PTB news
Scientific Newsletter
3
2019

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



## TECHNOLOGY TRANSFER



## MISCELLANEOUS



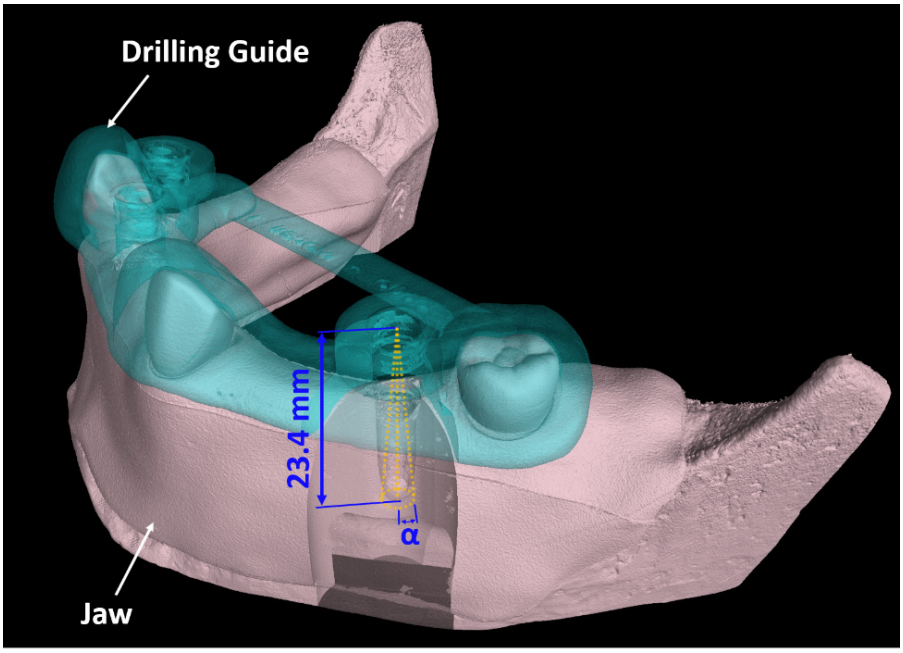
# Are implants made with a 3D printer good enough?

## Quality control of additively manufactured medical products using computed tomography

**Especially interesting for**
- additive manufacturing
- implantology in medicine and dentistry
- coordinate metrology

**Medicine is placing high expectations on implants and auxiliary materials that are manufactured specifically for each individual patient. This can be done by means of additive manufacturing (3D printing), which allows nearly any complex shape to be produced. Before starting to use such implants widely, the medical sector and certification bodies demand proof of the fact that their high quality is matched and will remain stable over time. Within the scope of a European project, MetAMMI, PTB has provided the basis for the quality control of medical implants and auxiliary materials produced by additive manufacturing.**

To find out how reliable medical implants and auxiliary materials from a 3D printer really are, numerous specimens (implants, medical guides and regular-geometry objects) were produced within the scope of the project. In this context, various materials and techniques of additive manufacturing were used. The examination focused, in particular, on those characteristics that may be relevant for the function of a given implant such as its shape, surface, density and mechanical properties. To this end, different measurement methods were used (use of Archimedes principle, coordinate metrology, computed tomography with X-rays and THz radiation). It turned out that the quality of an implant depends, in particular, on




Trial of a dental drilling guide produced by additive manufacturing for the drilling of holes to fit dental implants into artificial jaw models with only few abutment teeth. The drilling angle α and the drilling depth were measured by means of computed tomography

the material and on the manufacturing technique used.

Practical cases from everyday work in hospitals were also investigated within the scope of the project. One of these investigations dealt with drilling when inserting dental implants. In such surgical interventions, it is important to prevent adjacent dental roots or nervous tissue located in the lower part of the jaw from being damaged. The drilling angle and the drilling depth must therefore be checked very accurately. In order to ensure stable and accurate drilling, dental drilling guides are used.

In cooperation with a dental surgery, medical physicists and dental technicians, several dental drilling guides produced by additive manufacturing were used to drill holes for implants into lifelike artificial jaw models. Subsequently, the drilling depth and the drilling angle were determined by means of industrial computed tomography. The results have shown that the drilling depth differed by less than 2 mm, and the drilling angles by less than 6°. If the deviations are kept that small, no physical damage to the patient is to be expected. ■

**Contact**
*Fabricio Borges de Oliveira*
*Department 5.3*
*Coordinate Metrology*
*Telefon: +49 531 592-5258*
*fabricio.borges@ptb.de*

# Virtual mammogram

## Simulating realistic phantom images for mammography

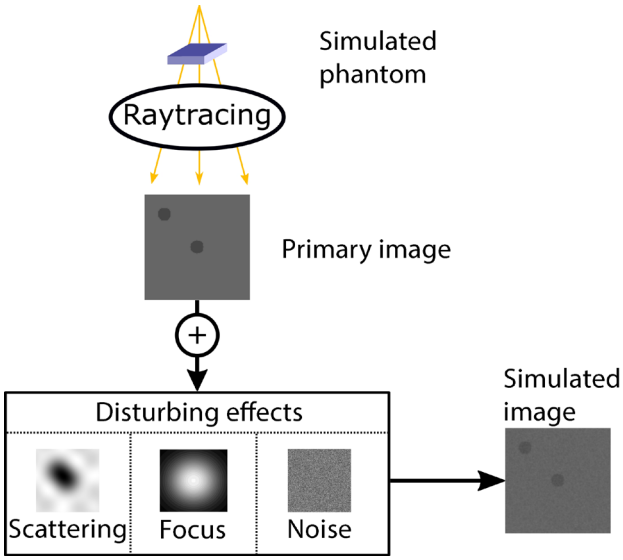
**Especially interesting for**
- medical physics experts (MPEs)
- the competent surveillance authorities
- equipment manufacturers

**Within the scope of the mammography screening program, approved devices must ensure that radiologists are able to reliably detect even small contrasts. The imaging quality of each device is therefore checked every year by means of monitoring measurements. For this purpose, test images of phantoms are taken and assessed by means of procedures of data analysis. PTB has developed a simulation software program that is able to simulate such images realistically. The procedures of data analysis used can thus be checked and optimized as to their fitness for purpose.**

Breast screening relies on X-rays to search for abnormalities in breast tissue in a non-invasive way. The following rule fundamentally applies: the stronger the radiation intensity, the more reliable the diagnosis. However, this also increases the risk of radiation detriment. The settings are optimal when the dose is as low as possible while the image quality remains sufficient. To ensure sufficient imaging quality for the physician to make a diagnosis, devices must be able to represent small structures with low contrast well enough. Within the scope of quality assurance, annual checks are carried out by generating images of a technical phantom that consists of small gold plates of different thicknesses and sizes. The phantom images taken are either assessed by a physician or automatically evaluated by means of procedures of data analysis that simulate human vision.

PTB has developed a simulation software program that simulates the technical phantom and generates realistic phantom images of the gold plates. This virtual mammogram provides images with properties that are exactly known. It therefore allows the analytical procedures used for quality assurance to be validated and optimized. This simulation tool is based on a mathematical model with which a primary image is computed from the transmission of simulated X-rays. Disturbing effects such as scattering or noise are then added. By comparing the generated images with real images, it has been shown that the simulation tool provides realistic mammograms.

This software program has already been used to successfully validate a new assessment procedure that was developed and improved at PTB. In the future, virtual mammograms are to be used in particular to provide a solid basis for the use of machine-learning methods in quality assurance for mammography. ■



Schematic setup of virtual mammography

**Contact**
*Tobias Kretz*
*Departments 8.4, Mathematical Modelling and Data Analysis, and 6.2, Dosimetry for Radiation Therapy and Diagnostic Radiology*
*Phone: +49 30 3481-7978*
*tobias.kretz@ptb.de*

**Scientific publication**
*T. Kretz, M. Anton, T. Schaeffter, C. Elster: Determination of contrast-detail curves in mammography image quality assessment by a parametric model observer, Physica Medica 62, 120–128 (2019)*

# Traceable geodesic data

## Reference radiation source for remote sensing of the Earth calibrated

**Especially interesting for**
- geophysics, geobiology, geochemistry
- remote sensing of the Earth
- climate research

**At PTB, the reference radiation source of the EnMAP satellite for the remote sensing of the Earth has been calibrated with high resolution. This ensures the long-term comparability and traceability of its global measurement data from the fields of geobiology, geochemistry and geophysics.**

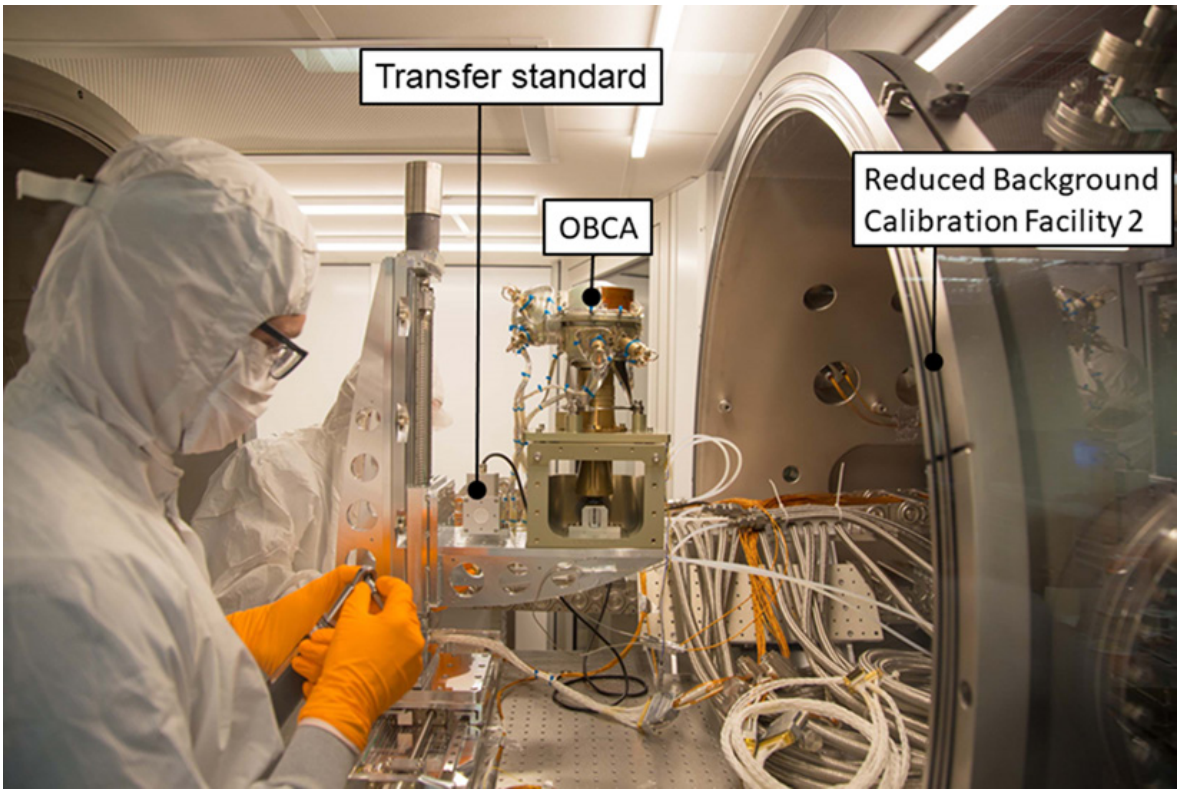
The Environmental Mapping and Analysis Program (EnMAP) is a German satellite mission for the global remote sensing of the Earth. For this purpose, a hyperspectral camera collects spatially and spectrally highly resolved data in the wavelength range from 400 nm to 2500 nm which are used to measure environmental data. They provide accurate information about parameters such as land cover, biodiversity, water quality and raw materials, which allow statements about the consequences of climate change or local environmental disasters.

For the radiometric and spectral traceability of the spectral data measured by means of the Hyper Spectral Imager (HSI), a combination of a solar reflector and an additional reference radiation source is used on board the satellite. This reference radiation source, the On-Board Calibration Assembly (OBCA), is to ensure in particular the radiometric and spectral stability of the Hyperspectral Imager during the course of the mission.

In cooperation with the manufacturer of this device, OHB System AG (Bremen und Oberpfaffenhofen), the radiance of the reference radiation source was determined with spectral and spatial resolution at PTB. In this context, a radiometric measurement uncertainty of 2 % at a spectral resolution of 0.1 nm had to be achieved in the whole wavelength range to be calibrated from 400 nm to 2500 nm. In order to comply with the critical service life limitations (amounting to 40 hours for the halogen lamps and 100 h for the LEDs of the OBCA), PTB developed a calibration procedure based on the spectral comparison with a radiometric transfer standard (RTS). Calibration was carried out by means of the new Reduced Background Calibration Facility 2 (RBCF2) for the first time. The transfer standard itself is traced to primary standards of PTB. Both the qualification model and the flight model of the OBCA have been successfully calibrated within the limits of the required measurement uncertainties.

The RBCF2 is currently being used in further applications, among other things for the traceability of the FORUM instrument within the scope of the Earth Explorer 9 Mission of the European Space Agency (ESA). ▪

**Contact**
*Christian Monte*
*Department 7.3*
*Detector Radiometry and Radiation Thermometry*
*Phone: +49 30 3481-7246*
*christian.monte@ptb.de*




The OBCA mounted next to the transfer standard on the translation system at PTB's Reduced Background Calibration Facility 2. (Photo credit: Fraunhofer IOF, CYMER)

# SI seconds ever more accurate

## Progress with fountain clocks

**Especially interesting for**
- metrology of time and frequency
- fundamental research in physics

**PTB's two caesium fountain clocks, CSF1 and CSF2, have been established as primary frequency standards and as the basis of PTB's time scale for a long time. Exhaustive investigations have now allowed the uncertainties of these two clocks to be reduced by a factor of 5 (CSF1) and 2.4 (CSF2). With relative uncertainties of $2.7 \cdot 10^{-16}$ reached for CSF1 and $1.7 \cdot 10^{-16}$ for CSF2, these two clocks range among the best in the world besides a few other fountain clocks.**

In caesium atomic clocks, caesium atoms are irradiated with microwaves of a suitable frequency to induce a change in the atomic state. The frequency of the microwave signal is determined by universal properties of the caesium atoms and is the basis of the atomic definition of the unit of time.

Using laser-cooling methods, it had become possible for the first time in the 1990s to form $mm^3$-sized "clouds" of a few millions of caesium atoms with velocities in the range of cm/s and to bring them onto a fountain-like trajectory with a maximum height of approx. 1 m so that they could be irradiated by microwaves. This new geometry allows frequency-shifting effects and the clock's frequency noise to be considerably reduced compared to conventional atomic beam clocks. PTB's caesium fountain clocks CSF1 and CSF2 have been used as primary frequency standards since 2000 and 2008, respectively. Both of them determine legal time that is disseminated by PTB in Germany and contribute to calibrating International Atomic Time (TAI). The CSF2 fountain clock is the national standard of time and frequency.

In addition to their multifaceted use, CSF1 and CSF2 have been subjected to exhaustive investigations of their frequency-shifting effects over the past few years. In this context, particular attention has been paid to effects of the phase of the microwave field and collisions between the caesium atoms. Novel experimental and theoretical investigations of the microwave field effects have been conducted in order to find an operating mode in which the phase variations of the microwave field experienced by the atoms and thus the frequency shifts resulting from these variations are minimized. In the case of CSF1, the collisional shift, and thus also its uncertainty contribution, are minimized by means of skillful manipulations of the motional parameters of the atoms contributing to the clock's signal. CSF2, however, is conceived in such a way that the collisional shift can be determined very accurately by operating the clock alternately at full atomic density and at exactly halved atomic density.

Due to its reduced uncertainty, CSF2 makes the largest contribution to the control of TAI among the whole group of internationally available primary caesium clocks. A comparison has recently been carried out, effectively as an acid test, between the fountain clocks at PTB and those located at LNE-SYRTE (Laboratoire National de métrologie et d'Essais – SYstème de Références Temps-Espace) in Paris via an optical fiber link of 1400 km in length. The results obtained showed excellent agreement between all of the four caesium fountain clocks involved. ■

PTB's caesium fountain clocks CSF2 (in the foreground) and CSF1. The atoms are cooled by lasers in the lower part of the vacuum setup and then launched upwards. In the upper part of the setup, they are irradiated with microwaves during their flight.

**Contact**
*Stefan Weyers*
*Department 4.4*
*Time and Frequency*
*Phone: +49 531 592-4410*
*stefan.weyers@ptb.de*

**Scientific publication**
*S. Weyers, V. Gerginov, M. Kazda, J. Rahm, B. Lipphardt, G. Dobrev, K. Gibble: Advances in the accuracy, stability, and reliability of the PTB primary fountain clocks. Metrologia 55, 789–805 (2018)*

# Photon drive for quantum flux transfer

## Josephson AC voltage standard with optical pulse drive successfully implemented

**Especially interesting for**
- metrology institutes
- calibration laboratories
- manufacturers of electrical precision measuring instruments

**At PTB, a pulse-driven Josephson standard for the generation of AC voltages has been realized where the voltage pulses are synthesized by means of optical components. This has advantages compared to the conventional operating procedure where the driving voltage pulses are conducted onto the superconducting chip via RF conductors.**

Josephson Arbitrary Waveform Synthesizers (JAWS) allow quantized AC voltages to be synthesized with arbitrary and spectrally pure waveforms. They are based on series arrays of superconducting Josephson junctions of the kind manufactured in the Clean Room Center of PTB. Effective output voltages of more than 2 V have already been demonstrated at PTB. For this purpose, 16 JAWS arrays were operated in series with the driving voltage pulses being conducted onto the superconducting Josephson junctions, which were cooled in a liquid helium dewar, via an RF conductor per array.

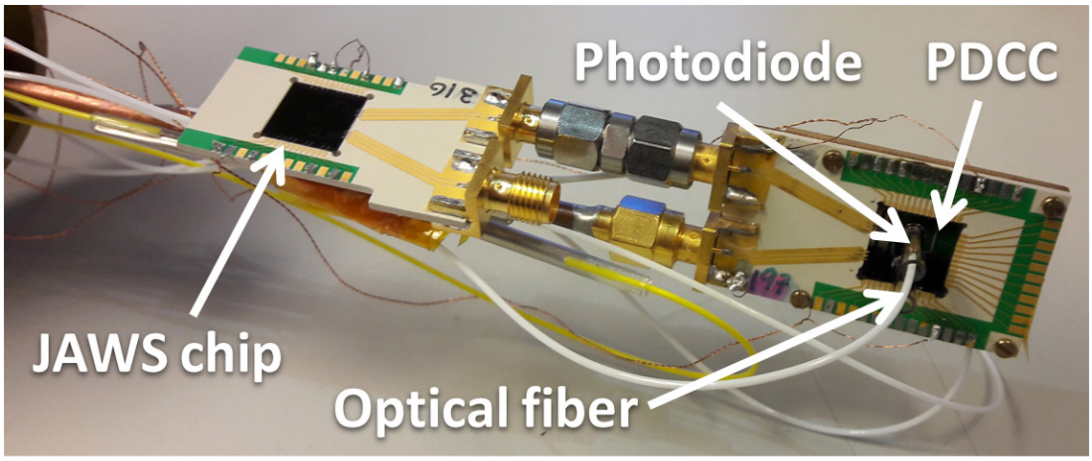
As an alternative to the use of several RF conductors, a procedure was developed within the scope of the QuADC EMPIR metrology research program in which the driving voltage pulses are generated optically in the immediate vicinity of the JAWS chips. This simplifies the experimental setup, which, in turn, will make it easier to further increase the output voltages and to market the system. The new procedure is based on the use of fast photodiodes which are resistant to low temperatures and are coupled to optical supply fibers. The photodiodes are mounted on a custom-made silicon carrier chip by means of flip chip technology. The optical pulses generated with a pulsed laser outside the helium bath are transmitted to the photodiodes via an optical fiber. At the photodiodes, they are converted into electric pulses and fed to the JAWS arrays over a short distance. In the first test conducted with an array consisting of 3000 Josephson junctions, effective sinusoidal output voltages of 6.6 mV (18.6 mV from peak to peak) and a frequency of 1875 Hz were generated.

Another advantage of this new procedure is the reduced noise background of the output signal generated. This considerably improves the signal-to-noise ratio of the waveforms generated, especially above 1 MHz.

The next step is to enhance the integration density of the photodiodes to enable several JAWS arrays to be operated at the same time and thus the output voltage to be increased. ▪

**Contact**
*Oliver Kieler*
*Department 2.4*
*Quantum Electronics*
*Phone: +49 531 592-2410*
*oliver.kieler@ptb.de*

**Scientific publication**
*O. Kieler, B. Karlsen, P. A. Ohlckers, E. Bardalen, M. N. Akram, R. Behr, J. Ireland, J. Williams, H. Malmbekk, L. Palafox, R. Wendisch: Optical pulse-drive for the pulse-driven ac Josephson voltage standard. IEEE Trans. Appl. Supercond. 29, 1200205 (2019)*




Picture of the JAWS chip with 3000 integrated Josephson junctions and of the photodiode chip carrier (PDCC) connected to the optical waveguide.

# Nanostructures in extreme light

## Femtosecond laser coils meet silicon nanowires to generate particularly hot and dense plasmas

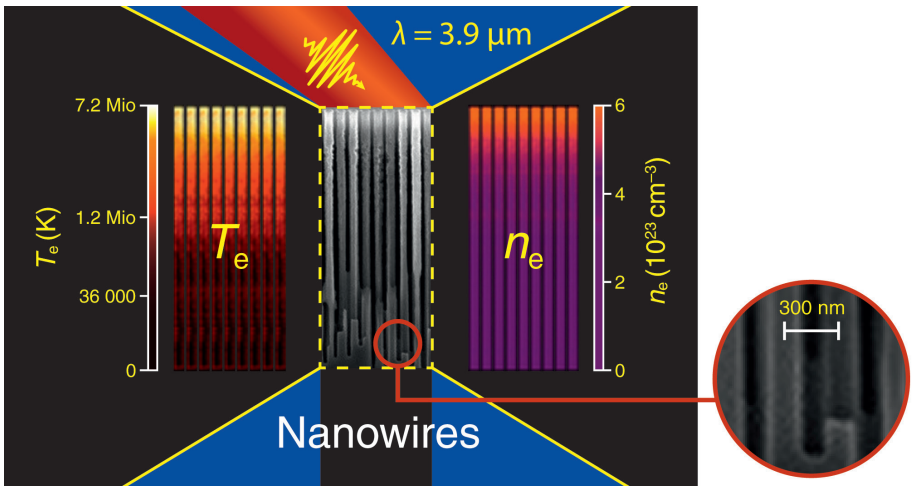
**Especially interesting for**
- nuclear physics
- astrophysics

**Within the scope of a research consortium, researchers from PTB have succeeded in advancing as far as to reach a new regime of relativistic light/matter interaction. In the context of a compact laboratory experiment, extremely hot and dense plasmas were generated. These plasmas open up new perspectives for experiments on laser-induced nuclear physics and laboratory astrophysics.**

Plasmas reaching high densities and high temperatures of more than 100 million kelvins may occur when high-intensity laser pulses interact with solids. At extremely high laser intensities, the electrons in the solid may then be accelerated up to velocities close to the speed of light. To achieve this, the incident light pulse must interact with the maximum volume of the plasma generated. With increasing wavelength, the laser intensity it takes to reach the relativistic regime may decrease, but at the same time, the plasma's state also changes more quickly, making it opaque to the incident light pulse. The light can then be absorbed only by a small volume near the surface and only there can it contribute to accelerating the electrons.

In cooperation with institutes from Jena, Düsseldorf, Vienna, Darmstadt and Frankfurt/Main, the LENA Junior Research Group for Metrology of Functional Nanosystems, which is a cooperation project of PTB and Braunschweig Technical University, have succeeded in solving this problem for the first time by combining femtosecond laser pulses with an average wavelength of 3.9 µm and nanostructured targets of crystalline silicon. Based on the X-ray emissions spectra measured and with the aid of numerical simulations, it has been demonstrated that the nanostructures change the properties of the thus created plasma in such a way that 80 % of the incident light are absorbed. At lab level, this allows long-lived plasmas with temperatures in the range of 300 million kelvins with highly charged ions and electron densities of $6 \cdot 10^{23}/\mathrm{cm}^3$ to be generated. The densities achieved are approximately a thousand time higher than those obtained with a conventional, unstructured target.

Instead of laser pulses in the UV spectral range like those previously used, which had energies in the range of a few joules, using laser systems with wavelengths in the medium IR spectral range only requires energies of a few tens of millijoules, which is very promising for laser-based nuclear physics applications. In addition, femtosecond laser pulses in the X-ray spectral range were generated during the experiments carried out. These laser pulses can be very interesting for the time-resolved characterization of plasmas. ■




Left: Color-coded spatial distribution of the electron temperature $T_e$ in the nanostructures. Center: SEM cross-sectional image of the nanostructure. Right: Electron density distribution $n_e$. The false color representations left and right show the results of simulations.

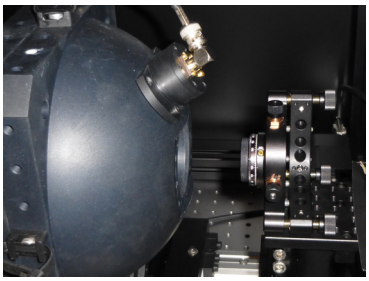
**Ansprechpartner**
*Stefanie Kroker*
*LENA Research Group "Metrology for Functional Nanosystems"*
*Phone: (0531) 592-4530*
*stefanie.kroker@ptb.de*

**Scientific publication**
*Z. Samsonova, S. Höfer, V. Kaymak, S. Ališauskas, V. Shumakova, A. Pugžlys, A. Baltuška, T. Siefke, S. Kroker, A. Pukhov, I. Uschmann, C. Spielmann, D. Kartashov: Relativistic interaction of long-wavelength ultrashort laser pulses with nanowires. Physical Review X 9, 021029 (2019)*

# Transmission of microscope lenses

**Especially interesting for**
- the optical industry
- microscope manufacturers

Integrating spheres are used to measure luminous flux; the same applies to the transmission measurement of microscope lenses. These transmission measurements can now be made more accurate thanks to a new additional element. The special insert developed at PTB serves as an adaptor between the aperture of the integrating sphere and the lens. Thanks to the insert, the lens is no longer in the critical range of the sphere and thus hardly generates any parasitic reflection at all. Luminous flux can now be measured with far less distortion, which makes the transmission measurement considerably more accurate. (Technology Offer 475) ■



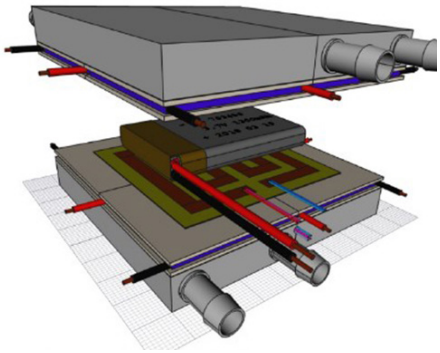
Inlet of an integrating sphere

**Advantages**
- reduced measurement uncertainty
- easy to fit onto existing spheres
- individually adaptable to different lenses

# Scalable battery calorimeter

**Especially interesting for**
- electromobility
- battery manufacturers
- calorimeter manufacturers

Battery cells must be tested with regard to their efficiency and operational reliability from the designing phase to the production process. For the thermal monitoring of batteries, a modular calorimeter has been developed at PTB. It consists of a variable number of practically identical components and allows the most diverse battery cell sizes to be examined. The modules are easily scalable with regard to their geometry. Different types of sizes are covered without having to buy a new device. The battery calorimeter can be integrated into existing systems at low cost. (Technology Offer 494) ■



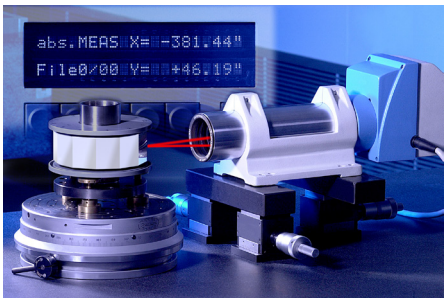
The calorimetric water-cooled modules fully enclose the battery cell and ensure good thermal contact.

**Advantages**
- adapts easily to the size of the module
- hghly accurate caloric measurement
- low cost

# More accurate angle measurement with CCD

**Especially interesting for**
- manufacturers of autocollimators
- manufacturers of measuring instruments with CCD

To measure small angular changes in objects, autocollimators are used. The detector used for this purpose, often a two-dimensional CCD sensor, is illuminated by a linear reticle pattern. Its position on the sensor is detected and has a limited resolution due to the pixel size. In the new procedure, this reticle is projected onto the sensor at an angle set specifically for this sensor, relative to the pixel grid. Its position is then calculated by means of line-by-line averaging. The interpolation errors in the sub-pixel range are minimized and allow a better resolution of the position of the reticle's image without additional components. (Technology Offer 428) ▪




Angle measurement using an autocollimator

**Advantages**
- reduces the measurement error without additional material needed
- easy to integrate into existing measuring instruments
- no special previous knowledge necessary

**Contact person for questions about technology transfer**
Andreas Barthel, Phone: +49 531 592-8307, andreas.barthel@ptb.de, www.technologietransfer.ptb.de/en

## Awards

**Oliver Hupe**

The Head of Working Group 6.31, "Photon Dosimetry", was elected to the Council at the EURADOS Annual Meeting 2019. He will be a treasurer on the Executive Board. The European Radiation Dosimetry Group (EURADOS e. V.) is a network of more than 70 European institutions and 600 scientists.

**Richard Lange**

The doctoral candidate at Department 4.4, "Time and Frequency", won the renowned poster prize of the "Joint Conference of the IEEE International Frequency Control Symposium & European Frequency and Time Forum 2019" for his submission "Reducing the Leading Uncertainty Contributions of the $^{171}Yb^{+}$ Single Ion Optical Clock to Below $10^{-18}$".

**Jan Spichtinger**

The doctoral candidate of Department 4.2, "Imaging and Wave Optics", won first prize for his submitted poster on the topic of "Konzept für eine hochgenaue und rückgeführte optische Formmessung an großen Optiken bis 1,5 Meter" ("Concept for a highly precise and traceable optical form measurement on large optics up to 1.5 meters") at the conference of the Deutsche Gesellschaft für angewandte Optik (DGaO – The German Branch of the European Optical Society) in Darmstadt.

## 40 years of cooperation with China

The German delegation in Peking. The Nobel Prize winner Klaus von Klitzing, PTB's President Joachim Ullrich, PTB's Vice President Roman Schwartz and PTB's former President Ernst O. Göbel were among the attendees.

Forty years of successful cooperation between Germany and China were celebrated during a three-day official ceremony in Peking and sent on to the next stage: On 21 August, representatives of the Federal Ministry for Economic Affairs and Energy (BMWi) and the Chinese State Administration for Market Regulation (SAMR) signed a memorandum of understanding concerning the continuation of the cooperation for another five years. The collaboration in the scientific-technical field is mainly borne by PTB. The President of PTB, Prof. Dr. Joachim Ullrich, praised the fruitful cooperation with the partner institution in China, the National Institute of Metrology (NIM). He emphasized that both metrology institutes cooperate as equals and that both countries benefit from industrial developments and innovations which are based on the highest metrological precision.

## Center for Accident and Emergency Informatics

Medical data which can be life-saving in the case of an accident have so far been saved at different places and independently of each other. A project which is initially planned for three years and is funded by the Lower Saxony Ministry of Research and the Volkswagen Foundation with a budget of 1.2 million euros is intended to change that. In the project, TU Braunschweig, MHH (Hannover Medical School) and PTB will join together for a "Center for Accident and Emergency Informatics". One goal of the project is to develop a "digital key". This "International Standard Accident Number" (ISAN) is intended to enable rescuers to access the virtual emergency register, where all emergency-related data on this patient has already been collected in advance, right at the moment of an accident. In the project, PTB will make sure that the new key is secure and harmless in terms of data protection law. To this end, PTB contributes its experience in the field of cryptographic processes, which has already found its way into the secure transmission of calibration and measurement data.

## Network for electrical energy measuring techniques

A new EURAMET metrology network called "Smart Electricity Grids" is dedicated to coordinating research activities related to intelligent power grids and establishing a sustainable European metrology research structure in this field. PTB is participating in operative efforts and is represented in the governing committees of the network.

## Network for laboratory medicine

A further new EURAMET network is intended to establish Europe-wide uniform structures related to quality assurance in laboratory medicine and to guarantee the metrological traceability of important quantities in this field. In this way, the requirements of a new EU regulation on in-vitro diagnostics will be implemented.

**Imprint**
PTB News 3/2019, English edition,
Issue February 2020, 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 > English Version > Publications > PTB News > Subscribe the PTB News
Publisher: Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin
Editors: Andreas Barthel, Alexander Gottwald, Tobias Klein, Christoph Kolbitsch, Christian Lisdat, 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

Federal Ministry for Economic Affairs and Energy

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.