NMIJ Newsletter

No.13, May 2021

Greetings from director of RIEM

Dr. OTA Akihiro

The Research Institute for Engineering Measurement (RIEM) has a lot of researchers and experts from mechanical engineering, applied physics, measurement and control, and information technology (number of staff: about 70). We have three important missions. The first mission is to contribute to international activities related to legal metrology and to steadily conduct legal metrology services such as type approval test of specified measuring instruments and inspection of verification standards used in local verification offices, in cooperation with the Ministry of Economy, Trade and Industry.

The second is to develop, maintain, and smoothly disseminate national measurement standards for length, mass, and their related derived quantities.

The third is to promote the advancement of high-precision measurement technology and data science technology on the basis of our measurement standards, and to connect their research outcomes to companies for future national and international businesses.

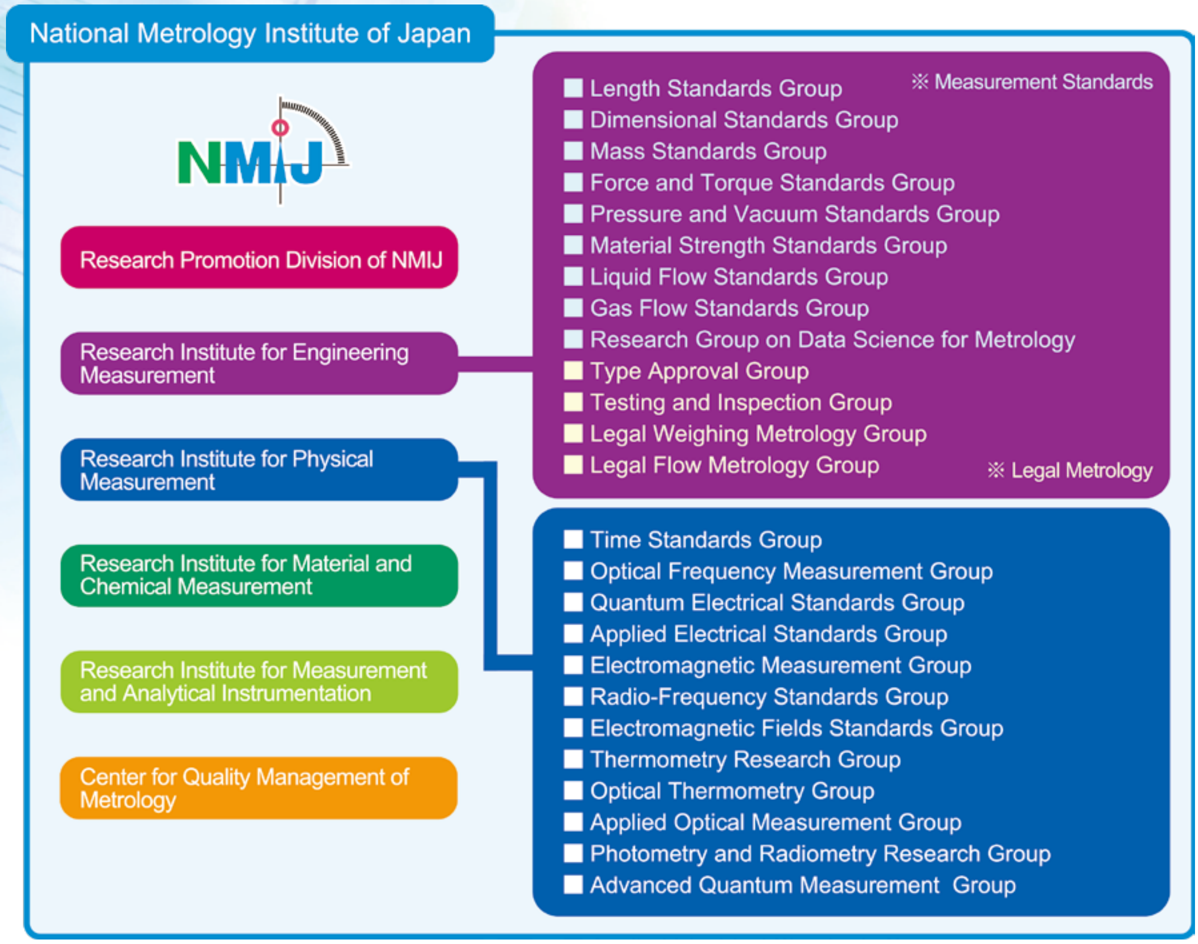
We hope to promote research activities to solve social problems such as energy and environmental constraints and COVID-19 infection, and to create innovations that will contribute to industrial competitiveness.

Greetings from director of RIPM

Dr. SHIMADA Yozo

According to the 5-year midterm plan of AIST which started in April 2020, the Research Institute for Physical Measurement (RIPM), which consists of twelve research groups with over 80 researchers, started new challenges to develop and disseminate the national measurement standards in the fields of electricity, time and frequency, temperature, and optical radiation – all of which underpin the industrial competitiveness, product reliability, and safety in our daily lives. In particular, the RIPM will contribute to cutting-edge research and development for measurement standards such as optical lattice clocks towards the redefinition of the second, and quantum current standards using single-electron pump devices for quantum metrology triangle experiments. Furthermore, in order to solve social challenges, the RIPM works on the development of electromagnetic and photonic sensing technologies for the Society 5.0, as well as radiation thermometry that can contribute to measures against infectious diseases. With our technologies, we hope that all humankind in the present and the future will survive this COVID-19 pandemic, and leave a bright future for the young generation.

Organization chart of RIEM and RIPM



Introduction of RIEM

The Research Institute for Engineering Measurement (RIEM) is one of the four research institutes of NMIJ. The RIEM contains two types of groups which are related to the national measurement standards and legal metrology. We have nine research groups which conduct research on the national measurement standards. We also have four groups engaged in legal metrology services.

The RIEM is responsible for developing, maintaining, and disseminating measurement standards and is deeply involved with manufacturing industries. The RIEM is also deeply engaged in legal metrology and plays a great role in that field. Even if appropriate solutions cannot be given by ourselves, we can introduce external organizations such as universities by using our accumulated information and human networks. The policy of RIEM is to provide metrological solutions in response to requests from industries by making use of these accomplishments. We contribute to the industries through our activities.

■ Length Standards Group

We are responsible for establishing metrological standards and calibration system in the area of one-dimensional length (end standards, line standards, EDM, laser interferometer, and refractive index) and geometrical deviations (flatness, sphericity, and roundness) metrology. We are also working on research and development regarding advanced length measurement science and technology. Current research activities include ultra-high-accurate surface profiler for large diameter substrates, high precision thickness measurement, laser interferometer module with nonlinearity error less than 10 pm, and high precision diameter measurement of the reference sphere used in μ-CMM.

■ Dimensional Standards Group

Dimensional Standards Group's mission is to establish, maintain and disseminate traceability for multidimensional length measurement, which is one of the key issues in the manufacturing industry, and to carry out basic research on related measurement techniques.

For 3D standards, we are proposing calibration gauges for a contact coordinate measuring machine (CMM) and for X-ray CT, and developing a new uncertainty analysis technology. For 2D standards, we calibrate surface roughness, steps and 2D grid plates. We are also developing calibration technology for rotary encoders and other angle devices that uses the AIST original self-calibration principle as for angle standard corresponding to 0D standards.

■ Mass Standards Group

In May 2019, the definition of the kilogram was revised for the first time in 130 years. The new definition is based on the Planck constant. Measurement technologies using ^{28}Si-enriched spheres developed by the Mass Standards Group played a crucial role in determining the Planck constant in the new definition. By using such technologies, we are now establishing and disseminating mass and density standards which are used as technical basement to ensure reliability and international consistency of measurement in industrial and scientific fields of Japan.

■ Force and Torque Standards Group

We establish and strengthen the traceability of measurement in the force and torque field. To ensure traceability in the traceability chain (force/torque national standard machines, force/torque measuring devices, and force/torque testing machines), we conduct R&D that will lead to solving problems. Such efforts include the development of precise and stable force & torque transducers. New principles are being applied to develop effective calibration and measurement techniques as well as force & torque standards, aiming to enhance precision and stability.

■ Pressure and Vacuum Standards Group

Our group is developing, maintaining and providing the national standards of pressure, vacuum and leak. The pressure and vacuum standards, ranging from ultra-high vacuum (10^{-9} Pa) to ultra-high pressure (10^{9} Pa), meet the fundamental needs from the industries and support the leading-edge technologies. The leak standards contribute to ensuring the reliability of leak testing in the key industries such as automobile and air-conditioning industries. We are also developing new pressure measurement systems using optical methods to upgrade our standards and to support dynamic pressure measurements.

■ Material Strength Standards Group

We conduct research and development on measurement techniques for material strength and ultrasonic field and are responsible for maintaining and disseminating related measurement standards. As for material strength measurement, we aim to contribute to evaluating hardness and other mechanical properties of materials needed in industry. We also develop precise measurement techniques of ultrasonic field on the basis of calibration techniques of ultrasonic power and hydrophone (ultrasonic microphone for underwater) sensitivity for performance and safety evaluations of ultrasonic equipment.

■ Liquid Flow Standards Group

Liquid Flow Standards Group has a mission in establishing, maintaining and disseminating traceability to the national standards for liquid flow and viscosity, as well as conducting fundamental research on related measurement techniques. Flow facilities providing calibration services in wide range of water flow rates and liquid hydrocarbon flow rates with high accuracy have been established. The test bench for the micro flow rate is now under development. Development of new measurement techniques, such as MEMS sensor for viscosity and flow diagnostic using non-intrusive ultrasonic method, is being conducted. Furthermore, we are also working on fundamental research in fluid mechanics for turbulence, and measurement of viscosity under absolute and high-pressure conditions.

■ Gas Flow Standard Group

Gas Flow Standards Group is engaged in the national standards for gas flow and air speed. We are also performing research and development of flow measurement technologies, especially aiming to contribute to realizing a carbon-free society by enhancing the use of hydrogen energy and preventing the spread of COVID-19 by controlling air flow.

■ Research Group on Data Science for Metrology

Our group has three missions. The first one is the software accreditation, which is the research and development on software evaluation technology in legal metrology. The second one is the applied statistics, which is the research on the evaluation of measurement uncertainty and statistical methods for the interlaboratory comparisons. In addition, we promote utilization of measurement uncertainty through the management of "Uncertainty Club." The third one is the data science for metrology, which is the research and development concerning digital transformation in new measurement system, including utilization of blockchain in metrology, digital SI, new measurement instruments using the machine learning, and related technology.

■ Type Approval Group

We are responsible for comprehensive evaluation of type approval for the specified measuring instruments under Measurement Act by examining their test results and designs.

■ Testing and Inspection Group

We conduct type approval tests and verification, inspection of verification standards, and develop technical requirements with regard to legal metrology.

■ Legal Weighing Metrology Group

We conduct type approval tests on various weighing instruments and inspections of verification standards for mass.

■ Legal Flow Metrology Group

We conduct type approval tests for specified measuring instruments concerning volume (e.g., water meters, gas meters, heat meters) and inspections of verification standards for volume.

Research topics of RIEM

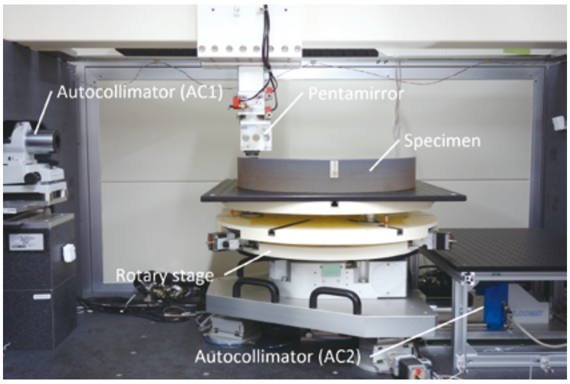
Ultra-high-accurate surface profiler for large diameter substrates

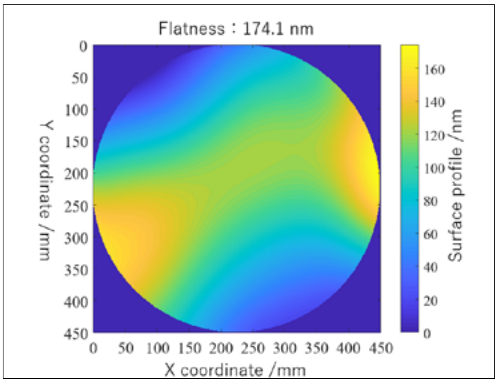
KONDO Yohan and BITOU Youichi

In advanced industries such as semiconductor and liquid crystal display manufacturing, there is a growing need for higher-accuracy, larger-diameter silicon wafers and liquid crystal substrates for device miniaturization and productivity enhancement. With the increasing use in basic sciences of ultra-high-accuracy optical devices such as astronomical telescope mirrors and X-ray focusing mirrors for synchrotron radiation facilities, there is an ever-growing demand for highly accurate surface profile.

At the NMIJ, flatness standards have been provided using a Fizeau interferometer with 10 nm uncertainty over a measurement range of Ø300 mm. To reduce the measurement uncertainty and increase the measurement range, we developed a three-dimensional scanning deflectometric profiler (3-D SDP). Unlike the Fizeau interferometer, the 3-D SDP does not require a reference surface and can directly measure a large-diameter surface profile. In the 3-D SDP, the distribution of local slope angle on a specimen is measured with several tens of nano-radian uncertainty, and the surface profile with sub-nanometer resolution is obtained by integrating the obtained distribution of local slope angle. The measurement range and measurement uncertainty of 3-D SDP are Ø600 mm and 5 nm. NMIJ will start a new surface profile measurement service.

Reference: Y. Kondo and Y. Bitou, Proc. SPIE 11492, Advances in Metrology for X-Ray and EUV Optics IX, 1149203, 2020.





The developed ultra-high-accurate surface profile system (left) and measurement result for a 450 mm planar substrate (right).

Fuel flow measurement traceability for low emission vehicles (LEV)

CHEONG Kar-Hooi, DOIHARA Ryouji, FURUICHI Noriyuki, SHIMADA Takashi

To overcome global warming, many countries in the world are planning to replace engine-driven vehicles with environment-friendly vehicles such as electric vehicles (EV), fuel-cell vehicles (FCV) and low emission vehicles (LEV). As it may take some time before humankind is fully capable of achieving the ultimate goal of zero greenhouse gases (GHG) emission, low emission vehicles such as hybrid vehicles (HV) and plug-in hybrid vehicles (PHV) will play a realistic role in reducing CO_2 emission.

Hence, from the viewpoint of market reliability and conformity to international regulations, the traceability for measurement of low fuel consumption rate is of critical importance for the automobile industry. Towards this end, NMIJ has developed a primary standard to meet the calibration needs of fuel meter used at engine test bench. Taking careful safety measures, we have successfully developed a calibration facility that works on actual liquid fuels, namely light oil (diesel), kerosene and industrial gasoline. By employing a self-developed gravimetric system, we achieved a high calibration accuracy of below 0.1 % for low flow rate of fuel down to 0.33 mL/min.

Reference: K-H. Cheong et al., Measurement Science and Technology, 29, 075304, 2018.

Gravimetric system using high-speed switching valves for calibration of low fuel flow rate.

Realization of the new kilogram by NMIJ and its international consistency

KURAMOTO Naoki, MIZUSHIMA Shigeki, FUJITA Kazuaki,
OTA Yuichi, ZHANG Lulu, AZUMA Yasushi, KUROKAWA Akira, INABA Hajime and OKUBO Sho

In May 2019, the International System of Units (SI) was essentially revised. In the new SI, the kilogram is defined by fixing the value of the Planck constant. Under the new definition, in principle, any national metrology institute (NMI) has the possibility to realize the kilogram independently. To confirm the consistency among the individual realizations by NMIs, the first international comparison of the realizations based on the new definition, CCM.M-K8.2019, was organized from 2019 to 2020. Six NMIs including NMIJ and BIPM participated in the comparison and used their own realization methods.

The NMIJ realized the new kilogram by the X-ray crystal density method. Fundamental concept of this method is the counting of Si atoms in a ^{28}Si-enriched sphere. The sphere is covered by a transparent surface layer with the main constituent of SiO_2, and the diameter of the Si core excluding the surface layer was measured by an optical interferometer developed by NMIJ (Fig. 1). The volume of the Si core was determined from the diameters in many different directions, and the number of Si atoms in the Si core was determined from the Si core volume and the lattice constant of Si crystal. The mass of a Si atom is derived from the Planck constant. From the number of Si atoms, the mass of the Si core was therefore determined on the basis of the Planck constant. The mass of the surface layer was determined by X-ray photoelectron spectroscopy and ellipsometry. By combining the mass of the Si core and that of the surface layer, the mass of the sphere was determined with a relative standard uncertainty of 2.1×10^{-8}. This corresponds to the realization of the new kilogram with a standard uncertainty of 21 μg for 1 kg.

Each participant determined the mass of one or two 1 kg transfer standards with their realization experiment. All transfer standards were sent to BIPM, and their masses were determined on the basis of the international prototype of the kilogram (IPK). Figure 2 shows the differences between the masses of the transfer standards based on the IPK and those based on the individual realizations by the participants. The error bars indicate the standard uncertainty of each value, and the consistency of the individual realizations was confirmed. The uncertainty of the realization by NMIJ is the third smallest in the world, significantly contributing to the consistency confirmation with high reliability. Following the completion of this key comparison, the internationally coordinated dissemination of the kilogram has entered into a new phase on 1st February 2021.

References: N. Kuramoto et al., IEEE Trans. Instrum. Meas., DOI: 10.1109/TIM.2021.3061805
S. Davidson et al., Metrologia, DOI: 10.1088/1681-7575/abef9f

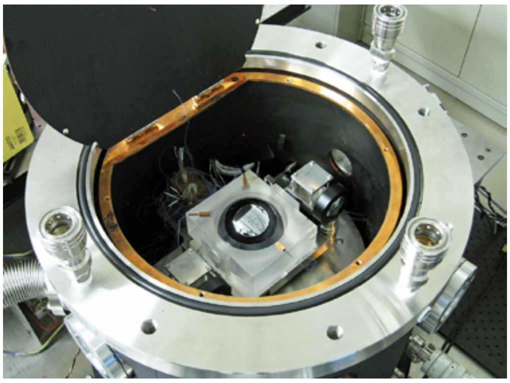


Fig. 1. Optical interferometer to measure the diameter of a ^{28}Si-enriched sphere with sub-nanometer uncertainty.

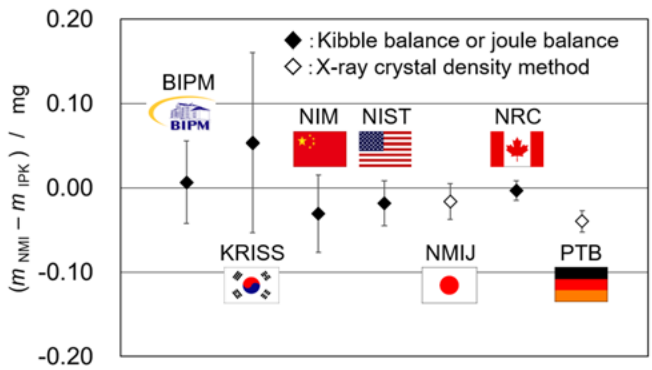
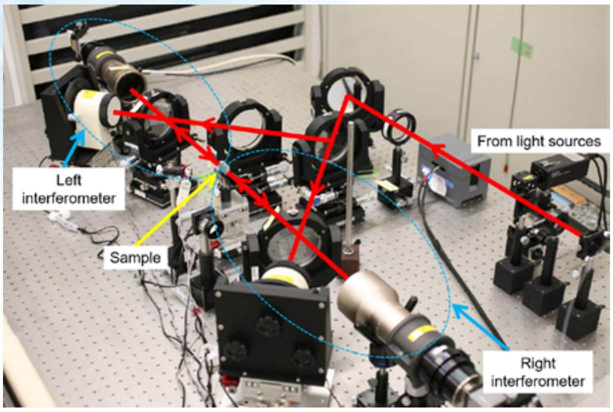


Fig. 2. Results of CCM.M-K8.2019. m_{NMI} is the mass of the transfer standards based on the individual realization experiment, and m_{IPK} is the mass of the transfer standards based on the IPK.

High precision measurement of the thickness of silicon wafers

HIRAI Akiko

We have developed a double-sided interferometer for thickness measurement that can measure the thickness of a silicon wafer without being affected by the refractive index inside the wafer. The spectral interference method using interference between the light beams reflected from a front surface and a back surface of a sample is widely used for non-contact measurement of thickness. With this method, light is transmitted through the sample, so measurement result is the optical thickness which is the product of the refractive index and geometric thickness. The geometric thickness is obtained by dividing the optical thickness by the refractive index, therefore is affected by the refractive index. Because the refractive index varies from one lot to the next and is dependent on the additive concentration, reliability of results from this method cannot be guaranteed. There is need for an interferometer for precise thickness measurement that is free from the effect of refractive index of the sample.



The developed double-sided interferometer for thickness measurement.

The developed method uses only front surface reflected light to measure the surface shape on both sides of the sample with two optical interferometers and determine the thickness. Because the method does not use transmitted light, it is not affected by the refractive index of the sample. Using SI-traceable frequency-stabilized lasers as the light sources, it can measure thickness with high precision and reliability. The precision of the developed interferometer was confirmed by gauge blocks. The expanded measurement uncertainty (k = 2) is evaluated as 19 nm for a silicon wafer with a thickness of 200 µm to 900 µm.

Featured Events

Plenary Lectures

■ Metrology and Digitalization

Dr. Martin J. T. MILTON
The International Bureau of Weights and Measures (BIPM), FR
Title:Comparable Measurements for a Digital World

Dr. Prof. H. C. Frank HÄRTIG
Physikalisch-Technischen Bundesanstalt (PTB), DE
Title:Metrology - a fundamental backbone for digitalization

■ International corporation and Diversity

Mr. Xiang FANG
National Institute of Metrology (NIM), CN
Title:Regional Metrology Cooperation in Addressing Global Challenges and Stakeholder Demands

Dr. Yong-Hyeon SHIN
Yonsei University, KR
Title:The Power of Women Scientists and Engineers in the Digital Transformation Era

■ Instrumentation and Sensors

Mr. Koichi TANAKA
(2002 Nobel laureate in Chemistry)
Shimadzu Corporation, JP
Title: The Mutual Contributions of Science and Analytical Instruments

Ms. Barbara L. GOLDSTEIN
National Institute of Standards and Technology (NIST), US
Title: NIST on a Chip: Revolutionizing Metrology through Quantum Sensors

■ Sustainability

Dr. Akira YOSHINO
(2019 Nobel laureate in Chemistry)
Global Zero Emission Research Center (GZR) AIST, JP
Title: Brief History and Future of Lithium Ion Battery

Dr. Hiroshi TSUDA
National Metrology Institute of Japan (NMIJ) AIST, JP
Title: New materials and inspection technology for sustainable infrastructures

■ Time and space, Connectivity

Prof. Hidetoshi KATORI
The University of Tokyo, RIKEN, JP
Title: Transportable optical lattice clocks to test and use gravitational redshift

Dr. Iwao HOSAKO
National Institute of Information and Communications Technology (NICT), JP
Title: Paving the way for the Beyond 5G/6G

Introduction of RIPM

The Research Institute for Physical Measurement has been conducting advanced researches and providing the measurement standards. Recent research activities of each group are as follows.

■ Time Standards Group

The research and development on optical lattice clocks are conducted with techniques such as laser manipulation of ultra-cold atoms and stabilization of lasers for contributing to the redefinition of the second. The CCTF WGPSFS (see page 10) recommended the publication of NMIJ-Yb1 optical frequency standard data in Circular T and its use in TAI steering in 2020. UTC (NMIJ) (one of the national time scales in Japan) is also continuously maintained as an ultra-precise microwave frequency standard remotely available via GPS satellites.

■ Quantum Electrical Standards Group

Quantum electrical precision measurements using quantum effects, the Josephson effect, the quantum Hall effect, and the single electron tunneling effect are the main topics of the group. Our research activities also include high speed control of single electrons and its application for quantum metrology triangle experiments and a quantum current standard. The national standards for DC voltage and DC resistance have been developed and maintained, and the calibration services have also been provided by the group.

■ Electromagnetic Measurement Group

Measurement techniques for vector network analyzers are researched in the frequency band from kHz to THz. The measurement techniques for 6G wireless communications are launched. Complex dielectric permittivity and conductivity measurements methods have been established over 100 GHz by resonator method. Then, planar circuit measurement over 100 GHz has been realized with highest accuracy in the world. Electromagnetic sensing techniques are also researched for agriculture qualification and infrastructure.

■ Electromagnetic Fields Standards Group

Measurement technology of the electromagnetic fields in free space over a wide frequency range using a probe and an antenna is one of our major investigation targets. Developed measurement technology of free fields can be applied to various EMC measurements, characterization of the communication antennas and infrastructure diagnosis. Antenna calibration services cover the frequency range from 9 kHz to 110 GHz, and the electric and magnetic-field probe calibrations are also available.

■ Optical Frequency Measurement Group

We are working on the generation and control of optical frequency combs, and several innovative applications of them. The applications include precise frequency measurement and laser control for optical clocks, gas analysis for environmental monitoring, and high-precision wavelength calibration of spectrometers. Furthermore, we maintain the optical frequency comb system, which is the length standards of Japan, and supply one of the SI base units, the meter, to JCSS Accredited Laboratories.

■ Applied Electrical Standards Group

The recent research topics are the precision measurements for thermoelectric conversion performance of flexible thermoelectric modules which are crucial for recovering waste heat, and the evaluation method of the electric power quality in which harmonics generated by the nonlinear devices have recently become a major issue. These researches are based on the techniques that our group has developed for the national standards for AC/DC transfer, AC voltage, voltage divider, current transformer, and harmonics.

■ Radio-Frequency Standards Group

Measurement standards and techniques for radio-frequency (RF) quantities are developed in a broadband frequency range. Current research topics are precision terahertz power measurement using a calorimeter, quantum-based technique for electromagnetic wave measurement, and chip scale atomic clock for accelerating the Internet of Things technologies. Calibration services for a wide variety of RF industry ranging from mobile communications to materials processing are also provided.

■ Thermometry Research Group

New sensing elements, such as resistance thermometers and thermocouples, and new techniques for temperature measurement are developed and evaluated in the temperature range from -260 °C to near 2000 °C on the basis of the national standards of temperature. We are also measuring thermodynamic temperature using an acoustic gas thermometer (AGT).

■ **Optical Thermometry Group**

A broad program of research in optical methods for non-contact, high-speed, and highly accurate temperature measurement has been carried out. We realize and disseminate the Japanese National Standards for radiation thermometry from -30 °C to 3000 °C. A novel method for temperature determination using dual-comb spectroscopy is being developed for various applications. Two/three-dimensional thermal imaging to promote practical realization of technologies are also developed.

■ **Photometry and Radiometry Research Group**

Development of the basis for advanced optical radiation measurement and its industrial application are the main topics of the group. Currently, optical detector characterization, absolute spectroradiometry, laser radiometry, standard light sources and optical properties of materials are studied. Another indispensable task of the group is the development, improvement and dissemination of national scales for the candela (cd) and other primary units in the field of photometry and radiometry.

■ **Applied Optical Measurement Group**

Advanced radiometry and its applications are studied on the basis of absolute measurement. Our ongoing R&D includes the development of radiometric measurement methods optimized for the light sources based on new technologies such as LEDs, and the development of optical materials/device technologies including ultra-low reflectance absorbers, near-field optical elements, and phosphor sensors, both with industrial applications in mind.

■ **Advanced Quantum Measurement Group**

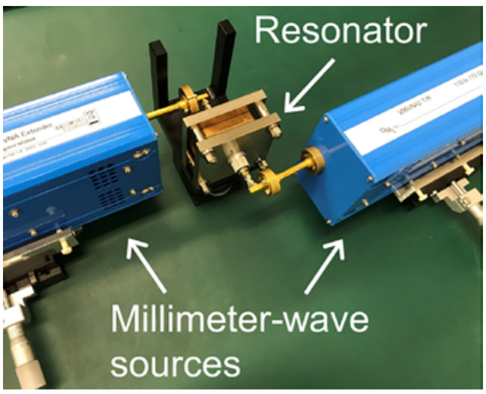
We are developing fundamental technologies for measuring microscopic electromagnetic information with high spatial and energy resolution on the basis of quantum optics and superconductivity phenomena. Ultimately, our goal is to use these measurement technologies as imaging tools in research fields such as medicine, biology, and space observation. We are also focusing on research to realize highly efficient cryogenic environments, which are important in quantum information technology and particle physics.

Research topics of RIPM

Ultra-wideband material measurement technique in the millimeter-wave bands for 5G/6G applications

KATO Yuto

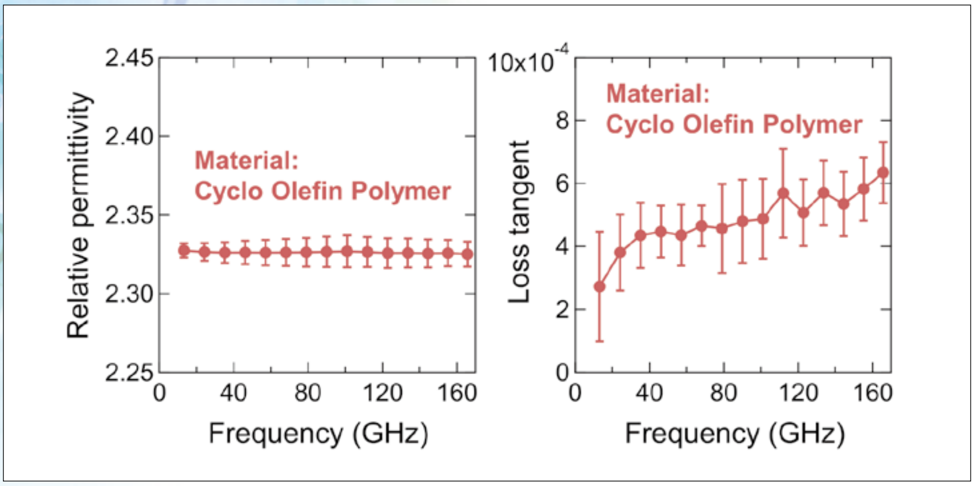
While the fifth generation (5G) wireless communication is currently being commercialized as industrial and social infrastructure, the research and development of the sixth generation (6G) wireless communication has garnered significant attention worldwide. 6G will use millimeter waves at frequencies above 100 GHz to realize high-speed and large-capacity communication with performances far exceeding those of 5G. The development of advanced materials for lower power consumption is crucial for realizing 6G because the transmission loss of a planar circuit generally increases as the frequency increases. In general, the total transmission loss in a planar circuit is determined by the dielectric and conductor losses, which are determined by the complex permittivity of a dielectric substrate and the conductivity of metallic lines, respectively. Therefore, ultra-wideband permittivity and conductivity measurements up to over 100 GHz is required for efficiently developing advanced low-loss materials and sophisticated implementation processes to reduce both the dielectric and conductor losses.



Photograph of the BCDR for material measurements up to 170 GHz.

We have developed an ultra-wideband permittivity and conductivity measurement technique in the millimeter-wave bands using a balanced-type circular disk resonator (BCDR) composed of two dielectric plates and a thin circular conductor disk. Because of the symmetric structure of the resonator, only the TM_{0m0} modes are selectively excited in a BCDR. Therefore, in contrast to conventional methods, the developed technique can provide broadband measurements from less than 20 GHz up to over 100 GHz by utilizing higher-order mode resonances with a single closed-type resonator. By developing a BCDR excited by ultra-fine 0.8 mm coaxial lines and improving an electromagnetic analysis method for the BCDR, we have realized permittivity and conductivity measurements up to 170 GHz. In the future, we aim to further increase the upper limit frequency of the technique up to 500 GHz.

In order to promote the dissemination of the technique to industry, we have achieved the IEC standardization (IEC 63185:2020) of this BCDR method for permittivity measurements up to 110 GHz.



Example of complex permittivity measurements up to 170 GHz.

Frequency noise measurement and its uncertainty estimation of an optical frequency comb using a delay-line interferometer

WADA Masato

Optical frequency comb enables us to compare arbitrary frequencies ranging from microwave to optical including their phase information and has had a great impact on metrology such as optical frequency measurements, optical clocks, and length measurements. In order to use frequency combs for these applications and to achieve their full performance, it is important to obtain its frequency noise power spectral density (PSD) which has the most noise information regarding frequency/phase and can be translated to a noise figure such as Allan deviation or spectral linewidth. Measuring the frequency noise PSD of a laser using conventional methods requires bulky and expensive equipment and complex system, such as a stable reference laser with a frequency noise lower than that of the laser under test. On the other hand, a delayed self-heterodyne method has been proposed as a simple measurement method without using a reference laser and has attracted much attention. In this study, we measured the frequency noise PSD of comb modes using the delayed self-heterodyne interferometer as shown in Fig. 1 and estimated the uncertainty of the measurement results. To validate the results, we also measured the frequency noise PSD of the comb modes by the conventional method using an ultra-stable reference laser and estimated its uncertainty. Figure 2 compares the results obtained by the delayed self-heterodyne method with those obtained by the conventional method. The results of both measurements were consistent within their uncertainties, which shows that the delayed self-heterodyne method provides high reliability. Therefore, we suppose that the self-heterodyne method becomes one of the standard frequency noise measurement methods for frequency combs.

Reference: M. Wada et al., Meas. Sci. Technol. 31, 125012, 2020.

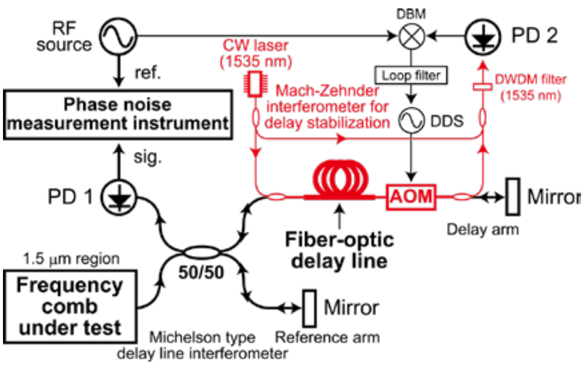


Fig. 1. Experimental frequency noise measurement setup for the comb modes of a frequency comb. AOM: acousto-optic modulator; PD: photodetector; DBM: double-balanced mixer; DDS: direct digital synthesizer; and DWDM: dense wavelength division multiplexing.

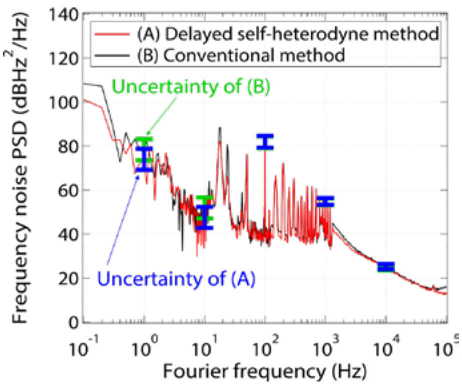
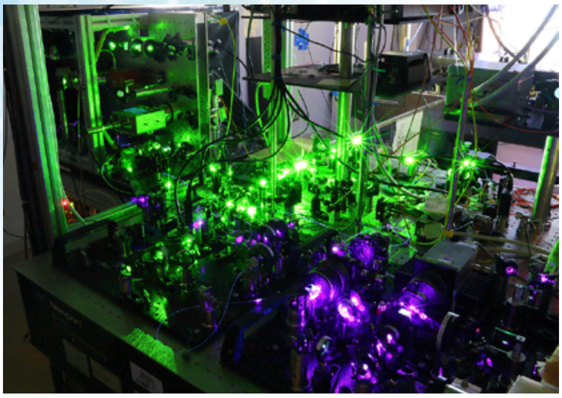


Fig. 2. Frequency noise PSDs of the free-running comb modes and its uncertainties.

Contribution to international atomic time by the nearly continuous operation of an Yb optical lattice clock

KOBAYASHI Takumi, AKAMATSU Daisuke, HOSAKA Kazumoto, and YASUDA Masami

Optical clocks such as single ion clocks and optical lattice clocks surpass primary Cs fountain clocks in frequency stability and accuracy, and are promising candidates for a redefinition of the SI second. As next-generation frequency standards, optical clocks are expected to regularly contribute to International Atomic Time (TAI). However, the robustness of optical clocks has not reached a level of Cs fountain clocks which can run nearly continuously. This is mostly due to the fact that the operation of an optical clock requires many frequency-stabilized lasers.



Yb optical lattice clock at NMIJ.

At NMIJ, we have developed an Yb optical lattice clock that can be operated nearly continuously for a long period. This clock incorporates some techniques for unattended operation including an automatic relocking scheme of the laser frequency stabilization and a remote monitoring system. During a half year period from September 2019, we demonstrated the operation of the Yb optical lattice clock with an uptime of 80.3 %, and measured the frequency of TAI against the Yb clock. Based on the measured results, the Consultative Committee for Time and Frequency (CCTF) Working Group on Primary and Secondary Frequency Standards (WGPSFS) recommended that the BIPM Time Department adopt our Yb optical lattice clock for calibrating TAI.

Featured Events

2020 APMP National Metrology Institute Directors' Workshop

SHIMIZU Yukiko

The 11th workshop was held online at 7:00-10:00 UTC, 24th November 2020, on the title of "Regional Cooperation in Response to the COVID-19 Pandemic and Beyond." This workshop focused on the following three topics that are relevant to COVID-19.

Topic 1 Metrological traceability for COVID-19 tests and related measurements
Topic 2 The strength of cooperation
Topic 3 Narrow the gap in developing economies

Dr. SHIMIZU Yukiko

The NMIJ reported on the Topic 1. The title was "Research activities at NMIJ towards improving validity and reliability of body temperature measurement: Activities of NMIJ at SARS and COVID-19 Disasters." The abstract of our report is as follows.

The ear thermometers and the thermal imagers have been frequently used to screen fever patients at airports and elsewhere. In 2003, when SARS expanded, in order to improve the validity and reliability of screening fever patients at airports and public facilities, we could timely provide our transportable standard blackbody as on-site temperature reference for calibration of ear thermometers to calibration laboratories in Singapore and Taiwan. This calibration instrument contains a blackbody cavity specially designed to match the ear thermometer and the platinum resistance thermometer is used as a reference thermometer. The highly accurate calibration can be carried out in the temperature range of 35 °C to 42 °C.

The NMIJ has recently developed a new blackbody material sheet that absorbs 99.9 % of radiation at mid-infrared region. This blackbody material sheet has a potential to be conveniently used as temperature references for on-site calibration of thermal imagers which are frequently used for fever screening in this COVID-19 pandemic.

A total of 12 speakers reported their activities on the subjects of inspection of virus, development of vaccine, personal protection wear, development and production of biomedical devices, and so on.

Each activity reported by NMIs indicates that the measurement standard technologies can steadily respond to this global crisis and make a great contribution not only domestically but also internationally as a support for pandemic countermeasures. I think these efforts have reminded industry and the local community of the value of metrological standards.

Reference Material Total Information Services in Japan (RMinfo)

"RMinfo" website now available in English

Reference Materials Office, Center for Quality Management of Metrology, NMIJ

The National Metrology Institute of Japan (NMIJ), National Institute of Advanced Industrial Science and Technology (AIST), Japan, produces and distributes Certified Reference Materials (NMIJ CRMs), and has been conducting promotional activities including lecture presentations, publications, and information dissemination. NMIJ has newly established a comprehensive information site "RMinfo" for reference material information not only on NMIJ CRMs but also on certified reference materials (CRMs) and reference materials (RMs) produced by other institutes and organizations.

RMinfo is a portal site for reference materials operated by the NMIJ, and more than 8,000 CRMs and RMs produced in Japan are registered. The CRMs and RMs are classified into eight main categories: (1) Ferrous Reference Materials; (2) Non Ferrous Reference Materials; (3) Inorganic Reference Materials; (4) Organic Reference Materials; (5) Reference Materials for Physical Properties; (6) Biological and Clinical Reference Materials; (7) Reference Materials for the Quality of Life; and (8) Reference Materials for Industry. When users choose an appropriate subcategory listed next to the main category, detailed list and information on CRMs or RMs will be displayed.

Reference material users will be able to find out an appropriate reference material for their purposes by visiting our RMinfo website at *https://unit.aist.go.jp/nmij/english/refmate/rminfo/index.html*, or by clicking the link on the NMIJ's index page at *https://unit.aist.go.jp/nmij/english/*.

We will keep updating and improving the website and hope to give a lot of information to RM users.

The 2020 OIML Award

Dr. MATSUMOTO Tsuyoshi

Dr. MATSUMOTO Tsuyoshi, Associate Manager, International Cooperation Office, Center for Quality Measurement of Metrology received the OIML (International Organization of Legal Metrology) Medal in October 2020 at the 55th CIML Meeting. Since 2002, 43 officials/experts, including Dr. MIKI Yukinobu of AIST in 2019, received this medal. During the CIML meeting, Dr. Roman Schwartz (CIML President) announced the award.

OIML provides more than 100 publications and revises them periodically. Japan submits opinions to the draft publications through the domestic mirror committee, Japan Committee for Survey Research on International Legal Metrology (JCILM), which is composed of 350 members from the organizations/manufacturers in legal metrology.

Dr. MATSUMOTO started his career as a researcher on thermophysical properties and has been involved in international legal metrology since 2003. He has played an important role in JCILM through coordinating/transferring domestic opinions to OIML. He also supported Dr. MIKI who served as Japan's CIML member and Second Vice President of CIML until 2019.

In addition, as the Secretary of OIML TC 8 (fluid measurement), he coordinated projects to revise two OIML Recommendations as new Documents, D 35 (petroleum table) and D 36 (pipe provers). In TC 6 (prepackaged products), he contributed to the revision of OIML R 87 used for inspecting the net quantity in prepackages with Dr. TANAKA Hideyuki of NMIJ. Besides publication, he supported several survey teams regarding the legal metrology systems in the OIML countries, and accommodated many foreign guests. His support contributed to building a close relationship between the OIML member states and Japan.

The APMP 2020 General Assembly and Related Meetings

From left: Dr. SHIMADA Takashi, Dr. USUDA Takashi and Dr. TAKATSUJI Toshiyuki

Dr. MORIOKA Takehiro

The 2020 APMP General Assembly and related meetings were held virtually from 2nd to 26th November. A lot of participants attended the meetings, and all the meetings and workshops were completed successfully. It was the last meeting for Dr. TAKATSUJI Toshiyuki as an Executive Committee member.

Dr. TAKATSUJI and Dr. SHIMADA Takashi, former TCFF chair, received the APMP technical activity award at the meeting. At the same time, Dr. MORIOKA Takehiro was elected one of the Executive Committee members. Also, Dr. ABE Hisashi was appointed as Chair-elect of TCT.

Internatnional Activity Data

The following numbers show international activities implemented by NMIJ from April 2020 to March 2021. Due to the coronavirus pandemic, all peer reivews during this period were conducted online.

Only a hands-on technical training was conducted for about two months at NMIJ while complying the regulations of border enforcement measures to prevent spread of COVID-19.

International comparisons (piloted by NMIJ in FY2020) - 25
Dispatched peer reviewers - 8 Invited peer reviewers - 3
Technical training - 1

Selected Research Reports

1) Y. Ota, S. Okubo, H. Inaba, N. Kuramoto, "Volume Measurement of a ^{28}Si-enriched Sphere to Realize the Kilogram Based on the Planck Constant at NMIJ", IEEE Transactions on Instrumentation and Measurement, 70, 1005506, 2021, DOI: 10.1109/TIM.2021.3061249
2) Y. Ota, M. Ueki, N. Kuramoto, "Evaluation of an automated mass comparator performance for mass calibration of sub-milligram weights", Measurement, 172, 108841, 2021, DOI:10.1016/j.measurement.2020.108841
3) Y. Takei, S. Telada, H. Yoshida, K. Arai, Y. Bitou, T. Kobata, "In-situ measurement of mirror deformation using dual Fabry–Pérot cavities for optical pressure standard", Measurement, 173, 108496, 2021, DOI:10.1016/j.measurement.2020.108496
4) Y. Kayukawa, "pρT property measurements for HFO-1123 by a single sinker magnetic levitation densimeter", International Journal of Refrigeration, 119, 349-355, 2020, DOI:10.1016/j.ijrefrig.2020.07.010
5) Y. Iwasa, Y. Su, Y. Tsuchiya, M. Tatsuda, K. Kishio, T. Yanagida, F. Takada, T. Nishio, Y. Tsujimoto, K. Fujii, M. Yashima, H. Ogino, "Synthesis, structure and luminescence properties of layered oxychloride $Ba_3Y_2O_5Cl_2$", Journal of Materials Chemistry C, 8, 48, 17162-17168, 2020, DOI: 10.1039/d0tc04415f
6) T. Kobayashi, D. Akamatsu, K. Hosaka, Y. Hisai, M. Wada, H. Inaba, T. Suzuyama, F.-L. Hong, M. Yasuda, "Demonstration of the nearly continuous operation of an ^{171}Yb optical lattice clock for half a year", Metrologia, 57, 065021, DOI:10.1088/1681-7575/ab9f1f
7) T. Misawa, S. Nakamura, Y. Okazaki, Y. Fukuyama, N. Nasaka, H. Ezure, C. Urano, N.-H. Kaneko, T. Sasagawa, "Single-surface conduction in a highly bulk-resistive topological insulator $Sn_{0.02}Bi_{1.08}Sb_{0.9}Te_2S$ using the Corbino geometry", Applied Physics Letters, 118, 033102, 2021, DOI:10.1063/5.0026730
8) Y. Kato, M. Horibe, "Broadband Conductivity Measurement Technique at Millimeter-Wave Bands Using a Balanced-Type Circular Disk Resonator", IEEE Transactions on Microwave Theory and Techniques, 69, 1, 861-873, 2021, DOI: 10.1109/TMTT.2020.3034646
9) N. Saito, T. Komatsu, T. Suematsu, T. Miyamoto, T. Ihara, "Unique Usage of a Classical Selective Homodecoupling Sequence for High-Resolution Quantitative ^{1}H NMR", Analytical Chemistry, 92, 13652-13655, 2020, DOI:10.1021/acs.analchem.0c03154
10) A. Takagaki, S. Nakamura, M. Watanabe, Y. Kim, J. T. Song, K. Jimura, K. Yamada, M. Yoshida, S. Hayashi, T. Ishihara, "Enhancement of solid base activity for porous boron nitride catalysts by controlling active structure using post treatment", Applied Catalysis A: General, 608, 117843, 2020, DOI:10.1016/j.apcata.2020.117843
11) H. Kato, A. Nakamura, "Particle density determination using resonant mass measurement method combined with asymmetrical flow field-flow fractionation method", Journal of Chromatography A, 1631, 461557, 2020, DOI: 10.1016/j.chroma.2020.461557
12) M. Ryu, J.-C. Batsale, J. Morikawa, "Quadrupole modelling of dual lock-in method for the simultaneous measurements of thermal diffusivity and thermal effusivity", International Journal of Heat and Mass Transfer, 162, 120337, 2020, DOI:10.1016/j.ijheatmasstransfer.2020.120337
13) J. Ye, N. Toyama, "Benchmarking Deep Learning Models for Automatic Ultrasonic Imaging Inspection", IEEE Access, 9, 36986-36994, 2021, DOI:10.1109/ACCESS.2021.3062860
14) D. Asakawa, H. Takahashi, S. Iwamoto, K. Tanaka, "Gas-Phase Peptide Fragmentation Induced by Hydrogen Attachment, from Principle to Sequencing of Amide Nitrogen-Methylated Peptides", Analytical Chemistry, 92, 15773–15780, 2020, DOI:10.1021/acs.analchem.0c02766
15) P. Xia, S. Ri, T. Inoue, Y. Awatsuji, O. Matoba, "Dynamic phase measurement of a transparent object by parallel phase-shifting digital holography with dual polarization imaging cameras", Optics and Lasers in Engineering, 141, 106583, 2021, DOI: 10.1016/j.optlaseng.2021.106583
16) N. Sei, T. Sakai, Y. Hayakawa, Y. Sumitomo, K. Nogami, T. Tanaka, K. Hayakawa, "Observation of terahertz coherent edge radiation amplified by infrared free-electron laser oscillations", Scientific Reports, 11, 3433, 2021, DOI: 10.1038/s41598-021-82898-7

Edited and issued by NMIJ International Cooperation Office (NMIJ ICO),
National Metrology Institute of Japan (NMIJ),
National Institute of Advanced Industrial Science and Technology (AIST)

For more information, please contact : *info_imco-ml@aist.go.jp*