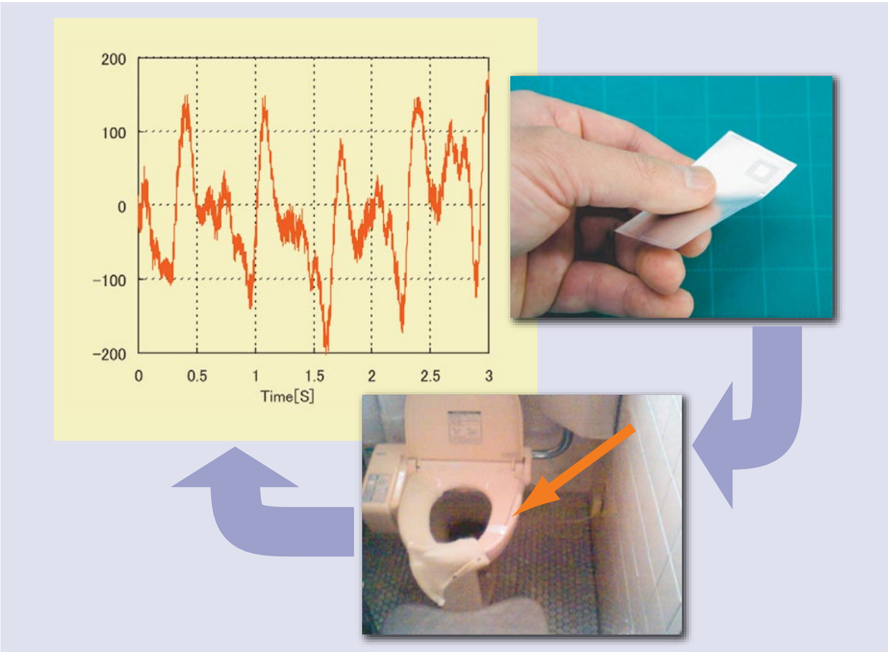


Fig. 1 : Foil-type flexible piezoelectric sensor and example of pulse data

Ubiquitous Echo

As another tool for health monitoring technology, a portable ultrasound echographic machine (Ubiquitous Echo) was developed through joint research between the AIST's Institute for Human Science and Bioengineering and Global Health Co. Ltd. The unit can be used in health care or beauty facilities, or even in the home, to visualize the key components of the body (muscles, bones, subcutaneous fat) and give fat and muscle measurements. New concept of “Visual Health Promotion” is based on the availability of graphical information to intend the user's attention for his/her own health. It was examined that visualization of subcutaneous fat layer as the result of training directly raises

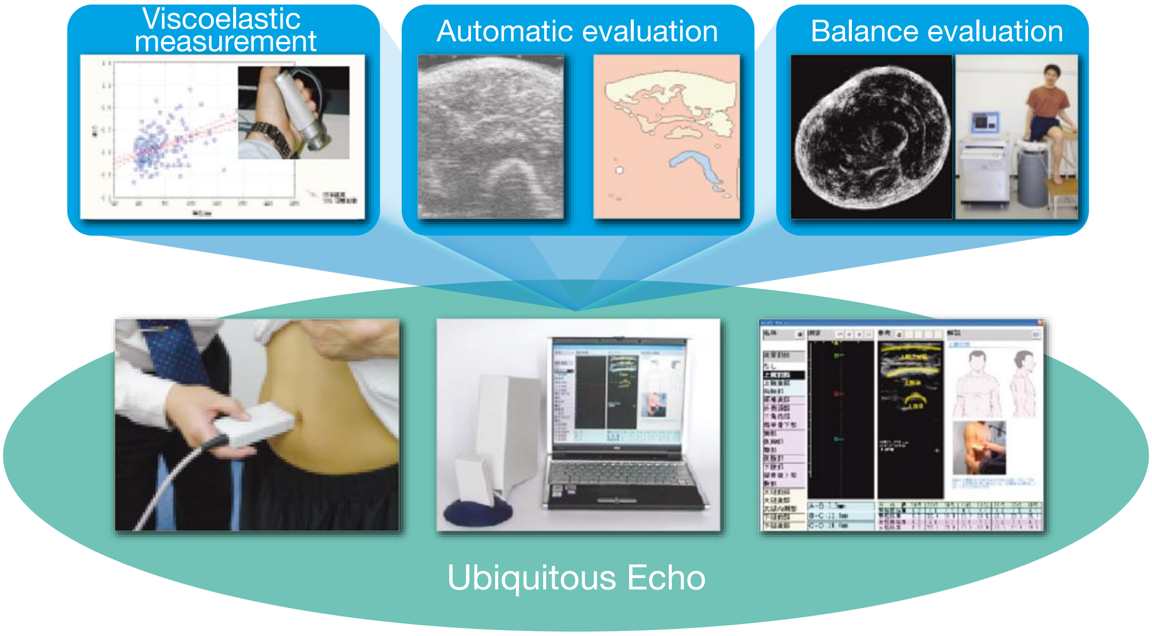


Fig. 2 : Ubiquitous Echo and its applications

attention and motivation to diet and exercise. Studies are in progress on applications of the Ubiquitous Echo for measurements of "stiffness" of skin, muscles, subcutaneous fat, and other tissues. This measurement technology provides quantification of skin aging and fatigue of muscles, etc.

Future works of the health monitoring technology

Our research jointly with universities and businesses is not limited to laboratory work for development of new sensors; we conduct lectures on physical measurement using those sensors. Actual data from Kyushu, where the population is aging more rapidly compared to other areas in Japan, provides valuable information for gerontological studies, e.g. declining muscle power due to aging.

Our R&D efforts are set in a whole structure from sensor materials to devices and measuring systems to actual measurements in medical practice. Actual data are then fed back to our laboratory for further development of useful products.

Fig. 3 : Physical measurement lecture in Nobeoka in cooperation with Hironori Sato (Hiroshima Institute of Technology) and Mr. Mitoda (IsLabo)

Multi-scale sensing/diagnosis:
Sensor emitting light in response to external stress

Xu Chao-Nan
On-Site Sensing and Diagnosis Research Laboratory

Concept of multi-scale measurement

Real-time monitoring of stress distribution in a structural member is highly desirable, but no simple and dynamic monitoring technique is yet available: the sensor size limits the size of the object to be measured, and time and costs for sensing and diagnosis have yet to be much reduced. AIST has proposed a novel concept of "ACHO", or measurement of pressure using a sensor that emits light in response to stress applied to it.

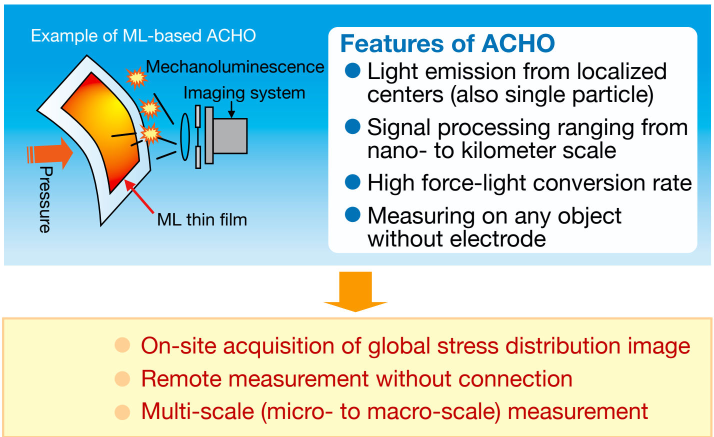


Fig. 1 : Concept of multi-scale measurement

Fig. 1 shows the concept of multi-scale measurement. A substance which converts stress applied to it into light (mechanoluminescent substance) is used as the sensor. An object covered with such a substance permits real-time optical observation in situ of stress distribution (including any abnormality) on its surface. Mechanoluminescence (ML)-based devices need no lead wire or electrode and therefore permit remote monitoring of any object. Other advantages of ACHO include observation of a single particle (because the centers of emission are localized), ease of scaling of a signal ranging from a nanometer to a kilometer, high conversion efficiency of force to light, and the possibility of wide-range multi-scale measurements.

Characteristics of ML sensors

The mechanoluminescent materials, which eliminate light in response to mechanical energy in a reproducible manner, were first developed in our laboratory. Unlike the well-known luminescence in fractures under a very strong force, the luminescence of our samples is observed in the region of elastic deformation under relatively low loads without destruction of the material. Their characteristics are illustrated in Fig. 2. The intensity of mechanoluminescence has been found to be a linear function of the mechanical energy input. The intensity under repeated stress is proportional to the deformation energy applied. The linearity has been observed not only for tension and compression but also for bending and torsion.

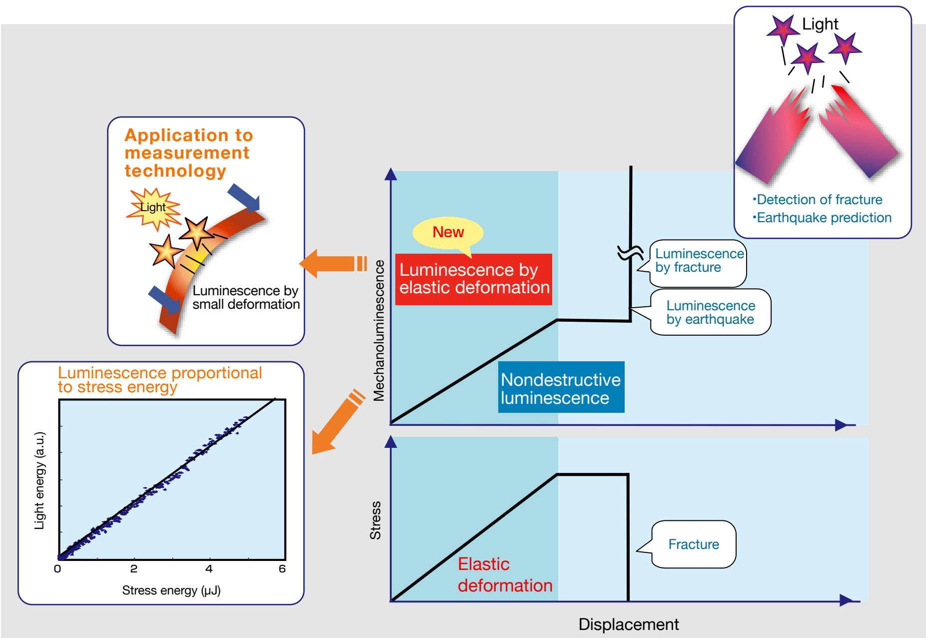


Fig. 2 : Features of mechanoluminescence

Several ceramics with certain crystal structures have been identified that show good mechanoluminescent performance. They are solid solutions of elements forming centers of luminescence in inorganic matrices with highly controlled structures. Various combinations of the additives and matrices provide mechanoluminescent crystals with the emitted light of various wavelengths ranging from UV to IR. Typical images of mechanoluminescence are shown in Fig. 3. A series of ML sensors have been manufactured with a variety of geometry, including fiber (resistant to electromagnetic interference),

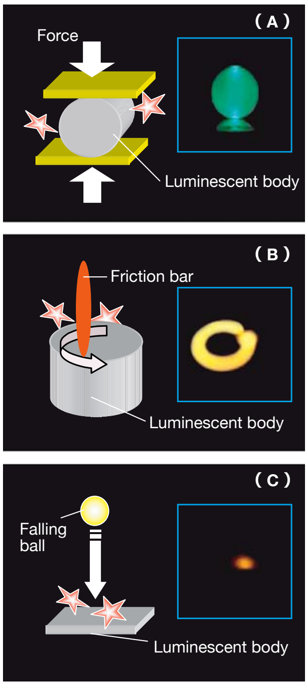


Fig. 3 : Examples of ML images
(a) Luminescence by deformation
(b) Luminescence by friction
(c) Luminescence by impact

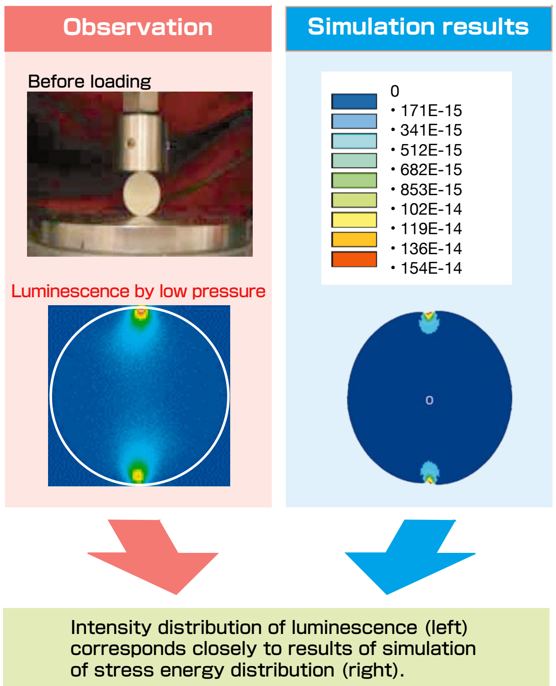


Fig. 4 : Visualization of stress distribution in an ML-coated aluminum disk and comparison with numerical calculation

sheet, block and diaphragm (suitable for detecting very low pressures).

Mechanoluminescent materials permit nano-scale measurements since the center of emission is a single atom. Mechanoluminescent fine particles have also been prepared successfully, which have greatly improved the spatial resolution over a wide-range (nano- to kilometer ranges) sensing for stress analysis.

Aspects of multi-scale sensing and diagnosis

Current development efforts of ML-based ACHO techniques are made with both particulate and bulk sensor materials.

ACHO using ML particles dispersed in biomolecules, cells or other fluids will realize micro- and nano-scale remote sensing and diagnosis. Recent success in surface modification of fine ML particles to improve dispersibility and stability opened the door to a wide variety of ACHO.

Continuous ML bodies are used in various forms of ACHO sensors. For example, an ML material can be applied as a coating with a particular function (“smart coating”). Fig. 4 shows some luminescent images obtained by applying stress to an aluminum sheet uniformly coated with an ML material which was visible in real time. The distribution of the emission intensity corresponded closely to the stress distribution obtained by finite element analysis, demonstrating that the ML image provides a direct visualization of actual stress distribution. This type of imaging is a promising method for nondestructive testing and the novel micro-scale stress distribution determination.

ACHO has many advantages: remote sensing, elimination of power supply, wide-range multi-scale measurement, ease of handling, to name a few. These features suggest various applications ranging from nano- and micro-scale monitoring of production processes to large-scale management of industrial facilities. For these applications to develop, however, the senor technology should be integrated with many other technological fields, such as information analysis, bidirectional signal transfer, or large-scale simulation and diagnosis. AIST intends to extend collaboration with other parties, standardize measurement methods, and to establish a database of relevant information in order to establish integrated sensing technology.

A More Vital Kyushu through Academia-Industry-Government Collaboration

Establishment of academia-industry-government collaborative body

We are fostering “On-Site Sensing and Diagnosis Systems Consortium,” an academia-industry-government collaborative body for the Kyushu area, established in April 2005. Through this activity, our catchword “Your laboratory - ready to serve you” becomes a practicable system.

AIST Kyushu will contribute to further vitalization of the Kyushu area by establishing networks involving the Kyushu Bureau of Economy, Trade and Industry, universities, public laboratories, and local businesses.

Formation of research and collaboration innovation hubs

AIST's mission is to create and develop industrial technologies that meet social needs.

AIST Kyushu was established as one of the AIST regional centers to form research and collaboration innovation hubs.

Research innovation hub means achieving world-class research performance, and collaboration innovation hub ensuring reliability as a regional research institute. AIST Kyushu strives to become a research innovation hub in the field of on-site sensing and diagnosis. To be a collaboration innovation hub, the Center aims at contributing to the development of Industry Cluster Initiative and at promoting collaboration with universities,public laboratories and local businesses in Kyushu.

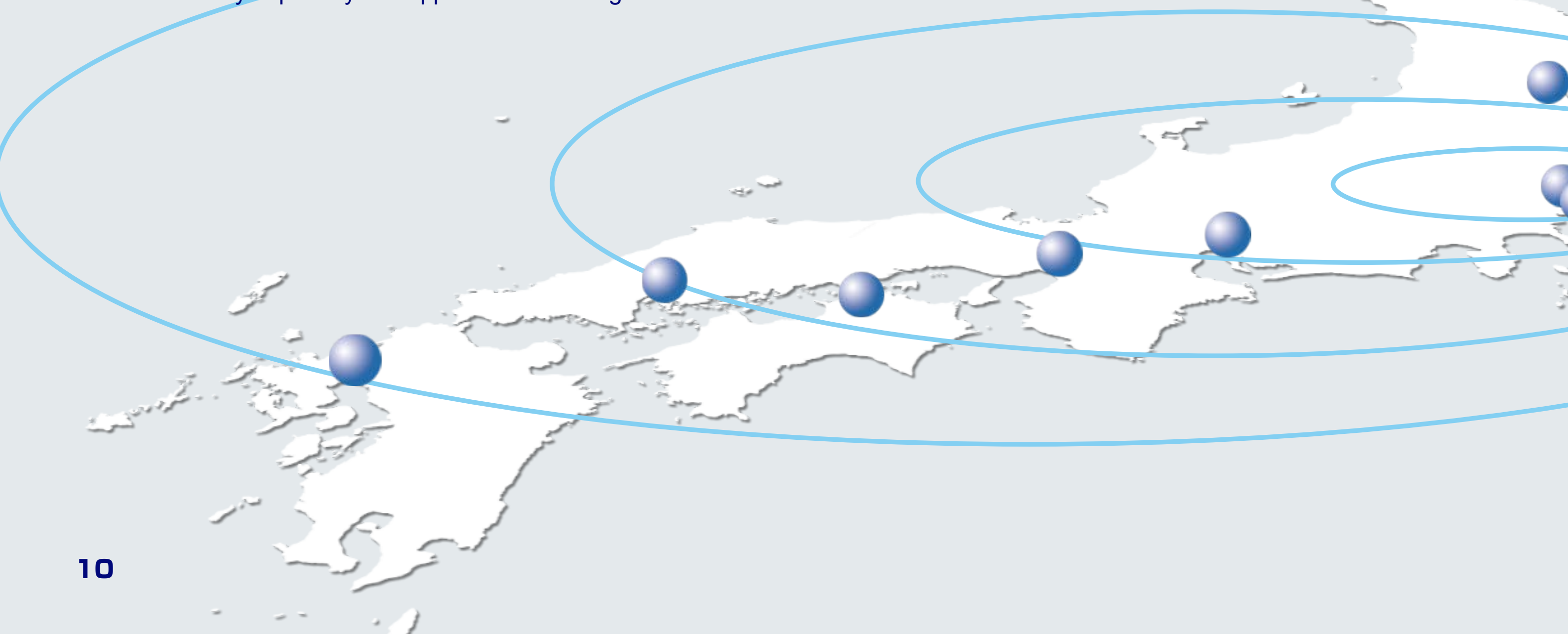
The On-Site Sensing and Diagnosis Systems Consortium is concerned with both innnovation hubs.

Research activities of AIST Kyushu

The On-Site Sensing and Diagnosis Research Laboratory, founded in April 2004, is the core research unit of AIST Kyushu. The Development program of on-site sensing and diagnostic technology covers three subprograms: (1) dynamic pressure measurement and diagnosis at high temperatures and pressures, (2) biofunctional measurements in everyday circumstances with low interference, and (3) sensors emitting light in response to external stress. The research unit will be reorganized in 2006 with two groups added: semiconductor process monitoring and biological measurements on food, for advancing contribution to the industry cluster and agriculture-industry cooperation initiatives by the Kyushu Bureau of Economy, Trade and Industry.

AIST Kyushu also consists of the Micro- and Nano-Space Chemistry Group, Environment-Friendly Alloys Research Group, Environment-Friendly Materials Research Consortium, and Biomass Research Center. All of the research groups in AIST Kyushu aim at the creation and development of industrial technologies that meet society’s needs.

We sincerely hope for your support and encouragement.



Academia-industry-government collaborative body

Invitation to " On-Site Sensing and Diagnosis Systems Consortium"

AIST has established On-Site Sensing and Diagnosis Systems Consortium as an academia-industry-government collaborative body in the Kyushu area. Its organization is shown in the diagram below. Its purpose is to provide basic solutions to the technical needs of industries in the area. AIST is always ready to serve you.

Major activities of the Consortium include:

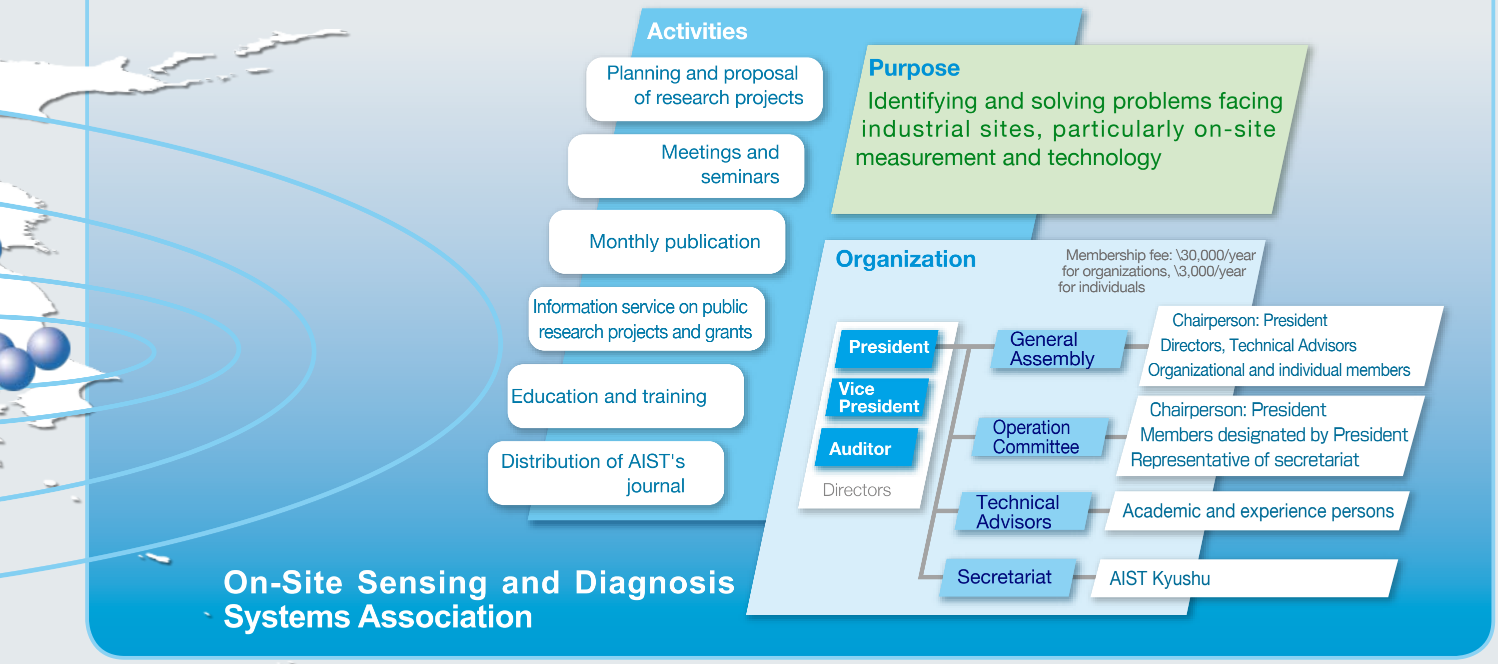
(1) meetings and seminars (twice a year) for personal communication,

(2) monthly publication for information exchange, and

(3) research groups for providing solutions to technical needs.

The research group activities conducted on a regular basis are particularly important for the purpose of the Consortium. Four research groups, i.e. Semiconductor Processing, Remote Monitoring, Biological Sensing/Diagnosis and Interfacial Technology groups, are active and invite you to participate.

[Contact]
National Institute for Advanced Science and Technology (AIST) Kyushu
Kyushu Collaboration Center (contact person: Kazuhiro Tanaka)
807-1 Shuku-machi, Tosu-shi, Saga 841-0052, Japan
Phone: +81-942-81-3674
E-mail: tanaka.k@aist.go.jp



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AIST NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

Publication Office, Public Relations Department, AIST
AIST Tsukuba Central 2, 1-1-1 Umezono, Tsukuba, Ibaraki, 305-8568, JAPAN
Tel:+81-29-862-6217 Fax:+81-29-862-6212 E-mail:prpub@m.aist.go.jp http://www.aist.go.jp/

AIST Kyushu (Kyushu Collaboration Center)
AIST Kyushu, 807-1 Shuku-machi, Tosu-shi, Saga 841-0052, Japan
Tel:+81-942-81-3606 Fax:+81-942-81-4089 E-mail:kyushu-collabs@m.aist.go.jp http://unit.aist.go.jp/kyushu/

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