

Three times a year, PTB News provides topical information from the varied spectrum of activities of the Physikalisch-Technische Bundesanstalt (PTB) consisting of fundamental research, legal metrology and PTB's various activities in the service of the economy.

**SCIENTIFIC NEWS**

**Angle measurement under pressure**

Air pressure – an underestimated factor in angle measurement carried out by means of autocollimators **2**

**EUV lithography goes live**

Metrology with synchrotron radiation for the semiconductor industry **3**

**LEDs bring the sunlight into our lab**

Measuring the power of solar modules **3**

**Precise characterization of nano-magnets**

Characterizing magnetic nanostructures on the macro-and nanoscale **5**

**How high is the radiation dose for a person during a CT examination?**

A mobile device for characterizing the CT X-ray beam. **5**

**New exhaust gas laboratory building completed in record time**

Type examination of motor vehicle exhaust meters **6**

**TECHNOLOGY TRANSFER**

Piconewton transfer standard, Multi-layer ion traps, Microparticles characterized optically **7**

**MISCELLANEOUS**

New SI, Silicon sphere from PTB, German-Japanese cooperation, First Smart Meters approved, First electric vehicle charging station tested, "Nano-Met" **8**

# Symmetry of space-time tested by means of atomic clocks

The comparison of two atomic clocks has confirmed their excellent accuracy as well as a fundamental hypothesis of the theory of relativity.

**Especially interesting for**

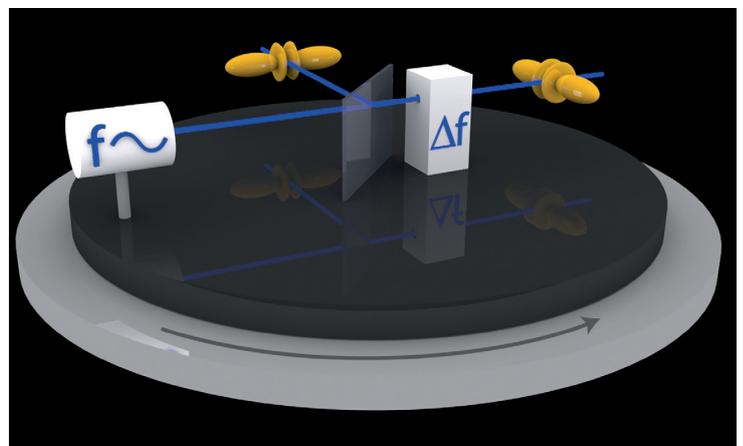
- fundamental research in physics
- developers of optical atomic clocks

The first long-term comparison of two optical ytterbium clocks has provided reliable results concerning their accuracy and stability at the limit of what has been measurable to date. At the same time, the Lorentz symmetry was confirmed for electrons in even tighter experimental limits.

One of the basic assumptions of Einstein's theory of relativity states that the speed of light is the same in all directions of space. This assumption was demonstrated by Michelson and Morley as early as 1887 by means of a pivot-mounted interferometer comparing the speed of light along two perpendicular optical axes. Now one could ask: Does this symmetry of space (which was named after Hendrik Antoon Lorentz) also apply to the motion of material particles? Or are there any directions along which these particles move faster or more slowly although the energy remains

the same? Especially for high energies of the particles, theoretical models of quantum gravitation predict a violation of the Lorentz symmetry.

An experiment has now been carried out with two atomic clocks in order to investigate this question with high accuracy. The frequencies of these atomic clocks are each controlled by the resonance frequency of a single Yb<sup>+</sup> ion that is stored in a trap. While the electrons of the Yb<sup>+</sup> ions have a spherically symmetric distribution in the ground state, in the excited state they exhibit a distinctly elongated wave function and therefore move mainly along one spatial direction. The orientation of the wave function is determined by a magnetic field applied inside the clock. The field orientation was chosen to be approximately at right angles in the two clocks. The clocks are firmly mounted in a laboratory and rotate together



A tunable laser excites an extremely narrow-band resonance in an Yb<sup>+</sup> ion of an atomic clock. Two ions with wave functions (yellow) that are oriented at right angles are interrogated by means of laser light with an adjustable frequency shift  $\Delta f$  to measure a possible frequency difference. The whole experimental setup rotates together with the Earth once a day relative to the fixed stars.

with the Earth once a day (or to be more precise: once in 23.9345 hours) relative to the fixed stars. If the electrons' speed depended on the orientation in space, this would thus result in a frequency difference between the two atomic clocks that would occur periodically, together with the Earth's rotation. To be able to differentiate such an effect clearly from any possible technical influences, the frequencies of the Yb<sup>+</sup> clocks were compared for more than 1000 hours. During the experiment, no change between the two clocks was observed for the accessible range of period durations from a few minutes up to 80 hours. For the theoretical interpretation and calculations con-

cerning the atomic structure of the Yb<sup>+</sup> ion, PTB's team worked in collaboration with theoretical physicists from the University of Delaware (USA). The recently obtained results have improved those obtained in 2015 by researchers from the University of California, Berkeley with Ca<sup>+</sup> ions drastically by a factor of 100.

Averaged over the total measuring time, the two clocks exhibited a relative frequency deviation of less than  $3 \cdot 10^{-18}$ . This confirms the systematic uncertainty of the clocks that had previously been estimated to be  $4 \cdot 10^{-18}$ . Furthermore, it is an important step in the characterization of optical atomic clocks at this level of accuracy. Only after roughly ten billion

years will these clocks potentially deviate from each other by one second. ■

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**Scientific publication**

C. Sanner, N. Huntemann, R. Lange, C. Tamm, E. Peik, M. S. Safronova, S. G. Porsev: *Optical-clock comparison for Lorentz symmetry testing. Nature* 567, 204-208 (2019)

# Angle measurement under pressure

## Air pressure – an underestimated factor in angle measurement carried out by means of autocollimators

**Especially interesting for**

- high-precision mechanical engineering
- the optical industry
- users of synchrotron radiation and free-electron laser radiation

High-precision angle measurements carried out by means of autocollimators are significantly influenced by the refractive index of air – and thus in particular by the ambient pressure. When comparing measurements that have been carried out at different locations, it is therefore necessary to take changes in pressure into account. PTB has developed suitable strategies both to correct the measurement results and to assess the measurement uncertainty.

Autocollimators allow the contact-free measurement of the inclination angle of reflecting surfaces. These devices are used for various applications in industry and research, in particular to measure the straightness and levelness of mechanical and optical components, for example for ultra-precise form measurements on X-ray mirrors for synchrotron radiation and free-electron laser radiation.

The measurement principle of autocollimators is as follows: the objective of the autocollimator converts the angle of the measuring beam which is reflected by

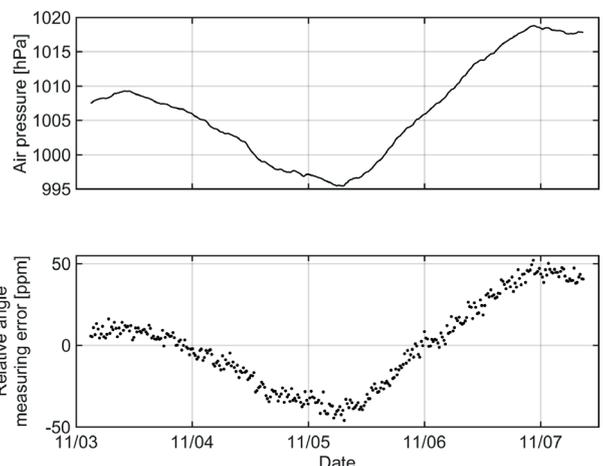
the surface into the spatial displacement of a measuring mark that is imaged onto the detector. The objective thus acts as a kind of optical lever that transforms small angles into measurable displacements. The leverage effect depends on the focal length of the objective, which, in turn, is influenced by the refractive index of air.

As recent investigations have shown, the influence which changes in the refractive index of air have on angle measurements that are carried out by means of autocollimators must not be neglected. These changes are due to changes in the environmental conditions (air pressure and humidity, temperature). Here, it is particularly important to emphasize the importance of air pressure, which is not only subject to variations due to the weather, but which also depends on altitude. In contrast to this, temperature and humidity are precisely controlled in air-conditioned laboratories, so that they remain practically constant. The error in the angle measurement of the autocollimator increases proportionally to the angle and to the ambient pressure. In addition, it is also scaled along with the distance (i.e. the air clearance) between the au-

tocollimator and the reflecting surface in relation to the focal length of the objective.

Environmental data, which were collected over a decade in PTB's Clean Room Center, have exhibited an ambient pressure range of 84 hPa, and thus a relative change in pressure of more than 8 % compared to the standard pressure. An international comparison was carried out with laboratories located at heights ranging from 2 m to 712 m above sea level. This comparison revealed pressure differences of up to 89 hPa. The resulting relative angle measurement errors were each on the order of up to  $10^{-4}$ .

As shown by these figures, both quantities that have an influence on the ambient



Simultaneous changes in the air pressure (top) and in the relative angle measurement error of the autocollimator (bottom; ppm: parts per million) as a function of time.

pressure (the meteorological conditions and the geographical elevation) must be taken into account when comparing angle measurements carried out by means of autocollimators at different locations and at different times in order to avoid substantial angle measurement errors. ■

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#### Scientific publication

R. D. Geckeler, P. Křen, A. Just, M. Schumann, M. Krause: Influence of the air's refractive index on precision angle metrology with autocollimators. *Meas. Sci. Technol.* 29, 075002 (2018)

# EUV lithography goes live

## Metrology with synchrotron radiation for the semiconductor industry

#### Especially interesting for

- the semiconductor industry
- EUV lithography
- optical industry

The announcement made by the large semiconductor manufacturers Samsung and TSMC in fall 2018 that they would start using EUV lithography (EUVL) to manufacture high-end processors marks the commercial breakthrough of this technology after a long research phase. For as many as 20 years, PTB has been supporting the development of projection lenses for EUVL by means of at-wavelength metrology with synchrotron radiation. For PTB's metrology research, these developments not only mean new challenges, but also prospects in the future.

The measurements performed at PTB at the working wavelength of 13.5 nm in the extreme ultraviolet (EUV) spectral range are carried out at the synchrotron radiation sources BESSY II and the MLS in Berlin-Adlershof, mainly within the scope of cooperation projects with partners from research and industry. Among these partners are, in addition to numerous research institutes as well as SMEs, in particular Carl Zeiss SMT GmbH and

the Dutch company ASML, which uses Carl Zeiss lens systems and currently holds a unique position in the field of EUVL devices.

In the next few years, the constant pressure for improvement in the semiconductor industry aiming for linewidths of 3 nm and less will lead to new challenges. These challenges will concern the further development not only of EUVL devices and the associated projection lenses, but also of new measurement procedures in order to characterize the semiconductor nanostructures. In this context, synchrotron radiation also offers excellent measurement possibilities, for example by (spatially resolved) reflectometry, fluorescence spectroscopy or diverse light scattering approaches in the spectral range from the EUV to X-rays. These methods have already been intensively developed and applied within the scope of scientific projects carried out over recent years at BESSY II and the MLS.

Based on measuring times of currently more than 6000 hours per year at two EUV beamlines at BESSY II and at the MLS, current and future developments in the field of EUVL promise excellent prospects for metrology with synchrotron radiation – particularly with respect to the envisioned synchrotron radiation source, BESSY III in Berlin-Adlershof.

Such a project requires a lead time of approx. 10 years. After 20 years' operation of BESSY II, the time has come to plan BESSY III. Metrology for EUVL will be a key aspect in this undertaking. ■



Collector mirror for an EUVL plasma source, mounted on the sample goniometer inside PTB's EUV reflectometer (photo: Fraunhofer IOF, CYMER)

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#### Scientific publication

F. Scholze, A. Fischer, C. Tagbo, C. Buchholz, V. Soltwisch, C. Laubis: Spatially resolved reflectometry for EUV optical components. *Proc. SPIE*, 108091U-1 (2018)

# LEDs bring the sunlight into our lab

## Measuring the power of solar modules by means of an LED-based solar simulator

#### Especially interesting for

- photovoltaics
- meteorology

PTB has recently started using an LED-based solar simulator that is capable

of varying the spectral composition, the brightness and the duration of the simulated solar irradiance independently of each other. The instrument thus provides decisive advantages over its conventional xenon counterparts. At PTB, solar modules can now be exam-

ined with a broad array of tests that are closer to real operating conditions.

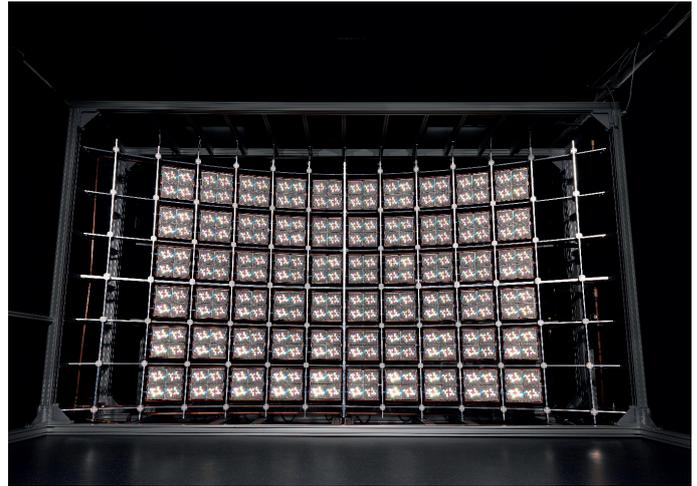
Solar modules are the main components of any photovoltaic facility. When planning a new solar facility, many different solar module variants are available.

Depending on the fabrication process, their price and the output to be expected vary. Conditions that are close to real operating conditions and low uncertainties in the power determination of solar modules support manufacturers and planners in selecting the best-suited module type for the location of a given facility. This provides better planning security.

In the field of photovoltaics, PTB currently provides calibration services mainly for reference solar cells with dimensions of  $(2 \times 2)$  cm<sup>2</sup>. It is planned to extend the range of services to measurements carried out on solar modules of up to  $(2 \times 1)$  m<sup>2</sup> in size. The LED-based solar simulator is a key element in this strategy. It bundles 16 320 high-power LEDs into one highly efficient light unit that can irradiate the desired surface with light that matches the brightness and spectral composition of midday sunlight. The simulator consists of 18 differently colored and individually adjustable types of LEDs with emission spectra ranging from 370 nm (UV) up to 1100 nm (NIR) that can be individually adjusted. If different LED colors are

combined, it is possible to simulate not only the usual PV standard spectrum, but also many irradiance conditions experienced by solar modules when exposed to real outdoor operating conditions.

This allows PTB to develop measurement sequences that lead to a more realistic evaluation of the module's energy output. Both the cloudiness and the sun elevation have a considerable influence on the solar radiation that reaches a solar module. This variation can be simulated by means of the new solar simulator. The measurements thus allow the yield of new PV facilities to be forecast more accurately. ■



Over its surface of 2.40 m × 4.70 m, the LED-based solar simulator is equipped with a total of 16 320 LEDs. On the measurement plane, the colored light of the LEDs mixes to yield a spectrum similar to that of the sun.

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# Precise characterization of nanomagnets

Characterizing magnetic nanostructures on the macroscale as well as on the nanoscale

**Especially interesting for**

- manufacturers of magnetic sensors and encoders
- biomedical applications

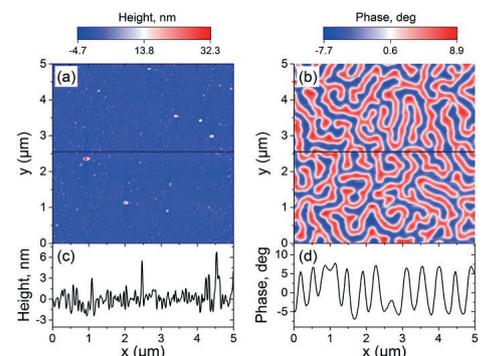
A microscope for the imaging of magnetic nanostructures has been developed at PTB. This microscope allows the magnetic field distributions to be determined quantitatively for the first time with nanometer resolution over sample areas of up to a few centimeters.

Magnetic components such as hard drives or magnetic memory chips are becoming increasingly small and have already reached the size of just a few nanometers today. Only with such small-scale structures is it possible to realize ever greater magnetic storage capacities. Other application areas such as magnetic sensors require ever smaller components, for example for the detection of individual magnetic nanoparticles in biomedicine. Currently, also important industrial ap-

plications – such as position-measuring magnetic encoders – require precise measurements of the magnetic properties of the encoder structures over a large range of up to a few centimeters. Until today, however, no suitable measurement technology has been available for characterizing nanomagnetic materials over such a large range.

A microscope developed at PTB combines for the first time the highest possible resolution and a large imaging range for measuring magnetic materials. The expertise required for this development came from two distinct departments of PTB. The *Precision Engineering* Department offers the necessary experience for the accurate characterizations of surface geometries. The microscope is based on an ultra-precision positioning stage referred to as a “nano-measuring machine”, which has been applied so far for the dimensional characterization of surfaces with nanometer resolution over measuring ranges of up to 2.5 cm × 2.5 cm.

This device was extended by measuring modes where a nanoscale magnetic measuring tip was used for the imaging of the magnetic field distribution. Its measurement principle is based on detecting the force which the magnetic field exerts on the magnetic sample and



Measurement results of a nanomagnetic thin film carried out with the quantitative magnetic force microscope recently developed by PTB. a) The height profile of the thin-film surface is very smooth and only shows infinitesimal height differences in the range of a few nanometers. b): In contrast, the measuring signal exhibits meandering magnetic domains of approx. 200 nm in width.

is therefore called quantitative magnetic force microscopy (qMFM). Such measurement procedures are used routinely in PTB's *Electricity* Division for the spatially resolved imaging of magnetic fields. Via adequate calibration routines, it is possible to quantitatively determine the magnetic field strength.

Operating the nano-measuring machine in the qMFM mode, it has been possible for the first time to characterize both the surface texture of magnetic materials and the magnetic field emitted by the surface with nanometer resolution over a measuring range of up to a few centimeters. The measuring system, which

is characterized by a particularly large measuring range, will be available for the characterization of the most diverse

nanomagnetic materials and system components used in fundamental research and in various fields of application. ■

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#### Scientific publication

*G. Dai, X. Hu, S. Sievers, A. F. Scarioni, V. Neu, J. Flügge, H. W. Schumacher: Metrological large range magnetic force microscopy. Rev. Sci. Instrum. 89, 093703 (2018)*

## How high is the radiation dose for a person during a CT examination?

A mobile device for characterizing the CT X-ray beam creates the prerequisite for determining the individual patient dose immediately after the scan

#### Especially interesting for

- radiologists as well as departments of radiology in hospitals
- medical physics experts (MPEs)
- surveillance authorities

Depending on the type of examination performed, the radiation burden incurred by patients due to CT imaging can be considerable. PTB has developed a mobile measuring device aimed at indicating the individual effective dose of a patient on a CT display within just a few minutes after a scan. Within approximately two minutes, this device is able to determine the characteristics of the CT X-ray beam that are needed for dose calculations at hospitals.

Over the past decades, CT imaging has experienced tremendous development. Today, it is an important instrument in modern diagnostics and numerous procedures exist to calculate the effective dose incurred by a patient. However, all of these procedures are based on phantom-related measurands from which the effective dose is estimated by means of calculated conversion factors for standard patients and for a reference scanner. Moreover, these procedures do not take

any patient-specific particularities (such as their size or their weight) into account.

Within the scope of a European cooperation project, PTB has now developed the dosimetric basis for a procedure in which a patient's individual data are to be used in the calculation for the first time. Together with the characteristics of the CT scanner used, the CT sectional views of the patient are entered into a Monte Carlo simulation. Using commercially available software, it is thus possible to generate a simulation of the dose distribution within just a few minutes. For this purpose, however, some important characteristics of the CT scanner used must first be determined experimentally. Among these characteristics are the characteristic fluence spectrum of the photons of the X-ray tube used and the attenuation properties of the integrated bow-tie filters. The latter serve to adapt the radiation intensity to the patient's section in order to reduce the dose and to achieve a more homogeneous noise distribution at the image detector.

The novel mobile measuring device determines these parameters, and within the scope of

the project it has been possible to constantly reduce the necessary installation effort and the measurement duration. The procedure has been combined with known techniques used to determine the equivalent bow-tie filter, so that only one single measuring arrangement and just a few minutes are needed to obtain all the data that are required for the full characterization of the computed tomography system.

To validate this procedure, CT images of anthropomorphic phantoms were taken. These phantoms were fitted inside



The mobile measuring device for the non-invasive determination of the X-ray spectra and for the characterization of the bow-tie filters of a computed tomography system. In contrast to other comparable measurement methods, it is not necessary for the CT system to be in service mode. The measurements can be performed on the CT system in just a few minutes using the existing clinical scan protocols.

with real-time dose detectors. The calculated and the measured doses were in agreement within the measurement uncertainties of less than 10 %. Thus, this new procedure has been validated, and an important step toward personalized dosimetry in computed tomography has been achieved. ■

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#### Scientific publication

S. Rosendahl, L. Büermann, M. Borowski,  
M. Kortensniemi, V.-M. Sundell, A. Kosunen  
and T. Siiskonen: CT beam dosimetric  
characterization procedure for person-  
alized dosimetry. *Phys. Med. Biol.* 64,  
075009 (17 pp.) (2019)

# New exhaust gas laboratory building completed in record time

## A new laboratory building for the type examination of motor vehicle exhaust meters

#### Especially interesting for

- exhaust gas measuring techniques
- motor vehicle workshops, test centers for vehicle inspections and emissions tests
- type examinations, local verification offices

The regular inspection of motor vehicle emissions became more stringent in several ways at the end of 2017. This required exhaustive research activities, and numerous type examination certificates for exhaust meters had to be issued or renewed promptly. For this purpose, a new building was planned, erected and commissioned within just one year in order to accommodate a new certification laboratory. This building contains state-of-the-art laboratories for opacimeters and CO meters as well as a laboratory for the calibration of particle counters.

German car owners have to prove their car's compliance with the legal emission limits every two years within the scope of the emissions test ("AU"), which is part of the general inspection ("HU", which the Germans colloquially also call the "TÜV"). This applies both to gasoline engines (which must comply with a maximum emission value for carbon monoxide), and to diesel engines (whose emissions of soot particles are subject to a threshold value). The latter are tested by checking the opacity of the exhaust gas, i.e. the extent to which soot attenuates light irradiated through the exhaust gas is measured.

Exhaust meters are subject to the Measures and Verification Act. For each

design, PTB tests a representative type model to see whether it fulfils the strict legal requirements; then a type-examination certificate is issued.

The emissions test process and the emission limits that must be complied with are laid down in the so-called Emissions Test Directive, which the German Federal Ministry of Transport and Digital Infrastructure (BMVI) considerably tightened in September 2017 by adding three new elements:

- 1) As of 1 January 2018, the so-called tailpipe test was introduced again without any exceptions.
- 2) As of 1 January 2019, the limit values for exhaust gas opacity and CO were halved for all EURO 6 vehicles.
- 3) As of 1 January 2021, a new particle number emission limit will be introduced for EURO 6 vehicles.

This tightening of the rules requires exhaustive and time-sensitive research and service activities. Point 3 on the list re-

quires a particle count traceability chain to be set up; point 2 has made an improvement to the traceability of opacimeters, exhaust meters and CO measuring instruments necessary, while the third point necessitated type examinations for

a large number of devices. Implementing all these requirements has demanded the immediate modernization as well as increased capacities of testing laboratories for CO measuring instruments and opacimeters. Therefore, a new 360 m<sup>2</sup> laboratory building was planned and commissioned for 4.4 million euros. It consists of two state-of-the-art laboratories where opacimeters and exhaust meters can be tested, as well as a novel calibration laboratory for particle counters. These laboratories allow up to 35 test gases (some of them highly toxic) to be fed sequentially – and mostly automatically – into the measuring instrument under test with great accuracy, and special, metrologically defined test aerosols to be generated. Process automation in particular is promising, since it allows significant acceleration of the test procedures, as well as improvements in terms of measurement quality and occupational safety. ■



The new building accommodates, among other things, testing laboratories for exhaust meters that are state of the art and a calibration laboratory for particle counters.

quires a particle count traceability chain to be set up; point 2 has made an improvement to the traceability of opacimeters, exhaust meters and CO measuring instruments necessary, while the third point necessitated type examinations for

#### Contact

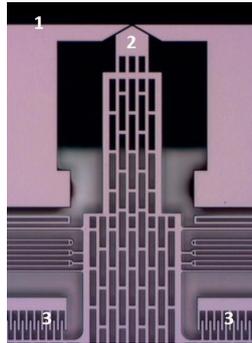
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# Piconewton transfer standard

## Especially interesting for

- manufacturers of scanning force microscopes
- medical engineering
- materials research

Scanning force microscopes are used not only to measure nanostructures and fine roughness, but also as force sensors in pharmacy and in materials research. To measure force precisely, it is important to determine the bending stiffness of the cantilever with great accuracy. Until re-



Piconewton transfer standard with the reference surface (1) and the contact body (2) that is moved by means of a comb drive (3).

cently, suitable measurement procedures did not exist. PTB's new transfer standard calibrates the smallest of forces for use

in force spectroscopy. It consists of a reference surface with a defined gap under which a MEMS force sensor with a flat contact surface is located. (Technology Offer 459) ■

## Advantages

- dynamic on-site cantilever force measurement
- fully passive calibration also possible
- can be integrated into commercially available scanning force microscopes

# Multilayer ion traps

## Especially interesting for

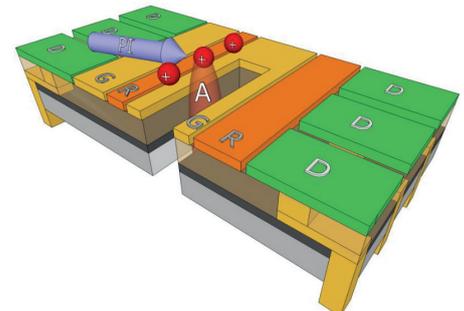
- quantum information processing
- the semiconductor industry

Microstructured ion traps are the technological basis for a future quantum computer based on single ions as qubits. In such ion traps, ions are trapped by means of inhomogeneous electric fields above the surface. Several procedures developed by PTB for manufacturing multilayer thick-film structures with interconnects fulfill the stringent requirements set by the application. These procedures allow the production of a wide range of microstructures with the most diverse shapes

and functions for different scopes of application. The process is also perfectly suited for producing atom traps for neutral atoms to be used in quantum sensors and for the investigation of Bose-Einstein condensates. (Technology Offer 460) ■

## Advantages

- scalable setup for versatile applications
- suitable for both atoms or molecules, charged or neutral
- suitable for UHV
- temperature range from 4 K to more than 520 K
- multilayer structure for interconnects



Multilayer ion traps with thick-film dielectric medium (gray area). On the surface, the ions are kept in the inhomogeneous electric field of the trap structure.

# Microparticles characterized optically

## Especially interesting for

- medical laboratories
- manufacturers in the field of environmental analysis
- manufacturers and operators of bioreactors

Until recently, size distributions and the wavelength-dependent refractive index of microparticles could only be determined with great effort. PTB has now developed a new procedure that simplifies such mea-

surements. The spectral extinction cross section is derived from the transmission spectrum of particles in suspensions, emulsions or aerosols and is then analyzed by means of a mathematical procedure. Based on a single transmission measurement carried out on solid or liquid microparticles, the new procedure allows the simultaneous determination of the size distribution, the concentration and the spectral refractive index of the particles. It allows the chemical composition to be analyzed. (Technology Offer 474) ■

## Advantages

- simultaneous determination of size distribution, spectral refractive index and concentration of microparticles
- short measuring and analyzing times allow real-time measurement and process control
- determination of complex refractive indices with high accuracy

## Contact person for questions about technology transfer

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## New SI into force

On 20 May 2019, World Metrology Day, the revised International System of Units (SI) entered into force. On 16 November 2018, the revision was adopted unanimously by the representatives of all member states of the Metre Convention at the 26<sup>th</sup> General Conference on Weights and Measures (CGPM) held in Versailles. Since 20 May 2019, all SI units are based on a set of 7 defining natural constants. Thus, the differentiation between base units and derived units de facto no longer applies. In everyday life and for any standard consumer, nothing has changed. The change is, however, relevant to precision metrology as well as to teachers who will no longer be able to tell their students the relatively simple story of the international prototype of the kilogram but will have to elucidate the far more complex universe of natural constants.

## Taiwan purchases silicon sphere from PTB



Taiwan has had its own silicon sphere since 24 November 2018. After the revision of the International System of Units (SI), it is possible to use this sphere to realize the unit of mass. The sphere – or to be more precise: the isotope-enriched 1 kg <sup>28</sup>Si mass standard – was handed over to the Industrial Technology Research Institute of Taiwan (ITRI) by PTB President Prof. Joachim Ullrich and by the Head of the competent Division, Frank Härtig. However, the Taiwanese scientists were provided not only with the silicon sphere itself, but also with the know-how that is necessary to measure the surface layer.

## German-Japanese cooperation for highest precision

A new research initiative, the MGP/PTB/RIKEN Center, is pooling the expertise of groups of the world's leading scientists in the fields of atomic and nuclear physics, antimat-

ter research, quantum optics and metrology. Together, the scientists are endeavoring to find answers to fundamental questions of physics – such as whether natural constants really are constant. This group consists of the Max Planck Institute for Nuclear Physics (Max-Planck-Institut für Kernphysik – MPIK), the Max Planck Institute of Quantum Optics (Max-Planck-Institut für Quantenphysik – MPQ), PTB with two of its departments as well as the QUEST Institute, and RIKEN from Japan with two groups of researchers.

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## First Smart Meter Gateways legally approved

For the first time, three Smart Meter Gateways have obtained a type-examination certificate from PTB. The Smart Meter Gateway is a key technology for digitalization in the context of the energy transition. Together with a modern power meter, it forms a smart measuring system that will soon be playing a central role in the energy-supply industry. Complying with the most stringent data security and data protection requirements, gateways allow the data provided by the energy meter to be processed locally and, what is even more important, the processed measured values to be forwarded on to consumers, grid operators, energy utilities and service providers via public communications networks. In this context, aspects related to legal metrology have to be taken into account. Therefore, PTB has accompanied this process since the beginning and has, in particular, supported the activities of the BMWi (the German Federal Ministry of Economic Affairs and Energy), the regional verification authorities, the BSI (the German Federal Office for Information Security), the BNetzA (the German Federal Network Agency) and industry. (Contact: Helmut Többen, 0531 592-1400, helmut.toebben@ptb.de)

## First electric vehicle charging stations tested at PTB

In 2018, PTB issued the first type-examination certificate for electric vehicle charging stations. This confirms that the stations meet all of the requirements of the measuring and verification legislation of Germany and not only guarantee exact measurements, but also a charging process that is transparent and comprehensible to the customers. This

system also states explicitly when, where and how much energy was charged; the subsequent bill is based on these data. PTB, as the currently only conformity assessment body for the field of electromobility, has developed an assessment procedure for charging stations and is actively assisting the German Federal Government's national development plan for electromobility in its work.

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## Research Training Group “Nano-Met” continued

The NanoMet Research Training Group, which has been managed jointly by TU Braunschweig and PTB since 2014, will be funded for another four and a half years by the Deutsche Forschungsgemeinschaft (DFG). Within the scope of this Research Training Group, doctoral theses on three topics from the field of nanometrology (“Complex Systems”, “Quantum Systems” and “Biological Systems”) have been mentored. The curriculum as well as any additional modules – such as summer schools or visits to institutes and companies – are coordinated with the “Braunschweig International Graduate School of Metrology”. This school has been jointly operated by TU Braunschweig and PTB since 2007. In 2018, it was extended for five more years.

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### Imprint

PTB News 2/2019, English edition, Issue August 2019, ISSN 1611-163X  
The PTB News is published three times each year in a German as well as in an English edition and can be subscribed to free of charge.  
Subscription form: [www.ptb.de](http://www.ptb.de) > English Version > Publications > PTB News > Subscribe the PTB News

Publisher: Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin  
Editors: Andreas Barthel, Ludger Koenders, Christoph Kolbitsch, Christian Lisdat, Mathias Richter, Hansjörg Scherer, Erika Schow, Jens Simon (responsible)  
Layout: Volker Großmann, Alberto Parra del Riego (concept)  
Translation: PTB Translation Office (Cécile Charvieux)  
Editorial Office: Press and Information Office, PTB, Bundesallee 100, D-38116 Braunschweig, phone +49 531 592-3006, fax +49 531 592-3008, e-mail: [ptbnews@ptb.de](mailto:ptbnews@ptb.de)



The Physikalisch-Technische Bundesanstalt, Germany's national metrology institute, is a scientific and technical higher federal authority falling within the competence of the Federal Ministry for Economic Affairs and Energy.